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The Influence of Biofuels on the Permeability of Sand-Bentonite Liners

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***Abstract*—**Liners are made to protect the groundwater table from the infiltration of leachate which normally carries different kinds of toxic materials from landfills. Although these liners are engineered to last for long period of time; unfortunately these liners fail; therefore, toxic materials pass to groundwater. This paper focuses on the changes of the hydraulic conductivity of a sand-bentonite liner due to the infiltration of biofuel and ethanol fuel. Series of laboratory tests were conducted in 20-cm-high PVC columns. Several compositions of sand-bentonite liners were tested: 95% sand: 5% bentonite; 90% sand: 10% bentonite; and 100% sand (passed mesh #40). The columns were subjected to extreme pressures of 40 kPa, and 100 kPa to evaluate the transport of alternative fuels (biofuel and ethanol fuel). For comparative studies, similar tests were carried out using water. Results showed that hydraulic conductivity increased due to the infiltration of alternative fuels through the liners. Accordingly, the increase in the hydraulic conductivity showed significant dependency on the type of liner mixture and the characteristics of the liquid. The hydraulic conductivity of a liner (subjected to biofuel infiltration) consisting of 5% bentonite: 95% sand under pressure of 40 kPa and 100 kPa had increased by one fold. In addition, the hydraulic conductivity of a liner consisting of 10% bentonite: 90% sand under pressure of 40 kPa and 100 kPa and infiltrated by biofuel had increased by three folds. On the other hand, the results obtained by water infiltration under 40 kPa showed lower hydraulic conductivities of 1.50×10^{-5} and 1.37×10^{-9} cm/s for 5% bentonite: 95% sand, and 10% bentonite: 90% sand, respectively. Similarly, under 100 kPa, the hydraulic conductivities were 2.30×10^{-5} and 1.90×10^{-9} cm/s for 5% bentonite: 95% sand, and 10% bentonite: 90% sand, respectively.

***Keywords*—**Biofuel, Ethanol; Hydraulic conductivity Landfill, Leakage, Liner failure, Liner performance Fine-grained soils, Particle size, Sand-bentonite.

I. Introduction

MANY liners are made using clayey materials, such as sand-bentonite mixtures, that retain liquid and solid toxic wastes. Although many cases of high leakage of bentonite liners have been reported [1], they remain in use. Over time, the principal function of liners was reduced due to contaminants leaking, a situation which has serious ramifications on the stability of constructions and the safety of humans and animals in the surrounding area.

Despite the existing municipal solid waste (MSW) landfill disposal practices, leaching still occurs, leading to heavy metal migration towards groundwater, regardless of the type of material used for the liners—synthetic or sand and bentonite mixtures [2].

Performance of landfill liners is a prime concern for engineers and governments, as their failure constitutes safety and environmental problems for the public. Clay liner deteriorates when exposed to organic fluids, resulting in a major increase in hydraulic conductivity [3].

Accordingly, the design of liners for natural landfills must be made to sustain environmental changes over its proposed lifespan. This is mainly due to the fact that the disposed materials in landfills and storage tanks are changing to include alternative fuels such as biofuel or ethanol fuel.

This paper focuses on the changes within the sand-bentonite liner structure due to the infiltration of biofuel and ethanol fuel.

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II. Experimental Investigation

The infiltration of leachate through sand-bentonite barriers was examined. Three liquids were used as leachate: first, water, as a control; then ethanol fuel; and finally biofuel. The sand-bentonite barriers (i.e. liners) were composed of sand and bentonite in proportions varying by weight and mixed together using the optimum moisture content. Then, each liquid was leached through each liner under specific pressure.

The infiltration was observed by means of a column-leaching test under different pressures. In these tests, the hydraulic conductivity, erodibility, particle-size distribution, surface fractures were measured.

In this investigation two types of minerals were used to make the liners: bentonite clay and silica sand.

Dried sand was obtained from the Province of Quebec in Canada, passed mesh # 40, (ASTM E 11-70 -1995). The properties of sand as measured in the laboratory were: CEC (meq/100g) =3, pH in water =8.52, size (mesh# 40, D= 0.42 mm), specific surface area (m^2/g, [4]) = 0.1, and percentage of organic matter =0.07 (ASTM D 2974).

Bentonite was obtained in the form of commercial powder, rich in Na-montmorillonite, obtained from Houston TX. The mineralogical composition of natural bentonite (X-Ray Analysis**:** Baroid 2008) was: 85% Montmorillonite, 5% Quartz, 2% Feldspars, 0.35% Cristobalite, 2% Illite, and 1% Calcium and Gypsum.

Leachates: Water (tap water-Montreal) (as the permeate reference for all tests), 100% ethanol and were used as permeates.

Materials were blended in different proportions by weight. Then water was added gradually to soil mixtures to reach the optimum moisture content of 20%, 19%, and 10% for sand: bentonite mixtures of 85%:5%, 90%:10%, and 95%:5%, respectively.

Testing was ended at a maximum of 10% bentonite as it satisfied the hydraulic conductivity required to construct the liners.

A standard proctor was used to compact the liner samples following the ASTM D 698-78.

Liners were tested for hydraulic conductivity for leachate infiltrating downward, which represents most field cases. Samples were collected from different depths along the liner samples to test for particle-size distribution.

III. Test Procedure

The column-leaching test was conducted to simulate a clay liner in a landfill or an underground storage tank. Liner materials were prepared and placed in the column in two layers. Each layer was compacted for optimum moisture content following the standard proctor test procedure. Then, the column was leached using different mixtures, liquids and pressure values.

To perform the test, a PVC wall permeameter was used. A PVC column consists of two equal parts; each has a height of 98 mm and an inside diameter of 96 mm, and is used to contain the liner samples during testing.

Three types of cells were manufactured (Fig. 1) and connected to a pressure vessel, made of PVC heavy-duty flanges and pipe (20.3 cm inside diameter and 50 cm height). The top part of the vessel was equipped with a pressure regulator and was connected to a pressure cylinder and a safety valve.

IV. Test Results

The coefficient of permeability or the hydraulic conductivity was measured in this investigation by means of the constant head method following ASTM D 2434-68 [5].

The velocity (v) as defined by Darcy's law is given as

$v = ki$

The volumetric flow rate $Q = kiA$, where $i = h/L$, Then,

$k = QL/Aht$

Fig. 1 Column leach test cells with pressure vessel setup

where

k is the hydraulic conductivity (cm/s),
i is the hydraulic gradient
Q is the quantity of fluid flow during time t (cm^3/s),
t is the time of water flow (s), L is the sample length (cm),
A is the liner's sample cross-section area (cm^2), and
h is the head loss .

Table I shows the coefficient of hydraulic conductivity for different liners saturated downward (with the same kind of permeate used as leachate) then leached by water, ethanol and biofuel under pressures of 40 kPa and 100 kPa.

After dismantling the column, disturbed samples were obtained from different depths along each liner to be tested for particle-size distribution using a laser-scattering particle-size analyzer (HORIBA LA-950V2). Four samples along the depth of each liner were tested to evaluate the changes in particle-size distribution in the liner infiltrated by water, ethanol and biofuel as illustrated in Fig. 2 and 3.

TABLE I
Coefficient of Hydraulic Conductivity (K, cm/s) for the Liners Infiltrated by Water, Ethanol and Biofuel Under Pressures of 40 kPa and 100 kPa

% Bentonite	Water	Ethanol	Biofuel
		40 kPa	
0	6.35×10^{-3}	5.72×10^{-3}	1.69×10^{-3}
5	1.57×10^{-5}	2.42×10^{-4}	5.10×10^{-4}
10	1.37×10^{-9}	1.53×10^{-9}	3.12×10^{-6}
		100 kPa	
0	7.20×10^{-3}	1.17×10^{-2}	2.11×10^{-3}
5	2.30×10^{-5}	8.13×10^{-4}	4.52×10^{-4}
10	1.90×10^{-9}	1.39×10^{-9}	2.73×10^{-6}

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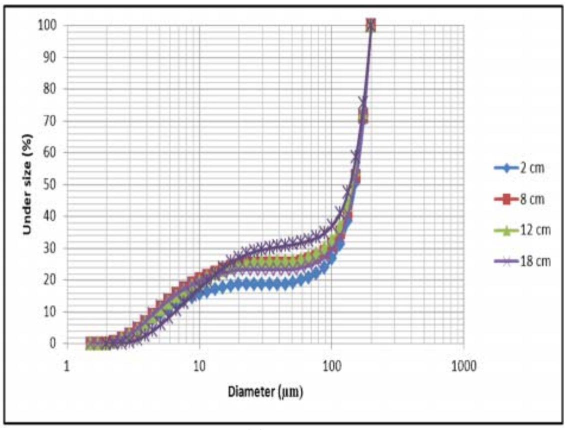
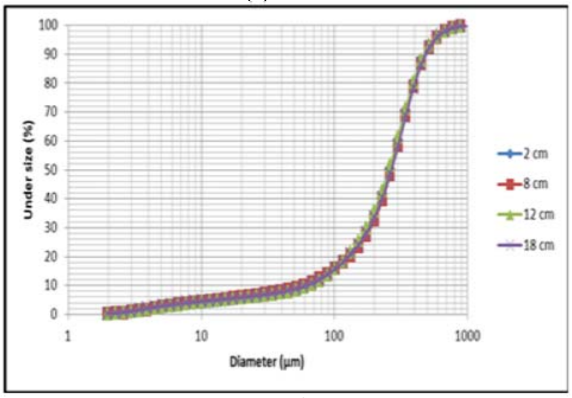
V. Discussion and Analysis

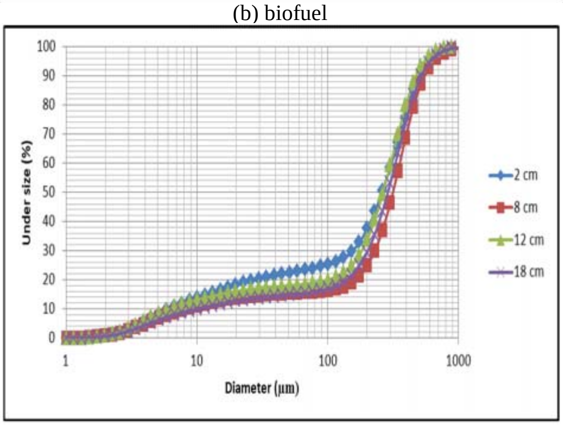
Fig. 2 shows the variation of the particle-size distribution of a liner composed of 95% sand and 5% bentonite. Under 40 kPa, the particle-size distribution due to water infiltration ranged from 1 to 200 µm at different depths (2, 8, 12 and 18 cm). Furthermore, the particle-size distribution was in the range of 1 to 1000 µm in the case of biofuel and ethanol infiltration. No significant changes were noticed under 100 kPa.



(a) water



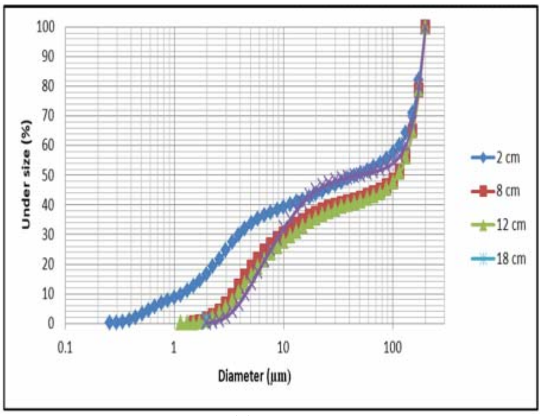
(b) biofuel



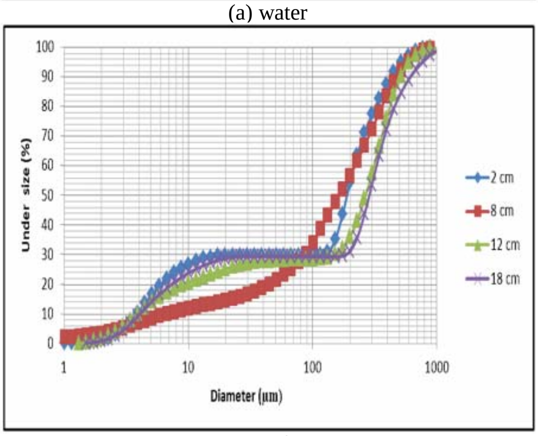
(c) ethanol

Fig. 2 Particle size distribution for liner (95% sand and 5% bentonite) permeated by water, biofuel and ethanol under 40 kPa

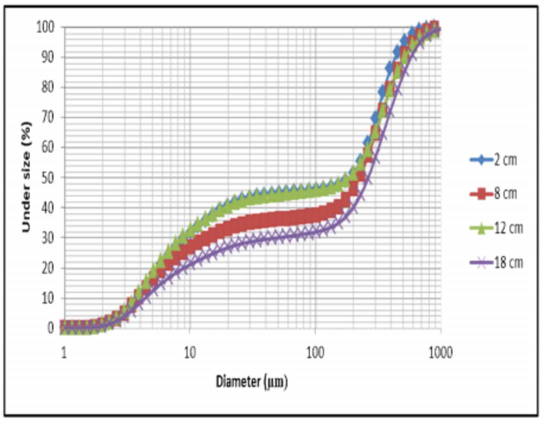
Fig. 3 shows the variation of the particle-size distribution of a liner composed of 90% sand and 10% bentonite. Under 40 kPa, particle-size distribution for a liner infiltrated by water ranged from 0.1 to 200 µm at different depths (2, 8, 12 and 18 cm). For a liner infiltrated by biofuel or ethanol, the particle-size distribution ranged from 1 to 1000 µm. Particle-size distribution curves along the liner's depths behaved in the same manner under 100 kPa. Fig. 3c shows the particle-size distribution for a liner of 90% sand and 10% bentonite permeated by ethanol under 100 kPa. Black spots were detected at 10 to 14 cm down from the liner surface. This could be attributed to the presence of anoxic microorganisms that used ethanol as carbon source causing ethanol biodegradation, and, therefore, no free droplets of organic liquid (ethanol) were detected by the laser particle size analyzer. The maximum particle size detected was 200 µm.



(a) water



(b) biofuel



(c) ethanol

Fig. 3 Particle size distribution for liner (90% sand and 10% bentonite) permeated by water, biofuel and ethanol under 40 kPa

It could be concluded that fine particles in the sand-bentonite mixture were highly susceptible to agglomeration when interacting with fuels. As a result, the sand grains and bentonite clay particles formed bigger flocs which led to an increase in the liner hydraulic conductivity, an increase in the rate of infiltration, and thus a remarkable fracture along the liner's depth as shown in Fig. 4.

Test results demonstrated that changes in liner behavior might take place, depending on bentonite content and the type of permeate. Many physico-chemical phenomena can be responsible for such behavior.

Furthermore, the hydraulic conductivity of liners can increase under a load of waste after the infiltration of alternative fuel leachates. This increase is due to many factors pertaining to the changes in the structure and composition of sand-bentonite mixtures. For instance, erosion of fine particles, as liquids infiltrate through the liner, affects the hydraulic conductivity. Also, the amount of fine particles flushed out of the mixtures increased with higher pressures, during the leaching of liquids, especially for water.

Fig. 4 Digital image for the upper surface of a 95% sand and 5% bentonite liner leached by biofuel under a pressure of 100 kPa (cracks are showed in circles)

It was also observed that biofuel caused higher cracks and surface fractures when infiltrating liners compared to ethanol fuel and water. In this study, grain-size distribution of particles increased drastically when liners were infiltrated by alternative fuels (ethanol or biofuel). This is due to the coagulation of fine particles in their interaction with fuel as they adhere together, forming larger oil-clay clusters that do not separate in emulsion used for particle-size analysis. However, many flocculated and single mineral fine particles remained, as shown in the particle-size analysis.

VI. Conclusion

Alternative fuels (e.g. ethanol and biofuel) have adverse impacts on landfill (or pond) sand-bentonite liners through which pores are filled with miscible and immiscible or polar and non-polar liquids/residuals. Thus, the properties of the soil matrix are subject to several physical changes such as surface tension and capillary forces. These changes could lead to the formation of oil-clay flocs, provoking fractures, erodibility, a consequential increase of the hydraulic conductivity and finally liner failure.

Based on the results of the present experimental investigation, the following conclusions were drawn:

- The voids in sand-bentinite mixtures increase due to the infiltration of alternative fuels, creating channels, which increase the flow of liquids and result in a higher coefficient of permeability of the liner. The hydraulic conductivity of a liner consisting of 5% bentonite: 95% sand under pressure of 40 kPa and 100 kPa and infiltrated with biofuel increased by one fold. In addition, the hydraulic conductivity of a liner consisting of 10% bentonite: 90% sand under pressure of 40 kPa and 100 kPa and infiltrated by biofuel increased by three folds. On the other hand, the results obtained by water infiltration under 40 kPa showed lower hydraulic conductivities of 1.50E-05 and 1.37E-9 cm/s for 5% bentonite: 95% sand, and 10% bentonite: 90% sand, respectively. Similarly, under 100 kPa, the hydraulic conductivities were 2.30E-05 and 1.90E-9 cm/s for 5% bentonite: 95% sand, and 10% bentonite: 90% sand, respectively.
- The biological growth of anoxic microorganisms was observed according to the reported substrate (ethanol) consumption and hence influenced the liner's performance.

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