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Comparative Performance of Compacted Clay Liner (CCL) and Geosynthetic Clay Liner (GCL)

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Abstract

The generation of solid waste is the inevitable result of all approaches in which materials are used. Wastes are generated by the Extraction of raw materials, manufacture of merchandise, consumption, and waste management. The waste generated will impact the environmental quality and human fitness worldwide if it isn't managed properly. The soil waste disposal is one of the important assets of soil and water contamination. On this experience, sanitary landfills have top notch significance for environmental protection. A landfill, also referred to as a sanitary landfill, is a land disposal site for waste, that is designed to shield from environmental pollutants and health dangers. Landfills are constructed to pay attention to the waste in compacted layers to reduce the quantity and monitored for the management of liquid and gaseous effluent with a purpose to guard the surroundings and human fitness. In these structures, the geosynthetics substances are extensively employed. Landfill liners are used to decrease the permeability of the inspiration and save you similar transportation of harmful contaminants and contaminated water. The goal of this look is to analyze the performance of compacted clay liners (CCL) and geosynthetic clay liners (GCL), which can be applied to prevent the penetration of leachate to groundwater through opportunity liner systems.

Keywords: Water Contamination, Landfill Liners, Leachate, Compacted Clay Lines (CCL), Geosynthetic Clay Liners (GCL)

List of Abbreviations:

USEPA: United States Environmental Protection Agency
CCL: Compacted Clay Liners
GCL: Geosynthetic Clay Liners
WHO: World Health Organization
MDD: Maximum Dry Density
ASTMD: American Society for Testing and Materials for Miscellaneous materials
ISO: International Standard Organization
TDS: Total Dissolved Solids

TA: Total Alkalinity
TH: Total Hardness
COD: Chemical Oxygen Demand
BOD: Biochemical Oxygen Demand
OMC: Optimum Moisture Content

Introduction

In many countries, a major attention is given to the safety of groundwater and surface water in the design of waste disposal centers. Usually, modern-day facilities which will bring about negligible impact through a barrier system by restricting the migration of contaminants into the surrounding environment to levels [16]. Wastes can be of different classes viz., municipal, industrial, volatile, and low degree radioactive. A spread of options were made regarding the disposal of wastes like incineration, composting, open dumping, pyrolysis, landfilling and so forth. Incineration process used to dispose Combustible solid waste by burning the refuse at high temperature. Composting is the process used to decompose organic material known as compost. Open dumping involves dumping of both solid and hazardous wastes. Pyrolysis involves thermal decomposition of materials at elevated temperature. In Landfilling, refuse is carried and dumped into low lying areas, under an Engineered operation. Landfilling remains the preferred in lots of developing international locations like India. It proves to be much less inconvenient. The landfill liner retards migration of leachate, and its toxic factors, into underlying aquifers or nearby rivers, stopping the leachate from coming into the close by water. The primary thing being it offers proper lining systems to save you groundwater contamination. Landfill liners need to have minimal thickness of 600mm and with hydraulic conductivity much less than 10^{-7} cm/sec as advised by USEPA (United states environmental protection agency) [20]. Geosynthetic Clay liners are a thin layer of sodium bentonite material which is placed between two geotextiles on both sides of the sodium bentonite layer [17]. GCL needs less skill labor for installation and is a smaller amount expensive and it also occupies less space compared to CCL. GCL has good resistance to freeze/thaw cycles, hence it is easily rectified [4,7,8]. Damages caused during the handling and installation process can be easily rectified by the good healing capacity of GCL. The small holes during installation are healed by bentonite within the GCL [3]. It may be easily transported within the form rolls of 0.75 m in diameter and 4-6 m long. GCL proves to be more cost-effective compared to CCL where clay soil is much far from the landfill site [1,2]. However CCL has large attenuation capacity compared to GCL due to its large thickness and it also inert to most of the permeant liquids that comes into contact. And also there's a break of geosynthetic components in GCL being degraded within the future [18].The compacted clay permeated with leachate has decreased hydraulic conductivity as compared with Distilled water [15]. With the significance of stopping contamination of groundwater and pollution of soil via leachate generated through wastes inside the landfills, the landfill beds have been designed within the manner that it is able to save you groundwater contamination and soil pollution [17]. Due to low permeability Geosynthetic Clay Liners (GCLs) and Compacted Clay Liners (CCLs) are the most generally used landfill liners. They act as hydraulic obstacles for landfill base liners and closures. Geosynthetic Clay Liners (GCLs) are used as an alternative to Compacted Clay Liners (CCLs) [13]. As geosynthetic clay liners (GCLs) are often and regularly used to replace hard to build compacted clay liners (CCLs) it's miles beneficial to examine the hydraulic overall performance of each liner with admire to general leakage to illustrate the heightened overall performance that may be acquired with GCLs [9].

Materials and Methods

Materials

Leachate: Leachate sample was collected from Ariyamangalam landfill site in Tiruchirappalli district. The layout of the landfill site is shown in Figure.1. The leachate sample was accrued from the surfaces of stagnant leaching water. Leachate is defined as any contaminated liquid that is generated when rainwater percolates through waste placed within the landfill, these liquid leaches the chemical constituents through the wastes. Leachate from a landfill is often found to incorporate main factors like calcium, magnesium, potassium, nitrogen and ammonia, trace metals like iron, copper, manganese, chromium, nickel, lead, etc., The attention of these within the leachate depends on the composition of wastes.

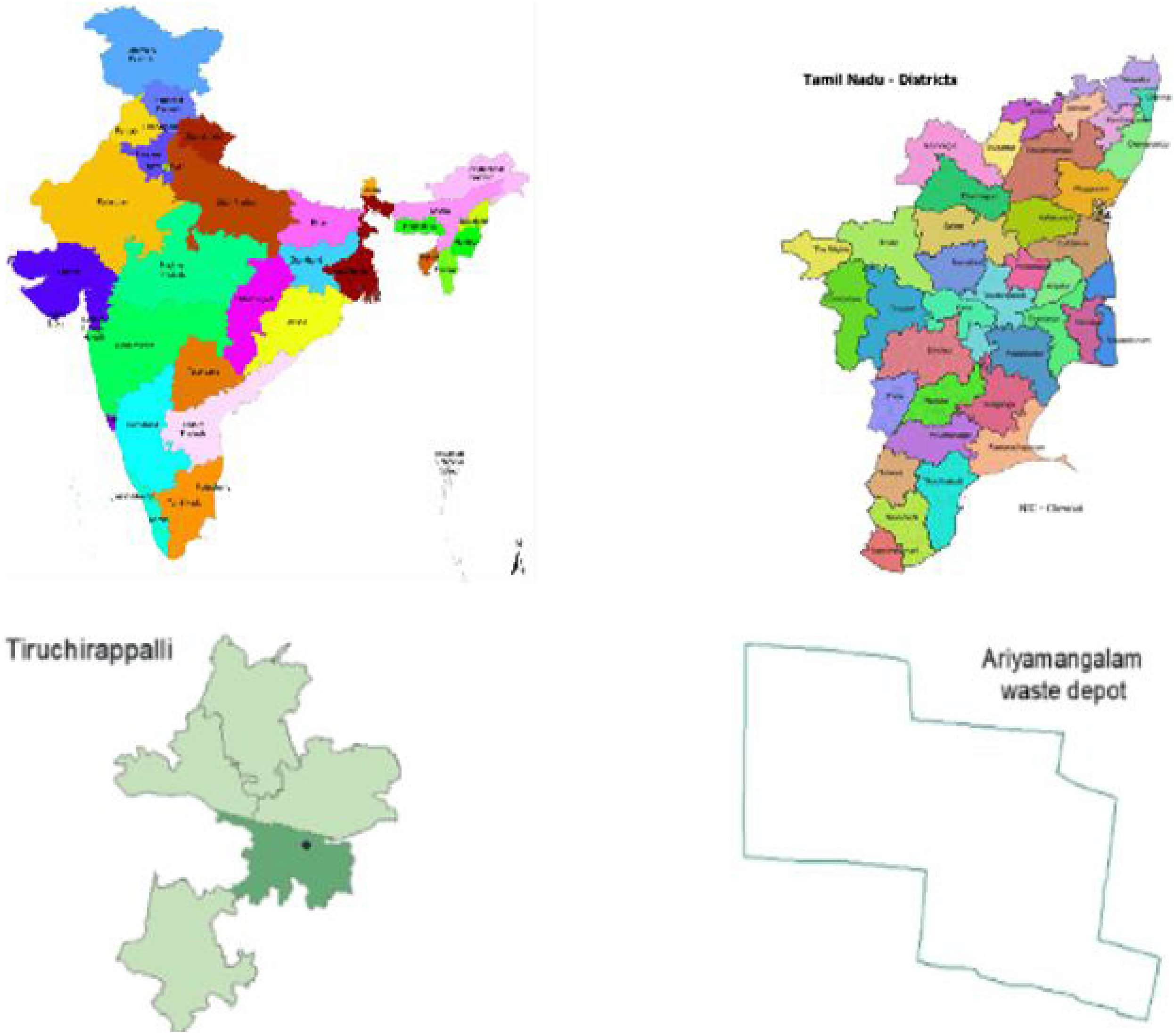

Figure 1: Layout of the landfill site

Clay: The clay sample utilized in this paper is collected from the agricultural land near Valudareddy in Villupuram district. Compacted soil liners are also commonly remarked as compacted clay liners (CCLs) because only soils that contain a sufficient amount of clay can provide the suitably low saturated hydraulic conductivity typically required for containment applications (e.g., $k_{sat} \leq 10^{-9}$ m s^{-1}). Compacted clay liners are less costly and it has accurate attenuation capacity [22].Consequently, it is utilized in a maximum of the landfills. although it has lot of perfect characteristics for liners such low permeability and desirable attenuation potential it has its own demerits together with excessive swelling and shrinkage thus causing instability trouble [6].The primary purposes of compacting a source clay to be used as a liner material are to cut back the saturated hydraulic conductivity by densifying the clay (i.e., reducing the pore sizes) and to destroy any small secondary defects (e.g., fissures or cracks) that will act as conduits for flow within the natural soil formation. CCLs typically are constructed in 150-mm-thick layers, or lifts, with the overall thickness of the CCL being capable of the amount of compacted lifts times the lift thickness.

Geosynthetic Clay Liners (GCLs): Geosynthetic clay liners (GCLs) sample of about 2 meters × 3 meters of 6 mm thickness are collected from Ashapura Group of Industries from their branch in Kerala, India. Geosynthetic clay liners (GCLs) are factory manufactured materials consisting of a geotextile and bentonite composites (usually sodium bentonite sandwiched among layers of geotextile) engineered for a spread of environmental containment applications [18]. Geotextiles-based GCLs are fortified with cement, needle punching, or stitch-bonding, with the bentonite contained by way of the geotextiles on both sides. The total structure can be held together by means of the bentonite and backside geotextile caused by a number of fibres from the best geotextile by the needle punching strategy [21]. GCLs offer an exquisite alternative to traditional Compacted Clay Liners via replacing a thick segment of compacted clay with a thin layer of pure sodium bentonite. Advantages consist of easy setup, better hydraulic performance and resistance to varying climate conditions. GCLs also have particular self-sealing attributes, lowering the chance of failure because of adverse fields and working conditions. ECOKLAY SPL40 is a reinforced GCL which consists of Nonwoven and Woven geotextiles which have a Sodium Bentonite provided between them which are needle-punched together to produce internal reinforcement. Due to the internal reinforcement, it can minimize clay shifting and maintain low permeability and under a variety of practical conditions it provides better performance. The Bentonite material of the GCL sample is Grain bentonite sodic and the mass of the bentonite is 5000 g/m^2. The woven polypropylene is the top-mat-polymer layer with the mass of 110 g/m^2. The Nonwoven polypropylene is the bottom-mat-polymer layer with a mass of 180 g/m^2. The total mass of the layer is about 5330 g/m^2.

Methods

Physicochemical Characteristics of Leachate

The various physicochemical characteristics of leachate such as Total dissolved solids (TDS), total alkalinity (TA), total hardness (TH) and calcium (Ca^{2+}) were analyzed by titrimetric methods, pH was analysed by using pH meter, chemical oxygen demand (COD) was estimated by closed reflux titrimetry method, while biochemical oxygen demand (BOD) was calculated by oxygen determination by Winkler titration and the heavy metals were determined using UV Spectrophotometer.

Index Properties of Clay

The various physical and engineering properties of Clay namely Natural moisture content, Specific gravity, Liquid limit, Plastic limit, Shrinkage limit, Differential free swell index, Grain size distribution, Optimum moisture content, Maximum dry density, Hydraulic conductivity were determined. The test procedure for Natural moisture content was followed as per IS: 2720 (Part 2)- 1973, for Specific gravity as per IS:2720 (Part 3) sec 1- 1980, the liquid limit and plastic limit tests were conducted as per IS:2720(Part 5)-1985. Shrinkage limit is determined as per IS:2720 (Part 6)-1972 and the soil was classified based on the plasticity chart as per Bureau of Indian Standards, the Grain size distribution conducted as per IS:2720 (Part 4)-1985, the free swell index was determined as per IS: 2720 (part XL)-1977, the optimum moisture content (OMC) and maximum dry density (MDD) was determined by conducting standard proctor tests as per IS: 2720(part 7)-1980, the Hydraulic conductivity of the sample is determined as per IS: 2720 (part 17)-1986.

Properties of Geosynthetic Clay Liners

The properties such as Index Flux, Hydraulic Conductivity, Tensile Strength, Puncture Resistance, Peel Strength, Thickness and Internal Shear strength were determined. The Index flux was of the geosynthetic clay liner is determined as per ASTM D 5887, the Hydraulic conductivity was determined as per ASTM D 5887, the Bentonite Mass/Unit Area was determined as per ASTM D 5993, the Tensile Strength was determined as per ASTM D 6768, the Puncture Resistance was determined as per EN ISO 12236, the Peel Strength was determined as per ASTM D 6496, the Thickness was determined as per EN ISO 9863-1, the Internal shear strength was determined as per ASTM D 6243, the Free Swell was determined as per ASTM D 5890, the Fluid Loss was determined as per ASTM D 5891, the Nonwoven Mass/Unit area was determined as per EN ISO 9864, the Woven Mass/Unit area was determined as per EN ISO 9864.

Batch Adsorption Experiment for Leachate

Batch adsorption experiments were performed to decide the most effective dosage of adsorbent i.e., clay that provides the maximum percent of removal of the contaminants in the leachate sample. It is performed by way of adding a certain quantity of adsorbent right into a leachate sample containing a particular concentration of contaminants with a specific solid/liquid (S/L) ratio. Those combinations are vigorously stirred or shaken throughout the entire reaction time. In order to find out the optimum amount of adsorbent at which maximum adsorption takes place, 150 ml leachate was taken in a series of flasks with different portions of adsorbent clay: 0.5, 1.0, 1.5 g, 2g and 2.5g . The leachate was kept on a shaking incubator for 30 min at 120 rpm. After that time period, content became filtered and absorbance was noted by means of the usage of UV visible spectrophotometer.

Results and Discussion

Results

Characterization of Leachate: For the collected leachate sample, the physicochemical characteristics such as pH, Alkalinity, total dissolved solid [TDS], Calcium, Total hardness, chemical oxygen demand [COD] and biological oxygen demand [BOD] and their heavy metal concentrations such as Iron, Zinc, Lead, Copper, Cadmium and Chromium were determined and are provided in Table1.

SI.No	Parameter	Result
1	pH	6.57
2	Alkalinity (mg/l)	11536
3	Total Dissolved Solids (mg/l)	2979
4	Calcium (mg/l)	642
5	Total Hardness (mg/l)	21125
6	BOD (mg/l)	1624
7	COD (mg/l)	14582
8	Iron (mg/l)	0.78
9	Zinc (mg/l)	1.59
10	Lead (mg/l)	0.51
11	Copper (mg/l)	0.85
12	Cadmium (mg/l)	0.72
13	Chromium (mg/l)	0.59

Table 1: Physicochemical Characteristics of leachate sample

Properties of clay: The properties of the clay sample collected such as Natural moisture content, Soil classification, tier Index properties, Optimum moisture content, Differential free swell, Maximum Dry density (γ_d), Hydraulic conductivity (k), etc., were analysed and are presented in Table 2. Through Figure.2, particle size distribution curve graph it can be concluded that the sample is having high clay content. From Figure.3, the Atteberg's limits such as Liquid limit, Plastic limit, plasticity index, etc., can be determined. Through Figure.4, the optimum moisture content and maximum dry density are obtained respectively as 16% and 1.74g/cc.

SI.No	Properties	Result
1	Natural Moisture Content	8.01%
2	Specific Gravity	2.75
3	Percentage of sand	26.2%
4	Percentage of silt	16.54%
5	Percentage of clay	57.25%
6	Liquid Limit (W_L)	54.8%
7	Plastic Limit (WP)	25%
8	Shrinkage limit (W_S)	11.1%
9	Plasticity index (I_P)	29.8%
10	Toughness Index (I_t)	2.37
11	Consistency Index (I_C)	1.43
12	Soil Classification	CH
13	Differential free swell	58%
14	Optimum Moisture Content	16%
15	Maximum Dry density (γ_d)	1.74 g/cc
16	Hydraulic conductivity (k)	0.67×10^{-7} cm/s

Table 2: Index and Engineering Properties of clay sample

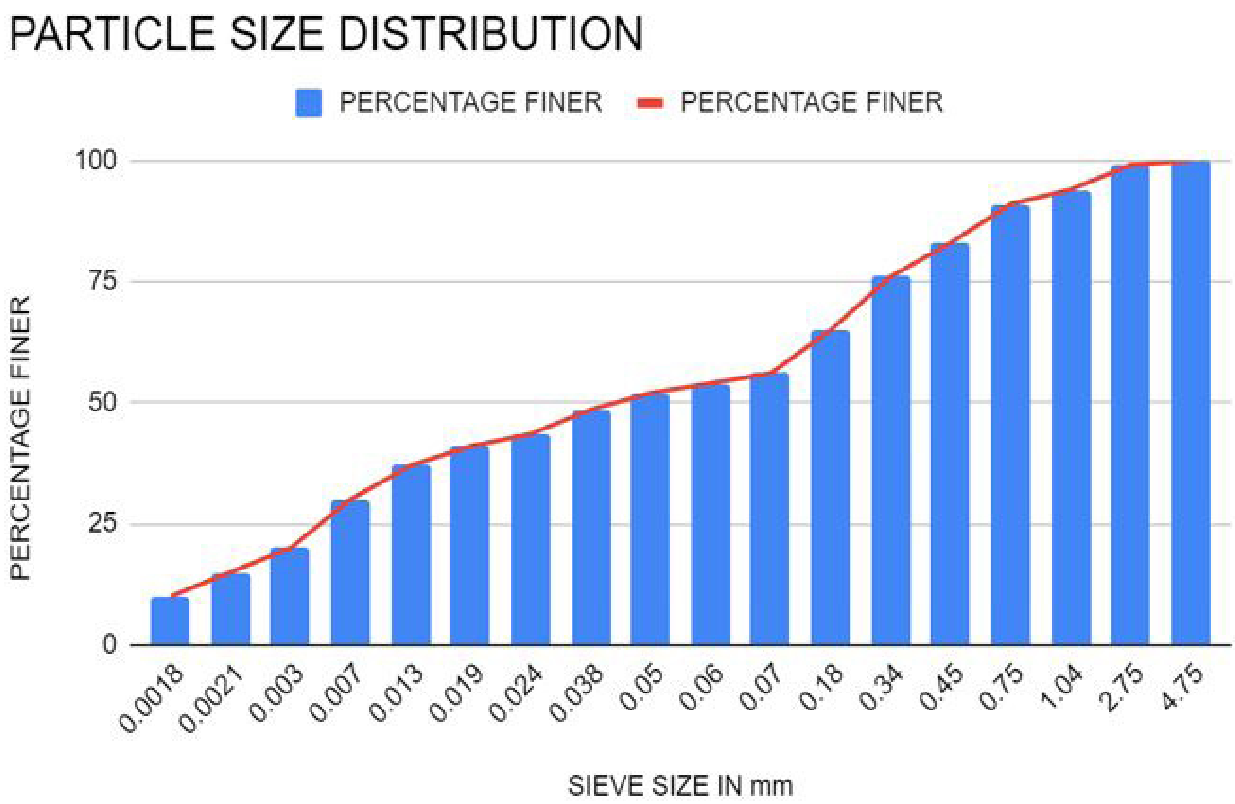

Figure 2: Particle size distribution curve of the clay sample

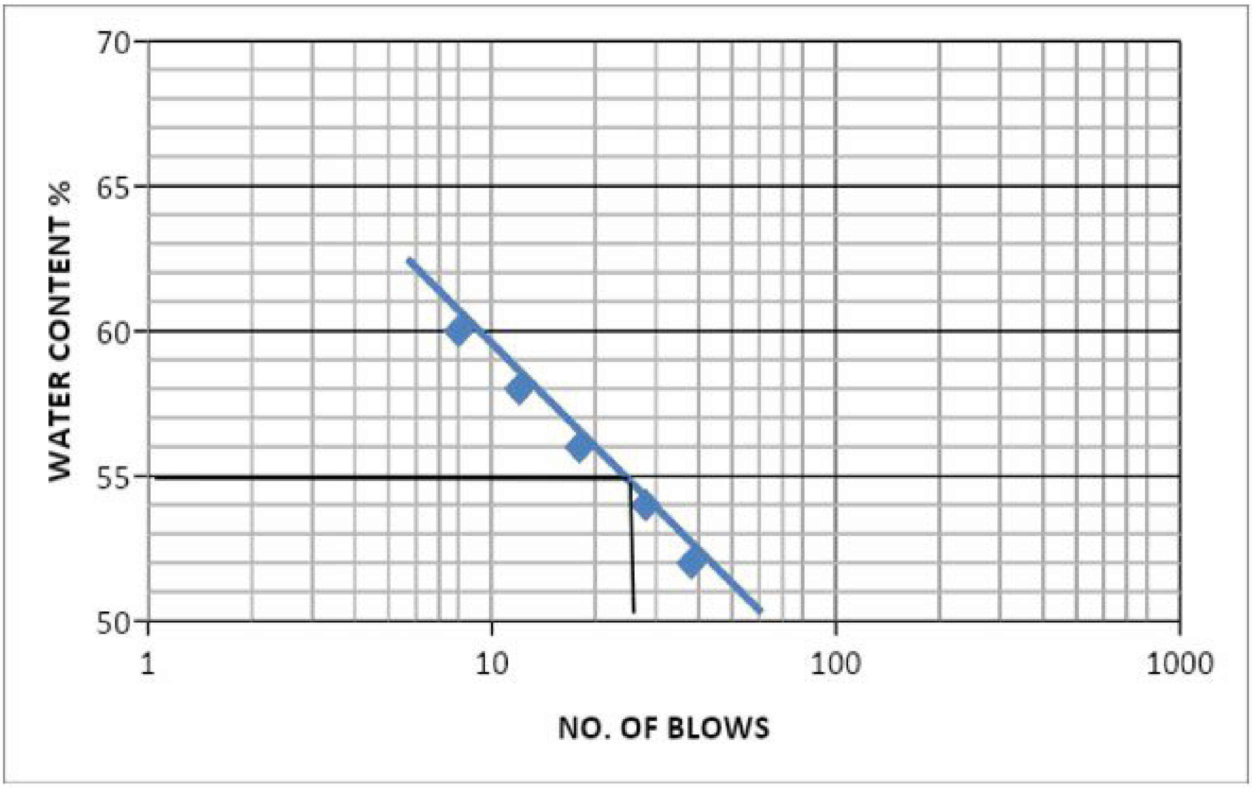

Figure 3: Atterberg's test of the clay sample

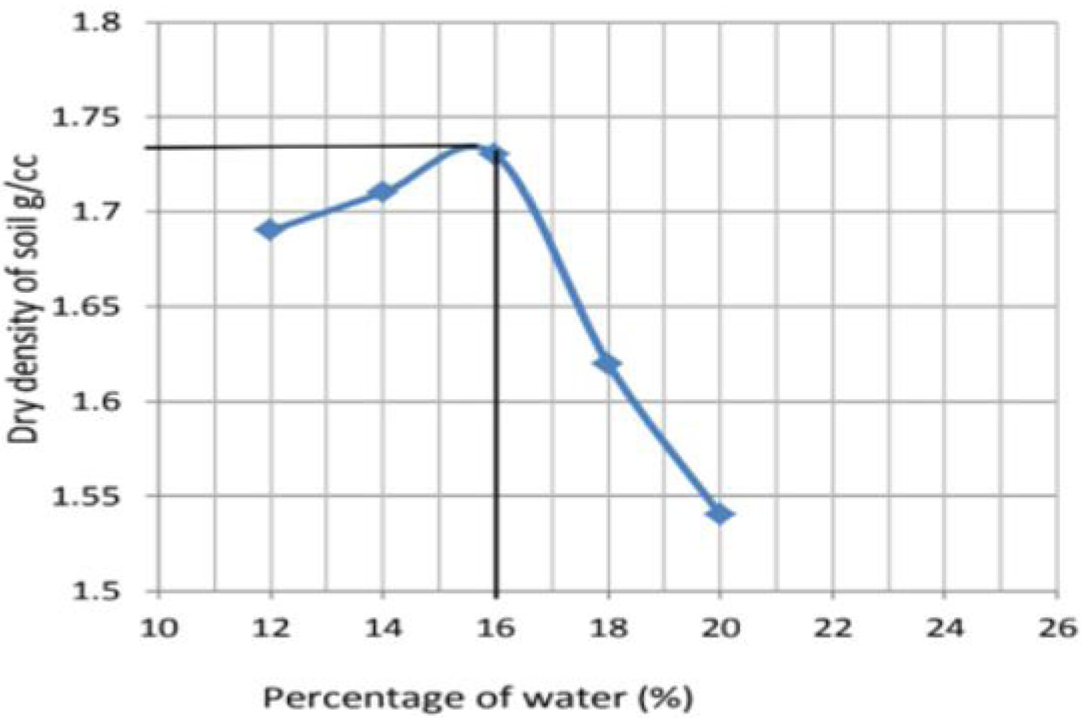

Figure 4: Standard proctor compaction test of the clay sample

Properties of Geosynthetic Clay Liners: The material properties of collected Geosynthetic clay liner sample such as Index Flux, Hydraulic Conductivity, Tensile Strength, Puncture Resistance, Peel Strength, Thickness and Internal Shear strength were determined and are presented in Table 3.

Material properties	Test Method	Specifications
Hydraulic Conductivity	ASTM D 5887	5.0×10^{-9} cm/sec
Bentonite Mass/Unit Area (MARV)	ASTM D 5993	Min.4.50 Kgs/m^2
Tensile Strength (MARV)	ASTM D 6768	12.00 KN/m
Puncture Resistance (CBR)	EN ISO 12236	1.8 KN
Peel Strength (MARV)	ASTM D 6496	Min.650N/m
Thickness	EN ISO 9863-1	6.0 mm
Bentonite		
Free Swell	ASTM D 5890	Min 25 ml/2g
Fluid Loss	ASTM D 5891	Max 18 ml
Geotextile		
Non-Woven Mass/Unit area	EN ISO 9864	200-240 g/m^2
Woven Mass/Unit area	EN ISO 9864	110-140 g/m^2

Table 3: Material Properties of Geosynthetic clay liner

Effect of Adsorbent Mass On Adsorption Using Batch Adsorption Experiment: The adsorption capacities of adsorbent i.e., for the collected clay sample, for the removal of several concentrations of heavy metal ions from the landfill leachate using batch experiments were done and the results are presented in the Table 4. The amount of dosage of the adsorbent and the percentage removal of the concentrations of the heavy metal ions were provided in the Figure 5.

Dosage 150ml	Zinc (mg/l)	Lead (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	% Removal
Blank	0.110	0.110	0.110	0.110	0.110	-
0.5	1.62	1.604	0.507	0.02	0.032	40
1.0	1.985	2.105	0.54	0.0027	0.038	54
1.5	2.062	2.372	0.631	0.031	0.044	67
2	2.133	2.74	0.698	0.036	0.047	75
2.5	2.376	2.972	0.73	0.004	0.054	86

Table 4: Effect of adsorbent mass on adsorption using Batch adsorption experiment

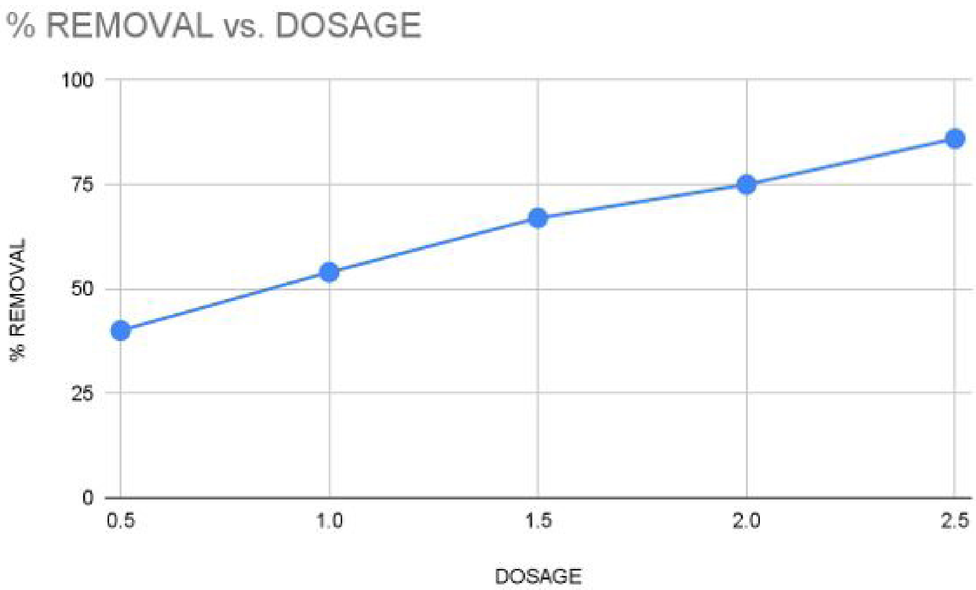

Figure 5 % Removal vs Dosage obtained by conducting Batch experiments using clay as adsorbent

Discussion

Characterization of Leachate: The pH of the leachate determined is 6.57, confirmed slightly alkaline in nature. According to WHO Standards, only the value of pH is within its permissible limits. The physicochemical characteristics and the heavy metal contamination within the gathered leachate sample rely generally upon the waste composition and water content material of the municipal solid waste (MSW) [5]. Other than pH, all other parameters are exceeding their permissible limits. The concentration range of heavy metals such as iron, copper, zinc, cadmium, chromium are very high.

Properties of Clay: The clay sample has high compressibility and it also has a high degree of expansion. The Shrinkage limit (W_S) lies between 7-12%, so the swell potential is high for the clay sample. The Plasticity Index IP > 17, so the clay sample has a high plasticity. The hydraulic conductivity of clay is low i.e., 0.67×10^{-7} cm/s. The clay soils own many benefits inclusive of low hydraulic conductivity, they have got high shrinkage and high expansive capability causing instability issues [12]

Properties of Geosynthetic Clay Liners: The hydraulic conductivity of the GCL sample is very low at the range of 5.0×10^{-9} cm/sec.Geosynthetic clay liners (GCLs) are more and more used as hydraulic barrier layers in bottom liner structures for landfills and impoundments that include waste [9]. Depending on the degree of effective overburden stress around the GCL during testing, the test values of GCL may vary. If the effective overburden stress increases, the hydraulic conductivity decreases. It has a minimum 4.50 Kgs/m^2 Bentonite Mass/Unit Area. The hydraulic conductivity of a GCL and bentonite swell is frequently related [10] .The Tensile Strength, Puncture Resistance, and Peel Strength of the collected GCL sample were very high and it proves that it has high durability. It is necessary to make sure that long-term contamination does not arise, it's far more important that the durability of GCL is maintained over the contaminating lifespan of the landfill [19].

Effect of Adsorbent Mass on Adsorption Using Batch Adsorption Experiment: The heavy metals which have been transferred to the environment are relatively toxic and might bioaccumulate inside the human body aquatic life and natural water our bodies and also probably get trapped in the soil [11]. Those toxic heavy metals entering within the aquatic environment are adsorbed onto particulate matter, although they can form loose metal ions and soluble complexes that are to be had for uptake by means of biological organisms [14]. The metal adsorption capacities generally increased with increasing initial metal concentration and decreased when adsorbent masses were increased in solution. With the increase in dosage of adsorbent, there is a constant increase in percentage of removal of heavy metals. The removal efficiencies of zinc, lead, chromium ion increased considerably with adsorbent mass addition

Conclusion

The leachate sample collected from landfill site is highly polluted and it is clearly seen by referring to the physico-chemical characteristics of the leachate sample and it will change the quality of the groundwater once it is mixed with it. So, the liner provided at the bottom of the landfill should be highly impermeable. Both Compacted Clay liners (CCLs) and Geosynthetic Clay liners (GCLs) can provide barrier systems for the landfill with low hydraulic conductivity (i.e., low permeability), which is the rate at which a liquid passes through a material. But Geosynthetic Clay liners (GCLs) have lower hydraulic conductivity than Compacted Clay liners (CCLs). So, Geosynthetic Clay liners (GCLs) can act as better impermeable liners than Compacted Clay liners (CCLs). GCL also has many advantages over CCL. It wants less talent labour for installation and is less costly. It additionally occupies much less space in comparison to CCL. It also has top recovery capacity when damaged for the duration of handling and installation. CCL has big attenuation potential in comparison to GCL due to its large thickness and it also inert to maximum of the permeant liquids that comes into contact. GCLs regularly are applied to replace traditional compacted clay barriers because of several advantages, which includes ease of production, much less consumption of air space, perceived resistance to environmental misery, and reduced leakage charges.

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