Hydraulic conductivity and chemical performance of Brazilian geosynthetic clay liner (GCL) using KCl and $CuCl_2$ $2H_2O$ solutions

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ABSTRACT: Clayey soils have been used as compacted clay liners (CCLs) in landfill, lagoons and embankments but this kind of soils do not exist in all places. Other solutions include the use as barriers of geosynthetic clay liners (GCLs), bentonite-soil mixture or geomembranes. When the GCL is used, performance evaluation is necessary in each application. Previous research shows an increase in the hydraulic condutivity as the concentration is increased for any solution, even with the monocation solutions. Research on GCL performance for long times and chemical compatibility with real lecheate have been necessary. This paper examines the behaviour of hydraulic conductivity and advection test of a GCL sodic bentonite using 0.023 M KCl and 0.0125 M $CuCl_2$ $2H_2O$ solutions. The hydraulic conductivity in the different specimens with distilled water was 10^{-11} m/s. The hydraulic conductivity obtained with KCl was similar to that obtained with distilled water. However the K^+ was adsorbed by the bentonite and the breakthrough curve was approximately linear, achieving C/C0 = 0.95 in 180 days. The Cu^{2+} ion was adsorbed in the first test days because ions were not detected in the effluent liquid. After 20 days, an increase of the hydraulic conductivity of the order of 200 times the initial value was observed and the Cu^{+2} concentration also increased in the effluent liquid. The different behaviour of the GCL with different valence ion solution are associated to changes in the thickness of the diffuse double layers.

1 INTRODUCTION

Methods of research to evaluate Geosynthetic Clay Liner (GCL) performances were developed in the last twenty years. The GCL has 10^{-11} to 10^{-12} m/s hydraulic conductivity when distilled water is used but this performance can be change if another liquid is percolated (Ruhl and Daniel, 1997; Petrov and Rowe 1997, Lee e Shackelford 2005 and others).

Ruhl and Daniel (1997) studied the hydraulic conductivity of different GCL using tap water and other fluids as real and simulated landfill leachate. Some GCLs were previously hydrated to being percolated with the simulated leachate. The hydraulic conductivity to distilled water was 10^{-11} to 10^{-12} m/s. This behaviour changed when other fluids were used. If the simulated leachate was used directly in the GCL, then the hydraulic conductivity increases about 1000 times. Mitchell (1993) suggests that this behavior can be related to changes in the thickness of the diffuse double layer of exchange cations clay.

Petrov e Rowe (1997) measured the hydraulic conductivity in GCL percolated by different NaCl concentration solutions in a fail head permeameter. The GCL was pre-hydrated with destilled water in different thick specimens. When the GCL was pre-hydrated the hydraulic conductivity value was about 10^{-11} to 10^{-10} m/s.

Results obtained by Shackelford et al. (2000) show changes in the hydraulic conductivity when 0,0125 M (≈ 500 mg/l) of $CaCl_2$ solution was used. The GCL had 10^{-11} m/s for 5 pore volume (PV) but the hydraulic conductivity increased to $3x10^{-10}$ m/s after 51 PV. The cation Ca replace the cation Na in the bentonite and this change reduces the thickness of the diffuse double layer increasing the hydraulic conductivity. Similar effects appeared in other GCL when they were percolated with different$ZnCl_2$ concentration solutions. The hydraulic conductivity value was reduced from 10^{-11} m/s to 10^{-7} m/s.

Lee and Shackelford (2005) described changes of 100 to 100.000 times in the value of hydraulic

conductivity when solutions of $CaCl_2$ higher than 1g/l were percolated through GCL.

These works show that both increase in the cation valence and solution concentration produced an increase in the hydraulic conductivity value of the GCL. The characteristic of permeant liquid was responsible for shrinking the double layer, which in turns generates an increase in the hydraulic conductivity.

The main goal of this work is to evaluate the hydraulic conductivity performance of the GCL under different solution percolation.

2 A BRIEF REVIEW

Transport by advection and dispersion of reactive solute in a homogeneous, isotropic and saturated soil is described by eq. 1 (Freeze and Cherry, 1979).

$$R_d \frac{\partial C}{\partial t} = D_h \frac{\partial^2 C}{\partial x^2} - v_x \frac{\partial C}{\partial x} \quad \text{eq. 1}$$

where R_d is the retardation factor, C concentration of the solute, t time, D_h hydrodynamic dispersion coefficient, v_x average pore water velocity.

The R_d can be calculated by eq. 2.

$$R_d = 1 + \frac{\rho_d K_p}{\theta} \quad \text{eq. 2}$$

where ρ_d is dry density, K_p partition coefficient, θ volumetric water content.

K_p represents the solute adsorption rate of the soil. R_d can be determined with batch tests (Roy et al., 1992) or by tests in column. This is preferred because it better represents the real situation in a clay barrier according to Shackelford (1994), but the batch tests are faster. Different adsorption isotherm models (linear, Freundlich and Langmuir) are used to determine K_p and the Freundlich and the Langmuir ones used more often.

$$S = K_f C^N \quad \text{Freundlich isotherm model}$$

K_f Freundlich constant, *N* Freundlich empirical constant, C equilibrium concentration, S amount of the solute adsorbed

$$S = \frac{s_m K_L C}{(1 + K_L C)} \quad \text{Langmuir isotherm model}$$

Sm monolayer capacity, K_L adsorption equilibrium constant, C equilibrium concentration, S amount of the solute adsorbed

3 MATERIAL AND METHODS

A Brazilian GCL was studied. This GCL is the same analysed by Bueno et al. (2002) and Pimental (2008). Differential-thermal analysis (DTA) was used for the identification and determination of clay minerals (Grim 1953, Mackenzie 1957). Cations exchange capacity was determined by methylene blue method (Pejon, 1992).

The hydraulic conductivity and advection-dispersion test were determined using a constant head method, in the equipment developed by Leite (2000).

Bentonite adsorption parameter was determined by Batch Test (Roy et al. 1992) using constant soil:solution ratio isotherm (CSI). Langmuir and Freundlich isotherm models were applied.

$CuCl_2$ $2H_2O$ (0,012 M) and KCl (0,024 M) solute was used to percolate GCL. The column test was performed as a continual source test.

4 RESULTS

The bentonite was analised by Bueno et al (2002). They determined 70 % of clay with LL 490 % and PI 432 %. The CEC (determined in this study) was 91 $cmol^+$/kg and the main clay mineral determined by DTA was sodic esmectite (Figure 1).

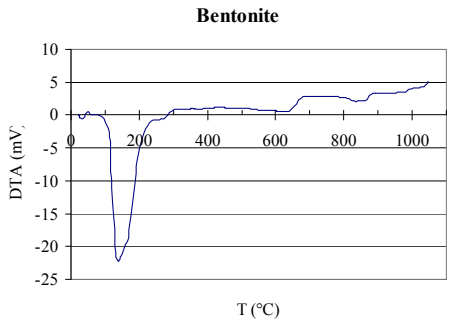

Figure 1. Bentonite diferential-thermal analyses (DTA) curve

The hydraulic conductivity value with distilled water was constant after 10 days and $1x10^{-11}$ m/s value was consistent with values finding by other researches (Figure 2).

The adsorption values determined in batch test are shown in Table 1. Using the isotherm model the retardation factor R_d can be estimated (Table 2). These values can be used to evaluate the R_d factor obtained in the advection-dispersion test.

The advection-dispersion test with KCl is shown in Figure 3. After 40 PV (195 days test), K^+ out flow solution has C/C0= 0,95 then the test can be stopped. The hydraulic conductivity does not change during the advection-dispersion test with values about 10^{-11}

m/s. The breakthrough curve of K^+ has a linear shape until C/C0= 0,8.

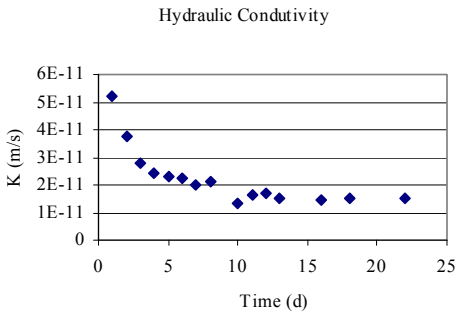

Figure 2. GCL hydraulic conductivity values (constant head test)

Table 1. Freundlich and Langmuir adsorption parameters to K^+ and Cu^{2+} cations.

K_f (cm^3/g)	N	r^2
K^+ 328.9	0.619	0.884
Cu^{2+} 9183.3	0.241	0.845
Sm (μg/g)	K_L ($cm^3/\mu g$)	r^2
K^+ 30769	0.00323	0.996
Cu^{2+} 39680	0.043	0.997

K_f Freundlich constant, *N* Freundlich empirical constant, Langmuir: Sm monolayer capacity, K_L absorption equilibrium constant

Table 2 Retardation factor computed with Langmuir and Freunlich isotherm parameters (secant method, Roy et al. 1992)

	Freundlich	Langmuir
K^+ R_d	21.1	21.9
Cu^{2+} R_d	39.9	40.1

The retardation factor value of Cl^- R_d is 1 when calculated by different methods (Freeze & Cherry 1979, Shackelford 1994). The retardation factor value R_d is 18.75 for the K^+ using $C/C_0 = 0.5$ criterion (Freeze & Cherry 1979). If the method proposed by Shackelford (1994) is used, then the retardation factor value for 46 PV is 19.3 as similar to the $C/C_0 = 0.5$ criterion.

The GCL did not showed the capacity to absorb anions, then the ion Cl^- could be considered as a tracer. The retardation factors for K^+ determined using isotherm parameters and advection-dispersion test are similar.

The advection-dispersion test with $CuCl_2.2H_2O$ is show in Figure 4. In the begining of the test the GCL had similar hydraulic conductivity as the distilled water test. But after 17 days tests, the hydraulic condutivity increased 200 times. The value of C/C_0 is of the 0.9 after 35 days of test. Some difficulties were present to calculate the retardation factor R_d of Cu^{2+} by the advection-dispersion test. The value obtained is $R_d = 22.3$, for more details see Musso (2008). This R_d value is less than the R_d obtained by isotherm model (Table 2).

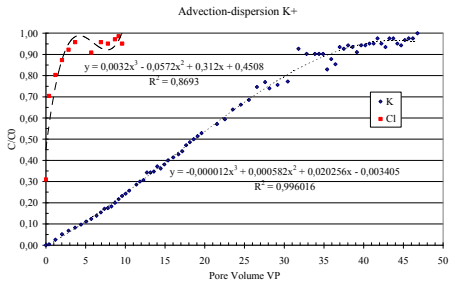

Figure 3. KCl solute breakthrough curves

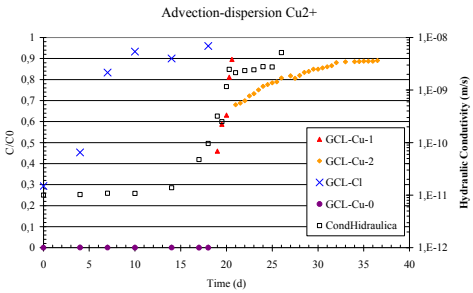

Figure 4 $CuCl_2.2H_2O$ solute breakthrough curves

The GCL percolated with Cu^{2+} had a similar behaviour than other GCLs percolated with divalent cations. The divalent cation replaces the Na^+ in the bentonite and this change reduces the thickness of the diffuse double layer increasing the hydraulic conductivity.

Some problems could be appear in the hydraulic conductivity if the liquid is not compatible with the GCL. If GCL is used as liner in the bottom then previous chemical compatibility test should be made beforehand to prevent change in the hydraulic conductivity of the GCL.

CONCLUSION

The Cl^- ion was not adsorbed in the specimen percolated with KCl and CuCl2 2H2O solutions. Then Cl^- ion can be considered as tracer.

The retardation factor to K^+ determined using isothermal parameters and advection-dispersion test are similar.

If a divalent ion is used, solution with lower concentration could increase hydraulic conductivity. This changes can be related to changes in the difuse double layer of the clay mineral.

Chemical compatibility test should be made beforehand to prevent change in the hydraulic conductivity of the GCL

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