# Performance Analysis of GCLs as Barriers-A Review

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**Abstract.** Geosynthetic clay liner have been used over a decade to stave off problems such as leaching of hazardous chemicals from landfill containments which otherwise could cause ecological issues and endanger the environment. Low permeability is a highly desirable property for use as a liner material in landfills to effectively control the seepage of highly contaminated leachate which can pollute the soil and groundwater in the vicinity. GCLs contain bentonite essentially, which has a high montmorillonite content imparting swelling characteristics. The usage of GCLs is booming day by day in engineered landfills and they are being extensively researched on their different characteristics such as hydraulic conductivity, diffusion characteristics, mechanical properties, reaction to various chemicals, durability etc. This paper presents an overview of the major findings on the critical aspects affecting the various characteristic properties of GCLs. The performance of GCLs upon coming in contact with a higher concentration of salts, considering the actual composition of leachate has also been dealt in this study.

**Keywords***:* Geosynthetic clay liners; Landfills; Bentonite; Hydraulic conductivity

## 1 Introduction

### 1.1 Background

Geosynthetic clay liners are made up of a layer of sodium or calcium bentonite which is sandwiched between two layers of geosynthetics or geomembrane. Clay liners have picked up a ton of consideration over years as treatment to leachate problems because of very low hydraulic conductivity to water, *k* ($\leq 10^{-10}$ m/s) [Shackelford et al.,2000;Jo et al.,2001,2005;Kolstad et al.,2004; Lee and Shackelford, 2005 a,b; Lee et al.,2005; Shackleford et al.,2010].Lesser the hydraulic conductivity lesser will be the permeation of water and hence can be used for waste containment [Ishimori katsumi,2012; Rosin-Paumier and Touza-Foltz,2012 Liu et al.,2013,2014,2015; Mazzieri et al.,2013; Bouazza and Gates,2014; Makusa et al.,2014.].

Apart from this there are different points of interest of utilizing GCLs such as they have limited thickness, can be installed easily, cost effective and can resist differential settlement in the soil. Besides having so many advantages GCLs can lose their properties with time. The characteristic property of GCLs is their low hydraulic conductivity which can deteriorate when subjected to higher concentration of salts.

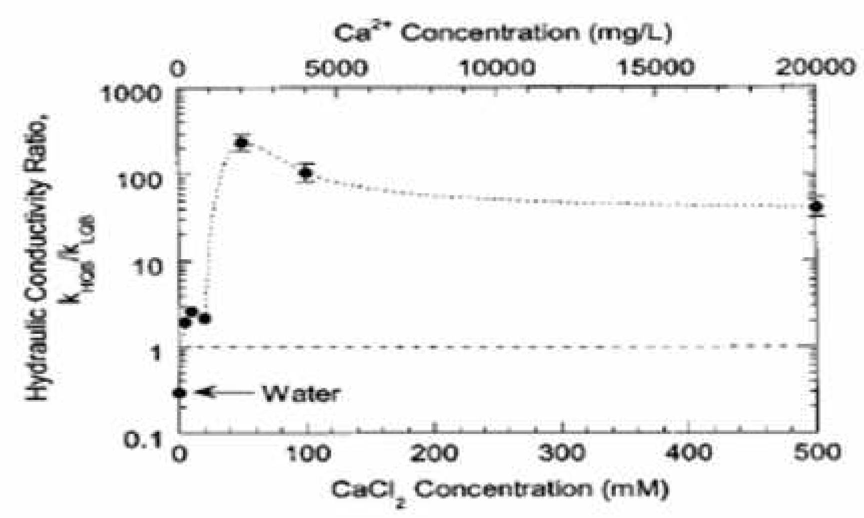
There are other aspects also which lead to the deterioration of GCLs and it has been a major concern to protect this property. Various researches have been carried out in which the hydraulic conductivity was analyzed and factors which led to its rise.

This study further discusses the factors analyzed by various researchers which lead to an increase in hydraulic conductivity.

## 2. **Bentonite Quality and Hydraulic Conductivity**

The characteristic property of bentonite that is hydraulic conductivity is principally influenced by montmorillonite content [Shackelford et al., 2000]. Bentonites are vulnerable to chemical composition of pore liquids that can cause the thinning of bentonite layer, can also cause increase in hydraulic conductivity [Mesri and Olson, 1971; Lin and Benson,2000].The distinction in hydraulic conductivity of two GCLs containing diverse characteristics of bentonite was evaluated based on permeation with water and chemical solution ($CaCl_2$) of different concentration [Jae-Myung lee and Charles D.Shackelford.,2005].The test were continued till chemical equilibrium in terms of solute concentration was not attained (i.e. $C_{out}$ / $C_{in}$ = 1) .Moreover it was found that GCLs having higher quality bentonite (GCL-HQB) which are characterized by having higher content of sodium montmorillonite (86%), higher plasticity index (548%) and higher cation exchange capacity (93 meq/100g) had three times lower hydraulic conductivity than GCL having lower quality bentonite (GCL-LQB) which have lesser montmorillonite content (77%),lesser plasticity index (393%) and lower cation exchange capacity (64 meq/100g), when permeated with water[Jae-Myung lee and Charles D.Shackelford.,2005] . However, when treated with $CaCl_2$ solution the GCL-HQB resulted in higher hydraulic conductivity. Subsequently it was noted that GCL-HQB are possibly more vulnerable than GCL-LQB.

The results in the difference of hydraulic conductivity were demonstrated by plotting the conductivity of specimen as a function of $CaCl_2$ liquid permeant.



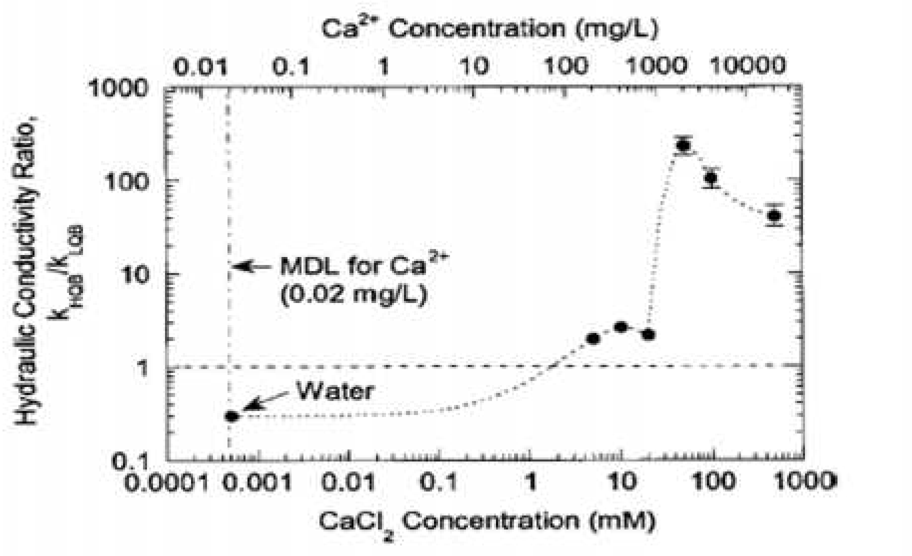



**Fig.1.** Ratio of Hydraulic conductivity of higher quality and lower quality bentonite. [Jae-Myung lee and Charles D. Shackelford.,2005]

## 3. Cation Exchange in GCLs

For bentonites utilized in GCLs, sodium (Na) is the essential interlayer cation, which binds water, boosts swelling, and lessens the pore spaces accessible for flow [Sabrina L. Bradshaw and Craig H. Benson]. Consequently, Na bentonites have very low hydraulic conductivity [Mesri and Olson 1971; Jo et.al. 2001;kolstad et al.2004;Guyonnet et al 2005,2009].Past studies have demonstrated that substitution of Na by multivalent cations can diminish the swelling ability of bentonite and resulting in increment of conductivity in GCLs [Shan and Daniel 1991; Petrov and Rowe 1997; Rahl and Daniel 1997; Lin and Benson 2000; Shackelford et al., 2000; Jo et al.,2001,2004; Vasko et al.,2001; Egloffstein 2002; Kolstad et al.,2004; Guyonnet et al.,2005,2009].This can also occur even when bentonites are permeated with low concentration of multivalent cations[Shackleford et al.,2000; Engloffstien 2002;Meer and Benson 2007;Jo et.al 2004,2005].

Most studies have researched how cation trade during permeation with simulated or actual MSW leachates can influence the conductivity of GCLs [Petrov and Rowe 1997; Ruhl and Daniel 1997; Ashmawy et al.2002; Shan and Lai 2002; Guyonet et al.2005, 2009]. For a given concentration, GCLs penetrated with arrangements containing monovalent cation displayed the best swelling and most minimal water driven conductivity, whereas GCLs provided with arrangements having trivalent cations had the least swelling and most elevated conductivity [Jo et al.2001]. Examinations were done that how circumneutral pH containing cations (both monovalent and divalent) disturbed swelling property of GCLs which is dependent on RMD [Kolstad et al.2004]. If the value of RMD lessens the swelling decreases and hence increase in hydraulic conductivity. RMD is the measure of relative abundance of monovalent and multivalent cations that is defined as

$$RMD = \frac{Mm}{\sqrt{Md}}$$

Where $M_m$ the molar concentration of monovalent cation; and Md is the molar concentration multivalent cation.

An equation is used to predict the hydraulic conductivity of GCLs to a chemical solution or leachate ($K_L$) as a function of the hydraulic conductivity to deionized water ($K_{DI}$) and the ionic strength and RMD of the permeant solution [Kolstad et al.2004]

$$\frac{logKL}{LogKD} = 0.965 - 0.976\,I + 0.0797RMD \quad + 0.251I^2\,RMD$$

**3.1. Effects of Municipal Solid Waste (MSW) and Stabilized inorganic hazardous waste.**

A few examinations have shown as to how the performance of GCLs is influenced by saturation with the leachate from municipal solid waste [Ruhl and Daniel,1997; Shan and Lai,2002; Gayonnet et al,2009; Bradshaw et al,2016].Liners which are passed through synthetic leachates can have conductivity multiple times (up to 50,000) higher than liners passed through deionized water (DIW), whereas hydraulic conductivities of GCLs permeated with actual MSW leachates generally are about the same as those obtained with actual MSW [Rauen and Benson,2008].The long term hydraulic conductivity of GCLs in equilibrium with MSW leachate is no greater than 5.6 times the hydraulic conductivity of DIW[Sabrina L. Bradshaw and Craig H.Benson,2013].The ratio of hydraulic conductivity of actual leachate relative to hydraulic conductivity of Deionized water ($K_L/K_{DI}$) is shown as a function of pore volume of flow (PVF) in fig 2.

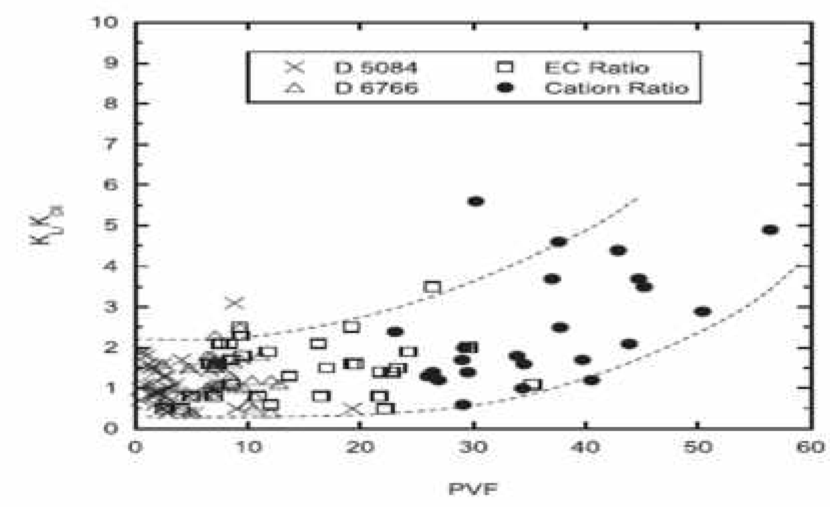


**Fig.2**. Hydraulic conductivity of synthetic MSW leachate relative to hydraulic conductivity of deionized water as a function of PVF [Sabrina L. Bradshaw and Craig H. Benson, 2013].

The permeation of bentonite with solidified/stabilized inorganic hazardous waste (SIHW) can possibly deteriorate the water retention property of GCLs [Bao Wang et al.,2019]. Effective stresses additionally assume a vital job in conclusion of hydraulics conductivity at 30 Kpa permeation with SIHW leachate had a detrimental effect on hydraulic performance [Bao Wang et al.2019]. However, it was also concluded that increasing stresses can check the negative impact initiated by SIHW leachate permeation. When the stresses were increased to 200 Kpa the GCLs had k values estimated below $1.0\times10^{-9}$ m/s, with the exception of non pre hydrated GCL-S specimen.

## 4. Diffusion and Membrane characteristics

Void ratio and confining stresses have a strong impact on diffusion coefficient in addition to this the solute concentration can have predominant effect on diffusion coefficient [Rowe, 1998 and Lake and Rowe, 2000]. Since solute restriction is a function of clay size, the size of the pores of clay fluctuates, the degree of solute limitations in clays, that behave as membrane, also fluctuates with the result that few pores confine solute movement while other do not [Malusis et al.,2003; Shackleford et al.,2003; Shackelford,2013a, b; Malusis and Daniyarov,2016].

Membrane behavior of GCLs depends primarily on the solute concentration because as the concentration of solutes increases in the pores, the DDLs (diffused double layer) and electric field, maintaining membrane behavior, also decreases which causes pores to expand and subsequently lessen the solute restriction [Fritz,1986].

The concentration at which membrane behavior ceases to exist is known as threshold concentration [Shackelford et al., 2003]. Chemico-osmotic pressure ($\Delta P$) is directly related to membrane efficiency coefficient, the reduction in $\Delta P$ results in decrease of solute restriction [Shackelford and Lee, 2003]. Studies have indicated that the relation between the membrane efficiency coefficient ($\omega$) and the logarithm of average salt concentration across the specimen (log $C_{ave}$) becomes nonlinear with increasing salt concentration [Shackelford et al., 2016]. It was found that the membrane behavior of GCL was demolished when the KCl concentration across the specimen was increased. The diffusion coefficient, D*, for both $Cl^-$ and $K^+$ increased by a factor of 1.6 and 2.0 respectively.

## 5. Conclusion

The main grail of this study was to collectively find the causes which fostered reduction in the performance of GCLs as a barrier. There is no unsureness that GCLs have proved to be the best substitute to the leaching problem of hazardous waste containments yet they should not be contemplated as a nostrum to perfectly control all problems. There are certain sources which can devastate the long-term service of GCLs and some of them have been discussed in this paper. The desiccation or thinning of bentonite can be related to many aspects such as quality of bentonite used, cation exchange, soil water characteristic curves, diffusion properties etc. The comprehensive contributions made by various researchers has led to the widespread knowledge of GCLs in using it as a barrier. However, there are certain aspects which need to be investigated more thoroughly such as effects of temperature on soil water characteristic curve because for wet paths the curves are difficult to measure. More importantly GCLs can be designed using different structural feature and inclusion of polymeric material fiber in such a way that they are recommendable for foreseen settlements.

## References


1. Ashmawy, A. K., El-Hajji, D., Sotelo, N., and Muhammad, N. (2002). Hydraulic performance of untreated and polymer-treated bentonite in inorganic landfill leachates. Clays and Clay Minerals., 50(5), 546–552.
2. Bouazza, A., Gates, w., 2014.Overview of performance compatibility issues of GCLs with respect to leachates of extreme chemistry. Geosynth. Int. 21(2), 151-167.
3. Fritz, S., 1986. Ideality of clay membranes in osmotic processes: a review. Clays and Clay Minerals 34, 214-223.
4. Guyonnet, D., et al. 2005.Geosynthetic clay liner interaction with leachate: correlation between permeability, microstructure, and surface chemistry. J. Geotech.Geoenviron.Eng.131:6(740), 740-749.
5. Guyonnet, D., et al.2009.Performance based indicators for controlling geosynthetic clay liners in landfill application. Geotext.Geomembr.,27(5),321-331
6. Ishimori, H., Katsumi, T., 2012.Temperature effects on the swelling capacity and barrier performance of geosynthetic clay liners permeated with sodium chloride solutions. Geotext.Geomembranes 33, 25-33.
7. Jo, H., Benson, C., Shackelford, C., Lee, J., Edil, T., 2005.Long-term hydraulic conductivity of non-prehydrated geosynthetic clay liner permeated with inorganic salt solution. J. Geotechnical Geoenvironmental Eng.131(4),405-417
8. Kolstad, D., Benson, C., Edil, T., 2004. Hydraulic conductivity and swell of non-prehydrated GCLs permeated with multi-species Inorganic solutions. J. Geotechnical Geoenvironmental Eng. 130 (12), 1236-1249.
9. Lake, C., Rowe, R., 2000. Diffusion of sodium and chloride through geosynthetic clay liners. Geotext. Geomembranes 18, 103-131.
10. Lee, J., Shackelford, C., 2005a.Concentration dependency of the prehydration effect for geosynthetic clay liner. Soils found. 45(4), 27-41.
11. Lee, J., Shackelford, C., 2005b.Impact of bentonite quality on hydraulic conductivity of geosynthetic clay liners. J. Geotechnical Geoenvironmental Eng. 131(1), 64-77.

12. Lee, j., Shackelford, C., Benson, C., Jo, H., Edil, T., 2005.Correlating index properties and hydraulic conductivity of geosynthetic clay liners. J. Geotechnical Geoenvironmental Eng.131 (11),1319-1329
13. Lin, L.-C., and Benson, C.H. (2000). Effect of wet and dry cycling on swelling and hydraulic conductivity of GCLs. J. Geotech.Geoenviron Eng., 126 (1), 40-49.
14. Liu, Y., Bouazza, A., Gates, W.P., Rowe, R.K., 2015.Hydraulic performance of geosynthetic clay liners to sulfuric acid solution. Geotext.Geoembranes 43(1), 14-23.
15. Liu, Y., Gates, W.P., Bouazza, A., 2013.Acid induced degradation of bentonite component used in geosynthetic clay liners. Geotext.Geomembranes 36,71-80
16. Liu, Y., Gates, W.P., Bouazza, A., 2014.Fluid loss as a quick method to evaluate hydraulic conductivity of geosynthetic clay liners under acidic condition. Can. Geotechnical J. 51(2), 158-163.
17. Makusa, G.p., Bradshaw, S.L., Berns, E., Benson, C.H., Knutsson, S., 2014.Freez-thaw cycling concurrent with cation exchange and the hydraulic conductivity of geosynthetic clay liners. Can. Geotechnical J.51, 591-598.
18. Malusis, M., Daniyarov, A., 2016. Membrane efficiency and diffusive tortuosity of a dense prehydrated geosynthetic clay liner. Geotext. Geomembranes.
19. Malusis, M., Shackelford, C., Olsen, H., 2003. Flow and transport through clay membrane barriers. Eng. Geol. 70 (2-3), 235-248.
20. Mazzieri, F., Di Emidio, G., Fratalocchi, E., Di Sante, M., Pasqualini, E., 2013. Permeation of two GCLs with an acidic metal-rich synthetic leachate. Geotext. Geomembrane. 40, 1e11.
21. Meer, S., and Benson, C. (2007). Hydraulic conductivity of geosynthetic clay liners exhumed from landfill final covers. J. Geotech. Geoenviron. Eng., 10.1061/ (ASCE) 1090-0241(2007)133:5(550), 550–563.
22. Mesri, G., Olson, R.E.1971.Mechanism controlling the permeability of clays. Clay liner miner., 19, 151-158.
23. Petrov, R.J., Rowe, R.K., 1997. GCL-chemical compatibility by hydraulic conductivity testing and factors impacting its performance. Canadian Geotechnical Journal 34 (6), 863–885.
24. Rauen, T. L., and Benson, C. H. (2008). Hydraulic conductivity of a geosynthetic clay liner permeated with leachate from a landfill with leachate recirculation. Proc., Geoamericas, International Geosynthetics Society (IGS), Jupiter, FL, 76–83.
25. Ruhl, J.L., Daniel, D.E., 1997. Geosynthetic clay liners permeated with chemical solutions and leachates. Journal of Geotechnical and Geoenvironmental Engineering 123 (4), 369–381.
26. Sabrina L. Bradshaw., Craig H. Benson., 2014.Effect of municipal solid waste leachate on hydraulic conductivity and exchange complex of geosynthetic clay liners. Geotech. Geoenviron Eng.140.
27. Shackelford, C., Benson, C., Katsumi, T., Edil, T., Lin, L., 2000.Evaluating the hydraulic conductivity of GCLs permeated with nonstandard liquids. Geotext.Geomembranes 18(2-4).133-162
28. Shackelford, C., Sevick, G., 2010.Hydraulic conductivity of geosynthetic clay liners to tailing impoundments solution. Geotext.Geomembranes 28(2), 149-162.
29. Shan, H. Y., and Lai, Y. J. (2002). Effect of hydrating liquid on the hydraulic properties of geosynthetic clay liners. Geotext.Geomembr., 20(1), 19–38.

30. Shan, H.Y., Daniel, D.E. (1991). Results of laboratory tests on a geotextile/bentonite liner material. Proceedings of the Geosynthetics 91, Vol. 2, pp. 517–535.
31. Vasko, S.M., Jo, H.Y., Benson, C.H., Edil, T.B., Katsumi, T., 2001. Hydraulic conductivity of partially prehydrated geosynthetic clay liners permeated with aqueous calcium chloride solutions. In: Proceedings of Geosynthetics'01. Industrial Fabrics Association International (IFAI), Saint Paul, Minnesota, pp. 689-699.