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EVALUATING THE IMPACT OF LIGHT CRUDE OIL CONTAMINATIONS ON GEOTECHNICAL BEHAVIORS OF THE SOIL

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Abstract

Crude oil spills contaminate the soil in many ways including environmental impact and physical and chemical changes of the properties of the host soils. Organic liquids will affect the geotechnical behaviors of the soils. For better understanding of the soil behaviors as a function of oil contaminations a deep experimental investigation was conducted on kaolinite clay and sandy soils. These soils that were polluted by various amounts of crude oils (0%, 3%, 6%, 9%, 12%, and 15% by weight of dry soil). The geotechnical characteristics of the uncontaminated and contaminated soils were determined including the plasticity indices, compaction characteristics, hydraulic conductivity, and linear shrinkage limit. The outputs revealed a decline in dry density and optimum moisture content. The hydraulic conductivity of both soil types decreased due to oil contaminations. Crude oil contamination increased the plasticity indices and raised the linear shrinkage limit of clay soil. Oil-contaminated soil obligates improvements and maintenance prior utilization as construction materials or agricultural purposes.

Keywords: Crude Oil, Soils, Geotechnical Behaviors, Plasticity Indices, Compaction, And Hydraulic Conductivity.

تقييم تأثير ملوثات النفط الخام الخفيف على السلوكيات الجيوتقنية للتربة

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الخلاصة

تلوث انسكابات النفط الخام على التربة بعدة طرائق، بما في ذلك التأثير البيئي والتغيرات الفيزيائية والكيميائية في خصائص التربة المضيفة. تؤثر السوائل العضوية على السلوكيات الجيوتقنية للتربة. من أجل فهم أفضل لسلوكيات التربة كدالة لتلوث النفط الخام، تم إجراء دراسة تجريبية عميقة على طين الكاولين والتربة الرملية. هذه الترب التي تلوثت بكميات مختلفة من النفط الخام (0٪، 3٪، 6٪، 9٪، 12٪، 15٪ بوزن التربة الجافة). تم تحديد الخصائص الجيوتقنية للتربة غير الملوثة بما في ذلك مؤشرات اللدونة وخصائص الضغط والتوصيل الهيدروليكي وحد الانكماش الخطي. أظهرت النتائج انخفاضًا في الكثافة الجافة ومحتوى الرطوبة الأمثل. انخفضت الموصلية الهيدروليكية لكلا النوعين من التربة بسبب تلوث النفط. أدى التلوث بالنفط الخام إلى زيادة مؤشرات اللدونة ورفع حد الانكماش الخطي للتربة الطينية. تلزم التربة الملوثة بالنفط التحسينات والصيانة قبل الاستخدام كمواد بناء أو لأغراض زراعية.

كلمات مفتاحية: النفط الخام، التربة، السلوكيات الجيوتقنية، مؤشرات اللدونة، الضغط، والتوصيل الهيدروليكي.

Introduction

Changes of soil behaviors due to oil spillage as contamination had been a topic of attention. Oil spills in several instances are inadvertent; amidst transportations (such as spillage from huge capacity tanks, or during the process of drilling oil wells), (15, 24). The immersion of soil by viscous fluids characterized by different physico-chemical properties influenced soil mechanical and filtration, plasticity, swelling, and other parameters (28). One of the most significant contaminants is crude oil constituents and its petrochemicals. Unintentionally oil leakage has become a widespread phenomenon that can cause environmental and social problems. Soil contamination with petroleum compounds is one of the most predominant ecological issues. Oil leakage will contaminate the soil and the associated water systems of water (31). The amount of defilement depends on soil characteristics and properties of the contaminants, making it un-expellable from the soil (20). Microstructural alterations of clay soil polluted with high viscous fluids have been studied (30). The impacts of contaminated clay soil with different chemical liquids on its plasticity, consolidation, and shear strength behaviors have been inspected by other researchers (22, 23), they examined the effects of crude oil on the plasticity indices and compaction properties of fine soils, but they got dissimilar results from others, making it's difficult to combine their explanations. Strength reduction, penetrability, maximum dry density, and atterberg limits with increasing contaminated oil content in sandy and clay soils have been investigated (23). The work of (6) established a decrease of the strength and permeability, but an increase within the union between the particles of sands in Kuwait. Other researchers (5) explored the long-time impact of decreasing oil concentration on the stabilization of sands, which might be minimized over time. Researchers (21) stated that increasing the contamination progresses the increments of the plastic limit, liquid limit, and coefficient of compressibility within the soil. The effects of oil contaminated sands tested by (3). They revealed that the increase in atterberg limits and cohesion, also a lowering permeability and moisture content were associated with increasing the percentage of oil contaminant. The goal of this investigation will concentrate to determine the drastic change in the physical and mechanical behaviors of soil when subjected to spillage of crude oil. The important properties linked to agricultural and construction purposes such as dry unit weight, moisture content, plasticity indices, and hydraulic conductivity of soils will be determined to expose a better understanding of the effects of oil contaminated soils.

Materials and Methods

Area of the study: Bazian is located in the northeast of Iraq, also, the east of the Kurdistan region and the southwest of Sulaimani Governorate. Bazian’s area is 368 kilometer square and 550 meter it’s heights above the sea. After 2003 this town has changed dramatically to an industrial city which provides 30% of the industry in Iraq due to its proper geography, climate and raw material, the government supports the businessmen too. Currently, there are 200 different economic projects in Bazian, for example, four cement factories, Bazian refinery, steel factory, etc. Oil spillage and tanker linkage of oil in Bazian area has been a public concern as a result of its frequent occurrence which has been linked with petroleum exploration, transport and refineries of crude oil by pipelines and tankers also producing crude oil derivatives from refiners, all those steps reason to contaminated soils in the area. Crude oil spill affects geotechnical properties of soils like; strength, compaction, hydraulic conductivity, swelling, etc. and also it affects the index properties of soils like; liquid limit, plastic limit, plasticity index and shrinkages of soils. The crude oil contamination may affects plants negatively which makes essential nutrients like nitrogen, oxygen etc. needs for plant growth unavailable to them from the affected contaminated soil (1). Therefore, the main aim of this research is to evaluate the effects of oil spillage and soil contamination on physical, chemical and geotechnical behaviors of different soil types. Evaluating the compatibility of contaminated soils for engineering purposes and agricultural uses.

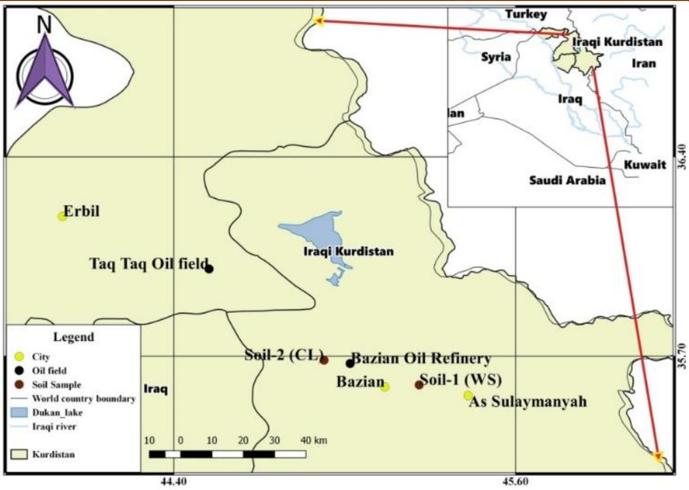

Figure 1. Map of the studied area showing location of oil refinery and the adjacent soil sample locations.

Samples of soil were collected from the area adjacent to the Bazian oil refinery at approximately 35 kilometers northwest of Sulaimaniyah city in Iraq. The refinery is located at latitude (35°40'26.04"N) and longitude (45°01'08.44"E) with an altitude of 890 meters. The soil samples were collected after removing the upper organic part, then a soil sample from 40 cm below the ground surface. The well graded sand (WS, location 1) and clay loam (CL, location 2) soil samples were obtained between latitude (35°35'55.36"N), longitude (45°15`35.58` E) at an altitude of 800m and latitude (35°41`3.85` N), longitude (45° 15'41.52" E) at an altitude of 817m respectively. Furthermore, the sample of light crude oil used in the study was obtained from Taq taq oil field, which is located 85 kilometers southeast of Erbil. It is located between latitude (36 º 00' 22.48" N) and longitude (44º 31' 24.33" E) at an altitude of 605 meters. (Figure 1). Table 1. The basic properties of utilized soils and applied criteria of the testing procedures for each soil property are shown in Table 1. The soil types were recognized according to the United Soil Classification system (USCS). The well graded sand (WS) soil has nonplastic, while the clay loam (CL) soil exhibits low plasticity behaviors. Other essential properties such as initial water content, pH, and organic matter contents were calculated based on standard tests. The particle size distribution curve of soils has been plotted in Figure 2. The crude oil used was obtained by experts of Taq taq oil field.

Table 1. Physio-chemical and geotechnical properties of the used soil samples (non- contaminated (WS and CL)).

Properties	Well graded sand (WS)	Clay loam (CL)
Sand (0.075-4.75 mm) (%)	90.5	22.21
Silt and Clay (< 0.075 mm) (%)	9.5	77.79
Unified Soil Classification system	WS - non- plasticity	CL - low plasticity clay
Color	Gray	Red
Initial water content	11.45	15.33
Organic material content	Non	1.5
Specific gravity (Gs)	2.660	2.629
Liquid limit (%)	Non	32.54
Plastic limit (%)	Non	20.69
Plasticity index (%)	Non	11.85
Shrinkage limit (%)	Non	9.43
Maximum dry density (g/cm^3)	1.91	1.77
Optimum moisture content (%)	12.1	17.6
Hydraulic conductivity (cm/s)	4.80E-02	1.55E-05
pH value	6.23	7.75

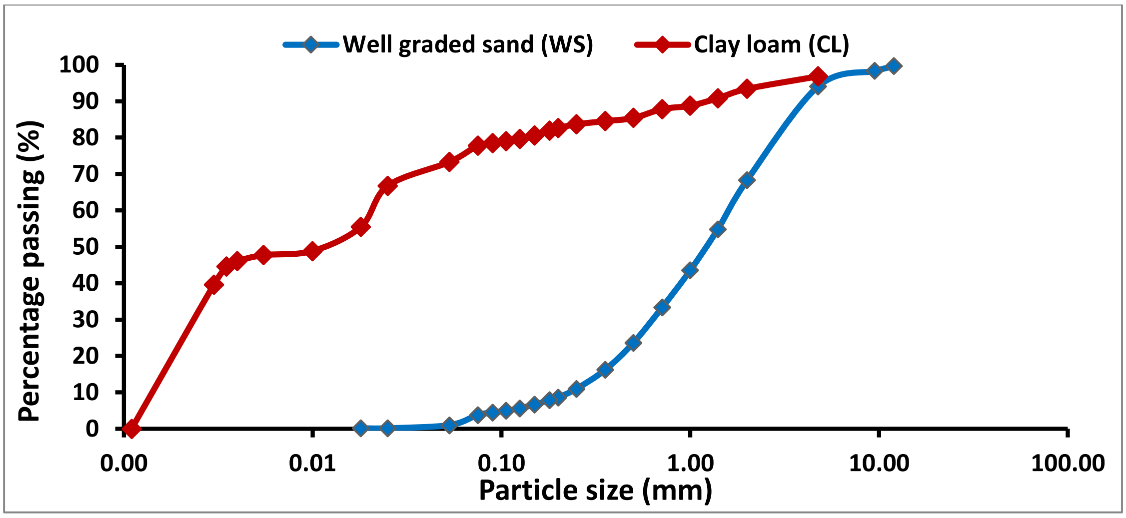

Figure 2. Particle size distribution and hydrometer test analysis of the non-contaminated soil samples (WS and CL).

Table 2 shows the properties of the crude oil utilized in present study. The crude oil sample has light because an API (American Petroleum Institute) index is greater than 38 degrees. Using the API index, different types of petroleum were identified; Light (˚API ≥ 31), Medium (22 ≤ ˚API < 31), Heavy (10 ≤ ˚API <22), Extra-heavy (˚API ≤ 10) (33).

Table 2 Physiochemical properties of used crude oil obtained from Taq Taq oil field (Light Crude Oil).

Properties	Value
Specific gravity at 60 F	0.791
API gravity (Degree)	47.5
Sulfur content (%)	0.6
Salt content (ptb)	45.5
Density at 60 F (g/cm^3)	0.788
Dynamic viscosity (cp)	16.5

Mixtures preparation: The intact soil samples were dried by oven at temperature 110 °C for 24 hours, and then the soil samples were contaminated by the mentioned contaminant ratios. Contaminated soil samples have been prepared manually blending crude oil with various percentages 0%, 3%, 6%, 9%, 12%, and 15% dry mass of soil samples. To avoid oil evaporation during the aging period, the soil samples were kept in thick plastic opaque containers for two weeks. Moreover, the required water was added to the samples one day before conducting the performed tests. Then, the samples brought back to the thick plastic containers to prevent water evaporation and to obtain saturation and uniform contaminated mixtures, the prepared mixtures were preserved at room temperature for 24 h in order to harmony and homogeneity prior conducting tests. After preparing the mixtures, each contaminated soils with the specified percentage of crude oil are subdivided in to four equal portions. The soil tests were conducted four times for each added percentage of crude oil to the soil samples($i.e. 6\ treatements \times 4\ replications = 24\ tests$) for each soil properties.

Experimental methodology: The standard routine laboratory methods according to American society for testing and materials (ASTM) were used to determine the following geotechnical soil properties: The particle size distribution was determined conducting dry sieving and hydrometer method (18). Organic matter content for clay soil (10). Specific gravity determined by using a pycnometer method (10), standard test for specific gravity of soil solids by water pycnometer, atterberg limits (8), standard test method for liquid limit, plastic limit, and plasticity index of soils, and linear shrinkage determined according to (7). Standard compaction test (11) was conducted in order to determine dry density and optimum water content of the soils, finally hydraulic conductivity (11) were performed to determine permeability of granular soils (Constant Head), and variable head method used for clay soil (13).

Results and Discussion

Table 1 shows the common properties of soils (uncontaminated samples), and some other geotechnical engineering properties. The properties for the soils are variable. The soil samples are intact and it is free from crude oil concentrations. When the soils are contaminated with the specified percentages of crude oil, the whole soil properties changed after oil content treatments. Table 3.

Specific gravity changes due to oil contamination: The specific gravity for uncontaminated soil samples is 2.66 and 2.63 for well graded sand (WS) and clay loam (CL) respectively. Figure.3 shows a graphical presentation of specific gravity variations of soils mixed with different percentages of crude oil contents. As the content of crude oil contaminated increased, the specific gravity of the mixture decreased noticeably. These reductions in specific gravity could be due to the lower specific gravity added by crude oil to the soil specimens (2). The correlation coefficient of the results are (-0.97, -0.96) for well graded sand (WS) and clay loam (CL) respectively.

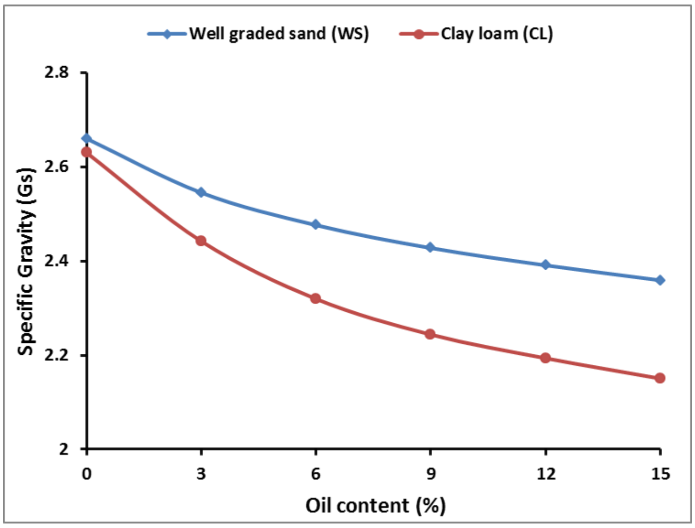

Figure 3. Specific gravity variation of soils contaminated with different content of crude oil

Variation of Atterberg limits of the soils: The results of the Atterberg limit tests are presented in Figure 4. The liquid limit, plastic limit, and plasticity index for clay soil increases as increase in crude oil increases. The contaminated soil becomes more workable indicating that an increase of oil contamination resulted in an increase in the cohesion of soil to working and a reduction in adsorption of water (25). Therefore, an increase in the double layer thickness of soil due to flocculating of soil particle, where the oily material has been absorbed in the clay mineral interlayer space, thus creating enough volume for the water penetration in clay minerals. This could be the underlying reason besides the increase of liquid and plastic limits (15, 20, 30, 28), an increase of oil-contaminated soil creates increments in the thickness of the diffused double layer. This is supported by the findings of (24) that the plastic limit of soil increases when the content of oil contamination raised. As shown in Figure 4 the liquid limit of non-contaminated soil increased sharply when the amount of crude oil added is at 3% content. This could be due to the flocculation mechanism of soil particles when the oil contamination is at the first contact of non-contaminated soil which makes the soil pore to be very high and alters the void distribution. As a result, the amount of water needed the soils increases to fill the pore spaces, and the liquid limit increased.

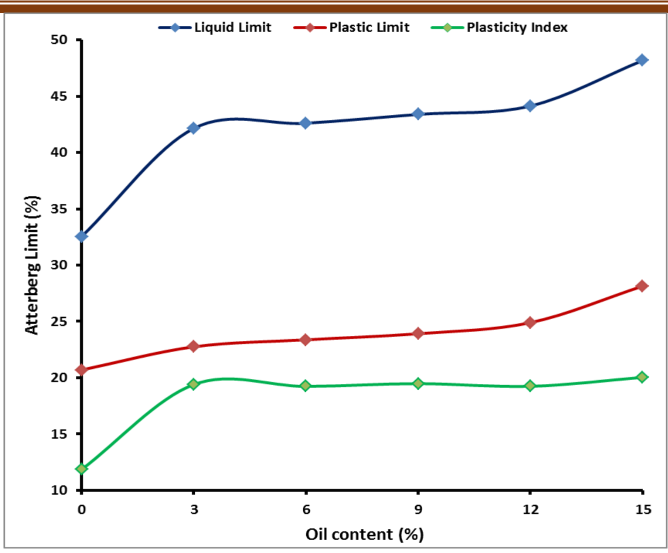

Figure 4. Variation of Atterberg limits with crude oil content of clay loam (CL) soil samples.

Effects of crude oil on linear shrinkage limit: The linear shrinkage limit increases by 1.21%, 2.54%, 4%, 5.54% and 7.16% for 3%, 6%, 9%, 12% and 15% of crude oil contaminated clay loam (CL) respectively to the non-contaminated clay sample. This is related to voids that are filled with crude oil and water where crude oil content mixed with soil samples makes the samples need more water based on the liquid limit determination, therefore with increasing crude oil content. The total fluid content in the pore spaces increases, as a result during drying the rate of water evaporation increased, and more shrinkage will be obtained. These results sort out with the results of (19). The sharp increase in shrinkage limit (Figure 5) could be due to a systematic rate in the amount of evaporation offered by the kaolinite clay type in this research. The correlation coefficient of the result is (0.98) for clay loam (CL) soils.

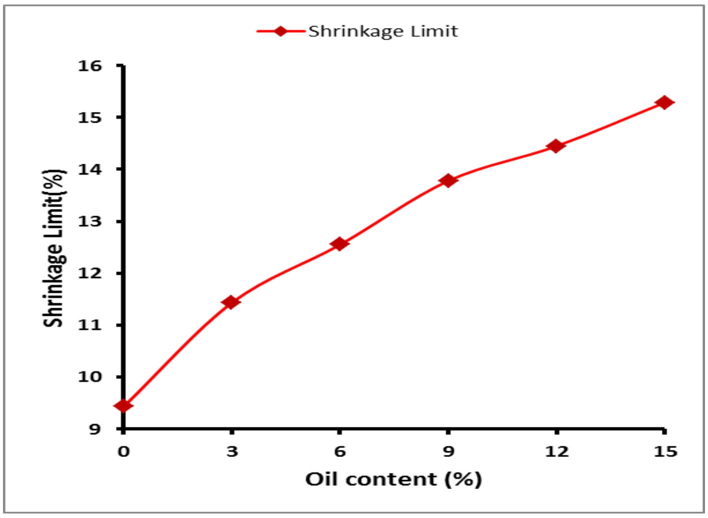

Figure 5. Variation of shrinkage limits with crude oil content of clay loam (CL) soil samples

Effects of crude oil on compaction characteristics: Standard proctor compaction tests (11) have been performed on oil-contaminated soil samples. The findings are presented in Figures 6. a and b. It can be understood generally that the dry density and optimum moisture content decrease as the percentages of oil content increased. The reduction of dry density in sandy soil (WS) is much quicker than the reduction in clay loam soil (CL) due to the porosity, and it holds greater oil in spaces than at the particle surfaces that do not permit sufficient water needed the soil to attain the maximum dry density, and greatest compaction applies. In contrast, more compaction does occur in uncontaminated soils. The trends of the curves in Figure 6. a. indicate a gradual decrease in dry density and moisture content while in Figure 6. b. indicate a sharp reduction and quick. This shows the difference in compaction characteristics of soils contaminated with various amounts of crude oil. The compaction curves of contaminated soil samples are placed to the left of uncontaminated soils especially after 6% of oil contents. This in reality shows that the moisture content needed to achieve maximum dry density decreases when the crude oil content increased. The oil content has partially occupied the interparticle spaces and altered the state of the soil samples into a porous medium as compared to uncontaminated soils. This is supported by the results of (4, 23, 31).

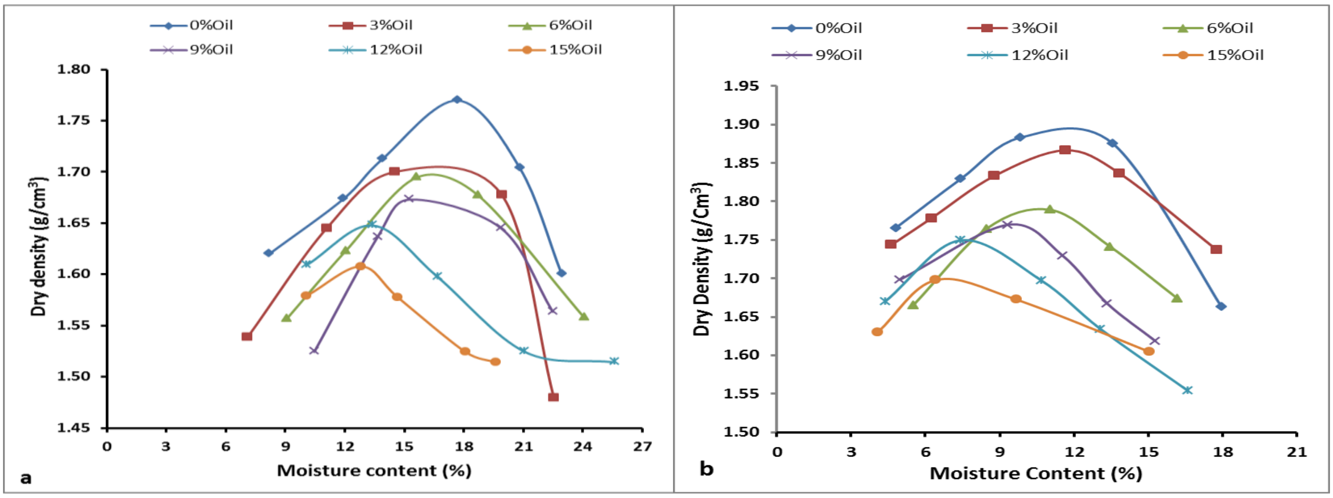

Figure 6, a and b Variation of compaction characteristics of soil samples contaminated with oil (a. clay loam CL, b. well graded sand WS).

The test results illustrate a drastic decline in maximum dry density and optimum moisture content, when the percentages of added crude oil increased. Figure 7. a and b. However, those effects are varied from different studies (6, 26)**,** they demonstrated a rise in maximum dry density with increasing oil up to about 4%, after which a reduction of maximum dry density occurred with extra oil percentages of contaminants. The usual shape of the compaction curve also alters the bell shaped showing for clay soils. The shape of compaction curves for WS and CL soils samples remains constant with a wide peak shape curve up to 9% of oil content and it becomes nearly odd shaped at higher oil content Figure 6, a and b. this suggests that too much amount of oil already exists inside the soil pores to achieve efficient compaction. The correlation coefficient of the results are (-0.98, -0.99) and (-0.97, -0.99) for well graded sand (WS) and clay loam (CL) respectively.

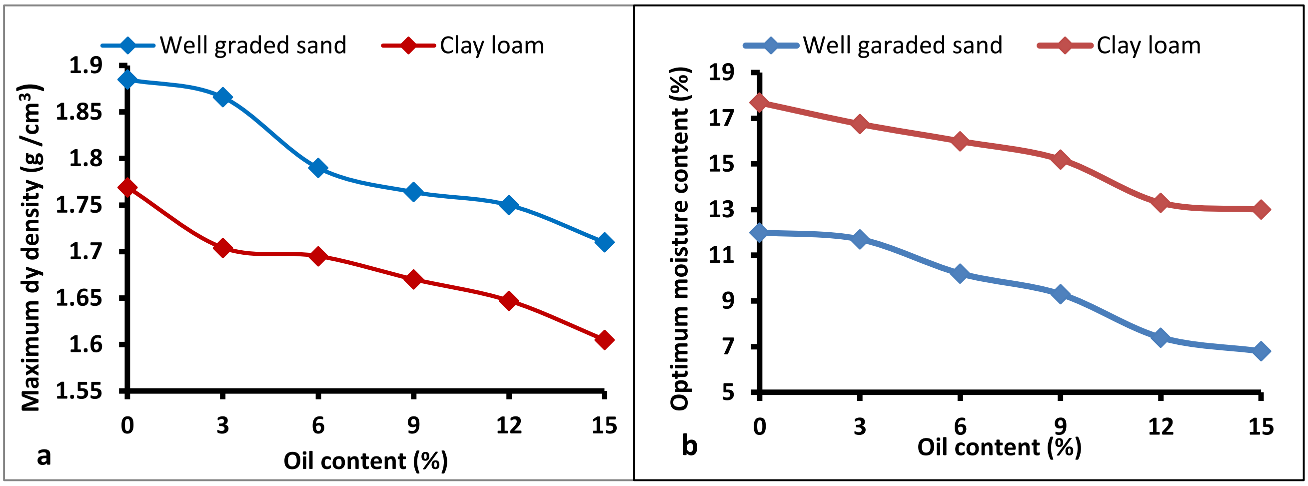

Figure 7, a and b Variation of maximum dry density (MDD) and optimum moisture content (OMC) of soils contaminated with crude oil

The WS soil gets the fastest decrements in maximum dry density; this is related to the fast expulsion of oil. The maximum dry density decreased sharply until 6% of crude oil content Figure 7, a. after that the increase of crude oil content affects the maximum dry density with the same value and patterns of reduction. The attributes of capillary tension effects make the maximum dry density decrease at the initial stage of increasing water content. The tensional forces decline with increasing oil content of samples, since the oil has hydrophobic characteristics, it prohibits the contact of water with soil particles (23). Figure 7, b presents a reduction in the values of optimum moisture of soils when contaminated with various percentages of oil. The present finding is consistent with that obtained by (36), agreeing to which in the oil-contaminated soils, the soil specimen obtain maximum dry density hurriedly with a lower value of optimum moisture in comparison to non-contaminated soils.

Effects of crude oil contaminations on hydraulic conductivity of soils: In order to calculate the permeability coefficient, permeability tests were executed on the soil samples with the constant head (12) and the variable head (13) for both well graded sand and clay loam soils samples respectively. To increase the accuracy, the hydraulic test was run four times for each sample, and their average was chosen. All specimens were tested with the compaction density of 1.6 g cm^{-1} at the constant and variable head methods. Adding crude oil to the soil samples makes a reduction in permeability coefficient as shown in Figure 8 the oil and water are immiscible, but using crude oil instead of water was occupied the interspaces of the soil particles and clogs the soil pores due to high viscosity, and reduces the total porosity of the soil samples. Since the oil has a very higher viscosity than water (40 times), it reduced the permeability coefficient of the soils. The results agree with the investigations of (31), and also agree with the work of (2). The drop in the permeability coefficient of WS and CL soil samples gives the same pattern of reductions but very less hydraulic conductivity was observed in CL soil sample because of the type of soil and presence of the high amount of clay and more affected by crude oil if it is compared to hydraulic conductivity in WS soil samples. These results coincide with the results of (6, 23). Therefore, the soils with high kinematic viscosities and higher relative densities were found to have a lower hydraulic conductivity, this coincides with the results of (32). The correlation coefficient of the results are (-0.98, -0.99) for well graded sand (WS) and clay loam (CL) respectively.

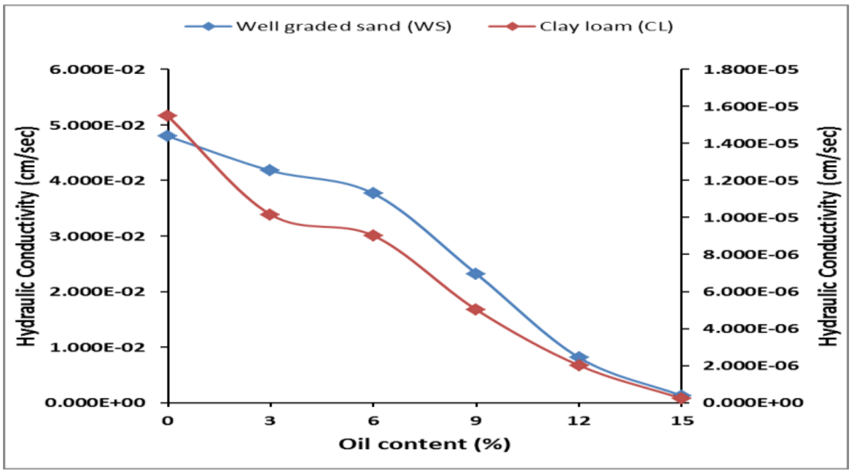

Figure 8 Variation of hydraulic conductivity of soils contaminated with different crude oil content

The oil content occupied the pores of the soils and controls the flow of water through the soils because of the higher viscous behavior. This approves with the findings explored each of (16, 35) who concluded that the presence of oil in soil results a decrease in hydraulic conductivity of contaminated soil due to pore clogging and high viscosity of the oil. The drop in the maximum dry density of the soils Figure 7, a. will lower hydraulic conductivity; thus the hydraulic conductivity was dropped with a drop in maximum dry density in consequence with oil content. Figure 8. This agrees with the observation of (14), that soils with lower maximum dry density had lower hydraulic conductivity.

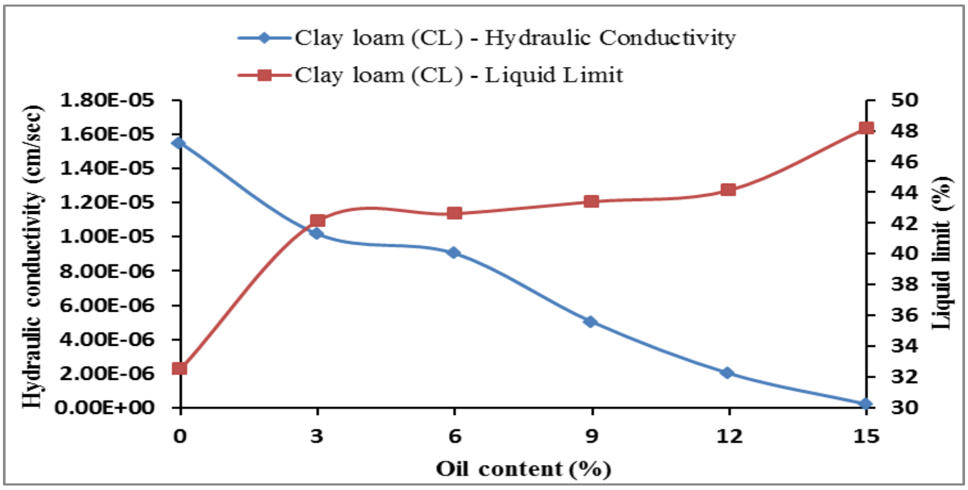

Figure 9 Relationship of hydraulic conductivity with liquid limit of clay loam (CL) soil contaminated with crude oil.

Figure 9 shows the variations in liquid limit and hydraulic conductivity when the clay soil was contaminated with different percentages of oil content. Liquid limit increased in each mixed ratio of the tested soil samples as oil content increased but in contrast, the hydraulic conductivity decreased for the same used oil contents. Therefore, the increase in liquid limit results in a dramatic decrease in hydraulic conductivity especially after 3% of crude oil. This could be due to a dispersion of the kaolinite in the CL soil samples and in the presence of water, the result compatible with the results of (25). Dispersion of oil contaminated kaolinite clay soil brought in a decrease in hydraulic conductivity because the dispersed kaolinite clay plugged the soil pores despite of the effects of crude oil clogging.

Table 3 shows statistical analysis of physio-chemical and geotechnical result tests of the contaminated and intact soil samples.

Soil samples	Crude oil %	Gs	L.L %	P.L %	P.I %	L.S.L %	MDD g/cm^3	OMC %	H.C cm/sec
Well – graded sand (WS)	0%	2.66	Non	Non	Non	Non	1.885	12	0.0479
	3%	2.54	Non	Non	Non	Non	1.866	11.7	0.0417
	6%	2.47	Non	Non	Non	Non	1.79	10.2	0.0376
	9%	2.43	Non	Non	Non	Non	1.764	9.3	0.0232
	12%	2.39	Non	Non	Non	Non	1.75	7.4	0.0081
	15%	2.36	Non	Non	Non	Non	1.71	6.8	0.0012
	Mean	2.47	Non	Non	Non	Non	1.79	9.57	0.0266
	STDEV	0.11	Non	Non	Non	Non	0.069	2.15	0.019
	SEM	0.045	Non	Non	Non	Non	0.027	0.881	0.0077
Clay loam (CL)	0%	2.63	32.54	32.53	20.69	11.85	1.77	17.69	1.55E-05
	3%	2.44	42.14	42.14	22.75	19.39	1.70	16.75	1.02E-05
	6%	2.32	42.60	42.60	23.37	19.23	1.69	16	9.02E-06
	9%	2.24	43.39	43.39	23.91	19.48	1.67	15.2	5.02E-06
	12%	2.19	44.13	44.13	24.89	19.24	1.64	13.3	2.01E-06
	15%	2.15	48.17	48.17	28.14	20.03	1.60	13	2.21E-07
	Mean	2.33	42.165	23.96	18.20	12.82	1.68	15.32	6.98E-06
	STDEV	0.18	5.183	2.484	3.127	2.153	0.055	1.876	5.67E-06
	SEM	0.073	2.116	1.014	1.276	0.879	0.0227	0.765	2.31E-06

Conclusion: The obtained results presented in this research paper show the following facts: The addition of various levels of oil contamination leads to an increase in liquid limit by 32.5%, plastic limit by 26.5% and plasticity index by 45.8%. This could be the result of oil wrapped both the clay minerals and the adsorbed water enclosed to the particle surfaces of the soil. Adding crude oil to the soil dropped the specific gravity by 12.75% for WS soil and 22.3% for CL soil. This is due to the low-density values of the oil used. An increase in linear shrinkage was observed when the levels of oil content in CL soil increase. The recorded increase is 1.21%, 2.54%, 4%, 5.54% and 7.16% for 3%, 6%, 9%, 12% and 15% respectively for an increase in the levels of contamination by crude oil. Results indicated that compaction behavior of contaminated soil adversely proportioned with crude oil content comparatively to intact soil because there was a reduction in maximum dry density. The reason behind this reduction is the lubrication effect instead of strong grain-to-grain contact (reduction of pore spaces of soil). Thus, the oil occupies the pores of the soil instead of water due to immiscibility properties and reduces the chance of water to contact with soil particles, resulting in a reduction of optimum water content. Oil contamination decreased the hydraulic conductivity for each of the oil increments ratios because oil occupied soil pores. The oil used for this research had a high viscosity that contributed in the entrapment of the crude oil within the pore spaces of the soil which decreased hydraulic conductivity. Inverse dramatically variation observed between liquid limit and hydraulic conductivity of clay soil, an increase in the liquid limit produce a noticeable reduction in hydraulic conductivity of soil when the levels of contamination ratio increased. Crude oil contaminated soils without appropriate stabilization or remediation are not convenient to use for engineering and agricultural purpose. So, require improvement before use because most soil parameters conflicted with the intact soil behaviors due to contamination.

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