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A GEOTECHNICAL STUDY ON TWO SELECTED OIL-CONTAMINATED SOIL SITES

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ABSTRACT

Oil contamination in soil represents a significant environmental challenge affecting soil properties and leading to a reduction in soil efficiency for use in engineering applications. To cover this gap of knowledge, the investigated soil in this study is an actual polluted soil taken from the Sabba oil field and the Nasiriyah oil field, which are both located in Thi-Qar Governorate, south of Iraq. The study aimed to provide realistic data showing the impact of oil contamination on the geotechnical behavior of soil. Two disturbed polluted samples were collected from a depth of 30-40 cm from oil field sites. The first sample corresponding to the Nasiriya oil field was named soil (A), while the second sample corresponding to the Sabba oil field was named soil (B). A series of lab experiments was executed on a contaminated soil, including particle size distribution, specific gravity, Atterberg limits, standard compaction, pH test, and vane shear test. It concluded that soil (A) was finer than soil (B). The maximum dry density of fine soil (soil A) was less than that of the coarser soil (soil B); oppositely, the optimum moisture content of soil (A) was far greater than that of soil (B). The results of the liquid limit, plastic limit, plasticity index, and specific gravity of both soils fit very well with previous literature. Since soil (B) was more polluted than soil (A), the pH value obtained for soil (B) was less than that of soil (A). Also, the pH of soil (A) decreases after washing with water for several weeks; that could reflect the inefficiency of soil washing as a treatment technique without using chemicals. The findings of the vane shear experiment, which was accomplished for soil (A), show that the undrained shear strength (Cu) is 20 kPa, which can be considered a moderate value. The outcomes of the tests, including particle size, liquid limit, plastic limit, plasticity index, specific gravity, pH, and undrained shear strength of both contaminated soils, are very well consistent with similar previous laboratory work and could be attributed to the degree of pollution and the soil texture.

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NOMENCLATURE

γ_{dry}	The dry unit weight
γ_{wet}	The wet unit weight
ω	The water content
Gs	The Specific Gravity
Cc	The coefficient of uniformity
Cu	The coefficient of curvature

1. INTRODUCTION

Contamination is the artificial or natural presence of hazardous compounds having short- or long-term effects Mekkiyah et al.,[1] . Oil is a complex mixture of hydrocarbons in various gaseous, liquid, and solid phases, these hydrocarbons may reach over 17,000 organic chemicals Aljamali et al., [2]. Oil varies in appearance, color and composition considerably depending on where it is extracted. Crude oil contains three major hydrocarbon components which are Parrafins, Naphthenes and PAH Ahmad et al., [3]. Crude oil is one of the most dangerous sources of soil pollution. It contains harmful compounds that are in the form of toxic organic petroleum pollutants. Hazardous compounds like benzene, toluene, ethylbenzene, xylene, and naphthalene, which are found in petroleum hydrocarbons, can be harmful to all aspects of the ecosystem, particularly the land Daâssi et al.,[4] . In polluted soil, petroleum hydrocarbons are typically present in high amounts, indicating an environmental risk. They change the biological properties of soil, impacting its physicochemical features Czarny et al.,[5].

In geotechnical engineering, oil contamination is a serious issue. Oil can significantly alter the physical and mechanical characteristics of soil Ali et al.,[6]. Soil characteristics such as pH and cation exchange capacity (CEC) are altered by oil pollution Sutormin et al.,[7]. These changes could damage the soil and make it less able to support loads, which could lead to structural instability. Due to the extensive distribution of oil wells and related procedures for oil storage and extraction, oil field sites in southern Iraq, especially those in Thi-Qar governorate, can be regarded as the most hydrocarbon-contaminated locations in the country Al-Obaidy et al.,[8]. Oil pollution due to an outflow from oil tubes, products transportation, or oil excavations can show a discrepancy in the mechanical, chemical, and biological features of the soil. Thus, the soil may or may not be qualified for building projects and it may require a substantial control. Thus, it is essential to acquire a deeper comprehension of the general behaviour of such soil and the relevant geotechnical characteristics upon contamination.

The environmental impacts of the oil contamination on the physical and mechanical characteristics of soils have been studied by many investigators. Ijimdiya[9] examined the influence of oil pollution on distribution of grain sizes for brown soil collected from a location at Zaria, Nigeria. The soil contained 87% silt and a significant proportion of kaolinite clay material. Various amount of oil (1, 2, 3, 4, 5 and 6%) was added to the dry tested soil samples. The results showed that the curve of grains distribution changed from finer to coarser. Al-Obaidy et al., [10] noticed a similar behavior when conducting a sedimentation test for a fine soil that was brought from a location at the south of Iraq in Thi-Qar Governorate. The increase in oil content caused shifting in the grain size distribution curve from finer to coarser ranges.

Some researchers explored the geotechnical behavior of oil- polluted soils by testing the soil consistency limits. Khosravi et al., [11] studied the effect of pollution by oil on Atterberg limits via polluting a low plasticity clay containing kaolinite with oil concentrations of 2, 4, 6, 12, 16 and 20% of the dry weight of soil. The results indicate that when the oil percentage rises to 12%, the PL declined and the LL increased, while, a reduction in the aforesaid parameters was observed by increasing the oil content from 12 to 16%. The earlier findings were validated by Al-Obaidy et al., [12] during their study on an artificially contaminated soil with crude oil. Atterberg limits experiments revealed that polluted samples had significantly higher liquid limits, plastic limits, and plasticity indexes than non-contaminated samples.

Moreover, the compaction features of soil contaminated by oil were studied. The studies indicated that after compacting soils, their compaction features varied because the soil composition differed. The maximum dry density (MDD) increased and the optimum moisture content (OMC) decreased with an increase in oil content, when Ota [13] compacted a kaolinite clay soil polluted by adding different percentages of light crude oil (2%, 5%, 8%, 10%, 15% and 20%). The compaction findings demonstrated a decrease in the OMC as the proportion of crude oil contamination increases up until 10% pollution. The MDD rises as the proportion of crude oil contamination increases up to 10% contamination, at which point the value decreases.

Furthermore, Harsh et al., [14] during their laboratory study, they explored how the specific gravity of soil could be affected by oil contamination. The study reported that soil specific gravity reduces by 15.44%, 29.73% and 40.54% for 3%, 6% and 9% of crude oil pollution for sands and 14.3%,32.71% and 50.1% for 3%, 6% and 9% of crude oil contamination for kaolinite clay respectively. Since the soil pH has a deep effect on form and behavior of other chemicals in soil, it was measured and evaluated in several researches such as Karkush et al., [15,16]. Exploring the pH of the soil is essential due to its influence on the effectivity of the remediation processes.

In literature, the undrained shear strength features of polluted soil have been scrutinized. Al-Obaidy and Shaia Al-Obaidy et al.,[10] studied and obtained this feature by conducting vane shear test. The results demonstrated an increase in shear strength as the oil ratio increased, except a small percentage of 2%, which indicated a decrease in the value. Table 1 summarizes numerous other studies that investigated the contaminated soils.

The previous investigations were achieved utilizing an artificially contaminated soils with crude oil. Therefore, evaluation based on these studies may be misleading and not accurately depict the actual situation. However, the geotechnical behavior of the soil upon contamination is still not understood. By focusing awareness of this knowledge gap in this area, the current lab study is the first study takes into consideration actual polluted soils in different oil field sites within Thi-Qar governorate to seek the influences of petroleum products on mechanical, physical, and pH measurements of soils.

There is an urgent need for identifying the efficient soil treatment strategies. Thus, it is important to explore the primary features of polluted soil and achieve a reliable evaluation. The aim of the present study is to gain a better understanding of the performance of oil-contaminated soil by conducting laboratory experiments on field soil samples to investigate the geotechnical behavior upon the extent of oil pollution. So, that can offer a beneficial guide for engineers and designers. The investigated soil in this study is taken from the Sabba oil field and Nasiriyah oil field within Thi-Qar governorate/ Iraq.

This study aimed to explore the geotechnical behavior of oil- contaminated soil. To achieve this goal, a study framework has been established, consisting of the following steps: (a) collecting soil samples; (b) conducting a series of laboratory tests on contaminated soil; (c) evaluating the amount of oil pollution by measuring pH values for the studied soil samples; (d) analyzing the effects of oil contamination on the geotechnical properties of the soil; and (e) treating the polluted soil by washing with water and assessing this remedy.

Table 1. An overview of the studies conducted on polluted soils.

Study/ Reference/ Location	**Soil type**	**Concentration /contamination type**	**Testing**	**Outcomes**
Mekkiyah et al.,[1] Iraq	Sandy loam, silty loam	4, 8, 12, 16% Artificial	Permeability Specific gravity Atterberg limits UCS	-Permeability decrease -Specific gravity decreases -LL and PL increase -PI decrease
Salimnezhad et al.,[17] Iran	Clayey soil	4, 8, 12% Artificial	Compaction Atterberg limits Consolidation UCS Direct shear	-MDD, OMC, UCS and shear decreased -Coefficient of consolidation decrease
Oyediran et al.,[18] Nigeria	High plasticity Clay	2-10% Artificial	UCS Atterberg limits Compaction Permeability Chemical composition Mineral composition	- When the oil content reached 4%, UCS and MDD peaked before declining. - LL, PL, and PI increased with oil up to 4%, then decreased
Oluremi et al. [19] Nigeria	lateritic soil	2, 4, 6, 8 % Artificial	Aterberg limits Compaction UCS	-UCS increase then decrease -MDD decrease and OMC increase -LL and PL decrease

Daka[20]	Bentonite/kaolinite-sand combinations.	1.8, 3.5, 5.3, 7.1% Artificial	Grain distribution Atterberg limits Compaction Consolidation Hydraulic conductivity	-PL and LL increase -MDD and OMC decrease -hydraulic conductivity decrease
Alhassan et al.,[21] Northern Nigeria	Sand, clay and lateritic soil	2, 4, 6% Artificial	Compaction Consolidation Atterberg limits CBR Triaxial test	-MDD increased -consolidation settlement reduced for clay and increased for lateritic soil -CBR of clay decrease, CBR of sand and soil increase then decrease -shear strength increase
Kermani et al.,[22] Iran	Low plasticity Clay	4, 8, 12% Artificial	Strength Atterberg limits Compaction	-Cohesion reduces -Friction angle and compressibility increase -LL and PL increase while PI decrease -MDD increase but OMC decrease

2. METHEDOLOGY

2.1. Materials

Two disturbed polluted samples were collected from a depth of 30-40 cm from Al-Nasiriyah oil field and Sabba oil field which are both located at the south of Iraq. Both locations are showed on the satellite map in Fig. 1. The first sample corresponding to the Nasiriya oil field was named soil (A) while the second sample corresponding to the Sabba oil field was named soil (B). The two locations were specially chosen to represent a fine-grained contaminated soil and coarse-grained contaminated soil, this description was based on the color and visual classification of soil samples at the Sabba field. It is worth mentioned here that Soil B was extruded from the oil storage area which characterized with relatively high contamination. Fig. 2 shows the site from which the samples were extracted.

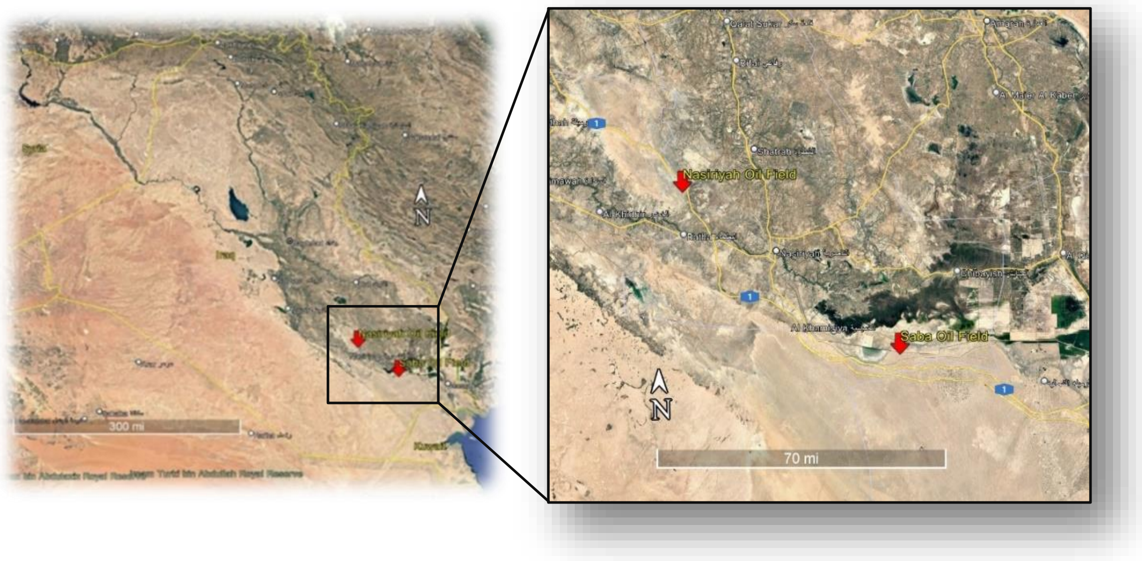

Fig.1. Locations where the contaminated samples were collected.

Fig. 2. The site from which the contaminated samples were collected.

2.2.Soil preparation

The standard specifications required dry samples before performing tests. Because the contaminated soil is sensitive to the high temperature of the oven, the soil samples were dried completely in the open air. However, in most experiments and for drying out the samples during the test, the samples were normally placed in the oven at a low temperature of 60°C.

3. EXPERIMENTAL TESTING PROGRAM

In this study, six experiments were conducted, including grain size distribution, specific gravity, Atterberg limits, standard Proctor compaction, pH test, and vane shear test. Outlining the study methodology is presented in Fig. 3. The experimental testing was performed in accordance with American Society for Testing and Materials (ASTM) standards. All the conventional tests were times than specified in the standards due to the unpredictable nature of the results and to ensure reliable readings. However, for the compaction test, the experiment was conducted only once for each sample because there was no more material available in the laboratory and because of the difficulty regarding having more material from the field.

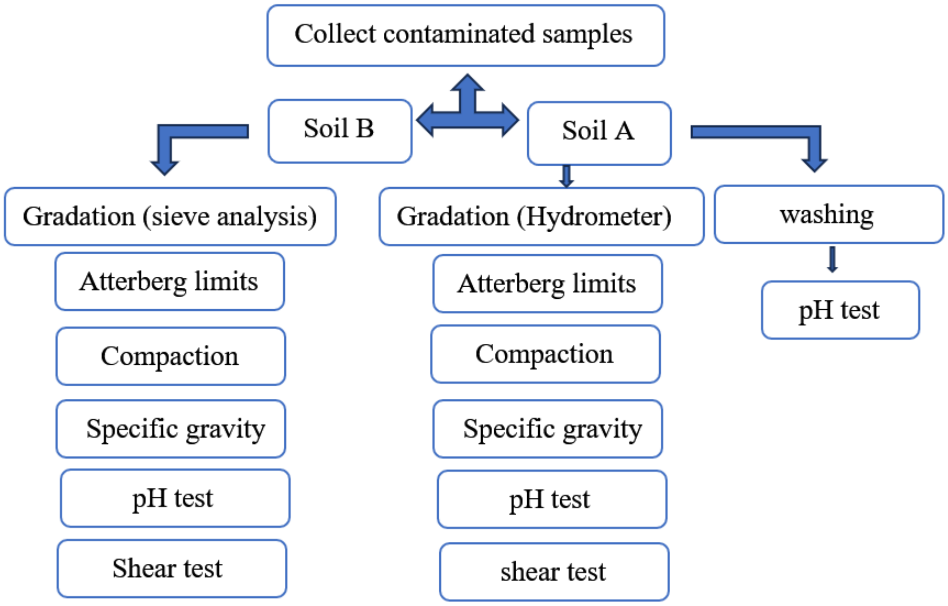

Fig. 3. Flowchart of the study methodology.

3.1. Grain size distribution

For gaining the grain distribution curves of both examined soils, the gradation analysis was performed. All procedures were implemented in accordance with ASTM D422 (Rock, 2007). For soil (A), a sedimentation test using a hydrometer was conducted as shown in Fig. 4(a), while a sieve analysis experiment was adopted for soil (B), as shown in Fig. 4(b).

Fig. 4. (a) Hydrometer test (b) Sieve analysis test.

3.2. Atterberg limits

The consistency of the investigated soils is evaluated using the Atterberg limits. The Liquid Limit (LL) and Plastic Limit (PL) for soil (A) and soil (B) were obtained using the Casgrande device and rolling plate. These parameters were determined in accordance with ASTM D4318 [23]. Fig. 5 displays the procedures of Atterberg limits test.

Fig. 5. The Atterberg limits test.

3.3. Specific gravity

The specific gravity of a soil sample is defined as the ratio of the unit weight of soil to the unit weight of water. This parameter was obtained for both studied soil by using the pycnometer in accordance with ASTM D854 [24]. Fig. 6 displays a part of the procedures of the test.

Fig 6. Heating the pycnometer on a hotplate.

3.4. Standard compaction

A standard Proctor compaction test was performed according to ASTM D698 [25]. 3500 gm of the investigated soil mixed with water at percentages (5, 8, 10, 20) % of dry weight for both soil (A) and soil (B). At each attempt the soil was compacted in the mold in three layers. Each layer was compacted with 25 blows by the rammer. From the wet unit weight of the soil and the corresponding water content (ω), the dry unit weight content was calculated as described in the following equation:

$$\gamma_{dry}=\gamma_{wet}/1+\omega \qquad (1)$$

Aspects of the experiment are demonstrated in Fig. 7.

Fig.7. Standard proctor compaction test.

3.5. PH test

The form and behavior of various compounds in the soil may be significantly impacted by the pH of the soil. Therefore, it is recommended that soil pH should be measured whenever other chemical constituents are to be evaluated. The pH test measures the hydrogen-ion concentration in soil-water. Soil pH is measured electrometrically on a 1:5 soil-water suspension at 25°C. Thus, a 20gm of soil weighting was put into a beaker, and 100 mL of deionized water was added.

A handheld digital pH meter called AD11, a waterproof pH and temperature tester sensitive to 0.01 pH, is employed. The pH buffer set and temperature unit can be chosen in setup mode. The tester is calibrated through two buffer solutions (pH 4.00 and 7.00). Therefore, the calibration (CAL) tag is displayed on the tester screen. Afterwards, measurements were taken for soil samples from the two locations before and after washing by submerging the tester electrode in the solution to be tested while gently stirring it. Measurements were recorded when the stability indicator disappeared. The pH value automatically compensated for temperature. The procedure recommended by (Soils, 1935) was followed. The procedure was repeated to ensure reliable measurements. Sides of the experiment are shown in Fig. 8.

Fig. 8. PH test.

3.6. Vane shear test

The shear strength of soil A was investigated; the contaminated soil specimen was compacted in three layers to achieve the maximum dry density and optimal moisture content that were gained from the corresponding compaction curve. The soil was mixed with distilled water. The soil paste was transferred to a cubic box of the length 18.75 cm, width 14.25 cm, and depth 6 cm (double feather depth). The soil sample was compacted in three layers by 120 blows for each layer. Afterward, the sample was sealed and left for about a week to ensure uniform water distribution over the contaminated specimen. The hand shear vane tester was utilized and the corresponding reading was taken from three different locations through the sample box. The readings were averaged to calculate the value of undrained shear strength. Fig. 9 shows the use of a vane tester to obtain the shear strength parameters.

Fig. 9. Undrained shear strength test.

4. RESULTS AND DISCUSSION

The basic features of the contaminated soils utilized in this study were summarized in Table 2.

Table 2. The identification of tested soil properties.

Soil	Gs	Mean Diameter of Particle (D_{50}) in micron	Atterberg Limits			Standard compaction		pH	Undrained Shear strength (kPa)
			LL %	PL %	PI %	MDD (gm/cm2)	OMC %		
Soil A	2.5	0.006	42	26.31	15.69	1.7	19.5	8.14	20
Soil B	2.25	3	21	11.43	9.57	1.72	7.25	6.95	
Washed soil A								7.89	

4.1. Grain size distribution

Analyzing the grain size distribution is crucial to understand the physical and chemical properties of the soil because it impacts the strength of the soil and its capacity to carry loads. The grain size distribution test was performed using the sedimentation test (hydrometer tests) for soil A, while the mechanical sieving was conducted on soil B. Fig. 10 illustrates the gradation analysis curves for both tested soils. It can be concluded that soil A can be classified as clay, while soil B can be classified as poorly graded gravel (GP). The uniformity of the soil particle size distribution was assessed by calculating the coefficient of uniformity (Cu). Cu for soil B is equal to 9.6, and Cc is found to be equal to 0.55, where CC is the coefficient of curvature. The mean diameter of particles (D50) for both soils A and B was 0.006 and 3 mm, respectively. It is expected that both soils were finer prior to contamination. It could be attributed that oil behaves as a viscous binder and covers the surfaces of silt and clay particles. then, several tiny particles group together to form bigger aggregates. Moreover, oil in soil makes the particles rougher and increases their size. This conclusion agreed well with that outlined in previous studies. However, this conclusion cannot be proven because of the difficulty of getting non-polluted samples and achieving a fair comparison.

4.2. Atterberg limits

The consistency limits of the polluted soils were examined according to ASTM [23]. The Casagrande apparatus was employed to measure the LL of the soils, and the thread-rolling method was used to identify the PL. Plasticity Index (PI) values were obtained too from the difference between the LL and PL. Table 3 summarizes the findings of Atterberg limits tests.

Table 3. Atterberg limits of soil (A) and soil (B).

Soil	**Atterberg Limits**		
	LL %	**PL %**	**PI %**
Soil A	42	26.31	15.69
Soil B	21	11.43	9.57

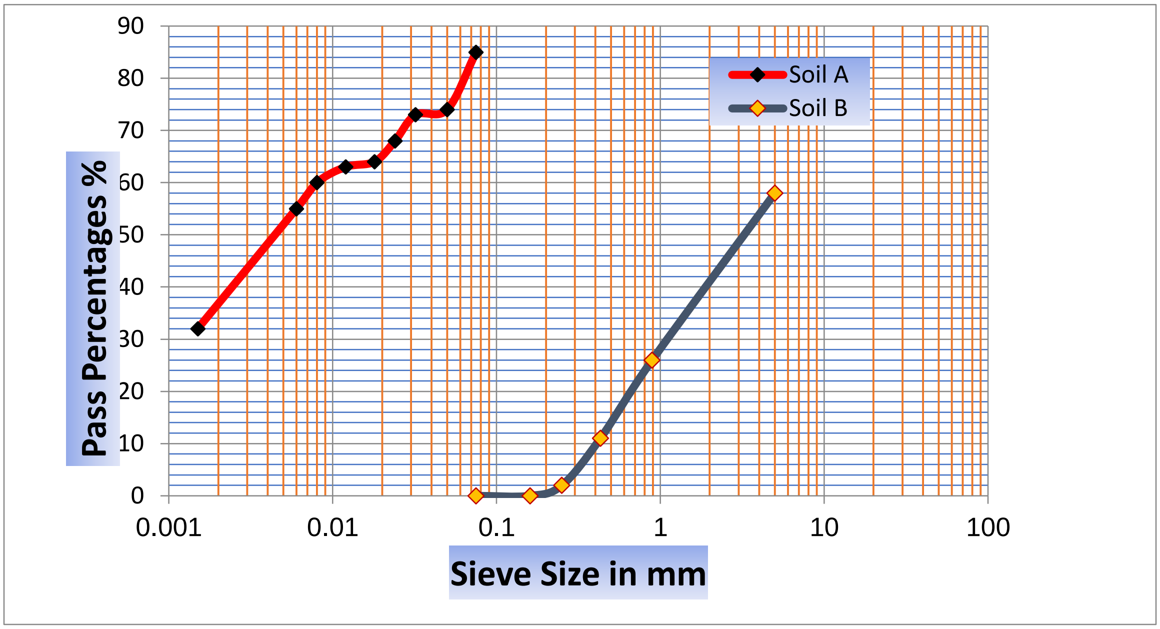

Fig. 10. The gradation analysis curves (hydrometer tests of soil (A) and (Sieve analysis tests of soil (B)).

4.3. Standard compaction

Compaction is the process of employing mechanical energy to remove air from the soil to reduce its void ratio. By reducing compressibility and increasing density, compaction enhances the quality of soil. The outcomes of the Proctor tests for soil A and soil B are presented in Fig. 11. For soil A, the associated curve shows an increasing in the dry density as the water content increases until reaching its maximum dry density of 1.7 g/cm3 at optimum moisture content of 19.5%. Afterward, the more water added, the lower the dry density. However, for soil B, the resulting compaction curve illustrates a decrease in dry density with the increase of water content. As a result, the maximum dry density was calculated as 1.72 g/cm3 at the optimum moisture content of 7.25%. The above behavior could be attributed to the mineral composition, particle size distribution, and texture of the soil samples. The presence of oil in the voids between the soil granules reduces the amount of water that the voids are supposed to accommodate, consequently minimizing the optimum water content.

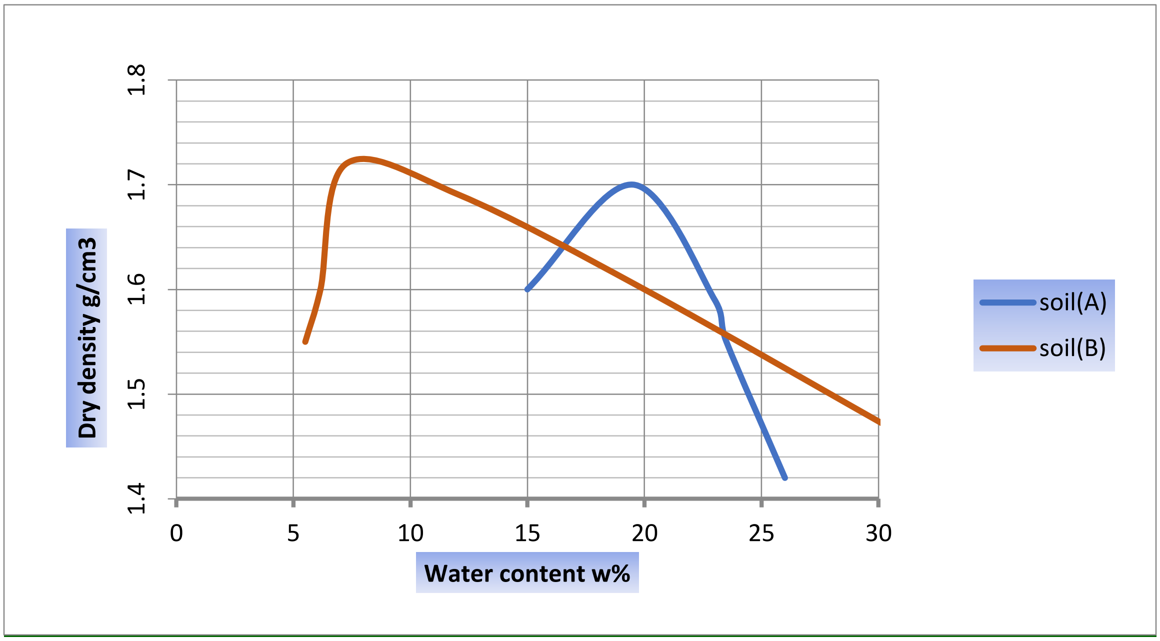

Fig.11. The compaction curves for the studied soils.

4.4. Specific gravity

The results obtained from the Gs experiments show that both contaminated soils (A and B) have a very low value of Gs, 2.5 and 2.25, respectively. This could be as a result of the organic composition of the polluted soils. It is worth mentioning that those results were significantly different from those found in previous literature because, in the latter and most of the cases, the soil was artificially polluted instead of being naturally polluted as the soil case in this study.

4.5. PH test

From the pH experiments, it is found that pH values for soil (A) and soil (B) are 8.14 and 6.95, respectively. Since it was reported in the previous literature that the pH decreases with the growing of hydrocarbon content. Thus, soil (B) was more contaminated than soil (A). After the manual washing of soil (A) with water, it was found that the washing process was inefficient because the pH value had slightly decreased. So, the chemical washing is required for decreasing the pollution percentage.

4.6. Vane Shear Test

The results obtained from the vane shear test showed that the contaminated soil (soil A) has the undrained shear strength of 20 kPa. This result can be deemed lower than expected compared to other types of similar fine soil. This behavior can be attributed to the effect of the pollution with oil, which can cause a decrease in soil particle cohesion.

5. CONCLUSION

The outcomes of the experiments demonstrated that the soil characteristics of both soils A and B showed an agreement with similar previous laboratory work and could be attributed to the degree of pollution and the soil texture.

Key findings that can be stated are as follows:

- The size of grains of soil (A) was finer than that of soil (B) due to the nature of soil and the change in the pollution percentages between the two investigated soils.
- The values of the Atterberg limits of the soil samples and their plasticity index were logical and fit very well with the previous work.
- The specific gravity experiments gave low ranges in comparison to the previous work; that could be as a result of the nature of the previous work, in which samples were mostly prepared artificially.
- The compaction characteristics of both soils illustrated that the maximum dry density of coarser soil (soil B) was greater than that of the Fine soil (soil A); oppositely, the optimum water content of soil (B) was far less than that of soil (A). That could be attributed to the quantity of oil contamination in both soils.
- The pH values obtained, as shown in Table 1 illustrate that soil (A) was more polluted than soil (B), as the value of pH gained for soil (A) was less than that of soil (B). A little drop in pH value of soil (A) was observed after washing with water for several weeks, which could reflect the inefficiency of soil washing as a treatment technique without using chemical surfactants.
- The findings of the vane shear test, which was accomplished for soil (A), show that the undrained shear strength (Cu) is 20 kPa, which can be considered a moderate value.

Comprehensive chemical investigations should be a part of future research to better link the observed changes in soil attributes with the chemical nature of the pollutant. It is recommended to investigate the behavior of a clean soil within the same sites and compare it with the present study findings. Furthermore, examining different types of soils, such as silty, and collapse soil, as well as the permeability of the polluted samples, is recommended to assess for knowing the behavior under seepage conditions. Furthermore, chemical substances are recommended to utilize for soil treatment.

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