HYDRATION AND PERMEATION PROPERTIES OF POLYMER BENTONITE COMPOSITE GEOSYNTHETIC CLAY LINERS (GCLs)

ABSTRACT

Hydraulic barriers for waste containment systems have been continuously studied to find suitable liners for said facilities. Geosynthetic clay liners (GCLs) have emerged as a viable candidates as hydraulic barriers in waste containment applications due to the ability of bentonite to swell and self-heal if punctured and the ease of installation. GCLs are made of two geotextiles sandwiching a thin layer of sodium bentonite or sodium bentonite glued to the geomembrane. Sodium bentonite can be either a granular or powdered form.

Conventional sodium bentonite GCLs were adequate as hydraulic barriers. However, leachates have become much harsher over time as more processing plants and more hazardous waste are produced. Dynamic environmental factors like rising sea levels lead to saltwater intrusion of groundwater, and higher water tables also negatively influence the integrity of conventional sodium bentonite GCLs, in regions like Florida where the water table is close to the ground surface. Hydration from groundwater of increasing salinity can hamper the swelling capabilities of bentonite.

Commercially available GCLs are now being modified with a polymer to improve the hydraulic performance of bentonite. Polymer mitigates the effects of harsh leachates. Polymer-modified GCLs show better hydraulic performance than conventional sodium bentonite GCLs. Polymers used in commercially available polymer-modified GCLs are proprietary; therefore, the specific

polymers used are unknown. With knowledge of the specific polymer, important information like repeating units, functional groups, molecular weight, and degree of polymerization are known. The polymer properties are pertinent for designing polymer-modified GCLs to withstand specific salt solutions. Gradation can also be a viable tool for designing conventional sodium bentonite GCLs. Though it is unanimously known that grainsize influences the hydraulic performance of bentonite, more work needs to be done on analyzing the gradation of bentonite as a viable design tool for sodium bentonite GCLs.

This study entails strategic projects intending to lead to the design GCLs for specific purposes and not in a random fashion. The hydraulic performance of commercially available conventional sodium bentonite GCLs and polymer-modified GCLs pre-hydrated with synthetic groundwater chemistry in Florida before permeation with landfill leachates was determined.

Based on the results with commercially available GCLs, a controlled study was done to analyze the hydraulic behavior of laboratory-manufactured conventional sodium bentonite GCLs of different gradations made from the same batch of bentonite. Gradation of GCLs becomes extremely important when bentonite is permeated with leachates of high ionic strengths or an abundance of divalent cations that inhibits osmotic swelling. At this point, the hydraulic behavior depends on the bentonite's specific surface area to seal macropores.

Hydraulic testing of laboratory-prepared polymer-modified GCLs using xanthan gum was performed. The GCLs had the same gradation with different xanthan gum loading. The specific polymer can provide information on molecular weight, functional groups, and repeating units. The mechanism responsible for the observed hydraulic improvement observed for xanthan gum-treated bentonite compared to conventional sodium bentonite GCLs is ascertained.

Pre-hydration of commercially available conventional sodium bentonite GCLs showed that coarse-grained GCLs attained higher gravimetric water content than fine-grained GCLs. The chemistry of the hydrating solution influenced the achieved gravimetric water content. Both coarse-grained and fine-grained GCLs achieved higher gravimetric water contents when hydrated with low ionic strength groundwater than with high ionic strength groundwater. The inclusion of polymers in GCLs caused an increase in the gravimetric water content of GCLs. Polymer-modified GCLs with a higher polymer content attained greater gravimetric water contents during pre-hydration.

Fine-grained conventional sodium bentonite GCL had a lower hydraulic conductivity than coarse-grained conventional sodium bentonite GCL. Polymer-modified GCLs with coarse-grained bentonite had lower hydraulic conductivity than conventional coarse-grained bentonite. Polymer-modified GCL with a higher polymer content resulted in lower hydraulic conductivity. Conventional sodium bentonite GCLs and polymer-modified GCLs pre-hydrated with low ionic strength groundwater before permeation with municipal solid waste (MSW), co-disposal (CD), and ash monofil (AM) leachates had lower hydraulic conductivity than GCLs pre-hydration high ionic strength groundwater.

A key observation of commercial conventional sodium bentonite and polymer-modified GCL of similar grainsize distribution is the similar hydraulic performance. Conventional GCL pre-hydrated with tap water (TW) had similar hydraulic conductivity to polymer-modified GCL permeated without pre-hydration. The similarities in the hydraulic conductivities of pre-hydrated conventional GCLs and non-pre-hydrated polymer-modified GCLs suggested that the polymer in bentonite acts as an agent of osmotic swelling in harsh leachate conditions.

Gradation is an important parameter when considering the preparation of conventional bentonite GCLs for hydraulic barrier applications. In dilute environments, the gradation of bentonite is less significant to achieve low hydraulic conductivity due to adequate osmotic swelling that can result in low hydraulic conductivity of coarse-grained and fine-grained GCLs. Gradation is essential when bentonite is permeated with harsh leachates, which causes the reduction or absence of osmotic swelling. The swell index does not represent the hydraulic performance for bentonite of the same quality but different grainsize distributions.

The effects of gradation on the hydraulic performance of sodium bentonite GCLs can only be achieved via hydraulic testing. Hydraulic conductivity tests of laboratory-prepared conventional bentonite GCLs of different gradations signify that coarse-grained and fine-grained bentonite GCLs had similarly low hydraulic conductivities when permeated with dilute solutions. An increase in the permeant's ionic strength and divalent cations caused an increase in the hydraulic conductivity of both GCLs. However, fine-grained GCLs consistently retained lower hydraulic conductivity than coarse-grained GCLs in harsh leachate environments. The better hydraulic performance of fine-grained GCL than coarse-grained GCL in harsh leachates where osmotic swelling is obsolete is attributed to fine-grained bentonite's high specific surface area. Fine-grained bentonite is more closely packed than coarse-grained bentonite for the same mass of bentonite in a fixed volume. The closer the bentonite granules are the fewer pathways for the leachate seepage.

A controlled study to determine the mechanism attributed to the improved hydraulic conductivity of polymer-modified GCLs was done using xanthan gum as an additive to sodium bentonite. Four GCLs of the same gradation were used with xanthan gum loading of 0, 1, 3, and 5%, respectively. The swell index of bentonite increased with an increase of xanthan gum. The hydraulic conductivity of the GCLs decreased as the xanthan gum loading in the bentonite increased. Fourier transform infrared spectroscopy (FTIR) spectra of eluted xanthan gum indicated that Ca^{2+} cations bond with the carboxylate group (COOH) on the xanthan gum. There is an evident downshift of the COOH group after Ca^{2+} - xanthan gum interaction which signifies complex coacervation of deprotonated carboxylic acid (COO^-) and Ca^{2+} cations. Scanning electron micrographs (SEM) of GCL with 0% xanthan gum permeated with deionized water resembles GCLs with 3% and 5% xanthan gum permeated with 200 mM $CaCl_2$ solution. GCLs with 0% xanthan gum permeated with deionized water had a similar hydraulic conductivity to GCLs with 3% and 5% xanthan gum permeated with 200 mM $CaCl_2$. Energy dispersive X-ray (EDAX) analysis of the same samples used for SEM show that Na+ cations in conventional and xanthan gum treated GCLs were negligible when permeated with 200 mM $CaCl_2$. The Ca^{2+} cations decrease as the xanthan gum concentration increases. GCL with 5% xanthan gum permeated with 200 mM CaCl2 had a similar Ca^{2+} concentration as observed for GCL with 0% xanthan gum permeated with deionized water. X-ray fluorescence (XRF) analysis of eluted xanthan gum shows that the polymer is saturated with calcium concentration as in the bulk solution.