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Research paper

Impacts of kerosene contamination on the geotechnical characteristics of cohesive soil

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Abstract

The soil contamination is a big problem which increased recently because of urbanization and development of industrial activities. The most common types of soil contaminants are petroleum products, fertilizers, heavy metals, pesticides, and organic compounds. This study focuses on the influence of kerosene on the chemical, physical, and engineering characteristics of cohesive soil. The soil samples are obtained from of a rural area in Al-Diwaniya city located in the south of Iraq. The soil samples are artificially contaminated with three ratios of kerosene (10, 30, and 50) % calculated based on the dry weight of soil. The process of contamination includes air dried the disturbed soil samples, then the soils samples placed in containers made from plastic and mixed with the field moisture content and the specified content of kerosene to ensure getting homogenous contaminated soil samples. The contaminated soil samples left for 30 days in plastic containers covered by nylon sheets to control the moisture content and the content of contaminant. A detailed testing program are conducted on these soil samples to determine the effects of kerosene on the chemical and geotechnical properties of silty clay soil sample. The results of tests proved that different percentages of kerosene have different influence on the chemical, physical, and mechanical properties of the tested soil samples.

Keywords: *Contamination; Kerosene; Clay; Soil; and Geotechnical Properties.*

1. Introduction

The development of industrial activities and urbanization produce very higher amount of gaseous wastes, wastewater and solid wastes which causes pollution of the environment. Soil contamination may be count as the presence of manmade chemicals in the natural soil medium. There are several types of materials causes soil contaminated are fertilizers, petroleum products, pesticides, heavy metals, and organic compounds. The different sources of soil contamination are oil fields, chemical plants, release of petroleum from a pipeline because accidents, refineries, leakage from storage tanks, the electric power plants and transport process. The soil contamination is important geo-environmental case that cause negative effects on the underground water, atmosphere and soil, especially the geotechnical properties of soil which responsible the stability of structures constructed on it or when used as structural material for embankments, earth dams, and so on. The influence of pollution depends on chemical composition of contaminate and soil properties. Oil contamination of soil causes changing the chemical and physical properties of soil. Also, the change in soil strata and engineering properties resulted in losing the bearing capacity and increasing the compressibility of soil. The oil contaminate depends on many factors such as specific composition of oil, soil type, adsorption properties, percentage of contaminated, and permeability of the soil. Several contaminated sites in Iraq resulting from military activities, combination of general industrial activities, looting and post-conflict damage.

Different of researchers have studied the influence of contamination in soil and study the change in the engineering properties of the soil such as Kermani and Ebadi (2012) who studied the influence of crude oil on the geotechnical properties of soil. This study showed increasing in the Atterberg's limits, angle of internal friction, maximum unit weight, and compression index as well as a decrease in optimums water content and cohesion with increasing the oil s in soil samples. Karkush et al. (2013) studied the influence of different contaminants on the geotechnical properties of intact cohesive soil. The contaminants were used (copper sulfate, kerosene, lead nitrate, and ammonium hydroxide). The process of soaking by contaminants continued for 30 day, where two percentage are used (10 and 25) % calculated from the dry weight of clay soil. The ammonium hydroxide had slight effects on the geotechnical properties of soil in comparison with kerosene, lead nitrate, and copper Sulfate. The ammonium hydroxide and kerosene make the particles of soil finer, but the copper sulfate and lead nitrate become coarser. The contamination causes increasing in plastic and liquid limits of soil samples except with lead nitrate. The collapse potential and initial void ratio are increased in the contaminated soils samples, while the sensitivity value, coefficient of consolidation parameters and the shear strength were decreased with increasing the concentration of contaminant in them soil samples. In the present study, the influence of several percentages of kerosene (10, 30, and 50) % calculated from the dry weight of soil sample on the chemical and geotechnical properties of soil samples have been investigated to measure the effects of these contaminant on the shear strength and compressibility of soil which responsible the stability of structures constructed on it.

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2. Influence of oil contamination on soil

The various types of contaminants and concentrations have diverse impacts on the geotechnical characteristic of soil, some of these effects are summarized below:

a) Decreasing the cohesion between soils particles with increasing the content of oil in soil (Kermani and Ebadi, 2012).
b) Reducing the permeability of soil with increasing the percentage of crude oil content in the soil (Elisha, 2012).
c) Increasing the initial void ratio with increasing the concentration of different types of contaminants (Karkush et al., 2013).
d) Decrease the specific gravity and optimum moisture content with increasing the percentage of crude oil in the soil (Akinwumi et al., 2014).
e) The shear strength and consolidation of soil are decreased with increasing the concentration of total petroleum hydrocarbons in the soil (Talukdar & Saikia, 2013; Karkush & Abdul Kareem, 2015; Karkush & Kareem, 2017; Karkush & Altaher, 2017).
f) The angle of internal friction (φ) is slightly increased with increasing the content of kerosene in the soil (Ali, 1999).
g) Decreasing the swelling pressure and liquid limit with increasing the content of kerosene and gas oil in soil (Al-Mashhidani, 1999).
h) Increase in the maximum dry density, angle of internal friction, Atterberg‟s limits, and compression index with increasing the crude oil percentage in the soil (Kermani and Ebadi, 2012; Talukdar, 2014).
i) Increasing CBR value, angle of the internal friction, and cohesions with mounting the crude oils content in the soil (Rasheed and Ahmed, 2014).

3. Sampling and contamination of soil

The soil samples used in the present study are obtained from of a rural area in Al-Diwaniya city located in the south of Iraq. The GPS coordinates of soil sample location are (UTM: 32N515276, 44E28102).

3.1. Soil sampling and classification

The soil samples are obtained from study area to determine the influence of kerosene on the chemical geotechnical properties of cohesive soil samples. The depth of sampling was 4.5 m from natural ground level and the groundwater table encountered at 4 m from the natural ground level. After the excavation, the undisturbed soil samples were gained by pushing Shelby tubes of 75 mm diameter and 300 mm length into the soil under hydraulic pressure. The undisturbed samples were covered by wax and nylon paper from top and bottom to control the moisture content as shown in Figure 1, while the disturbed soil samples are placed in taut polyethylene bags. The samples are labelled with necessary information and after that transported to the laboratory of soil mechanics at the University of Baghdad to use it in tests. The soil samples are classified as high plasticity clay (CH) according to the Casagrande's plasticity chart. The field tests include measuring natural moisture content and the field unit weight. The moisture content is 35% which measured according to the ASTM (D 2216) and the unit weight of soil in field is 17.98 kN/m^3 which measured according to ASTMs (D 29370-00).



Fig. 1: Soil Sampling in the Field.

3.2. Contamination process

The disturbed soil samples used in the process of contamination are firstly air dried, then the soils samples placed in containers from plastic and mixed with the field moisture content and the specified content of kerosene to ensure getting homogenous contaminated soil samples. The contaminated soil samples left for 30 days in plastic containers covered by nylon sheets to control the moisture content and the percentage of contaminant as shown in Figure 2. The soils samples are contaminated with three ratios of kerosene (10, 30, and 50) % determined based on the dry weight of soil. The designation of tested soil samples is explained in Table 1.



Fig. 2: Preparation of Contaminated Soil Samples.

Table 1: Designation of Tested Soil Samples

Soil sample	Description
C0	intact soil sample
C2	Soil sample contaminated with 10% of Kerosene
C4	Soil sample contaminated with 30% of Kerosene
C6	Soil sample contaminated with 50% of Kerosene

4. Testing of soil samples

Chemical, physical and mechanical properties tests are performed on intact and contaminated soil to determine the alteration of geotechnical properties in soil due to the effect of Kerosene on it. The tests were executed in University of Baghdad/Civil Engineering Department. The soil samples are tested according to ASTM standard (ASTM, 2003). The summary of testes conducted on soil samples are listed in Table 2.

Table 2: Tests Conducted on Soil Samples

Type of test	Property	ASTM Standard
Chemical	pH value	D 4972
	Chloride content (Cl^-)	D 512 A
	Three sulfate ions (SO_3)	D 516
	Total dissolved solids (TDS)	D 5907
	Calcium oxide content (CaO)	D 4373
	Sodium content (Na)	D 4191-03
	Gypsum content	D 518
Physical	Particle size distribution	D 422
	Atterberg's limits (LL and PL)	D 422-63
	Specific gravity (Gs)	D 854
	1-D Consolidation test	D 2435
Mechanical	Unconfined compressive strength test (UCS)	D 2166
	Unconsolidated undrained triaxial test (UUT)	D 2850-95

5. Results and discussion

The contamination by kerosene has different effects on the chemical, physical, and mechanical properties, these effects varies from slight on the chemical and physical to significant on the mechanical properties of cohesive soils which controls the shear strength and compressibility of soil.

5.1. Results of chemical tests

The results of chemical tests conducted on the intact and contaminated soil samples are given in Table 3. The pH is a measure of the activity of the hydrogen ion where the clay minerals surfaces carry negative chargers and the edge of clay particles usually have a positive charger at low to moderate pH, but increasing pH may change into negative charge. The pH value of soil increases with increasing the content of kerosene in soil due to decreasing the exchange capacity of cation and the contamination in soil causes accumulative in exchangeable bases and decrease in exchangeable acids (Benka-Coker and Ekundayo, 1995; Ekundayo and Obuekwe, 1997; Osuji and Onojake, 2006; and Ag-bogidi et al., 2007).

The result of tests showed significant increasing in the magnitudes of chloride ions (Cl^-) and total dissolved solids (TDS) with increasing the content of kerosene in the soil. Three sulfate ions (SO_3), calcium oxide (CaO), and gypsum are decreased with increasing the content of kerosene in the soil, but increasing the content of kerosene in soil above 10% causes slight increase in these compounds in comparison with the content of intact of these compounds.

Table 3: Soil Samples Coding

Soil Sample	pH	SO_3 %	Cl^{-1} %	CaO %	Gypsum %	TDS %
C0	8.58	0.92	0.5	0.64	1.978	3.92
C2	8.61	0.64	0.78	0.45	1.376	4.08
C4	8.59	0.92	0.78	0.64	1.978	4.64
C6	8.62	0.94	0.79	0.67	2.021	4.66

The results of X-ray diffractions tests showed that the predominant minerals are quartz, calcite, illite, and albite and the minor are kaolinite, calcium sulfate dehydrated gypsum, montmorillonite, and calcium magnesium carbonate dolomite. The content of some minerals such as calcite, quartz, calcium sulfate dehydrated gypsum, albite, illite, and calcium magnesium carbonate dolomite showed different contents with increasing the concentration of kerosene. The content of kaolinite, montmorillonite and palygorskite are decreased with increasing the percentage of kerosene in soil samples.

5.2. Results of physical tests

The physical tests conducted on the intact and contaminated soil samples are specific gravity, Atterberg's limits, particle size distribution, and the compaction tests. The results of Atterberg's limits tests showed the values of liquid and plastic limits are slightly increased in the contaminated soil samples, while the plasticity index value remains approximately constant as shown in Table 4. The chemical composition of contaminant will reaction with the mineral composition of soil and causes alteration in composition and structure of the trellis of the clay mineral and the kerosene will remove the organic matter form interlayer of montmorillonite, so the water molecules to reach the double-layer water needs more water to achieve to the plastic limit and the liquid limits.

Table 4: Soil Samples Coding

Soil Sample	LL %	PL %	PI %	Silt %	Clay %	Classification
C0	72	31	41	60	40	CH
C2	74	33	41	57	43	CH
C4	76	34	42	56	44	CH
C6	78	36	42	50	50	CH

The results of specific gravity of tested soil samples are given in Figure 3. The specific gravity of contaminated soil sample decreased with increasing the content of kerosene in the soil sample, where kerosene has density less than soil and water. Also, kerosene will adsorb by the particles of soil which causes lowering in the density of soil and the covering of soil particles with kerosene causes increasing the size of soil particles.

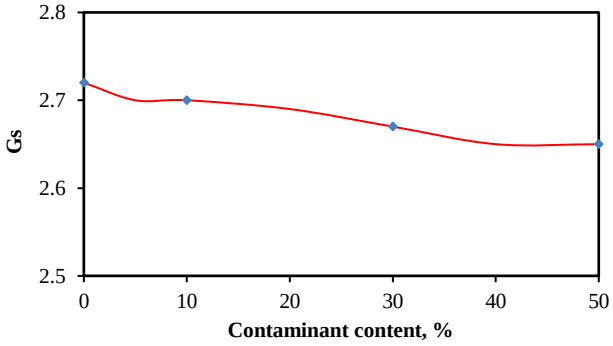


Fig. 3: Variation of Specific Gravity with Kerosene Content.

The particle sizes distribution curves are shown Figure 2 and percentages of silt and clay are given in Table 4. The results of test shown the particles soil become coarser after contamination, thus increasing the percentages of contaminant in the soil will causes decreasing the percentages of finer particles. The kerosene will adsorb on the surface of particles and causes coating these particles and increasing their sizes so it will be shifted from finer to coarse, but the change in percentage of finer is slightly. Also, the results of tests showed decreasing the time required for sedimentation the particles in hydrometer analysis with increasing the percentage of kerosene in the soil due to decreasing the percentages of finer particles, this action will increase the rate of sedimentation.

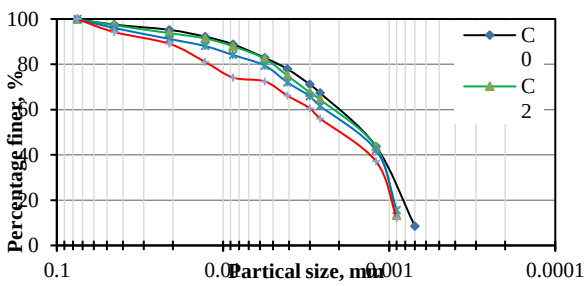


Fig. 4: Particle Size Distribution Curves of Tested Soil Samples.

5.3. Results of mechanical tests

The mechanical properties of intact and contaminated soil samples are measured by one dimensional consolidation test, unconfined compressive strength test, direct shear test, and unconsolidated undrained triaxial test. The parameters determined by 1-D consolidation test are the coefficient of volume compressibility (m_v), initial void ratio (e_o), final void ratio (e_f), coefficient of permeability (k), coefficient of consolidation (c_v), compression index (c_c), swelling index (c_s) and recompression index (c_r). From the results of 1-D consolidation tests listed in Table 5, the values of initial and final void ratio decreased with increasing the content of kerosene in soil samples due to decreasing the percentage of fine particles in the soil matrix. The coefficient of consolidation (c_v) decreased due to changing the structure of clay minerals that may occur because the interaction between the clay particles and kerosene. Also, this decrease can be attributed to the reduction of void ratio which causes decreasing the permeability and this causes increasing the time required for consolidation.

The coefficient of volume compressibility increased with increasing the percentage of kerosene due to change the bonding between the particles during the compaction of the soil and because the change of particles size affected by kerosene. The contamination of soil with kerosene will lead to increase the compression index due to decreasing the bonding forces between the particles of soil so less load produces greater consolidation, while the swelling index decreased with increasing the percentage of kerosene due to the force between the particles not enough to return the soil to its original state as it was in intact soil. The permeability of soil samples calculated theoretically from the results of oedometer tests showed decreasing the permeability with increasing the content of kerosene in the soil samples due to decreasing the connected void ratio so the rate of water flow will be reduced.

Table 5: Compressibility Characteristics of Tested Soil Samples

Soil Sample	e_o	e_f	c_c	c_r	c_s	$m_v\times10^{-2}$ m^2/kN	$k\times10^{-5}$ cm/s	$c_v\times10^{-3}$ cm^2/s
C0	1.03	0.8	0.166	0.1	0.066	0.26	0.1844	7.23
C2	0.87	0.58	0.199	0.13	0.053	0.32	0.1953	6.22
C4	0.59	0.29	0.232	0.15	0.038	0.42	0.1636	3.97
C6	0.48	0.15	0.298	0.185	0.03	0.45	0.0914	2.07

The shear strength of soil depends on the particle–size distribution, nonclay mineral, clay minerals, shape of the particles, and the arrangement of the particles. Three tests are conducted on intact and contaminated soil samples to determine the impacts of kerosene on the shear strength parameter. These tests are unconfined compressive strength test, direct shear test, and unconsolidated undrained test. The undrained compressive strength (c_u) obtained from the unconfined compressive strength tests is decreased significantly with increasing the kerosene content in the soil. The sensitivity of soil sample is 2.58, so the soil sample is considered of medium sensitivity (Skempton et al., 1952; Rosenquist, 1953) which means the disturbance of soil has medium effects of the geotechnical properties of soil sample. The values of cu decreased by 3-59% in the soil samples contaminated by 5-50% of kerosene. The kerosene worked as lubricant agent and causes sliding the soil particles each over another, and this causes failure in short time. These results well agreed with those obtained by Ijimdiya and Igboro (2012) and Karkush et al. (2013). The variation of stress with axial strain for the tested soil samples is shown in Figure 5 and the undrained shear strength of soil samples is given in Table 6.

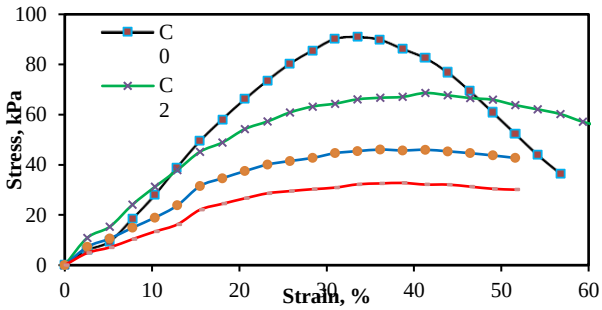


Fig. 5: Variation of Stress with Axial Strain of Tested Soil Samples.

Table 6: Shear Strength of Tested Soil Samples

Soil Sample	UCT c_u kPa	DST c_u kPa	DST φ^o	UUT φ^o
C0	32.0	53	21	96
C2	26.5	36	18	81
C4	18.5	23	15	53
C6	13.0	18	10	41

The cohesion and the angle of internal friction obtained from direct shear test are decreased with increasing the content of kerosene in the soil samples due to the lubricating effects of kerosene when coating the soil particles and weakened the bonds between the particles of soil and facilitation the sliding of soil particles over each other as shown in Table 3. The coating of kerosene for soil particles may causes decreasing the specific surface area and the contaminant may causes decreasing the cation exchange capacity in clay (Ur-Rehman et al., 2007). The contamination of soil with kerosene will lead to decrease the adsorption of water molecules on the clay particles surface and the contact of water with soil particles will reduced, thus leads to lowering in cohesion. From the results, the decreases in cohesion ranged 22.6 to 66% and in the angle of internal friction ranged 4.7 to 52.3% in the soil samples contaminated with kerosene ranged 5-50%. The reduction in cohesion is larger in reduction in angle of internal fiction because the soil samples are considered cohesive samples.

The undrained shear strength of soil calculated from unconsolidated undrained triaxial tests is decreased in contaminated soil and this reduction increases with increase the percentage of kerosene in soil. The kerosene in soil causes reduction in shear strength because it's viscosity less than water and this action helps in sliding the particles of soil more than water's action. The kerosene helps in removing of organic matter (OM) which acts as cementing material bonding the particles of soil together as shown in Table 6.

6. Conclusions

The main objective of the present study is to investigate the influence of several percentages of contamination by kerosene on the the chemical, physical, and mechanical characteristics of silty clay soil. The influence mainly depends on content of kerosene in the soil, where the kerosene causes:

- Increasing the values of chloride ions (Cl^{-1}), pH, and total dissolved solids (TDS), but the values of gypsum, three sulfate ions (SO_3) and calcium oxide (CaO) are decreased until percentage 10% of kerosene and continues to increase after that ratio.
- The X-ray diffractions tests are shown some of minerals decreases with increasing the kerosene but other minerals shown variable contents.
- The values of liquid and plastic limits are slightly increased with increasing the percentage of kerosene in soil while the value of plasticity index remains approximately constant.
- The kerosene makes the particles of soil coarser than in intact soil.
- Decreasing the values of initial and final void ratio, swelling index, permeability and the coefficient of consolidation,

while the compression index and the coefficient of volume compressibility are increased.

- Significant decreasing in the unconfined compressive strength of soil. Also, the same trend noticed for the cohesion and the angle of internal friction between soil particles measured by direct shear test.

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