The use of Geosynthetics in the Reclamation of an Oil Sands Tailings Pond

Full scale closure and reclamation activities have been underway at Suncor's Pond 1 since 2007. The cap cross-section consists of (from top to bottom), a 500-mm thick vegetated cover soil layer, a 610-mm coarse sand layer, a low-permeability layer, and a prepared sand subgrade. The intent of the low permeability layer was to limit surface water percolation into the capped sands until the vegetation and reclamation soil layers are sufficiently established. The initial design called for a 2 foot compacted soil liner with a hydraulic conductivity of 1×10^{-7} cm/s. However, a plastic-laminated geosynthetic clay liner (GCL), Bentomat CL, was selected as the hydraulic barrier in place of the 2 feet of compacted clay.

This paper presents a comparison between compacted clay liners and GCLs. Typically compacted clay liners are selected as barrier layers when adequate borrow sources are available nearby. Compacted clay liners are typically thick, between 0.6 to 0.9 meters and cannot be accidentally punctured, like thinner geosynthetics can. However, compacted clay liners are difficult to construct and are subject to deterioration from factors such as differential settlement, desiccation, and freeze-thaw action. Of particular importance in this project was the cold climate. Studies have shown that compacted clay liners can experience an increase of several orders of magnitude in hydraulic conductivity due to freeze-thaw cycles. In addition, compacted clay liners can be difficult to construct due to the variability of borrow source characteristics and the ability to consistently meet the required hydraulic conductivity.

In comparison, GCLs have been determined to be equivalent, or superior, to compacted clay liners in regards to hydraulic issues and physical/mechanical issues. With regards to construction issues, because they are thinner, GCLs are more susceptible to puncture damage and lateral squeezing/thinning during construction than compacted clay. However, this type of installation damage can be limited with sound construction practices. In addition, GCL hydraulic conductivity is not susceptible to freeze-thaw cycles; testing has shown that after 150 freeze thaw cycles, GCLs maintained a low hydraulic conductivity. This was an especially important factor due to the average temperatures of -19°C at the Northern Alberta site.

Because of the lack of nearby clay borrow sources and material consistency, the cold temperatures, and the ease and speed of installation, Bentomat CL, a plastic-laminated GCL was selected as the hydraulic barrier layer in the Pond 1 reclamation cover. This GCL consisted of 3.6 kg/m^2 of sodium bentonite clay, needlepunched between woven and nonwoven geotextiles. In addition, a 0.1-mm (4-mil) HDPE plastic geofilm was laminated to the nonwoven geotextile for improved hydraulic performance. This GCL is certified to a hydraulic conductivity of 5×10^{-10} cm/sec. When compared to the compacted clay liner, this GCL is expected to allow only a small fraction of the percolation expected through a conventional compacted soil cover.

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ABSTRACT: Suncor Pond 1, near Fort McMurray, Alberta, serves as an industry milestone — the first surface reclamation of an oil sands tailings pond. During the design and infill operations, a low-permeability hydraulic barrier was identified as an element of the reclamation cap needed to limit percolation. A plastic-laminated geosynthetic clay liner (GCL) was selected as the barrier layer in lieu of a traditional compacted soil liner. The GCL was selected for several reasons, including: low hydraulic conductivity ($5x10^{-10}$ cm/sec), material consistency and quality control, simplicity and speed of installation, and ability to install in extreme cold temperatures. The paper will discuss each of these design and installation considerations, as well as providing performance data from other similar applications. Construction of the geosynthetic capping system began in late 2009, with capping operations to be completed in 2010.

1 BACKGROUND

Full scale closure and reclamation activities have been underway at Suncor's Pond 1 since 2007. Densified tailings (DT) sand has been beached from north to south, progressively displacing mature fine tailings (MFT) to the south end of the deposit for pumping to other ponds. Infilling was completed in late 2009, with landform construction and capping progressing into 2010.

The Pond 1 reclamation landscape will feature a small shallow wetland in the southwestern corner of the site connected to a series of swales intended to collect surface water from throughout the pond and transport the flows to the wetland and eventually away from the area. Hummocks and mounds at various scales will promote surface water drainage between the swales as well as add landscape diversity to the beach area. These features are shown in Figure 1, with a reclamation cap area of approximately 244 hectares. Reclamation material will be placed over the site to promote plant growth and establish a boreal forest environment and also provides the primary barrier against infiltration of water from the surface. The cap cross-section consists of (from top to bottom), a 500-mm thick vegetated cover soil layer, a 610-mm coarse sand layer, a low-permeability layer, and a prepared sand subgrade (Figure 2). The intent of the low-permeability layer was to limit surface water percolation into the capped sands until the vegetation and reclamation soil layers are sufficiently established. Initially, the design called for the low-permeability layer to be a thick compacted soil liner, with a hydraulic conductivity of $1x10^{-7}$ cm/sec. However, a geosynthetic clay liner (GCL) was selected as the hydraulic barrier layer in the Pond 1 reclamation cover in lieu of the compacted clay liner. A technical comparison of two types of hydraulic barrier layers, and the rationale for selecting a GCL, is presented in the following sections.

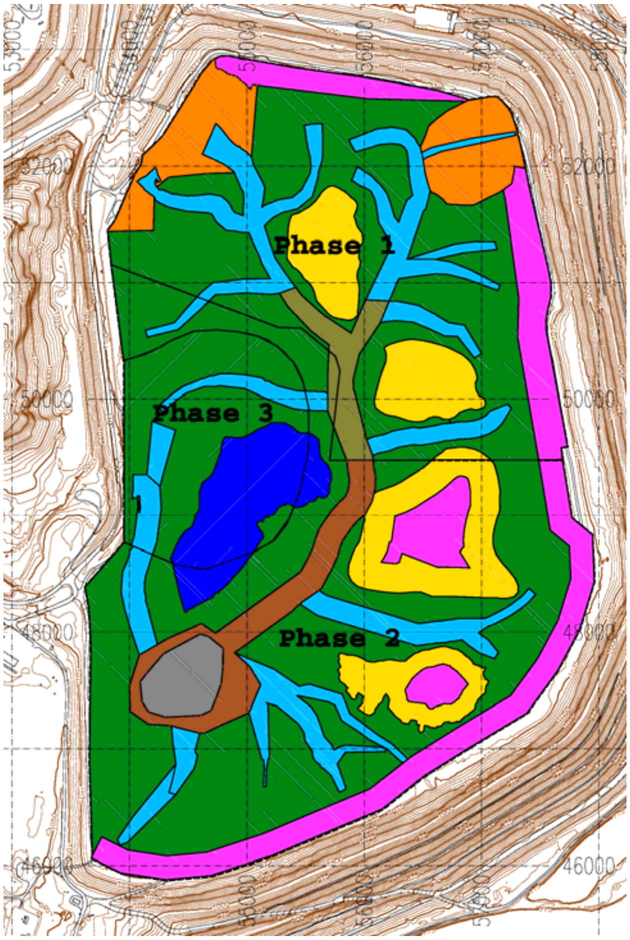

Figure 1. Site Map

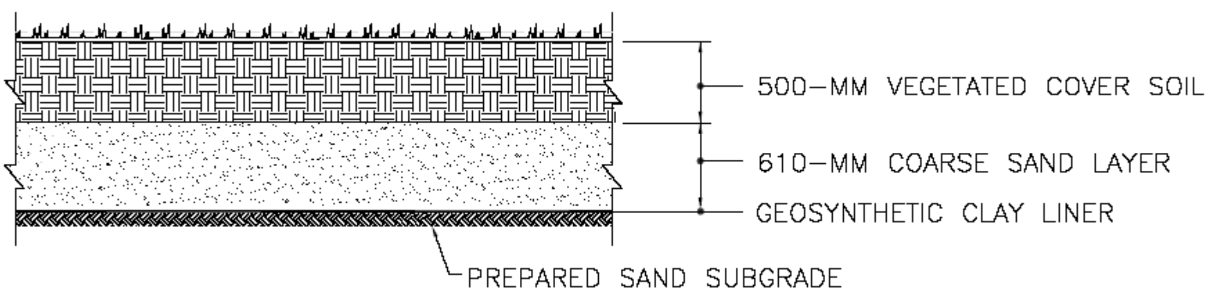

Figure 2. Typical cap cross-section

2 COMPACTED CLAY LINERS

Compacted soil liners have been traditionally used as barrier layers in landfill and mine closures to limit the infiltration of surface water into the buried waste. Soil liners are often selected because an adequate borrow source is located nearby. Assuming a clay-rich soil, a low hydraulic conductivity liner can be achieved if the soil is compacted within a specific range of water contents and dry unit weights. Compacted clay liners are generally thick, usually between 0.6 to 0.9-meters thick, and cannot be accidentally punctured, like thinner geosynthetics can. However, compacted clay liners can be difficult to construct and are subject to deterioration from various factors, including differential settlement, desiccation, and freeze-thaw action (Koerner and Daniel, 1993).

A factor of particular importance in cold weather regions like Northern Alberta is resistance to freeze-thaw cycles. Numerous studies have shown that freezing of compacted clay liners can produce significant increases in hydraulic conductivity [including, Erickson et al (1994), Benson and Othman (1993), and Kraus and Benson (1994)]. Kraus and Benson performed hydraulic conductivity tests on specimens obtained from compacted clay liner test plots before and after a winter season. Results indicated that the compacted clay liners had an increase in hydraulic conductivity of several orders of magnitude, from approximately 1 x 10^{-8} cm/sec to greater than 1 x 10^{-5} cm/sec. Extensive crack networks were present in the after-winter specimens. These cracks serve as preferential flow paths and are the primary cause of the high measured hydraulic conductivities. During freezing, cracks form in the clay due to the formation of ice lenses. As the temperature increases, the ice thaws, and voids in the clay are left behind, allowing preferential pathways for flow. Similarly, Benson and Othman (1993) found that clay hydraulic conductivity increased by 2 orders of magnitude after three to five freeze-thaw cycles. Erickson et al (1994) saw increases in CCL field test pads of up to 4 orders of magnitude.

Even without such long-term environmental factors, soil liners are susceptible to erratic field performance due to the many hard-to-control variables involved in their construction. Factors such as borrow source characteristics (e.g., clay variability, clay clods, or excessive amounts of gravel), moisture content, compaction equipment/procedures, inter-lift bonding, and slopes, cause practical difficulties which result in fluctuating permeability values in the field. For example, Rogowski (1990) constructed a homogeneous compacted clay liner over a small, 0.05-acre area, using specifications commonly used in constructing liners. Based on leakage rate measurements through the clay, the actual hydraulic conductivity of the liner varied by 4 orders of magnitude throughout the test area.

3 GEOSYNTHETIC CLAY LINERS

Geosynthetic clay liners (GCLs) are bentonite clay-based liners that often used as a substitute for compacted clay in solid waste and mining applications. Koerner and Daniel (1993) evaluated the differences between GCLs and compacted clay in terms of three technical issues: Hydraulic; Physical/Mechanical; and Construction. They determined that GCLs are equivalent, or superior to, compacted clays in regards to hydraulic issues and physical/mechanical issues. In regards to construction issues, the authors determined that, because they are thinner, GCLs are more susceptible to puncture damage and lateral squeezing/thinning during construction than compacted clay. However, they also noted that this type of installation damage can be limited with sound construction practices.

A plastic-laminated GCL was selected as the hydraulic barrier layer in the Pond 1 reclamation cover. The GCL consists of 3.6 kg/m^2 (0.75 lbs/ft^2) of sodium bentonite clay, needlepunched between woven and nonwoven geotextiles. A 0.1-mm (4-mil) HDPE plastic geofilm was laminated to the nonwoven geotextile for improved hydraulic performance. Overall, the GCL was selected for several reasons, including: low hydraulic conductivity (5x10^{-10} cm/sec), lack of nearby clay borrow sources, material consistency and quality control, simplicity and speed of installation, and ability to install in extreme cold temperatures. These considerations are discussed in more detail below.

3.1 *Hydraulic Performance*

The theoretical hydraulic performance (i.e., leakage) of either a compacted clay liner or a GCL can be estimated using Darcy's Law, which states that the flow through a porous medium is proportional to the hydraulic head and the hydraulic conductivity. Figure 3 presents the results of these theoretical calculations. The compacted clay liner was assumed to have a thickness of 0.6-m and a hydraulic conductivity of 1×10^{-7} cm/sec. The plastic-laminated GCL was assumed to have a thickness of 1 cm and a hydraulic conductivity of 5×10^{-10} cm/sec. A comparison of the graphs in Figure 3 shows that a GCL is the superior hydraulic barrier, expected to only allow a small fraction of the percolation expected through a conventional compacted soil cover. Although these are only theoretical calculations, based on several assumptions, the calculated values do seem consistent with measured field data, as discussed below.

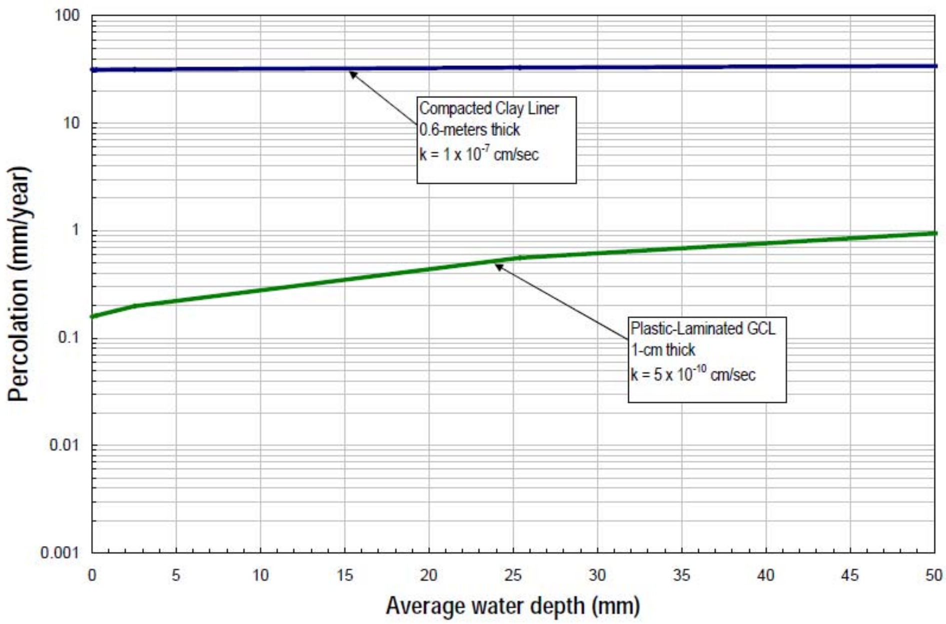

Figure 3. Theoretical Percolation Estimates Through Selected Cap Alternatives

3.2 *GCL Field Performance at Past Similar Sites*

Benson et al. (2007) present a case history describing the hydraulic performance of a final cover for a coal ash landfill, where the barrier layer consisted of a composite GCL in lieu of a compacted clay layer. The site, which is located in southwestern Wisconsin, receives 892 mm of precipitation per year. The composite GCL installed at the Wisconsin site is very similar to the material used to cap Suncor Pond 1. The GCL contained 3.6 kg/m^2 of granular sodium bentonite, was encased between nonwoven and woven geotextiles, and was laminated with a 0.1-mm thick polyethylene geofilm. The cover profile consists of a 760-mm-thick vegetated surface layer (silty sand), the GCL, and a 150-mm-thick layer of interim cover soil (silty sand) placed over the ash.

Two 4.3 x 4.9 m pan lysimeters were installed beneath the cover to monitor the percolation rate (discharge from the base of the cover). The lysimeters were filled with pea gravel and drained to a still well, which was periodically pumped to determine the volume of water collected by the lysimeter. Two separate plots were constructed: the first had the laminated GCL installed with the geofilm downward; the second had the geofilm oriented upward. Percolation rates remained low in both lysimeters. Over a five-year period, the average measured percolation rates for the two lysimeters were 2.6 mm/yr and 4.1 mm/yr. These percolation rates represent less than 0.5% percent of precipitation, indicating that the GCL is serving as a very effective hydraulic barrier at the Wisconsin landfill site.

3.3 *GCL Cold Weather Performance*

Northern Alberta has long, very cold winters, with an average winter temperature of -19 °C, and a record low temperature of -50 °C. Clearly, the ability to withstand and perform in cold weather were important considerations when selecting the low-permeability liner for Pond 1. Kraus et al (1997) found that after being frozen and thawed 20 times, GCLs maintained a low hydraulic conductivity. A similar evaluation of freeze-thaw resistance of GCLs was performed in 2006 by the Idaho National Engineering Environmental Laboratory (INEEL). GCL samples were exposed to repeated freeze-thaw cycles in the laboratory at pressures encompassing final cover (20 kPa) and bottom liner (60 kPa) applications. Samples were tested in the laboratory after 3, 9, 15, 21, 30, 45, 75, 100, 125, and 150 freeze-thaw cycles. Hydraulic conductivity testing found no appreciable changes, even after 150 freeze-thaw cycles. Examination of the GCLs while frozen and after thawing reveal that ice segregation does occur in GCLs, but the cracks formed during ice segregation close when the bentonite thaws because the thawed bentonite is very soft and compressible.

Additionally, to determine whether the plastic-laminated GCL could be handled and installed in extreme cold temperatures without undue risk of damage, Precision Geosynthetic Laboratories was contracted to perform a low-temperature testing program on the material in their Anaheim, California laboratory. Specifically, the following tests were performed:

- ASTM D6768, Tensile strength. Tests performed at both room temperature and after cooling to -40 °C.
- ASTM D4833, Puncture strength. Tests performed at both room temperature and after cooling to -40 °C.
- ASTM D1790, Brittleness temperature of plastic sheeting by impact. Samples were first cooled to -40 °C, wrapped in a closed loop on an anvil, struck with a 6-lb swinging arm, and then checked for signs of cracking.
- ASTM D1970, Low-temperature flexibility. Samples were cooled to -40 °C, bent repeatedly around a 1-inch mandrel, and then check for signs of cracking.

The laboratory test results in Table 1 show that samples of the plastic-laminated GCL cooled to subzero temperatures (-40 °C) did not experience any reduction in tensile or puncture strength, and passed both the ASTM low-temperature brittleness and flexibility tests. These data, together with the freeze/thaw data cited in the literature, indicate that GCLs can withstand the rigors of cold weather installation. Installation of a compacted clay liner or a polyethylene geomembrane would not likely have been possible for temperatures less than 0°C. The use of a GCL therefore allowed construction to proceed through the cold winter months, reducing the overall construction schedule, as discussed further below.

Table 1. Cold-Weather Testing Results

Property	*Room Temperature (22 °C)*	*Cold Weather (-40 °C)*
Puncture Resistance (ASTM D4833)	552 N (σ = 35 N)	640 N (σ = 18 N)
Tensile Strength (ASTM D6768)	480 N (σ = 45 N)	561 N (σ = 9 N)
Brittleness Temperature by Impact (ASTM D1790)	--	Passed (no signs of cracking)
Low Temperature Flexibility (ASTM D1970)	--	Passed (no signs of cracking)

4 OTHER PRACTICAL CONSIDERATIONS

In addition to the technical considerations outlined above, the GCL also offered several practical benefits:

- Freight. GCLs are packaged and delivered in rolls. One truckload of GCL rolls can cover approximately 3,350 square meters (36,000 square feet). By comparison, over 200 truckloads of clay, hauled from a borrow source 10 km away, would have been required to cover the same area with a 0.6-meter thick compacted clay liner. Over the entire Pond 1 cap area, this represents a dramatic difference in the number of trucks; tens of thousands of truckloads of clay compared to only a few hundred truckloads of GCL. In addition to the obvious safety and logistical issues involved with routing such a large number of trucks to the job site, time was also a factor: The majority of the GCL was delivered within a 1-month timeframe, which would not have been possible with clay.

- Speed/Ease of Installation. Since GCLs are supplied in large rolls that are simply unrolled into 4.57-m x 45.7-m rectangular panels in the field, they are more straightforward to install compared to compacted clay liners, which require careful moisture conditioning and compaction. GCLs are seamed by overlapping adjacent panels 0.15- to 0.3-m and applying supplemental granular bentonite (0.4 kg/m) to the overlap area. In addition, a pneumatically-powered geosynthetic installation device was used to deploy the GCL at Suncor Pond 1. The installation device was mounted on a large-capacity tractor, as shown in Photograph 1. As the tractor operator drove forward, a ground operator used a control cable to unroll the GCL onto flat panels. Using this equipment, more than a hectare per day of GCL was safely deployed. No issues with liner puncturing were noted during the installation.

- Quality Control. Since GCLs are manufactured under controlled factory settings, they are much more consistent materials requiring less on-site quality control testing compared to compacted clay liners. Manufacturing quality control testing is performed at the plant in accordance with ASTM D5889, Quality Control of GCLs. In contrast, compacted clay liners have high inherent variability, requiring numerous and frequent field tests, including Atterberg limits and soil particle size (1 every 800 m^3), water content and density (13 tests per hectare per lift), and hydraulic conductivity (3 tests per hectare per lift).

- Schedule. A major project driver was schedule. As indicated previously, at low ambient temperatures, it would not have been possible to construct a compacted clay liner. Cold weather delays related to compacted clay would have pushed the project completion date well past 2010. The use of a GCL allowed construction to proceed through the cold winter months, reducing the overall construction schedule.

5 SUMMARY

Geosynthetics were critical in successful design and completion of the Suncor Pond 1 reclamation project. A GCL was selected as the low-permeability hydraulic barrier in the cover system for several reasons, including: low hydraulic conductivity ($5x10^{-10}$ cm/sec), lack of nearby clay borrow sources, material consistency and quality control, simplicity and speed of installation, and ability to install in extreme cold temperatures. Construction of the geosynthetic capping system began in late 2009, with capping operations to be completed by September 2010. Because of the tight deadline, much of the construction activities took place during the cold winter months in late-2009 and early-2010. This would not have been possible if a traditional compacted clay liner was used.

Photograph 1. GCL Installation

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