Diffusion Characteristics of Naturally Available Local Clays for Their Application in Engineered Landfills

S. S. Surya[#1], S. L. Joshmi Raj [2], S. V. Vimal [3]
[#]*Assistant Professor, NSS College of Engineering Palakkad, Kerala Technological University, India*

Abstract

Development of municipal solid waste management technologies is important in the developing countries like India to safeguard the nature and effective utilization of our resources. An engineered landfill comprising of low permeable reactive clay liner is one of the most eminent technologies of municipal solid waste management. In view of this, the abundant and low cost natural clays are characterized for their contaminant transport properties especially solute diffusion characteristics in response to the concentration gradient developed across the liner. Natural clays are characterized for their diffusion properties in terms of their effective diffusion coefficient at their maximum dry density state. Further, it is intended to compare two naturally available clays for their diffusion characteristics and propose the best suited clay as landfill liner in terms of their diffusion coefficient.

Keywords — *Diffusion, Natural clays, Engineered Landfills, Landfill Liner.*

I. INTRODUCTION

An engineered landfill is becoming an essential part in developing countries to manage the huge quantity of municipal solid wastes. For an efficient and safe engineered landfill, the components of it especially landfill liners must be thoroughly characterized. There is hardly a landfill but an un-engineered way of open dumping is the usual practice of waste management in Kerala. This will lead to the contamination of our environment and spreading of water born and air born diseases. Considering this, it is the high time for us to think about an engineered landfill for our safety as well as that of future generation.

An engineered landfill is a pit in which solid wastes are filled in layers, compacted and covered for final disposal. A liner is provided at the bottom to prevent contamination of ground water. Reactive clays are the essential component of the liner as it has favourable contaminant transport properties like low permeability and diffusion characteristics as well as high sorption affinity towards the contaminants. But the use of manufactured clay may take huge quantity of money and energy and thereby reduce the interest of common people to go for it. Whereas, if we can replace the reactive clays with our locally available natural clays by considering their major design criteria, we will be able to implement an engineered landfill in our state also. In view of this, it is intended to study the major parameters, i.e., the contaminant transport properties of locally available clays and comparing them with that of reactive clays and thereby proposing the locally available clays for their use in engineered landfills. There are three major contaminant transport mechanisms that should be considered for an efficient landfill liner. Those are advective flow, diffusive flow and sorption characteristics. Among these, the present study aims at the diffusion characteristics of locally available clays.

In view of the above, primary objective of the present work is to identify the suitability of locally available natural clays for landfill liners and thereby replace the synthesized clays with natural clays. This is achieved by characterization of locally available clays for their physical, chemical and engineering properties and contaminant transport properties particularly their diffusion characteristics. Finally, the clay with minimum diffusion characteristics will be proposing as the suitable material for landfill liners.

II. EXPRIMENTAL INVESTIGATION

A. Material Selection

Soil samples were collected from different places in Kerala according to the instruction from a geologist. Samples were collected from Akathethara, Kollam, Chittur, Thiruvananthapuram etc. The selection of clay was on the basis of higher liquid limit and plastic limit. These properties for soils from Pallipuram (sample1) and Chittur (sample 2) were found higher. Hence these soils were selected as Sample 1 and Sample 2. Sample 1 was brown in colour and Sample 2 black in colour. Physical and geotechnical characteristics of the selected samples were obtained by following the guidelines presented in ASTM D422 (2007), ASTM D6913 (2009), D5550 (2006), ASTM D4318 (1994), ASTM D427 (1994), and ASTM D2487 (1994) and mineralogical characteristics were obtained using X-ray diffraction (XRD) technique. The obtained results are presented in Table 1. XRD patterns obtained for the selected samples are depicted in Figs. 1 and 2. From the diffractograms, it can be seen that the soil samples were characterized with muscovite, kaoline, quarts, microcline etc. Compared to montmorillonite, muscovite and microcline have less swelling and adsorption capacity.

Further, compaction characteristics of the selected soil samples were established as per the guidelines presented in ASTM D698 (2012) and the compaction characteristic curve obtained for the samples are given in Figs. 3 and 4.

TABLE I

Physical and geotechnical characteristics of selected soil samples

Properties	Sample 1	Sample 2
Liquid Limit (%)	75	61.9
Plastic Limit (%)	30.3	25.3
Plasticity Index (%)	44.7	36.7
Specific Gravity	2.96	2.85
Maximum Dry Density (g/cc)	2.03	1.74
Optimum Moisture Content (%)	13.5	16.3
Permeability (cm/sec)	$4.016x10^{-4}$	$3.123x10^{-4}$
Grain Size Distribution	CH	CH

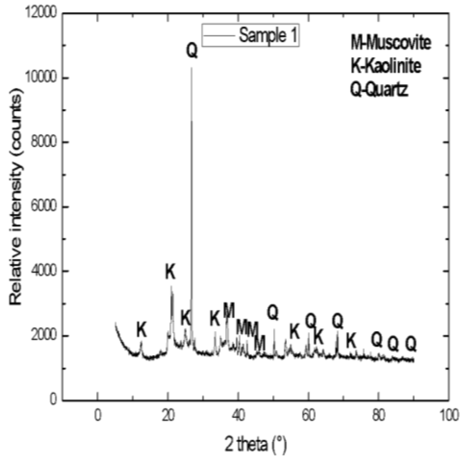

Fig. 1 X-ray Diffractogram of Sample 1

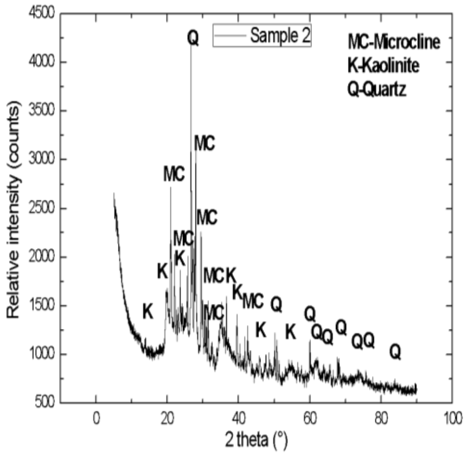

Fig. 2 X-ray Diffractogram of Sample 2

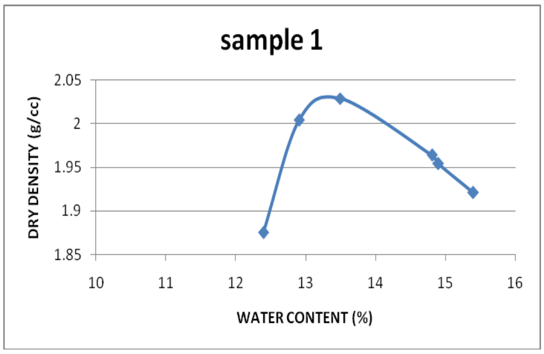

Fig. 3 Compaction characteristic curve obtained for sample 1

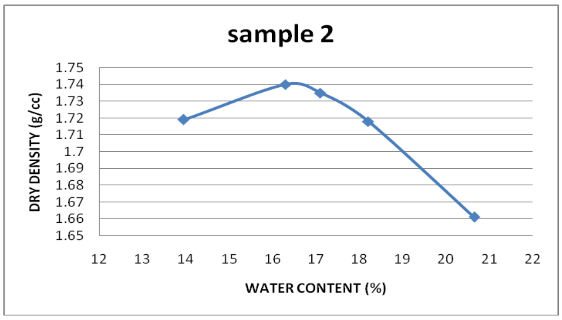

Fig. 4 Compaction characteristic curve obtained for sample 2

Later, the permeability (hydraulic conductivity) characteristics of the selected soil samples were quantified using the conventional falling head permeability test (ASTM D5856, 2012). The United States Environmental Protection Agency, USEPA, recommended that the hydraulic conductivity of compacted clay liners used for disposal of hazardous waste should not be more than 1×10-6 m/s (USEPA, 1989). It could be observed that both the samples satisfies the required permeability coefficient for its use as a landfill liner. Table 2 presents the coefficient of permeability values obtained for the soil samples.

TABLE II

COEFFICIENT OF PERMEABILITY OF THE SELECTED SAMPLES

	h_1 (cm)	h_2 (cm)	t (s)	k (m/s)
Sample 1	141.7	131.7	140	$4.016x10^{-6}$
Sample 2	141.7	131.7	180	$3.123X10^{-6}$

B. Selection of contaminant

Soils and ground water may become contaminated by the accumulation of heavy metals and metalloids through emissions from the rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition. Heavy metals constitute an ill defined group of inorganic chemical hazards, and those most commonly found at contaminated sites are lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni). Heavy metal contamination of soil may pose risks and hazards to humans and the ecosystem through direct ingestion or contact with contaminated soil, the food chain (soil-plant-human or soil-plant-animal-human), drinking of contaminated ground water, reduction in food quality, reduction in land usability for agricultural production causing food insecurity, and land tenure problems. Among the contaminants mentioned above Copper was selected as the contaminant for the study as this is one of the major components of landfill leachate. The permissible amount of copper in drinking water is 1.5 mg/l (Drinking water standard of BIS). The harmful effects of copper are Nasuea, Vomitting, Diarrhoea, Cancer and it enhances genotoxicity.

C. *Diffusion test*

Diffusion apparatus consists of three cylindrical chambers made up of PVC connected together with acrylic end plates and intermediate plates. The two chambers were of 12 cm length and 10 cm diameter called as source and receiver reservoirs and the third one was of 4.5 cm diameter and 5 cm length called as sample holder. The chamber where higher concentration of the contaminants filled was called as the source reservoir and the one in which the diffused contaminants were collected was called as receiver reservoir. Selected soil sample was compacted and filled in the sample holder at its maximum dry density state. After compacting the sample in the sample holder, all the three chambers were connected together with threaded rods using nuts and bolts. In order to make the whole set up leakage free, the joints between the reservoirs and plates were sealed with M-seal. The whole assembly is shown in Fig. 5.

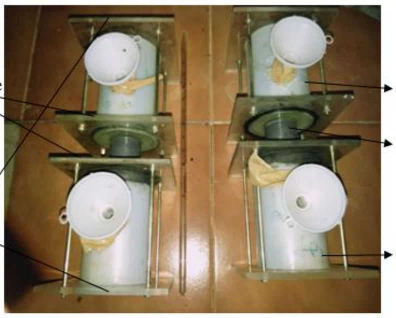

Fig. 5 Diffusion test setup

Once the sample was prepared and the set up was arranged, the source reservoir was filled with the contaminant solution (C_0=500 ppm copper sulphate) and distilled water with zero initial concentration of the contaminant was filled in the receiver reservoir. Then the contaminant started flowing from the higher concentration region (source) to the lower concentration region (receiver) because of concentration gradient across the sample. The variation of the contaminant concentration in the receiver reservoir was obtained by collecting samples from the receiver reservoir at regular intervals and the concentration (Ct) of the collected sample was measured using atomic absorption spectrometer (AAS). From the concentration data, the variation of normalized concentration with initial concentration (Ct/C0) versus time was obtained which is called the break through curve (BTC). Further, from the BTC the diffusion coefficient of the soil sample was determined by solving Fick's second law with the help of a numerical tool called STANMOD (studio of analytical models). The basic principle used in STANMOD is described below.

Mobility of metal contaminant through porous medium can be described by the advective-dispersive transport equation.

$$Rd\ (\partial C/\partial t) = D^*(\partial^2 C/\partial x^2) - v(\partial C/\partial x) \quad (1)$$

where, Rd is the retardation coefficient, C is solute concentration, t is time of transport and x is transport distance from the contaminant source.

In the present study, x is 2 cm, which is constant, D* diffusion coefficient and v is advection coefficient or seepage velocity. Diffusion is the random movement of liquid or gas from high concentration region to low concentration region. The movement of solute carried by the velocity gradient of contaminants across the soil is advection. Retardation factor retards the permeation of contaminant through soil. For a clay liner, diffusion and advection coefficients are less and retardation factor is high. Fine grained materials are used for compacted clay liners to ensure a sufficiently low hydraulic conductivity. In this situation the migration of contaminants occurs mainly by diffusion and the transport equation can be simplified to a pure diffusion equation (no advective transport) with the form of Fick´s second law:

$$\partial C/\partial t = (D^*/Rd)\ \partial^2/\partial x^2 \quad (2)$$

Solving the above partial differential equation the transport parameters were determined with the help of numerical tool, STANMOD.

For finding the transport parameters (diffusion coefficient D, advection coefficient v and retardation factor R) of selected samples in STANMOD, inverse type problem with deterministic equilibrium equation CDE was used. Time and position were dimensional and normalized concentration was dimensionless. Using the input data and the experimental results, the BTC for the selected contaminant through the soil samples were established.

The effluent concentration was measured periodically for 50 days. The BTCs obtained for the selected samples are presented in Figs. 6 and 7. The transport parameters determined using STANMOD is depicted in Table 3. It can be seen that the diffusion coefficient of both the samples are very less and the samples are characterized with comparatively high retardation coefficient which are favourable for their use as landfill liners. Sample 1 shows more favourable diffusion coefficient compared to sample 2.

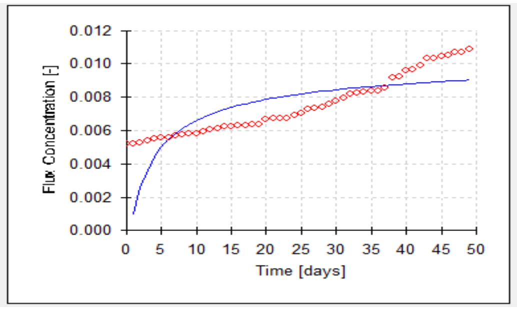

Fig. 6 Breakthrough curve obtained for Sample 1

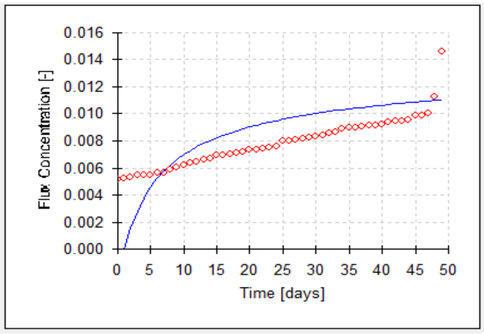

Fig. 7 Breakthrough curve obtained for Sample 2

TABLE III
Transport Parameters of the selected samples

Transport Parameters	Sample 1	Sample 2
Diffusion coefficient (D) m^2/sec	1.157x10^{-16}	1.157x10^{-15}
Retardation factor (R) mg/L	1x10^{-5}	1x10^{-5}

III. SUMMARY AND CONCLUSION

This study investigated the feasibility of natural clay as landfill liner material. A series of laboratory tests were conducted to study the physical, geotechnical, mineralogical and transport parameters of selected soils. Based on the results presented in the study the following conclusion can be drawn:

1. For the selected samples index properties are found to be favourable for their use as a liner material.
2. Fine grained clay is suitable for landfill liners, particle size less than 75 microns.
3. Mineralogical study of soil samples were done using X-ray Diffraction technique. Main constituents of samples were muscovite, kaoline, quarts, microcline etc. Compared to montmorillonite muscovite and microcline have less swelling and adsorption capacity.
4. Permeability studies of soil samples were done by falling head method. The ranges of coefficient of permeability for sample1 and sample 2 are 4x10-6 m/s and 3x10-6 m/s which are favourable for a liner material.
5. Transport parameters were estimated using a numerical tool called STANMOD.
6. Diffusion coefficients are comparable with that of bentonite clays. Diffusion coefficient for sample 1 is less compared to sample 2. But retardation factor for soil samples are less.
7. As a whole, the suitability of natural clay as landfill liner is identified using geotechnical and contaminant transport parameters. Both the samples have similar properties and experimental results were found to be favourable for the use as landfill liners from diffusion point of view.

However, further studies for other contaminant transport parameters are necessary to completely establish the suitability of natural clay as clay liner in landfill construction.

REFERENCES

[1] ASTM (2006) D5550 Standard Test Method for Specific Gravity of Soil Solids by Gas Pycnometer. Annual Book of ASTM Standards **04.08**, ASTM International, West Conshohocken, PA, USA.

[2] ASTM (2007) D422 Standard Test Method for Particle Size Analysis of Soils. Annual Book of ASTM Standards **04.08**, ASTM International, West Conshohocken, PA, USA.

[3] ASTM (1994) D4318 Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of Soils. Annual Book of ASTM Standards **04.08**, ASTM International, West Conshohocken, PA, USA.

[4] ASTM (2009) D6913 Standard Test Methods for Particle Size Distribution (Gradation) of Soils using Sieve Analysis. Annual Book of ASTM Standards **04.09**, ASTM International, West Conshohocken, PA, USA.

[5] ASTM (2012) D698 Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 [600 kN-m/m3]).Annual Book of ASTM Standards **04.08**, ASTM International, West Conshohocken, PA, USA.

[6] Lei Li, Cheng Lin and Zhigang Zhang (2016) "Utilization of shale clay as a landfill liner material to retain heavy metals" Material and Design Journal.

[7] Mather Omar, Abdallah Shanableh and Maewan Al Zaylaie (2016) "Modification of the swelling characteristics and phosphorous retention of bentonite clay using alum" Soil and Foundation Journal.

[8] Maria Eugenia gimenez Boscov and Walder Coelho Hachich (2011) "Properties of a lateritic red soil for pollutantcontainment" Journal of environmental protection.

[9] Soumya M Das and Sudha A. R (2016) "A Study on the effect of chemicals on the geotechnical properties of bentonite and bentonite sand mixtures as clay liners" International Journal of Engineering Research and Technology.

[10] Sarayu Kasar, Sumit Kumar and R.K Bajpal (2016) "Diffusion of Na(I), Cs(I), Sr(III) and Eu(III) in smetic rich natural clay" Journal of environmental Radiatio activity.

[11] J.H Li, L.Li and R. Cheng (2016) "Cracking and vertical preferential flow through landfill clay liners" Engineering Geology.