THE USE OF GEOSYNTHETIC CLAY LINERS IN HEAP LEACH PADS

Geomembranes have been used in the mining industry since the early 1970s in solution and evaporation ponds, tailings impoundments, and heap leach pads. In particular, heap leach pads can involve extreme conditions such as aggressive chemical environments and enormous compressive loads. Heap leach heights can reach 180 meters (600 feet), corresponding to normal loads of up to 3450 kPa (500 psi) on the leach pad liner system. When under such loads, geomembranes are vulnerable to damage from large stones both in the soil subgrade and in the overlying drainage layer. These holes serve as open pathways for leakage into the soil below.

Considering the recent price increases in precious and commodity metals, and the increased environmental sensitivity of the mining industry, there may now be even stronger incentive to limit geomembrane punctures and loss of pregnant leach solution (PLS) through heap leach pad liners. To reduce leakage through defects, a low-permeability layer can be used beneath the geomembrane to form a “composite” liner system. The low-permeability material beneath the geomembrane can be either a compacted soil liner or a GCL.

Results of high-load static puncture tests have shown that geomembrane/GCL composite liners may be subject to less puncture damage than geomembrane liners alone over compacted soil subgrades. A feasibility study of two lining alternatives for an example copper heap leach pad was performed. Theoretical liner leakage calculations revealed that, for a reasonable set of assumptions for a hypothetical copper heap leach, a geomembrane/GCL composite liner would be expected to allow only a fraction as much leakage as a geomembrane/compacted soil composite. The resulting improvement in PLS capture is expected to result in a significant increase in copper recovery and increased revenue (potentially hundreds of thousands of dollars per year).

TR-276
01/11

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Introduction

Geomembranes have been used in the mining industry since the early 1970s in solution and evaporation ponds, tailings impoundments, and heap leach pads. Traditionally, heap leach pad lining systems have consisted of a single geomembrane liner placed directly over a prepared subgrade of locally available soil. Heap fills are constructed by placing a layer of highly-permeable drainage stone (overliner) over the geomembrane. Crushed ore is then placed on the leach pad in 3- to 10-m (15- to 30-foot) thick lifts, sometimes reaching final heights of several hundred feet. The crushed ore is irrigated with a chemical solution which dissolves the precious metals from the ore. The nature of the chemical leaching solution depends on the metal being targeted. Low pH sulfuric acid solutions are generally used to leach copper and nickel; high pH cyanide solutions are used to leach gold and silver. The metal-laden pregnant leach solution (PLS) passes down through the ore pile and is captured in a drainage system. Metals are extracted from the leach solution and the solution is then recycled back onto the leach pile.

When under load, geomembranes are vulnerable to damage from large stones both in the soil subgrade and in the overlying drainage layer. Although intact geomembranes are virtually impermeable, installed geomembranes will have a small number of holes due to imperfect seams or damage during construction and filling operations. These holes serve as open pathways for leakage into the soil below. Smith and Welkner (1995) estimated liner leakage rates ranging from 5 to 10,000 L/ha/day, depending on the type of heap pad liner and level of construction quality assurance (CQA). Thiel and Smith (2003) reported liner leakage rates up to 2,000 L/ha/day for a valley fill facility with heads ranging from 15 to 35 m.

To reduce leakage through defects, a low-permeability layer can be used beneath the geomembrane to form a "composite" liner system. The low-permeability material beneath the geomembrane is typically either a compacted soil (clay or silt) liner or a geosynthetic clay liner (GCL). Compacted soil liners are typically constructed within a specific range of water contents and dry unit weights to achieve a maximum hydraulic conductivity of either 10^{-6} or 10^{-7} cm/sec, depending on performance and regulatory requirements. GCLs are factory-manufactured liners consisting of sodium bentonite, with a laboratory-certified hydraulic conductivity of 5 x 10^{-9} cm/sec. Several factors affect the rate of leakage through composite systems, including the number of holes in the overlying geomembrane, the hydraulic conductivity of the underlying soil layer, and the contact factor between the geomembrane and the low-permeability layer (Giroud, 1997). Based on liner leakage measurements collected by the USEPA at 287 landfill cells, spanning 91 sites (Bonaparte et al., 2002), GCL-based composite liner systems have been shown to allow less leakage than clay-based composite liner systems.

Previous Testing

Heap leach pads can involve extreme conditions such as aggressive chemical environments and enormous compressive loads. Heap leach heights can reach 180 meters (600 feet), corresponding to normal loads of up to 3450 kPa (500 psi) on the leach pad liner system. Such loads exceed the limits of most standard laboratory testing devices, making it difficult to properly evaluate the behavior of geosynthetic materials in these applications. To address this limitation, Athanassopoulos et al (2009) tested geomembrane/GCL puncture at normal loads up to 5172 kPa (750 psi), GCL chemical compatibility at normal loads up to 1440 kPa (200 psi), and geomembrane/GCL interface shear strength at normal loads up to 2758 kPa (400 psi).

The results of the high-load puncture testing showed that geomembranes alone are expected to experience more puncture damage (puncturing and/or strain deformation past yield) from the overliner than a geomembrane with an underlying GCL or a geomembrane covered by a protective geotextile cushion. Geomembrane samples subjected to stresses greater than 2586 kPa (375 psi) experienced over 300 permanent deformations per m^2 (>30 per ft^2). A geomembrane sample tested alone at the highest normal stress, 5172 kPa (750 psi), also had two punctures, each measuring 2 mm in diameter. The protection offered by a GCL was found to be comparable to that of a 540 g/m^2 (16 oz/yd^2) nonwoven cushioning geotextile placed above the geomembrane. The GCL's benefit, in terms of reducing biaxial strains in the geomembrane, appears to be greater at higher normal stresses. Although protective measures (either GCL below or cushioning geotextile above the geomembrane) showed reduced typical strain values, the study found that these measures may not be enough to protect the geomembrane from puncture in all cases, especially where sharp crushed rock particles in the overliner happen to be aligned with a sharp point or edge in direct contact with the geomembrane.

The results of the high-load compatibility / permeability tests performed on GCL samples permeated with a low-pH copper PLS showed that at low effective stress, the GCL permeability was on the order of 10^{-6} cm/sec. As effective stress was increased to simulate increasingly higher ore heights on the liner system, the permeability decreased significantly, reaching a value of approximately 5 x 10^{-11} cm/sec at 1440 kPa (200 psi) effective stress.

High-load direct shear testing of geomembrane/GCL liner components showed peak secant friction angles of 19 to 20 degrees and large displacement secant friction angles of 6 to 7 degrees at 2758 kPa (400 psi) normal stress. To minimize the potential for internal failure/rupture of the GCL (and residual conditions representative of unreinforced hydrated bentonite), a GCL with high peel strength (>900 N/m by ASTM D6496) is recommended for heap leach liner applications where extremely high normal stresses are expected.

Heap Leach Pad Liner Feasibility Study

A comparison of expected hydraulic performance and metal recovery was performed for two proposed liner options for a hypothetical copper heap leach project: (1) a 1.5-mm (60-mil) geomembrane overlying a GCL; and (2) a 1.5-mm (60-mil) geomembrane overlying a 0.3-m (1-foot) thick layer of compacted soil with a permeability of 10^{-6} cm/sec. (Regulatory agencies in the western United States commonly require the low-permeability soil layer beneath the geomembrane to have a maximum hydraulic conductivity of 10^{-6} cm/sec). A hypothetical copper heap leach has been selected as a “worst-case” example due to potential GCL chemical compatibility concerns between the acidic PLS and the bentonite in the underlying GCL. A gold heap leach, which employs a high-pH dilute cyanide solution, has been shown to be compatible with sodium bentonite (CETCO, 2000), and is therefore expected to result in a low long-term GCL hydraulic conductivity, on the order of 10^{-9} cm/sec).

Flow through Geomembrane Defects

Theoretical leakage calculations were performed using the semi-empirical Giroud equations (1997). These equations are similar to the equations used in the Hydrologic Evaluation of Landfill Performance (HELP) model, which were also developed by Giroud (Schroeder et al, 1994). Since geomembranes are virtually impermeable, the only liquid migration through the composite liner system will occur through geomembrane defects.

The high load puncture testing discussed previously found that GCLs can serve as effective cushions, limiting geomembrane punctures. Additionally, the benefit provided by the GCL appears to be greater at higher normal stresses. Based on these results, 100 defects per hectare were assumed for the compacted clay option and 50 defects per hectare were assumed for the GCL option. These were felt to be reasonable assumptions, considering the large disparity in geomembrane punctures seen at the highest loads ( ), Each installation defect was assumed to be circular, with an area of 1 cm^2.

GCL Hydraulic Conductivity

Sulfuric acid solutions are used to leach copper from the ore. This results in an acidic PLS containing high levels of sulfates, dissolved metals, and total dissolved solids. Jo et al. (2001) found that sodium bentonite samples exhibited approximately a 50 percent decrease in swell at pH values less than 3. As part of the same study, GCL permeability values on the order of 10^{-6} to 10^{-5} cm/sec were measured at pH values less than 2. However, Ruhl and Daniel (1997) found that when exposed to strong acid, a GCL's buffering capacity was not exhausted until after 15 pore volumes of flow. At the low water flow rates expected in a liner, it may take months or years for the first 15 pore volumes to flow through liner. By this time, the liner will likely be covered and compressed by several hundred feet of ore, when the GCL’s permeability will be greatly reduced.

The hydraulic conductivity of bentonite is dictated by not only the pore water chemistry, but also the compressive stress acting on the GCL. Daniel (2000) permeated GCLs with concentrated calcium chloride (5000 ppm) solutions at various confining pressures. At low compressive stress, the calcium solution had a dramatic effect on GCL performance. But as the pressure increased to 400 kPa (58 psi), the hydraulic conductivity to distilled water and concentrated calcium solution was virtually identical. These results are consistent with the findings of Thiel and Criley (2005), who found that at effective stresses greater than 58 to 72 psi (400 to 500 kPa), the hydraulic conductivity of a GCL is independent of the leachate chemistry. Since modern heap leach piles are typically several hundred feet high, the GCL will be under a very high confining pressure, and is therefore expected to maintain a relatively low hydraulic conductivity.

Considering the combined effects of low pH, high ionic strength, prehydration, and high confining pressure, a GCL in this example application was conservatively assumed to exhibit a hydraulic conductivity less than 10^{-7} cm/sec, or an increase of almost two orders of magnitude from the value expected with clean water.

Estimated Liner Leakage Rates and Recoverable Copper

Giroud's equation requires knowledge of the hydraulic head on the liner system. For purposes of this calculation, it is assumed that the head is 1 foot (0.3 m). It should be noted that head levels can vary depending on annual rainfall, leach solution application/collection rates, and the type of fill (e.g., valley or heap).

Using these assumptions, the calculations in Table 1 show that a geomembrane/GCL composite liner would be expected to allow only a fraction as much leakage as a geomembrane/0.3-m thick compacted soil composite.

Table 1. Liner Leakage Calculations

	1.5-mm LLDPE/ compacted soil	**1.5-mm LLDPE/ GCL**
Soil hydraulic conductivity	10^{-6} cm/sec	10^{-7} cm/sec
Soil thickness	0.3 m	0.006 m
Hydraulic head	0.3 m	0.3 m
Contact quality factor	1.15	0.21
Number of defects	100 per hectare	50 per hectare
Size of each defect	1 cm^2	1 cm^2
Liner leakage	1692 lphd	82 lphd

Note: lphd = liters per hectare per day.
Calculations performed using the methodology in Giroud (1997).

By multiplying the leakage rates in Table 1 with 3000 ppm of copper, a copper price of $8.20 per kilogram (as of October 2010), and a estimated recovery of 90%, copper recovery rates for each liner option were calculated (Table 2). The example calculations show that because of the large disparity in leakage rates between the two liner options, the improved recovery rate afforded by adding a GCL below the geomembrane could potentially translate to hundred of thousands of dollars per year of added revenue. Over the life of the project, this would exceed the cost of the initial investment in the GCL.

Table 2. Copper Recovery Calculations

	1.5-mm LLDPE/ compacted soil	**1.5-mm LLDPE/ GCL**
Copper in PLS	3000 ppm	3000 ppm
Copper lost due to leakage	1853 kg/ ha / yr	90 kg/ ha / yr
Copper price (October 2010)	$8.20 / kg	$8.20 / kg
Copper recovery	90%	90%
Cost of recoverable copper lost	$13676 / ha / yr	$661 / ha / yr
Gain in Revenue	--	$13015 / ha / yr

Please note that the example above is only for one hypothetical site, and that site-specific variables such as, frequency/size of defects (related to the normal load and the overliner stone), hydraulic head on the liner, metal concentrations, and hydraulic conductivity, will all strongly affect the calculations. Therefore, site-specific evaluations should be performed.

Additional factors not discussed above include a comparison of the installed costs of GCLs and compacted soil liners, as this is a highly variable, strongly site-specific consideration. The authors' experience at past sites, including a recent mine site in Nevada, has shown that the installed cost of a GCL is roughly equivalent to or lower than the installed cost of a compacted soil liner when the soil is transported from an off-site location, or when soil amendments such as bentonite are required. Another factor is the revenue gained through faster heap leach pad construction when using GCLs. GCLs can often be deployed at a faster rate than compacted low-permeability soil liners can be constructed, and offer a preferable working surface for deploying and welding the overlying geomembrane. Additionally, GCLs are factory-controlled materials, with consistent bentonite distribution and hydraulic performance. As such, GCLs are less likely than compacted soil liners to yield failing CQA test results. These factors suggest that GCLs allow for a shorter construction schedule and an earlier start to leaching operations.

CONCLUSIONS

Lining systems in mining applications can consist of a geomembrane underlain by either a soil liner or a GCL. When under load, geomembranes are vulnerable to damage from large stones both in the soil subgrade and in the overlying drainage layer. There has been limited information published regarding geomembrane puncture in mining applications, where extreme loads are encountered and angular, large-diameter crushed ore is often used as the drainage medium above the geomembrane. Considering the recent price increases in precious and commodity metals, and the increased environmental sensitivity of the mining industry, there may now be even stronger incentive to limit geomembrane punctures and PLS loss through the liner system in mining applications.

Results of high-load static puncture tests have shown that geomembrane/GCL composite liners may be subject to less puncture damage than geomembrane liners alone over compacted soil subgrades. A feasibility study of two lining alternatives for an example copper heap leach pad was performed. Theoretical liner leakage calculations revealed that, for a reasonable set of assumptions for a hypothetical copper heap leach, a geomembrane/GCL composite liner would be expected to allow only a fraction as much leakage as a geomembrane/compacted soil composite. The resulting improvement in PLS capture is expected to result in a significant increase in copper recovery and increased revenue (potentially hundreds of thousands of dollars per year).

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