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Application of nanoclay filter to permeability reduction for bed soil from industrial effluent transmission channels (Case Study)

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ABSTRACT

The presented article is attempted to use the nanoclay filter to provide the natural restrictor to prevent the spread of industrial effluents transmission channels related to Kaveh Soda company in Maragheh, northwest of Iran. For this purpose, a laboratory model has been designed to evaluate the performance ability of nanoclay filters to reduce soil permeability. In the experiment used 0%, 3%, 6% and 9% nanocaly contents specimens to create the filter columns which are performed by permeability test. In this test, the inlet fluid was the factory industrial effluent instead of water. According to the results, it can specified to the permeability coefficient was 3.18×10^{-4} cm/s (0% nanoclays) which decreased to 7.71×10^{-7} (9% nanoclays). This indicates the ability of the nano-filter to significantly reduce the permeability coefficient.

1. Introduction

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. Theses 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 (Bergaya and Lagaly, 2013). Figure 1 is present the clay minerals classification (Wang and Wang, 2019).

Montmorillonite is a very soft phyllosilicate group of clay minerals that form when they precipitate from water solution as microscopic clay. Montmorillonite, a member of the smectite group, is 2:1 clay, meaning that it has two tetrahedral sheets of silica sandwiching a central octahedral sheet of alumina. The particles are plate-shaped with an average diameter around 1 µm and a thickness of 0.96 nm; magnification of about 25,000 times, using an electron microscope, is required to 'see' individual clay particles. Montmorillonite characterized as having greater than 50% octahedral charge; its cation exchange capacity is due to isomorphous substitution of Mg for Al in the central alumina plane. The substitution of lower valence cations in such instances leaves the nearby oxygen atoms with a net negative charge that can attract cations. In contrast, beidellite is smectite with greater than 50% tetrahedral charge originating from isomorphous substitution of Al for Si in the silica sheet. The individual crystals

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of montmorillonite clay are not tightly bound hence water can intervene, causing the clay to swell. The water content of montmorillonite is variable and it increases greatly in volume when it absorbs water. Chemically, it is hydrated sodium calcium aluminium magnesium silicate hydroxide, potassium, iron, and other cations are common substitutes, and the exact ratio of cations varies with source [$(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$.] (Swineford, 2015).

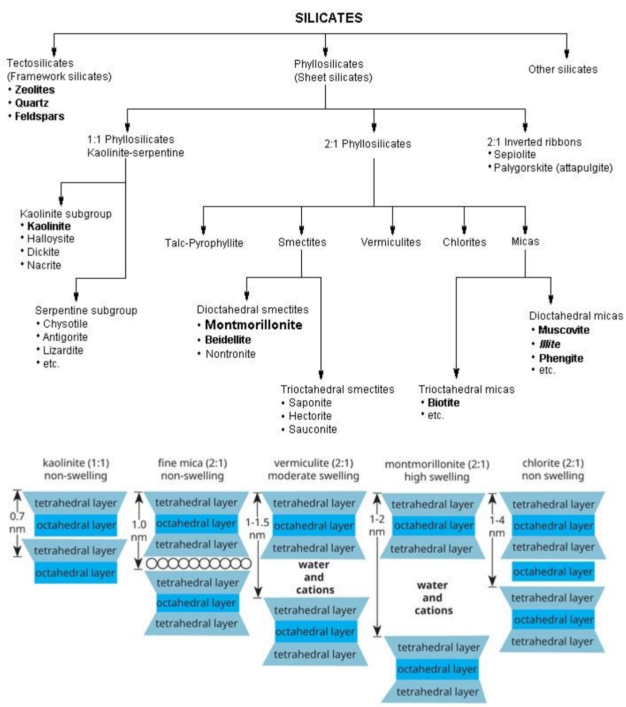

Figure 1. The main structure types of clay minerals (Wang and Wang, 2019)

In nanotechnology application of such these clays is very important to reach positive aims like reducing permeability, controlled swelling, natural restrictions, and natural waterproofing. In this regard, nanoparticles of montmorillonite are used successfully and achieved significant results. Generally, nano-particles of montmorillonite clay used for swelling and reducing permeability in different aspect of environmental or geotechnical engineering based on soil specimens combination were can be classified as CH class by the unified soil classification system (USCS). The USCS is a soil classification system used in geo-engineering to describe the texture and grain size of a soil. The classification system can be applied to most unconsolidated materials, and is represented by a two-letter symbol which each letter is described as gravel (G), sand (S), silt (M), clay (C), organic (O) as first symbol and poorly graded for uniform particle sizes (P), well-graded for diversified particle sizes (W), high plasticity (H), low plasticity (L) as second symbol. If the soil has 5-12% by weight of fines passing a #200 sieve ($5\% < P_{\#200} < 12\%$), both grain size distribution and plasticity have a significant effect on the engineering properties of the soil, and dual notation may be used for the group symbol. For example, GW-GM corresponds to 'well-graded gravel with silt'. If the soil has more than 15% by weight retained on a #4 sieve ($R_{\#4} > 15\%$), there is a significant amount of gravel, and the suffix 'with gravel' may be added to the group name, but the group symbol does not change. For example, SP-SM could refer to 'poorly graded sand with silt' or 'poorly graded sand with silt and gravel'. The USCS used standard charts to prepare the description of soils (Budhu, 2010). However, the CH is class of clay materials with high plasticity which is used to create a mixed environment with low permeability and high plasticity that can act as a natural limiter in contact with water. Utilize this capability in nano-scale can be used as an ability to controlling the soil permeability. For example, leachate control, environmental restrictor, landfill liner design, etc. (Azarafza et al., 2015; Bethi and Sonawane, 2018; Abbasi et al., 2018). The presented study used the nano-scale montmorillonite clay to prepare the natural restrictor to prevent the spread of industrial effluents transmission channels related to Kaveh Soda Company in Maragheh. In this regard, the experimental test was design for evaluate the capability of modified soil column with different amount of nonoparticles (nanoclays) to achieve minimum permeability for the filter.

2. Material and Methods

The presented study attempted to design the natural filter based on nanoclays to prevent the industrial effluents transmission channels related to Kaveh Soda Company in Maragheh. Kaveh Soda Company has started its appearance by glassware production back in 1984 which the group has done much advancement such as establishing Iran float factory to produce glass and mirror in 1991. It is valuable to state that the latest technologies have been applied to produce float glass which is processed through floating molten glass on the surface of molten tin. The industrial water outlet of this factory has created the most important environmental concerns for the region during the past years. Figure 2 present the view of the Kaveh industrial effluents transmission channel in Maragheh. The Maragheh city is the ancient city and capital of Maragheh County, East Azerbaijan Province, Iran. The city is situated in a narrow valley running nearly north and south at the eastern extremity of a well-cultivated plain opening towards Lake Urmia, the world's sixth-largest saltwater lake, which lies 30 km to the west. The town is encompassed by a high wall ruined in many places, and has four gates.

Figure 2. The view of the Kaveh industrial effluents transmission channel

The presented article tried to build 5 series of soil columns mixed with nanoclay based on soil samples taken from the area of industrial effluent transfer canal related to the Kaveh Soda Company. For this purpose, first by performing routine geotechnical experiments such as particle size distribution (ASTM D6913), hydrometer (ASTM D7928) and Atterberg limits (ASTM D4318) tests. Then used the permeability tests (ASTM D5084) to evaluate the permeability coefficient (k) to all specimens. It should be noted that in permeability tests, factory effluent was used instead of water, which was obtained by sampling. Figure 3 is illustrated the sewage sampling steps.

Figure 3. The view of sewage sampling from factory effluent

After sampling of soil and industrial effluent of the factory, soil samples have been transferred to the laboratory for geotechnical and permeation tests. The soil sample was first divided into two parts, the first part was used for Atterberg limits, particle size distribution and hydrometery. The second part is used for permeability testing and preparation of filters. In order to accurately mix nanoclay materials with clay materials of the study area an ultrasonic stirrer is used. The reason for using such a device has been to increase the mixing and homogenization accuracy of nanoclay filters. It should be noted that the clay nanomaterials are made of montmorillonite and mixed in a mixer for 30 minutes, such a time is considered experimentally suitable for implementing the work and creating a homogeneous mixture.

3. Results and Discussions

The most important role of clay filters in controlling biological or non-biological elements that are pollutants in the environment which it can be expressed. This issue has always caused the behaviors related to clay filters to be considered by environmentalists and engineers. In clay filters, soil is usually used with some additives to improve some of the properties of the soil; it causes changes in mechanical behavior as well as soil stress-strain relationships, which in turn affects the strength and structure of the soil. In clay filters, due to the fact that the soil is compacted in layers and is usually used as a compact, in this case, the prominent feature for the soil is the permeability coefficient, which is the most important factor in estimating soil permeability were considered. For this purpose, various approaches to estimate soil permeability are considered, of which laboratory methods are the most important. In the present study, direct permeability test by drop load method and audiometric test were performed during 4 repetition stages in order to prepare an improved clay filter with clay nanomaterials (0%, 3%, 6% and 9%). In this regard, the taken soil samples are classified in two groups. The first group used for geotechnical test concluded particle size distribution (ASTM D6913), hydrometer (ASTM D7928) and Atterberg limits (ASTM D4318) tests. The second group was used for permeability tests for nanoclay filters. According to the USCS, the site soil is medium to fine-grained soils of ML and MH. Figs. 4 and 5 are presented the results of the particle size distribution and Atterberg limits tests. As can be seen in these Figs, particle size distribution and hydrometer tests have been implemented to prepare the granulation diagram of the studied soil materials. Liquid limit (LL), plastic limit (PL), plasticity index (PI) has been done. Atterberg test results indicate the presence of fine to high (ML-MH) fine-grained soils. Figure 6 shows the variation in Atterberg boundaries for the studied soil.

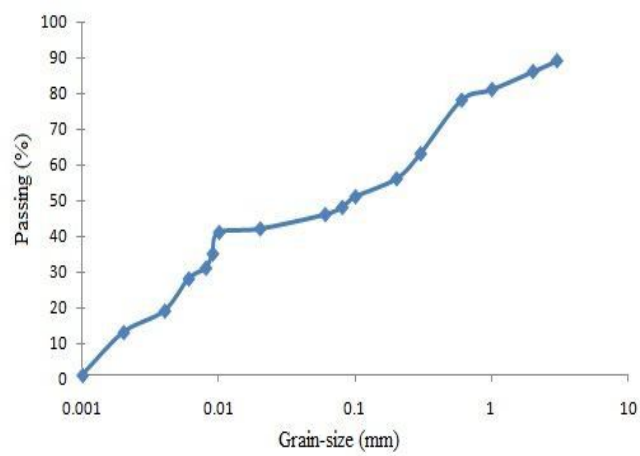

Figure 4. The results of the particle size distribution test for studied soil

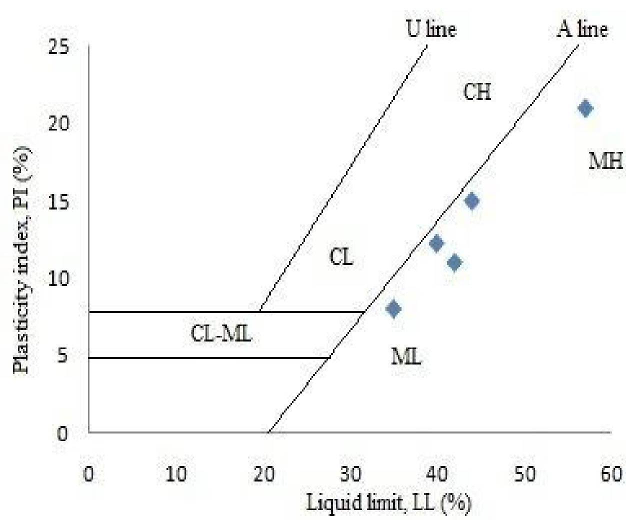

Figure 5. The results of the Atterberg limits test for studied soil

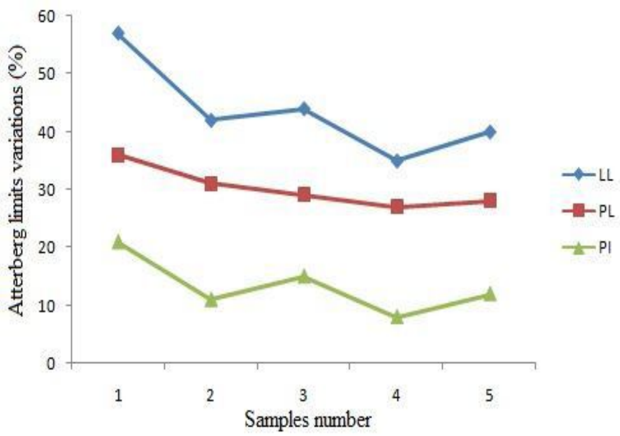

Figure 6. The variation of Atterberg limits for studied soil

In order to achieve the permeability status of the studied soil sample, permeability test for soil without nanoclay additives was performed to evaluate the effect of clay nanoparticles on this important property as a function of the purpose of this study. This test considered as 'basic mode' and industrial effluent has been used as a fluid instead of water. The first part of the water sample/basic column of soil (0% nanoclay) is considered as input in permeability tests, which has been calculated for different porosity ratios during 3 tests. Based on the averaging of the obtained results, the studied soil sample has 3.18×10^{-4} cm/sec permeability coefficient. In order to evaluate and implement the nanoclay filter, 4 stages of making the filter cylinder from the tested soil by mixing 3%, 6% and 9% nanomaterials containing montmorillonite clay have been used. These cylinders have been used to evaluate the properties of the paste as well as the permeability. The Atterberg test has been used to calculate the paste changes. Figs. 7 to 9 show the results related to the changes of pulp indices in terms of the percentage of nanoclay increase in the soil. Fig. 10 also shows the general changes of materials in terms of the amount of clay nanomaterial additive. As can be seen in this figure, the PI and LL indices increase and PL shows a decreasing trend.

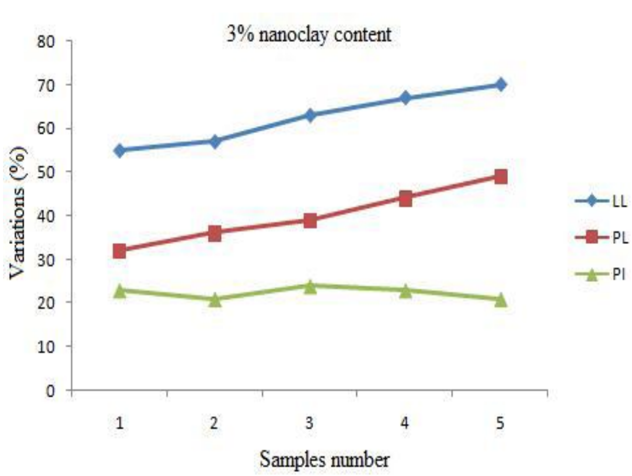

Figure 7. Variation of plasticity indices by 3% nanoclay

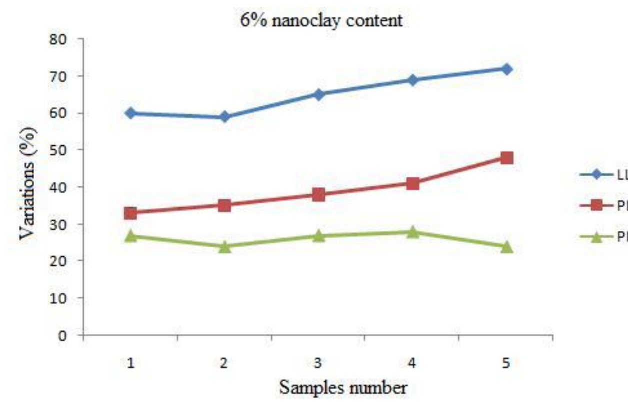

Figure 8. Variation of plasticity indices by 6% nanoclay

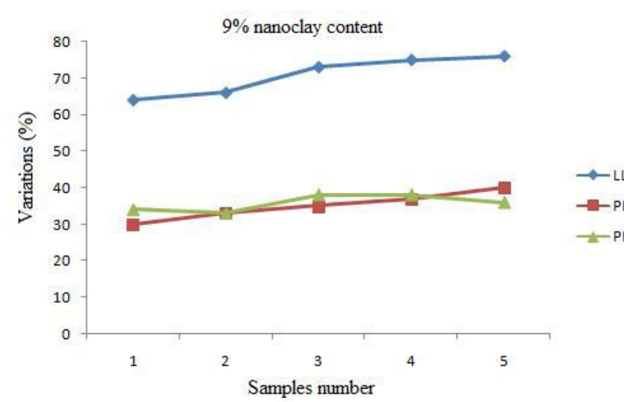

Figure 9. The variation of plasticity indices by 9% nanoclay

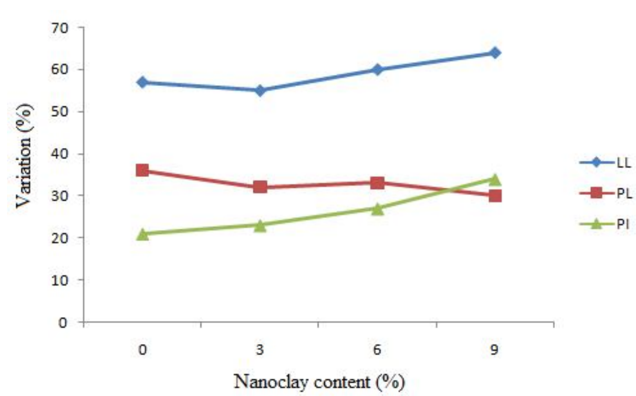

Figure 10. The variation of Atterberg limits for studied soil

In order to evaluate the permeability properties of the soil improved by different percentages of clay nanomaterials, 4 stages of permeability testing with drop load have been performed, each stage with a specific percentage of nanoclay has been prepared and tested. Figure 11 results demonstrated the permeability changes by nanoclay additives for two series of tests with pH 6 and 7. As can be seen, with increasing the percentage of nanoclay from 0% to 9%, the permeability rate has decreased significantly.

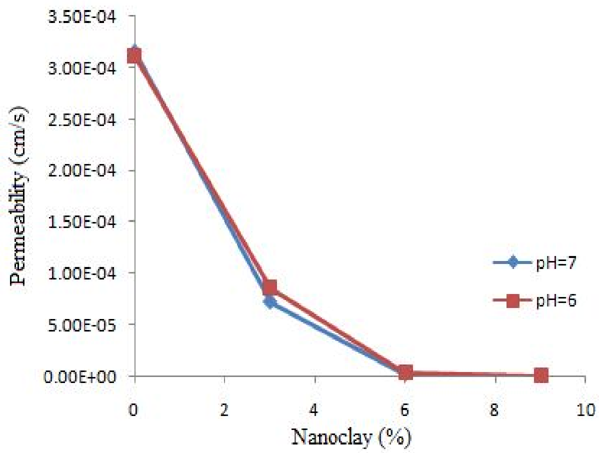

Figure 11. Permeability for samples with different percentages of nanoclay

As shown in this figure, the permeability of the studied soil can be improved by adding clay nanomaterials up to 7.71×10^{-7}. This permeability coefficient is very low and has the ability to control and inhibit the passage of water significantly. It is expected that with the implementation of such clay filters, the rate of industrial wastewater development of Kaveh Soda Company will be significantly reduced and clay filters can play a good role in limiting the spread of pollutants.

4. Conclusion

The present study is a laboratory evaluation to assess the feasibility of the ability of nanomaterials, especially nanowires (due to their high adsorption and their success in reducing the spread of heavy metals and their isolation) in the filtration of industrial water related to the pond. Kaveh Soda Glass manufacturing company has been implemented. In this regard, first by designing the physical model of a distillation column and filter profile for the clay layer containing 3%, 6% and 9% nanoclay which the model is structurally evaluated. In this regard, the taken soil samples are classified in two groups. The first group used for geotechnical test concluded particle size distribution, hydrometer and Atterberg limits tests. The second group was used for permeability tests for nanoclay filters. As first group evlautions, the PI and LL indices increase and PL shows a decreasing trend. In order to evaluate the permeability properties of the soil improved by different percentages of clay nanomaterials including 0%, 3%, 6% and 9% during 4 stages of permeability test with drop load, which was averaged by the results of indirect audiometric test; It has been done that each step has been prepared and tested with a certain percentage of nanocells. Based on the results, the permeability of the soils of the study area was 3.18×10^{-4} cm/s (0% clay nanomaterials) in the base condition, which decreased to 7.71×10^{-7} in 9% of montmorillonite clay nanomaterials. This indicates the ability of the nanofilter to significantly reduce the permeability coefficient.

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