Hydraulic Stability of Sanitary Landfills liners

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Abstract:

Compacted sand-clay mixture of low permeability has been used as low cost barrier for the sanitary landfills to prevent the waste from reaching the surroundings. The low Hydraulic conductivity of such barrier layer and its efficiency of isolating the sanitary landfills have been studied. The impact of two inorganic anions on the hydraulic conductivity of a compacted sand-clay mixture was evaluated. Ammonium chloride and ammonium sulphite solutions at different concentrations were employed as permanent fluids in this study. The concentration of SO_4^- ranged from 100 ppm to 100×10^3 ppm, while the concentration of Cl^- ranged from 50 ppm to 50×10^3 ppm. The change in the compacted sand-clay mixtures hydraulic conductivity resulting from switching the permanent fluid to either ammonium chloride or ammonium sulfate were primarily attributed to the effect of the anion spices species because the cation and all other condition were kept constant during the tests.

Introduction:

Disposal of solid and liquid wastes will, in the ultimate, be in the ground regardless of the steps taken in between to neutralise or "eliminate" the material (Yong, 1989). This requires an extensive application of geotechnology to host these wastes without endanger the surroundings. In other. words, polluted waters passing through the boundaries of a sanitary landfill will leach hazardous material. (organic and inorganic) from tile waste disposed of in the facility to the surrounding. These contaminant leachates must not be permitted to complete their migration through the sanitary landfill boundaries to reach tile environment. This can be achieved by lining the containment by a low permeable blanket, e.g., compacted low permeable soils.

The main function of low-permeability, compacted soil (Barrier layers) is either to restrict infiltration of water into buried waste (in cover system), or to limit seepage of leachate from the waste (in the liner system). Other objectives may include enhancement of efficiency of an overlying drainage layer, development

of composite action with a flexible membrane liner, adsorption and attenuation of leachate, restriction of gas migration, and others. In case of a cover. system, compacted soil must also have the ability to withstand subsidence and must be repairable if damaged by freezing, desiccation, or burrowing animals. For liner, system compacted soil must also have the ability to withstand chemical degradation from the liquid to be contained (Daniel and Estortlell,1990). In addition, low-permeability compacted soil must have adequate shear strength to support it self on slops and to support the weight of overlying .materials or equipment.

Many organic chemicals tend to shrink the diffuse double layer that surrounds clay particles, causing the clay particles to flocculate, the soil skeleton to shrink, and cracks, called syneresis cracks, to from (Gregory and Broderrick, 1990).

The permeability of three clays to five simulated liquid wastes have been investigated by Sanks and Gloya (1977). The aqueous waste solution tested were chosen to be representative of materials that might leak from containers of solid wastes. The various substances contained acid, base, and heavy metals. Tested clays contained large percentage of montmorillonite. Among the authors' observations are the following: (1) permeability value using deionized water as a permeant ranged from 4×10^{-10} to 1.2×10^{-9} m/sec. (2) Using the acid waste as a permeant resulted in higher permeability; (3) On the other hand, lower; permeabilities were observed when basic waste was used as a permeant; and (4) No effects were shown by using salts of heavy metals $HgCl_2$ at 8100mg/l and $ZnSO_4$ at 8610 mg/l.

Materials and Method:

It Is the main objective of this study to examine the compatibility of compacted soil as clay liner with certain chemical species (namely: $SO4^{--}$ and Cl^-) which can be found in the leachate. Kaolinite was mixed with fine sand in preparing the soil samples investigated in this study. Kaolinite was a commercially processed soil obtained from the Georgia Kaolin Company, Elizabeth, New Jersey. The sand was natural 1900 grain, silica sand, obtained from the Ottawa Silica Company, Ottawa, Illinois. Several laboratory tests were performed to characterise the soils used in the study with respect to their physical and chemical properties. The pertinent physical and chemical properties are presented in Tables 1 and 2, respectively. In addition to deionized water, two inorganic chemical solutions were employed in the study as permeant fluids. The two main functions of deionized water in the experimental program were: (1) to saturate the samples and establish their base values of hydraulic conductivity before switching to the chemical solution as a permeant fluid; and (2) to permeate the reference samples, used for comparison purpose ,parallel to the other samples.

Ammonium chloride and ammonium sulfate solutions, used individually as permeant fluids, were prepared by dissolving the proper weight of pure inorganic chemical (either ammonium chloride NH_4Cl or ammonium sulfate

Table (1): Physical Properties of Soils used in the Present Study:

Property	Reference	Fine Sand	Kaolinite	Mixture
% of Kaoliiiife		0	100	33.33
% of Fine Sand		100	0	66.67
Source of Soil		Ottawa Silica Co.	Georgia Kaolin. Co.	Laboratory. Prepared
Atterberg Limits	ASTM D4318-84			
LL (%)			64	17
PL (11/0)			34	12
Specific Gravity	ASTM D854-8	2.65	2.60	2.63

Table (2): Chemical Properties of Soils used in the Present Stddy

Property	Reference	Fine Sand	Kaoliniie	Mixture
PH	McLean, (1982)	5.85	4.73	5.55
Specific Surface Area $(m,^2lg)$	Carter, et al., (1982)	N/A	50	31
CEC (meq/100 g)	Jackson, (1958)	N/A	37.73	13.88
NH_4 (% w/w)	Keeney, (1982)	N/A	0.000889	0.000215
cl- (%w/w)	Pfafft (1991)	0.000495	0.001017	0.00,1107
S O_4- - (%w/w)	Pfaff, (1991)	0.000954	0.001165	0.005178

$(NH_4)_2SO_4$ in deionized water to yield specific concentrations of the chemical species (NH4-1-, Cl^-, or SO_4^-) in the solution. The different properties of both NH_4Cl and $(NH_4)_2SO_4$ salts are presented in Table 3 according to the manufacture's information.

Table (3) Properties of Chemicals used in Preparing the Penneant Fluids

Chemical — Property	Ammonium chloride	Ammonium Sulphate
Formula	$(NH_4)Cl$	$(NH_4)_2SO_4$
Molecular Weight	53.5	132.14
Assay $(NH_4)Cl$	99,7%	N/A
Assay $(NH_4)2 SO_4$	NIA	99,1%
pH of 5 % Solution @ 25 c	4.9	5.2
Specific Gravity @ 20 C	1.53	1.77
Solubility in water @ 20 C	37 % (by wt.)	75.4% (by wt.)
Chloride	N/A	< 3 ppin
Sulphate	N/A	
Nitrate	< 5 ppm	< 0.0005 %
Heavy Metals	< 2 ppm	< 2 ppm

The initial concentrations of the different chemical species, mentioned above, in the permeant fluid was calculated based on the solubility of the chemical salt in water, according to (lie manufacturer's information, in addition to the molecular weight. The leaching and/or permeation equipment used in this study is a system of ten leaching and/or permeation cells assembled together (in

addition to all the necessary fittings, measuring and controlling devices, and hydraulic system) in one board.

The leaching and/or permeation cell constructed in this study is, more or less, a flexible-wall permeameter consistent in design and construction with that in literature (Daniel, et al., 1984). A schematic diagram of the cell is shown in *Figure (1)*.
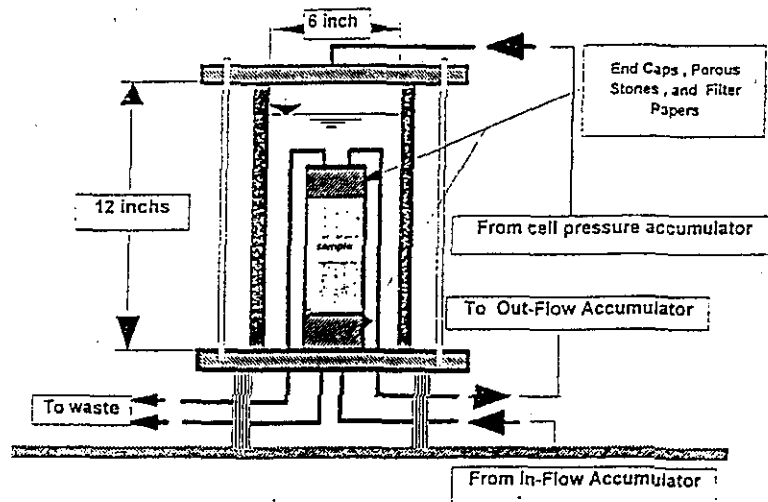

Fig. 1. Schematic Diagram of the Flexible-wall Permeameter cells

The cell consists mainly of: (1) Cast acrylic tube that fits In recesses machined into the end plates. The cast acrylic tube is sealed between the two end plates with 0-rings and has the dimensions of 1/4in. thick wall, 6 in. inner diameter, and 12 in.- length. This tube with those specifications is suitable for a confining pressure up to 80 psi which is enough in the present study; (2) Top and bottom plates are machined from acrylic sheets 1.0 in. thick, and (3) Six nuts screwed onto three stainless steel all-thread rods to clamp the two end plates together. The soil specimen is located inside tile acrylic tube between a base pedestal and top cap, which are machined from PVC. PVC was selected because of its light weight, low cost, easy machineability and enough resistivity to the permeant fluid used.

Results and Discussion:
Leaching with Chloride Anion:
In this phase of the experimental programs two sets of experiments were conducted. In the first set, the investigated soil was permeated with $(NH_4)Cl$ solutions of different concentrations. Figure 2 shows the results of hydraulic conductivity investigation in terms of the change in k (relative k_0 which is the base value of hydraulic conductivity determined at the steady state condition using deionized water as a permeant) versus the initial concentration of cl⁻ in the permeant fluid.
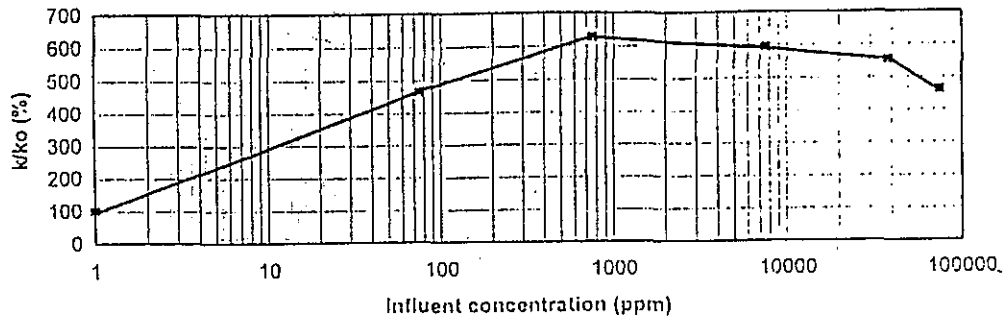
Fig. 2. Effect of (NH₄)Cl concentration upon the liner's hydraulic conductivity.

In the second set of experiments, the investigated soil was permeated with the same permeant fluid (=38,000 ppm NH_4Cl solution) untill different volumes (1,2,4 & 8 pv) of the effluent has been collected . Figure (3) shows the results of hydraulic conductivity investigation in terms of the change in k (relative k_o which is the base value of hydraulic conductivity determined at the steady state condition using deionized water as a permeant) versus the initial concentration of cl⁻ in the permeant fluid.
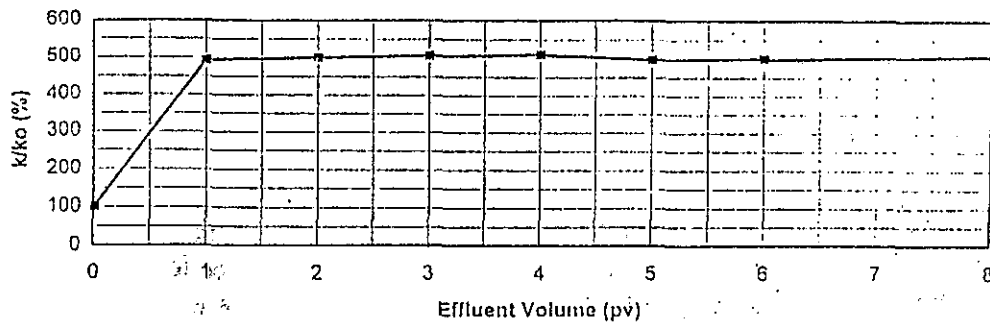

Fig. 3. Effect of (NH4)CI seepage volume upon the liner's hydraulic conductivity.

Leaching with Sulphate Anion:

In this phase of the experimental program, two sets of experiments were conducted. In tile first set, the investigated soil was permeated with $(NH_4)_2SO_4$ solutions of different concentrations. Figure (4) shows tile results of hydraulic conductivity investigation in terms of the change in k (relative k_0 which is the base value of hydraulic conductivity determined at the steady state condition using deionized water as a permeant) versus the initial concentration Of SO4⁻ in the permeant fluid.

In the second set of experiments, the investigated soil was permeated with the same permeant fluid (=69,000 ppm $(NH_4)_2SO_4$ solution) until different volumes of the effluent has been collected. Figure (5) shows the results of hydraulic conductivity investigation in terms of the change in k (relative to k_n which is the base value of hydraulic conductivity determined at tile steady state condition using deionized water as a permeant) versus the initial concentration of SO4⁻ in the permeant fluid.
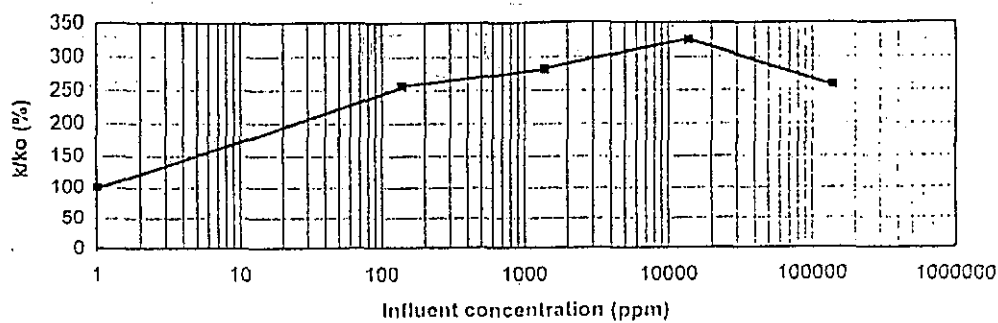
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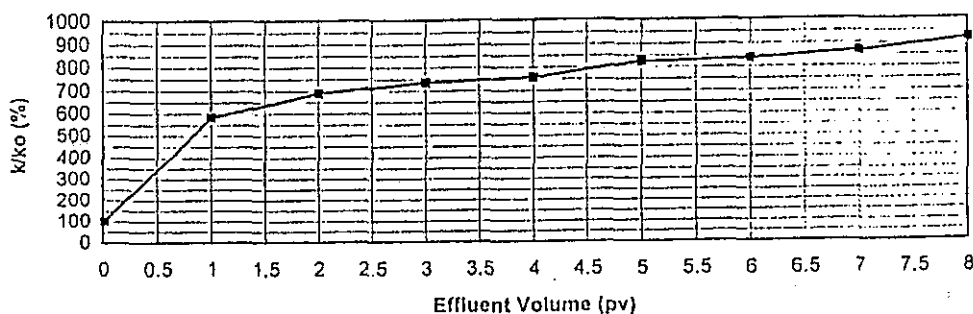Fig. 4. Effect of (NH4)2SO4 concentration upon the liner's hydraulic conductivity.

Fig. 5. Effect of (NH$_4$)$_2$SO$_4$ seepage volume upon tile liner's hydraulic conductivity.

Effect of Electrolyte Concentration:

The electrolyte concentration is important for inorganic saline permeants such as those encountered in drilling waste. However, to determine the effect of the electrolyte concentration as well as seepage volume and ion type on the hydraulic conductivity of the tested material, the base line hydraulic conductivity has been determined using deionized water at the start of each permeation run before switching to the different permeant fluids.

From those results presented in Figures 2 and 4 it is observed that introducing either ammonium chloride or ammonium sulfate solutions in different concentrations to compacted soil samples saturated with deionized water causes an increase in permeability of the tested soil.

On the one hand, this increase reached values of 325 and 600 times greater than the base line value of the hydraulic conductivity in case of ammonium sulfate and ammonium chloride respectively. That amount of increase in permeability of the liner material means a dramatic decrease in its containment effectiveness. On the other hand, the changes in hydraulic conductivity shown in Figures 8 and 9 may be attributed to the permeant fluid chemistry which can influence permeability apart from altering the clay fabric by its hydropliobicity or solubility in water, and by precipitation of certain chemicals or growth of micro-organisms in porous (Pauls et al., 1988). In other words, these changes in hydraulic conductivity upon increasing the chemical concentration in the permeant fluid may be attributed to the resulting change in double layer

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thickness which is inversely proportional to the electrolyte concentration.

This change in double layer thickness due to changing the electrolyte concentration can affect the fabric and/or behaviour of clays (Anderson and Brown, 1981). Also, Alter et al., 1985 studied the influence of inorganic permeants on the permeability of bentonite. They found that K^+ and Cl^- anions had a greater effect of increasing flocculation and permeability than did the Na^+ and CO^{2-} anions. They explained the effect of inorganic solutions on the bentonite clay with the Gouy-Chapman diffuse double layer. Also, they observed that bentonite clay displayed the greatest amount of shrinkage and resulting increase in permeability when exposed to divalent cation salts such as Ca^{++} and Mg^{++} but a saturation limit of these salts is reached so that above this concentration, the salt has no greater effect.

Influence of Seepage Volume

The tested soil was permeated with the same permeant for different time intervals under the same conditions to assess the impact of the exposure of a clay liner to those solutions for a long-term periods. In presenting and discussing the results of that part of the experimental study in the present paper, the exposures time periods are expressed in terms of the outflow (effluent or seepage) volumes which in turn measured in terms of the initial volume of voids in the soil sample (pv). Based on the properties of the tested materials and under the testing conditions, about one week was needed to collect one pore volume (1 pv) of the outflow.

Permeating the tested soil with ammonium chloride solution of constant concentration for different time intervals (or until different volumes of the out flow has been collected) yielded the "pv - k" relationship in Fig. 3. Within the first two weeks starting from switching the permneant fluid from deionized water to ammonium chloride solution, the permeability of the tested soil increased to five times greater than the base value established using deionized water as a permeant. Then, after about one month of permeation (the time required for 4pv of the out-flow to be collected), there was no increase in the permeability. Two of replicates were tested for 1.5 and 2 months, respectively (times required for 6 and 8 pv to seep through the test sample), but there was no trend toward increased permeability during the passage of the applied permeant.

These results are consistent with the results of the test series run for nearly 30 years and described by Brandi, 1992. From that test series he found that: "most effects of chemicals on soil do not follow a general pattern . So, soil parameters may increase or decrease depending on pollutant concentration, lime, temperature, ..., elc". Similarly, Van Ree et al., 1992 concluded that: "liners composed of tertiary clay and sand-bentonite mixture are physically and geochemically dynamic systems. So, time-dependent behaviour for example is tlie consequence of consolidation process, shrinking and cracking related to changes in moisture content. Furthermore, oxidation and reduction

processes as well as acid and base reactions, and precipitation and dissolution provide mechanisms which probably will influence the behaviour and effectiveness of a barrier system".

A possible explanation of the first increase in permeability after two weeks permeation with ammonium chloride is the increase in electrolyte concentration of the permeant fluid.

Figure 5 presents the "pv - k" relationship of the tested soil when it was permeated with ammonium sulfate solution of constant concentration. Compared with the base value of hydraulic conductivity established using deionized water, there was an increase in tile hydraulic conductivity of the tested soil upon permeation with ammonium sulfate at the tested concentration. The rate of that increase differs from that occurred upon permeation with ammonium chloride. Also, most of the increase occurred within the first two weeks (or during collecting the first 2 pv) and then the rate of increase decreased. Changing tile rate and amount of increase in hydraulic conductivity upon changing the permeation fluid to either ammonium chloride or ammonium sulfate may be attributed to the change of type of anion ill the permeant fluid from chloride to sulfate.

Concluding Discussion:

A comparison of the permeability, compressibility, and shear strength of the samples permeated with chemical solutions and those permeated with deionized water shows significant changes in those properties upon changing the permeant fluid chemistry. In other words, the consolidation and the rheological processes as well as the shear strength will develop in a different way under the action of chemical species on the soils and the hydraulic conductivity is no different.

Based on the experimental program executed in this research, and limited to both the tested materials and the testing procedures employed, the following conclusions could be drawn:

(1) Introducing either ammonium chloride or ammonium sulfate solutions in different concentrations (ranged from 75 to 75,000 ppm and from 137 to 137,000 ppm respectively) to compacted soil samples, initially saturated with deionized water, causes an increase in permeability of the tested soil. This *increase ranges between 325 and 600 times greater than the base line value of* the hydraulic conductivity (i.e., compared with the. hydraulic conductivity of the reference samples permeated with deionized water) in case of ammonium sulfate and ammonium chloride respectively *(Figure 2 & 4)*

(2) The changes in clay behaviour (regarding the hydraulic conductivity) due to changes in pore fluid composition (especially electrolyte concentration) were found to be consistent with the changes predicted by the use of Gouy-Chapman theory.

(3) Permeating the tested soil with ammonium chloride solution of constant concentration (=38,000 ppm) for different time intervals (or until different

volumes of the out flow has been collected) yielded that:

(a) Within the first two weeks starting from switching the permeant fluid from de-ionized water to ammonium chloride solution, the permeability of the tested soil increased to five times greater than the base value established using de-ionized water as a permeant. (Figure 3).

(b) Then, after about one month of permeation (tile time required for an amount of effluent equivalent to 4pv to be collected), there was no increase in the permeability.

(c) The two replicates permeated for 1.5 and 2 months, respectively (times required for 6 and 8 pvs to seep through the test sample), there was no trend toward increased permeability during the passage of the applied permeant.

(4) Permeating the tested soil with amonium sulfate solution of constant concentration (=69,000 ppm) for different time intervals (or until different volumes of the outflow has been collected) produced:

(a) An increase in the hydraulic conductivity of tile tested soil upon permeation with Ammonium sulfate at the tested concentration compared with the base value of hydraulic conductivity established using deionized water.

(b) The rate of that increase differs from that occurred upon permeation with ammonium chloride. Also, most of the increase occurred within the first two weeks (or during collecting the first 2pvs) and then the rate of increase decreased *(Figure 5)*.

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استقرار نفاذية مبطنات مقالب القمامة

د. ضياء المنيري - د. صلاح بيومي

يتم استخدام التربة المكونة من خليط من الطين والرمل قليلة النفاذية ومنخفضة التكاليف في تبطين مقالب القمامة ، ولقد تم في هذا البحث دراسة كفاءة استخدام مثل هذه التربة في عمليات التبطين لهذه المقالب.

ولقد تم بحث تأثير الأيونات الغير عضوية على نفاذية هذه الطبقة ولهذا فقد تم استخدام محاليل كلوريدات الأمنيوم وكبريتات الأمنيوم ذات تركيزات مختلفة في هذه الدراسة.

وتراوحت تركيزات الكبريتات من ١٠٠ إلى ١٠٠,٠٠٠ جزء في المليون والكلوريدات من ٥٠ إلى ٥٠,٠٠٠ جزء في المليون.

وقد تم بحث تأثير هذه التركيزات على نفاذية التربة المكونة من الطين والرمل ومـــدى كفاءة هذه التربة مع الزمن.