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Effect of Crude Oil Spill on Geotechnical Properties of Silty Sand Soil by Using Taguchi Method

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ABSTRACT

To investigate the effects of crude oil leakage on silty sand soil, a functional device was set up; it is highly similar to column test. Some factors were altered during tests such as time leakage, porosity, and water content. Direct shear and permeability tests have been also done on contaminated soil and the curves of tests results were extracted by Taguchi method and Minitab software. This method could present the effects of each factor on internal friction angle, cohesion and permeability separately. Results indicate that by increasing the time leakage, shear strength parameters raised while permeability considerably reduced. Furthermore, with increase in porosity of soil samples, the values of shear parameters were decreased while permeability was increased. The only factor which has brought a positive impact to shear strength parameters is water content; because this factor has fallen permeability and improved the shear parameters. Taguchi method is the most effective method to investigate the behavior of contaminated soil, which can be used in other related studies.

Keywords:

Crude oil, Contaminated soil, Permeability, Shear strength, Taguchi design method.

1. Introduction

Soil contamination has been considered as a controversial issue in most countries. This contamination has threatened the human life through the deepest place of the world (miners, oceans and underground water) to the biosphere and troposphere. Undoubtedly, the hydrocarbon contaminations remarkably affect the engineering properties of soils (such as, soil compressive strength, settlements, compressibility, permeability and etc.) and also disturb the physical characteristics of them. Consequently, it can cause major geotechnical drawbacks related to the existing structures and their foundations built on oil-contaminated sites for instance, tunnels, bridges, roads and buildings. During the last decades, the usage of fossil fuel has dramatically increased and its transfer has brought wide range of issues. The considerable problem it has caused is environmental issues. During the leakage, the oil passes through the soil pore space and it can gradually make saturated soil; although, the degree of saturation depends on the time and discharge of leakage. Also, the capillarity force causes to extend the oil in horizontal direction. Recently, more investigations have been carried out on the soil contamination and a lot of efforts Such as, stabilization with chemical materials, biological methods, soil washing, vacuum extraction and separation methods have been done to improve these sorts of soils. This study has been done on soil properties which are affected by oil sludge; also, the long-term effect of oil on soil characteristic has been studied. In some studies, contaminated soil is used to investigate [1-2] whereas; there are studies in which uncontaminated soils are artificially polluted in laboratory [3-4]. In author's opinion, contaminated soil has not got similar properties in all soil samples which are sampled from local places; thus, it can dramatically reduce test accuracy. In this article, uncontaminated soil is examined in soil laboratory with special method which is completely discussed. In addition, there are various oil derivatives which are essential to examine the effect of these oils on soil sample. Reduction of electrolyte concentration, cation exchange from high to low concentrations, cation exchange of cation with a small radius to a large one, increase in dielectric constant of cavity fluid and etc. can cause the strength of soil reduce. The effect of oil contamination on three different soils has been investigated by Khamehchiyan et al. [2]. By increasing the contamination amount in soil, the optimum moisture and maximum dry density of the soil reduces; and also, raising the contamination amount in SM and SP specimens cause to decrease the permeability value, uniaxial compressive strength and friction angle. But it does not have any changes in soil cohesion. The effect of the crude oil contamination on the remaining soil of the two residual soils has been examined by the Rahman et al. [5]. The results of this study present that adding petroleum products to two different soils have sought the reduction of the Atterberg Limits and the soil compaction parameters; they have also led to the decline of undrained shear strength in unconsolidated condition. Khosravi et al. studied about the effects of the gasoline on kaolinitic soils [6]. Results indicate that increasing the gasoline content in Kaolinitic soli has brought remarkable rise in the amount of cohesion and considerable drop in the amount of friction angle and compressibility. Shin and Das investigated the bearing capacity of contaminated sand in non-saturated state [3]. According to authors, the viscosity of the fluid increases the bearing capacity whereas increasing in the moisture of the specimens causes to decrease the bearing capacity. And also, the effect of the engine oil on the geotechnical properties of the soil has been investigated by Nazir [7]. The permeability coefficient has noticeably climbed with the rise of oil content while it has a marginal effect on over-consolidation ratio. The results of the study by Kermani and Ebadi's indicate a substantial increment in the amount of internal friction, maximum dry density, compression index and Atterberg limits as well as a significant decrement in the amount of optimum water content and cohesion with the raising of oil content [8]. The effects of oil contamination on the mechanical properties of soil have been investigated by Akinwumi et al. [9] and Rahman et al. [10]. The results of these three studies prove that the liquid limit, plastic limit and plasticity index of the soil have climbed with the increment of oil content whereas it has caused to drop in the amount of specific gravity, optimum moisture content, maximum dry unit weight, CBR and permeability of the soil. The extensive laboratory tests have been done to improve the characteristics of clay samples mixed with gasoil. The Response surface Methodology (RSM) is used to analyze the data and behavioral equations. According to these results and RSM outputs, decreasing in Atterberg limits and increasing in maximum dry density are the results of oil content rise. Although the shear strength parameters have experienced turning point at 8% gasoil content, their variation trends are completely in opposite direction [11]. All in all, the results present that the increasing of oil content has brought negative effect on the geotechnical properties of the residual soil. In addition, some of the oil contamination removals have been proposed by Singh et al. [12]. Oil and heavy metals contamination alter the soil properties dramatically [13]. In this study, lots of efforts have been done to examine the effect of crude oil on the mechanical and resistance properties of Tabriz Refinery's soil. The effect of crude oil leaking has been considered and studied with special method which has not been examined in the past studies. The laboratory tests include: Atterberg limits, compaction, Permeability, direct shear test. Taguchi's design of experiment method, whose efficiency has been revealed in issues and related to crude oil in contaminated soils, was used to investigate the effect of crude oil leaking in silty sand soil. Taguchi's methods, a statistical method or sometimes called a robust design method, developed by Genichi Taguchi to improve the quality of manufactured goods, and it has recently been used in engineering problems too [14-15].

Taguchi's designs use orthogonal arrays, which estimate the effects of factors on the response mean and variation. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can independently assess all other factors, so the effect of one factor does not affect the estimation of different factors. This can reduce the time and cost associated with the experiment when fractionated designs are used. We can also add a signal factor to Taguchi's design in order to create a dynamic response experiment. A dynamic response experiment is used to improve the functional relationship between a signal and an output response. Minitab calculates response tables, linear model results, and generates main effects and interaction plots for:

- signal-to-noise ratios (S/N ratios, which provide a measure of robustness) vs. the control factors
- means (static design) or slopes (Taguchi dynamic design) vs. the control factors
- standard deviations vs. the control factors
- natural log of the standard deviations vs. the control factors

Use the results and plots to determine what factors and interactions are important and assess how they affect responses [16-17].

An analysis of the signal-to-noise (S/N) ratio is used to evaluate the experimental results. Three types of S/N ratio analysis are applicable: (1) Lower is Better, (2) Nominal is Better and (3) Larger is Better. The Larger is better analysis is selected when goal is to maximize the response. The S/N ratio is calculated in Eq. (1) for larger the better analysis. Generally, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). A noise factor refers to a measurable product or process characteristic to deviate from its target value.

$$S/N = -10 \times \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{\,2}\right) \qquad (1)$$

Where n is the number of repetitions under the same experimental conditions and the parameter y shows the measured value of each response.

2. Materials and Methods

2.1. Soil and crude oil characteristics of Tabriz refinery

The sampling from soil should be done in the depth which is homologous and uniform; actually, soil should not be humus and debris. Moreover, it is essential to know crude oil pipe are buried in what depth, sampling is better to extract and examine from this depth of soil. Therefore, to satisfy these conditions, samplings have been done in 2 to 3 meters of the soil. The physical properties of the soil have examined with accuracy such as, the plasticity index, the specific gravity, the optimal moisture content and the maximum dry density. The amounts of these properties and their standards have been shown in Table 1 and the particle size distribution curve is displayed in Figure 1. The crude oil, which is used in this study, has been provided from Tabriz refinery with the following specifications (Table 2).

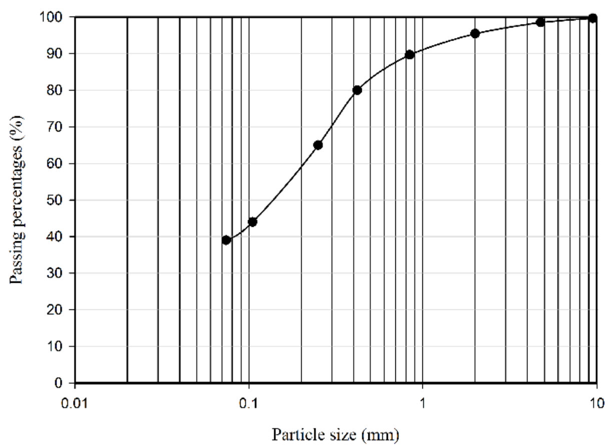

Figure 1. Particle size distribution curve of the soil.

Table 1. Engineering properties of silty sand soil.

Soil Characteristics	Standard	Description
Liquid limit (%)	ASTM D4318	Non plastic
Plastic limit (%)	ASTM D4318	Non plastic
Plasticity index	ASTM D4318	-
Specific gravity	ASTM D854	2.61
Maximum dry density(g/cm^3)	ASTM D698	1.84
Optimum moisture content (%)	ASTM D698	13.6
pH	ASTM D4972	7.1
Natural moisture content (%)	ASTM D2216	5.6
Silt and clay	ASTM D422	39%
Sand	ASTM D422	55%
Gravel	ASTM D422	6%
USCS classification	ASTM D2487	SM

Table 2. The specification of Tabriz refinery crude oil

specification	magnitude
Viscosity (gm−1 s−1)	41.2
Density (g/cm3 at 25◦C)	0.895
API gravity (at 60◦F)	26.8
Flash point (◦C)	44.2
Specific gravity (at 25◦C)	0.89

2.2. Experiment procedure

First of all, in order to have homogeneous soil, extracted soil samples have been put in oven under 105 C; in addition, they were struck by plastic hummer to separate the attached piece of soil. Then, in order to separate the major part of coarse soil which can stuck in the pipe of oil leaking and cease the process of permeating, all soil samples were passed through the sieve no.4. To contaminate soil with the leaking of crude oil, a device has been designed which is shown in Figure 2. Indeed, crude oil through the two upper tanks with constant flow rate, controlled by float, was conducted to cylindrical specimen and after passing crude oil through the soil particles, it was poured to final tanks. One noticeable point is passing crude oil from the bottom of the cylindrical pipe which included soil samples. There is one logical reason which can justify the direction of crude oil leaking in the soil sample. On the one hand, if the direction of leaking is from down to up, after a short time (approximately 24 hours), soil sample will be saturated; therefore, soil sample can be examined in critical condition. On the other hand, if the direction of leaking is from up to down, the flow path of crude oil will be constant in the soil sample; actually, the fluid does not try to pass from other ways, especially in low flow rate. Thus, it will take so much time to reach saturated condition; even there is strong possibility to never reach saturated condition and no chance to examine critical condition which is necessary in engineering project. In order to compare the effect of leaking direction, the study have been done in both directions, up to down and down to up. It is obvious, soil sample has not been saturated by crude oil during the test. The effect of other fluids leaking by time passing on characteristics of porous media (i.e. permeability, coarse swelling and the rate of porosity) can be simulated with this device. The pipe in which soil sample is placed has 30 Cm length and 9 cm inner diameter. Two justifiable reasons to choose these dimensions are extracting undistributed soil sample to examine and simulate one-dimension soil to control and restrict the path of leaking. In order to, extract undistributed soil sample, pipe has been cut through the middle of it and, after placing samples in the pipe, these two halves have been stuck to each other and then have been insulated by strong sticky substances. After crude oil leaking, the pipe has been separated from the stuck place and then undistributed soil samples have been extracted carefully. Since soil is silty sand, it is necessary to have abundant accuracy.

The Taguchi design of experiment method was used to investigate the effect of crude oil leaking in soil. Three factors of Fluid flow time (hrs), soil void ratio and Initial water content (%) at three levels were considered to evaluate their effects on the direct shear test parameters and permeability of contaminated soil. These are control factors with a range of settings which is controlled by the user during utilization. In Table 4, the values of the most important factors in the tests are reported.

The suggested design by Taguchi method for three factors at three levels is L9 (3^3) array in accordance with Table 4. The notation L9 (3^3) indicates the following:

L9 = number of runs

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(3 ^ 3) = number of levels for each factor ^ number of factors

Table 5 gives nine experiments program obtained by Taguchi method using Minitab software. The columns of arrays are balanced and orthogonal. This means that in each pair of columns, all factor combinations occur the same number of times. Table 6 shows the parameters of the total nine proposed experiments.

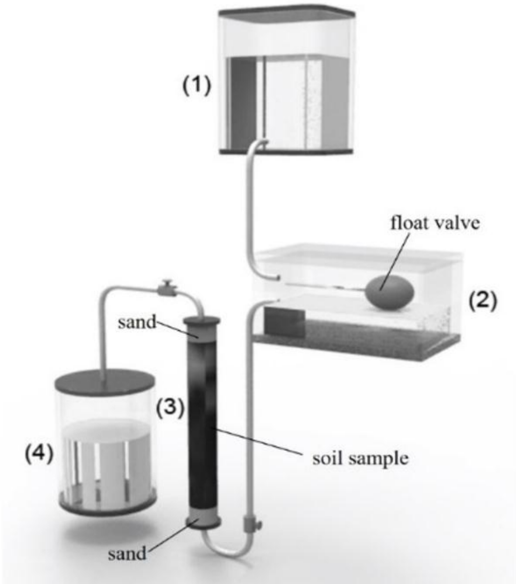

Figure 2. Schematic picture of the oil spill set.

Table 3. Factors and their levels considered in the experiment design.

Factors	Level 1	Level 2	Level 3
Fluid flow time (H)	100	200	300
soil void ratio (E)	0.3	0.4	0.5
Initial water content (W)	3	6	9

Table 4. L9 (3^3) array proposed by Taguchi method.

Experiment series	Parameter1	Parameter2	Parameter3
	Levels		
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

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Table 5. Parameters of the nine proposed experiments.

Experiment series	Sample designation	Fluid flow time (H)	soil void ratio (E)	Initial water content (W)
1	T1	100	0.3	3
2	T2	100	0.4	6
3	T3	100	0.5	9
4	T4	200	0.3	6
5	T5	200	0.4	9
6	T6	200	0.5	3
7	T7	300	0.3	9
8	T8	300	0.4	3
9	T9	300	0.5	6

3. Results and Discussion

In a Taguchi designed experiment, noise factors are manipulated to force variability to occur and from the results, identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize the effects of the noise factors. After the experiment is performed and the data are collected, they are entered into the worksheet. The measured characteristic is called a response. Then, with the appropriate settings, software does analysis based on equation (1) and gives the graphs which are discussed. In each section. Results are provided in two sections which include direct shear and permeability test. In every section, the effects of mentioned factors on the trend of shear strength and permeability have been investigated.

3.1. The results of direct shear test

The effects of various factors on the internal friction angle and cohesion in contaminated soil with crude oil are examined completely which are presented in figures 3 and 4. Overall, it is obvious that adding crude oil to soil causes the reduction of shear strength parameter but main aim of this study is recognizing the most effective factor and the maximum value of parameters and examining the level of soil risk in future projects and structures. In reality, it is possible that contaminated soil does not cause harmful and significant drawbacks to different structures.

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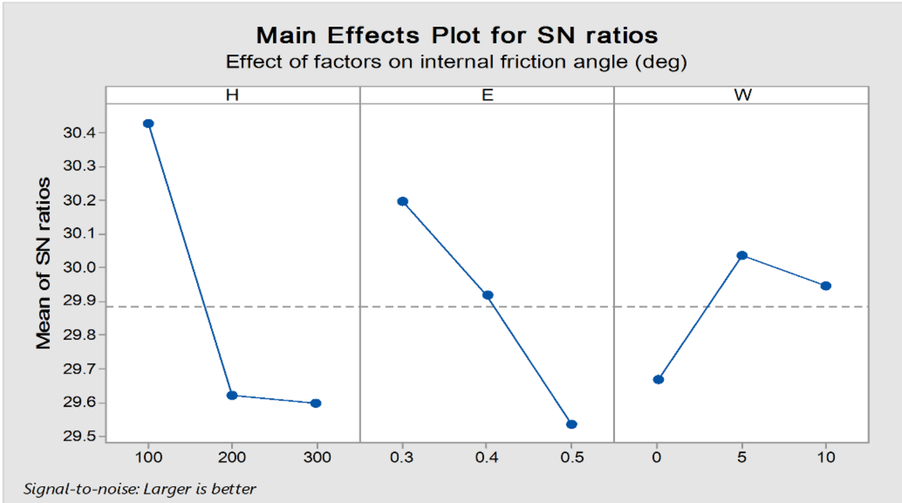

Figure 3. The Comparison of the effects of three factors on internal friction angle. Part H: indicates the leaking time (hr), part E: shows the initial porosity of soil and part W: shows the water content related to soil.

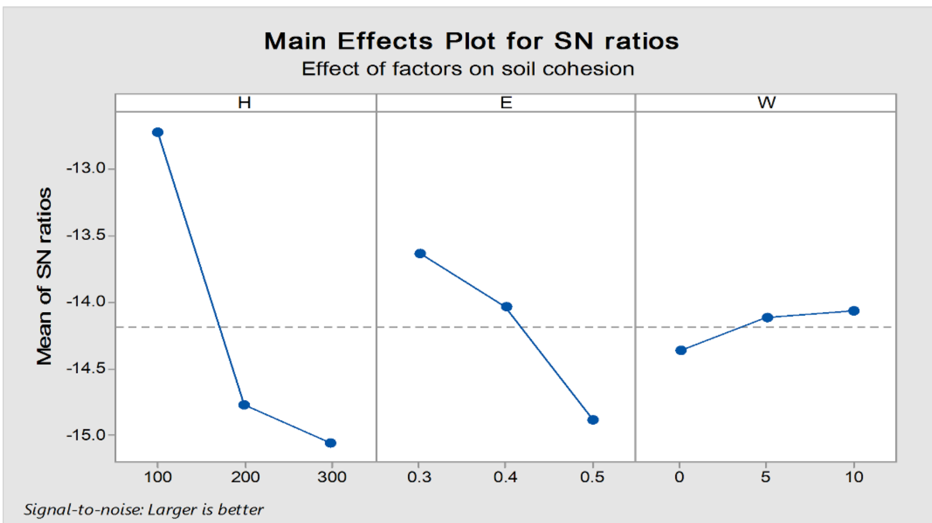

Figure 4. The Comparison of the effects of three factors on soil cohesion. Part H: indicates the leaking time (hr), part E: shows the initial porosity of soil and part W: shows the water content related to soil.

3.1.1. The effect of factors on internal friction angle

Figure 5 shows the internal friction angle of the samples. As it is shown in this figure, sample T1 and sample T6 had the highest and the lowest amount. The impact of three factors which include leaking time, porosity and water content has been shown separately in the Figure 3. As it is clear, with the increasing of leaking time from 100 to 200 hours, the value of internal friction angel has significantly decreased. As it is obvious, the alterations of this reduction have declined and reached to constant value after 300 hours. The main reason of this phenomenon is the lubrication of soil particles by the means of crude oil which can lead to slide the soil particles on each other easily [18]. As it is presented in figure 3, until 200 hours the lubrication of soil particles has been done almost completely and after that, crude oil leaking has not had considerable effect on the amount

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of internal friction angel. All direct shear tests of past studies on grain soil prove these alterations [19-2]. In the studies using sticky soils, it has been observed that the amount of internal friction angel has grown with the increase of crude oil value. When clay soils are contaminated, by permeating uncontaminated soil specimens with contaminants, a reduction in dielectric constant of pore fluid reduces the physicochemical interaction in the clay pore fluid electrolyte system, and hence, it should be resulted in a higher strength [20]. The alterations of internal friction angel with the increase of empty space between soil particles are presented in the section 2 of Figure 3. This figure shows that with the increase of porosity the internal friction angel of soil decreased. This argument is true for uncontaminated soil; undoubtedly, adding crude oil to soil significantly helps to reduce the internal friction angle more by lubricating soil particles. In general, increasing water content in the soil causes the reduction of internal friction angel by lubricating; although, as it is showed in the above curve, increasing the water content until 5% has reduced the internal friction angel and then rising the water content until 10% has declined its amount. The descending section of the curve seems more logical but one compelling reason to justify the initial increase in the first part is the lower viscosity of water in comparison with crude oil. Therefore, replacing crude oil by water leads to climb the amount of internal friction angel. By raising the water content, empty space increases between soil particle and thus, internal friction angel remarkably falls.

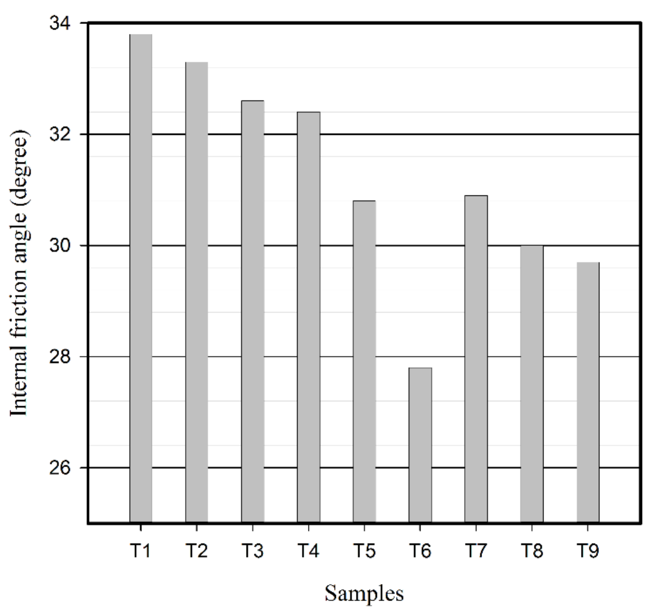

Figure 5. Internal friction angle of different mixtures

3.1.2. The effect of factors on cohesion

Figure 6 illustrates the cohesion of mixtures. Sample T1 provided the highest strength. The lowest strength was obtained by T6. In this study, investigated soil is silty sand which contains negligible clay. Indeed, this little amount of clay causes remarkable cohesion in soil. On the other hand, crude oil has a complicated compound in which everyone has a special role to conduct the reaction with soil. These compounds include the heavy hydrocarbons. One of the distilled fuels which have a 150 centigrade until 385 centigrade distilled domain and has an appropriate function in domestic and industrial torch and diesel fuel engines is named hydrocarbon. Heavy Hydrocarbons contain organic compounds mainly built with C and H. In these molecules, the bonds between hydrogen and carbon are the kind of covalent bond. Atoms containing sulfur (S), nitrogen (N) and Oxygen (O) are usually in the form of carbon substitution in the hydrocarbons. The increase of sulfur (S) value in hydrocarbon compounds leads to alter in the physical behavior and makes corrosion condition. As compounds become heavier, the purifying procedure becomes harder. Moreover, as the numbers of substitution ingredients become lower in hydrocarbons, crude oil becomes lighter and purer [21]. The existence hydrocarbons in crude oil, due to higher density in comparison with other crude oil compound, gradually sediment in the soil texture and because of higher viscosity reduce the cohesion of compound. As it is obvious in Figure 4, by increasing of crude oil leaking, cohesion slightly decreased. Porosity rising causes the reduction of cohesion because of increasing the empty spaces of soil particles. This procedure is showed in the second curve. With comparing the water and crude oil viscosity, it is concluded that as the crude oil content reduced and water content increased, the amount of cohesion considerably improved. On the other hand, water can separately cause the fall in the cohesion of grained soil, however it can lead to additive impact on cohesive soil. As it is presented in the third curve, the slope of these curves is very slow and it is extracted that water content has not got any significant effect on the amount of soil cohesion.

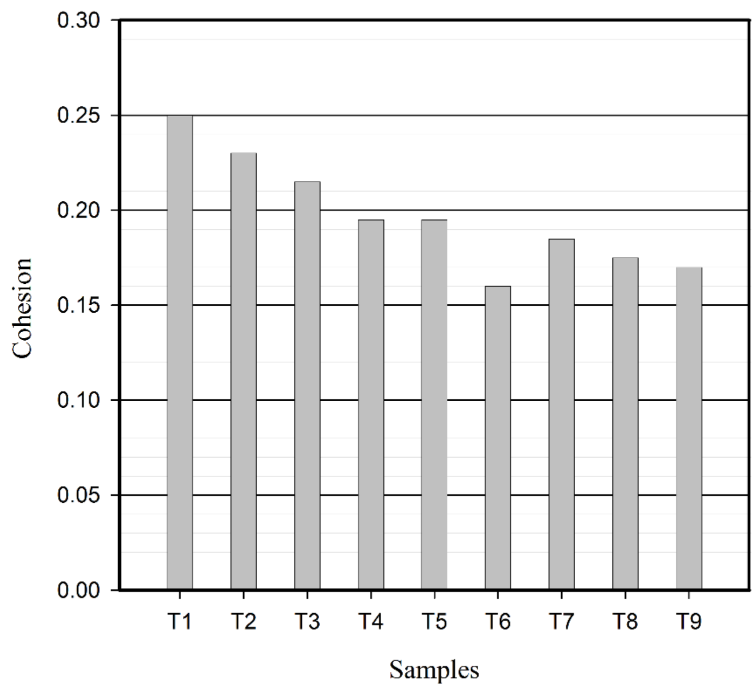

Figure 6. Cohesion of different mixtures.

3.2. The results of permeability test

The permeability test with constant head is carried out by the special device designed by other authors and its mix designs are mentioned in Table 6. As it is presented, although the general permeability test is conducted by passing water through soil samples, in this study crude oil is used to cross among soil particles. The permeability test results are shown in Figure 7. As illustrated in this figure, Sample T3 provided the highest permeability. As it is clear, with passing water through the soil particles, the soil permeability has gradually decreased and finally it has attained a constant value. In the past study of the recent years, it has been observed that the permeability of contaminated soil and its derivatives, slightly reduces by raising oil content. In reality, in refineries surroundings, the leaking of oil pollutants is possible; therefore, it is essential to examine the effect of crude oil on the soils of these environments. In the following, the results of three factors have been investigated separately. As it is mentioned in the first part of Figure 8, with time elapsing, the permeability of soil samples noticeably declines. By increasing time passing from 200 hours to 300 hours, the decrement process of permeability has become gentle; indeed, the alteration of decrease gradually declined. The main reason to justify these results is the growth of crude oil around the soil particles and consequently reducing the porosity and empty places among them.

By increasing the porosity in soil samples, permeability value considerably fell which was the anticipated result. One argument commonly put forward is increasing the empty spaces among soil particles by raising the porosity among them which have caused that more crude oil can pass through the soil particles. In the third section of Figure 8, the alteration of permeability by initial water content has been mentioned clearly. For instance, by increasing the water content from 0% to 5% of soil weight, permeability climbed remarkably, whereas by the rising of this amount from 5% to 10 %, the slope of alteration is become slow and mostly steady. As it is mentioned, crude oil is built from the wide range of compounds one of which is heavy hydrocarbons. Actually, soil particles are surrounded by these kinds of hydrocarbons and gradually, these compound sediments on particles surface. By increasing the water content in the samples, water fills the empty spaces among soil particles; indeed, water does not permit crude oil to surround the soil particle. It can be strong argument to legitimize the climbing permeability by raising the water content. There is one significant point that would be considered; water can fill the empty spaces until determined level, after that it accumulates in soil. This value can be considered as the optimum moisture content of silty sand soil; because optimum moisture is the moisture which can smear and lubricate the soil particles and can slip on each other easily. This situation can make a denser structure in the soil but with adding more water to soil, soil compaction reduces considerably. On the other hand, extra water conducts to out of the soil samples by the flow of crude oil; consequently, permeability value becomes constant gently.

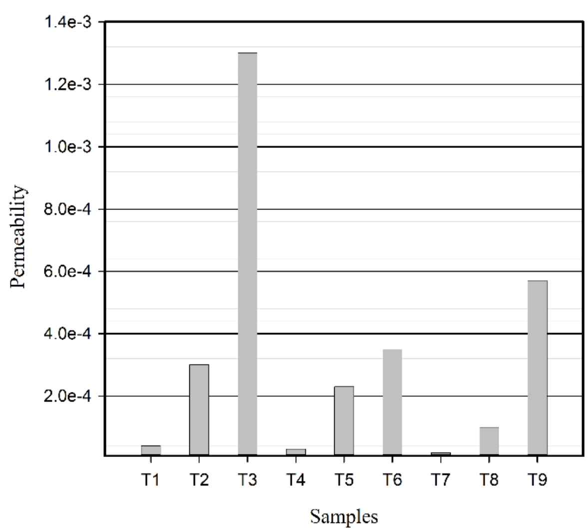

Figure 7. Permeability of different mixtures.

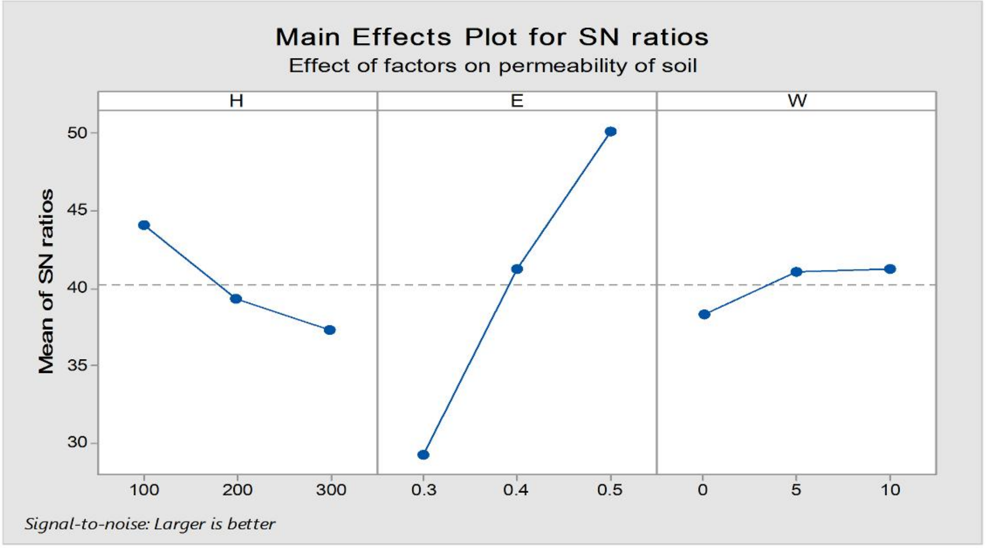

Figure 8. The Comparison of the effects of three factors on soil Permeability. Part H: indicates the leaking time (hr), part E: shows the initial porosity of soil and part W: shows the water content related to soil.

3.3. The validation of Taguchi method

For the validation of Taguchi method, there is a menu in Minitab software which can anticipate the most effective components (including water content, porosity value and leakage time) in soil samples; actually, this sample has critical values in the shear strength parameters and permeability amount. Then, the real sample will be made in laboratory and compared with the value of Taguchi method. The results can be seen in Tables 6–8. In this study, the error of Taguchi method was less than 10 percent in comparison with laboratory results so it can be used to reduce the number of test samples and economize time and cost dramatically.

Table 6. Comparison of Taguchi prediction and experimental result of internal friction angle.

Mix	H (hr)	E	W (%)	S/N	Mean	Experimental result	Percentage error
M2	100	0.3	5	30.891	34.88	33	+5.38

Table 7. Comparison of Taguchi prediction and experimental result of soil cohesion.

Mix	H (hr)	E	W (%)	S/N	Mean	Experimental result	Percentage error
M1	100	0.3	10	-12.051	0.245	0.225	+8.16

Table 8. Comparison of Taguchi prediction and experimental result of permeability.

Mix	H (hr)	E	W (%)	S/N	Mean	Experimental result	Percentage error
M2	100	0.5	10	55.107	537.77	490	+8.75

4. Conclusion

- The simulation of crude oil leakage is one of the most effective ways to reach the reasonable results of real life which occur in engineering projects. Not only can it simulate the effect of crude oil leakage more efficiently and properly but also it can model the soil samples in critical situation by conducting the oil spillage from down to up to saturate samples.
- Crude oil has a larger viscose in comparison with water; thus, by increasing of crude oil value, internal friction angle reduces significantly. In addition, as it is presented in curves, by the rising of water content, internal friction angle is improved relatively. This increment can be useful to improve and consolidate the contaminated soil by crude oil.
- The increase of crude oil value leads to the reduction of soil cohesion; one argument commonly put forward is the existence of heavy hydrocarbons in crude oil structure which can sediment among soil particles and increase the lubrication process and decrease the soil cohesion consequently.
- As it is observed in the SEM images, crude oil sediments on the surface of soil particles and whelms them; therefore the size of soil particles increases significantly; furthermore, in this case study, Refinery's soil contains little clay particles which can amplify the swelling process; as a result, empty spaces and porosity were declined in soil samples and reduce permeability; Although, , the alterations of this reduction declined by increasing the water content, permeability gradually reached to the lowest point and became almost steady.
- The anticipation of Taguchi method strongly confirms the results accuracy of this investigation and also this method is beneficial to economize the time and costs by reducing the number of tests.

List of notation

S/N is the ratio of the mean (signal) to the standard deviation (noise)
H is Fluid flow time (hrs)
E is the soil void ratio
W is the Initial water content (%)

5. References

[1]- Ola, S. A., 1991, **Geotechnical properties and behavior of Nigerian tar sand**, Engineering geology, 30(3-4), 325-336.
[2]- Khamehchiyan, M., Charkhabi, A. H. and Tajik, M., 2007, **Effects of crude oil contamination on geotechnical properties of clayey and sandy soils**, Engineering geology, 89(3-4), 220-229.
[3]- Shin, E. C. and Das, B. M., 2001, **Bearing capacity of unsaturated oil-contaminated sand** International Journal of offshore and polar Engineering, 11(03), 5-15.
[4]- Ghadyani, M., Hamidi, A. and Hatambeigi, M., 2019, **Triaxial shear behavior of oil contaminated clays**, European Journal of Environmental and Civil Engineering, 23(1), 112-135.
[5]- Rahman, Z. A., Hamzah, U., Taha, M. R., Ithnain, N. S. and Ahmad, N., 2010, **Influence of oil contamination on geotechnical properties of basaltic residual soil**, American journal of applied sciences, 7(7), 954.
[6]- Khosravi, E., Ghasemzadeh, H., Sabour, M. R. and Yazdani, H., 2013, **Geotechnical properties of gas oil-contaminated kaolinite**, Engineering Geology, 166, 11-16.

[7]- Nazir, A. K., 2011, **Effect of motor oil contamination on geotechnical properties of over consolidated clay**, Alexandria Engineering Journal, 50(4), 331-335.
[8]- Kermani, M. and Ebadi, T., 2012, **The effect of oil contamination on the geotechnical properties of fine-grained soils**, Soil and Sediment Contamination: An International Journal, 21(5), 655-671.
[9]- Akinwumi, I. I., Diwa, D. and Obianigwe, N., 2014, **Effects of crude oil contamination on the index properties, strength and permeability of lateritic clay**, International Journal of Applied Sciences and Engineering Research, 3(4), 816-824.
[10]- Rahman, Z. A., Hamzah, U. and Ahmad, N., 2010, **Geotechnical characteristics of oil-contaminated granitic and metasedimentary soils**, Asian Journal of Applied Sciences, 3(4), 237-249.
[11]- Hosseini, F. M. M., Ebadi, T., Eslami, A., Hosseini, S. M. M. and Jahangard, H. R., 2019, **Investigation into geotechnical properties of clayey soils contaminated with gasoil using Response Surface Methodology (RSM)**, Scientia Iranica. Transaction A, Civil Engineering, 26(3), 1122-1134.
[12]- Singh, V., Kendall, R. J., Hake, K. and Ramkumar, S., 2013, **Crude oil sorption by raw cotton**, Industrial & Engineering Chemistry Research, 52(18), 6277-6281.
[13]- Nazari Heris, M., Aghajani, S., Hajialilue-Bonab, M. and Vafaei Molamahmood, H., 2020, **Effects of Lead and Gasoline Contamination on Geotechnical Properties of Clayey Soils**, Soil and Sediment Contamination: An International Journal, 1-15.
[14]- Aghamiri, S. F., Kabiri, K. and Emtiazi, G., 2011, **A novel approach for optimization of crude oil bioremediation in soil by the taguchi method**, Journal Petroleum Environment Biotechnology, 2(2), 1-6.
[15]- Khayati, G. and Barati, M., 2017, **Bioremediation of petroleum hydrocarbon contaminated soil: optimization strategy using Taguchi design of experimental (DOE) methodology**, Environmental Processes, 4(2), 451-461.
[16]- Toufigh, V., Barzegari Dehaji, M. and Jafari, K., 2018, **Experimental investigation of stabilisation of soils with Taftan pozzolan**, European Journal of Environmental and Civil Engineering, pp.1-24.
[17]- Davari Algoo, S., Akhlaghi, T. and Ranjbarnia, M., 2019, **Engineering properties of clayey soil stabilised with alkali-activated slag**, Proceedings of the Institution of Civil Engineers-Ground Improvement, pp.1-12.
[18]- Ratnaweera, P. and Meegoda, J. N., 2005, **Shear strength and stress-strain behavior of contaminated soils**, Geotechnical Testing Journal, 29(2), 133-140.
[19]- Shin, E. C., Omar, M. T., Tahmaz, A. A., Das, B. M. and Atalar, C., 2002, **Shear strength and hydraulic conductivity of oil-contaminated sand**, In Proceedings of the Fourth International Congress on Environmental Geotechnics, Rio de Janeiro, Brazil (Vol. 1, pp. 9-13). AA Balkema Publishers Lisse.
[20]- Sridharan, A. and Venkatappa Rao, G., 1979, **Shear strength behavior of saturated clays and the role of the effective stress concept**., Geotechnique, 29(2), 177-193.
[21]- Vassiliou, M. S., 2018, **Historical dictionary of the petroleum industry**. Rowman & Littlefield.