Kuwait Environmental Remediation Program (KERP) : Limited Site Soil Characterization in South East Kuwait

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Abstract

During the 1991-1992 Gulf War about 114 square kilometers of Kuwait's desert environment was severely damaged by detonated oil wells at the hands of Iraqi troops leading to the largest environmental and ecological disaster in Kuwait's history. Aerial fall-out from oil spray and combustion products from oil fires and spills combined with regional/local topographic depressions resulted in the formation of large dry oil lakes and tarcrete on the land surface. The damaged oil wells spilled crude oil across the land surface and created "Oil lakes" in low lying land. These oil lakes covered several square km of land in the northern and southern oil fields of Kuwait. Consequently, contaminated soil estimated to be around 26 Million m^3 altered desert soil properties and ecological landscape, which caused the deaths of plants and/or animals; and posing a threat to the precious fresh groundwater resources. The United Nations Compensation Commission (UNCC), Kuwait National Focal Point (KNFP) and Kuwait Oil Company (KOC) cooperated in a joint project to undertake comprehensive and collaborative efforts to remediate the contaminated Soil.

In 2003, preliminary soil characterization was conducted within all features all over Kuwait to delineate the extent of the contamination and concluded in the construction of engineered landfills to contain these oil contaminated soils. In late 2014, KOC conducted a limited soil characterization study in Burgan –South East Kuwait in order to refine the earlier approach of Landfills by way of evaluating potential natural degradations that occurred over the years and to update the oil contamination levels, distributions and constituents. This also aimed at developing a new strategy by prioritization of the remediation areas and decisions for no action for minimal risk areas and to decide on the best available treatment technologies for treatment.

TPH fraction were found to be of 65 % resins/asphaltenes and 35% of saturated/aromatics components within layer 1 as compared to 52% resins/asphaltenes to 48 % of saturated/aromatics components with layer 2 in the dry oil lakes. These analytical data also indicate that low concentrations of light-end TPH fractions and moderate concentrations of mid-range TPH fractions persist in subsurface material. More pronounced pattern is identified in wet oil lakes materials between the two layers, which indicate potential extreme weathering and physico-chemical changes of oil saturated material, which have occurred in layer 1. Limited data analysis revealed that some of TPH degradation trend is identified at localized area within the wet and dry oil lakes subsurface soils. These limited data information will require confirmation across the larger areas to refine the Conceptual Site Models (CSM) for evaluating the risks to health and environment and to establish best applicable and cost effective technologies for the identified oil contaminated soil.

Keywords: Oil lakes, South East Kuwait (SEK), and Total Petroleum Hydrocarbons (TPH).

1. Introduction

The state of Kuwait is situated at the North-western corner of the Arabian Gulf. The total area of Kuwait is about 17,818 km^2. On 2 August 1990, Iraqi troops invaded the State of Kuwait. The country was liberated on 26 February 1991.

After the Gulf War, over than 700 oil wells in Kuwait were ignited, causing the largest environmental and ecological disaster in its history. Approximately 20-25 million barrels of ignited crude oil were extinguished using 12 billion gallons of seawater collected in artificial pounds to control the fire. The damaged oil wells spilled crude oil across the land surface and created “Oil lakes” in low lying land. The oil lakes covered several square kilometres of northern and southern oil fields. The crude oil released had negative short-term and long-term impacts on physical characteristics of the soil, vegetation, and wildlife and threatening precious groundwater resources. These oil lakes are mostly dry oil materials, but some features still containing semi-liquid, oil/sludgy material are referred to as wet oil lakes. In some places, contaminated soil from the oil lakes had been scraped up into oil-contaminated piles. Today, over than 26 years, these large oil lakes and oil contaminated piles (~26 million cubic meters of heavily oil contaminated soils) still exist in KOC oil field areas.

KOC carried out the Limited Site Soil Characterization works in Burgan oilfields under the Kuwait Environmental Remediation Program (KERP), which has been developed pursuant to the compensation awarded by the United Nations Compensation Commission (UNCC) due to direct environmental damage and depletion of natural resources resulting from the 1991 Gulf War. KERP must address a range of soil characteristics and remediation processes (e.g., landfill disposal, oil sludge treatment, bio-remediation) currently being instigated. The Limited Site Soil Characterization project is a fundamental and essential project that will form the foundation for remediation decision making. The Site Soil Characterization Project was undertaken at identified contaminated areas located in North and South Kuwait oilfields. The project consisted of field sampling and collection of soil samples and shallow groundwater for laboratory analyses pertaining to the oil-contaminated features within KOC oilfields.

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2. Soil Contamination Characteristics

Characteristics of oil lakes and soil piles vary in type, area, volume, and depth of oil penetration.

2.1. Wet contamination areas

Wet oil lakes: are areas covered with black liquid (highly weathered oil) and semi-solid oil saturated material resulting from oil flow damaged oil wells. Wet oil Lakes occur in areas where large liquid oil accumulated because of local topography and micro relief. Oil lakes cover a surface area of over 7.18 km^2. Previous investigations revealed that the average depth of oil contamination in the wet contaminated areas is approximately 0.65 m below surface grades.

2.2. Dry contamination areas

Dry oil lakes: are areas covered with thin and moderately hard dry black tar layer. Dry oil lakes are generally found in shallow depressions and/or flat areas. Dry contamination areas cover almost 98 km^2 of the desert, with an average mean depth of approximately 0.27 m below surface grades.

2.3. Oil-Contaminated Piles

Contaminated piles: are oil-contaminated soil collected as mounds. The soil piles were made to stop the spread of oil flows caused by the destruction of the oil wells or clear areas with heavy oil contamination during fire-fighting. Height of piles is range from 0.45 m to 7.0 m and the estimated land coverage is approximately 8.6 km^2.

3. Laboratory Bench Scale Tests

Previous laboratory bench tests conducted in 2003 to assess the feasibility and performance of three selected technologies mainly thermal desorption treatment, biological treatment, and soil washing technologies in remediating mixtures of heavily oil contaminated soil and oil sludge from various features. The thermal desorption and soil washing bench scale laboratory tests showed significant TPH levels (e.g. over 90%) reduction in the treated soils. Ex situ biological treatment was shown to be generally ineffective in treating the heavily weathered oil deposits. Asphaltene constituents, which represent 1/3 of that are resistant to biodegradation processes.

4. Data Analysis and Discussion

4.1. Historic Data

Between 2002 and 2004, Kuwait's monitoring and assessment consultants analyzed remotely data and performed mapping and analytical sampling surveys to delineate the extent of the oil lakes (wet and dry) and contaminated piles. During the monitoring and assessment, high-resolution IKONOS satellite imagery was used to produce preliminary base maps of oil contamination. The sampling survey involved collecting soil samples at nearly 1,300 sites at up to three depths/ layers (layer 1, contaminated surface; layer 2, subsurface contaminated layer; and layer 3, the layer below all visible contamination as represented in Fig. 1). Table 1 show the mean of total petroleum hydrocarbon (TPH mg.kg-1) concentration using EPA method 9071 in each type of layer for all categories of oil contamination. The previous preliminary investigations lacked some basic elements to define the layer boundaries in each feature, the volumetric estimations for each layer under consistent TPH range levels; and the fractions of Total Petroleum Hydrocarbons to evaluate risk health based approach of carbon ranges present within the subsurface materials.

Table 1: TPH (mg/Kg)- 2003

		Dry Oil Lakes			Wet Oil Lakes			Contaminated Piles		
Oil Field	Layer	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
All Oil Fields	1	73,500	447	694,000	194,000	18,100	679,000	40,900	937	242,000
	2	25,000	420	413,000	34,500	1,040	349,000	46,800	1,190	258,000
	3	703	0	107,000	679	0	27,100	44,700	470	190,000
Sabriyah, Raudhatain, Bahra	1	46,800	447	558,000	130,000	18,100	679,000	45,100	1,180	242,000
	2	24,400	1,050	259,000	37,600	1,040	154,000	60,400	5,860	258,000
	3	197	0	1,810	1,140	0	14,400	42,100	1,190	131,000
Greater Burgan (Ahmadi, Magwa, Burgan)	1	89,800	556	694,000	224,000	20,800	647,000	38,700	937	223,000
	2	24,700	420	413,000	32,000	2,200	349,000	45,000	1,190	204,000
	3	962	0	107,000	461	0	27,100	48,000	470	190,000
Minagish, Umm Gudair	1	49,300	2,930	526,000	342,000	88,900	596,000	34,200	12,900	55,500
	2	20,300	1,070	91,600	44,300	38,000	50,700	10,700	9,210	12,200
	3	837	0	18,500	65	60	70	15,800	7,450	24,200

4.2. Limited scope Investigation- Burgan - South East Kuwait

KOC conducted a limited soil characterization study in November and December 2014. The soil sampling exercise carried out in a 35 (km^2) area of the South-East Burgan oilfield. The focus of the limited investigation was to characterize soils that may be suitable for treatment technologies and to update the current understanding of soil contaminants and refine the aerial and vertical extent with carbon brandings to support remediation strategy. The sampling was focused on features known as 'Dry Oil Lakes'. A limited number of samples were collected from the periphery of 'Wet Oil Lake' features and from Layer 1 crust and sludge at both Dry and Wet Oil Lake features. A total of 310 samples (inclusive of duplicates) were collected from 208 locations of which

252 soil samples were analysed for various chemical analyses.

Figure 1: Dry and Wet Oil Lakes

4.2.1.Total Petroleum Hydrocarbons

The most abundant environmental analytical data relates to total petroleum hydrocarbon (TPH) analysis. TPH was analyzed using various test methods, as provided in the tables below. The summary data for TPH analysis has been split into feature type, (i.e., wet oil and dry oil lake features), and into different layers: Layer 1 and Layer 2; and Layer 3 which represents underlying visually clean soils. Table 2 provides summary statistics for total TPH by method EPA 9071B which broadly provides analysis for non-volatile hydrocarbons of equivalent carbon (EC) <40.

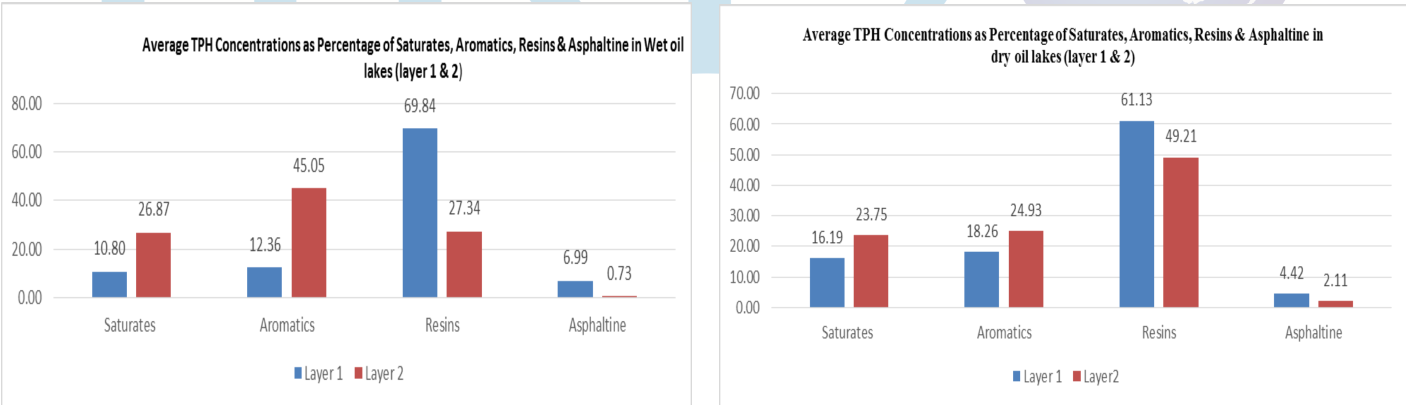
The mean TPH concentrations in the surface layer of wet and dry oil lake areas were higher (the mean TPH of was 133,373 $mg.kg^{-1}$ for wet oil lakes and 80,000 $mg.kg^{-1}$ for dry oil lakes) than those in the oil-contaminated layer 2 (the mean for all oil fields was 17,202 $mg.kg^{-1}$for dry oil lakes and 32,847 $mg.kg^{-1}$ for wet oil lakes).

Furthermore, the analysis included in Figure 2a and Figure 2b clearly shows that the average mean TPH level is made up of Saturate Aromatic Resins and Asphaltene (SARA) method (IP 469/01 2006) which illustrated in Figures.2a and 2b for both layers 1 and 2 in dry and wet oil lakes, respectively. Two figures 2a and 2b clearly indicate that layer 1 of both dry and wet oil lakes contained less light and medium range compounds due to highly weathering and exposure of oily material.

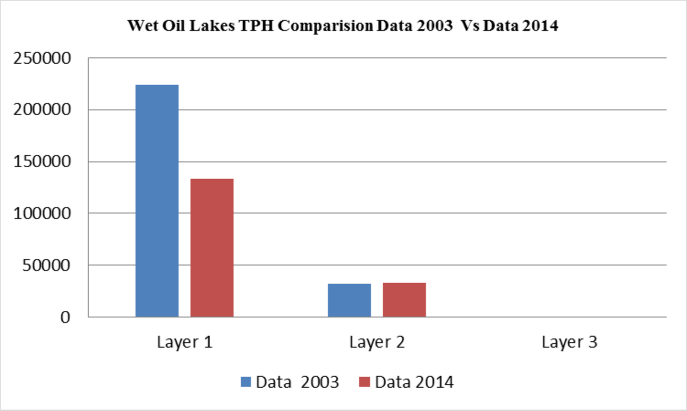
More pronounced pattern (e.g. figure 2.b) is identified in wet oil lakes materials between the two layers, layer 1 & 2), which indicate potential extreme weathering and physico-chemical changes of oil saturated material, which have occurred in layer 1. In attempt to evaluate the natural degradation of petroleum hydrocarbons over the years in subsurface material, figure 3a and figure 3b are drawn to establish degradation trends in layers 1, 2 and 3 from Data 2003 to Data 2014. These figures clearly show that natural degradations have occurred over these years and it is more pronounced in the dry oil lakes materials with a general trend of over 10% degradation rates across the layers in dry oil lakes.

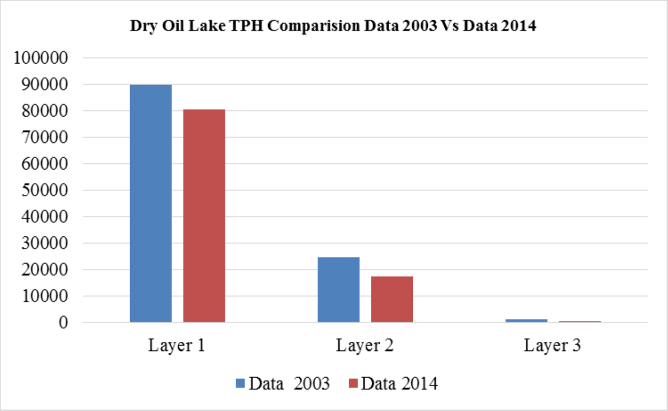
Table 2: TPH (EPA 9071B)

Material Type / Analysis	Number of Samples	Maximum (mg/kg)	Minimum (mg/kg)	Geometric Mean (mg/kg)	Arithmetic Mean (mg/kg)	Standard Deviation (mg/kg)
Wet Oil Lake						
Layer 1	7	166,171	94,835	133,373	135,557	25,310
Layer 2	16	87,450	11,585	32,847	39,749	24,840
Layer 3	2	1,883	174	572	1,029	1,208
Dry Oil Lake						
Layer 1	4	106,209	17,538	80,510	81,637	16,553
Layer 2	65	66,878	2,257	17,202	21,613	14,542
Layer 3	12	1,161	103	488	583	307



Figures. 2a and 2 b: Mean TPH Concentrations as percentages of Saturates, Arommatics, Resins and Asphalt Level in Wet and Dry Oil lakes in 2014





Figures. 3a and 3 b: Mean TPH level Trends in Wet and Dry Oil lakes from 2003 to 2014

5. Conclusion

The recent data analysis has been conducted in Burgan –South East Kuwait to refine the Conceptual Site Model (CSM), evaluate potential natural degradations over the years, update the oil contamination levels, distributions and constituents; improve the remediation prioritization areas and decisions for no action, minimal risks, treatment technologies, landfilling ; and obtain supporting data for the planned strategy. These limited data information will require confirmation across the larger areas to refine the conceptual CSM, the risk assessment is a tool to evaluate potential risks to human health and the environment. Moreover, risk assessment process includes hazard identification, exposure assessment, toxicity assessment, and risk characterization; and establish best applicable and cost effective technologies or actions for the identified oil contaminated soil.

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