

STUDY OF IN-SITU AND LABORATORY HYDRAULIC CONDUCTIVITY OF CONTAMINATED SOIL WITH OILY WASTEWATER

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ABSTRACT

This study aims to investigate the effect of contaminated soil samples with oily wastewater which were taken from Kawergosk refinery (20 km west of Erbil city). Laboratory constant head permeability tests on contaminated soil samples with oily wastewater have been conducted. Also, One-Dimensional (1-D) and Three-Dimensional (3-D) in-situ permeability tests were performed. A noticeable decrease in the values of hydraulic conductivity coefficient (k) have been observed for Contaminated Soil Samples comparing with uncontaminated samples. Results of hydraulic conductivity coefficient obtained from one dimensional consolidation tests were increased with increasing of applied stresses. The results of field permeability tests revealed that the surrounding lands of Kawergosk refinery lies within the range of semi-permeable area for urban development while the majority part of the area lies within the range of moderate area for agricultural and conservation purposes.

KEYWORDS: Soil contamination; Permeability; Oily wastewater; soil pits; consolidation

1. INTRODUCTION

The increase of the industrial wastes, especially in the petroleum industry leads to many environmental pollution problems such as air, water and soil. Regarding the soil contamination, a various geotechnical characteristic change has been observed in the surrounding areas of oilfields and refineries. The main source of oil pollution is from the oil spill leakage in the oilfields and during transportation through damaged and old pipelines in the refinery. The source of the polluted oil is somehow difference if it comes from the transportation of oil products by trucks during accidents and leaks from the truck itself as this traditional way is widely used to reach the end-users. On the other hand, the riskiest source

of oil pollution in the refineries is in the untreated wastewater (Oily wastewater), which will be released from some refineries to the nearby area; this type of pollution has been widely observed in this investigation. Before this study, the effect of Kawergosk refinery wastewater on surrounding water resources has been studied. (Aziz and Fakhrey (2016), in their study about the effect of Kawergosk oil refinery on surrounding water resource they have observed high pollutants in the refinery wastewater treatment plant.

The degree of soil contamination depends on Oily wastewater properties, (Fine et al, 1997). The influence of the various oil products on the geotechnical properties of soils have been studied by many researchers, (Abdul-Resol, 1999; Al-Sanad & Ismael, 1997; Karkush &

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Kareem, 2017; Khamehchiyan, Charkhabi, & Tajik, 2007).

In general, adding oily wastewater to the soil induces a small reduction in permeability due to the properties of the additives, because the first contact of the oil will be with the soil particles and decreases void ratio which in turn reduces hydraulic conductivity, (Akinwumi, Diwa, Obianigwe, & Research, 2014; Rahman, Hamzah, Taha, Ithnain, & Ahmad, 2010; Ur-Rehman, Abduljawwad, & Akram, 2007), found that k values obtained from consolidation tests for laboratory contaminated soil samples

varied with variation of applied stresses, this results have been noticed already by other researcher (Khamehchiyan, Hossein Charkhabi, & Tajik, 2007; Shah, Shroff, Patel, Tiwari, & Ramakrishnan, 2003).

2. MATERIALS AND METHODS

The polluted areas around the refinery (especially the west side, where most villages exist there) are shown in Figure (1). The contaminated soil samples with oily wastewater were taken from the outlet of the Kawergosk refinery units that contain more than 80% water.

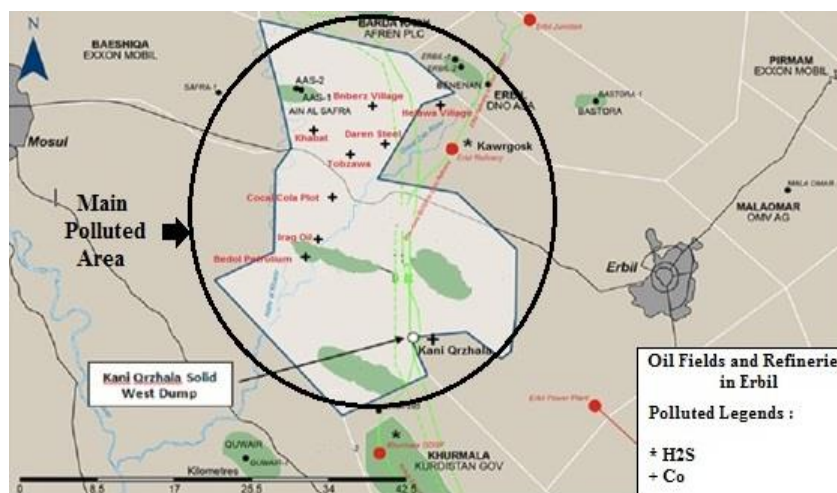


Fig. (1): polluted map in Kawergosk area

Which the physical and compressibility characteristics were determined and given in Table (1) while the specifications of oily wastewater are given in Table (2). The experimental works in this study includes;

- *Field permeability tests for contaminated soil with oily wastewater
- *Laboratory permeability tests for contaminated soils using, Falling head method.

*One dimensional consolidation test method.

In-situ permeability tests were carried out in two pits, 30 cm diameter and 50 cm depth, inside one of these pits a steel pipe has been fixed for measuring one-dimensional penetration (diffusion), while the other one was used for measuring a three-dimensional penetration of oily wastewater.

Table (1): The characteristics of investigated soil sample

Properties		Soil Sample
Field water content (m)%		5.6
Specific Gravity (Gs)		2.7
Atterberg limits	Liquid Limit (LL), %	37.8
	Plastic Limit (PL), %	14.7
	Plasticity Index (PI), %	23.1
Particle size distribution	Gravel, %	4.0
	Sand, %	26
	Silt, %	24
	Clay, %	46
Unified Soil Classification		Sandy lean clay (CL)
Field density (ρ_t) gm/cm ³		1.40

Table (2): The physical properties of oily wastewater

Test	Unit	In-let	FAO 1992standards for irrigation	Turkish standards for irrigation	WHO 2011, standards for drinking water
ECw	µs/cm	1745	700-3000	700-3000	1000
TDS	ppm	872.5	450-2000	500-2000	500
Calcium (Ca)	ppm	5	20	20	200
Magnesium (Mg)	ppm	3.13	60	30	30
Sodium (Na)	ppm	14.11	900	900	200
Chloride (Cl)	ppm	0.33	4-10	4-10	5
Iron (Fe)	ppm	2.3	5	0.1-1.5	0.3
Nitrate (NO ₃)	ppm	26	5-30	10-30	50
pH		9.4	6.5-8.4	7-8	6.5-9.5
Oil	%	15			
Water Content %	%	85			

The oily wastewater has been spilled into the two pits at the same time and the rate of penetration (diffusion) were recorded until the disappearance of the oily wastewater, then the k

values were determined (ASTM D6391 -2011). Figure (2) shows one- and three-dimensional diffusion rates for examined soil.

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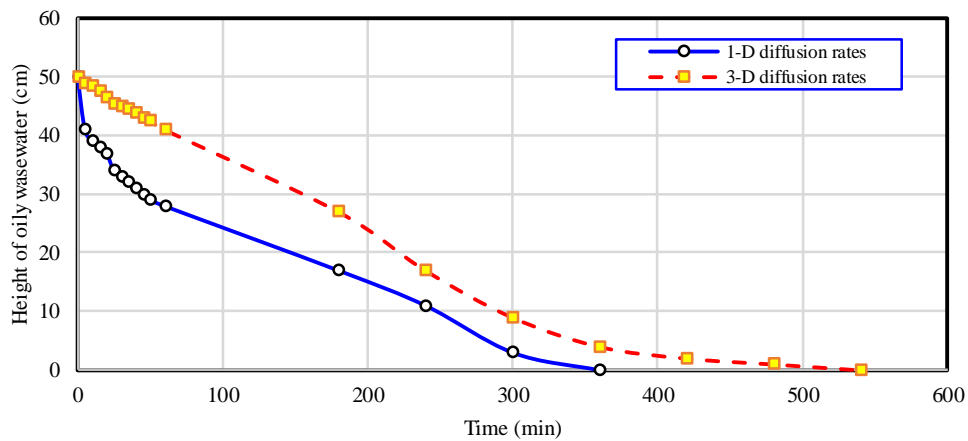


Fig. (2): One- and three-dimension diffusion rates

Results of k values have been determined, (ASTM D6391- 2011), using this Equation (1);

$$k = [(D/2) * \ln (h_1/h_2)] / 2(t_2-t_1) \quad (1)$$

Were; $(D/2)$ is the radius of the hole in meters. In refers to the natural logarithm, $(h_1$ and $h_2)$ are the two consecutive depths of oily wastewater in

meters. $(t_2- t_1)$ expresses the time interval between two consecutive measurements in seconds. The value of k is in m/sec (neglecting the effect of viscosity of the oily waste water, because it contains less than 15% waste oil). Test results are shown in Table (3).

Table (3): The 3D field permeability test results (Diameter of hole = 40 cm)

Elapsed time (min)	Height of wastewater in the Hole (H) (cm)	Change in Height with time (ΔH) (cm)	k (m/sec)
0	50	0	6.73424E-06
300	49	1	3.41883E-06
600	48.5	1.5	6.9447E-06
900	47.5	2.5	7.09247E-06
1200	46.5	3.5	7.24666E-06
1500	45.5	4.5	3.68328E-06
1800	45	5	3.72443E-06
2100	44.5	5.5	3.76652E-06
2400	44	6	7.66317E-06
2700	43	7	3.89868E-06
3000	42.5	7.5	5.80188E-06
3600	41	9	5.80188E-06

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10800	27	23	1.28507E-05
14400	17	33	1.76664E-05
18000	9	41	2.25258E-05
21600	4	46	1.92541E-05
25200	2	48	1.92541E-05
28800	1	49	1.92541E-05
32400	0	50	1.92541E-05

Note: k value for the field test is 1.92541E-05 m/sec.

At the end of the tests, the samples were taken from the base and sides of the two holes for examining laboratory falling head permeability tests. Regarding the laboratory tests for the determination of k values, a contaminated soil samples have been investigated in the laboratory, for conducting permeability tests (falling head method). The remolded soil sample was prepared in the lab, having the same field density inside the permeability mold. Oily wastewater has been used instead of water for the test; this process is similar to the one that had been conducted in the field.

Laboratory permeability tests were carried out using falling head method (ASTM D 5084-03), in this test the oily wastewater was used instead of water on remolded soil samples by duplicating initial water content and field density for comparison purposes of field and laboratory tests. Another set of laboratory falling head permeability tests were carried out on contaminated soil samples with four different percentages (5%,10%,15% and 20%) of oily wastewater, in order to investigate the effect of pollution percentage on the k value and also to be used as a base for estimating the degree of contamination of the soils in the field.

Finally, one-dimensional consolidation tests have been carried out (ASTM D 2435) on laboratory polluted soil samples with oily wastewater for the purpose of comparing of the k values with field permeability tests, and to what extend the small-scale laboratory tests represent the field performance of contaminated

soil with oily wastewater, this is important for the surrounding areas of the refineries in which they are usually subjected to oily wastewater pollutions.

3. RESULTS AND DISCUSSIONS

Refer to Table (1), the physical characteristics and Table (2), the oily wastewater properties, the contaminated soil samples with oily wastewater have been investigated regarding its penetration (diffusion) through sub soils. From the results obtained in the diffusion rate curves, Figure (1) and k values obtained from Table (3), it can be observed that higher values are seen for 3-D penetration because the oily wastewater spreads in all directions and took less time until the oily wastewater disappear in the pits. because of the 3-D field diffusion which is most likely are occurred on the polluted lands, determination of field permeability or (field diffusion) becomes necessary.

Regarding the results of in-situ permeability test values, Table (3) for field contaminated soil samples with oily wastewater, the results of 3-D filed permeability (1.92541E-05 m/s) shows that the field clay soil is within the range of low permeable for civil engineering purposes (ASTM, D 6391, 2011; Ishibashi & Harazika, 2015), and within the range of moderate for agricultural and conservation purposes, the effect of oily wastewater on the contamination of existing soil would be seen in long and medium-term periods.

The word diffusion could be better to use

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instead of permeability, due to the Viscosity effect, although this factor has a small effect, because the refineries oily wastewater contained more than 80% of water. The permeability result obtained was (0.272 E-3 cm/sec =0.0063E-5m/year). Details of the test results are shown in Table (4).

Table (4): Laboratory permeability test results for field

ΔH (cm)	Time (sec)	$k (\times 10^{-3})$ cm/sec	Modified k for 19c° cm/sec
23	24.56	0.2498	0.2374
26	13.57	0.1427	0.1355
32	27.65	0.5139	0.4882
33	53.5	1.2615	1.1984
52.5	20.66	0.6372	0.6053
31	28.44	1.227	1.1656
24.5	44.65	1.948	1.8506
30	44.63	2.3249	2.2086
22	18.43	1.3363	1.2694
36	21.78	0.7315	0.6949
29	14.22	0.2566	0.2437
34	46.57	1.864	1.7708
24	17.25	1.0143	0.9635
45	27.75	0.431	0.4095
Modified Value of $k = 0.272 \times 10^{-3}$ cm/sec,			
Average value of $k = 0.285 \times 10^{-3}$ cm/sec			

Another method for preparing a contaminated soil samples have been used for determining k values, by contaminating the samples with various percentages of oily wastewater (5%, 10%, 15% and 20%), then conducting a falling head permeability method for determining k values. For comparison purpose with the other values of k , the results are shown in Table (5). The results obtained from the Table, it can be noted that k values decreases with increase of the percentage of the contamination, this phenomenon happened also for field contaminated samples, this is because of the fact that the oil wastewater will enter the voids between the soil particles and hence reduces the void ratio which intern reduces the hydraulic conductivity. According to the values obtained in the Table (6), that shows a comparison between k value results obtained from consolidation test for uncontaminated soil samples for both laboratory and field samples. From the Table it can be noted that the laboratory results decreased by 15%, this could be because of the test procedure. A comparison between the results of k for a laboratory contaminated soil samples with oily wastewater and the field test shows that the contamination was within the range of 10%.

Table (5): Falling head method k values for laboratory contaminated soil samples

Percentage of contamination	0%	5%	10%	15%	20%
$k (X 10^{-6})$ in (m/year)	2.0659	0.951	0.643	0.412	0.348

Table (6): *k* values for uncontaminated and contaminated soil samples

Falling head permeability tests for	<i>k</i> ($\times 10^{-6}$) (m/year)
Uncontaminated soil sample	2
Laboratory contaminated soil sample	0.08
Field contaminated sample	0.6

A serial of 1-D laboratory consolidation tests and field permeability for contaminated soil samples have been carried out for determining *k* values and comparing the results with the other results obtained before. Results of laboratory contaminated soil samples are illustrated in Figure (3), it can be observed that *k* values decreases with increasing degree of contamination, for all applied stresses especially for highest one in which the significant increase

were (0.002) for all contaminated percentages .In general, adding oily wastewater to the soil induces a small reduction in permeability (*k*), due to the properties of oily wastewater mixture, because the first contact of the oil will be with the soil particles and decreases the volume of voids. Our results agree with the investigations of, Rahman et al. (2010) also agrees with the work of Akinwumi et al. (2014)

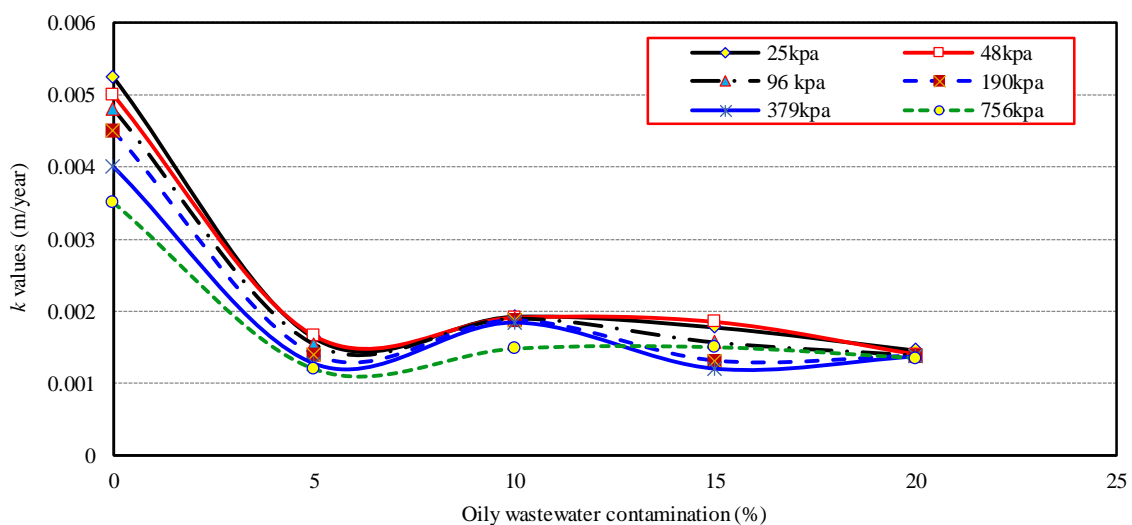


Fig (3): Effect of surcharge pressure on *k* values for different percentage of oily wastewater contamination by Odometer test.

Results of *k* obtained from consolidation test for field contaminated samples (1-D and 3-D diffusion rates) and comparison between their *k* values with *k* values from the laboratory consolidation tests are given in Table (7). The Tables illustrates that the *k* value decreases for both field and laboratory contaminated soil samples obtained from field permeability and

consolidation tests respectively, especially for high-applied stresses. The reason for that is, because the voids were partially filled with oil which at the end rejects the movement of the fluid. Similar results were obtained by other researchers, (Akinwumi et al., 2014; Ur-Rehman et al., 2007).

Table (7): Comparison between (k) values obtained from consolidation test of field and laboratory contaminated soil samples

Stresses (kPa)	k values for filed Permeability samples (m/year)			k values for contaminated soil samples for consolidation test (m/year)				
	1-D V	3-D V	3-D H	0%	5%	10%	15%	20%
25	0.0157	0.02	0.0094	0.00525	0.00163	0.00193	0.00178	0.00146
48	0.0156	0.0012	0.009	0.005	0.00160	0.00191	0.00185	0.0014
96	0.0122	0.0011	0.012	0.0048	0.00154	0.00190	0.00157	0.00139
190	0.0112	0.0366	0.0065	0.0045	0.0014	0.00187	0.00131	0.00138
379	0.0111	0.003	0.0111	0.004	0.00127	0.00184	0.0012	0.00137
756	0.011	0.0028	0.011	0.0035	0.0012	0.00148	0.0015	0.00135

Finally comparing the results of k for field and laboratory contaminated soil samples obtained from permeability falling head method with those obtained from consolidation tests, shows a considerable increase for consolidation results that is most possibly due to applied stresses during consolidation test procedure.

4. CONCLUSIONS

In this study the following conclusions have been made,

1. In general, adding oily wastewater to the soil induces a considerable reduction in permeability for both field and laboratory falling head and consolidation methods.
2. Results of permeability obtained from consolidation tests in general have decreased with increasing stresses, for both field and laboratory soil samples.
3. The k values for laboratory contaminated soil samples that obtained from falling head permeability methods are inverse proportional with the percentages of contamination with oily wastewater, because the first contact of the oil will be with the soil particles which reduces the porosity.

4. The results show that the degree of oily wastewater contamination of the in-situ Kawergosk refinery was between 10%-15%.

5. Regarding the results of field permeability test values, for field contaminated soil samples with oily wastewater, the results of 3-D filed permeability, showed that the field clay soil is within the range of low permeable for civil engineering purposes, and within the range of moderate for agricultural and conservation purposes, it can be observed that the effect of oily wastewater on the contamination of existing soil would be seen in long and medium-term periods.

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