

Long-Term Hydraulic Conductivity and Cation Exchange of a Geosynthetic Clay Liner (GCL) Permeated with Inorganic Salt Solutions

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Abstract

Hydraulic conductivity tests were conducted on a geosynthetic clay liner (GCL) for more than 2.5 yr using inorganic salt solutions to evaluate how the long-term hydraulic conductivity is affected by cation concentration and valence. Only small changes (i.e., $\leq 2X$) in hydraulic conductivity (K) occurred during the test duration when the permeant solution was deionized (DI) water or 100 mM KCl and NaCl solutions. For weak CaCl_2 solutions (≤ 20 mM), the hydraulic conductivities initially (< 0.2 yr) were comparable to the hydraulic conductivity obtained with DI water, but gradually increased by a factor of 2 to 13 over a period of nearly 2 yr. In contrast, the GCL permeated with strong CaCl_2 solutions (≥ 50 mM) reached equilibrium nearly immediately, with a hydraulic conductivity approximately 2 orders of magnitude higher than the hydraulic conductivity to DI water.

key word : hydraulic conductivity, cation exchange, geosynthetic clay liner, cation concentration, cation valence, waste containment

Introduction

Geosynthetic clay liners (GCLs) are hydraulic barriers that consist of a thin layer of bentonite (5-10 mm) sandwiched between two geotextiles or glued to a geomembrane. GCLs are used in waste containment facilities because of their low hydraulic conductivity ($< 10^{-8}$ cm/s) to water, ease of installation, and perceived resistance to environmental distress. When there is no geomembrane, the hydraulic conductivity of a GCL is controlled by the hydraulic conductivity of the bentonite, which is directly related to the physical properties (e.g., water content, void ratio, free swell) and chemical composition (e.g., exchangeable cations) of the bentonite (Shackelford et al. 2000, Jo et al. 2001).

Several studies have shown that permeation with either strong (≈ 50 mM) solutions or solutions containing a large fraction of polyvalent cations can cause the hydraulic conductivity of GCLs to

increase an order of magnitude or more. On the other hand, the hydraulic conductivity of GCLs permeated with weak (≈ 20 mM) solutions tends to be comparable to the hydraulic conductivity obtained with deionized (DI) or tap water. However, the durations of most tests employing weak solutions typically have been too short (< 0.5 yr and 10 pore volumes of flow, or PVF) to establish chemical equilibrium (Shackelford et al. 2000, Jo et al. 2001). Since most field applications of GCLs are intended to last for several decades (or even hundreds of years) where hundreds of PVF may occur, hydraulic conductivities obtained from short-term tests with a modest PVF may not reflect the long-term hydraulic conductivity, i.e., after chemical equilibrium is established. The objectives of the study were to evaluate the long-term temporal behavior of the hydraulic conductivity of a GCL as a function of concentration and cation valence.

Materials and Methods

The GCL used in this study contained granular sodium bentonite encased between a slit-film monofilament woven geotextile and a staple-fiber non-woven geotextile. Results of X-ray diffraction showed that the bentonite consists primarily of montmorillonite (78 ± 5 %), but also contains quartz, opaline silica, feldspars, calcite, and illite/mica. The cation exchange capacity (CEC) of the bentonite ranges between 53 - 75 meq/100g. The exchange complex is dominated by Na^+ and has the following composition : $\text{Na} = 43.8 \pm 16.8$ meq/100g, $\text{Ca} = 16.5 \pm 5.4$ meq/100g, $\text{Mg} = 6.0 \pm 3.4$ meq/100g, and $\text{K} = 0.8 \pm 0.4$ meq/100g. The salt solutions used in this study consisted of the 100 mM KCl and NaCl solutions and CaCl_2 solutions having various concentrations (5 mM - 50 mM). DI water was used as the reference solution.

The hydraulic conductivity tests were conducted in flexible-wall permeameters using the falling head water-constant tailwater procedure on GCL specimens. No backpressure was applied so that effluent samples for chemical analyses (i.e., pH, EC, and salt concentrations) could be conveniently collected. After termination of each hydraulic conductivity test, the bentonite was characterized for final thickness, final water content, and composition of the exchange complex.

Results and Discussion

Temporal characteristics of the hydraulic conductivity (K), the pH and EC ratios, and the cation concentrations in the effluent are shown in Figs. 1 to 4 for GCLs permeated with DI water and the NaCl, KCl, and CaCl_2 solutions.

Only a small change ($\approx 2X$) in hydraulic conductivity occurred during the long test duration (> 2.3 yr) when DI water was used as the permeant solutions (Fig. 1). The hydraulic conductivity was initially 1.7×10^{-9} cm/s and increased by at most a factor of 1.8 by the end of testing, indicating that from a practical perspective, no change in hydraulic conductivity occurred during the long-term tests conducted with DI water. Hydraulic conductivities obtained with 100 mM NaCl and KCl solutions were comparable to those obtained using DI water, and varied by at most a factor of 1.8 throughout the test duration (Fig. 2).

The exchange complex of the bentonite after permeation with DI water was comparable to that of bentonite in a new GCL (i.e., mole fraction of sodium on the exchange complex, $X_{Na} \sim 0.7$, mole fraction of calcium on the exchange complex, $X_{Ca} \sim 0.2$). A similar condition was observed for the tests with the 100 mM NaCl solution (i.e., $X_{Na} \sim 0.8$, $X_{Ca} \sim 0.15$), even after approximately 3 yr permeation. In contrast, for the KCl solution, exchange of K^+ for Na^+ was essentially complete ($X_{Na} \sim 0$, mole fraction of potassium on the exchange complex, $X_K \sim 1.0$) at the end of testing (~ 2.5 yr). Despite these chemical changes, the long-term K (test duration > 2.3 yr) obtained with DI water, the KCl solution, and the NaCl solution differed at most by a factor of 1.3 relative to short-term K (test duration ~ 0.2 yr), indicating that exchange of Na^+ by K^+ had no practical effect on the hydraulic conductivity even though Na and K have different hydrated radii.

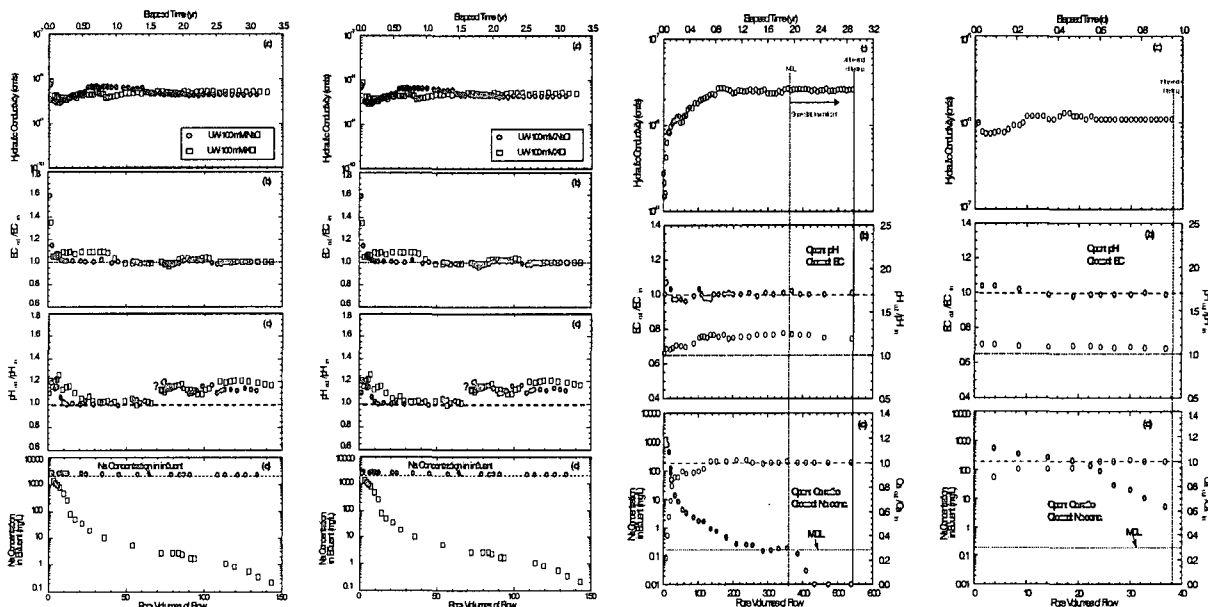


Fig. 1 DI water solutions (a) Hydraulic conductivity, (b) EC ratio, (c) pH ratio, and (d) Na concentration in the effluent) Fig. 2 NaCl and KCl solutions (a) Hydraulic conductivity, (b) EC and pH ratios, and (c) Na concentration in the effluent) Fig. 3 20 mM CaCl₂ solution (a) Hydraulic conductivity, (b) EC ratio, (c) pH ratio, and (d) Na concentration in the effluent) Fig. 4 50 mM CaCl₂ solution (a) Hydraulic conductivity, (b) EC ratio, (c) pH ratio, and (d) Na concentration in the effluent)

For weak CaCl₂ solutions (i.e., = 20 mM), the hydraulic conductivity initially stabilized at approximately 2.0×10^{-9} cm/s after 3 to 15 PVF (~ 0.2 yr) had passed through the GCL (Fig. 3). This is essentially the same hydraulic conductivity as obtained with DI water (3.0×10^{-9} cm/s). At this time, the influent and effluent EC and chemical composition still were appreciably different (Fig. 3). After approximately 20 to 50 PVF, the hydraulic conductivity continued to increase at a slow and statistically significant rate. The hydraulic conductivity did not become stable (i.e., statistically insignificant trend) until 360 PVF, when the Na concentration dropped below the Method Detection Limit (MDL) (Fig. 3). Exchange complex measurements made after testing showed that exchange of Ca^{2+} for Na^+ was essentially complete ($X_{Na} \sim 0$, $X_{Ca} \sim 1.0$) at the end of testing, regardless of concentration of the permeant solution. Thus, by the end of testing, chemical interactions between the permeant liquid and the bentonite were effectively complete.

The hydraulic conductivity of GCLs permeated with solutions having high concentration (=50 mM) was approximately two orders of magnitude higher than the hydraulic conductivity of GCLs permeated

with DI water (Fig. 4). Equilibrium was reached quickly (< 1 d) for these tests because the high Ca concentration results in rapid exchange for Na, which results in high hydraulic conductivity.

Summary and Conclusions

Long-term hydraulic conductivities obtained with 100 mM NaCl and KCl solutions were within a factor of two of those obtained using DI water. For weak divalent solutions (i.e., $\text{CaCl}_2 = 20$ mM), the GCL initially had low hydraulic conductivity (2.0×10^{-9} cm/s), and no change in hydraulic conductivity occurred during the first 3 ~ 15 PVF (< 0.2 yr). Subsequently, the hydraulic conductivity gradually increased by a factor of 3 to 15 ($\sim 3.0 \times 10^{-8}$ cm/s) until the concentration of the permeant salt in the influent and effluent were comparable and the Na concentration in the effluent was negligible. On the other hand, the hydraulic conductivity of GCLs permeated with strong divalent solutions ($\text{CaCl}_2 > 50$ mM) was approximately 2 orders of magnitude higher (1.0×10^{-6} cm/s) than the hydraulic conductivity of GCLs permeated with DI water, and the equilibrium hydraulic conductivity was reached nearly immediately.

References

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