

EVALUATING GCL CHEMICAL COMPATIBILITY

Sodium bentonite is an effective barrier primarily because it can absorb water (i.e., hydrate and swell), producing a dense, uniform layer with extremely low hydraulic conductivity, on the order of 10^{-9} cm/sec. Water absorption occurs because of the unique physical structure of bentonite and the complementary presence of sodium ions in the interlayer region between the bentonite platelets. Sodium bentonite's exceptional hydraulic properties allow GCLs to be used in place of much thicker soil layers in composite liner systems.

Sodium bentonite which is hydrated and permeated with relatively "clean" water will perform as an effective barrier indefinitely. In addition, past testing and experience have shown that sodium bentonite is chemically compatible with many common waste streams, including Subtitle D municipal solid waste landfill leachate (TR-101 and TR-254), some petroleum hydrocarbons (TR-103), deicing fluids (TR-109), livestock waste (TR-107), and dilute sodium cyanide mine wastes (TR-105).

In certain chemical environments, the interlayer sodium ions in bentonite can be replaced with cations dissolved in the water that comes in contact with the GCL, a process referred to as ion exchange. This type of exchange reaction can reduce the amount of water that can be held in the interlayer, resulting in decreased swell. The loss of swell usually causes increased porosity and increased GCL hydraulic conductivity. Experience and research have shown that calcium and magnesium are the most common source of compatibility problems for GCLs (Jo et al, 2001, Shackelford et al, 2000, Meer and Benson, 2004, Kolstad et al, 2004/2006). Examples of liquids with potentially high calcium and magnesium concentrations include: leachates from lime-stabilized sludge, soil, or fly ash; extremely hard water; unusually harsh landfill leachates; and acidic drainage from calcareous soil or stone. Other cations (ammonium, potassium, and sodium) may contribute to compatibility problems, but they are generally not as prevalent or as concentrated as calcium (Alther et al, 1985), with the exception of brines and seawater. Even though these highly concentrated solutions do not necessarily contain high levels of calcium, their high ionic strength can reduce the amount of bentonite swelling, resulting in increased GCL hydraulic conductivity.

This reference discusses the tools that can be used by a design engineer to evaluate GCL chemical compatibility with a site-specific leachate or other liquid.

HOW IS GCL CHEMICAL COMPATIBILITY EVALUATED?

Ideally, concentration-based guidelines would be available for determining GCL compatibility with a site-specific waste. Unfortunately, considering the variety and chemical complexity of the liquids that may be evaluated, as well as the many variables that influence chemical compatibility (e.g., prehydration with subgrade moisture [TR-222], confining stress [TR-321], and repeated wet-dry cycling [TR-341]), it is not possible to establish such guidelines. Instead, a three-tiered approach to evaluating GCL chemical compatibility is recommended, as outlined below.

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Tier I

The first tier is a simple review of existing analytical data. 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 (2004/2006), reported the results of several long-term hydraulic conductivity tests 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 long-term hydraulic conductivity (as determined by ASTM D6766) can be estimated if the ionic strength (I) and the ratio of monovalent to divalent ions (RMD) in the permeant solution are both known, using the following empirical expression:

$$\frac{\log K_c}{\log K_{DI}} = 0.965 - 0.976 \times I + 0.0797 \times RMD + 0.251 \times I^2 \times RMD$$

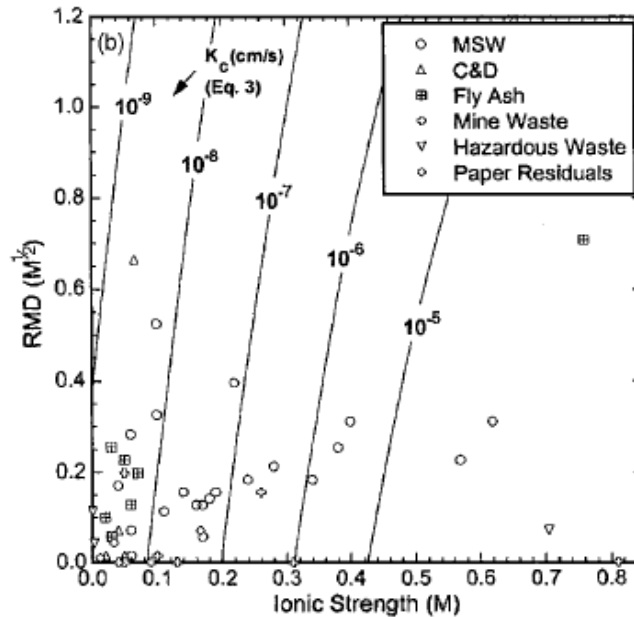
where:

I = ionic strength (M) of the site-specific leachate.

RMD = ratio of monovalent cation concentration to the square root of the divalent cation concentration ($M^{1/2}$) in the site-specific leachate.

K_c = GCL hydraulic conductivity when hydrated and permeated with site-specific leachate (cm/sec).

K_{DI} = GCL hydraulic conductivity with deionized water (cm/sec).



Using this tool, a Tier I compatibility evaluation can be performed if the major ion concentrations (typically, calcium, magnesium, sodium, and potassium) and ionic strength (estimated from either the total dissolved solids [TDS], or electrical conductivity [EC]) of the site leachate are known. For example, using the relationship above and MSW leachate data available in the literature, Kolstad et al. were able to conclude that high hydraulic conductivities (i.e., $>10^{-7}$ cm/sec) are unlikely for GCLs in base liners in many solid waste containment facilities.

In many cases, the Tier I evaluation is sufficient to show that a site-specific leachate should not pose compatibility problems. However, if the analytical data indicate a potential impact to GCL hydraulic performance, or if there is no analytical data available, then it is necessary to proceed to the second tier, involving bentonite "screening" tests, which are described below.

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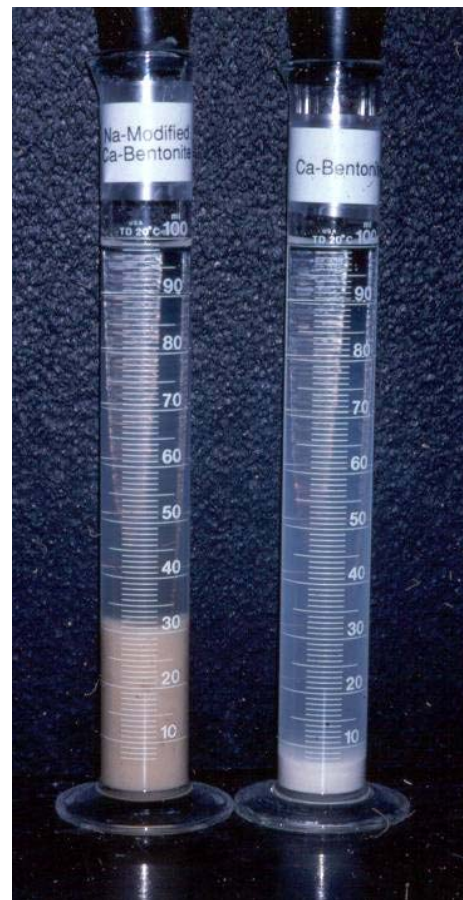
Tier II

The next tier of compatibility testing involves bentonite screening tests, performed in accordance with ASTM Method D6141. These tests are fairly straightforward, and can be performed at one of CETCO's R&D laboratories or at most commercial geosynthetics testing laboratories.

Liquid samples should be obtained very early in the project, such as during the site hydrogeological investigation. It is important that the sample collected is representative of actual site conditions. Synthetic leachate samples may also be considered for use in the compatibility tests. The objective is to create a liquid representative of that which will come in contact with the GCL. At least 1-gallon (4-Liter) of each sample should be submitted for testing. Samples should be accompanied by a chain-of-custody or information form. When a sample is received at the CETCO laboratory, the following screening tests are performed to assess compatibility:

- Fluid Loss (ASTM D5890) – A mixture of sodium bentonite and the site water/leachate is tested for fluid loss, an indicator of the bentonite's sealing ability.
- Swell Index (ASTM D5891) – Two grams of sodium bentonite are added to the site water/leachate and tested for swell index, the volumetric swelling of the bentonite.
- Water quality – The pH and EC of the site water/leachate are measured using bench-top water quality probes. pH will indicate if any strong acids (pH < 2) or bases (pH > 12) are present which might damage the bentonite clay. EC indicates the strength of dissolved salts in the water, which can hamper the swelling and sealing properties of bentonite if present at high concentrations.
- Chemistry – The site water/leachate is analyzed for major dissolved cations using ICP. The analytical results can then be used to perform a Tier I assessment, if one has not already been done.

As part of this testing, fluid loss and free swell tests are also performed on clean, deionized, or "DI" water for comparison to the results obtained with the site water/leachate sample. Sodium bentonite tested with DI water is expected to have a free swell of at least 24 mL/2g and a fluid loss less than 18 mL. Changes in bentonite swell and fluid loss indicate that the constituents dissolved in the site water may have an impact on GCL hydraulic conductivity. However, since it is only a screening tool, there are no specific values for the fluid loss and swell index tests that the clay must meet in order to be considered chemically compatible with the test liquid in question. Differences between the results of the baseline tests and those conducted with the site leachate may warrant further hydraulic testing.



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A major drawback of the D6141 tests is the potential for a false “negative” result, meaning that the bentonite swell index or fluid loss might predict no impact to hydraulic performance, where in reality, there may be a long-term adverse effect. This is primarily a concern with dilute calcium or magnesium solutions, which may slowly affect GCL hydraulic performance over months or years. Short-term (2-day) bentonite screening tests would not be able to capture this type of long-term effect. This is not expected to be a concern with strong calcium or magnesium or high ionic strength solutions, which have been shown to impact GCL hydraulic conductivity almost immediately, and whose effects would therefore be captured by the short-term bentonite screening tests. Another limitation of the bentonite screening tests is their inability to simulate site conditions, such as clean water prehydration, increased confining pressure, and wet/dry cycling. These limitations can be in part addressed by moving to the third tier, a long-term GCL hydraulic conductivity test, discussed below.



Tier III

The third-tier compatibility evaluation consists of an extended GCL hydraulic conductivity test performed in accordance with ASTM D6766. This test method is essentially a hydraulic conductivity test, but instead of permeating the GCL sample with DI water, the site-specific leachate is used. Since leachates can often be hazardous, corrosive, or volatile, the testing laboratory must have permeant interface devices, such as bladder accumulators, to contain the test liquid in a closed chamber, and prevent contamination of the flow measurement and pressure systems, or release of chemicals to the ambient air.

Method D6766 provides some flexibility in specifying the testing conditions so that certain site conditions can be simulated. For example, in situations where the GCL will be deployed on a subgrade soil that is compacted wet of optimum, the GCL will very likely hydrate from the relatively clean moisture in the subgrade (TR-222), long before it comes in contact with the potentially aggressive site leachate. Lee and Shackelford (2005) showed that a GCL which is pre-hydrated with clean water before being exposed to a harsh solution is expected to exhibit a lower hydraulic conductivity than one hydrated directly with the solution. Depending on the expected site conditions, the D6766 test can be specified to pre-hydrate the GCL with either water (Scenario 1) or the site liquid (Scenario 2).

Another site-specific consideration is confining pressure. Certain applications, such as landfill bottom liners and mine heap leach pads, involve up to several hundred feet of waste, resulting in high compressive loads on the liner systems. Although the standard confining pressure for the ASTM D6766 test is 5 psi (representing less than 10 feet of waste), the test method is flexible enough to allow greater confining pressures,

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thus mimicking conditions in a landfill bottom liner or heap leach pad. Petrov et al (1997) showed that higher confining pressures will decrease bentonite porosity, and tend to decrease GCL permeability. TR-321 shows that higher confining pressures will improve hydraulic conductivity even when the GCL is permeated with aggressive calcium solutions.

ASTM D6766 has two sets of termination criteria: hydraulic and chemical. To meet the hydraulic termination criterion, the ratio of inflow rate to outflow rate from the last three readings must be between 0.75 and 1.25. It normally takes between one week and one month to reach the hydraulic termination criterion. To meet the chemical termination criterion, the test must continue until at least two pore volumes of flow have passed through the sample and chemical equilibrium is established between the effluent and influent. The test method defines chemical equilibrium as effluent electrical conductivity within $\pm 10\%$ of the influent electrical conductivity. This requirement was put in place to ensure that a large enough volume of site liquid passes through the sample to allow slow ion exchange reactions to occur. Two pore volumes can take approximately a month to permeate through the GCL sample. However, reaching chemical equilibrium (effluent EC within 10% of influent EC), may take more than a year of testing, depending on the leachate characteristics.

ASTM D6766 is a very useful tool which provides a fairly conclusive assessment of GCL chemical compatibility with a site-specific leachate. However, the major drawback of the D6766 test is the potentially long period of time required to reach chemical equilibrium. This limitation reinforces the need for upfront compatibility testing early in the project. Clearly, requiring the contractor to perform this testing during the construction phase is not recommended.

WHAT DO THE ASTM D6766 COMPATIBILITY TEST RESULTS MEAN?

ASTM D6766 is currently the state-of-the-practice in the geosynthetics industry for evaluating long-term chemical compatibility of a GCL with a particular site waste stream. An ASTM D6766 test that is properly run until both the hydraulic (inflow and outflow within $\pm 25\%$ over three consecutive readings) and chemical (effluent EC within $\pm 10\%$ of influent EC) termination criteria are achieved, provides a good approximation of the GCL's long-term hydraulic conductivity when exposed to the site leachate. Jo et al (2005) conducted several GCL compatibility tests with weak calcium and magnesium solutions, with some tests running longer than 2.5 years, representing several hundred pore volumes of flow. The intent of this study was to run the tests until complete ion exchange had occurred, which required even stricter chemical equilibrium termination criteria than the D6766 test. The study found that the final GCL hydraulic conductivity values measured after complete ion exchange were fairly close to (within 2 to 13 times) the hydraulic conductivity values determined by ASTM D6766 tests, which took much less time to complete.

The laboratory that performs the chemical compatibility test, whether it is the CETCO R&D laboratory or an independent third-party laboratory, is only reporting the test results under the specified testing conditions, and is not making any guarantees about actual field performance or the suitability of a GCL for a particular project. It is the design engineer's responsibility to incorporate the D6766 results into their design to determine whether the GCL will meet the overall project objectives. Neither the testing laboratory nor the GCL manufacturer can make this determination.

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Also, it is important to note that the results of D6766 testing for a particular project are only applicable for that site, for the specific waste stream that is tested, and only for the specific conditions replicated by the test. For instance, D6766 testing performed at high normal loads representative of a landfill bottom liner should not be applied to a situation where the GCL will only be placed under a modest normal load, such as a landfill cover or pond. Similarly, the results of a D6766 test where the GCL was pre-hydrated with clean water should not be applied to sites located in extremely arid climates where little subgrade moisture is expected, unless water will be applied manually to the subgrade prior to deployment. And finally, since D6766 tests are normally performed on continuously hydrated GCL samples, the test results should not be applied to situations where repeated cycles of wetting and drying of the GCL are likely to occur, such as in some GCL-only landfill covers, as desiccation can worsen compatibility effects.

REFERENCES

1. Alther, G., Evans, J.C., Fang, H.-Y., and K. Witmer, (1985) "Influence of Inorganic Permeants Upon the Permeability of Bentonite," Hydraulic Barriers in Soil and Rock, ASTM STP 874, A.I. Johnson, R.K. Frobel, N.J. Cavalli, C.B. Peterson, Eds., American Society for Testing and Materials, Philadelphia, PA, pp. 64-73.
2. ASTM D 6141, Standard Guide for Screening Clay Portion of Geosynthetic Clay Liner for Chemical Compatibility to Liquids.
3. ASTM D 6766, Standard Test Method for Evaluation of Hydraulic Properties of Geosynthetic Clay Liners Permeated with Potentially Incompatible Liquids.
4. CETCO TR-101, "The Effects of Leachate on the Hydraulic Conductivity of Bentomat".
5. CETCO TR-103, "Compatibility Testing of Bentomat (Gasoline, Diesel and Jet Fuel)".
6. CETCO TR-105, "Bentomat Compatibility Testing with Dilute Sodium Cyanide".
7. CETCO TR-107, "GCL Compatibility with Livestock Waste".
8. CETCO TR-109, "GCL Compatibility with Airport De-Icing Fluid".
9. CETCO TR-222, "Hydration of GCLs Adjacent to Soil Layers".
10. CETCO TR-254, "Hydraulic Conductivity and Swell of Nonprehydrated GCLs Permeated with Multispecies Inorganic Solutions".
11. CETCO TR-321, "GCL Performance in a Concentrated Calcium Solution; Permeability vs. Confining Stress".
12. CETCO TR-341, "Addressing Ion Exchange in GCLs".
13. Jo, H., Katsumi, T., Benson, C., and Edil, T. (2001) "Hydraulic Conductivity and Swelling of Nonprehydrated GCLs with Single-Species Salt Solutions", *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 127, No. 7, pp. 557-567.
14. Jo, H., Benson, C., Shackelford, C., Lee, J., and Edil, T. (2005) "Long-Term Hydraulic Conductivity of a GCL Permeated with Inorganic Salt Solutions", *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 131, No. 4, pp. 405-417.

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15. Kolstad, D., Benson, C. and Edil, T., (2004) "Hydraulic Conductivity and Swell of Nonprehydrated GCLs Permeated with Multispecies Inorganic Solutions", *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 130, No. 12, December 2004, pp.1236-1249.
16. Kolstad, D., Benson, C. and Edil, T., (2006) Errata for "Hydraulic Conductivity and Swell of Nonprehydrated GCLs Permeated with Multispecies Inorganic Solutions".
17. Lee, J. and Shackelford, C., (2005) "Concentration Dependency of the Prehydration Effect for a GCL", *Soils and Foundations*, Japanese Geotechnical Society, Vol. 45, No. 4.
18. Meer, S. and Benson, C., (2004) "In-Service Hydraulic Conductivity of GCLs Used in Landfill Covers – Laboratory and Field Studies", Geo Engineering Report No. 04-17, University of Wisconsin at Madison.
19. Petrov, R., Rowe, R.K., and Quigley, R., (1997) "Selected Factors Influencing GCL Hydraulic Conductivity", *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 123, No. 8, pp. 683-695.
20. Shackelford, C., Benson, C., Katsumi, T., Edil, T., and Lin, L. (2000) "Evaluating the Hydraulic Conductivity of GCLs Permeated with Non-Standard Liquids." *Geotextiles and Geomembranes*, Vol. 18, pp. 133-162.

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