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RESEARCH ARTICLE

Effects of Some Chemicals on the Permeability of Compacted Clayey Soil

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ABSTRACT

Clay soils are natural materials with generally low permeability properties. Due to their low permeability properties, they are preferred in impermeable barrier structure applications. Impervious base and cover mats are constructed in solid waste landfill areas using clay soils. These impermeable structures constructed with clay soils are exposed to liquids with different chemical compositions as well as natural water. Contaminated water and other liquids other than natural water adversely affect these impermeable structures. In this study, the permeability behavior of impermeable clayey soil material compacted using different chemical agents was investigated. Permeability tests were conducted on compacted clay soil samples using pure water, ferric chloride, acetic acid, kisilene and n-heptane. Permeability test results showed that the chemicals increased the permeability values of the clay soil samples. After pure water, the lowest permeability value was obtained in permeability tests with ferric chloride. The highest permeability value was obtained in permeability tests with n-heptane. The results show that fluids other than pure or natural waters have a high potential to have negative effects on the permeability properties of impermeable structures made of compacted clay soils.

Contents

1. Introduction

Increase in urban conglomeration has resulted in more and more solid/liquid waste production and to cater the needs of the people, landfills have been created near metropolitan areas to act as a waste dump. These landfill sites are normally located in the suburbs and its main purpose is proper waste management, acting as temporary storage that should be processed and recycled in waste management facilities. Waste is compacted in these sites to reduce volume and provide area for more waste storage. There are many hazards

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associated with landfills. Landfills are the major contributors to leachate pollution; a process by which water from precipitation percolates into the groundwater and thus pollutes the water table making it harmful for human consumption [1].

Landfill liners are designed and constructed to create a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. This is done to prevent the uncontrolled release of leachate into the environment [2]. A clay barrier consisting of either a natural clayey deposit or compacted clay liner is the most widely used as the bottom liners of landfills in worldwide due to their low permeability and relatively good compatibility with the leachate contaminant [3–6]. The landfill liner and final cover systems in sanitary landfill were illustrated in Figure 1.

Compacted clay liners are widely used in solid waste landfills due to their cost effectiveness and large capacity of attenuation. Traditionally, clay barriers for the containment of landfill leachate are made up of compacted clay liners. In the absence of impermeable natural soils, compacted mixtures of bentonite and sand have been used to form barriers to fluids [7–11].

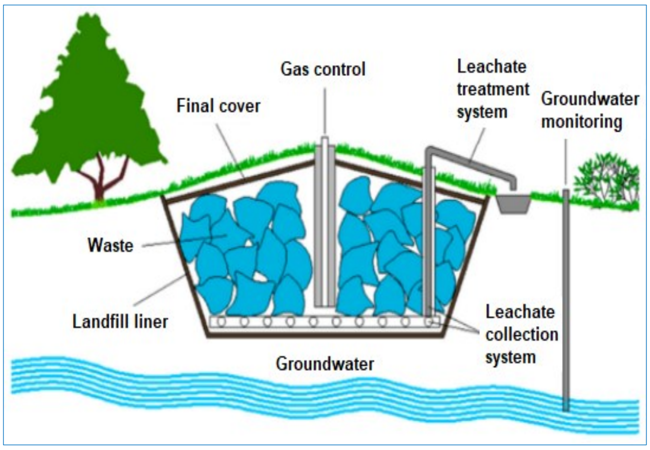

Figure 1 Sanitary landfill [4]

The existing literature reviews on landfill leachate can be divided into three types. One is focused on the treatment techniques of landfill leachate, while the connections between leachate properties/characterizations and treatment efficiencies have not been systematically discussed. The second is mainly about a certain type of treatment approach, such as Fenton/ozone-related advanced treatment, electrochemical processes, and membrane techniques or a certain type of pollutant, such as ultraviolet quenching substances and heavy metals, which are too specialized. The third type summarizes various characterization methods [12–27].

In landfills, the liner and cover systems utilize natural materials such as compacted clay, bitumen, soil sealant, synthetics and membranes [28–31]. The main requirements of liners are that they minimize pollutant migration, exhibit low swelling and shrinkage, and resist shearing. Compacted clay liners are widely used in solid waste landfills due to their cost effectiveness and ability to attenuate hydraulic conductivity [9, 28, 32].

Leachate migration from inside the landfill cell to the vadose zone is prevented by low permeability liners [33–35], which usually have multiple layers of compacted clay, granular filters and geosynthetics. Compacted clays or mixtures of local soils with clay are frequently used to achieve very low hydraulic conductivity barriers and prevent subsurface contamination. The hydraulic conductivity can be further reduced by the addition of bentonite to local soils to attain the values specified by international regulations ($k < 10^{-7}$ cm/s) [36–43].

Inorganic salts generally do not significantly affect the permeability of mattress structures constructed from clay soils. However, mattress structures constructed from clay soils are often affected by the interaction between the pore fluid and minerals [44]. Previous studies have shown that permeability increases with increasing salt concentration for clays with high liquid limit and decreases for clays with low liquid limit [45, 46]. The results of permeability tests using pure organic chemicals cause a large increase in the permeability of compacted clay soils, while the effect of diluted organic chemicals on permeability is much less [47, 48].

Chemical materials are effective on the permeability behavior of liner systems constructed from clayey soils [45, 49]. In literature, there is a great number of experimental studies dealing with the effects of chemicals on permeability of liner system constructed from clayey soil materials. [35, 46, 50–64].

The main objective of this research was to investigate the permeability properties of compacted clayey soil samples for liner and cover systems of landfill sites by using different chemicals. In this study, the falling-head permeability tests were carried out by using pure water and chemicals such as ferric chloride, acetic acid, n-heptane and xylene.

2. Materials and Methods

2.1. Clayey Soil

The clayey soil has been supplied from the clay deposits of Oltu Oligocene sedimentary basin, Erzurum, NE Turkey. The disturbed expansive soil has been collected by open excavation, from a depth of 0.75 m from natural ground level of this sedimentary basin.

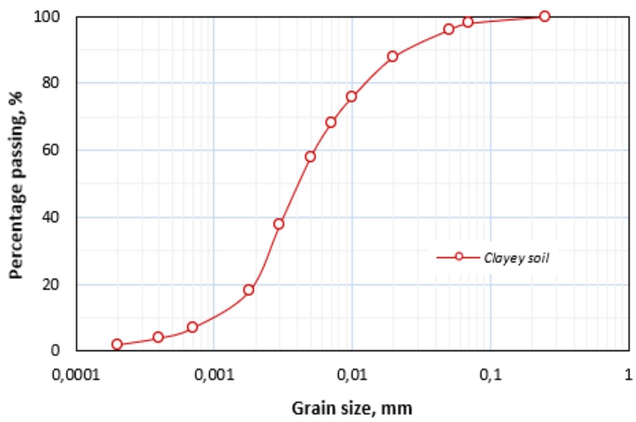

Figure 2 Grain size distribution of clayey soil

Supplied soil has placed in plastic bags and transported to a soil mechanics laboratory. This clayey soil is over-consolidated and it has clayey-rock characteristics in natural conditions. It is defined as a high plasticity soil (CH) according to the Unified Soil Classification System [10, 37, 65–67]. The grain-size distribution was given in Figure 2.

2.2. Chemicals

In this experimental study, ferric chloride, acetic acid, n-heptane and xylene were used as chemical material. Ferric chloride is an orange to brown-black solid that is soluble in water. Acetic acid known as ethanoic acid, ethylic acid, vinegar acid, and methane carboxylic acid is an acidic, colourless liquid and organic compound with the chemical formula CH_3COOH. n-heptane widely used in laboratories as a non-polar solvent is the straight-chain alkane with the chemical formula $H_3C(CH_2)5CH_3$. Xylene, an organic chemical compound, is a colorless, flammable liquid with a sweet odor. Its chemical formula is C_8H_{10}.

2.3. Sample Preparation

The clayey soil material used in the experimental study was firstly dried in an oven at 60 °C and then ground in a grinding machine. To yield compacted clayey soil samples, the clayey soil materials were compacted at their optimum water contents. The compaction processes were performed by Standard Proctor tests in accordance with ASTM D 698. For the permeability test, compacted clayey soil samples in Standard Proctor molds were used. The compaction mold used for the permeability test had a diameter of 102 mm and a height of 117 mm (Figure 3).

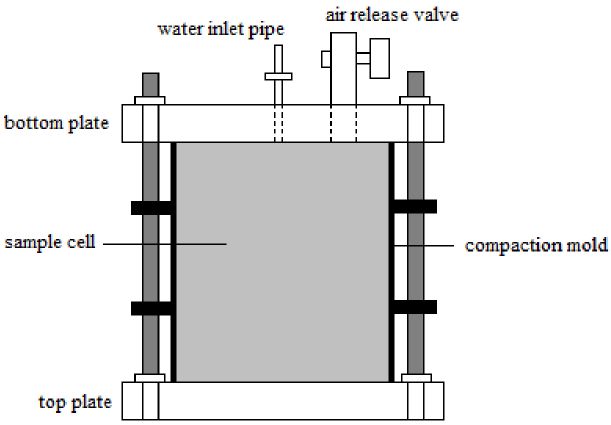

Figure 3 Schematic section of the compaction mold for permeability test used in the experimental study [67]

2.4. Compaction Test

Within the scope of the study, Standard Proctor tests were carried out to determine the optimum water content of the clayey soil material and to prepare samples for the permeability test. Standard Proctor tests were performed according to ASTM D 698. During the compaction process, a soil at selected water content was placed in three layers into a mold of standard dimensions, with each layer compacted by 25 blows of rammer dropped from a distance of 305 mm, subjecting the soil to total compaction effort. The clayey soil materials were compacted at the optimum water content to prepare samples for the falling-head permeability tests.

2.5. Falling-head Permeability Tests

The falling-head permeability tests were performed according to the ASTM D 5084. The samples were placed inside a cylindrical mold with a 102 mm in diameter and 117 mm in length and allowed to flow through the sample. The test apparatus consists of a mold with lids and a standpipe 10 mm in diameter and 100 mm in length. The permeability values were calculated for 48 h.

3. Results and Discussion

In this study, compacted clay soil samples were used to investigate how the permeability properties of clay soils would be improved when iron chloride, acetic acid, n-heptane and xylene were used instead of pure water as fluid. Compacted clay soil samples were subjected to falling-head permeability tests using pure water, ferric chloride, acetic acid, n-heptane, xylene as fluid. In the experimental study, pure water and 25% solutions of ferric chloride, acetic acid, kisilene and n-heptane chemicals prepared pure water addition were used as fluids. The results of the permeability tests are given in Figure 4.

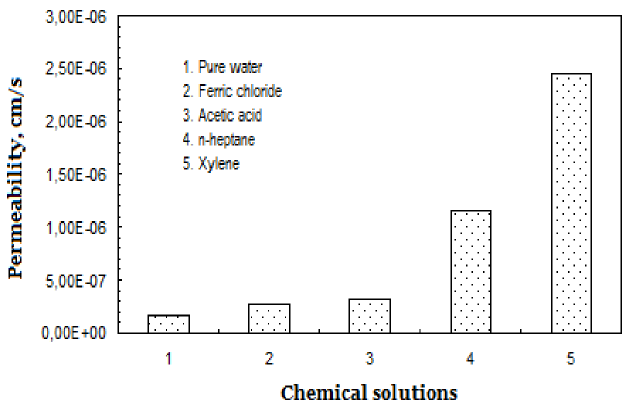

Figure 4 Permeability test results using pure water and some chemicals

According to the permeability test results, it was observed that all four chemicals used increased the permeability of the clay soil samples. While the average permeability value of clay soil samples with pure water was $1.65x10^{-7}$ cm/s, this value was $2.78x10^{-7}$ cm/s with ferric chloride, $3.52x10^{-7}$ cm/s with acetic acid, 1.15x10-6 cm/s with kisilene and $2.45x10^{-6}$ cm/s with n-heptane (Figure 4).

The amount of increase was low in ferric chloride and acetic acid and very high in xylene and n-heptane. As can be seen in the Figure 4, the highest permeability value was obtained in the experiments using n-heptane. The increase in permeability values of compacted clay soils using chemical materials is attributed to the interaction between the clay grains and the chemical material. With the introduction of the chemical material into the environment, dissolution of the clay soil material occurred and the grains were separated from each other, making it easier for the fluid to pass through the environment. There are studies in the literature where similar results were obtained [17, 53, 68–77].

Quigley [78] indicated that clay minerals might undergo large interlayer shrinkage in contact with certain chemicals. This is accompanied by enormous loss in Diffuse Double Layer (DDL) thickness, potential cracking and increase in hydraulic conductivity values. The thickness of the DDLs is an important controlling factor for the structural development, permeability, and other physico-chemical and mechanical properties of soils [49, 79]. Furthermore, Bowders and Daniel [48] advocated that the many chemicals tended to reduce the thickness of the DDL, causing the soil skeleton to shrink and causing a decrease in repulsive forces, thus promoting flocculation of clay particles, and to dehydrate interlayer zones of expandable clays, which subsequently became gritty or granular. As indicated by Gouy-Chapman theory, the thickness of the DDL decreases as the ion concentration increases, resulting in flocculation of the clay particles and larger pore channels through which flow can occur [45, 49, 61, 80].

Furthermore, chemical methods have been applied to reduce the permeability of soils at the bottom of landfills as an alternative to compacted clay mats or polymeric membranes. It is emphasized that the permeability of soils can be reduced by dissolution and precipitation of clay minerals using chemical methods [81]. In landfill sites, remediation is achieved with a suitable chemical that allows the clays to dissolve and re-precipitate. The dissolved clay particles move forwards in the soil and go as far as they can go and fill very small gaps in the soil, thus reducing the permeability of the soil [82]. Smith and Fey [83] reported that different concentrations of sodium chloride reduce the permeability of clay soils in landfills.

4. Conclusion

After the clay soil samples were compacted, falling level permeability tests were performed using pure water, ferric chloride, acetic acid, n-heptane and xylene. The results of falling level permeability tests using pure water and chemicals were compared. It was observed that all chemicals increased the permeability values of compacted clay soil samples compared to pure water results. The amount of increase was low in ferric chloride and acetic acid and very high in xylene and n-heptane. The highest permeability value was obtained in the experiments using n-heptane.

Conflict of Interest

The author declares that he has no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

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