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# Design Considerations of Heap Leaching at Sarcheshmeh Open Pit Copper Mine

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ABSTRACT: Copper heap leaching uses a diluted sulfuric acid solution. Copper leaching solutions vary in chemical composition, including sulfuric acid concentration and organic constituent composition. Leach pad sites are generally selected for a combination of geotechnical and economic considerations. Slope failures on geomembrane liners are far less frequent, but have occurred on landfills, leach pads and liner caps. The three main conditions of instability before or during heap leaching are: sliding along the slope due to a low value of the interface friction of the granular veneer with the geomembrane, tensile tearing of the geomembrane, normally at the crest of the slope where the force is at a maximum, and failure of the anchorage of the geomembrane when its maximum pull-out strength is achieved. The purpose of this paper is to present the design considerations of the steepest heap leaching at Sarcheshmeh Open Pit Copper Mine.

## 1 INTRODUCTION

The second site of Sarcheshmeh heap leaching area extends over 300,000 m" on a steep valley which is situated on the western side of the mine.

The leaching process has literally made many mines by taking low grade geological resources and transforming them into the proven ore category.

The leach pad supports the ore heaps, collects solution flowing through the heaps, and transports the solution laterally to drainage pipes or ditches. The leach pad site and its topography should be selected so that it is free of flooding or other hazards. The foundation must be stable to prevent movement or cracking of the pad liner under the weight of ore heaps, which may eventually reach heights of nearly 80 meters.

This paper outlines some of the selection and design considerations for geomembrane-lined heap leaching.

## 2 HEAP LEACHING CONSTRUCTION AT SARCHESHMEH

Before installation of the liners, the subgrade was prepared by clearing, grubbing, stripping, rough grading and compacting. All the fill materials should be free of excessive vegetation, debris, organic matter and other deleterious materials. Random fill may be obtained from excavation of areas of the leach pad, solution channels, pond excavation or other borrow areas. It can be placed at the base of the deeper fills. Random fill should contain no particles larger than 200 mm in nominal diameter and have a plasticity index of no more than 15. Perforated high-density polyethylene (HDPE) pipe 355 mm in diameter was placed within collection ditches with sized gravel of 13 to 76 mm surrounding the pipe as an underground water drainage system.

The bottom lining system of the heap is composed of 2 sections: one section constructed over the rock, which consists of a 0.3-m compacted impermeable clay layer that acts as a "second liner", and another section constructed over the second liner which comprises a 0.2-m-thick fine-grained protective "cushion layer".

The 1.5-mm HDPE geomembrane liner is laid on the cushion layer with a minimum slope of 1 % and a maximum average slope of 30%. Another cushion layer is constructed over the HDPE liner, comprising a 0.2-m-thick fine-grained protective layer

Over the second cushion layer, perforated HDPE pipe was placed within collection ditches with sized gravel surrounding the pipe to prevent plugging by fines. Finally, the liner was covered with 350 mm of select granular material.

Oxide ore is hauled to heap leaching pads located outside the pit, north of the oxide dump. Heap construction practices have progressed to one of the steepest valleys, with a heap lift height of 7 m and maximum average slope of 30%. Heaps are built on top of one another with a final overall height expected to exceed 80 m $H_2SO_4$ solution is applied through the heap pipe network to saturate the ore before leaching.

Low-grade copper ores are often processed by heap leach technology, where the ore is hauled to heap leaching pads, to top sizes of about one or two centimeters and sometimes only to top sizes of about 10 centimeters, stacked in heaps. For periods ranging up to several months, a sulfuric acid solution is sprayed on top of the ore, leaches through it, reacting with the copper, and carries the solution to the drainage system, where it is collected.

With standard heap leach technology, metal recoveries are generally only in the range of 70 percent, since the copper minerals may be locked inside the large ore particles and may be inaccessible to the leaching agent, or because diffusion of the leaching agent into the large ore particles may be extremely slow.

Separation of the ore from the leachate occurs in an on-site processing plant. The leaching solution is renewed and the process is repeated until it is no longer economical.

## 3 DESIGN CRITERIA

The design criteria can be outlined as given below.

- The leach pad must form a suitable foundation and a low permeability liner for the heap, as well as facilitate solution collection and heap construction. The collection ponds must provide adequate storage capacity for operation, storm runoff, and winter shutdown, as well as have a low-permeability liner.
- The major criteria affecting the design of heap leach facilities is the optimization of recovery. Meeting these criteria means that seepage losses through pad and pond liners must be minimized, liner permeabilities should be as low as possible, and the zone of saturation on top of the liners should be minimized.
- Site conditions have an important effect on the design. The major site condition is topography. It is desirable for leach pads to have a slope of 1 to 4 percent to accommodate drainage and to direct solution flow toward the collection ponds.
- The collection system consists of a series of components to collect solutions in the heap and convey them to the pregnant solution pond. The collection system within the heap is designed to maintain zones of saturation above the liner at levels as low possible so as to provide adequate stability and minimize seepage.
- Good drainage minimizes the head on the leach pad liner, reduces the detail of collection facilities in the heap and enhances the slope stability of the heap.
- The slope of the pad and associated liners is very often controlled by the existing topography. The slope of the pad *must be steep* enough to allow efficient drainage of the leachate but not so steep that the stability of the heap is jeopardized or that erosion of the liner occurs.
- One or several lifts are used in constructing the heaps. The height of the heaps depends on the condition of the foundation, the strength of the leach pad and liner, and the topography as well as the physical and leach chemistry conditions of the ore. The outer slopes of the heap depend on the shear strength and durability of the ore, and the extent of saturation in the heap.
- When cut-and-fill techniques are used to prepare the pad foundation, careful attention must be paid to compaction of the fill so that a stable, high-density base is obtained to minimize differential settlements beneath the heap. The most sensitive location for differential settlement is at the interface of the cut-and-fill.

### 3.1 *Clay liners*

Soil liners consist of selected materials placed in lifts and compacted to a prescribed moisture content and density specifications in order to produce a liner with a permeability below a predetermined value. This maximum value is commonly $10^{-6}$ or $10^{-7}$ cm/sec. Geotechnical index tests, such as grain-size distributions and Atterberg limit tests, give an inexpensive but indirect indication of the suitability of a potential liner material. The values of maximum dry unit weight and optimum moisture content are mostly dependent on the soil type and the compaction energy. There is a significant change in soil permeability with change in compaction water content, and therefore dry unit weight.

### 3.2 *Geomembrane*

The material widely used in the first heap leach facilities was polyvinyl chloride (PVC). The use of PVC in new application diminished with the development of hypalon. Currently, the most widely used material is high density polyethylene (HDPE).

The method of liner installation must suit the construction schedule and climate conditions. Most membrane liners are manufactured panels that are spread out and seamed on site. Techniques for field-seaming the panels vary with the liner material, from solvent welding for hypalon to heat-fusion welding for HDPE.

HDPE liners are flexible, nonstructural elements and therefore are not intended to provide structural support. The liner's tensile strength and ability to resist puncture, deformation, abrasion and tear should be examined in order to determine the liner's ability to withstand the stresses, strains and environmental conditions within the unit without suffering damage. Another property that should be reviewed is elongation due to temperature changes, which can cause wrinkles with an increase İn temperature or bridging with a decrease in temperature (Koerner 1997).

### 3.3 *Site selection*

The selection of sites for leach pads, collection ponds and the extraction plant is often a very obvious choice for many operations in order to stay on patented claims or to be near the mine. Site selection can be outlined as given below.

- The first step in the site selection process is the delineation of an area of interest where sites can be defined and selected. Because sites a long distance from the mine may be uneconomic, this distance is dictated by hauling costs and other operational factors.
- Within the area of interest, there may be areas where facilities should not be used. The reasons for this include ownership, topography, potential flooding, subsoil conditions and mineralization. Therefore, regions within the area of interest where sites should not be located are screened out.
- The remaining sites are then logically compared to determine the best site. Comparisons should be made according to some fair or unbiased technique.

## 4 POTENTIAL MODES OF FAILURE

At Sarcheshmeh mine, geomembrane will be applied to an inclined surface. This will lead to a component of gravitational force acting in the plane of the geomembrane, which can cause it to slide down the inclined surface. Consequently, it is important to be able to assess the bond properties of the interface between the geomembrane and inclined surface. The bond strength which can be made available may be frictional, cohesive or a combination of the two.

The critical failure surface and factor of safety depend upon the shear strength of the weakest material in the heap, liner and subsoil system. For synthetic materials, the critical failure surface and factor of safety may depend upon the frictional resistance between the ore and geomembrane or between a sand blanket and the geomembrane.

On the other hand, the mechanical behaviour of a geogeomembrane İs quite different from that of a mineral liner and, consequently, a new geomechanical approach is necessary.

There are far fewer slope failures on geomembrane liner. The three main conditions of instability before or during heap leaching are:

- sliding along the slope due to a low value of the interface friction of the granular veneer with the geomembrane;
- tensile tearing of the geomembrane, normally at the crest of the slope where the force is maximum;
- failure of the anchorage of the geomembrane when its maximum pull-out strength is achieved.

The shear strength developed at a geosynthetic interface is dependent on both the normal stress applied to the interface and the displacement at the interface. Several authors (e.g., Seed et al., 1988, Byrne 1994, etc.) have shown that most geosynthetic interfaces are strain softening.

At Sarcheshmeh, HDPE geomembrane in heap leaching is placed in direct contact with clay liners. Very little is known about the interface friction of polypropylene geomembrane against soil due to its relatively new use. It is known that a heap leaching liner system must not only provide a barrier, but must also be structurally stable. The failure of a liner system can be catastrophic in terms of the harm it can do to the environment and the financial cost to the community. The sudden slope failure of Kettleman Hills waste landfill in California, U.S.A. (Mitchell et al., 1990, Seed et al., 1990, Byrne et al., 1992) is a perfect reminder to our profession of how important it is to evaluate the strength of liner system components and interfaces.

The potential failure modes against which the pad system must be designed are given below.

- Settling of the underlying foundation may lead to disruption of the leach pad system. Differential settling is usually of bigger concern than overall and even settling.
- When a pad is constructed on fill of low shear strength or on fill of significant height, slope failure through the fill or subsoil is a concern. In a number of cases, instability has been due to the build-up of a high water level in the heap resulting from poor heap drainage or high rates of infiltration due to high rates of leachate application or rainfall. Instability has also been due to low frictional resistance between the geofabric and liner materials.
- Deterioration of liners may occur due to exposure to the elements.

Failure of a clay liner occurs when the permeability increases considerably above the design value, either locally or over a larger area. A clay liner can fail for a number of reasons. The major causes are:

- differential settling of the foundation leading to localized cracking of the clay liner,
- drying out of the clay liner leading to the development of microcracks,
- alteration of the permeability of the liner due to geochemical reactions between the liner and the leach solution.

## 5 ENVIRONMENTAL CONTROL

The key to effective environmental control of leaching solutions is nearly always contaminate of solutions under a worst case scenario of possible emergencies so that environmental contamination is prevented. The cleaning up of solution spills and leaks is usually only partially accomplished, is often not feasible, and nearly always proves to be much more expensive than prevention. The key to contaminate is proper design and construction of the leaching system, coupled with an adequate monitoring system to give early warning of any failures so that small leaks and problems can be corrected before they become big leaks and disasters.

## 5 CONCLUSIONS

A review of different parameters was presented here in design considerations of geomembrane-lined heap leaching. Risk analyses, quality assurance, and regulation environmental geotechnics refer not only to the sitting, design, construction, operation, aftercare, monitoring, etc., of heap leaching but also to contaminated land evaluation and remediation. The risk of environmental impact from heap leaching can be minimised by proper site supervision and control in the long term.

The selection of an appropriate liner should be based upon performance requirement. The liner must be compatible with the leaching conditions and also be resistant to stresses, strains and environmental conditions to which it will be exposed during installation and operation. It must adequately retain its design properties and characteristics throughout its intended life.

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