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Migration of inorganic ions from the leachate of the Rio das Ostras landfill: A comparison of three different configurations of protective barriers

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ABSTRACT

Batch tests and diffusion tests were performed to analyze the efficiency of a protective barrier in a landfill consisting of compacted soil with 10% bentonite compared to the results obtained for only compacted soil and for compacted soil covered with a 1-mm-thick HDPE geomembrane; the soil and leachate were collected from the Rio das Ostras Landfill in Rio de Janeiro, Brazil. The diffusion tests were performed for periods of 3, 10 and 60 days. After the test period, the soil pore water was analyzed and the profiles for chloride, potassium and ammonium were determined along a 6-cm soil depth. The results of the batch tests performed to define sorption parameters were used to adjust the profiles obtained in the diffusion cell experiment by applying an ion transfer model between the interstitial solution and the soil particles. The MPHMTP model (Multi Phase Heat and Mass Transfer Program), which is based upon the solution of the transport equations of the ionic contaminants, was used to solve the inverse problem of simultaneously determining the effective diffusion coefficients. The results of the experimental tests and of the model simulation confirmed that the compacted soil with 10% bentonite was moderately efficient in the retention of chloride, potassium and ammonium ions compared to the configurations of compacted soil with a geomembrane and compacted soil alone, representing a solution that is technically feasible and requires potentially lower costs for implementation in landfills.

1. Introduction

Landfills have been increasingly used in developing countries for the disposal of urban solid wastes. Liners at the base of landfills serve as a protective barrier and can be constructed of low-permeability clay soils (CCL) either alone or in composite liners with geomembranes (GM) and geosynthetic clay liners (GCLs). Natural materials are typically used to form a protective base with compacted soil. The addition of bentonite to these materials improves the performance of the protective layer, reducing the hydraulic conductivity and increasing the cation exchange capacity of the soil. Ideally, these materials should meet the specifications of permeability and minimum thickness that are required to form a barrier to the migration of contaminants contained in the leachate (Rowe et al., 2004; Rowe, 2005). Field studies (Goodall and Quigley, 1977; Crooks and Quigley, 1984; Quigley et al., 1987; Johnson et al., 1989) have indicated molecular diffusion as a predominant mechanism for the transport of the contaminants that are present in the solutions that migrate in fine soils with low permeability and through geomembranes (Rowe et al., 2004; Rowe, 2005); as a result, this transport mechanism has been receiving increasing attention (Rowe et al., 1988; Cheung, 1989; Shackelford, 1994; Shackelford and Redmond, 1995; Ritter and Campos, 2006; Ishidera et al., 2008). Laboratory studies of mechanical sorption and dispersion or molecular diffusion parameters have been performed using different materials for liners and solutions (Shackelford and Daniel, 1991; Lake and Rowe, 2000; Leite et al., 2003; Sato and Miyamoto, 2008; Lange et al., 2009) and using different soils and leachates at the landfill base (Rowe et al., 1988; Barone et al., 1989; Azevedo et al., 2003).

There is substantial concern about the presence of heavy metals in leachate; however, a number of inorganic ions are present at significant concentrations in the leachate of MSW landfills, including

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chloride, sodium, calcium, potassium, magnesium, iron and ammonium (Christensen et al., 2001). A study on the composition of 25 Brazilian MSW landfills leachates showed that chloride and ammonium ions were present at high concentrations in all the leachates (Souto and Povinelli, 2007). Organic contaminants in Brazilian leachates have not yet been researched. Brazilian law limits the ammonium content in treated leachate 20 mg/L (CONAMA 430/2011), and the maximum allowable chloride content for human consumption is 250 mg/L (Ordinance 518/2004).

The effective diffusion coefficients for chloride in different clay soils range from 1.5×10^{-10} to 10×10^{-10} m^2/s, the coefficients for potassium range from 5×10^{-10} to 19.6×10^{-10} m^2/s, and only one coefficient for ammonium has been reported, 5.7×10^{-10} m^2/s (Rowe et al., 2004). Chloride diffusion tests on a 2-mm-thick HDPE geomembrane with an aqueous sodium chloride source solution performed over 12 years (Rowe, 2005) indicate that diffusion coefficients range from 0.8×10^{-17} to 3×10^{-17} m^2/s; further studies have been performed on organic compounds. Lake and Rowe (2000) used different source solutions to study the diffusive migration of NaCl in GCL at porosities ranging from 0.56 to 0.80 and determined chloride diffusion coefficients ranging from 0.35×10^{-10} to 3×10^{-10} m^2/s.

Seeking to analyze a technically feasible alternative for the construction of protective barriers in landfills, the objective of the present study was to investigate and compare the migration of some inorganic ions present in landfill leachate through laboratory testing. Local soil and leachate were used from the Rio das Ostras landfill (ROL), located in the state of Rio de Janeiro (Brazil). The aim was to define sorption parameters for ammonium and potassium and diffusion coefficients for chloride, ammonium and potassium, which are present in landfill leachate, through laboratory testing using three different liner configurations: a compacted mixture of local soil with 10% bentonite (CCBL) (Lacerda, 2009), compacted local soil (CCL) alone and a composite liner composed of compacted soil covered with a 1 mm thick HDPE geomembrane (CCL/GM) (Valadão, 2008).

2. Materials and methods

The ROL soil (CCL) is composed of a sandy clay with light-yellow-colored rocks, with a 37% clay (<5 μm) fraction. The soil characterization is shown in Table 1. The predominant clay mineral is kaolinite, and the cation exchange capacity (CEC) is 2.9 $cmol_c/kg$. The CCBL was prepared with 20 g (10%) of commercial sodium bentonite for every 180 g (90%) of CCL, both by dry weight; the CEC of CCBL is 7.2 $cmol_c/kg$. The Normal Proctor compaction (ABNT NBR 7182/86) results indicated a dry specific weight of 16.51 kN/m^3 with 20.9% optimum moisture for the CCL and a dry specific weight of 16.03 kN/m^3 with 21% moisture for the CCBL, which are effectively equivalent results. The permeability coefficient determined for the CCL was 1.87×10^{-7} cm/s. Table 2 presents the chemical analyses of the pore water for both soils. The differences observed were due to the presence of sodium bentonite, which resulted in a greater cation exchange capacity and higher sodium concentration.

The chemical characterization of the leachate from the ROL is shown twice in Table 3. Leachates 1 and 2 are from four and three years after the onset of operations, during periods of low and high rainfall, respectively. Consequently, significantly different concentrations were observed for chloride, ammonium, sodium and potassium. The organic content was not quantified. The leachate pH values were consistent throughout the tests. Leachate 1 was used for tests with CCBL, and the other leachate was used for CCL and CCL/GM (Valadão, 2008).

Table 1
Characterization of the soil of the Rio das Ostras Landfill.

Grain density	26.6
Liquid limit – LL	54.89%
Plasticity limit – PL	32.88%
Plasticity index – PI	22.01%
Fraction < 5 μm	37%

Table 2
Chemical composition CCL and CCBL porewater.

Parameters	CCL	CCBL
pH	6.2	7.1
Chloride (mg/L)	5.4	23.07
Sodium (mg/L)	3.4	104.7
Ammonium (mg/L)	2.2	1.2
Potassium (mg/L)	0.8	0.99

2.1. Batch tests

Batch tests were conducted to determine the parameters of the interaction between the soil and the contaminants (EPA/530/SW-87/006-F, 1992). Tests conducted previously, using only the soil and a mixture of soil and 10% bentonite, have shown that the time needed to achieve balance between the solid and liquid phases was 48 h. A portion of moist soil equivalent to the amount of dry soil established by a soil solution ratio (SSR) of 1:10 was weighed in a polyethylene bottle. Eighteen grams of soil and 2 g of sodium bentonite were weighed per 200 ml of solution. The solutions were prepared from the leachate and deionized water at concentrations of 0%, 10%, 20%, 30%, 50%, 75% and 100% and were added to the adsorbent mass in a polyethylene bottle and then stirred. After a 48-h stirring time, the samples were filtered, and the solutions were subjected to analysis. Batch tests were not performed for the geomembrane.

2.2. Diffusion tests

The diffusion test cell was adapted from Barone et al., 1989. The cell consists of a 100-mm internal diameter Plexiglass cylindrical body with five parts: a square base, water reservoir, soil reservoir, leachate reservoir, and cover (Fig. 1a and b). The cell base had an internal drainage system consisting of radial channels and a lowered cylindrical centre, which was covered by a 4-mm-thick porous stone that allows water in during the saturation process. The

Table 3
Chemical composition of the ROL leachate.

Parameters	Leachate 1[a]	Leachate 2[b]
pH	7.74	7.6
Total alkalinity (mg/L)	5908	3670
Conductivity (ms/cm)	13.5	7.8
Chloride (mg/L)	2305	1650
Chemical oxygen demand (mg/L)	1153	ND
Total suspended solids (mg/L)	101	ND
Total dissolved solids (mg/L)	6396	ND
Volatile suspended solids (mg/L)	89	ND
Total solids (mg/L)	6497	ND
Ammonium (mg/L)	1235	606
Cadmium (mg/L)	0.05	ND
Chromium (mg/L)	0.04	ND
Copper (mg/L)	0.07	ND
Sodium (mg/L)	1230	700
Calcium (mg/L)	134	ND
Potassium (mg/L)	1114	395

ND – not determined
[a] 09/25/08 date of leachate collection.
[b] 11/30/07 date of leachate collection.