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Characterization of Oil Contaminated Soil

Kuwait Oil Lakes

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Abstract—**During the Gulf War (1991) more than 600 oil wells were set on fire. The gushed oil from Kuwait wells created what is known as oil lakes by filling natural depressions in the topography and artillery trenches which even contain live ammunition. Since the liberation of Kuwait, individual efforts tried to decontaminate the soil with only partial successes. Recently, a joint project between the United Nation Compensation Commission (UNCC), Kuwait National Focal Point (KNFP), and Kuwait University (KU) has been initiated to conduct a comprehensive work to eliminate the contaminated soil and its environmental impacts. The objective of this study is to characterize oil contaminated soil by the assessment of its physical, chemical, and geotechnical properties. The results estimate the contaminated volume to be between 16.5×10^6 m^3 and 22.7 ×10^6 m^3, and show that its physical properties were heavily deteriorated and chemical characteristics were highly affected as well as the geotechnical properties due to the presence of oil.**

Keywords-Kuwait,* *oil lakes; oil contaminated soil charactaristics

I. INTRODUCTION

The State of Kuwait lies at the northwestern corner of the Arabian Gulf; it covers an area of about 17,818 km^2 and is bordered by the Republic of Iraq from North and West, and to the South and South-West by the Kingdom of Saudi Arabia. Kuwait has an approximately 290 km of coastline (Arabian Gulf) on the East. The state contains a total of 10 oil fields, which include 909 oil wells, divided based on their location into southern and northern parts. The northern oil fields include Ratga, Raudhtain, Sabriay, and Bahra, fields containing 143 oil wells. The southern oil fields are Ahmedi, Burgan, and Maqwa, which are grouped together to form the "Greater Burgan" oil filed. Along with Greater Burgan oil field, Minagish, Umm Gudair, and Wafra are also southern fields, where altogether, the southern fields, contain 766 oil wells. After the Gulf war in 1991, it was estimated that 613-798 oil wells were set on fire, 76 were gushing oil, 99 were damaged, and 155 remained in intact .Approximately 20-25 million barrels of ignited crude oil were extinguished using 12 billion gallons of seawater collected in artificial pounds. The accumulated spilled oil in the slightly depressed area of Kuwait desert formed over 300 large spots consisting a mixture of water (28% on average), salt (more than 10%), oil and sand which are called "oil lakes" distributed as shown in Fig. 1. As a result, 114 km^2 of the Kuwait desert was contaminated with oil causing environmental problems for air, land, coast, ground water, and surrounding life. Fortunately, Kuwait Oil Company (KOC) recovered approximately 21 million barrel of the oil lakes since the liberation of Kuwait leaving 34–49 km^2 of oil lakes with (16.5-22.7) ×10^6 m^3 in volume. The aim of this paper is to characterize the oil lakes based on its type, physical, chemical, and geotechnical properties in addition to its level of contamination.

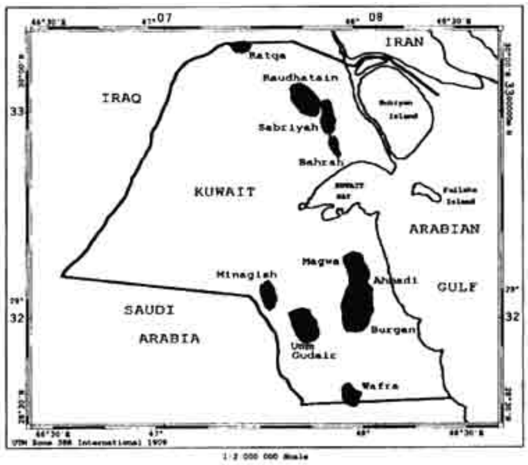

Figure 1. Oil lakes distributions in Kuwait

II. OIL LAKES CHARACTERISTICS

A. *Oil lake types*

Oil lakes vary in their type, area, volume, and depth of penetration. They differ in type due to the different formation condition. Studies categorized them into four types [4]:

1) *Wet oil lakes contamination* which is formed in areas of shallow depression and drainage channels. It's

described as black, highly weathered and viscous liquid or semi-solid oil sludge over a thickness of oil-contaminated soil that in turn overlies clean soil.

2) *Dry oil lakes contamination:* occurs in shallow depression and flat areas and it is comprised of a black, moderately hard, tar-like dry surface layer overlying dark brown oil contaminated soil that in turn overlies clean soil.
3) *Oil-Contaminated piles:* occur when earthmoving equipment has been used to consolidate oil-contaminated and/or liquid oil into mound. These piles were made to stop the flow of oil from Kuwait wells, to clean areas of heavy oil contamination to facilitate fire-fighting or subsequent KOC field operation.
4) *Oil trenches and associated oil spill* which consist primarily of oil-contaminated soil from back-filled trenches. Including in this category are oil-contaminated soils associated with oil spills from Iraqi-constructed pipelines.

Table 1 shows the type of contamination in term of effected area, volume, materials, and depth of penetration represented from several studies. The data indicates that the majority of Kuwait oil lakes are represented in dry oil lake while the least contaminated volume is occupied by the Tarcrete. It also shows that the dry oil lakes have a maximum penetration of 25 cm while trenches have more than 3 m.

B. Oil Lakes Distribution, Dimension, and Extent:

Oil lakes were formed in nine major oil fields with different contamination volume (Fig. 2). Burgan field corresponds to the largest contaminated field, it account for 40% of the total contaminated volume, hence, it was chosen as a case study for this research. Burgan's oil lakes dimensions and extent are listed in the Table 2.

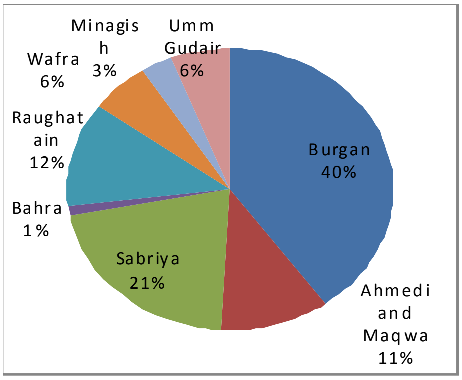

Figure 2. Oil fields contaminated volume

III. Oil Lakes Properties

A. Physical and Chemical Properties:

Soil properties are categorized into physical, chemical and geotechnical properties. In this study physical and chemical properties of Burgan soil were analyzed while the geotechnical properties were found for similar soil sample. Physical Properties were determined for different soil layers in Burgan area (Table 3). The soil was characterized with extremely low permeability [(1.15 – 10) × 10 $^{-6}$ m/sec] due to the presence of oil deposit on the top layer. This hydrophobic layer prevents water penetration. On the other hand, soil chemical properties were examined by evaluating eight ions concentrations and other chemical properties (Table 4). Results indicate the high availability of several ions (Ca^{2+}, Mg^{2+}, K^+, Na^+, and Cl^-). This is possibly due to the formation and seawater used for fire extinguishing.

B. Geotechnical Properties:

In 1995, several tests were carried out to determine the geotechnical properties of the oil lakes in order to find an alternative for the usage of the contaminated soil for engineering purposes rather than clean it. Actual contaminated site was inaccessible hence the study used a similar soil sample represented in Jahra sand mixed with 3-6% by weight of heavy crude oil to represent contaminated soil. Several soil tests like compaction, tri-axial, consolidation, and direct shear test were carried out for both clean and contaminated soil samples. The results shown below (Table 5) indicate that the strength of the soil decreased while the compressibility increased due to the presence of oil. Fortunately, the geotechnical properties tests are carried out again in 1997 to determinate the aging effect on oil contaminated soil within a period of six months. The results are shown in Table 6 shows that the impact of contamination is decreasing within time due to the evaporation of oil volatile compounds. As a result, the strength of the soil is increasing where the friction angle ö is increasing and the compression index C_c is decreasing within time. Hence, the represented data shows an improvement of the contaminated soil geotechnical properties due to the aging effects and the polluted soil can be used for engineering purposes, road construction for example, where the presence of oil, within certain percentage, causes insignificant difference in the geotechnical properties.

IV. Contamination Levels

Several tests were carried out on the contaminated Burgan soil to determine the Total Organic Content (TOC), Total Petroleum Hydrocarbons (TPH), Cadmium, Lead, Vanadium, and Nickel. The same parameters where compared with an uncontaminated soil samples. The results are summarized in Table 7, and confirm the contamination of the soil. Hydrocarbons concentrations tend to decrease with soil depth showing limited penetration. The extend of penetration was examined and the results indicate that the TOC and TPH return to its natural limits at depths below 65 cm.

V. Conclusion and Recommendations

During the Gulf War, Highly contaminated oil lakes were formed covering a large area of Kuwait desert. As a result of Oil presence, soil properties including physical, chemical, and geotechnical properties were affected negatively. Moreover, the contamination levels were sufficiently high

TABLE 1. OIL LAKES TYPES AND CHARACTERISTICS

Contamination type	Dry oil lake	Tarcrete	Wet oil lake	Oil contamination piles	Oil trenches & related spills	Total
Material	Tar mat & oily soil	Not indicated	Oil sludge & oily soil	Oily soil	Oily soil & oil sludge	--
Average depth (cm) [6][8][9]	25	1	64 – 65	173	351	--
Area (km^2) [6][8][9]	98.4 – 100	267.8	7.19–8.0	8.5 – 8.59	1.63 – 2.63	116.0 – 383.59
Average volume × 10^6 (m^3)	25	2.678	4.64 – 5.16	14.7	5.72 – 9.23	52.74 – 56.77

TABLE 2. KUWAIT OIL LAKES DIMENSION AND EXTENT

Oil field	Number of lakes[5][6][7]	Area[5][6] (km^2)	Volume[5][6] (m^3)	Depth of penetration[5] m)	Amount of oil[5] (bbl)
Burgan	45 – 204	6.717 – 16.0333	4,484,000– 7,950,450	0.15 – 1.2	28,200,000

TABLE 3. PHYSICAL PROPERTIES OF SOIL SAMPLES FROM BURGAN AREA[1]

Tested depth range (cm)	Mean (mm)	Sorting φ	Skewness	Kurtoses	Permeability K × 10^{-6} (m/sec)	Dry density (t/m^3)	BD (gm/cm^3)	K_{sat}×10^{-3} (cm/sec)	S.P. %	0.1 bar w%	15 bars w %	PAWC %
0–300	0.17–1.85	0.213 – 0.94	−1.761 – 1.58	−1.61 – 1.1663	1.15 – 10.0	1.46 – 1.72	1.13 – 1.695	0.13 – 0.5	15 – 27	5.17 – 15.35	2.53 – 6.45	0.23 – 9.2

TABLE 4. CHEMICAL PROPERTIES OF SOIL SAMPLES FROM BURGAN AREA[10]

Tested depth range (m)	K_{sat}×10^{-2} (m/s)	pH	EC (dS/m)	SAR	Soluble ions in paste extract (cmol kg^{-1})							
					Cations				Anions			
					Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0–300	0.13–3.4	7.59–8.1	3.9–22.75	0.7–10.7	11.5–72.6	10.5–37.8	4.28–112.5	0.05–1.9	0–0.1	0.8–1.3	11.9–228.5	1.8–26.9

Cmol kg^{-1} = meq L^{-1}., Ksat = saturated hydraulic conductivity measured in m/s., EC = electrical conductivity measured in decisiesmens per meter (dS/m). and SAR = sodium adsorption ratio.

TABLE 5. GEOTECHNICAL PROPERTIES RESULTS FOR CLEAN AND CONTAMINATED JAHRA SAND (1995)

Test type	Soil parameter	Initial volume (clean sand)	Initial volume after contamination	Aging period		
				One month	Three months	Six months
Extraction	Percent contamination	0	6	5.5	5	4.75
Direct shear	Friction angle, φ	35	28	30.5	31.5	32
Triaxial	Friction angle, φ	33	28	29.5	30.5	31
Consolidation	Compression index, C_c	0.033	0.065	0.055	0.04	0.04

TABLE 6. AGING EFFECTS ON CONTAMINATED JAHRA SAND (1997)

Test type	Soil parameter	Clean soil (0% oil)	Contaminated soil (6% oil)
Compaction	Maximum Dry Density, ρ (kg/m^3)	1900	1830
Tri-axial	Friction angle, φ	32	30
Consolidation	Compression index, C_c	0.03	0.07

compared with the clean soil. Hence, it is recommended to remediate the contaminated soil in order to reduce its impact on the environment or use the contaminated soil for engineering purposes.

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