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Study the Effect of Lead on the Engineering Properties of Landfill Liners

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Abstract
Landfills are engineered waste containment systems, designed to minimize the impact of solid waste on the environment and human health. In landfills, the waste is contained by a liner system at the bottom and cover system at the top. The barrier layer, the most important component of liner or cover system which is also simply called as a liner, normally consist of a layer of clay or amended clay. The clay barrier layer prevents the leachates/gas generated in the landfill from spreading. Leachate consists of water and heavy metal that accumulate as water percolates through the landfill liner cover or due to squeezing of waste itself. Heavy metal contamination can cause significant changes in properties of clayey soil used as barrier layer, leading to an improvement or degradation in the engineering behaviour of soils. The barrier layers in liner undergo various chemical, biological and physical changes as the leachate percolate through them. This study, details a clay liner designed using locally available soil in Kerala(South India) and evaluate the effect of lead in synthetic leachate on the liner.

Keywords: *MSW, leachate, landfill liner, Heavy metal*

Introduction

In the present day scenario of rapid urbanization and industrialization, large quantities of wastes in different forms are generated. Solid Waste (SW) also called Municipal Solid Waste (MSW) is a mixture of organic and inorganic waste mainly from domestic or commercial activities. The major components of MSW are food waste, paper, plastic, rags, metal and glass, although demolition and construction debris is often included in collected waste, also small quantities of hazardous waste, such as electric bulbs, batteries, automotive parts and discarded medicines, chemicals and e-wastes. They may be degradable and non-degradable. Degradable wastes are mainly organic substances. The composition of waste in terms of its physical characteristics will give a clear idea regarding the consumption pattern, waste and waste disposal in an area. Large amount of wastes with a higher content of inorganic materials could have significant impact on human health and the environment. Quantity of waste generated is increasing day by day as a result of human activities and its disposal becomes a major problem. Hence it is also necessary to reduce, reuse and recycling of waste. One of the major challenges all nations face is the disposal of waste in a safe and environmentally sound manner. Waste disposal by landfilling is one of the modern most popular methods currently in practice. A landfill or a sanitary landfill is an engineered method of disposing solid wastes in a containment facility by spreading them in thin layers and compacting in thin layer with in liner and cover system.

During the natural degradation of solid waste, leachate is formed. The major potential impacts related to leachate are pollution of ground water and surface water. The purpose of a landfill is to protect the environment through isolation of waste and the leachate generated in landfill. Leachate contains a wide variety of chemicals and biological constituents that can be categorized into four groups, dissolved organic matter, inorganic macro components, heavy metals and xenobiotic organic compounds (Christ, 1994). The volume of leachate produced depends on the adsorption capacity, composition and placement of waste cover material, operation of landfill and the amount of recharge water available for infiltration at any particular site (Chermis, 1983).

Landfill consists of liner system at the base, cover system at the top, leachate collection facility, gas collection system. Compacted clayey soil is widely used as barrier layer in liners to isolate hazardous and other waste materials from environment and to prevent the heavy metals commonly found in landfill leachates from migrating into ground water. Fig.1shows the typical cross sectional view of engineered landfill. Because clay liners are not perfectly impermeable, contaminant transport through clay liners depends mainly on their hydraulic conductivity and related advection-diffusion phenomenon (Rajasekaran et.al, 2005). In addition, the compatibility of a clay liner to a specific contaminant depends on two factors, the ability of the clay in the liner to resist the variation in hydraulic conductivity caused by the contaminant and its capacity to retard the migration of contaminants through sorption.(Li and Li, 2001).

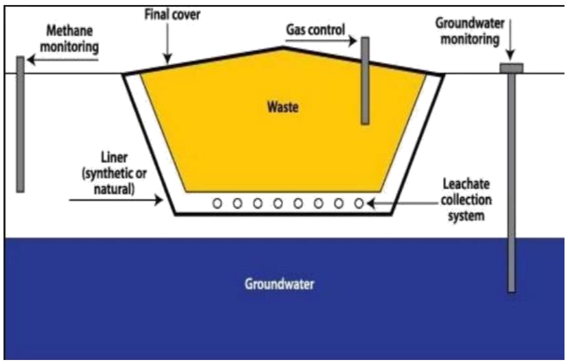

Fig.1 Sectional view of a Landfill

As per USEPA, Solid waste disposal facility criteria, the minimum thickness of clay liner should be 60 cm and maximum hydraulic conductivity, 1 x 10^{-7} cm/sec. The selected clayey soil for barrier layer percentage fines should be < 20% and the plasticity index between 10 and 30.

If suitable clayey soil is not locally available, bentonite enhanced soil mixture (amended soil) can be used as an economic alternative to liners. Bentonite is a naturally occurring clay deposit containing montmorillonite group of clay minerals. It has particular properties including the ability to absorb large quantities of water molecule into their crystalline structure. The incorporation of bentonite into a naturally occurring soil will significantly alter the physical and chemical properties of the soil. The net effect of the addition of bentonite to a soil is to improve the plasticity, workability and to decrease permeability of the mixture. Albright (1995) investigated the physical and hydraulic characteristics of bentonite and amended soil and found that addition of 6.5% bentonite to the sandy soil reduced the hydraulic conductivity by more than two orders of magnitude. Bentonite has been considered as a candidate buffer material because of its low hydraulic conductivity, high sorption capability and self healing characteristics.

The engineering properties of bentonite get modified on interaction with contaminants in leachate produced from the waste. The properties of bentonite are greatly affected by interaction between particles and the surrounding leachates (Gleason.et.al.1997). Many studies have shown that compacted clays undergo large changes in physio-chemical properties when exposed to shrink-swell or freeze-thaw cycling (Othman & Benson1995). By the combination of different material liner always fulfills low hydraulic conductivity for an effective long term behaviour of landfill except the hydraulic conductivity,the other properties such as shrinkage volume,unconfined compressive strength and compressibility play an important role in assessing long term behaviour.(Giridhar and Praveen,2015)

In this paper, the effect of lead in synthetic leachate on the three amended clay liners using local soilsare discussed in detail.

I.Design of liners

Design of landfill liner have been made based on the literatures and EPA (2013) guide lines. The three local soils used for the liner L1, L2 and L3 are Marine soil, Thonnakkal soil and Kuttanad soil respectively. Bentonite and sand are used as a additives. By mixing different trials of local soil and additives the mix conferring the guidelines were chosen. Selected guidelines are presented in table 1.

Table 1: Guidelines selected for the design of liners. [EPA (2013)**]**

Properties	Values
Hydraulic conductivity	<1x10 $^{-7}$ cm/s
Fines	$\leq$ 20 to 30 %
PI	$\geq$ 12-30 %
Quantity of gravel	$\leq$ 30 %
Max particle size	25-50 mm

A. Local Soils

The Marine soil collected from Cochin Coastal area, Thonnakkal soil from Thonnakkal area, Trivandrum district and Kuttanad soil is obtained from the Kuttanad region in Allapuzha district of Kerala from a depth of 2m below the ground level. The collected samples were first air dried, pulverized into fine powder and geotechnical characterisations were done as per Bureau of Indian standards. Kuttanad and Marine soil are dark brown colour medium sensitive alluvial deposits and the dominant mineral constituent in these clay is montmorillonite. Thonnakkalsoil consist of mainly Kaolinte mineral. They are characterized by high compressibility, low shear strength and high percentage of organic matter. The geotechnical properties of the local soils are presented in table 2.

B. Additives

The additive bentonite is a clay with extra ordinary properties such as very high expansion capability by absorbing water (swelling capacity), high ion exchange capacity and very low water permeability. Two types of commercially available bentonites like calcium bentonite and sodium bentonite are commonly used. Calcium bentonite is less sensitive to leachate compared to sodium bentonite. Calcium bentonite is used in the study.The geotechnical properties of calcium bentonite is found out as per Bureau of Indian standards are presented in table 2. The other additive is sand passing through 2mm sieve and retained on 0.075mm sieve for this study.

Table 2: Geotechnical properties of local soils and bentonite.

Property	Marine Soil	Thonakkal soil	Kuttanad soil	Bentonite
Liquid limit (%)	48	64	112	265
Plastic Limit (%)	26	38	62	54
Shrinkage limit (%)	35	29	17	6
Specific Gravity	2.3	2.3	2.4	2.6
Percentage clay	26	44	32	74
Percentage silt	44	49	58	35
Dry density (g/cc)	1.74	1.30	1.56	---
OMC(%)	19	34	27	----

II. Proportioning of Liners

The quantity of constituents of L1, L2 and L3 were fixed by making trial mixes by keeping the quantity of Bentonite as 10%. The ratio of Bentonite: Thonakkal soil/ Marine/ Kuttanad soil: Fine sand was 2:13:5. The composition based on particle size for L1, L2 and L3 are presented in Table 3, 4 and 5. Geotechnical characteristics and the referred standards of L1 , L2 and L3 are presented in table 6.

Table 3. Constituents of Liner (L1)

Composition	Marine Soil 80%	Bentonite	Fine sand	Total
		10%	10 %	100 %
Clay	208	66	0	274
Silt	352	34	0	386
Sand	240	0	100	340

Table 4.Constituents of Liner (L2)

Composition	Thonnakkal Soil 65%	Bentonite	Fine sand	Total
		10%	25%	100 %
Clay	286	66	0	352
Silt	319	34	0	353
Sand	45	0	250	295

Table 5. Constituents of Liner (L3)

Composition	Kuttanad Soil 65%	Bentonite	Fine sand	Total
		10%	25%	100%
Clay	210	66	0	276
Silt	377	34	0	411
Sand	63	0	250	313

Table 6.Geotechnical properties of Liner 1, Liner 2 and Liner 3.

Physical property	Standard used for determination	Liner 1	Liner 2	Liner 3
Liquid Limit (%)	IS 2720- Part 5	57	52	58
Plastic Limit (%)	IS 2720- Part 5	34	28	28
Plasticity Index	IS 2720- Part 5	22	24	29
Shrinkage Limit (%)	IS 2720- Part 6	23	24	26
Free Swell (ml/2g)	ASTM D 5890-02	4	6	6
Optimum moisture content (%)	IS 2720- Part 7	28	27	21
Maximum Dry Density (g/cc)	IS 2720 – Part 7	1.52	1.40	1.58
Unconfined compressive strength (kN/m^2)	IS 2720 – Part 10	216	67	67
Coefficient of permeability(cm/s)	IS 2720 – Part 15	0.87×10^{-7}	4.15×10^{-8}	1.61×10^{-8}

III. Preparation of Synthetic leachate with lead

To prepare synthetic leachate with lead as the main component in the actual leachate from three municipal solid waste dump were collected and the quantity of the lead was analysed and presented in table 7. Three waste dumps are Vilappilshala, Attingal landfill in Trivandrum district and Njeliyanparamba landfill, Kozhikode district. It is a municipal solid waste landfill that handles around100 tons of waste per day. Leachate samples are collected from its leachate plant which is shown in the Fig.2,3 and 4. Main content containing lead simulating actual leachate and chemical analysis was carried out using Atomic Adsorption Spectrophotometer (AAS) to determine the heavy metals present. The sample was tested to identify thequantity of lead present in the leachate is shown in table 7.

Fig .2 Vilappilshala (Trivandrum) leachate pond

Fig 3.Kozhikkode leachate pond

Fig 4.Attingal(Trivandrum) waste dump

Table.7 Chemical analysis of collected sample.

Constituent	Kozhikkode	Vilappilsala	Attingal
Pb (mg/L)	0.23	0.11	0.04

A. Methodology

The synthetic leachate of standard concentration as per the quantity presented on table 7. The concentration of lead in Kozhikode landfill leachate is the highest and selected for the preparation of synthetic leacghate of standard concentration as it designated as C1 (0.23mg/L). Synthetic leachate designated as C2 and C3 were prepared with twice and thrice the concentration of C1.

After designing the liners, check the design and characterization of the liners. The check was based on consistency limits, permeability, free swell and unconfined compressive strength. To study the effect of lead on the liner, the liners were soaked in synthetic leachate and the variation on the geotechnical properties over a period of 2 months, at time interval of 7, 14, 28, 35, 42 and 60 base.

Permeability was found out by allowing the synthetic leachate to pass through the fresh liner sample by falling head method

V. Effect of leachate on geotechnical properties of liners

The effect of synthetic leachate on geotechnical properties of Liners L1, L2 and L3 with time and varying concentrations are detailed below.

A. Variation in consistency limits of Liners L1, L2 and L3 with and concentration and time

To study the variation of consistency limits in liners due the concentration of heavy metals laboratory experiments such as liquid limit, plastic limit and shrinkage limit were conducted.

a) Variation of liquid limit

Variation of liquid limit of L1, L2 and L3 due concentrations with time are in fig. 5, 6 and 7.

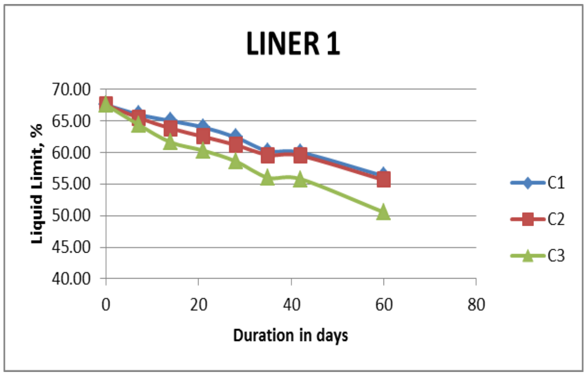

Fig 5.Variation in liquid limit of L1 with time.

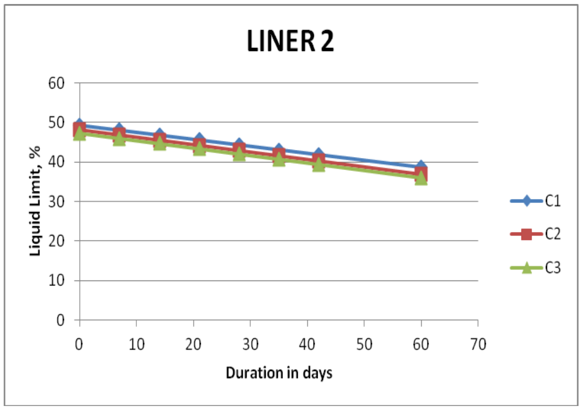

Fig 6.Variation in liquid limit of L2 with time.

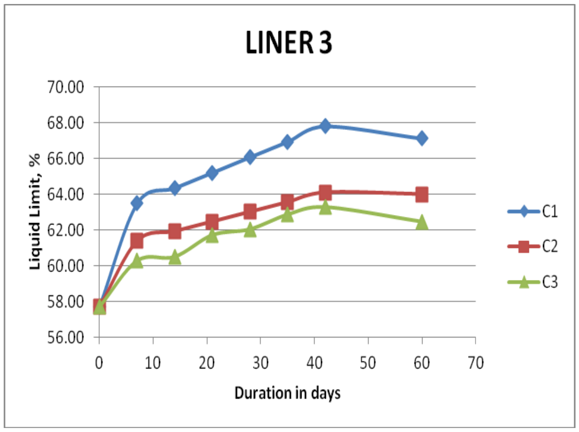

Fig 7. Variation in liquid limit of L3 with time

b) Variation of Plasticity Index

Variation of plasticity index of L1, L2 and L3 due concentrations with time are presented in fig.8, 9 and 10

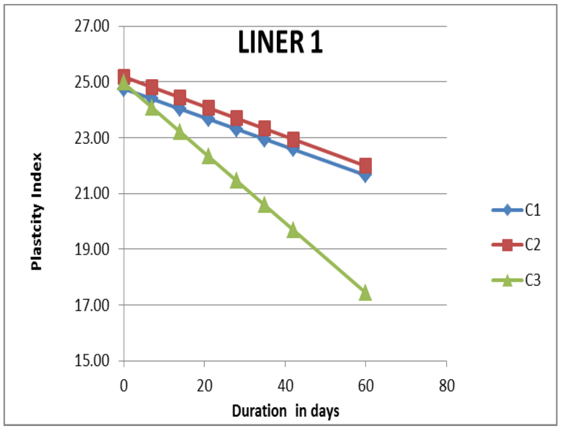

Fig 8.Variation in Plasticity index of L1 with time

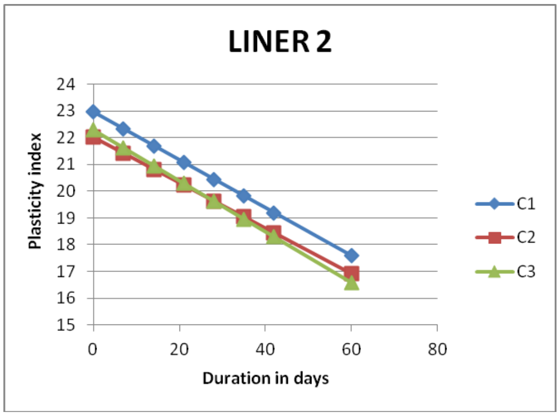

Fig 9.Variation in Plasticity index of L2 with time

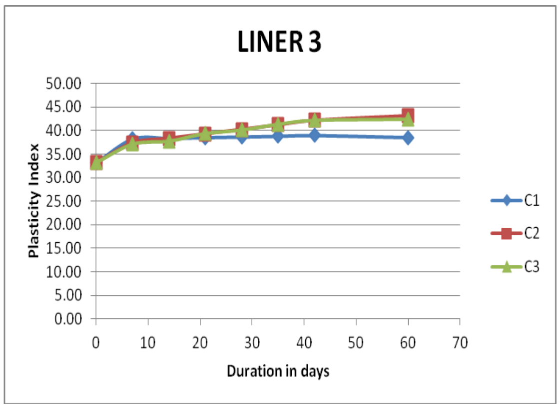

Fig 10.Variation in Plasticity index of L3 with time

c) Variation of Shrinkage Limit

Variation of shrinkage limit of L1, L2 and L3 due to concentrations with time are presented in fig.11,12 and 13

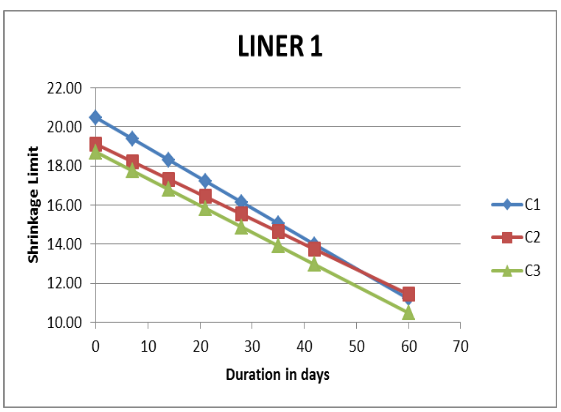

Fig 11. Variation Shrinkage Limit of L1 with time

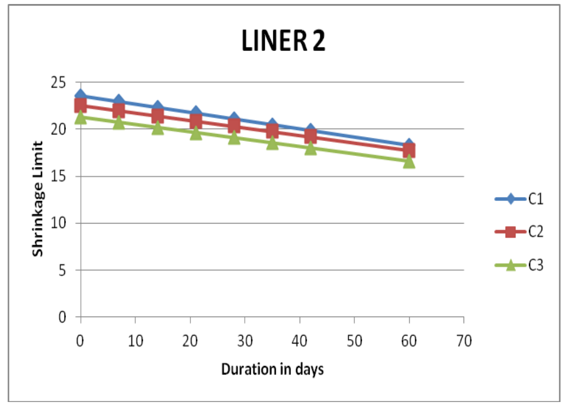

Fig 12. Variation Shrinkage Limit of L2with time

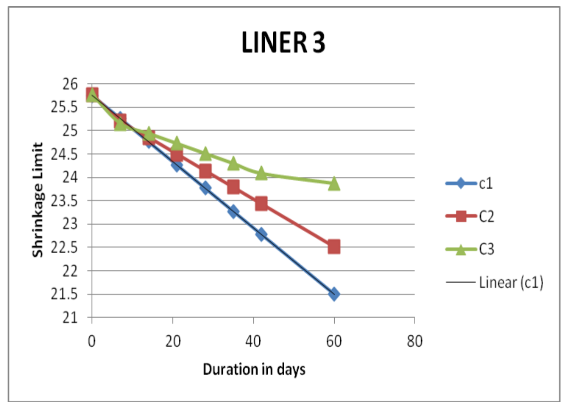

Fig 13. Variation Shrinkage Limit of L3 with time

Results of the consistency limits are presented in fig.5 to13. It can be seen that soil contaminated by lead appreciably reduces the liquid limits on liners with increase duration and also increase in concentration. This reduction can be explained by the nature of water in the clay mineral structure. It is a typical behaviour of clays as the liquid limit and plastic limit of these soils varies directly with the thickness of the diffuse double layer surrounding the clay particles (Mitchell 1993).

Dipolar water is attracted both by the negatively charged surface of the clay particles and by the cat ions in the double layer. The force of attraction between water and clay decreases with distance from the surface of the particles. All of the water held to clay particles by the force of attraction is known as double layer water.

The innermost layer of double layer-water, which is held very strongly by clay is known as adsorbed water. This orientation of water around the clay particles gives clayey soils to their plastic properties. The reduction in consistency limits observed in the tests could be attributed to the reduction in the thickness of double layer due to heavy metals.

It is also observed that the values of limits are not appreciably affected low concentration of lead. Results obtained indicates that when the heavy metal concentration in the liners are high, the diffuse double layer thickness decreases resulting in reduction of liquid limit and plasticity index.

B. Variation in free swell index of Liners

Variation of free swell index of L1, L2 and L3 due to concentrations presented in fig. 12

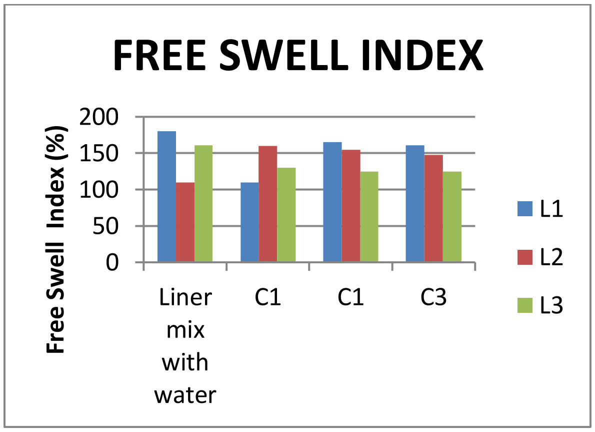

Fig.14.Variation in Free Swell Index of Liners with Leachate

Free swell index of L3 decrease with increase in concentration of synthetic leachate.

C. Variation in Unconfined Compressive Strengthof Liners

Variation of unconfined compressive strength of L1, L2 and L3 due to different concentrations of synthetic leachate with time are presented in fig 15, 16 and 17

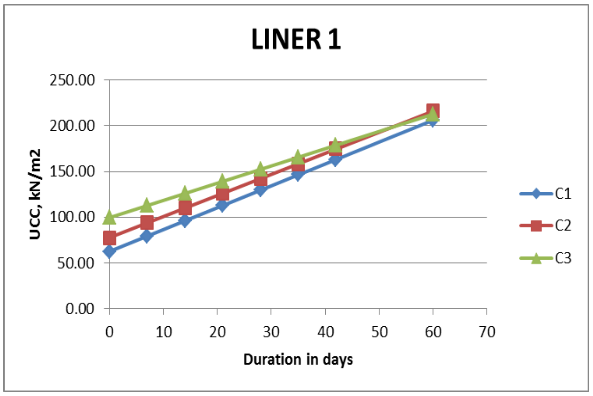

Fig 15.Variation in Unconfined Compressive Strength of L1 with Time

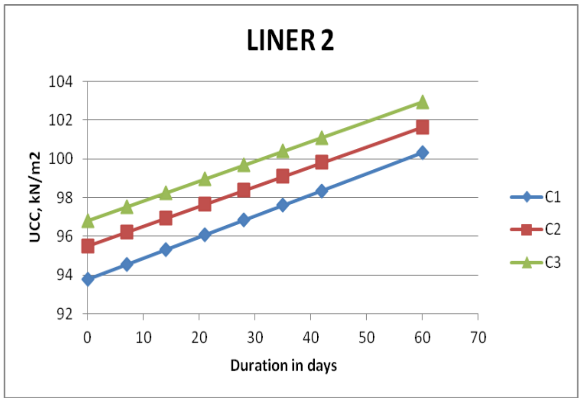

Fig 16.Variation in Unconfined Compressive Strength of L2 with Time

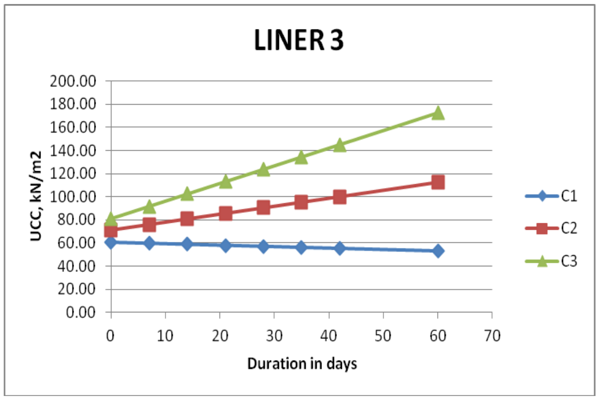

Fig 17.Variation in Unconfined Compressive Strength of L3 with Time

The variation in unconfined compressive strength of the liners were determined and presented from fig.15 to 17. When liners were contaminated by lead, the unconfined compressive strength which is clear from the graph, with the increase in concentration the liners more cation particles enter the liner material which results in the reduction of the diffuse double layer thickness and there by inter particle repulsion decreases and particles comes closer and this imparts cohesion and there by strength. With increase of duration variation of UCC was observed that the UCS value showed an increase, this may be because of the chemical action that have added binding property to the material.

D. Variation in permeability of Liners

Variation of permeability of L1, L2 and L3 due to different concentrations of synthetic leachate with time are presented in fig 18,19&20

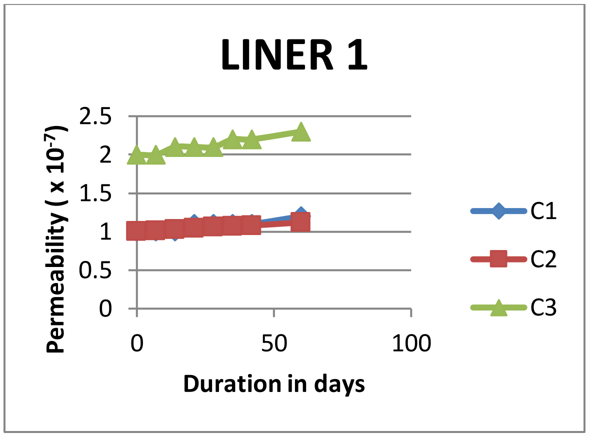

Fig 18.Variation in permeability of L1 with time

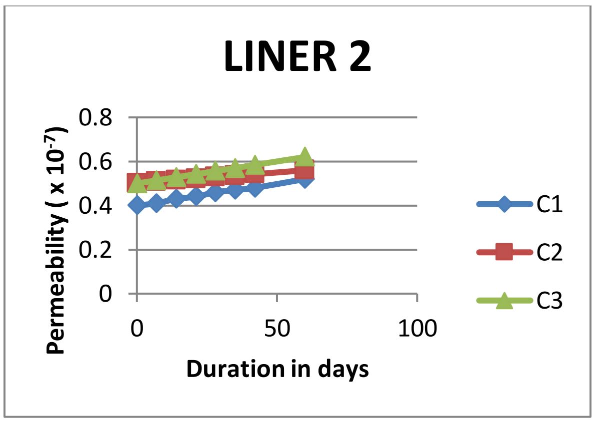

Fig 19.Variation in permeability of L2 with time

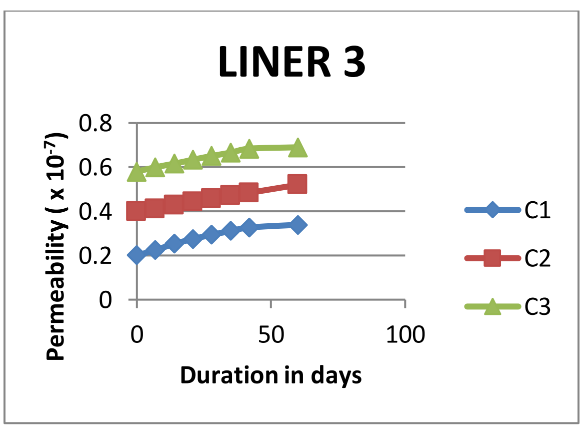

Fig 20.Variation in permeability of L3 with time

The changes in permeability of three liners were determined for different concentrations with varying time. There is no large change in permeability on liners with duration. However the liners shows, the permeability increase due to the permeation of leachate solution containing lead ions and the value further increase with the increase of leachate concentration which is clear from fig.16 to 18. The reason for this increase may be attributed to the shrinkage of the diffuse double layer due to the chemicals or cations in contact. This results in flocculation of the clay particles leading to the formation of cracks. With the increase of duration of time the hydraulic conductivity increased with time for every considered concentration, this may be due to the shrinkage of diffuse double layer thickness. The chemical reactions that might have taken place within the liner materials may result in the weakening of its expansive property and there by paving way to a widened pore space.

Conclusion

In this paper, three liners were designed and verified with the EPA regulations. From the experimental study on the designed liner, it satisfies the conditions and the most important condition being low hydraulic conductivity that is less than $1x10^{-7}$ cm/s.

The impact of heavy metals on the index and engineering properties of three liners was studied by conducting a series of tests in the laboratory. Tests were conducted on liners contaminated with different concentrations of heavy metal such as lead .

There is no large variation in the properties of liners with leachate. So the liners are compatible with leachate and hence can be used for field applications. Contamination of liners with heavy metals causes reduction in consistency limits. The unconfined compressive strength of the soil liner increases with increase in the heavy metal concentration and also with duration. This increase is due to the interlayer shrinkage allowing a closer packing and imparts more cohesion that imparts strength. Hydraulic conductivity of the liners increases with heavy metal concentration that is due to the concentration of the diffuse double layer, resulting in the increase in permeability value. With duration, the permeability shows a slight increase. Comparing with the three liners, it is seen that, liner prepared by marine soil shows larger variation in permeability than other liners.

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