Assessment of Municipal Solid Waste Clay Liner System Using Consolidation Test

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Abstract: The present study has been carried out to provide landfill clay liner soil with admixture microsilica in different proportions. The geoenvironmental and physico-chemical characteristics were carried out to characterize the clay mixed with definite portion of microsilica in mass ratio. An experimental investigation was performed to determine the effect of clay and microsilica consolidation of leachate. The microsilica- clay composites were mixed in ratios of 0:100, 1:10 and 1:20 and experiment carried out with leachate as the permeation liquid. The quantitative reductions in coefficient of permeability increase in the effective stress for the all ratios. The chemical reaction of water and soil are lower than that in the leachate. In real field the leachate as permeation liquid after construction of liners, is retained by adding microsilica in clay liner system. 1:10 ratio of microsilica-clay composites was found to be more suitable municipal solid waste leachate as permeating liquid.

Keywords: Clay, consolidation, leachate and microsilica.

1. INTRODUCTION

There are more criteria that are usually used for evaluating clay liner materials using liner construction. The composition, compaction, compressive strength and permeability are main requirements of clay liner material. The performance of clay liners depends to a greater extent on compaction effect on the soil. To achieve minimum permeability value in the field, soils used for the construction of compacted clay liners are required to meet specification with respect to plasticity. Clay materials are used as natural or engineered barriers for containment at municipal solid or industrial waste disposal facilities. Earlier studies carried out in the field of environmental geo technology attempted to address the need for a comprehensive understanding of the mechanical behavior of solid waste liner materials indicated [1-4]. The aim of the study as to assses permeability Characteristics of clay liner materials using consolidation test.

Benson *et al*. [5] evaluated the hydraulic conductivity using triaxial cell for clayey till and transition till. The study follows with an analysis of different versions of the Kozeny- Carman equation and developed regression models in function of physical properties. Benson *et al*. [5] suggested that the using particle size analysis curves and Atterberg limits and five essential conditions hydraulic conductivity of 1×10^{-9} m/s or less could be achieved. The five conditions are percentage of fines grater or equal to 30%, percentage of clay grater or equal to 15%, liqid limit (WL) grater or equal to 20%, Plasticity index(Ip) grater or equal to 7and activity ratio (Ip/%C) grater or equal to 0.3.

Abichou *et al*. [6] investigated the feasibility of twelve foundry green sands for constructing hydraulic barrier layers. Relationships between hydraulic conductivity and compaction water content and compaction energy for foundry sands exhibits trends similar to those of natural clays. However, the hydraulic conductivity of foundry sands was found, not as sensitive to compaction conditions as compacted clays. The hydraulic conductivity of foundry sands decreases with increasing liquid limit, plasticity index, and bentonite content. Foundry sands having liquid limit greater than 20%, plasticity index greater than 2, or bentonite content greater than 6% was reported be compacted to achieve hydraulic conductivities less than 10^{-7} cm/s. Short and long-term tests were conducted to assess the chemical compatibility of foundry sands with liquids that they may permeate in liner applications. Specimens were tested for permeability with deionized water, tap water, 0.1 N $CaCl_2$ solution, and Municipal solid waste leachate. The short-term tests were conducted for 75 days.

(Approximately one pore volume) and the long-term tests were conducted for 433 days (approximately five pore volumes). The hydraulic conductivity varied by less than a factor of 1.8 for the four foundry sands tested in the shorter-term tests. Similarly, the hydraulic

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conductivity remained essentially unchanged or decreased slightly during the long-term tests. This study also showed that the similarities between the behavior of foundry sands and sand bentonite mixtures. Therefore commonly used construction specifications for constructing sand bentonite barriers can likely be extended to barrier layers constructed with foundry green sands. Field testing is essential to confirm that barrier layers can be constructed with foundry sands in the field that have a low hydraulic conductivity. Field hydraulic conductivity is also necessary to identify potential differences from the results obtained from the laboratory tests conducted reported in this study.

Yewande Awe *et al*. [7] studied the lime-activated pulverized fuel ash (PFA) as liner materials. They found that PFA as a chemical and physical barrier to metal ion migration with the potential to form low permeability barriers. Md Sazzad Bin-Shafique *et al*. [8] studied leaching of heavy metals from fly ash Stabilized soils used in highway pavements.

Ahmet Tuncan *et al*. [9] studied the behavior of mixture of bentonites and zeolites (B/Z) for different mix ratios compacted at optimum moisture content. Tests were conducted on soil specimens to determine the strength parameters, permeability, pH, heavy metals concentration and other properties. Bentonites-zeolites ratio of 0.10 was found to be an ideal landfill liner material, because its low hydraulic conductivity and high cation exchange capacity. The use of bentonites-zeolites mixtures as an alternative to clay liners would provide potential to significantly reduce the thickness of base liner for landfills.

The influence of synthetic and actual hazardous liquid wastes on the permeability of earthen liners made of sand-bentonite and natural zeolite-bentonite mixture as well as that of sand and micro cement were also investigated [10, 11]. In the absence of impermeable natural soils, compacted mixtures of bentonite and sand were reported to serve as barriers to fluids.

Marie-pierre carignan [12] conducted experiments for thermally treated drilling mud waste used as liner system. The study was about the volatile organic compounds (VOC) migration through the liner system. The level of attenuation were observed, Results indicated that level of attenuation increases with Dichloromethane < benzene < Trichloroethylene < toluene for batch and diffusion tests.

Osinubi *et al*. [13, 14] tried lateritic soils as soil liners and covers. Hydraulic conductivity tests were conducted for eightyfour specimens of lateritic soil. The specimen were compacted at various moulding water contents and then permeated with distilled water in the laboratory. Test results showed that hydraulic conductivity of the soils decreased with the increase in dry unit weight and initial saturation, especially at higher fines content. Hydraulic conductivity values less than $1x10^{-9}$ m/s was obtained at dry unit weights and initial saturations greater than16.0 KN /m^3 and 86.0% respectively. They observed that the difference in hydraulic conductivity values due to variations in moulding water contents and compactive efforts was statistically significant as shown by the two-way analysis of variance tests. The test results also agrees with the results obtained by Daniel and Wu [15] for compacted clayey soil.

Compacted natural clay soils are used as liners and covers in waste containment facilities. Compacted clay liners are widely used in solid waste landfills due to their effectiveness in the prevention of migration of leachate into soil, thereby protecting the quality of ground water. A clay liner consists of one or more layers of cohesive soils that are compacted to achieve a low permeability in the order of 10^{-7} cm/s [9,16,17]. The purpose of a clay liner in a landfill is to serve as a barrier between waste materials and the hydro environment by preventing the seepage of leachate from the landfill.

Soils with grains smaller than 0.002 mm and exhibiting plasticity are classified as clays. Their properties are governed by the nature and size of the mineral grains constituting the soil and the water content. Clay minerals are by products of the chemical disintegration of rocks. Natural clays are formed by sedimentation of the fine particles in large bodies of water such as lakes (lacustrine clays) or seas (marine clays).

The clay liners attenuate organic and inorganic contaminants. Inorganic contaminants, while transported through the clay liner, are chemically adsorbed onto the particle surfaces and experience a delay in solute breakthrough in hydraulic barriers. In the absence of impermeable natural soils, compacted mixtures of bentonite and soil have been used to form barriers to fluids. Solute transport through the liner should be minimized, while maintaining appropriate shear strength and compaction characteristics.

Mircrosilica is also known as silica fume, which is a by-product of the reduction of high purity quartz with coke, in the electric arc furnaces while manufacturing silicon and ferrosilicon alloys. The American Concrete Institute (ACI) defines silica fume as "very fine non-crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon" (ACI 116R). It is usually a gray coloured powder, having similarity to Portland cement or fly ash as far as the physical texture and color is concerned. The microsilica is mostly used in the construction industry as an admixture of concrete and soil stabilization and liners.

A compacted clay liner system should have low permeability, should be robust and durable and should be resistance to chemical attack, puncture and rupture.

2. MATERIALS

Leachate is simply the off-colored ooze, which flows from buried solid wastes. During rains, water infiltrates into the waste and reacts physically and chemically with the waste to produce leachate. As the water seeps into the landfill, the water combines with material from the wastes to form leachate. The leachate infiltrates into the subsurface causing subsoil and groundwater contamination. The solid waste continues to stay at the location where it is placed for years, hence the process of leachate infiltration into subsurface environment continues slowly and steadily over several years. Leachate, by itself is very complex in nature. It contains a wide spectrum of chemical compounds from organic solvents to inorganic salts.

2.1. Determination of Permeability Using Consolidation Test

For each pressure increment, the change in the thickness of sample was measured from the readings of the dial gauge and the change in the void ratio corresponds to an increase in the overburden pressure was calculated. The coefficient of permeability calculated using the Eq.1.

$$K = \frac{C_v a_v \gamma_\infty}{1+e} \tag{1}$$

Where K- Coefficient of permeability - cm^2/s,

C_v - Coefficient of Consolidation – cm^2/s,

a_v - Coefficient of compressibility

a_v = Change in Void ratio/Change in stress

= e_o- e/σ'-σ_0' m^2 /K.N.

γ_∞ = Weight of water

The coefficient consolidation Cv is calculated by using Casagrande log time method. Construct a plot of dial reading Vs log time. To find H_{50} using Eq.2.

$$H_{50} = \frac{H_o - (R_{50} - R_{start})}{2} \tag{2}$$

Where H_o is the Initial height of specimen, R_{start} = 0 (if you zeroed the dial at the beginning of the test), R_{50} determine from the plot

$$c_v = \frac{T_{50} \times H_{50}^2}{t_{50}} \tag{3}$$

Where c_v (cm^2/sec),

T_{50} = time factor at U = 50%,

H_{50} = height of drainage at U = 50%,

t_{50} = Time at U = 50%, T_{50} = 0.197

The Coefficient of volume change (m_v) constrained modulus (1/m_v) obtained the following equation in Eq.4.

$$m_v = -\frac{\Delta H}{H_0}\frac{1}{\Delta\sigma} \tag{4}$$

Where m_v - Coefficient volume change (m^2 /K.N)

1/ m_v = Constraint modulus

ΔH = Consolidation settlement

H_0 = Initial thickness of clay layer

$\Delta\sigma$ = Change in stress

2.2. Consolidation Test on Clay Liner Materials

The consolidation tests were carried out for raw clay and the clay mixed with definite portion of microsilica in mass ratio. The consolidation test was carried out to determine the permeability of as leachate through the porous medium. The microsilica- clay composites were mixed in ratios of clay, 1:10 and 1:20 experiments were carried out with leachate as the permeation liquid.

The permeability was determined by the experiment using a consolidometer by incremental loading consolidation test. The consolidation test is an indirect permeability test in which a sample of soil is compressed in a rigid ring at various vertical stress levels. The permeability of soils can be computed from the definitions of the coefficient of consolidation, and fitting the Terzagi consolidation theory to the consolidometer time rate of settlement data to evaluate the coefficient of consolidation. In the present investigation, Casagrande log time fitting method. Consolidation- permeability testing is carried out in order to determine the relationship between effective stress, void ratio and permeability for fine textured potential cover or waste materials samples. The test specimens are slurred with distilled water to an over-saturation condition and placed into a stainless steel oedometer ring, which has an inside diameter of 60 mm and a height of 20 mm. After the compacted specimen, together with the ring, was installed in a consolidometer cell. In order to reduce side friction, the inner surface of the test rings was coated with a thin layer of silicone grease. Filter paper was placed at the bottom and top of the sample. A top cap with a porous stone was placed above the soil sample. The entire assembly was placed in the consolidation cell and positioned in the loading frame. The consolidation ring was immersed in the liquid with the same composition as the saturating fluid. Vertical consolidation pressures are generally applied to the sample using a load increment ratio of one, with minimum load duration of 24 hours.

The permeability studies of clay liner materials added with microsilica were conducted using incremental loading consolidation test as per ASTM:D 2435-04 [18, 19] with the following time interval of 1,2,4,8,15,30,60,120,1440 minutes.

The dial gauge was set and the initial reading was taken load of 100 KN/m^2. These tests were conducted for 10 days with increment of 100 KN/m^2 per day. After the test, the soil sample was weighed, dried for 24 hours at 110°C and weighed again to obtain the mass of solids. Analysis of the test results include plots of dial readings Vs log time (Casagrande method), and dial reading Vs log time (logarithm of time fitting method), Void ratio Vs pressure, Void ratio Vs permeability, permeability Vs log pressure and constrained modulus Vs log pressure. The Cv values were determined using logarithm of time fitting method from the graph dial reading Vs log time.

2.3. Incremental Loading Consolidation Test Results for Clay with Mircrosilica for Leacahte

The consolidation tests were carried out for raw clay and the clay mixed with definite portion of microsilica in mass ratio. The microsilica- clay composites were mixed in ratios of 0:100, 1:10 and 1:20 and experiment carried out with leachate as the permeation liquid. The tests were conducted similar to the one done for consolidation test for water. The chemical reaction of water and soil are lower than that in the leachate. In real field the leachate as permeation liquid after construction of liners, is retained by adding microsilica in clay liner system.

3. RESULTS

3.1. Correlation Between Vertical Stress and Permeability of Leachate Interaction for Clay Liner Composites

The Correlation between vertical stress and permeability of leachate interaction shown in Figure **1**. to Figure **3**. The combined graph of compressive stress and permeability of the entire ratio are shown in Figure **4**.

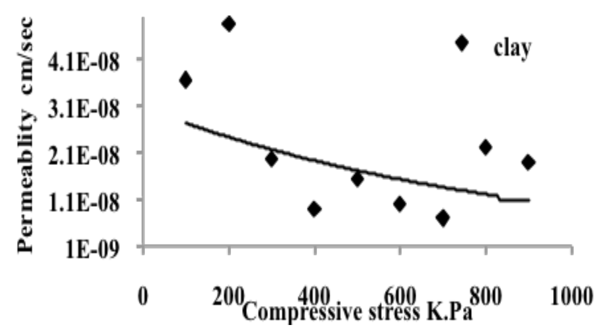

Figure 1: Compressive stress and permeability for clay permeation liquid as leachate.

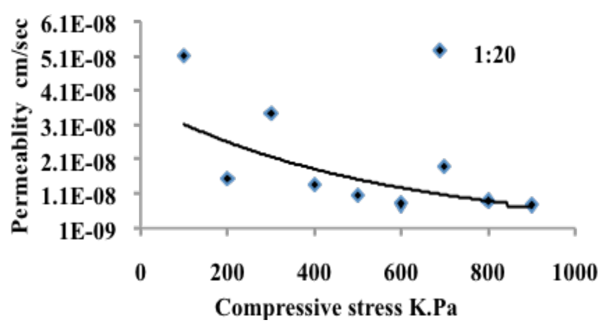

Figure 2: Compressive stress and permeability microsilica-clay 1:20 ratio of composites permeation liquid as leachate.

The permeability values decrease with increase of compressive stress for all ratios. From the Figure **1**. It may be inferred that the permeability values decrease for raw clay form the as 3.65 x 10^{-8} cm/s to 1.89 x 10^{-8} cm/s (0.92%), for 1:20 ratio form the Figure **2**. as 5.10 x 10^{-8} cm/s to 7.54 x 10^{-9} cm/s (5.76%) and for 1:10 ratio form the Figure **3**. as 5.19 x 10^{-8} cm/s to 9.69 x 10^{-9} cm/s (4.37%). The three ratios of compressive stress and permeability interaction with leachate were presented in Figure **4**.The 1:20 ratio higher decreasing percentage than other two ratios.

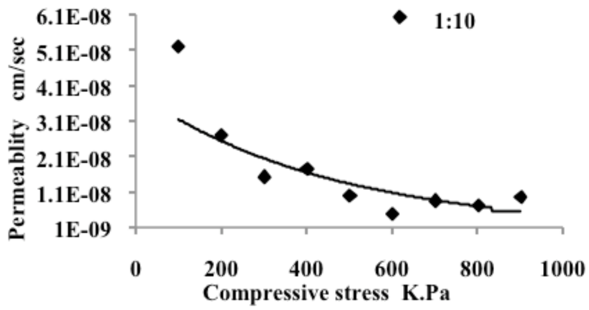

Figure 3: Compressive stress and permeability microsilica-clay 1:10 ratio of composites permeation liquid as leachate.

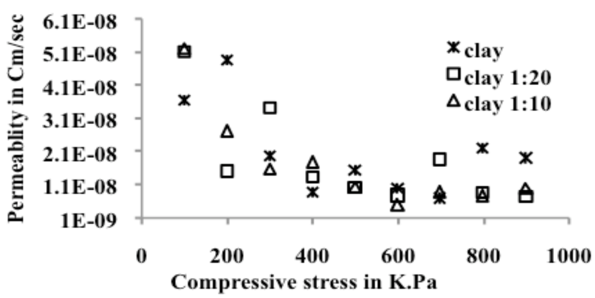

Figure 4: Combined graph of all ratio of compressive stress and permeability interaction with leachate.

3.2. Variation of Permeability Respect with Void Ratio of Clay Added Mircrosilica with Leachate as Permeating Fluid

Variation of Permeability respect with void ratio of clay added mircrosilica with interaction leachate are shown in Figure **5** to Figure **7**. It is clearly revealed from Figure **5** that the permeability of raw clay and microsilica: clay composites increases with increasing void ratios with leacahte. The permeability is higher at higher void ratio simply due to the amount of higher voids in the particles and space of flow exit in the specimens. The coefficient of permeability is a function of void ratio and usually takes the form of linear trend on a void ratio versus permeability.

The EDX spectra (Energy Dispersive X-ray analysis) were analyzed for raw clay soil calcium content as 11.1%, calcium oxide Cao 12.8% of total composition. The leachate pH present in the study as 7.9 The reduction in permeability in clay liner composite was at least in part related to the precipitation of free calcium from the dissolution of the carbonate [20].

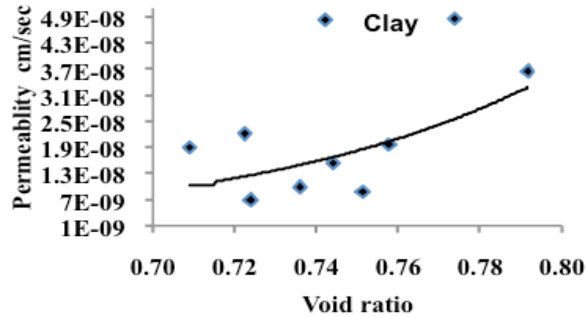

Figure 5: The relationship between void ratio and permeability of clay leachate as permeation liquid.

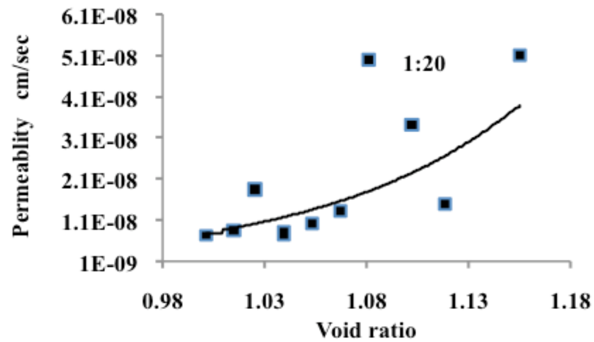

Figure 6: The relationship between void ratio and permeability of microsilica -clay 1:20 ratio composites leachate as permeation liquid.

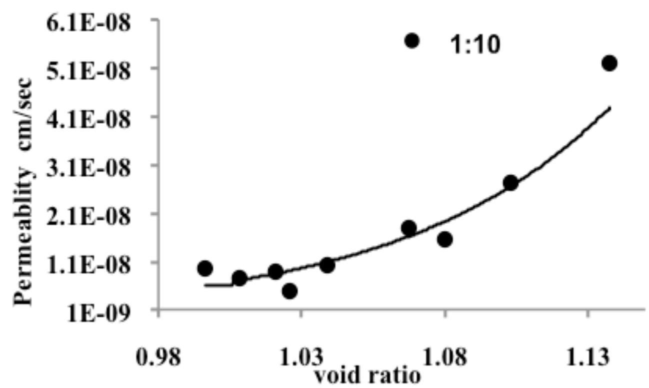

Figure 7: The relationship between void ratio and permeability of microsilica - clay 1:1 0 ratio composites leachate as permeation liquid.

3.3. Correlation Between Time and Settlement of Micro Silica -Clay Composites Leachate as Permeation Liquid

Part of consolidation test, the settlement of the specimen was measure against the time. The settlement Vs time curves were drawn for clay, microsilica – clay composites for different ratio of 1:20 and 1:10. Figure **8** shows the variation between settlement and elapsed time for micro silica-clay composites.

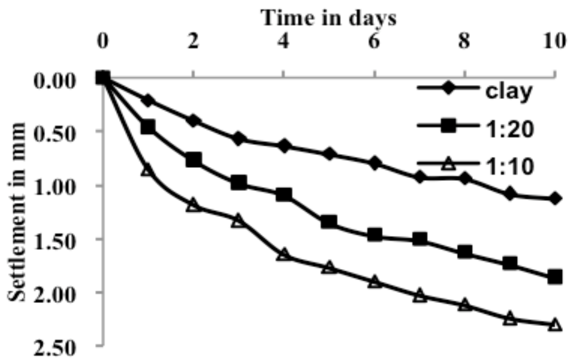

Figure 8: Correlation between time and settlement of clay liner composites leachate as permeation liquid.

Figure **8**. shows the Settlement and time is directly proportional. Every day increment of 100 K.Pa loading condition the settlement of specimen was also increased. The final settlement registered after final loading (1000 k.Pa) as specimen of clay, microsilica–clay composites are 1:20 and 1:10 ratio as 1.12 mm, 1.86 mm, 2.29 mm. Compared to three composites raw clay had minimum settlement to 1:20 and 1:10 ratio. The highest settlement registered for 1:10 ratio for leachate is 2.29 mm.

3.4. Correlation Between Time and Permeability of Clay Liner Composites with Interaction Leachate as Permeating Liquid

Permeability test results for municipal solid waste leachate in the clay and microsilica-clay composites are shown in Figure **9**. to Figure **11**.

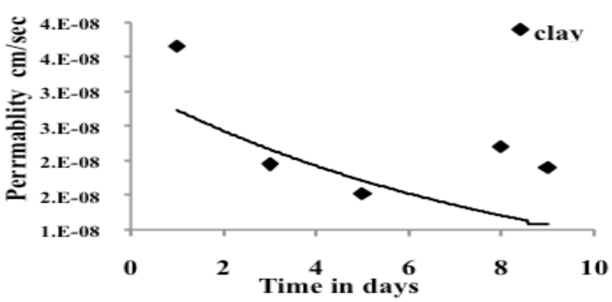

Figure 9: Permeability Vs duration for clay liner with leacahte as permeation liquid.

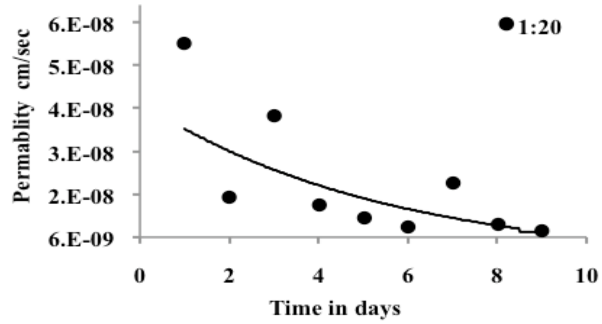

Figure 10: Permeability Vs duration for clay - microsilica 1:20 ratio with leacahte as permeation liquid.

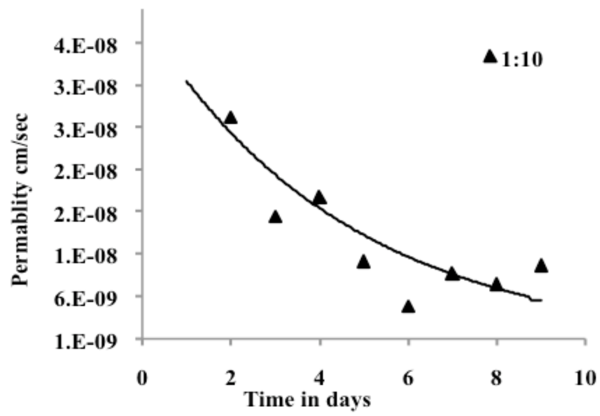

Figure 11: Permeability Vs duration for clay - microsilica 1:20 ratio with leacahte as permeation liquid.

It can be seen from Figure **9** that the variation of coefficient of permeability for raw clay varying from 3.65 x 10-8 cm/s to 1.9 x 10-9 cm/s, microsilica: clay ratio of 1:20 from 5.1 x 10-9 cm/s to 7.54 x 10-9 cm/s and microsilica – clay ratio of 1:10 as from 5.19 x 10-8 cm/s to 9.69 x 10-9cm/s. The average permeability values are presented in Table **1** with leachate as the permeating liquid.

It can be observed, that for the raw clay mean permeability value is 2.07 x 10^{-8} cm/s. For microsilica: clay composites, the permeability was found to decrease to the value of 1.86 x 10^{-8} cm/s for 1:20 ratio and 1.70 x 10^{-8} cm/s for 1:10 ratio.

Consolidation performance. The lowering of permeability values clay and microsilica-clay

Table1: The Average Permeability Values for Leacahte

Sl. No	Ratio of Microsilica: Clay	Mass % of Micro Silica Content	Average Permeability Value for Leachate 10^{-8} cm/s
1.	Clay	0	2.07
2.	1:20	5	1.86
3.	1:10	10	1.70

composites of a 1:20 and 1:10 were 48%, 85% and 81% respectively. 1:10 ratio of microsilica-clay composites was found to be more suitable.

The permeability values of earlier researcher found that Abichou *et al*. [6] using foundry sand Bentonite content as 6.6% to 10% and permeability values are 3.9 x 10^{-8} cm/s to 4.6 x 10^{-8} cm/s for leachate. The average hydraulic conductivity of the clay mixtures ranged from 1x10^{-8} to 5 x 10^{-8} cm/sec. Ahmet Tuncan *et al*. [9].

3.5. Variation of Void Ratio for Different Compressive Stress in the Clay, Micro Silica-Clay Composites Leachate as the Permeating Liquid

The study was carried out for the void ratio Varied for vertical stresses in the clay, microsilica-clay composites with water as the permeating liquid in a consolidation test. The result presented in Figure **12**.

In the Figure **12** the void ratio indirectly proportional to compressive stress, commonly referred as compression curves. The void ratio versus vertical stress relationship which was observed during the consolidation test on clay composite specimens shown is Figure **12**. The decrease in percentage of void ratio of samples is raw clay (10.9%), 1:20 ratio (13.85%) and 1:10 ratio (13.58%). It can be seen that there is not much difference in terms of their compressibility characteristics although the mixture containing 1:10 and 1:20 ratio of microsilica have a slightly higher void ratio than that of raw clay soil. It can be concluded from Figure **12** the sample which have more microsilica content shows a stiffer consolidation performance.

3.6. Variation of Constraint Modulus for Different Compressive Stress in the Clay, Micro Silica-Clay Composites with Leachate as the Permeating Liquid

The compressive stress and constraint modulus for leachate are shown in Figure **13**. The constraint modulus of clay varies from 1.55 x 105 KN/ m^2 to 4.55 x 105 KN/ m^2, for ratio 1:20 it various from 6.06x 104 KN/ m^2 to 3.45 x 105 KN/ m^2 and for 1:10 ratio it various from 6.41 x 104KN/ m^2 to 1.64 x 105 KN/ m^2.

This study was centered on incremental consolidation of microsilica added with clay for permeation of leachate and water. The test results show that pore fluid chemistry had no effect on clay liner composites of hydraulic conductivity. Similar to the findings [21,22], the results indicate that hydraulic conductivity follows the same relationship for leachate and water as permeation liquid.

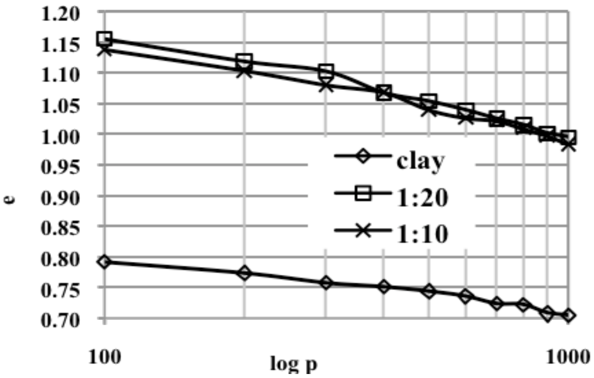

Figure 12: Void ratio and compressive stress of clay, micro silica –clay Composites for leachate.

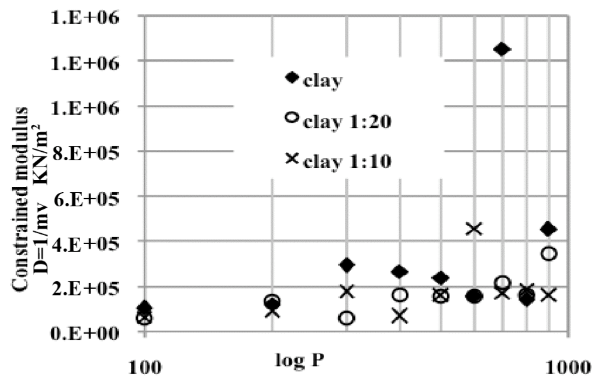

Figure 13: Constraint modulus for clay, micro silica –clay composites permeating liquid for leachate.

Predictions of contaminant transport are strongly dependent on the hydraulic conductivity and for the clay layer in particular this has been found to be very dependent on slight changes in the physical properties. A further complicating factor is that the in-situ tests tend to measure lateral flow and do not give an indication of the vertical connection between sand lenses.

4. CONCLUSION

This paper presents the results of an investigation of the behavior in solid waste clay liner system using consolidation test leachate as permeating liquid:

1. The permeability of the specimens was studied with a leachate solution over a period of 24 days. While raw clay, 1:20 ratio and 1:10 ratio decreased in permeability over a time.

2. The Average permeability for raw, microsilica-clay composites 1:20 and 1:10 are the leachate raw, microsilica-clay composites 1:20 and 1:10 are 2.07 x 10-8 cm/sec, 1.86 x 10-8 cm/sec and 1.70 x 10-8 cm/sec.

3. The incremental consolidation test results show that the optimum average permeability is obtained for microsilica-clay composites of 1:10 ratio of microsilica addition leachate IS 1.06 x 10-8 cm/sec.

REFERENCES

[1] Robert W Day and Marsh ET. Triaxial A value versus swells or collapse for compacted soil, Journal of Geotechnical Engineering 1995; 566-570.

[2] Gilbert BR, Federico Fernandez and David Hosfield W. Shear strength of reinforced Geosynthetic clay liners. Journal of Geotechnical Engineering 1996; 122(4); 259-266. http://dx.doi.org/10.1061/(ASCE)0733-9410(1996)122:4(259)

[3] Hoe I Ling, Ahmet Pamuk, Montri Dechasakulsom, Yoshiyuki Mohri, and Christopher Burke. Interactions between PVC Geomembranes And Laboratory Studies on Unconfined Compressive 1205 Compacted Clays. Journal of Geotechnical and Geoenvironmental Engineering 2001; 950-954.

[4] Iman Bagherpour, Asskar J and Chorbasti. Stabilization of fine-grained soils by adding microsilica and lime or microsilica and cement, Electronic journal of Geotechnical Engineering 2003; 8(B).

[5] Benson CH, Zhai H and Wang X. Estimating hydraulic conductivity of compacted clay liners. Journal of Geotechnical Engineering 1994; 120(2): 366-387. http://dx.doi.org/10.1061/(ASCE)0733-9410(1994)120:2(366)

[6] Abichou T, Benson C and Edil T. Foundry green sands as hydraulic barriers: Laboratory study. Journal of Geotechnical and Geoenvironmental Engineering 2000; 126(12): 1174-1183. http://dx.doi.org/10.1061/(ASCE)1090-0241(2000)126:12(1174)

[7] Yewande Awe and Chris Cheeseman. Permeability of lime-activated pulverized fuel ash to metal-containing permeants. Waste Management & Research 2001; 19: 35-44. http://dx.doi.org/10.1177/0734242X0101900105

[8] Md Sazzad Bin-Shafique, Benson and Edil TB. Leaching of heavy metals from fly ash stabilized soils used in highway pavements. Geo Engineering Report No. 02-14, University of Wisconsin-Madison 2002.

[9] Ahmet Tuncan, Mustafa Tuncan, Hakan Koyuncu and Yucel Guney. Use of natural zeolites as a landfill liner. Waste Manage Res 2003; 21: 54-61. http://dx.doi.org/10.1177/0734242X0302100107

[10] Kayabali K and Mollamahmutoglu M. The influence of hazardous liquid waste on the permeability of earthen liners. Environmental Geology 2000; 39(3-4): 201-210. http://dx.doi.org/10.1007/s002540050001

[11] Ekrem Kalkan and Suat Akbulut. The positive effects of mircosilica on the permeability, swelling pressure and compressive strength of natural clay liners. Engineering Geology 2004; 73: 145-156. http://dx.doi.org/10.1016/j.enggeo.2004.01.001

[12] Marie-pierre carignan. Assessment of thermally treated drilling mud waste as value added martial for liner system. MS Thesis Dalhousie University 2005.

[13] Osinubi KJ and Nwaiwu CMO. Hydraulic conductivity of Compacted Lateritic Soil. Journal of Geotechnical and Geoenvironmental Engineering 2005; 131(8): 1034-1041. http://dx.doi.org/10.1061/(ASCE)1090-0241(2005)131:8(1034)

[14] Osinubi KJ and Nwaiwu CMO. Design of Compacted Lateritic Soil Liners and Covers. Journal of Geotechnical and Geoenvironmental Engineering 2006; 132(2): 203-213. http://dx.doi.org/10.1061/(ASCE)1090-0241(2006)132:2(203)

[15] Daniel DE and Yung-Kwang Wu. Compacted clay liners and covers for arid sites. Journal of Geotechnical Engineering 1993; 223-237. http://dx.doi.org/10.1061/(ASCE)0733-9410(1993)119:2(223)

[16] Taha MR and Kabir MH. Tropical residual soil as compacted soil liners. Environmental Geology 2005; 375-381. http://dx.doi.org/10.1007/s00254-004-1160-7

[17] Jae-Myung Lee, Charles D Shackelford, Craig H Benson, Ho-Young Jo and Edil TB. Correlating Index Properties and Hydraulic Conductivity of Geosynthetic Clay Liners. Journal of Geotechnical and Geoenvironmental Engineering 2005; 131(11): 1319-1329. http://dx.doi.org/10.1061/(ASCE)1090-0241(2005)131:11(1319)

[18] ASTM D2435 Standard Test Method for One-Dimensional Consolidation Properties of Soils 2004.

[19] ASTM D5084 Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter 2005.

[20] Noureddine Hamdi, Aidi Marzouki and Ezzeddine Srasra. Comparison of three Tunisian clayey soils for containing acid. Waste Bull Eng Geol Environ 2008; 67: 245-249. http://dx.doi.org/10.1007/s10064-008-0130-9

[21] Lee J and Fox PJ. Efficiency of seepage consolidation for preparation of clay substrate for centrifuge testing. Geotechnical testing Journal 2005; 28(6): 577-585.

[22] Fox PJ. Coupled large strain consolidation and solute transport II: Model verification and simulation results. Journal of Geotechnical and Geoenvironmental Engineering 2007; 133(1): 16-29. http://dx.doi.org/10.1061/(ASCE)1090-0241(2007)133:1(16)

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