Sand bentonite mixture as a secondary liners in landfills

La mélange sable-bentonite comme une membrane secondaire dans les sites d'enfouissement

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ABSTRACT
Engineering specifications for a compacted clay liner are based mainly on a permeability coefficient less than 10^{-7}cm/s. Sand-bentonite mixtures are often used as a barrier material when there is a lack of naturally occurring clayey soils at a site. The addition of small amounts of bentonite (5-15%) improves the performance of a granular material providing a low permeability and an enhanced mechanical stability. In addition, bentonites, obtained in dry, powdered forms, are much easier to blend with onsite sandy soils and to be compacted than wet, sticky clods of clay. Thus, this paper investigates the permeability coefficient of the sand bentonite mixtures. The factors affecting it such as the bentonite content and the impact of real municipal solid waste leachate on the liner permeability are investigated. Volume change after inundation is also investigated taking into consideration the effect of the bentonite content and the type of the permeating fluid. The composite liner consisting from geomembrane (HDPE) sheets as a primary liner and sand bentonite mixture as a secondary liner is tested. The effect of imperfections of the HDPE sheets on the overall permeability of the composite liner is emphasized to clarify importance of the secondary liner in the prevention of the groundwater table contamination.

RÉSUMÉ
Les spécifications techniques d'une couche d'argile compactée sont gouvernées principalement par un coefficient de perméabilité généralement inferieur à 10^{-7}cm/s. Au cas du manque d'argile au site, les mélanges sable-bentonite sont souvent utilisés comme le matériau de la barrière. L'ajout des quantités relativement faibles de bentonite (5-15%) peut améliorer la performance du matériau granulaire apportant à la fois une faible perméabilité et une stabilité mécanique plus sécuritaire. En outre, les bentonites sèches en poudre sont beaucoup plus faciles à mélanger avec les sols sableux sur place et à compacter que les mottes d'argile humides et visqueuses. Ainsi, cet article examine le coefficient de perméabilité des mélanges sable-bentonite. Les facteurs affectant la perméabilité de membrane sont aussi examinés tels que la teneur en bentonite et l'impact du lixiviat réel obtenu des déchets solides municipaux. La membrane composite d'étanchéité constituée de géomembrane (HDPE) comme membrane primaire et de mélange sable-bentonite comme membrane secondaire, a été testé. L'effet des imperfections de couche en HDPE sur la perméabilité globale de la membrane étanche composite, a été souligné pour clarifier l'importance de la membrane secondaire dans la prévention de la contamination de la nappe phréatique.

Keywords : MSW landfills, sand bentonite mixtures, geomembrane, MSW leachate, coefficient of permeability, and composite liner.

1 INTRODUCTION

Land-filling has been and continues to be the most economical, and hence, popular method of solid waste-waste disposal in many parts of the world. In nonacid climates, it is practically impossible to eliminate leachate production. As a result, modern landfill design practices call for containment of the leachate formed or for migration under acceptable conditions. I

Compacted bentonite-sand mixture is an example of a bentonite-based material which is widely used as clay liner for landfills and as sealing and buffer elements for nuclear waste and highly toxic waste containments. The behavior of compacted bentonite-sand mixtures is controlled largely by the properties of bentonite. However, at a certain composition (or bentonite content) the behavior of the compacted mixture is influenced by the properties of the sand, (A. Samingan, 2005). The influence of sand on the behavior of a mixture takes effect at low bentonite content. This type of mixture is often referred to as "bentonite-enhanced sand" in which properties of the mixture at different dry density are influenced by load-deformation characteristics of the sand. Stewart et al., (1999), Graham et al. (1995) and Blatz et al. (2000) studied the influence of suction on the shear strength and stiffness of an unsaturated compacted bentonite-sand mixture.

Depending on the bentonite percentage of the mixture, the state of sand grains in the compacted mixture can be classified into two categories (figure 1), (A. Samingan, 2005).

There is a limiting bentonite content beyond which bentonite dominates the behavior of a mixture. This occurs at a particular dry density (or void ratio) of the compacted mixture depending on the swelling properties of the bentonite. The coefficient of permeability of the compacted bentonite-sand mixture may become even lower than that of the compacted pure bentonite at the same dry density. Studds et al. (1998) reported that "bentonite-enhanced sand" with 10% bentonite content had a lower coefficient of permeability than the mixture with 20% bentonite content.

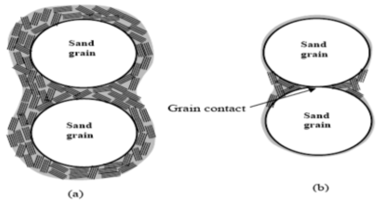

Figure 1: Two possible states of sand grains in a deflocculated clay system: (a) clay particles 'coating' sand grains and (b) clay particles 'welding' sand grains.

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Sand-bentonite mixtures are often used as a barrier material when there is a lack of naturally occurring clayey soils at a site. The addition of relatively small amounts of bentonite (5-15%) can improve the performance of a granular material providing both a low permeability and an enhanced mechanical stability.

The purpose of this paper is to investigate the Bentonite sand mixtures as to be used as municipal solid waste (MSW) landfill liner. Bentonite sand mixtures can be used as an alternative for the compacted clay liner in MSW landfill. A laboratory testing program is conducted to investigate the characteristics of bentonite sand mixtures in terms of compressibility, coefficient of permeability and compaction and the effect of leachate on the coefficient of permeability of the mixture. The obtained results were compared with that of clay liner.

2 MATERIALS AND METHODS

The main materials used in this research to investigate the performance of sand bentonite in the MSW landfill liner and the composite liner are sand, bentonite, clay and geomembrane. Different laboratory tests are conducted on these materials and their mixtures.

The sieve analysis is conducted on the retained soil which shows that the sample is, graded sand with some fine gravel. The matrix properties of the used sand are shown in table (1).

Table 1: The matrix properties of the used sand.

D10 (mm)	D30 (mm)	D60 (mm)	Cu	Cc
0.2870	0.5030	0.8189	2.8531	1.0764

The main additive used in this study to be added to the sand is bentonite. The bentonite used is of type OCMA where the properties are supplied by the manufacture. OCMA bentonite is specially treated, superior quality sodium bentonite. Table 2 shows the chemical composition of the bentonite.

Table 2: The chemical composition of the OCMA bentonite.

element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Combined H_2O	w.c at 105°C
%	54.62	20.35	4.05	1.02	0.10	2.92	0.19	6.09	6-10

- The cation exchange capacity ranges from 65-70 meq/100g.
- The natural water content is 6.78%.
- PH value for 6% slurry : 9.2-9.9

3 PERMEATING FLUIDS IN THE TESTING PROGRAM

The used permeating fluids are tape water, which is the ordinary tape water used for drinking, or leachate.

Leachate produced in a landfill is a liquid which has percolated through the waste. Wastes are decomposed both through chemical reactions with landfill liquids and the action of bacteria and other microbes that occur. The leachate used is collected from the leachate ponds of the MSW landfill in East Cairo, Egypt, belongs to FCC Company.

Chemical analysis is conducted on the leachate used to determine the chemical by products of the leachate used. Table 3 shows the chemical, Physio-Chemical, Nutrients and Heavy metals analysis.

Table 3: The Chemical Composition of the MSW leachate used in the study.

Chemical analysis:

Cations Milli-equivelent/ liter				**Anions Milli-equivelent/ liter**				**S.A.R**
Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	
136.5	103.5	300.6	222	0.10	5.10	325	216.7	27.43

Physio-Chemical analysis:

pH	**EC Milliohms/cm**	**T.D.S mg/l**	**T.S.S mg/l**	**T.V.S mg/l**	**COD mg/l**
8.90	54	32900	6.82	4.99	7350

Nutrients:

$N-NH_4$ (mg/l)	**$N-NO_3$ (mg/l)**	**PO_4 (mg/l)**
12124	4088	33.50

Heavy metals:

Al (mg/l)	**Pb (mg/l)**	**Cr (mg/l)**	**Cu (mg/l)**	**Zn (mg/l)**
0.666	**0.855**	**2.260**	**15.360**	**5.40**

Biological analysis:

$(BOD)_5$	**$(BOD)_{20}$**
18632	25108

3.1 *Testing Sand Bentonite Mixtures*

The most important characteristic of sand bentonite is to achieve a low coefficient of permeability, that it can be used as MSW landfill liner which must be less than 10^{-7} cm/sec. Oedometer tests were conducted on the different bentonite sand mixture (4, 7, 10, 14% bentonite) to determine the permeability and the compressibility of the mixtures in terms of the bentonite percent. Sand and bentonite are mixed in the dry condition and the optimum water content is added to the mixture and hence the samples were compacted to get the maximum dry density.

3.2 *Testing Composite Liner*

A 10% sand bentonite mixture was prepared, the sand and bentonite are mixed in the dry condition and the optimum water content was added to the mixture determined by the compaction test results. Falling head permeameter mold is filled with the mixture and compacted on five layers to give 8cm of compacted sand bentonite mixture (Figure 2).

HDPE sheet is placed over the soil specimen and sealed with silicon. The specimen is saturated by passing tape water through the sample till a steady flow is obtained. Falling head permeability test was conducted using leachate as the permeating fluid. The test is repeated several times with different number of holes in the HDPE.

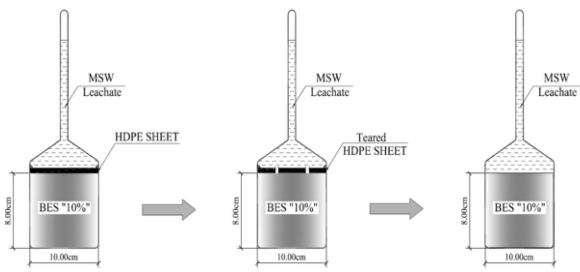

Figure 2: Falling Head Test on the Composite Liner

Table 4: The composite liner test specimen's initial conditions

Test no.	HDPE status	Holes diameter(cm)	% of holes	Permeating Fluid
1	no	------	0.00	Leachate
2	yes	0.25	0.06	Leachate
3	yes	0.5	0.25	Leachate
4	yes	0.75	0.56	Leachate
5	yes	1	1.00	Leachate
6	yes	1.25	1.56	Leachate

4 RESULTS AND ANALYSIS

Modified Proctor Tests (ASTM test designation D-1557) were carried out on the raw sand and sand mixed with 0, 4%, 7%, 10%, and 14% bentonite by weight.

4.1 *Permeability results using oedometer.*

The coefficient of permeability vs. the vertical stress for the mentioned five samples is shown in Figure 3. The coefficient of permeability drops dramatically (by more than six orders of magnitude) by adding bentonite to raw sand. It can also be observed that the coefficient of permeability of the natural clay lies between these of the 7% to 10% bentonite sand mixture. An example of the coefficient of permeability vs. bentonite content at different stresses is shown in figure 4. The permeability decreases as the bentonite content increases, as has been observed by many investigators (e.g. Chapuis, 1990; Kenney et al., 1992; Mollins et al., 1996; Komine and Ogata, 1996). In the first stage, the coefficient of permeability drops dramatically by more than six orders of magnitude as the bentonite content increases from zero to 4%. In the second stage, the coefficient of permeability drops again (about 3 times) as the bentonite content increases from 4 to 7%. Thereafter, the coefficient of permeability decreases gradually with increasing bentonite content. In this stage as the bentonite content increases from 7 to 10% the coefficient of permeability decreases by factor of 1.5.

The behavior can be explained by the following hypothesis: When the mixture has no bentonite, the voids between the sand grains are large and act as preferential flow paths. The coefficient of permeability is dictated by the geometry of the void space. As the bentonite is first introduced into the mixture (BC = 4%), the bentonite coats the sand particles and because of the vertical and horizontal deformation of the sample are restricted (due to constant volume test in an oedometer), the montmorillonite minerals swell during water uptake and fill most of the voids in the compacted sand bentonite mixtures. This causes a severe reduction in the cross sectional area of the flow and thus a severe decrease in the coefficient of permeability. As more bentonite is introduced (4 to 7%), the thickness of the coating increases and also the volume of the swelling bentonite increases, fill the pore-throats between particles, and eliminate more flow paths responsible for permeating flow through the mixture.

4.2 *The effect of the Permeating Fluid*

In terms of groundwater contamination, the elements of greatest concern are the heavy metals which are chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) because they are often found in large amounts in landfill leachate and are potentially toxic to plants and animals (Thornton et al. 2003; Whittle and Dyson 2002; Urase et al. 1997; Cherry et al. 1984). The chemical analysis of the MSW leachate indicates elevated levels of Cu and Zn. It also contains high concentrations of monovalent cations such as Na^+ and K^+.

Figure 4 shows the effect of the permeating fluid on the coefficient of permeability of the Sand bentonite mixtures at different vertical stress. It can be seen that the coefficient of permeability is decreased when leachate rather than the tape water permeate the sample. The decrease in permeability due to the combination of the following:

1. Due to the high cation exchange capacity (CEC) of the bentonite (65-70 meq/100g) which leads to the adsorption of the monovalent cations (Na^+, K^+) from the leachate at the exchange sites of the soil resulting in the expansion of the diffuse double layer, thus dcreasing the mixture voids.
2. The precipitation of heavy metals by the carbonate and hydroxide fractions in the leachate followed by the adsorption at the exchangeable sites may contribute in the plugging of the soil voids, thus decreasing the liner permeability (Kaoser et al., 2005),
3. Plugging of the soil voids as a result of microbial growth as a result of bacterial degradation of small amounts of dissolved organic compounds, presumably much more plugging would be expected in the permeability tests involving permeation with leachate with high organic and nutrients content (Griffin et al., 1976).

Figure 5 summaries the relation between bentonite content, the vertical stress and the permeability in the 3-D relation.

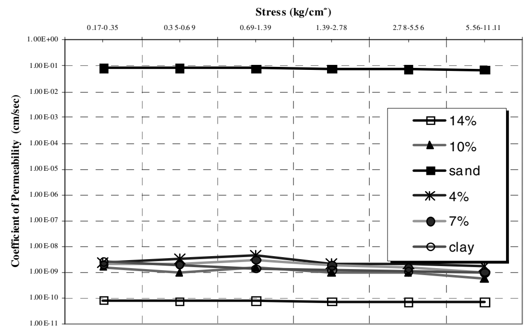

Figure 3: Vertical stress vs. coefficient of permeability (tape water).

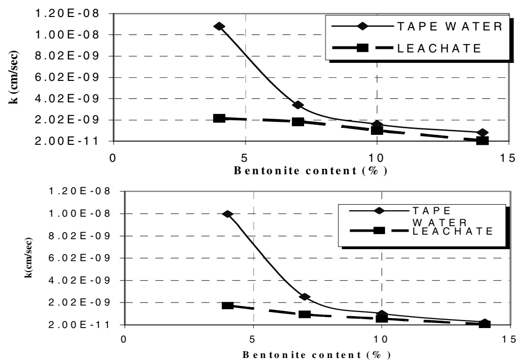

Figure 4: Bentonite content vs. the coefficient of permeability at different vertical stress

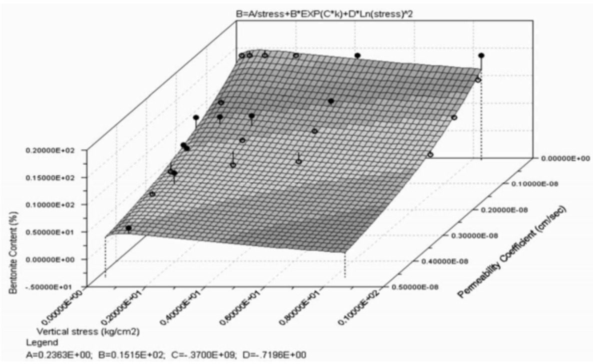

Figure 5: Relation between Bentonite Content, the Vertical Stress and the Permeability Coefficient.

4.3 *Composite liner testing*

Behavior of composite liner consisting from High Density Polyethylene (HDPE) sheet as a primary liner and 10% sand bentonite mixture as a secondary liner is tested. The effect of the HDPE tearing on the coefficient of permeability of composite liner is inspected by Falling Head Permeameter.

The test results are illustrated in figure 6, which shows the relationship between the permeability coefficient and the percentage of holes in the HDPE sheets. The permeability coefficient increases as the percentage of holes increases in the HDPE. In zone A, the permeability coefficient of the composite liner increase only slightly to reach 8% of the permeability coefficient of the sand bentonite mixture alone as the percentage of holes increases from 0.0625 to 0.25%.. In zone B, the permeability coefficient of the composite liner elevated dramatically to reach 75% of the permeability coefficient of the sand bentonite mixture, as the percentage of holes increases from 0.25 to 0.5625%.Thereafter, in zone C the permeability coefficient increases gradually with increasing percentage of holes. At the highest percentage of holes (2.25%), the permeability coefficient of the composite liner approaching that of sand bentonite alone ($2.65x10^{-8}$ cm/s).

At low percentage of holes in the HDPE the increase in the permeability coefficient is slight due to the full contact between HDPE and the sand bentonite liner thus, the leachate permeates from the holes to the sand bentonite liner directly. The severe increase in the permeability coefficient when the percentage of holes increase (>0.25%) as the defects had allowed leachate to migrate between the HDPE and the sand bentonite liner thus, the permeation is through the whole cross-section of the sand bentonite mixture. If the percentages of holes increase more the HDPE liner will become worthless and the coefficient of permeability of the composite liner will be equal to that of the sand bentonite liner alone.

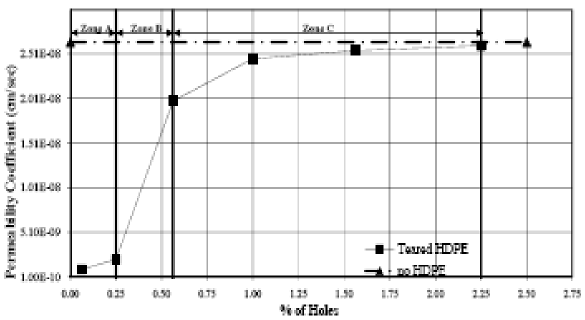

Figure 6: Percentages of Holes in the HDPE vs. Permeability.

5 CONCLUSIONS

1. At constant vertical stress, the coefficient of permeability decreases as the bentonite content increases. The dramatic decrease in the coefficient of permeability (by more than six orders of magnitude), happens when bentonite content increases from zero to 4% in the mixture. However, at high bentonite contents the decrease in the coefficient of permeability is gradual.
2. In order to comply with the engineering standards for the permeability requirements of the Municipal solid waste landfill liners (to be less than 10^{-7} cm/sec), bentonite content should not be less than 7 % of the mixture's weight. However, bentonite content should not be more than 10% for more economic mixture design.
3. MSW leachate reduces the coefficient of permeability than the case of using tape water. This reduction in the coefficient of permeability is significantly high in case of low bentonite content and low vertical stress due to the plugging of most of the mixture voids, thus, eliminating most of the flow paths in the mixture.
4. In composite liner system consisting of HDPE as a primary liner and 10% sand bentonite mixture as a secondary liner, when the HDPE is not torn, the composite liner is theoretically impermeable. When the percentage of tears exceeds 0.25% of the surface area of HDPE the overall coefficient of permeability is dependent mostly on the coefficient of permeability of the secondary liner (Sand Bentonite mixture), moreover, if the percentage of tears the HDPE exceeds 0.5625% the permeability coefficient of the composite liner approach that of sand bentonite alone ($2.65x10^{-8}$ cm/s), this emphasizes the importance of the secondary liner to act as the only hydraulic barrier against ground water contamination in case of tore HDPE sheets.

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