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Impact of Lead on the Geotechnical Properties and Adsorption Characteristics of Landfill Liner

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Abstract

Landfills are highly 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 / cover, is normally constructed with clay or amended clay. The clay barrier layer prevents the lead solutions/gas generated in the landfill from spreading. Lead solution consists of water and heavy metal that accumulate as water perculates through the landfill liner / cover or due to squeezing of waste itself. Heavy metal contamination can cause significant changes in properties of 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 lead solution percolate through them. In this study the impact of lead in lead solution on the geotechnical properties of landfill liners using bentonite and kaolinites are reported.

Keywords: MSW, lead solution, landfill liner, Heavy metal.

1. INTRODUCTION

The rapid urbanization and changes in life style have increased the waste generation and thereby leading to pollution on the urban environment to unmanageable and alarming proportions. There has been a significant increase in waste generation in India in the last few decades, largely due to rapid population growth and economic development. Waste management especially of Municipal Solid Waste (MSW) has become a serious issue in Kerala, as well.

MSW is a mixture of organic and inorganic waste generated by domestic or commercial activities, such as wastes generated from households, offices, hotels, shops, schools and other institutions. They may be degradable and non-degradable wastes. Degradable wastes are mainly organic substances. The major components of MSW are food, paper, plastic, rags, metal, glass, demolition and construction debris, small quantities of hazardous waste, such as electric light bulbs, batteries, automotive parts and discarded medicines, chemicals and e-wastes.

One of the major pollution problems caused by the MSW landfill is lead solution which is generated as a consequence of precipitation, surface run-off and infiltration or intrusion of groundwater, biochemical processes and squeezing of inherent water of wastes themselves. Lead solution from MSW and hazardous waste disposal facilities contain a wide range of potential environmental contaminants. The major potential environmental impact of landfill lead solution is that it leads pollution of groundwater, surface waters and soil. Among these contaminations, groundwater pollution is probably the most severe environmental impact from landfills. This can be prevented by proper design of barrier layers of liner and cover system in landfills. One of the best materials for the construction of barrier layer in is clay or modified clay, due to its low permeability and ability to absorb contaminants from lead solution. Lot of researches has been carried out on efficiency of clay liner in retarding the movement of contaminants in leachate.

In this paper, the variation in geotechnical properties due to the impact of lead in leachate is reported such as swell, consistency limits, unconfined compressive strength, and consolidation. Also the adsorption characterizations of liners are reported based on the column test.

2. MATERIALS AND METHODOLOGY

2.1 Liner

The materials selected for the preparation of liner were Thonnakkal clay and Bentonite. Thonnakkal clay is white clay consisting of kaolinite mineral collected from Thonnakkal region of Thiruvananthapuram of Kerala. Bentonite is naturally occurring clay with high swelling capacity, high ion exchange capacity and very low water permeability. The term bentonite represents either calcium montmorillonite or sodium montmorillonite where as the material used in this study was calcium bentonite /montmorillonite.

Properties of liner and its constituents as per IS 2720:1991 are presented in Table 1.

Table 1. Properties of Kaolinite and Bentonite.

Property	Thonakkal	Bentonite	Liner
Specific Gravity	2.30	2.65	2.33
Free Swell (ml/ 2g)	2	16	-0.30
Liquid Limit (%)	55	265	57.5
Plastic limit (%)	29.3	54	28.5

2.2. Methodology

The constituents of the leachate from Attingal and Trivandrum were analyzed and found that it contains lead. In addition to the presence of lead organic matters and heavy metals were also found in the actual landfill (technically waste dump) leachate. The synthetic lead solution was prepared similar to the actual leachate by mixing Lead nitrate $Pb(NO_3)$, salt of analytical reagent gradient in distilled water. Concentrations of lead selected for study are 10gm/L, 20gm/L, 30gm/L and 40gm/L was mixed with clay as well as allowed to pass through the clay liner samples through column test apparatus continuously. In order to study the impact of lead on the liner, lead solutions were mixed with soil at its optimum moisture content and geotechnical properties and adsorption characteristics were found out as per IS standards.

Liner was prepared by mixing 95 % Thonakkal clay and 5 % bentonite considering the minimum requirements of percentage finer of minimum 20% and the plasticity index should be between 10 and 20 according to Environmental Protection Agency, 2003.

3. TEST ON CONTAMINATED SAMPLES.

The column apparatus were fabricated using the acrylic material of dimensions 60cm x 10cm x 10cm. Mould was filled with liner mix to a height of 10cm at its maximum dry density as shown in fig 1.

Fig 1. Column test apparatus

The permeated lead solution from the column was filtered and the residual concentration of the filtrate was analyzed using Atomic Adsorption Spectrophotometer (238 VNICAM AAS). The amount of adsorbed (mg/g) was calculated using the formula reported by Vanderborgh and Van Griekenm [16].

$$Q = \frac{V(Ci-Ce)}{W}$$

Where, Ci and Ce are the initial and equilibrium lead concentrations respectively, V (L) is the volume of solution and W (gm) is the mass of the adsorbent.

Two types of adsorption isotherms are used.

(i) Langmuir and (ii) Freundlich.

The adsorption isotherm is the equilibrium relationship between the concentration in the fluid phase and the concentration in the adsorbent particles at given temperature.

As per Langmuir model, the amount of lead adsorbed at equilibrium (q_e, mg/gm) is calculated using the equation.

The Langmuir isotherms are given by the equation

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{q_m K_L}\frac{1}{C_e}$$

Where, q_m (mg/g) and K_L (L/g) are the Langmuir constants

As per Freundlich model, the amount of lead adsorbed per unit mass of dry soil

i.e., $\frac{x}{m} = K_F C_e^{1/n}$

x = amount of solute adsorbed by the soil in gm,

m = amount of soil in the column in gm,

K_F = Freundlich adsorption constant,

$^{1/n}$ = Freundlich exponent components,

C_e = lead concentration in solution at equilibrium (gm/L)

4. RESULTS AND DISCUSSION

The results of tests on Consistency limits, Free swell index, Permeability are presented as follows.

4.1 Variation in Liquid Limit of Liner with varying concentrations of lead solution.

The liquid limit values obtained when treated with lead solution are found to be lower than with water. The variation of the liquid limit is presented in Fig.2

The marginal increase in liquid limit could be attributed to the dispersion of the clay particles when the liner was permeated with lead solution.

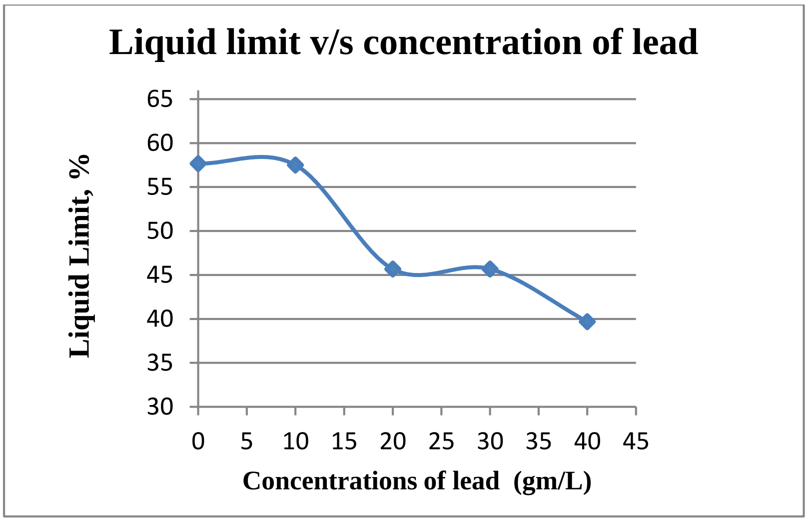

Fig 2. Variation in liquid limit of liner with varying concentrations of lead solution.

As the concentration of lead solution increased, the liquid limit decreased. Increasing the lead solution concentration decreases the inter-particle repulsion which results in particles moving more freely in lower water contents, thus decreasing the liquid limit.

4.2 Variation in Plasticity Index of Liner with concentrations of lead.

The changes in the plasticity index of liners with varying concentrations of lead solution. The plastic limit decreases with increase in the concentration of lead solution.

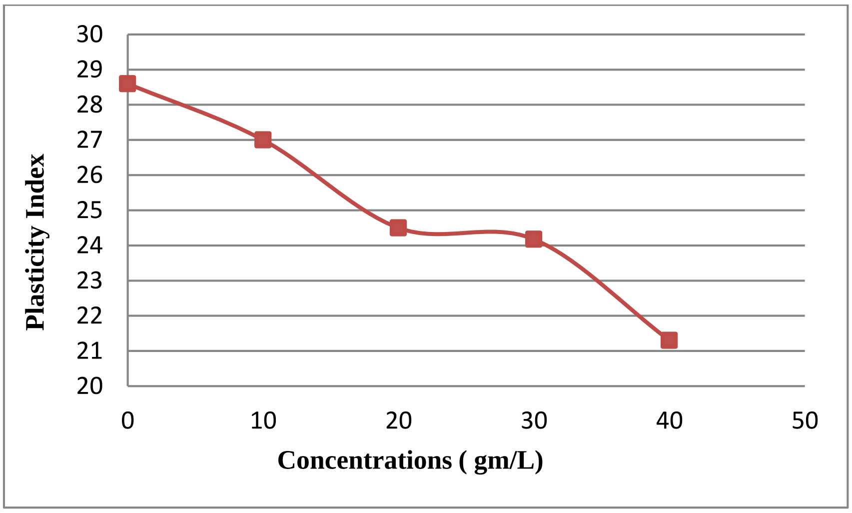

Fig 3. Variation in plasticity index of liner with varying concentrations of lead solution.

4.3 Variation in Shrinkage Limit of Liner with concentrations of lead.

In all the cases, the shrinkage limit increases with increase in concentrations. Fig.4 shows the variation in shrinkage limit of the liner with the increase in concentration respectively. The concentration of lead solution had larger effect on the shrinkage limit of liners compared to liquid limit and plasticity index.

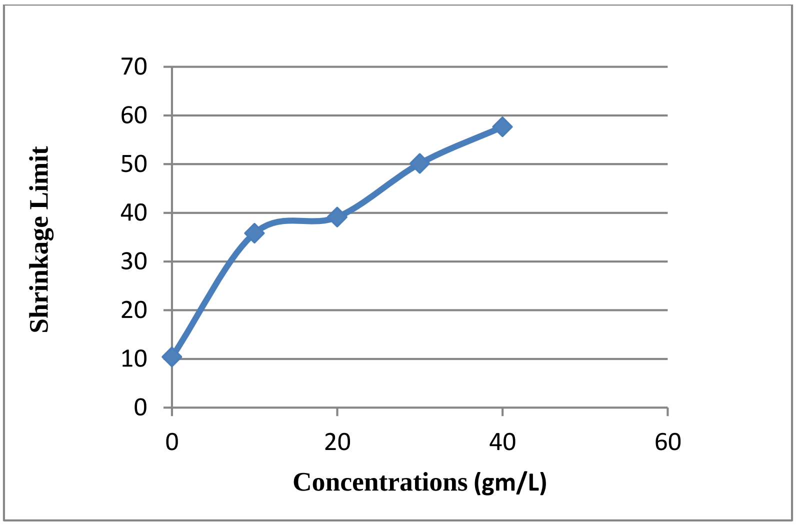

Fig 4. Variation in shrinkage limit of liner with varying concentrations of lead solution

4.4 Variation in Free Swell index of Liner with concentrations of lead.

Free swell of liner in water as well as lead solution of different concentration and shown in Fig.5 done as per IS 2720: Part 40. From the graph, it can be seen that the percentage free swell index increases and then decreases.

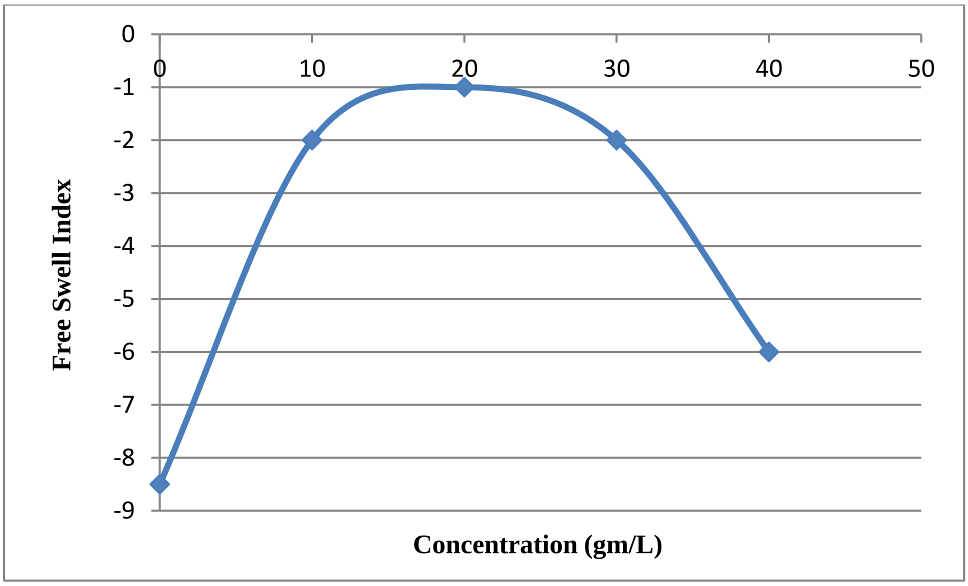

Fig 5. Variation in free swell index of liner with varying concentrations of lead.

Liner exhibited comparatively lower free swell index (FSI) values when tested using water as the testing liquid. It can be seen that, when lead solution was used as the testing liquid, the FSI values are reduced. The montmorillonite clay mineral, when in contact with water, due to its higher cation exchange capacity readily reacted with dipolar water molecules to form a thick electric double layer which is also referred to as the diffuse double layer. This double layer formation creates repulsive forces along the sides of the clay particle making it difficult for individual clay particles to stay closer to each other. Under these repulsive forces, these clay particles align themselves in a more parallel orientation forming a dispersed structure, hence sedimenting to much larger volumes. Due to this, the tests conducted with liner using water produced higher FSI values.

4.5 Variation in Unconfined Compressive Strength of Liner with concentrations of lead.

Fig.6 shows the graphical representation of the variation in the unconfined compressive strength of liner with the increase in time and with concentration respectively. As the concentration

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of lead solution increased, the unconfined compressive strength increases.

Unconfined compressive strength tests were carried out in both contaminated and uncontaminated with varying concentrations. Typical load -deflection curves of the two liners are presented in Fig 6.

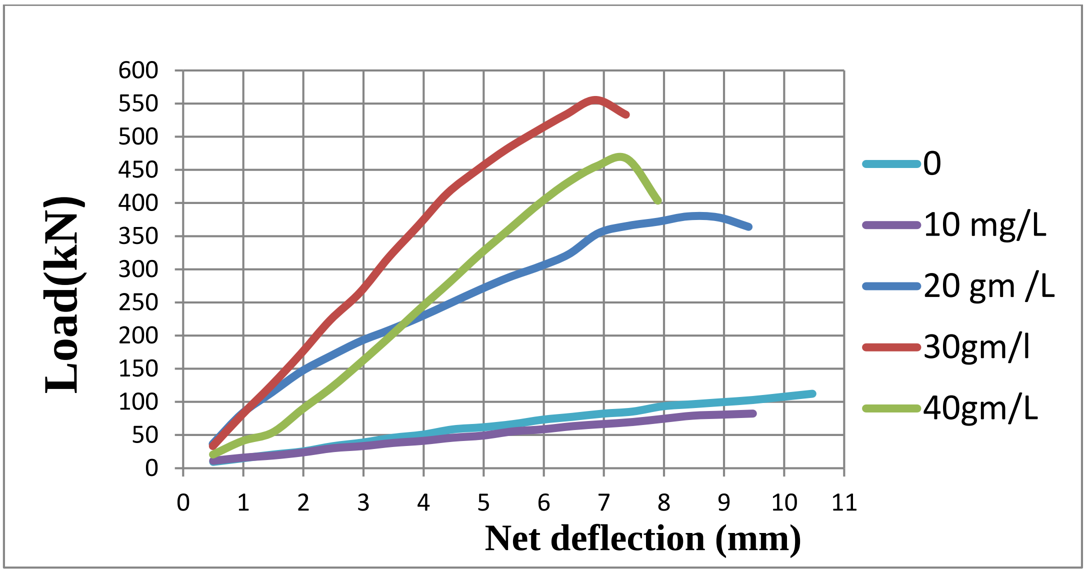

Fig 6. Variation in unconfined compressive strength of liner with varying concentrations of lead solution.

The peak values from the stress-strain curves were reported as the values of the UCC. It can be seen that the UCC values decrease with increase in the level of contamination of the liner. Except in lower concentration of 10 gm/L, all other concentrations of liners attained the above value of 200kPa .

4.6 Variation in Permeability of Liner with concentrations of lead.

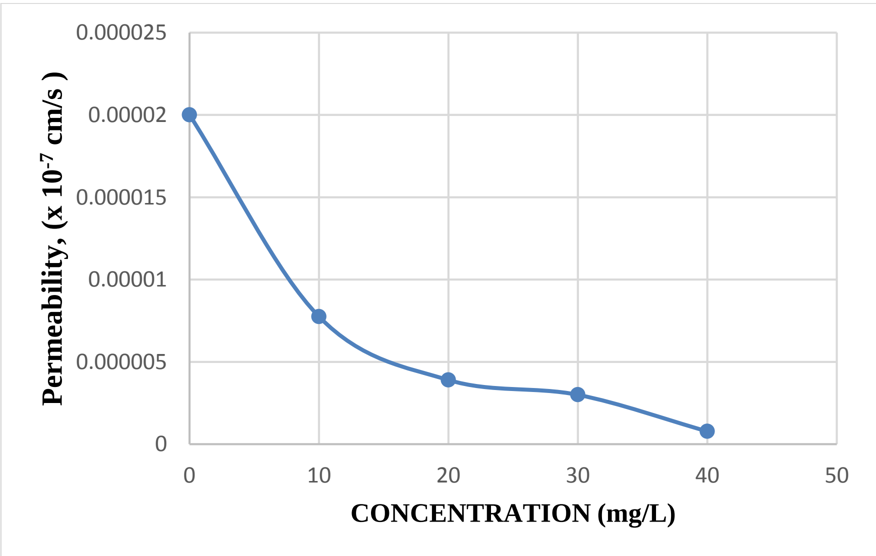

Fig 7. Variation in permeability of liner with varying concentrations of lead solution.

For liner, the permeability value was 2×10^{-5} cm/s. Permeation of lead solution resulted in a higher permeability values for the liner when permeated with lead of different varying concentrations. The permeability of liner decreases from 7.75×10^{-6} cm/s (when permeated with water) to 7.8×10^{-7} cm/s. As the concentration increases, the permeability also decreases.

4.7 Variation in Adsorption Isotherm of Liner with varying concentrations of leachate

1. Langmuir **method**

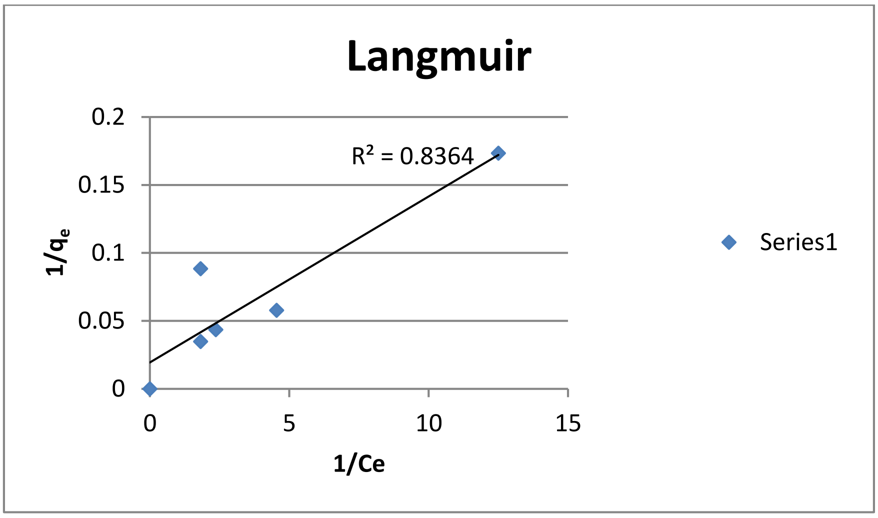

Fig.8 Variation in Adsorption Isotherm of liner with varying concentrations of leachate by Langmuir method

2. **Freundlich method**

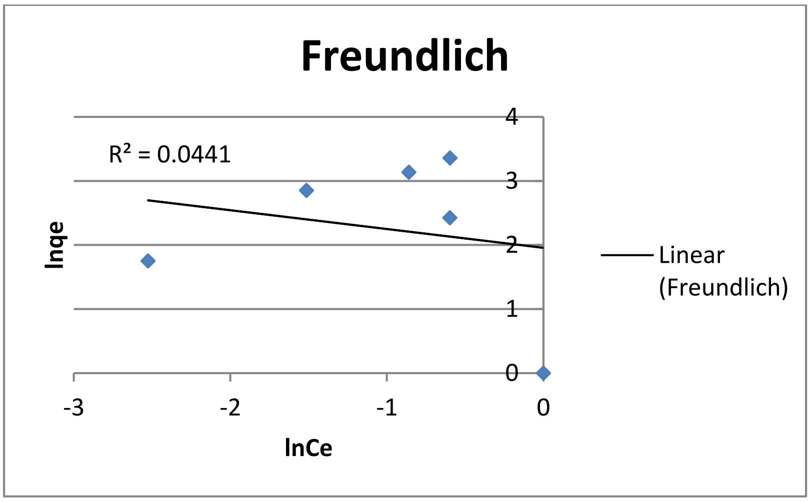

Fig 9. Variation in Adsorption Isotherm of liner with varying concentrations of leachate by Freundlich method

5. CONCLUSION

The main purpose of the study was to provide a new landfill liner using Thonakkal clay and Bentonite in the ratio 95:5. The impact of lead on new landfill liner was evaluated by finding the variation in engineering properties such as consistency limits, permeability, unconfined compressive strength, free swell index and adsorption characteristics. From the experimental study, it is found that the most important condition i.e., a low hydraulic conductivity is less than 1×10^{-7} cm/s. As the lead concentration increases, permeability reduces and shear strength increases. Langmuir and Freundlich models were used for the evaluation of adsorption characteristics of the new liner. The Langmuir model is found to be the best fit for this new liner.

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