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The use of Geosynthetics in Mining Works

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ABSTRACT

Heap leach facilities are some of the largest man-made fill structures in the world. The design and construction of heap leach facilities has to follow the existing regulations to protect the environment against the very harsh and hazardous conditions. A very important but also critical component in the design, construction and operation of heap leach facilities is the basal lining system. It has to be carefully designed to guarantee a sufficient quality, to increase the solution recovery and thus improve the operational benefit. The surrounding or climate/weather conditions in the area of a heap leach facility can lead to the requirement of a capping sealing system upon completion of the mining activities. This paper presents a summary of the common heap leach pad design using geosynthetic components.

1. INTRODUCTION

Heap leaching is an industrial mining process to extract precious metal components from ore. The mined ore is crushed into smaller chunks and heaped on an impermeable geomembrane and/or clay lined leach pad where it can be irrigated with a leach solution (e. g. cyanide or sulphuric acid) to dissolve the valuable metals.
The solution then percolates through the heap and leaches out the precious metals until it reaches the liner at the bottom of the heap where it drains into a storage pond. The leach solutions containing the dissolved metals will be separated e. g. via electrolysis. Heap leach pads can be built in different structures:

- "Flat" pads
- Dump leach systems
- On/off pads
- Valley fill systems (Thiel R., Smith M.E, 2003).

Impermeable lining systems have to be designed taking into consideration all boundary site conditions. The target is an economic lining system to optimize the costs while maximising the operational profit by conforming to the applicable regulations. Some design issues with regard to the geotechnical and containment perspective and for the impermeable liner design approach are listed in Table 1, without the claim to be exhaustive.

Table 1. Design issues of heap leach pad liner systems

Assumed boundary site conditions	The effects on design conditions and stability analysis
extreme heights of the heaps (up to approx. 240 m)	global and deep seated failures of the foundation
extreme base pressure	settlement analysis (a regular homogeneous pad is required)
extreme mechanical loads (construction equipment; crushed ore)	overall stability of the heap (incl. sliding), choice of geosynthetics
seismic activities	
biological and chemical degradation of the ore	slope stability of the heap
extreme chemical conditions (H_2SO_4, 96% concentration)	chemical resistance of chosen materials
high saturation due to the leaching process (e. g. significant leachate mound in valley fills)	stability analysis against sliding of the sealing system (shear planes between the layers and stability of the single components)
Topography, climate and construction materials	Observation of the local, national and international environmental standards

2. LINER SYSTEMS USED AS HEAP LEACH PAD

Generally single and double composite liner systems are utilised. Both systems and their application area are described in the following sections.

2.1 Single composite liner

Single liner systems are used in heap leach facilities (flat pad, on-off pads, or valley pads) where the hydraulic head (= leachate mound height) is low. A single liner system consists of the existing foundation (subgrade), the low permeable layer underneath the geomembrane (either a Compacted Clay Liner (CCL) or a Geosynthetic Clay Liner (GCL)), the geomembrane, a protection layer (e. g. geotextile), and the mineral drainage layer (including solution collection/air injection piping) (Lupo J. F.). In Fig. 1 a single composite liner system is shown.

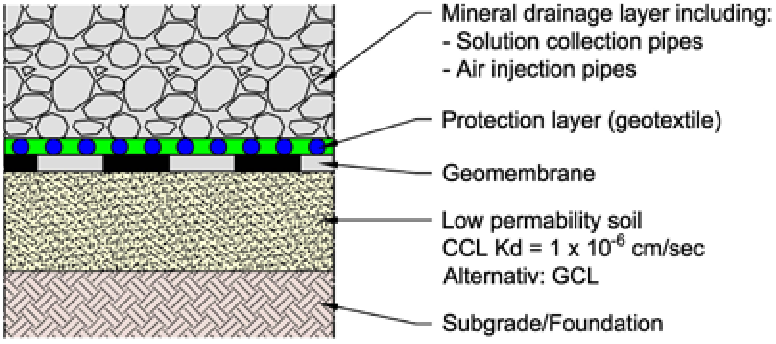

Figure 1. Single composite liner system (Lupo J. F.)

A lining system with either an HDPE geomembrane or a clay layer only is no longer state of the art and thus in most of the cases a combination of both is accepted by the licensing authorities.

2.2 Double composite liner

Double liner systems are used if higher leach solution hydraulic heads are expected on top of the liner system (valley fill), to reduce the hydraulic head on the bottom geomembrane and to minimise the leakage of solution from the facility. A double liner system as shown in Fig. 2 will be built on top of the prepared surface/foundation, starting with the low permeable layer, either a Compacted Clay Liner (CCL) or a Geosynthetic Clay Liner (GCL). On top of the low permeable soil the secondary geomembrane liner, the leak detection and recovery layer and the primary geomembrane will be placed. Finally the mineral drainage layer including the piping is installed (Lupo J. F.).

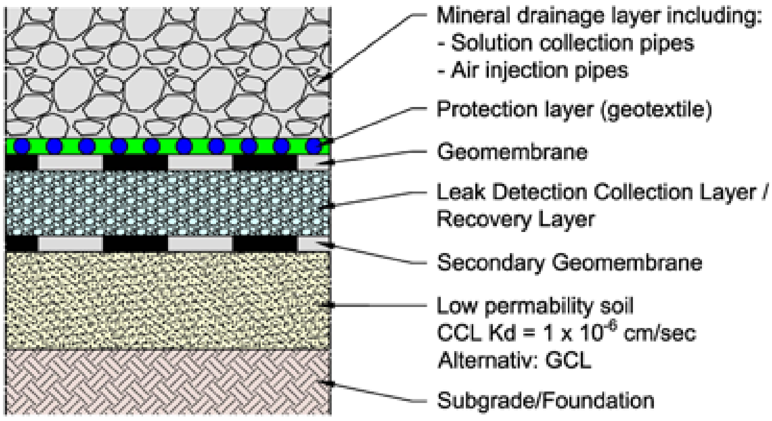

Figure 2. Double composite liner system (Lupo J. F.)

Variations of the systems depending on the site conditions, licence requirements and the leaching process are possible.

3. GEOSYNTHETIC COMPONENTS AND THEIR SELECTION

Heap leach pads have evolved significantly over the last twenty years. Geosynthetic products, such as geomembranes, geosynthetic clay liners (GCL's), protection geotextiles and geopipes, are some of the main components used in the system to maximise the solution collection.

The most preferred pad base liner system in current heap leach practice is the single composite soil and geomembrane liner system with a mineral drainage layer for gravity solution flow to external ditches and ponds (Breitenbach, 1999). Several leach pad sites have used the Geosynthetic Clay Liner (GCL) where the Compacted Clay Liner (CCL) borrow material is not naturally available (Breitenbach, Thiel, 2007).

3.1 Geosynthetic clay liner

A GCL generally contains of a woven carrier layer, a powder bentonite layer and a geotextile cover layer.
The equivalence of a GCL compared to a 30 cm thick CCL can be calculated based on the CCL´s typical hydraulic conductivity as of $1x10^{-6}$ cm/s ($1x10^{-8}$ m/s). The transmissivity q of a 30 cm thick CCL is $3x10^{-7}$ m²/s (q = thickness(s) k-value).

To achieve the same transmissivity for a typically 10 mm thick GCL with a minimum bentonite content of 4,000 g/m² the k-value has to be $3 \cdot 10^{-9}$ m/s. The lab test has to be performed by using de-mineralised, de-aired water and has to reach a value of less than $5x10^{-11}$ m/s under a load of 35 kPa. With increasing loads the GCL´s k-value decreases so for example, under a load of 500 kPa the k-value reduces to about $1x10^{-12}$ m/s. As the sodium bentonite in the GCL becomes subjected to ionic exchange the k-value can increase. Taking both load and ionic exchange into consideration the effective k-value of a GCL will not be less than 3×10^{-9} m/s and thus a GCL will perform similar or better than a 30 cm CCL.

In addition to the better k-value of the GCL, the self-healing capability even after dry-wet cycles as well as the easy and quick installation are benefits for the quality of the construction as well as for the construction process.

3.2 Geomembranes

The geomembrane is the most important component. It is manufactured of semi-crystalline polyethylene-materials and has to be sufficiently resistant to chemical attacks and mechanical loads.
Because of the harsh conditions in the area of heap leach pads, the correct choice of the synthetic liner is crucial. The specified geomembrane has to survive the:

- High chemical attack
- Point loads from mineral drainage layer on top of the geomembrane (requires a protection layer)
- Heap loading conditions
- Site specific topography
- Site specific climate conditions
- Site specific construction conditions (quality control during installation)

The geomembrane should be chosen taking into consideration the

- Assumed foundation settlements
- Max. allowed strain of the geomembrane
- Planned ore loads
- Definitions of the low permeable soil underneath the geomembrane and the slope stability of the facility (considering the particle size, the internal friction angle of the soil and the contact friction angle to adjacent layers)
- Definition of the mineral drainage layer (Lupo J. F.)

The thickness and the type of the geomembrane (e. g. raw material, surface structure) have to be determined. Geomembranes between 1.0 and 3.0 mm thickness have been used (5 mm in tanks) (Defilippis M.O.) while in the area of heap leach pads typically 1.5 mm thick geomembranes are common. Under the physical loading conditions of mining works this is, in the opinion of the authors, to thin. GRI GM13 requires a minimum average thickness for geomembranes and allows a lowest individual of 10 values to be at -10% tolerance. For a 1.5 mm HDPE membrane this can be as low as 1.35 mm. Thus the recommendation is to use at least 2.0 mm thick liners.

Conveyer channels for example, which convey to the solution containing the copper to the facility or the collection pond are mostly lined using thicker geomembranes of up to 3 mm (Defilippis M.O.). The selection of the geomembrane thickness can be derived using the "Liner-Load Test" (Giroud et al (1995)). For liner-load tests, rock particles are manually placed on the underliner surface and directly on the geomembrane to simulate field conditions. It gives an important key to choose a sufficient geomembrane thickness. Nevertheless it is a laboratory approach which cannot cover all possible risks. Long term creep of the geomembrane at point loads and stress cracking cannot be proven with this laboratory approach.

Many of the leaks that develop in heap leach facilities are related to rock particles left on the underliner surface or that have been collected at the bottom of the mineral drainage layer. As the leach pad is loaded with ore, point loads (from the rock particles) developed on the geomembrane surface, might result in puncture (Lupo J. F.).

In the case of intense deformations the relating force concentrations from point loads can, when the liners are influenced by the wetting media, the chemicals and the warm temperature, lead to stress cracking within the material.

3.2.1 Liner raw material

The most common geomembrane liner raw materials used in the design of heap leach facilities are Linear Low-Density Polyethylene (LLDPE), High Density Polyethylene (HDPE) and to a limited extent, Polyvinylchlorid (PVC).

HDPE is being used for approximately 40 years already and has proven its efficiency both in landfill construction materials (pipes, membranes) as well as in other industries because of its high chemical resistance. A large range of laboratory and field tests have been worked out using HDPE which leads to a good knowledge concerning the product properties. This knowledge improves the design work and finally the quality of the liner system. The design life of HDPE liners used in German landfills is estimated with up to 450 years (GDA-Empfehlungen).

LLDPE has not been used as long and as intensive as HDPE and thus LLDPE membranes have not been subjected to the same amount of research as done on HDPE geomembranes.

For the efficiency of heap leaching facilities the long term performance of lining systems plays an important role. Based on the available test results and the positive experience as well as the better chemical resistance the required performance can be guaranteed for HDPE geomembranes.

Some significant HDPE geomembrane properties are part of the common standard tests performed in the geosynthetic industry to ensure a good long term performance. The thickness, the carbon black content, the carbon black dispersion, the stress crack resistance, the Oxygen Induction Time (OIT), the oven aging and the UV aging are endurance related and are key to the geomembrane durability (Defilippis M.O.).

Butene resins do not exhibit such good resistance to stress cracking as geomembranes made with hexane or octene polyethylene resins. Carbon black represents the most important protection against UV radiation. GRI GM13 requires a carbon black content in between 2.0 - 3.0 % with a dispersion of class 1-2. High Pressure Oxidation Induction Time (HPOIT) is an index about the durability of the geomembrane in combination with the UV and oven aging test. HPOIT values increase with the quality (and price) of the additives used by the manufacturer.

3.2.2 Shear behaviour

In order to guarantee a reliable dimensioning and design of heap leach pad liner systems, detailed information on the single shear planes predetermined by the system are required and have to be measured.

The shear forces that can be generated in the contact shear plane between the geomembrane and the mineral protection layer are higher than between a membrane and a geotextile protection layer, but due to a high possibility of an interlocking of fine mineral drainage particles into the geomembrane and thus a high risk of failures, the use of protection geotextiles is recommended. By a project specific dimensioning of the geotextile as referred to further down in this paper the long term durability of the prescribed sealing system can be guaranteed.

3.3 Protection Geotextiles

The effects of gravel particles and settlement in the heaps sub base lead to strains and stresses in the geomembrane: The load of an ore heap is forwarded into the subsoil via the granular structure of the coarse gravel drainage layer. Due to the small footprint of the gravel particles its load is as more or less local compressive strength transferred into the protection layer below the drainage layer. The protection layer should distribute these puncture form compressive strengths in such a way that the geomembrane or the heaps sub base, respectively, are - in the ideal case - only loaded by a homogenous compressive strength without local point loads. In the real case the protection efficiency of a protection layer is sufficient if the load distribution in the protection layer already occurred in such a way that "practically" no impressions occur in the geomembrane (S. Seeger; 1995).

To avoid deformations in the membrane, a protection layer, either natural or artificial, has to be designed. In case the choice is being made for a protection geotextile a modified plate bearing test can be carried out in the laboratory.

Such testing is common practice in Europe within the landfill business. This test (documented in detail in the GDA-Empfehlung E3-9, Eignungsprüfung für Geokunststoffe, der Deutschen Gesellschaft für Geotechnik (DGGT)) shows how effective the geotextile protection layer performs. A soft metal plate placed under the geomembrane is used to visualize the deformation in the geomembrane. Results from such testing are shown in Fig. 3. Different mass per unit area geotextiles of (from left to right) 317 g/m², 608 g/m² and 1,332 g/m² have been considered. These compression tests using the same gravel under the same test conditions clearly show that the deformation of the geomembrane decreases and the geotextile protection efficiency increases at increasing mass per unit area geotextiles (NAUE GmbH & Co. KG). The maximum allowable geomembrane deformation for the landfills in Germany is limited to a maximum of 0.25%. Transferring this into the mining business the authors consider a deformation below 1 % tolerable for heap leach pads.

Figure 3. Plate bearing test using protection geotextiles with different mass per unit area on top of a 1.5 mm thick HDPE geomembrane at the same test conditions (NAUE GmbH & Co. KG)

To achieve such deformation limitation within the synthetic liner the grain size of the soils in contact with the liner must be rigorously controlled and higher mass per unit area geotextiles should be used as protection layers. For a load of 1,500 kN/m² a 2,000 g/m² geotextile was necessary in a landfill project to limit the deformation of the geomembrane to less than 0.25%. We recommend that such testing is carried out for the mining industry to establish the effectiveness of the geotextile protection layer chosen (S. Seeger; 1995).

The good load distribution performance of the protection layer to be required must also be effective in an enduring way. Beyond the functionality of the geomembrane to be expected no changes concerning the load distributing efficiency must occur, nor any through chemical attack.

4. CLOSURE

This paper presents an overview about common heap leach pad liner systems and their design requirements. Especially the geosynthetic components, the geomembrane and, if used, the geosynthetic clay liner have to be chosen in consideration of the harsh conditions of a heap leach pad. Therewith the requirement of well-designed and qualitative geosynthetic components comes up which achieve their function over a sufficient period of time.

The long term performance of the geosynthetic performance can be influenced by using appropriate values in the specification text together with proper design, installation and site quality control.

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