Geosynthetic Clay Liners in Coal Combustion Residual Containment Applications

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Introduction

Compacted clay liners have been historically used as barrier layers in waste and liquid containment applications. Compacted clay is often selected because an adequate borrow source is located nearby; 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[1]. Geosynthetic clay liners (GCLs) are sodium bentonite clay-based hydraulic barriers commonly used as alternatives to conventional compacted clay liners in waste and liquid containment applications. GCLs consist of a minimum of 0.75 lbs/ft^2 of sodium bentonite, typically between two geotextile layers, with a certified laboratory hydraulic conductivity of 5×10^{-9} cm/s. This paper discusses the use of GCLs in coal combustion residual (CCR) applications in lieu of compacted clay liners, as well as important design considerations related to these materials, including:

- Hydraulic Performance.
- Chemical Compatibility.
- Shear Strength and Slope Stability.

Hydraulic Performance

USEPA regulations for solid waste landfills (40 CFR Part 258) require that landfill liners be designed as composite systems, consisting of two components: a geomembrane liner, and a minimum 2-foot thick low-permeability soil layer with a maximum permeability of 1×10^{-7} cm/s. As discussed below, hydraulic equivalency of GCLs to compacted clay liners has been demonstrated through theoretical calculations and field performance data, allowing GCLs to be considered an acceptable alternate to the low-permeability soil component of landfill liners.

Giroud[2] formulated semi-empirical expressions for estimating leakage rates through defects in geomembranes. These formulas indicate that the leakage rate through a geomembrane defect is in part controlled by the hydraulic conductivity of the underlying clay. Using input values and assumptions representative of typical landfill conditions, the Giroud equations show that a geomembrane/GCL composite liner would be expected to have a lower leakage rate than a geomembrane/compacted clay composite liner. These theoretical predictions are supported by actual liner leakage measurements. As part of a major study completed for the USEPA, researchers collected measurements from 91 different landfills, spanning 289 cells[3]. Three different types of primary liners were studied (geomembrane alone, geomembrane/compacted clay and geomembrane/GCL), all with underlying leak detection layers (either sand and geonet). As shown in Figure 1, based on the measurements from all sites with sand leak detection layers, average leakage rates through the geomembrane/GCL composite liners were significantly less than through the geomembrane/compacted clay rates. As a result, USEPA concluded that "GCL technology is an alternative that performs at or above standard federal performance levels"[4].

Chemical Compatibility

Chemical compatibility is another important design consideration, as it can influence hydraulic performance. The amount of bentonite swelling, and therefore, the GCL permeability, can be influenced by the presence of divalent cations (e.g., calcium and magnesium) and high ionic strength solutions. Laboratory test methods are available in cases of uncertainty over GCL chemical compatibility. ASTM has developed both short-term screening-level bentonite tests (ASTM D6141[7]) and long-term hydraulic conductivity tests (ASTM D6766[8]).

The topic of GCL chemical compatibility has been the subject of much study in recent years, with several important references available in the literature. One of these references, Kolstad et al[5], reported the results of several long-term hydraulic conductivity tests (ASTM D6766) involving GCLs in contact with various multivalent (i.e., containing both sodium and calcium) salt solutions. Based on the results of these tests, the researchers found that a GCL's hydraulic conductivity can be estimated if the ionic strength (I) and the ratio of monovalent to divalent ions (RMD) in the permeant solution are both known.

CCRs are generated during power generation processes, and can include fly ash (FA), bottom ash (BA), boiler slag, and flue gas desulfurization (FGD) residuals. These different CCRs are either managed separately, or more commonly, are mixed together and co-managed. In a report prepared by the Electric Power Research Institute (EPRI)[6], researchers analyzed field leachate samples collected from 33 different CCR facilities in 15 states. The sites were located primarily in the Eastern and Midwestern US, where coal-fired power plants predominate. The objective of the study was to evaluate leachate samples associated with a range of coal types, combustion systems, and management methods. The study found that the chemical constituents in a given CCR waste stream and their leachability can vary by coal type and combustion/collection process. Major constituents included sulfates, sodium, calcium, and magnesium. CCR leachates associated with subbituminous and lignite coals tend to be sodium-rich, and have higher ionic strength compared with leachates associated with bituminous coal. Concentrations of most constituents are generally highest in FGD leachate, then in ash landfill leachate, and then in ash impoundment samples. In general, most CCR leachates are moderately to strongly alkaline regardless of coal type or process.

Using the chemical data provided in the EPRI report, GCL chemical compatibility with CCR leachates was evaluated using the method developed by Kolstad. This evaluation is presented in Figure 2. The overall database (77 samples) showed a wide range of ionic strength and RMD values, resulting in a wide range of predicted GCL hydraulic conductivity values, between 1.8 x 10^{-10} and 3.1 x 10^{-6} cm/s, with a geometric mean value of 2.8 x 10^{-9} cm/s. However, the highest hydraulic conductivity and ionic strength values were associated with one specific site, an FGD impoundment where sluice water was recirculated, resulting in higher concentrations. CCR leachate chemistries from the remaining sites indicate much better expected performance: Over 96% of the samples corresponded to expected hydraulic conductivity values less than 10^{-7} cm/s, and over 90% of the samples corresponded to expected GCL hydraulic conductivity values less than 10^{-8} cm/s. In particular, the leachate chemistry associated with fly ashes and bottom ashes predicted GCL hydraulic conductivity values between 10^{-10} and 10^{-8} cm/s.

The GCL hydraulic conductivity values predicted by the Kolstad model appear to be consistent with past laboratory testing results. Figure 3 presents an excerpt of hydraulic conductivity testing performed on GCLs in contact with a CCR leachate derived from a Western fly ash. The Western fly ash was chosen as the most conservative due to its higher calcium content. Eight hydraulic conductivity tests were performed under four different hydration conditions to model potential field conditions. The final hydraulic conductivity of the GCLs ranged from 5 x 10^{-10} to 1 x 10^{-9} cm/s, on the same order of magnitude as the Kolstad predictions for fly ash leachates.

In the case of some FGD leachates, specifically those where sluice water is recirculated to produce higher concentration solutions, GCL manufacturers have developed polymer-amended bentonite clays, which have been successfully used on selected projects involving higher-strength FGD leachates. In such cases, project-specific testing is recommended during the design stage to confirm compatibility.

In addition to leachate chemistry, another project-specific consideration that can influence chemical compatibility is confining pressure. The hydraulic conductivity values predicted in Figure 2 assume a confining pressure of 2.9 psi (representing less than 5 feet of waste or soil cover). Certain applications, such as landfill bottom liners, involve up to several hundred feet of waste, resulting in high compressive loads on the liner systems. Petrov et al[9] showed that higher confining pressures will decrease bentonite porosity, and decrease GCL permeability. Daniel[10] found that higher confining pressures will improve hydraulic conductivity even when the GCL is permeated with a concentrated (5,000 mg/L) calcium chloride solution.

Additional laboratory testing, intended to provide a better understanding of the hydraulic performance of GCLs (both those manufactured with standard bentonite clay and with polymer-amended clays) in contact with different CCR leachates under different confining pressures, is currently underway.

Slope Stability

Stability is an important consideration whenever soil or waste is placed on a lined slope. The weight of the soil or waste will induce a downslope shear force on the layers beneath it. Geosynthetics, such as geomembranes and GCLs, can serve as a preferential slip plane. The challenge in these situations is to ensure that the driving force is not greater than the resisting forces keeping the liner stable. Two types of slope stability assessments are important for CCR applications: Global stability, where sliding of the waste mass along the bottom of the liner system is evaluated, and veneer stability, where sliding of the thin cover soil layer on top of the liner system is evaluated. Both types of slope stability assessments require an understanding of the slope geometry, the unit weights and shear strengths of the waste, soils, and liner materials, pore pressures, and external loadings, such as construction vehicles or seismic events. When evaluating GCLs, the internal and interface shear properties of GCLs must also be considered. There are two categories of GCLs, unreinforced and reinforced, each with very different shear properties. Since hydrated unreinforced bentonite has relatively low shear strength, unreinforced GCLs are not recommended for slopes greater than 10H:1V. Reinforced GCLs, on the other hand, are manufactured using an aggressive needlepunching process, allowing them to be used in many applications with slopes steeper than 3H:1V. Direct shear testing, performed using project-specific materials, over the range of normal loads expected in the field, is recommended to verify the shear strength values used in the slope stability analysis.

Summary

GCLs are hydraulic barriers commonly used as alternatives to compacted clay liners in various waste and liquid containment applications. There are three main design considerations when using these materials: hydraulic performance, chemical compatibility, and shear strength/slope stability. Liner performance data collected from 91 municipal solid waste landfill sites have demonstrated that GCLs are hydraulically equivalent or superior to compacted clay liners. A review of a large database (77 samples) of CCR leachate chemistry from 33 different sites shows that, with the exception of some higher-strength FGD residuals, CCR leachate is generally compatible with GCLs. Additional laboratory testing, intended to provide a better understanding of the hydraulic performance of GCLs (both those manufactured with standard bentonite clay and with polymer-amended clays) in contact with different CCR leachates under different confining pressures, is currently underway. In order to ensure slope stability, direct shear testing is recommended to verify the shear strength values used in the slope stability analysis.

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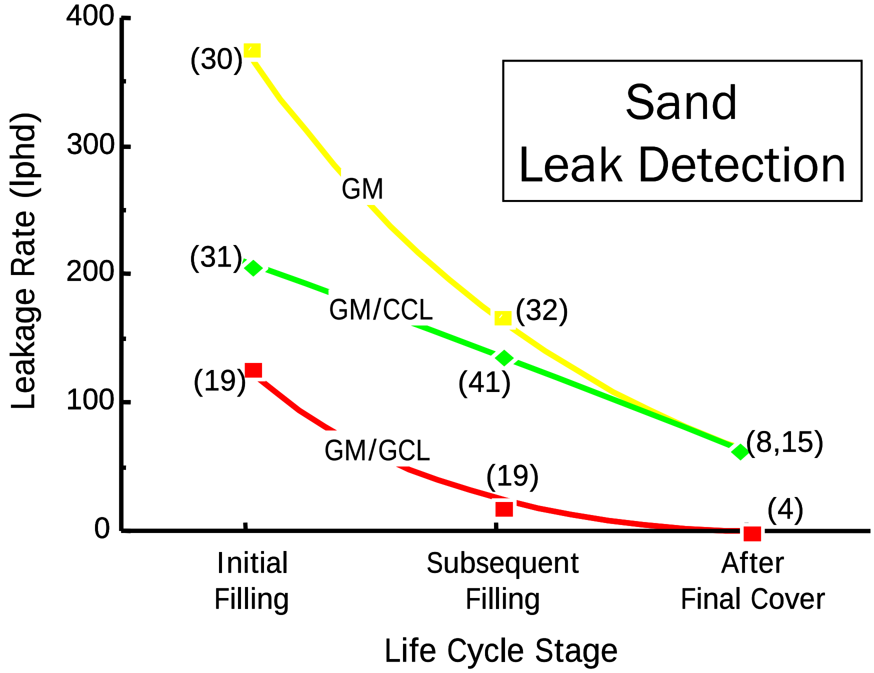

FIGURE 1 – LINER LEAKAGE RATE COMPARISONS (GRAPH PROVIDED BY THE GEOSYNTHETIC RESEARCH INSTITUTE, BASED ON DATA FROM BONAPARTE ET AL, 2002)

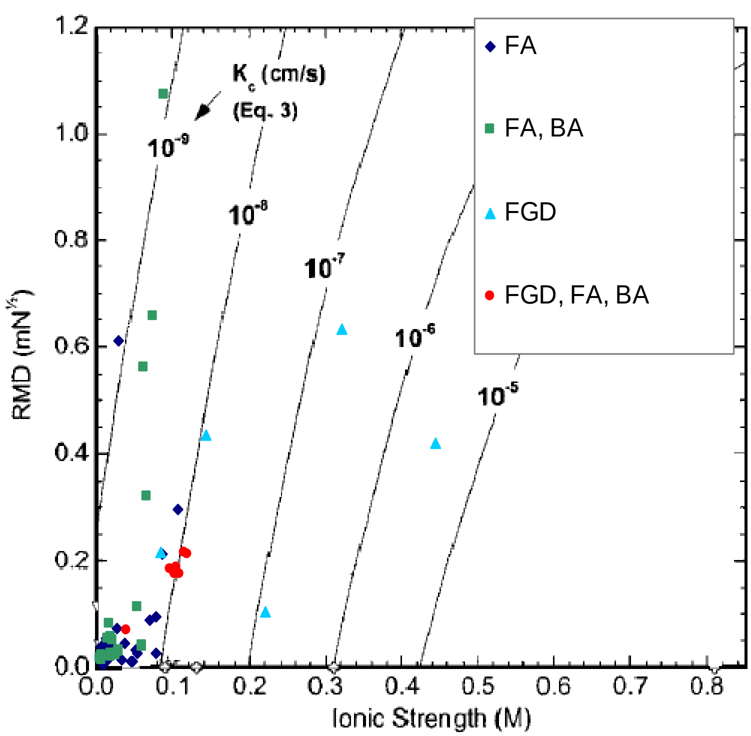

FIGURE 2 – PREDICTED GCL HYDRAULIC CONDUCTIVITY VALUES WITH CCR LEACHATES (BASED ON EPRI, 2006 AND KOLSTAD ET AL, 2004)

TEST #	CONDITION			HYDRAULIC CONDUCTIVITY (cm/s)
	PERMEANT	EXPOSURE (48 hours)	PREHYDRATION	
1	Water	Water	Yes	1.0×10^{-9}
2	Water	Water	Yes	9.2×10^{-10}
3	Leachate	Leachate	No	7.9×10^{-10}
4	Leachate	Leachate	No	9.0×10^{-10}
5	Leachate	Water	Yes	6.5×10^{-10}
6	Leachate	Water	Yes	5.9×10^{-10}
7	Leachate	None	No	5.2×10^{-10}
8	Leachate	None	No	6.3×10^{-10}

FIGURE 3 – GCL HYDRAULIC CONDUCTIVITY RESULTS WITH FLY ASH (CONFIDENTIAL CCR PROJECT, WISCONSIN)