Triaxial Permeability Testing on the Synthetic Leachate Effect on the Hydraulic Conductivity of Clayey Soil

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Abstract

Triaxial permeability apparatus with the fabricated bladder accumulators were used to examine the effect of synthetic leachate on the change of hydraulic conductivity of clayey soil. A silty clayey sand sample was obtained from Urmia City landfill site and mixed with 12% clayey soil to obtain a soil with optimal characteristics suitable as a liner material for landfill. The synthetic leachate was prepared with three different Ca^{++} *concentrations. The mixed soil was compacted and permeated with tap water. After equilibrium, the tap water was replaced with synthetic leachate. Three different* Ca^{++} *concentrations were used in synthetic leachate and the hydraulic conductivities of* 1.33×10^{-8} *cm/s,* 1.81×10^{-8} *cm/s, and* 1.77×10^{-8} *cm/s were obtained for the soil permeated with synthetic leachate, compared with the average hydraulic conductivity of* 1.52×10^{-8} *cm/s when permeated with tap water. The synthetic leachate with 1000 mg/L* Ca^{++} *concentration caused about 13% reduction in hydraulic conductivity in the first test which could be due to decrease in void ratio because of consolidation of the sample induced by osmotic flow. The percentages of increase of hydraulic conductivity for two other tests in comparison with the values for tap water permeation were 18% and 20%, respectively. This increase is attributed to double layer contraction and increased pore space, resulting from the adsorption of divalent cations into the soil matrix.*

Keywords: *Triaxial permeability, Hydraulic Conductivity, Synthetic leachate, Calcium.*

1- Introduction

Natural liners, because of their availability, low cost for a relative thick lining, long life, and attenuating ability, are usually the most attractive barriers to use in waste disposal facilities [1-4]. The hydraulic conductivity of soil liners is the most variable, the easiest to misjudge, and too hard to measure accurately. Interest in soil hydraulic conductivity has increased substantially in recent years because of concern over ground-water contamination. Assessments of the potentially continued or future contamination at a site are only possible if accurate information is available concerning the hydraulic conductivity of subsoil. The objective of this study was to investigate the effect of synthetic leachate with different calcium ion concentrations on the hydraulic conductivity of compacted mixed clayey soil obtained from Urmia City landfill site and nearby location.

2- Materials

2.1- Soil Sample

The soil sample obtained from the Urmia City landfill site had a plasticity index of 6% which does not meet the minimum requirement of 10% for the plasticity index for a compacted soil to be used as a landfill liner. Hence, 88% of Urmia landfill soil was mixed with 12% of clayey soil obtained from nearby location and the plasticity index of the mixed soil was found to be 10%. These percentages were obtained by trial and error tests on different fractions of soils. Table 1 shows the physical properties of the mixed soil.

Table 1: *Characteristics of mixed soil sample*

Property	*Value*
Plastic Limit (%)	14
Liquid Limit (%)	24
Plasticity Index (%)	10
Fraction Passed through No. 200 Sieve (%)	48
Clay size Fraction (< 2μm, %)	19
Specific Gravity	2.67
Optimum Moisture Content (%)	12
Maximum Dry Density ($\rho_{d\ max}$, g/cm^3)	1.98

2.2- Synthetic Leachate

A synthetic leachate was used instead of natural leachate in the experiments to prevent the complicating effects of natural leachate on the hydraulic conductivity tests. Some researchers have used synthetic leachate to evaluate the effect of chemical permeants on the hydraulic conductivity of landfill soils [5-13].

The differing parameter in the three leachate samples was the calcium ion concentration in order to study the effect of divalent cation concentration of calcium ion on the hydraulic conductivity of soil sample. The chemical species of Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, and SO_4^{2-} usually constitute the major inorganic components of the most municipal solid waste leachates [8, 14, 15]. The composition of synthetic leachates is similar to what already reported by Rowe et al. [8]. Table 2 shows the concentration of chemical ions and other chemical characteristics of leachates A, B, and C used in Tests A, B, and C, respectively.

Table 2: *Chemical ions concentrations and other characteristics in the synthetic leachates used in Tests A, B, and C*

Test No.	Concentration of Chemical Ions (mg/L)								*pH*
	Ca^{++}	Mg^{++}	Na^+	K^+	SO_4^-	Cl^-	CO_3^-	NO_3^-	
A	1000	31.5	580	183	125	2642	140	36.5	7.13
B	2500	31.5	580	183	125	5294	140	36.5	7.24
C	4000	31.5	580	183	125	7946	140	36.5	6.83

3- Methods

3.1- Test Equipments

The flexible-wall triaxial permeability apparatus (Tri-Flex 2 Permeability Test System, ELE Inc.) was used in this study. A pair of bladder accumulators was fabricated to facilitate the synthetic leachate permeation in the test apparatus. Figure 1 shows a picture view of the test equipments.

Figure 1: A picture view of the triaxial permeability test equipments

3.2- Permeability Tests

The mixed soil was air dried, passed through a No. 4 sieve, and mixed with tap water to a water content of 14% (2% wet of optimum water content). The wet soil was compacted using standard Proctor method, extruded from the compaction mold, and trimmed to a diameter of 7 cm using a thin walled sharp edge pipe. The trimmed soil had a height to diameter ratio (aspect ratio) of 0.714.

After preparation of the test specimen it was mounted in the permeability cell. The sample was then saturated using a backpressure. The soil was then permeated with de-aired tap water under the hydraulic gradient of 101 and the average soil effective stress of 65 kPa. This test configuration was identical for all three tests. The volumes of inflow and outflow were recorded and plotted against elapsed time. When the rates of inflow and outflow became equal, the final hydraulic conductivity values were calculated based on Darcy's law. Test durations for Tests A, B, and C were 5, 7, and 8 days, respectively.

After completion of the hydraulic conductivity test with tap water, the synthetic leachate was replaced with tap water as a permeant. The bladder accumulators were used in this stage of the operation. Samples from the effluent solution were regularly collected for concentration and other characteristics measurement of the solution. The criterion for termination of the tests with synthetic leachate was when the effluent concentrations reached the influent concentrations when a certain volume of synthetic leachate, equivalent to a certain number of soil pore volumes, passed through the soil sample [3]. The values of calculated soil pore volumes for Tests A, B and C was 53 cm^3, 50 cm^3, and 49 cm^3, respectively. For synthetic leachate permeation the number of pore volumes for Tests A, B, and C were 4.5, 5, and 4.7, respectively. The total test durations (including tap water and synthetic leachate permeation) for Tests A, B, and C were 49 days, 53 days, and 54 days, respectively. All tests were performed at the room temperature of 24±2 °C and the measured hydraulic conductivities were corrected for the room temperature.

The effluent samples were analyzed for the concentrations of chloride, sodium, calcium, and potassium ions. Samples were also tested for pH, TDS, EC, and Salinity. The results for calcium, potassium, and pH are presented here.

4- Results

The hydraulic conductivity values along with other data for Tests A, B and C is given in Table 3. The change in hydraulic conductivity values against permeated pore volumes are shown in Figure 2. The following conclusions were made:

1. Synthetic leachate with 1000 mg/L Ca^{++} concentration caused reduction of about 13% in hydraulic conductivity of test A. The decreased hydraulic conductivity could be attributed to low concentration of Ca^{++} in test A compared with two other tests. Consolidation of the soil sample induced by osmotic flow and small reduction of void ratio could also result in small reduction of the hydraulic conductivity [16].
2. The synthetic leachates that were intentionally made rich in calcium (2500 mg/L and 4000 mg/L) caused 18% and 20% increase in hydraulic conductivity in tests B and C compared to water permeation, respectively. This could be explained by double layer contraction and increase in pore space, resulting from the adsorption of divalent cations (Ca^{++} and Mg^{++}).
3. As indicated above the effect of synthetic leachate with calcium concentrations up to 4000 mg/L, on the hydraulic conductivity of the soil samples was minimal. It could be concluded that assuming similar properties for the real landfill leachate and using the mixed soil as a liner material, and considering similar physical and chemical conditions at site as the conducted test conditions, change of soil hydraulic conductivity due to leachate will be minimal and is not considered critical.

Some chemical constituents in the effluent (at the outflow end) were monitored during the tests. The effluent concentrations of chemical ions (C) were divided to the initial concentration of the ion in the synthetic leachate (C_o) and plotted in the vertical axes of the figures as relative concentrations (C/C_o). The results are shown in Figures 3 to 6 and the following conclusions were made:

1. The relative calcium concentrations in the effluent versus pore volume are shown in Figure 3. As shown the relative concentrations of calcium did not reach to 1.0 which was due to adsorption of calcium ion into the soil matrix. The adsorption rates of calcium ion were 18%, 19%, and 21%, for Tests A, B, and C, respectively. The calcium

Table 3: *Hydraulic conductivity values along with other data in Tests A, B, and C*

Properties	Test A	Test B	Test C
Hydraulic Gradient	101	101	101
Inflow Pressure, u_1 (kPa)	70	70	70
Outflow Pressure, u_2 (kPa)	20	20	20
Cell Pressure, σ_3 (kPa)	110	110	110
Hydraulic Conductivity for Water ($x10^8$ cm/s)	1.538	1.527	1.484
Hydraulic Conductivity for Leachate ($x10^8$ cm/s)	1.335	1.809	1.766
Elapsed Time for Water Test (days)	5	7	8
Elapsed Time for Leachate Test (days)	44	46	46

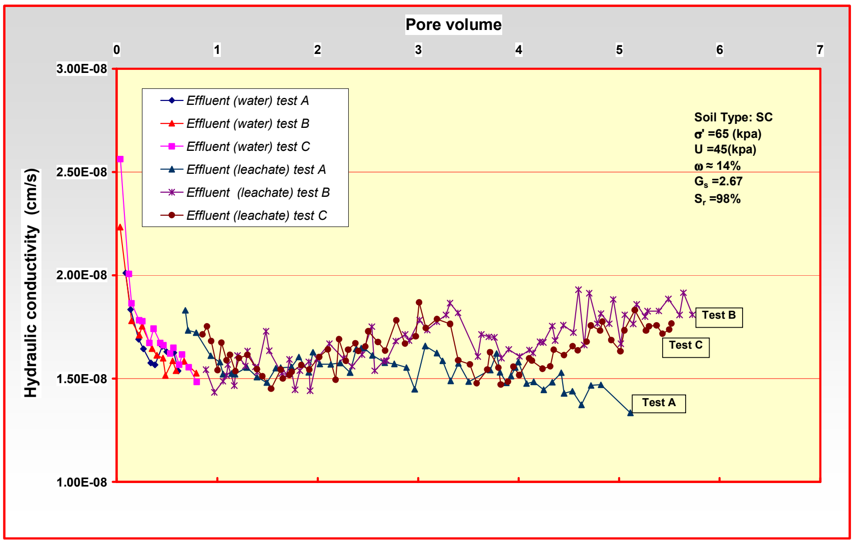

Figure 2: *Hydraulic conductivity against pore volume in Tests A, B, and C*

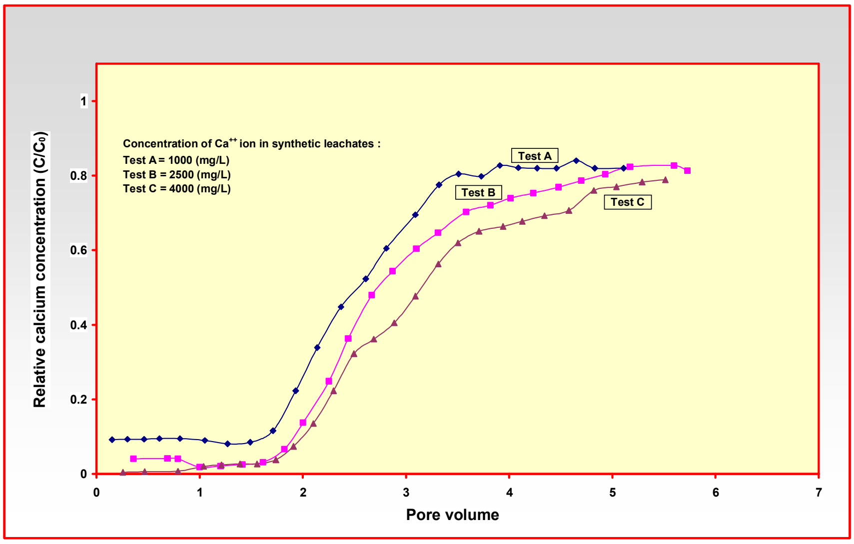

Figure 3: *Relative calcium concentrations in effluent against pore volume in Tests A, B, and C*

concentrations curves are fairly asymmetrical breakthrough curves with extension of the trailing ends.

2. Figure 4 shows the relative potassium concentrations in the effluent versus pore volume. As shown the potassium ion was strongly retarded and was totally retained by the soil matrix. This substantial retardation has also been observed in tests conducted by Rowe et al. [3] and Yanful et al. [6] on similar soils. Potassium retardation was due to interlayer K^+ fixation and not due to adsorption at the clay exchange sites [3, 6]. K^+ retardation increases the time required for the soil sample to reach complete chemical equilibrium with leachate. As shown in Figure 4, K^+ relative concentrations were gradually increasing with time and complete chemical equilibrium did not occur during the tests. According to Yanful et al. [6] much longer time is required to reach complete equilibrium.

3. The change of effluent pH values with pore volumes are shown in Figure 5. The average effluent pH values for Tests A, B, and C were 7.83, 7.64, and 7.60,

respectively. The effluent values for pH were higher than the influent values. The release of aqueous phase carbon dioxide into the atmosphere resulted in increase of pH during the tests. Due to respiration by organisms, the carbon dioxide concentration in the soil pore liquid in a relatively closed system may be several hundred times greater than it would be when exposed to the atmosphere [17]. As a result, when a sample is exposed to the atmosphere, $CO_{2\ (aq)}$, H_2CO_3, and H^+ all decrease in accordance with the reactions mentioned above and equilibrium with the atmosphere re-establishes and cause the pH to increase [18].

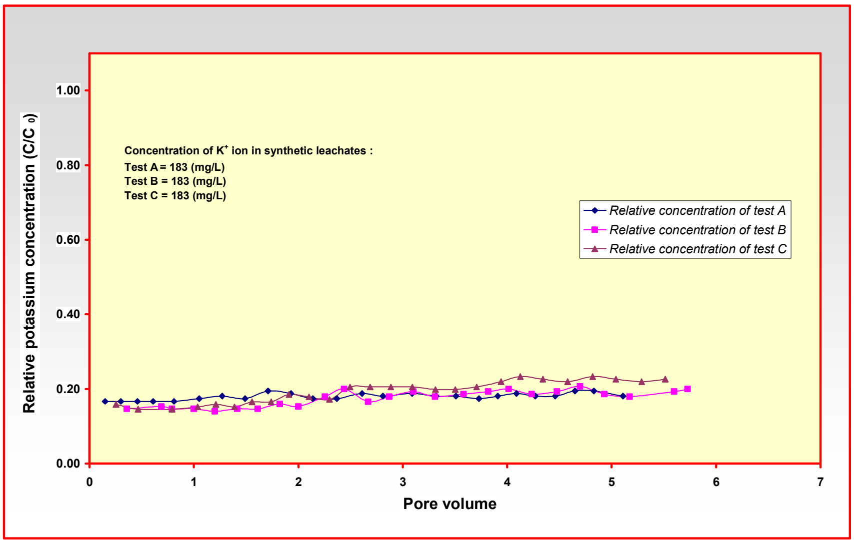

Figure 4: *Relative potassium concentrations in effluent against pore volume in Tests A, B, and C*

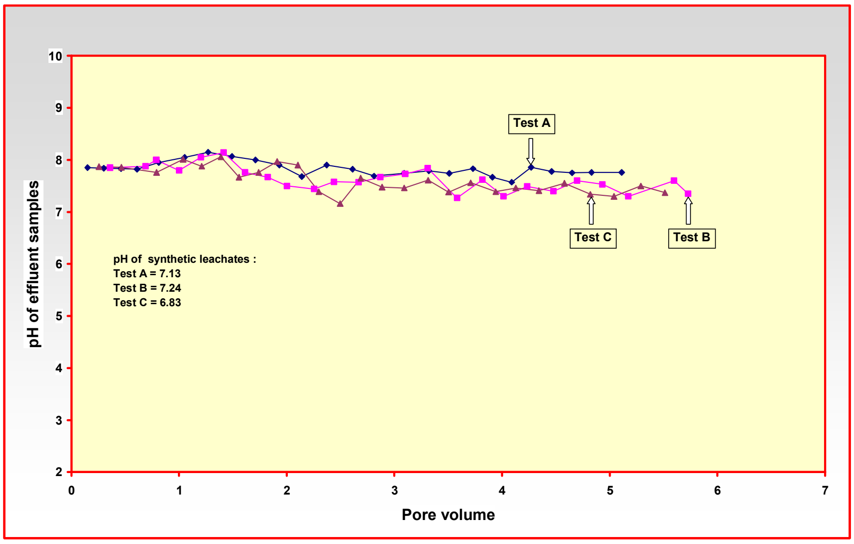

Figure 5: *Effluent pH values versus pore volume in Tests A, B, and C*

5- Summary and Conclusions

The effect of different calcium concentrations in the permeated synthetic leachate through compacted mixed clayey soil samples from Urmia City landfill site, on the hydraulic conductivity of the soil samples was investigated. A flexible wall hydraulic conductivity apparatus and accompanying bladder accumulators were used as testing equipment. The results of the hydraulic conductivity values for tap water were compared with the values obtained for the synthetic leachate. In test A with 1000 mg/L calcium concentration in the synthetic leachate, about 13% reduction in hydraulic conductivity was observed after about 5 pore volumes of leachate permeation, compared with tap water permeation. The decreased hydraulic conductivity could be attributed to low concentration of Ca^{++} in test A compared with two other tests. Consolidation of the soil sample induced by osmotic flow and small reduction of void ratio could also result in small reduction of the hydraulic conductivity. In tests B and C with 2500 mg/L and 4000 mg/L calcium concentrations in the permeated synthetic leachates, about 18% and 20% increase in hydraulic conductivity values (respectively) were observed after permeation of about 5.5 pore volume of synthetic leachate compared with tap water. This could be attributed to double layer contraction and increase in pore space, resulting from the adsorption of divalent cations (Ca^{++} and Mg^{++}). Although slight reduction (Test A) and increase (Tests B and C) of hydraulic conductivity was observed when soil samples were permeated with synthetic leachate, but this effect is minimal.

Effluent samples were collected and tested for some chemical properties. On the average about 20% of calcium ion was adsorbed into the soil matrix during synthetic leachate permeation in three tests. Potassium ion was strongly retarded and was totally retained by the soil matrix in all tests. The effluent values for pH were higher than the influent values in all tests. The release of aqueous phase carbon dioxide into the atmosphere resulted in increase of pH during the tests.

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7- References

[1] Rowe, R.K., "Liner Systems", Chapter 25 of *Geotechnical and Geoenvironmental Engineering Handbook*, Kluwer Academic Publishers, Norwell, USA., 2001, pp. 739-788.

[2] Rowe, R.K., Caers, C.J., Reynolds, G. and Chan, C., "Design and construction of barrier system for the Halton Landfill", *Canadian Geotechnical Journal*, Vol. 37 No. 3, 2000, pp. 662-675.

[3] Rowe, R.K., Quigley, R.M. and Booker, J.R., "*Clayey barrier systems for waste disposal facilities*", E & F N SPON, London, UK, 1995, 390 p.

[4] Pacey, J.G., "Design of a sanitary landfill to minimize its impact on the environment", *Proceeding of the 2nd National Conference on Complete Water Use, Water's Interface with Energy, Air and Solids*, Chicago, 1975, pp. 758-761.

[5] Ruhl, J.L., Daniel, D.E., "Geosynthetic clay liners permeated with chemical solutions and leachates", *ASCE Journal of Geotechnical and geoenvironmental Engineering*, Vol. 123, No. 4, 1997, pp. 369-381.

[6] Yanful, E.K., Haug, M.D., Wong, L.C., "The impact of synthetic leachate on the hydraulic conductivity of a smectitic till underlying a ladfill near Saskatoon, Saskatchewan", *Canadian geotechnical Journal*, Vol. 27, 1990, pp. 507-519.

[7] Joseph, J.B., Styles J.R., Yuen, S.T., and Cressey, G., "Variation in clay mineral performance in the presence of leachates", *Proceeding of the Eighth International Landfill symposium*, Sardinia, Italy, October 2001.

[8] Rowe, R.K., VanGulck, J.F., Millward, S.C., "Biologically induced clogging of a granular medium permeated with synthetic leachate", *Journal of Environmental Engineering Science*, Vol. 1, 2002, pp. 135-156.

[9] Shang, J.Q., Rowe, R.K., "Detecting landfill leachate contamination using soil electrical properties", *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, Vol. 7, No. 1, 2003.

[10] Kolstad, D.C., Benson, C.H., Edil, T.B., "Hydraulic conductivity and swell of non-prehydrated geosynthetic clay liners permeated with multispecies inorganic solutions", *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 130 No. 12, 2004, pp. 1236-1249.

[11] Hrapovic, L., Rowe, R.K., "Intrinsic degradation of volatile fatty acids in laboratory compacted clayey soil", *Journal of Contaminant Hydrology*, Vol. 58, 2002, pp. 221-242.

[12] Rittmann, B.E., Banaszak, J.E., Cooke A., Rowe, R.K., "Biogeochemical evaluation of mechanisms controlling $CaCO_{3(s)}$ precipitation in landfill leachate collection systems", *ASCE Journal of Environmental Engineering*, Vol. 129, No. 8, 2003, pp. 723-730.

[13] Weber, W.J., Jang, Y.C., Towsend, T.G., Laux, S., "Leachate from land disposed residential construction waste", *ASCE Journal of Environmental Engineering*, Vol. 128, No. 3, pp. 237-245.

[14] Clark, T.P., and Piskin, R., "Chemical quality and indicator parameters for monitoring landfill leachate in Illinois", *Environmental Geology*, Vol. 1, No. 6, 1977, pp. 329-340.

[15] Koerner, R.M., "*Construction and Geotechnical Methods in Foundation Engineering*", McGraw-Hill, New York, 1984.

[16] Barbour, S.L., "Role of physiochemical effects on the behavior of clay soils", *Proceedings of the 40th Canadian Geotechnical Conference*, Regina, Sask., 1987, pp. 323-342.

[17] Stumm, W., and Morgan, J.J., "*Aquatic Chemistry*", 2nd Ed., John Wiley and Sons Inc., New York, 1981, 780 p.

[18] Shackelford, C.D., "Waste-soil interaction that alter hydraulic conductivity", *Hydraulic conductivity and waste contaminant transport in soil*, ASTM STP 1142, Daniel, E.D., Trautwein, S.J., Eds., *American Society for testing and Materials*, Philadelphia, 1994.