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Effect of Chromium on The Engineering Properties of Amended Clay Liner

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Abstract**:** ***Waste generated by the full extent of human activities range from dumping relatively innocuous substances such as food and paper waste to toxic substances, dumping of waste in a disposal facility serves to minimize the effect of waste on the environment. In many region centralized disposal facility has been formed by landfilling. In order to prevent ground water contamination liners are provided in a landfill. Barrier layer in a liner system prevents the migration of leachate and from polluting the ground water. In this study amended soil liner was prepared using the clay mineral Calcium Bentonite, locally available kaolinite soil and fine sand. The liner was mixed with chromium solution of four different concentrations and the change in engineering properties of the liner is reported in this paper. It is found that there is only marginal increase in permeability of liner due to chromium where as there are noticeable variation on the other geotechnical properties***

Index Terms**:** ***Landfill, Liner, Chromium***

I. INTRODUCTION

As a part of population growth and urbanization, the quantity of municipal solid waste generated also increased rapidly. Thus, waste disposal has become a serious environmental problem. One of the preferred methods of dealing with this kind of environmental problem is to dispose the waste in sanitary landfills. Landfill is a highly engineered waste containment facility. The most important problem in designing and maintaining a landfill is the management of the leachate, which is formed due to squeezing of waste or due to the reaction of percolating water and waste.

In landfill operations, the safe containment of waste and control of leachate is of paramount importance in the mitigation of ground and ground water pollution and the protection of public health. Careful selection of materials coupled with rigorous design of containment cells are a vital part of engineered waste disposal systems. The linings to these cells generally consist of low permeability clays possibly in conjunction with a synthetic liner or liners. Cross section of a landfill is shown in fig 1.

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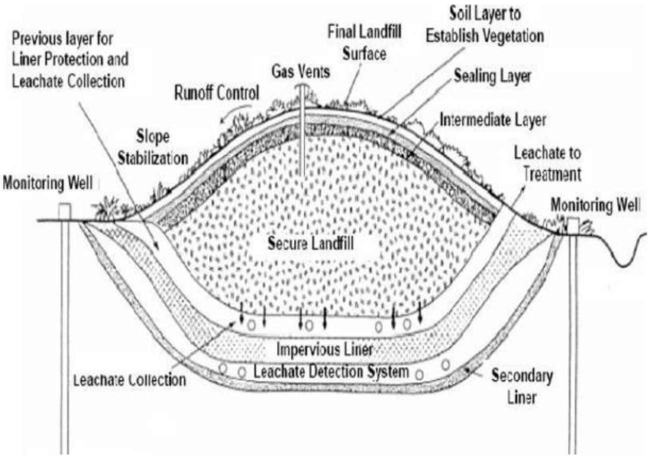

Fig. 1: Cross Section of a Landfill

The behavior of soil depends on the pore fluid. So the properties of the liner change when comes in contact with leachate. Hence, it is important to study the chemical compatibility of the liner material with different pore fluids or the leachate that the liner may be subject to. In this sense, when attempting to define the geotechnical characteristics of clay liners, the use of distilled water or tap water is far from being representative of the in-situ conditions. So, theoretical and experimental study is needed to investigate the variation of engineering properties with chemicals. Hence in this study the variation in engineering properties of designed liner using local soil due to chromium contamination is reported.
Procedure for Paper Submission

II. LITERATURE REVIEW

Leachate which is generated as a consequence of precipitation, surface runoff and infiltration or intrusion of ground water percolating through a landfill, bio chemical process and the inherent water content of the waste themselves. Leachate is the liquid residue resulting from various chemical, physical, and biological processes taking place within the landfill. The transfer of pollutants from the waste material to percolating water is due to combination of physical, chemical and microbial processes in the waste (Christensen and Kjeldsen, 1989). The quantity of leachate generated mainly depends on the climatic factors in its vicinity. The volume of leachate is also affected by initial moisture contents of wastes, solid waste composition, biochemical and physical transformations taking place in them and causing changes in their humidity and by the inflow of water from outside a landfill. The amount of leachate in a scale of a year is not constant. It increases in rainy season and decreases in dry season (Slomcynska and Slomscynski, 2004).

To prevent the passing out of leachate from the landfill, liners are designed. Using very low permeable clay like bentonite. Local soil is sometimes mixed with bentonite to form amended soil liners. There are various specifications for a soil to be used for liner. All authors specify a maximum hydraulic conductivity of 1 x 10^{-7} cm/s (Daniel, 1993; Datta and Juneja, 1997; EPA, 1992). Bagchi in 1989 gave a criterion based on which the percentage of fines should lie between 10 to 50% and plasticity index should be between 10 and 30 %.According to Environmental Protection Agency of USA (1992), at least 20% of the soil should be fines and plasticity index should be between 10% and 30 as they become sticky and due to difficulty in compaction. Rowe et al., 1995 suggests a minimum CEC of 10 meq/100g and a minimum 15 to 20% of soil particles should be smaller than 2µm. The liner should be compatible with leachate. Well graded soil has to be mixed with 5 to 10% bentonite and uniformly graded soil has to mixed with 10 to 50% bentonite to form amended soil liners.

Soil waste interactions affect almost all soil properties. The effects of pollutants on soil are complex, they can be better understood if various factors are isolated and considered independently. Ions exchange or mature pore fluid influence the properties of soil (Oluremi, 2012). With migration of contaminated fluids and replacement of pore fluids of soil, the chemistry as well as physicochemical properties of the pore fluid is changed, and soil is contaminated. This can change soil properties, such as hydraulic conductivity and shear strength behaviour and make the soil collapsible. Increased stresses in soil and the reduction of shear strength by contamination together make the clay liner more prone to failure, leading to underground water pollution (Naeini and Jahanfar, 2011).

Presence of Calcium sulphate increases shear strength of low plasticity silts. In the soil, the exchangeable cation Ca^{2+} was attracted to the negative part of the clay mineral resulting to formation of strong bond as a result of involvement of divalent ion in bond formation. The bond was responsible for the high values of cohesion and angle of internal friction obtained for the contaminated soil samples on each day of test. The bond formation took less time to complete and was never permanent. Thereafter, loosening of the bond took place leading to reduction in the sample cohesion and angle of friction (Mathew et al., 2009).

The liquid limit, plastic limit, shrinkage limit of low plasticity clays decreased when came in contact with cyanide, acids like sulphuric acid and nitric acid, salt solutions containing sodium chloride, calcium chloride and magnesium chloride. Synthetic leachate containing ammonia, nitrate, iron, manganese, copper and carbon also decreased the Atterberg's limits (Oluremi et al., 2012; Meril and Beena, 2011; Pankaj et al., 2011).

Increasing the salt concentration and the cation valence decreases the inter-particle repulsion which results in particles moving more freely in lower water contents, thus the liquid limit of the mixture decreases. Higher cation valence and salt concentration cause high decrease in liquid limit (Shariatmadari, 2011). Arasan and Temel (2008) studied the effect of ammonium chloride, potassium chloride, copper sulphate and iron sulphate salt solutions on high plasticity clay. They reported that all salt solution exhibited almost the same variation.

The liquid limit and plastic limit decreased whereas shrinkage limit increased.(Pankaj et al. ,2011) The degree of variation in the consistency characteristics of the soil depends on factors like type of soil, electrical charge of exchangeable cation absorbed by soil particles and concentration of cations in soil water. Due to leaching of cations and de flocculation the value of shrinkage limit is attributed to increase in inter particle distances due to reduction in the forces between soil particles.Lime can reduce permeability of both laterite and saprolitic soils, which are clays of low and high plasticity (Elsharief et al., 2004). Acetic acid reduced permeability of high plasticity clay (Raji and Sheela, 2009). Ammonia, nitrate, iron, manganese, copper, carbon, calcium, magnesium, potassium, sodium, sulphate, chloride, carbonate can also decrease the permeability of low plasticity clay (Badv and Omidi, 2008; Meril and Beena, 2011). In the case of high plasticity silt, ammonium chloride, calcium chloride and magnesium chloride salt solutions increased permeability (Sunil et al., 2008). For low plasticity silts, permeability increased when treated with sodium chloride, calcium chloride and magnesium chloride. This can be because of the change of soil from dispersive to flocculative structure with addition of high concentrations of cations Ca^{2+} and Mg^{2+}. This effect could be explained by double layer contraction and increase in pore space (Shariatmadari et al., 2011). In the case of mixture of low plasticity silt and high plasticity clay, when reacted with a synthetic leachate containing mainly lead, sodium and magnesium, permeability increased (Francisca and Glatstein, 2011).

The highest swelling volume is obtained when high plasticity clay is permeated with water. Increase of salt concentration and cation valence decrease swelling volume. Increasing the cations in the bulk solution, results in a gradient of free energy which forces water to leave the interlayer region (Shariatmadari et al., 2011).

III. MATERIALS AND METHODOLOGY

A. Materials Used

The details of the materials selected for the present study, i.e. Bentonite, Kaolinite and fine sand are explained in the following sections. The properties of these materials are as follows.

1. Bentonite

Bentonite is naturally occurring 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. Calcium bentonite used in the study was procured from a quarry in south India Coimbatore in Tamilnadu. The engineering properties of calcium bentonite is found out in laboratory as per Bureau of Indian Standards are presented in Table 1.

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Table 1. Physical Properties of Bentonite

Physical property	Value
Specific Gravity	2.6
Liquid Limit (%)	265
Plastic Limit (%)	54
Free swell (ml/2g)	16
Percentage free swell Index	15
Percentage of clay (%)	66
Percentage of silt (%)	34
Coefficient of permeability (cm/s)	1.537 x 10^{-8}

2. Kaolinite Soil

Kaolinite is low expansive clay with very small percentage of fine sand. The properties of Kaolinite are presented in Table 2.

Table 2. Physical Properties of Kaolinite

Physical property	Value
Specific Gravity	2.18
Liquid Limit (%)	64
Plastic Limit (%)	38
Plasticity Index (%)	26
Shrinkage Limit (%)	29
Maximum dry density(g/cc)	1.33
Optimum moisture content(%)	34
Percentage of clay (%)	81
Percentage of silt (%)	19

3. Sand

5% of total volume of liner was fine sand passing through 425µ and retained on 75µ

4. Properties of liner

Amended clay liner designed with Bentonite, Kaolinite soil and fine sand from Kerala in the ratio 2:13:5 was used (Paulose et al., 2013). The properties of the liner were found out as per the standards are as presented in table 3.

Table 3. Physical Properties of Liner

Physical Property	Standard used for determination	Value
Liquid Limit (%)	IS 2720-Part 5	52
Plastic Limit (%)	IS 2720-Part 5	28
Plasticity Index(%)	IS 2720-Part 5	24
Shrinkage Limit (%)	IS 2720-Part 6	24
Free swell (ml/2g)	ASTM D 5890-02	6
Optimum moisture content (%)	IS 2720-Part 7	27
Maximum Dry Density (g/cc)	IS 2720-Part 7	1.4
Unconfined Compressive Strength (kN/m^2)	IS 2720-Part 10	67
Coefficient of permeability (cm/s)	IS 2720-Part 15	4.15 x 10^{-8}

5. Synthetic Leachate with Chromium

The leachate was collected from the landfill situated at Attingal in south India. In addition to the presence of organic and inorganic matters, heavy metals are also found in the leachate. The constituents of the leachate are presented in Table 4.

Table 4. Composition of Leachate, from Attingal landfill (South India)

Sample Name	Cd	Co	Cr	Cu	Ni	Pb	Zn	Pd
Leachate Sample	BDL*	BDL*	0.03	0.015	0.01	BDL	0.04	0.04
Detection Limit	**0.01**	**0.05**	**0.01**	**0.01**	**0.01**	**0.05**	**0.01**	**0.04**

*BDL-Below Detection Limit

To prepare a chromium solution potassium dichromate was mixed with distilled water to give 1M, 2M, 3M and 4M solution. 1M solution is equivalent to concentration in landfill leachate.

B. Methodology

The prepared amended liner was mixed with Chromium solution of varying molarity and its Geotechnical properties were found out at varying periods as per Indian Standards. Free swell test were conducted as per ASTM D 5890-02.

IV. RESULTS AND DISCUSSION

A. Effect of Chromium on The Liner Properties of Liner

The liner was mixed with 1M, 2M, 3M and 4M concentration of chromium solution and its properties were found out after 7, 14, 8 and 60 days and the variation in plasticity index of liner due to Chromium index is presented in Table 5 and fig 2.

1. *Effect of Leachate on Plasticity Index*

Table 5. Variation of Plasticity Index due to the Effect of Chromium

Plasticity index				
Conc. of Cr Duration	1M	2M	3M	4M
7 Days	23.39	22.49	22.14	21.88
14 Days	22.44	21.73	20.44	20.54
28 Days	18.47	18.81	18.75	17.75
60 Days	18.2	17.97	17.91	16.08

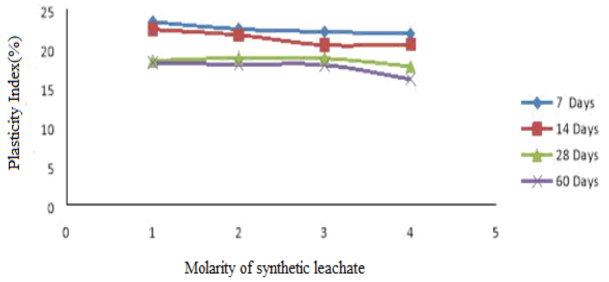

Fig.2 Variation in Plasticity index with increase in concentration of chromium in synthetic leachate

The plasticity index decreased with time as the concentration of chromium increased. The liquid limit also decreased as time increased .At the end of 60 days, using Chromium the percentage reduction in plasticity index is 32.58 %. This may be due to, diffuse double layer contracted by the adsorption of cations and the interparticle repulsion decreased due to which the particles moved closely in lower water contents, reducing plasticity index.

2. *Effect of leachate on shrinkage limit*

Table 6 and fig 3 shows the effect of Chromium on shrinkage limit of the liner. Similar to plasticity index, shrinkage limit decreased as the concentration increased. The shrinkage limit also decreased as time increased for all the cases. The reason for these changes can be due to reduction in diffused double layer thickness due to adsorption of cations, inter particle repulsion reduced and particle came closer leading to reduction in voids.

Table 6. Variation in Shrinkage Limit

Shrinkage Limit				
Conc. of Cr / Duration	1M	2M	3M	4M
7 Days	22.59	21.46	20.12	19.02
14 Days	21.56	21.02	20.45	19.25
28 Days	20.05	19.86	18.82	17.36
60 Days	18.32	17.95	17.09	15.62

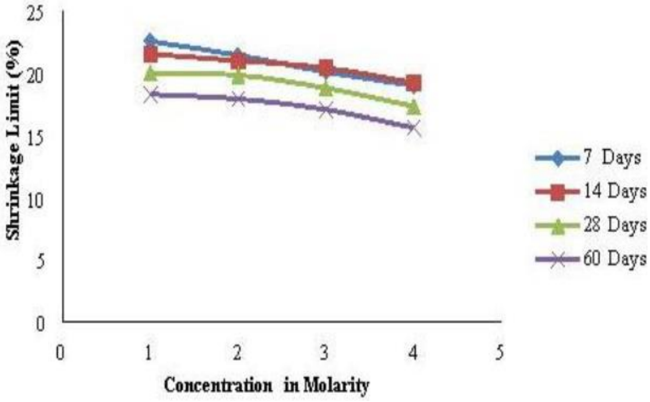

Fig.3 Variation in Shrinkage Limit with Increase in Concentration of Chromium

3. *Effect of Chromium on Unconfined Compressive Strength*

Variation in UCC strength with different concentration and time is presented in Table 7 and figure 4

Table 7. Variation of Unconfined Compressive strength in kPa due to the effect of Chromium

Unconfined Compressive Strength(kPa)				
Conc. of Cr / Duration	1M	2M	3M	4M
7Days	96.25	98.85	99.48	101.2
14 Days	97.8	98.98	100.4	103.7
28 Days	99.12	100.53	100.98	102.75
60 Days	100.98	102.85	103.12	104.84

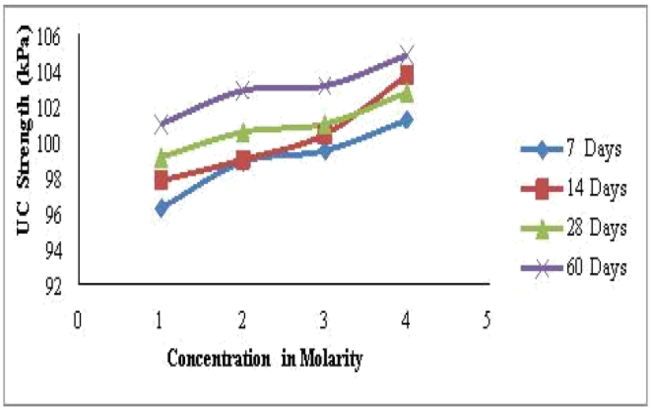

Fig.4 Variation in UC Strength with Increase in Concentration of Chromium

As the concentration of chromium solution increased the unconfined compressive strength increased with varying time for all the cases. At the end of 60 days, the percentage increase in unconfined compressive strength was 56.48 % .This observation is similar to studies of Naeini and Jahanfar (2011) when the shear strength of high plasticity clay increased with small percentage of sodium chloride. Mathew et al. (2009) in which case the shear strength of low plasticity silt increased on treatment with calcium sulphate. The increase in unconfined compressive strength is also due to diffused double layer contracted due to adsorption of cations and the inter paticle repulsion decreased, rising the shear strength.

4. *Effect of Leachate on Permeability*

The variation in permeability of liner due to chromium solution is presented in Table 8 and fig.5

Table 8. Variation of Permeability in cm/s due to the Effect of Chromium

Permeability in (cm/s)				
Conc. of Cr(10^{-8}) / Duration	1M	2M	3M	4M
One month	5.19	5.87	6.36	6.84
Two months	5.81	6.06	6.42	6.98

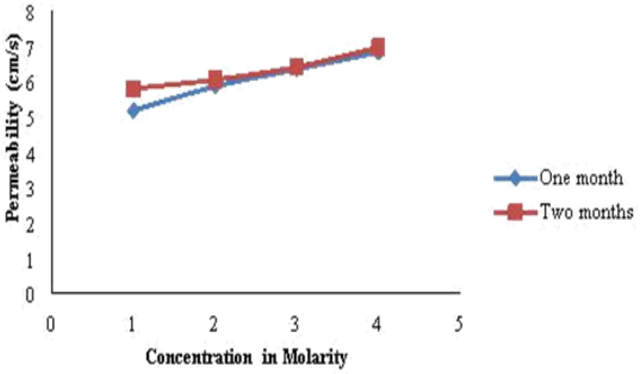

Fig.5 Variation in Coefficient of Permeability with Increase in Concentration of Chromium

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With the increase in concentration of Chromium and time the permeability increased but it is within the allowable maximum limit of 10^{-7} cm/sec.

5. Effect of leachate on free swell

Table 9 gives the effect of Chromium on free swell of the liner with time. Free swell decreased as the concentration of chromium and time.

Table 9. Variation of free swell (mL/2g) due to the effect of Chromium

Free swell (mL/2g)				
Conc. of Cr(ml/2g) Duration	1M	2M	3M	4M
7 Days	6	5.5	5	4.5
14 Days	5.5	5	4.5	4
28 Days	5	4.5	4	3.5
60 Days	4	4	3.5	2.5

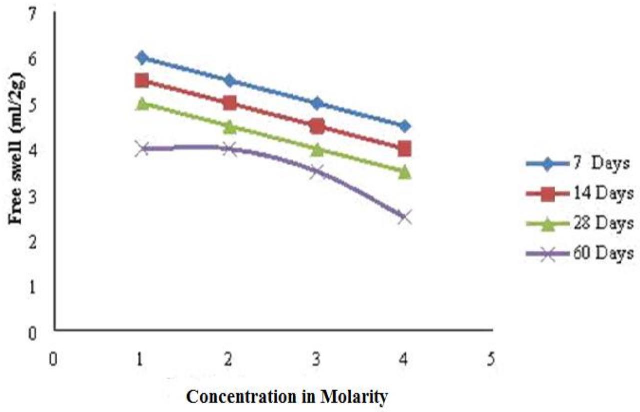

Fig. 6 Variation in Free Swell with Increase in Concentration of Chromium

In this case, the free swell decreased as the concentration increased. The free swell also decreased as time increased for all the cases. At the end of 60 days, the percentage reduction in free swell is 58.33 %.These results are similar to those obtained by Raji and Sheela (2009) when acetic acid decreased percentage of swelling and free swell of high plasticity clays. Free swell decreases with increase in time as well. Increase in time of contact of leachate with liner may have reduced double layer thickness reducing the free swell of the liners

V. CONCLUSION

The variation in the engineering properties of the amended liner designed using Bentonite, Kaolinite and fine sand; taken in the ratio 2:13:5 due to chromium solution are reported in this paper. The following are the conclusions on the variation in engineering properties:-

- The plasticity index, Shrinkage Limit and free swell of liner was decreased with increase in concentration and increase in time.
- Unconfined compressive strength was found to be increasing with concentration and duration. Since the increase in permeability was marginal and unconfined compressive strength shows an increasing trend, the liner is suitable for the dumping of waste containing the heavy metal Chromium.

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