INFLUENCE OF INORGANIC SALT SOLUTIONS ON HYDRAULIC AND DIFFUSION CHARACTERISTICS OF COMPACTED BENTONITE

Aakash Dhruv[1], Anil Kumar Kushwah[2], Rishabh Kumar[3]

Department Of Civil Engineering

IIMT College Of Engineering, Greater Noida(India)

ABSTRACT

In this work an effort is made to study the long term hydraulic conductivity and diffusion characteristics of montmorillonite rich bentonite soils. The engineering properties of soil like hydraulic conductivity and diffusion characteristics get modified by the nature of the permeating fluid. The lower the hydraulic conductivity and diffusion coefficient, the better it will be for use as liners at landfill sites.So in our work an attempt will be made to understand the behavior of bentonite soil under the effect of various pore water chemistry and also the diffusion studies would be carried out at a particular concentration to understand the migration rates of the contaminating species. All the work done on diffusion till date is by assuming and considering that the material property remains the same throughout the design life of the landfill which might not be true in all cases. So, the influence of various pore fluids having different cationic radius and different concentrations and their influence on hydraulic conductivity and diffusion characteristics is studied.

Keywords: Surface and Index Properties of the Studied Bentonite, Grain Size Analysis Test, Moisture Content, Specific Gravity, Atterberg's Limits, Cation Exchange Capacity.

I. INTRODUCTION

Landfills are engineered barrier systems used for encapsulating the waste to minimize the exposure to surrounding environment. Biodegradation is a natural processproduces harmful leachate within the landfills due to aerobic and anaerobic reactions (Quigley 1976). Compacted expansive clay material iswidely used as landfill liners/barriersto prevent the migration of the leachate. Such barriers limit the flow of contaminants to an extent where the contaminant migration needs to be restricted (Barone et al., 1992).The main reason of having plastic clays as the liner material is to constrain the leachate considerably because of hydraulically impervious nature and high sorption potential of the clays. The clays used in liners have hydraulic conductivity as low as 10^{-9} cm/sec (Shackelford, 1991a). Clayey soil is also widely used as a hydraulic barrier in water retention reservoirs, solid waste landfills, sludge ponds, waste lagoons, and other types of impoundments.

One important phenomenon controlling the contaminant transport is sorption which slows the contaminant transport and thereby delaying its presence in groundwater (Kau et al, 1998). The breakthrough time of the clays increases with time because of high sorption potential to particular contaminant species. For liners the clays also should have very low effective diffusion coefficient. The effective diffusion coefficient and the retardation coefficient (model parameters) are required for design of the liners to prevent the migration of any waste constituents through the barrier during the operational life of the containment facility, including a post-closure monitoring period (Shackelford, 1988). The thickness of the liner is decided based on the model parameters. As the clays used in liners have hydraulic conductivity as low as 10^{-9} cm/sec for which the advective flow is less significant in such a case proper assessment of the effect of landfill wastes on the groundwater would require modelling of diffusive contaminant transport through the fine grained soil.

II. LITERATURE REVIEW

In the double reservoir technique as described by Barone et al., 1992, Rowe et al., 1988 and Shackelford, 1989, 1991, Garcia et al., 2010; the intact plug of barrier material (clay) is placed within the diffusion cell. A source and a collector reservoir is connected to the clay plug as shown in figure 2.2. The solution that is placed in the source solution may be distilled water spiked with the concerned organic species. And the collector solution is of pure distilled water. The initial concentration of the source solution is c_0. After the introduction of the leachate in the source reservoir mass transport of the chemical constituents takes place by molecular diffusion due to concentration gradient (Shackelford, 1989). Due to the mass transport the concentration of the source reservoir decreases with time and the concentration in the collector reservoir increases with time.

It is found thought that if the hydraulic conductivity of the highly plastic clay is low and if there are no structural defects, then the liner will provide an adequate barrier between the waste and the underlying hydrogeological domain (Richard et al., 199). Guidelines for the properties of clay liners commonly specify that they should have a saturated hydraulic conductivity (Ks) less than 10^{-9} cm/s (Bharat, 2013) in order that the rate of advective transport will be small. However, even when advection is minimal, contaminants can migrate through clay by simple Fickian diffusion at rates that can be significant (Richard et al., 1999). One important properties of clay barrier material is swelling. Once in the constrained condition swelling happens, swelling physically impedes advectivetransport of solutes and gases by decreasing the size and connectivity of pores, thereby increasing tortuosity, or the length of the diffusive flow path. However leachate incompatibility can reduce expected swelling and increase internal pore size and connectivity, therefore increasing advective transfer of the pore fluid (Gates et al., 2016, Rao et al., 1995, Shackelford et al., 2009). Which as a result increases the hydraulic conductivity of the liner materials that may hamper the long term performance of the liner material. The diffusion coefficient is also expected to rise due to the reduced tortuosity because and hence the usefulness of the liner material no longer prevails.

III MATERIALS AND METHODS

In order to understand the effect of the cation characteristics on the mass transport parameters and the hydraulic conductivity of the bentonite soil laboratory through-diffusion test and the falling head permeability tests are conducted in the restrained condition. The details of the tests are discussed in this chapter.

Soil used in the present study is a bentonite soil rich in montmorillonite mineral collected from a site in Rajasthan. The physical properties of the soil is given in Table 4.1.

Table 4.1: Details of the soil used in the present study

Property	Value
Liquid limit	393
Plastic limit (%)	50
Shrinkage limit (%)	18
Specific gravity	2.77
Percentage of clay (%)	78
Specific surface area (m^2/g)	495
Cation exchange capacity (meq/100 g)	71.7
Montmorillonite content (%)	55
Hydraulic conductivity(m/s)	6.89×10^{-12}

3.1 SURFACE AND INDEX PROPERTIES OF THE STUDIED BENTONITE:

3.1.1 Grain Size Analysis (IS: 2720 Part 4)

Particle-size distribution for bentonite was determined using hydrometer analysis as most of the soil particles passed 75-micron. As expected, the particle-size distributions based on

the hydrometer analysis indicate that bentonite is comprised primarily of clay-sized particles (i.e.,<5µm) and classify as high plasticity clay (CH) according to the unified Soil Classification System (USCS) as per ASTM D 2487-98.

3.1.2 Moisture Content (IS: 2720 Part 2)

The standard method (Oven drying method) was used to determine the moisture contents of soil samples. Small representative specimens obtained from large bulk samples were weighed and the oven-dried at 110^0 C for 24 hours. The sample was then reweighed to obtain the weight of moisture. The difference in weight was determined by the weight of the dry soil, giving the water content on dry weight basis.

3.1.3 Specific Gravity (IS: 2720 Part 3)

The specific gravity value of soil solids was determined by placing a known weight of oven-dried soil in a bottle and then filled up with kerosene. The weight of displaced kerosene was then calculated by comparing the weight of soil and kerosene in the bottle with the weight of bottle containing only kerosene. The specific gravity was the calculated by density of kerosene again.

3.1.4 Atterberg's Limits (IS: 2720 Part 5)

Representative samples of the soil were taken to determine the Atterberg's limits (plastic and liquid limits) by using the size fraction passing through 0.425 mm sieve. Casagrande apparatus was used to determine the soil liquid limit. The plastic limit was determined by thread-rolling method.

3.1.5 Cation Exchange Capacity

The cation exchange capacity (CEC) was determined by ammonium acetate extraction technique at pH= 7.0 and the subsequent determination of the exchangeable cations by a standard method given by Chapman (1965).

3.2 LABORATORY FLOW TESTS

3.2.1 Long-term Hydraulic conductivity Tests:

Hydraulic conductivity was conducted by the falling head technique which is in accordance with ASTM D5856, except that the hydraulic gradient is kept higher than recommended. The reason of keeping higher gradient is to reduce the test duration in case of the bentonite soil which is considered to have very low hydraulic conductivity soil. The air-dried soil sample is compacted in a perxpex cell of 2.4 cm diameter and 1 cm length by statically compacting the soil to a bulk density of 1.3 g/cc. The soil sample is then held tightly in the rigid wall permeameter by fixing the caps of the cell on the either end. A head of 10.4 meters is provided so as to saturate the soil quickly. The saturation was ensured after the fall in head became constant for consecutive days. Also the weight of the soil sample during saturation process was monitored daily. A constant weight of the soil sample ensured complete saturation. After saturation process is over the saturated hydraulic conductivity is measured by taking the falling head readings regularly. The test is terminated when the hydraulic conductivity becomes stable over time. The tests are carried out by introducing leachate of various concentration like 0.05 M, 0.1M, 0.2M of both NaCl and KCl to understand the effect of the monovalent cations and also the effect of the varied concentration of a particular pore fluid on the soil. The hydraulic conductivity cell is depicted in figure 4.1.

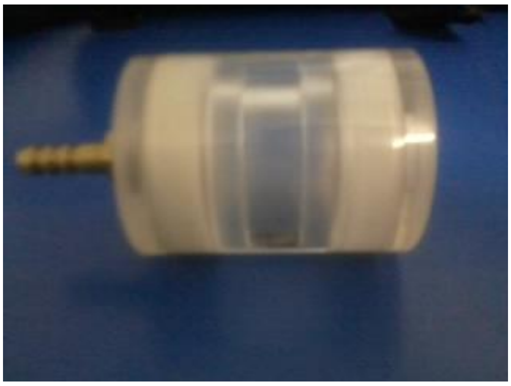

Fig 4.1: Hydraulic conductivity cell

3.2.2 Through-Diffusion Technique

In the double reservoir technique, the intact plug of barrier material (clay) is placed within the diffusion cell and compacted at a density of 1.5g/cc. A source and a collector reservoir is connected to the clay plug. A schematic diagram of the laboratory diffusion testing set-up is shown in Fig. 4.2 and 4.3 (Bharat et al., 2013; Binning, 1998). Initially the soil sample is saturated by putting distilled water in both the reservoirs. The saturation time for the soil sample is found to be 21 days and the saturated water content is 41.4%. Now after saturation the source reservoir is filled with the contaminant solution (here NaCl and KCl solution) and the collector reservoir solution is of pure distilled water. The initial concentration of the source solution is c_0. After the introduction of the leachate (here 0.2M) in the source reservoir, mass transport of the chemical constituents takes place by molecular diffusion due to concentration gradient. After suitable intervals the solution in both the reservoirs are collected and analyzed for the sodium ion concentration by using flame photometer.

Using mathematical models, mass transport parameters are analyzed from the variation of the observed concentration profiles with time (Bharat, 2013). The initial and boundary conditions of the model as depicted in are discussed in the chapter 2. Values of D^* and R_d, are determined from the inverse analysis by using the software SOLTRANDIFF. The details of which is discussed in the later part of this chapter.

Fig 4.2: Diffusion cell for through diffusion testing

Fig 4.3: Laboratory through diffusion set up

3.3 DEVELOPMENT OF INVERSE ANALYSIS SUIT SOLTRANDIFF TO DETERMINE THE MODEL PARAMETERS FROM EXPERIMENTAL DATA

The name SOLTRANDIFF stands for "**SOLuteTRA**nsport due to **DIFF**usion. Most of the works available till date mainly utilizes a semi-analytical solution to the governing differential equation. The solution is incorporated in a commercially available software POLLUTE and by assuming various combinations of the model parameters theoretical concentration profiles are obtained and compared with the experimental data. Although the development of POLLUTE reduced lot of computational effort but it is very expensive and it is not capable of performing inverse analysis.

The present software was built by Partha Das et al, (2016) for overcoming the limitations of POLLUTE. The software can perform inverse analysis to estimate the diffusion and linear sorption parameters of soils such by comparing the experimentally measured and theoretically computed concentration data by minimizing the RMSE (root mean square error). The software incorporates all the initial and boundary conditions as discussed in chapter 2. SOLTRANDIFF canperform inverse analysis and can accurately estimate the model parameters which is very less time consuming and which requires negligible computational effort. SOLTRANDIFF utilizes the closed-form analytical solution developed by Bharat (2013), which is computationally powerful. The model parameters are accurately estimated using optimization techniques that minimizes the error between the estimated theoretical data and the experimental concentration profile.

IV. CONCLUSION

As seen from the results, one can infer that the nature of the permeating liquid has a significant influence on the hydraulic conductivity and diffusion properties of bentonite. As compared to NaCl, KCl has a greater influence. So a lot more research is required to be done in this field with different permeating mediums at different concentrations. In a period of just 30 days the hydraulic conductivity, with the taken permeating liquids, increases significantly. This must be taken into account while designing landfill liners. The hydraulic radius of Na^+ is more than K^+, so the permeability of KCl solution is more as compared to NaCl also the diffusion coefficient value shows the similar trend for both the salt solutions. Increase in the cationic radius leads to more tortuous pathways for the permeating fluid because of the expansion of the DDL as was observed for KCL with different electrolyte concentration. On the other hand any decrease in the cationic radius has led to the reduction in DDL, due to which the hydraulic conductivity was lower for NaCl in all the three cases as compared to KCl. Also an increase in the electrolyte concentration leads to a significant increase in the hydraulic conductivity of the bentonite giving an indication of the degradation of the material with time.

Most of the designers adopt the current practice of designing of landfill liners assuming constant permeability with time which is unscientific and needs to be modified. Similar experiments need to be performed with more ions having different cationic radius.

REFERENCES

[1.] Alther, G., Evans, J.C., Fang, H.Y., Witmer, K., 1985. Influence of inorganic permeants upon the permeability of bentonite. In: Johnson, A.I., Frobel, R.K., Petterson, C.B. (Eds.), Hydraulic Barriers in Soiland Rock. ASTM STP 874. *American Society for Testing and Materials, Philadelphia*, pp. 64–73.

[2.] Barone FS, Rowe RK and Quigley RM (1992) A laboratory estimation of diffusion and adsorption coefficients for several volatile organics in a natural clayey soil. *Journal ofContaminant Hydrology*10: 225–250.

[3.] Bear, J. and Verruijt, A., 1987. Modeling Groundwater Flow and Pollution. D. Reidel, Dordrecht, 414 pp. Biggar, J.W. and Nielsen, D.R., 1960. Diffusion effects in miscible displacement occurring in saturated and unsaturated porous materials. J. Geophys. Res., 65(9): 2887-2895.

[4.] Benson, C. H., Daniel, D. E. and Boutwell, G. P. (1999) "Field performance of compacted clay liners*",* *Journal of Geotechnical and Geoenvironmental Engineering,* ASCE, Vol. 125, No. 5, pp. 390-403.

[5.] Bharat TV, Sivapullaiah PV and Allam MM (2012) Robust solver based on modified particle swarm optimization for improved solution of diffusion transport through containment facilities. *Expert Systems with Applications*39(12): 10812–10820.

[6.] Bharat, TV. (2013) Analytical model for 1-D contaminant diffusion through clay barriers. *Environmental Geotechnics*1.4 (2014): 210-221

[7.] Binning PJ, Hitchcock PW and Smith DW (1999) Experimental analysis of fluoride diffusion and sorption in clays. *Journal of Contaminant Hydrology***36**: 131–15

[8.] Bouazza A (2002) Geosynthetic Clay Liners ,*Geotextiles and Geomembranes*, 20 (2002) 3–17

[9.] Fetter, C. W. (1992) "Contaminant hydrogeology", Macmillan publishing Company, New York

[10.] Garcia-Gutieirrez, M., Missana, T., Mingarro, M., Samper, J., Dai, Z., Molinero, J., (2001). Solute transport properties of compacted Ca-bentonite used in FEBEX project. J. Contam. Hydrol. 47, 127– 137