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 have 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 liner system. It has to be designed to guarantee a sufficient quality, in consideration of the long-term responsibility for the environment, as well as in consideration of enhancing solution recovery and therewith operational benefit. Due to the long-term responsibility of the environment 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. It shows the design and operation-related requirements for the single components of a heap leach pad (low permeable soil, geomembrane, mineral drainage layer) and the interaction of the layers by project-specific boundary conditions.

This paper does not include any design requirements or recommendations for the solution collection piping and the air injecting piping. The authors do not want to introduce themselves as mine experts, but with a large experience in landfill lining systems and geosynthetics.

1 Introduction

Heap leaching is an industrial mining process to extract precious metals 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 solution containing the dissolved metals which will be separated e. g. via electrolyse (Wikipedia). Heap leach pads can be built in different structures

1. "flat" pads
2. dump leach systems
3. on/off pads
4. valley fill systems (Thiel R., Smith M.E, 2003).

The impermeable lining systems have to be designed considering of all boundary site conditions. The goal of the owner is that the liner has to be as economic as possible (minimising the coast, maximising the operation profit) but still conforming to the applicable regulations.

Some design issues looking at the geotechnical and containment perspective and for the impermeable liner design approach are listed in the following, without the claim to be exhaustive:

Table 1 Design issues of heap leach pad liner systems

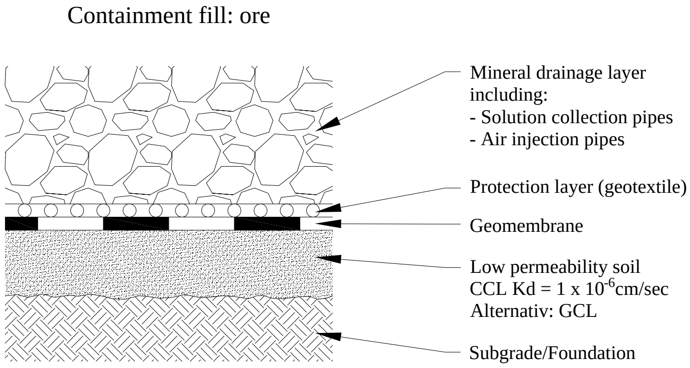
Assumed boundary site conditions	The effects on design conditions and stability analysis
• extreme heights of the heaps (up to approx. 240 m)	• global and deep seated failures of the foundation
• extreme base pressure	• settlement analysis (a regular homogeneous pad is required)
• extreme mechanical loads by the construction equipment	• overall stability of the heap (also sliding)
• 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 materials used
• mechanical load (construction equipment; crushed ore)	• liner system designed in consideration of the long-term responsibility
• very large leach pads (varying conditions)	• right choice of the geosynthetic products in consideration of the project specific conditions
• high saturation due to the leaching process (e. g. high solution levels 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 have to be considered	• observation of the local, national and international and 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 below.

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

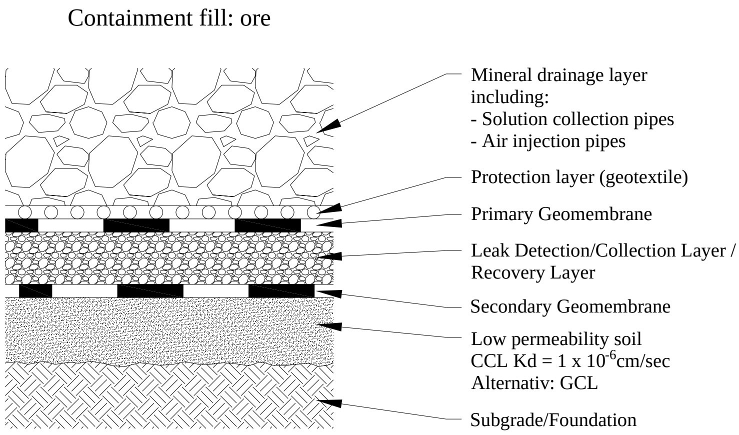
Figure 1 Single composite liner system (Lupo J. F.)



A lining system with a geomembrane by itself or a clay layer by itself is no longer the state of the art and is seldom accepted by the licensing authorities.

Double composite 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 will be built on top of the prepared surface/foundation, and starting with the low permeable soil. 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.)



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

3 Geosynthetic components and their selection

3.1 Geomembranes

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

The geomembrane is the most important component. They are manufactured of semi-crystalline polyethylene-materials and have 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 (requirement of a geotextile)
- the heap loading conditions
- site specific topography
- site specific climate conditions
- site specific construction conditions (quality control during liner installation and installation of initial mineral layers),

The geomembrane should be chosen in consideration of the

- assumed foundation settlements,
- the max. allowed strain of the geomembrane,
- the planned ore loads,
- the 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),
- the definition of the mineral drainage layer (Lupo J. F.).

The thickness and the type of geomembrane (e. g. raw material, surface structure) have to be determined. Geomembrane thicknesses between 1 mm and 3 mm have been used (5 mm in tanks) (Defilippis M.O.). 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: With a 1.5mm nominal thickness liner (which can be as low as 1.2mm (-20%) in single locations and 1.35mm thick in (-10%) in larger areas) the possibility of holing a nominal 1.5mm geomembrane is too great. Such variations in product thickness comes from the blown sheet manufacturing process by specifying that only flat sheet process manufactured geomembranes such thickness variations can be limited to minus 5%.

Conveyer channels for example, which lead to the solution comprising 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 the geomembrane thickness. Nevertheless it is a laboratory approach which can not cover all possible risks. Long term creep of the geomembrane at point loads and stress cracking can not 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 collected at the bottom of the mineral drainage layer. As the leach pad is loaded with ore, point loads (from the rock particles) develop on the geomembrane surface, resulting in puncture (Lupo J. F.).

In the case of intense deformations the relating force concentrations from point loads can, when they liners are influenced by the wetting media, the chemicals involved and warmness, lead to stress cracking within the material. The effect of the partials in the drainage layer can be represented in the laboratory using a modified plaid bearing test.

Figure 3 **Plaid bearing test using different protection geotextiles on top of a 1.5 mm thick geomembrane considering the same test conditions (NAUE GmbH & Co. KG)**

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 plaid placed under the geomembrane in this test is used to measure the geomembrane deformation. Results from such testing are shown in Figure 3. The mass of the left geotextile 317 g/m², middle 608 g/m² and right 1332 g/m² has been used. These compression tests using gravel under the same test conditions show clearly on the soft metal plate which was under the 1.5 mm HDPE geomembrane, that the deformation on the geomembrane decreases and the geotextile protection efficiency increases as the unit mass of the geotextile increases (NAUE GmbH & Co. KG). The geomembrane deformation for the landfill work in Germany is limited to a maximum deformation of 0.25%. We are of the opinion that the maximum limit within the mining industry should be kept below 1%.

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 1500 kN/m² a 2000g/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).

Not only settlements in the heaps sub base but also the effects of gravel grains of the drainage layer 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 footprints of the gravel grains this 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).

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.

3.1.1 Shear behaviour

In order to guarantee a reliable dimensioning and design of heap leach pad liners 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 – mineral protection layer increases when a protection geotextile is not used. But this also means that the grain particles are interlocking into the geomembrane which can finally leads to failures in the geomembrane as described above.

It is attractive for the designer not to use protection geotextiles to achieve the necessary transfer of shear forces within his lining system. However this can lead to a shortening operation life of the paramount liner.

3.1.2 Liner raw material

The most common geomembrane liner materials used in the design of heap leach facilities include LLDPE, HDPE and to a much lesser extent, PVC.

HDPE for example has been used for approximately 40 years to produce geomembrane. The raw material HDPE has proved its efficiency both in construction of landfill areas (pipes, membranes) and in chemical industry because of its of chemical resistance. A large range of laboratory and field tests have been worked out using this material 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 landfills is about 450 years (GDA- Empfehlungen).

LLDPE has not been used as long as HDPE geomembranes. LLDPE shows some advantages - based on laboratory tests but the product has not been subjected to the same amount of research as that done on HDPE geomembranes, nor has it been used as long. For the efficiency of heap leaching facilities the long term performance of lining systems plays an important roll. Based on the existing experience this can be given with the use of HDPE geomembranes. Because of the higher density of HDPE it has better chemical resistance.

Some significant geomembrane properties which are part of the common standard tests that are performed in the geosynthetic industry to ensure a good long term performance are given here:

The geomembrane density gives an idea about the resin. This is important in regard to diffusion. The thickness, the carbon black content, the carbon black dispersion, the stress crack resistance , the OIT (oxygen induction time), the oven aging and the UV aging are endurance related and are key to the geomembrane durability (Defilippis M.O.).

Carbon content and carbon black dispersion represent the most important protection against UV radiation.

Carbon black dispersion is an indicator for a homogeneous UV-protection of the geomembrane. Where a geomembrane will be exposed to the sunlight, class 3 dispersion (ASTM D 5596) or worse levels should be excluded in the material specifications.

Butene resins do not exhibit such good resistance to stress cracking as geomembranes made with hexane or octene polyethylene resins.

Oxidation induction time is an index about the durability of the geomembrane in combination with the UV and oven aging test. OIT values increase with the quality (and price) of the additives used by the manufacturer.

3.2 Geosynthetic clay liner

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 available (Breitenbach, Thiel, 2007).

The typical hydraulic conductivity of a compacted clay layer is defined with 1 x 10-6 cm/s (1 x 10-8 m/s) for the composite liner of a heap leach pad. The transmissivity θ of such a 30cm thick clay layer is 3 x 10-7 m^2/s (θ = thickness(s) x k-value). A GCL has typically a thickness of 10mm. To achieve the same transmissivity of this clay layer the k-value of the GCL has to be 3 x 10-9 m/s. The k-value given for a GCL is achieved using de-mineralised, de-aired water and has a value less than 5 x 10-11 m/s when loaded to 35kPa. As the load increases the GCL k-value reduces. For example, under a load of 500kPa the k-value reduces to about 1x10-12m/s. As the sodium bentonite in the GCL becomes subjected to ionic exchanges the k-value can increase. Taking both load and ionic exchange into consideration it is unlikely that the effective k-value of a GCL will become less than 3 x 10-9m/s. In other words the GCL will perform similar or better than a 30cm compacted clay layer.

One measurement of the sodium bentonite quality used in GCL's is the swell index (ASTM D 5890). Bentonites with a swell index less than 20ml/2g/24h are more susceptible to ionic attack than those with a value of 24ml/2g/24h (NAUE).

If clay is not available in the area of the planned heap leach pad an alternative sealing element, which provides equal or better sealing properties, such as geosynthetic clay liners can be used. A heap leach pad liner system using a well chosen GCL underneath will lead to the same or better quality of the liner system. One additional positive aspect is the self healing capability during dry-wet cycles, which is not given using a CCL. Another advantage is the easy and quick installation of GCLs.

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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