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Experimental study of the nanoclays effects on soil permeability reduction to preparing Landfill liners vs leachate

Bagher Jafari[1], Karim Abbasian*,[2]

[1] *School of Engineering - Emerging Technologies, University of Tabriz, Tabriz, Iran*

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ABSTRACT

The present study attempt to investigate the soil permeability behavior in landfill liners, which is very valuable in controlling municipal waste leachate runaway. In this regard, laboratory experiment is conducted on 20 soil samples which are modified with 0%, 3%, 6% and 9% nanoclays, respectively. For this purpose, permeability test are performed for each case of samples with various nanocaly contents and obtained permeability results are compared. The nature of the utilized nanoclay, in this research, is of the mentomorillonite type. According to the results of the study, by increasing the nanoclay percentage from 0 to 9, the soil permeability reduces. The permeability in samples with 0% nanoclay reduces from 3.16×10^{-4} cm/s to 4.09×10-7cm/s by increasing the naniclay percentage up to 9%. This value for acidic conditions made by leachate (pH = 6) is 2.12×10-5 cm/s; which also reduces to 6.22×10-7 cm/s by nanoclay ratio increasing with the same percentage. The obtained resultsrepresents the capability of nanoclays to controlling the municipal waste leachate runaway in landfill liners.

1. Introduction

Leachate is a commonly used term in the environmental sciences, where it has the specific meaning of a liquid that has dissolved or entrained environmentally harmful substances. It is most commonly used in the municipal waste land-filling context, chemical or industrial wastes. Leachate from a landfill varies widely in composition depending on the landfill age and the waste type that it contains (Aziz and Amr, 2015). It usually contains both dissolved and suspended material (Raghab et al., 2013; Brennan et al., 2016; Moody and Townsend, 2017; Tabarsa et al., 2018). The leachate generation is caused principally by precipitation percolating through waste deposited in a landfill. Once in contact with decomposing solid waste, the percolating water becomes contaminated, and if it then flows out of the waste material it is termed leachate (Budihardjo et al., 2012; Salemi et al., 2017; Salemi et al., 2018).The leachate generation risks can be mitigated by properly designed and engineered landfill sites, such as those are constructed on geologically impermeable materials or use impermeable liners as engineered clay or geomembranes (Jeon, 2016; Dolez et al., 2017).In older landfills and those with no membrane between the waste and the underlying geology, leachate is free to leave the waste body and flow directly into the groundwater. In such cases, high concentrations are often found in nearby springs and leachate flushes. As leachate first emerges it can be black in color, anoxic, possibly effervescent, with dissolved and entrained gases. As it becomes oxygenated it tends to turn brown or yellow because of the presence of iron salts in solution and in suspension. It also quickly develops a bacterial flora often comprising substantial growths of Sphaerotilusnatans (Majeed and Taha, 2013; Abbasi et al., 2018; Taghvaei et al., 2018).This phenomenon is environmental breakdown and widespread pollution which poses many dangers to biological ecosystems, animals, humans and plants (Lee and Nikraz, 2011).To prevent such a catastrophic event used the engineering design and leachate collection systems in landfills (Azarafza et al., 2015).

*** Corresponding author.**
E-mail address: k_abbasian@tabrizu.ac.ir
Associate Professor, Academic staff

The primary criterion for leachate systems design is that collecting all leachates and removed from the landfill at a sufficient rate to prevent an unacceptable hydraulic head occurring at any point over the lining system (Aziz and Amr, 2015).There are many collection system components including manholes, liners, pumps, and liquid level monitors. But, liners, filters, pumps and sumps are four main components which govern the system overall efficiency (Bethi and Sonawane, 2018). Liners are main defensive lines for aggregation and isolation of the leachate in landfill body which protect the soil and groundwater below. To effectively serve the containing leachate purpose in landfill, liner systems must possess several of physical properties like durability, strength, maintain integrity and impermeability over the landfill life (Aziz and Amr, 2015). One of the most effective materials used in liners which provide these properties is engineered clay, geosynthetics, and geocomposites were used widely in the work. The engineered clays are the most commonly used because of their cost-effectiveness (Kananizadeh et al., 2011). The presented study is focused on the engineered clay to provide the modified application for improving the performance of the clay particles in the landfill liners. To this end, we attempt to design an experimental study on nanoclays impacts on soils to prepare more efficient liners for leachate controlling in landfills.

2. Material and Methods

Clay minerals are hydrous aluminium phyllosilicates, sometimes with variable amounts of iron, magnesium, alkali metals, alkaline earths, and other cations found on or near some planetary surfaces were common weathering products and low-temperature hydrothermal alteration products. Clay minerals can be classified as 1:1 or 2:1sheets, this originates because of their fundamental building from tetrahedral silicate sheets and octahedral hydroxide sheets, as described in the structure section in following. A 1:1 clay would consist of one tetrahedral sheet and one octahedral sheet, and examples would be kaolinite and serpentine. A 2:1 clay consists of an octahedral sheet sandwiched between two tetrahedral sheets, and examples are talc, vermiculite and montmorillonite. Montmorilloniteis member of smectite group (is 2:1 clay) that it has two tetrahedral silica and central alumina octahedral sheets which is characterized as having greater than 50% octahedral charge; its cation exchange capacity is due to Mg for Al isomorphous substitution in the central alumina sheet. The lower valence cations substitution in such instances leaves the nearby oxygen atoms with a net negative charge that can attract cations. The individual montmorillonite crystals clay are not tightly bound hence water can intervene, causing the clay to swell. The montmorillonite water content is variable and it increases greatly in volume when it absorbs water. This advantage used to prevent the soil permeability behavior and leachate controlling (Bergaya and Lagaly, 2013). The montmorillonite clay used as the main type of the nano-particles part of the survey which is combining on the soil specimens and is classified as CH by the unified soil classification system. The soil specimen's characteristics obtained by particle size distribution (ASTM D6913), hydrometer (ASTM D7928) and Atterberg limits (ASTM D4318) tests in geotechnology laboratory. The aim of conducting these tests providing the knowledge of the physiomechanical behavior of used soils. The permeability test (ASTM D5084) is conducted on all samples to investigate the permeability of samples. The used fluid is municipal waste leachate samples as obtained characteristics were presented in Table 1 which has been tested in both acidic (pH=6) and normal (pH=7) conditions.

Table1 Cations amount in used leachate

Cations	Amount (PPM)	Cations	Amount (PPM)
Mg	1714	Mn	128
Na	16992	Al	89
Ba	1.9	Be	12
Ni	3.6	Li	2.2
Pb	1.3	Sr	52
Ca	5788	Co	1.07
Cr	3.9	Ti	0.12
Cu	0.34	V	1.5
Fe	565	K	7700
Zn	17		

In the main assessment, the 20 samples from the studied soils are taken and prepared the modified compact of the specimens then classified as 4 groups named 'A', 'B','C' and 'D'. These groups contained different amounts of the nanoclays concluded 0% in group 'A', 3% in group 'B',6% in group 'C' and 9% in group 'D'. According to the ASTM standard on permeability test (ASTM D5084) falling head perform on all specimens after preparation as well as five moulds (5×10×2.5 cm) and two porous stone were subjected above and beneath the specimens. The moulds material was stainless steel in order to prevent corrosion. During the test noswelling was allowed to occur. The coefficient of permeability or hydraulic conductivity (*k*) is determined as standard relationship presented in ASTM standard based on h_1-$h_2$heads. The used leachate fluid before testing was filtered by qualitative P5 filter paper (# 5-10 μm) to remove solid particles.

3. Results and Discussions

Figure 1 presents the particle size distribution conducted on studied soil, which was analyzed based on ASTM D6913 and ASTM D7928 standards to investigate the soil characteristics. According to this test, the soil type is ML to MH as unified soil classification system (USCS). The soil contains 30% fine grain and 70% coarse grain that indicate the coarseness of the soil. But fine-grained particles also have a considerable presence in the soil. Sand is a main geo-material with some gravel as coarse part, silt and clay form fine parts in studied samples. The Atterberg limits are conducted to evaluate the plasticity and soil mechanical behavior. The main limits and indexes concluded liquid and plastic limits, liquidity (LI) and plasticity (PI) indexes are estimated based on Casagrande tests. The Atterberg limits tests results are presented in Figs. 2 and 3. According to these figures, the variation of the Atterberg limits indicate that the used soil are mainly inactive based on clay content which create the prone condition for leachate runaway in landfill liners design. Thus, the soil must be improved by using the engineering methodologies like i and geomembranes.

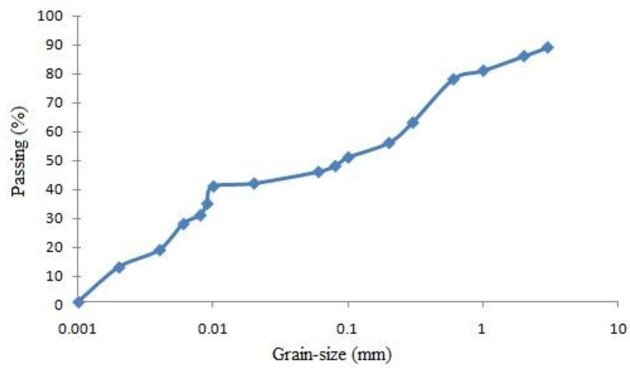

Figure 1. Particle size distributions for studied soil

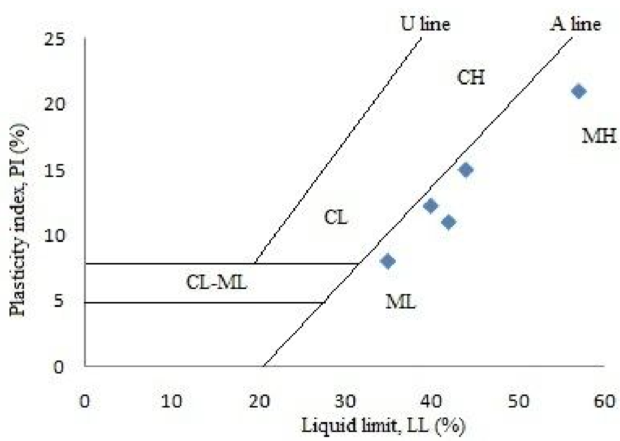

Figure 2. Plasticity chart of studied soil

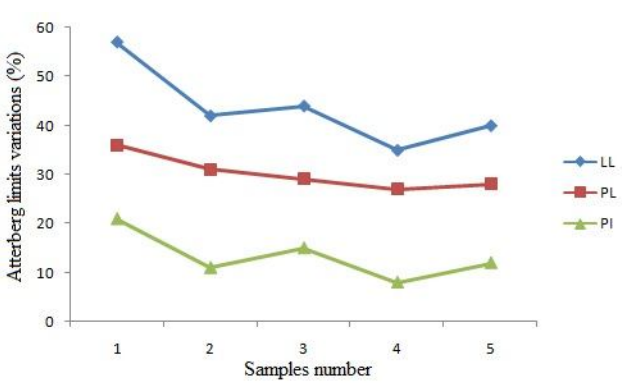

Figure 3. Atterberg limits variations in studied samples

The used samples are saturated in water for a week and prepared for the permeability tests. Each group of samples are named and classified based on nanoclays amounts. The test conducted by waste leachate with different pH (pH=6 and 7) was controlled by pH meter.It should be noted that the pH municipal wastes leachate normally in acidic conditions. Figures 4 to 8 present the Atterberg properties with nanoclays variations. As seen in these figures, the nano-particles impact on the consistency limits which limit plasticity limits increment with nanoclay content increasing. It may be due to increasing composition aspect ratio caused to absorb more water in clay structures. Figure 9 represents the effect of nanoclay content on the permeability in different groups of the specimens with various pH. The permeability tests result in samples with 0% nanoclay from 3.16×10^{-4}cm/s reduced to 4.09×10^{-7}cm/s in samples with 9% nanoclay. This value for acidic conditions provided by leachate (pH = 6) is 2.12×10^{-5}cm/s reduced to 6.22×10^{-7}cm/s which is represented the capability of nanoclays to controlling the municipal waste leachate runaway in landfill liners. As can be seen in this figure decrease in permeability value was in acidic condition is less than normal condition.

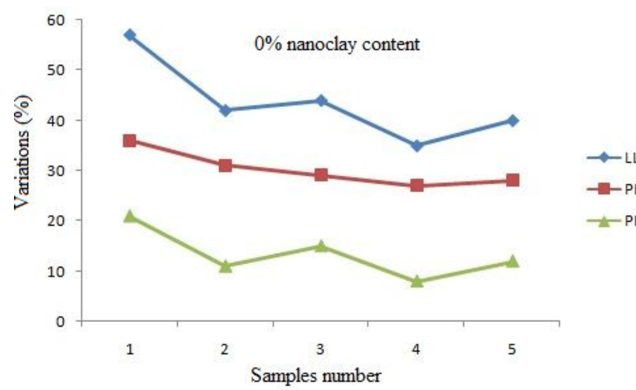

Figure 4. Nanoclays effect on the samples consistency limits (0%)

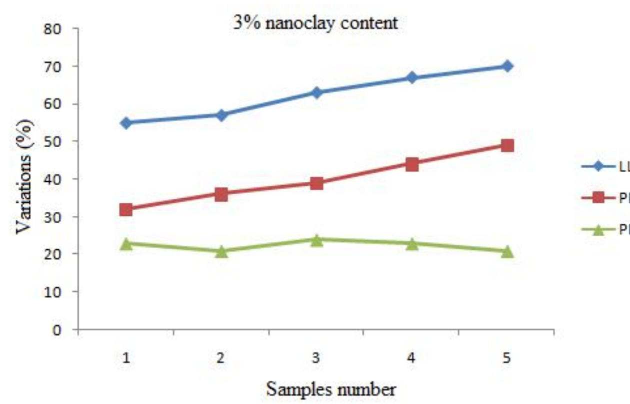

Figure 5. Nanoclays effect on the samples consistency limits (3%)

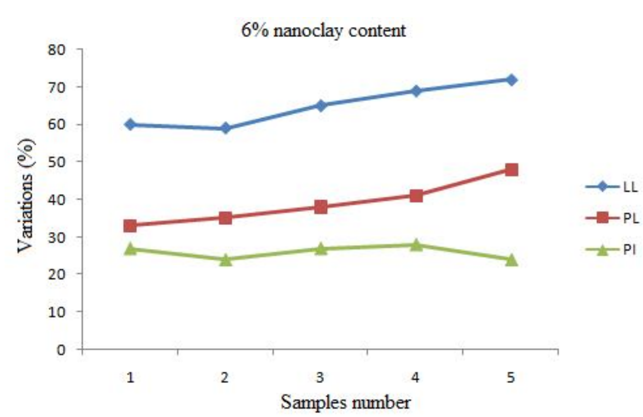

Figure 6. Nanoclays effect on the samples consistency limits (6%)

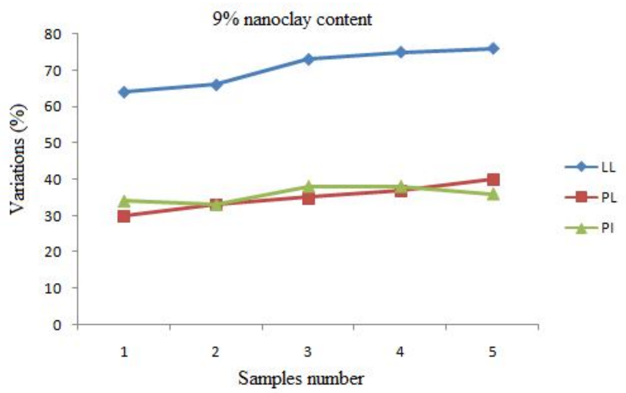

Figure 7. Nanoclays effect on the samples consistency limits (9%)

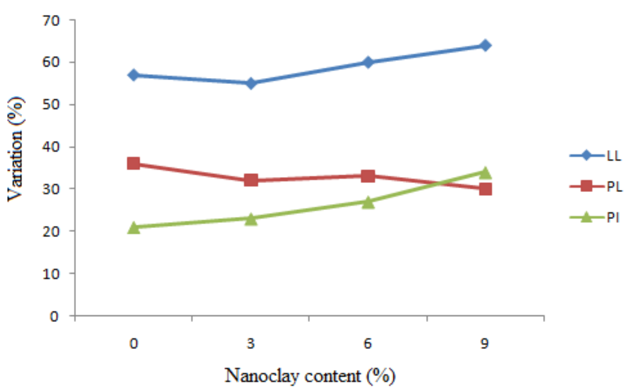

Figure 8. Nanoclays percents on the samples consistency limits

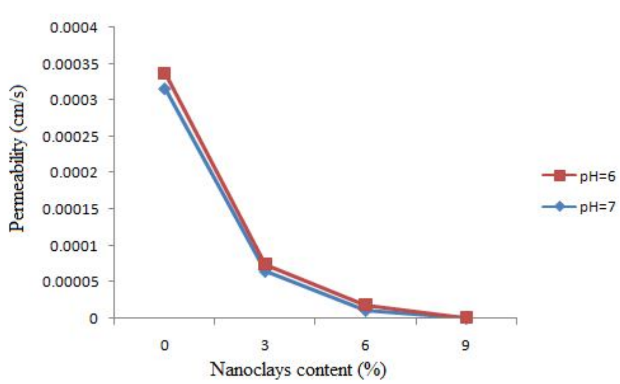

Figure 9. Nanoclay effect on leachate permeability

4. Conclusion

The present study attempts to intestate the effects of adding nanoclay to reducing the leachate permeability in soil samples, which is provided by experimental tests. The main aim of assessment is soil behavior improvement in front of municipal waste leachate runaways, used in landfill liners. To achieve this, laboratory experiments are conducted on 20 soil samples, which are modified with 0%, 3%, 6% and 9% montmorillonite type nanoclay contents classified as CH in USCS. The soil specimen's characteristics obtained by nano-particles size distribution and Atterberg limits tests in geotechnology laboratory. Based on the nanoparticles size distribution test, the soil type can extend from ML to MH, while containing 30% fine grain and 70% coarse grained materials. Atterberg variations indicate that the used soil are mainly inactive based on clay content, however, it create the prone condition for leachate runaway in landfill liners design. Thus, the soil must be improved with engineered clays. The Atterberg results show that the nanoparticles impact on the consistency limits, which liquid plasticity limits increment with nanoclay content increasing. It may be due to increasing composition aspect ratio caused by absorbing more water in clay structures. After preparing the soil specimens with adding the 0%, 3%, 6% and 9% nanoclays, the permeability test conducted by waste leachate with different pH (pH=6 and 7) on the samples. In samples including 0% nanoclay, the permeability results values 3.16×10^{-4}cm/s; which reduces to 4.09×10^{-7}cm/s for samples including 9% nanoclay. This valuefor acidic conditions, provided by leachate (pH = 6), is 2.12×10^{-5}cm/s; whichreduces to 6.22×10^{-7}cm/s with the other same experimental conditions. This improved result demonstrates the capability of nanoclays to controlling the municipal waste leachate runaway in landfill liners. The permeability value reduction in acidic condition is less than normal condition.

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