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# Kuwait Environmental Remediation Program (KERP): Remediation Demonstration Strategy

Dhari Al-Gharabally, Aisha-Al-Barood
*Kuwait Oil Company, Soil Remediation Group, PO Box 9758, ahmadi 61008, Ahmadi, Kuwait*

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**Abstract:** Kuwait had 114 square kilometers of its desert severely damaged by 798 detonated oil wells at the hands of Iraqi Troops. Crude oil gushed from the damaged oil wells, forming lakes that contaminated over 40 km2 of the land. Consequently, wet and dry oil lakes were created in low-lying areas of the desert and contaminated soil piles were generated during the recovery phase to stop the spread of oil. Contaminated land desert altered soil properties, which caused the deaths of plants (e.g. biota) and animals; and penetrated deeper into the soil layers and threatening pollution of precious groundwater resources. The United Nation Compensation Commission (UNCC), Kuwait National Focal Point (KNFP), and Kuwait Oil Company (KOC) cooperated in a joint project to undertake comprehensive efforts to remediate the approximate 26 million cubic meters of heavily oil contaminated soils. Demonstration remediation technologies are sought as viable solutions to develop suitable action plans for remediating the heavily oil contamination soil. The objective of this field demonstration study is to determine the viability, applicability and effectiveness of proven remediation technologies in treating oil contaminated soil. This project will be implemented within selected sites in the KOC's operational oil fields in South-East Kuwait (SEK) to remediate of three features (i.e. wet, dry oil lakes and oil contaminated piles). A successful remediation technologies demonstration project will be a key indicator for developing soil remediation strategy plans for full-scale implementation in SEK and other eligible areas.

**Key words:** Demonstration strategy, oil lakes, oil contaminated soil, remediation technologies, total petroleum Hydrocarbons (TPH).

## 1. Introduction

The state of Kuwait is located in the northwestern corner of the Arabian Gulf and covers an area of about 17,818 km2. Kuwait contains 10 oil fields in two main areas: Northern Kuwait, which comprises the Ratqa, Raudatain, Sabriya, and Bahra oil fields, and Southern Kuwait, which includes the Greater Burgan, Managish, and Umm Qudair, oil fields (oil wells). Greater Burgan consists of three distinct oil fields, namely, Al-Ahmadi, Burgan, and Maqwa. 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

**Corresponding author:** Aisha-Al-Barood, Kuwait Oil Company, Soil Remediation Group, PO Box 9758, ahmadi 61008, Ahmadi, Kuwait. E-mail: eng.aisha27@hotmail.com.

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 kilometers of land in both side of Kuwait; 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 20 years ago, 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 will be performing field trial tests in order to devise remediation technologies demonstration strategy as a first step process to decontaminate the oil contaminated soils at three distinct soil features in SEK.

The literature reviews focused on insights into the following three environmental study areas:

Al-Duwaisan et al. [1] focused on the joint project between the United Nation Compensation Commission (UNCC), Kuwait National Focal Point (KNFP), and Kuwait University (KU). The project focused on the oil lakes covering large areas of the Kuwaiti desert during the Gulf War. The project was initiated to conduct comprehensive work consisting of characterization of the contaminated soils and its environmental impacts. This paper sought to characterize oil contaminated soil by assessing its physical, chemical, and geochemical properties. The project estimated the soil contaminated volume to range between 16.5×106 m3 and 22.7 ×106 m3. The soil physical properties were deteriorated and the chemical and biological characteristics were highly affected by the presence of highly weathered crude oil. Moreover, the oil contamination levels were identified greater than 40% as total petroleum hydrocarbons (TPH) and were sufficiently high compared to background or clean soil conditions. Subsequently, remediation of the oil contaminated soil was recommended to reduce its impact on the environment and ecosystem or to use the oil contaminated soil for engineering purposes.

Al-Awadhi et al. [2] focused on the joint research program between the Kuwait Institute for Scientific Research (KISR), Japan Petroleum Energy Center (PEC), and Kuwait Oil Company(KOC).The project’s objective was to demonstrate biological and physical-chemical technologies for the remediation of oily sludge and oil contaminated soil in Kuwait. One hectare area of oil Lake was selected for field treatment testing and evaluation. The paper summarizes the research over a period of 7years to investigate and field test selected remediation technologies, to establish feasibility, applicability and effectiveness criteria and develop a suitable plan of remediation action for large-scale soil remediation. In general, the five remediation techniques tested in this study showed valuable oil biodegradation and oil recovery results. Four tested bioremediation techniques consisting of windrow soil piles, soil bioventing piles, soil composting and land farming were able to reduce oil concentrations significantly within 15 months. Satisfactory reductions in oil pollutant levels were achieved for bioremediation TPH up to 94%, aliphatic components to up 80% and aromatic components up to 60 %Asphalten component, which makes up 1/3 of oil contaminated soil hardly degraded during the 15 months period. Oil sludge material was successfully treated using a two-stage physical/chemical treatment process (e.g. kerosene solvent wash followed with warm water wash). Physical/chemical treatment process significantly reduced the oil content in the soil/oil sludge from 50% to 2%. Treated soil with physical/chemical process was subjected to land farming to evaluate further degradation of residual oil contamination. The results showed significant degradation of oil residual levels from 2% to less 0.25% with or without nutrient amendments.

Al-Sarawi et al. [3] studied the physical properties of the soil contaminated profiles within oil lakes in Al-Ahmadi and Burgan oil fields, which include 80% of the Greater Burgan oil wells in Southern Kuwait. In this research, 60 samples were sampled and measured. The two soil profiles (oil free and oil contaminated sites) have, on average, similar saturation percentages (total water content of soil) (20.6%), field capacities (9.86%), and wilting coefficients (4.71%), with low available water capacities due to stratification, very low matric potential, and high bulk densities due to compaction by vehicle wheels. The fluviatile origin has affected the soil layers in Burgan. This issue led to lower soil hydraulic conductivity, thereby impeding the downward movement of oil and restricting its penetration mainly to the upper top layer 25-45 cm. In contrast, the eolian origin and relatively excellent sorting and stable structure of Al-Ahmadi soil structure have led to higher soil hydraulic conductivity , which facilitated the migration of oil over much greater depths (down to 150 cm). Finally, results of this paper show that the value(s) of the hydraulic conductivities is relatively very low and the available water capacities (2.5% on average) of the zone(s) lying below the impervious Gatch layer in Al-Ahmadi and Burgan soil profiles suggesting that this layer acts as a moisture barrier impeding any further downward of oil penetration.

## 2. Soil Contamination Characteristics

Characteristics of oil lakes and soil piles are various in their type, area, volume, and depth of penetration. These variations in type are the result of different formation conditions as discussed by Al-Sarawi et al. [3]. Previous studies categorized these features into three types in SEK.

### 2.1. Wet contamination areas

The distinguishing features of Oil Lakes with a surface area of over 7 square kilometers include a surface layer of weathered crude, oily liquid, or sludge, sometimes covered by a thin, hardened crust. Investigations revealed that the average depth of oil contamination in the wet contaminate areas is approximately 63 centimeters. Sludge material has been found to contain mean total petroleum hydrocarbon (TPH) concentrations in excess of 19 percent. The underlying contaminated soil was found to contain a mean TPH concentration of 3.4 percent.

### 2.2. Dry contamination areas

The main feature of dry oil lakes is a heavily contaminated thin layer of material, however they are without wet oily layers or oil sludge. The dry contamination areas cover almost 100 square kilometers of the desert, with an average depth of approximately 25 centimeters. The surface tar material in areas of dry soil contamination was found to contain mean TPH concentrations of about 7.3 percent. Underlying contaminated soil was found to contain a mean TPH concentration of 2.5 percent.

### 2.3. Oil-Contaminated Piles

Contaminated piles consolidate oil-contaminated soil and/or liquid oil into mounds. These piles were made in an effort to stop the spread of oil flows caused by the destruction of the oil wells and to clear areas of heavy oil contamination as necessary to facilitate fire-fighting or subsequent KOC field operations. Oil-contaminated pile surface materials were found to contain mean TPH concentrations of about 4.0 percent. The underlying contaminated soil was found to contain a mean TPH concentration of 4.6 percent.

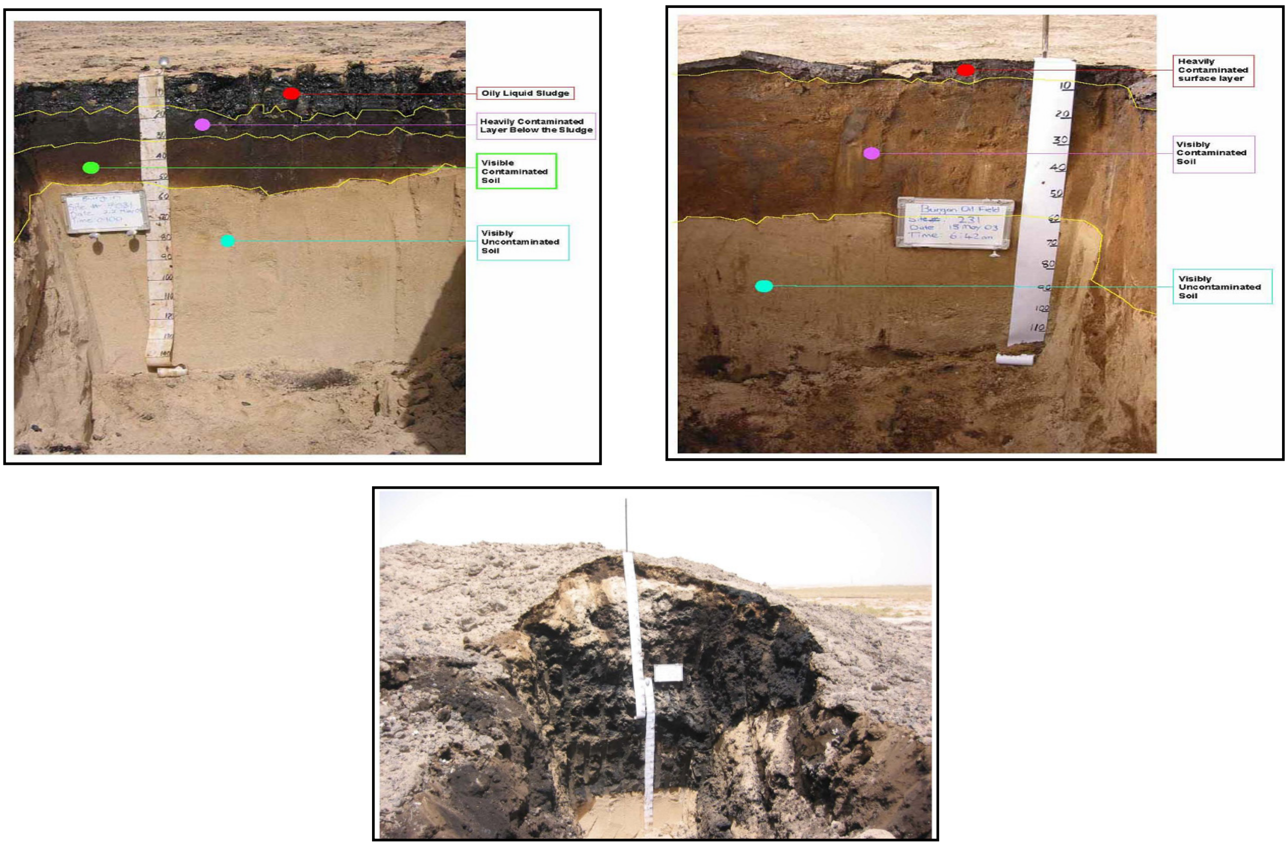


**Fig.1 Wet contamination area, Dry Contamination area and Oil Contaminated Pile**

## 3. Results and Discussion

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 demonstrates the mean of total petroleum hydrocarbon (TPH mg.kg-1) concentration in each type of layer for all categories of oil contamination. The mean TPH concentrations in the surface layer of wet and dry oil lake areas were higher (the mean for all oil fields was 73,500 mg.kg-1 for dry oil lakes and 194,000 mg.kg-1 for wet oil lakes) than those in the oil-contaminated layer 2 (the mean for all oil fields was 25,000 mg.kg-1for dry oil lakes and 34,500 mg.kg-1 for wet oil lakes). The mean concentrations in oil-contaminated piles were 40,900 mg.kg-1 in the surface layer, 46,800 mg.kg-1 in the oil-contaminated layer, and 44,700 mg.kg-1 in the layer where no visible contamination was present. The mean concentrations of TPH in the surface layer of wet oil lakes area was higher (mean value for Sabriyah, Raudhatain, Bahra was 130,000 mg.kg-1for wet oil lakes, and mean value for Greater Burgan, Ahmadi, Magwa was 224,000 mg.kg-1) than dry oil lakes areas and contaminated piles. Finally, the results of this recent data analysis reveal that significant high TPH levels are persistent in the surface and subsurface soils which is above the soil remediation goal of 5000 mg.kg-1 (as reference in Kuwait Environmental Public Authority).

**Table 1- TPH (mg/Kg) - 2003**

| Oil Field | Layer | Dry Oil Lakes | | | Wet Oil Lakes | | | Oil Contaminated Piles | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 | 223,00 |
| | 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 | 271,000 | 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. 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. Based on the bench scale laboratory results coupled with the other studies, a field demonstration strategy is sought to clean and restore the damaged land.

# 5. Remediation Technologies

The objectives of the demonstration strategy are as follows:

- To apply a risk based methodology of remediation concurrent with recognized international protocols adapted to the prevailing environmental conditions in Kuwait.
- To clean or restore the damaged environment to pre-invasion conditions, in terms of soil remediation
- To demonstrate the effectiveness of proven technologies in remediating the highly oil contaminated soil by considering viability, cost, volume scale, time bound, and the final results of soil decontamination.
- The effectiveness of the demonstrated technology (ies) should be supported with quality assured/controlled analytical and monitoring program to be obtained during the demonstration project. The selected technology (or technologies) should have the capability to treat high volume of highly oil contaminated material within a reasonable time frame and economically feasible.

## 5.1. Remediation Demonstration Strategy

KOC has identified the locations of the technology demonstration sites based on appropriate risk assessment methodologies. The risk assessment methodologies were used to evaluate impacts on geology, hydrology, hydrogeology, groundwater quality, field development, and environment within the selected sites. The selected demonstration sites provide sufficient volumes of contaminated materials for the in-situ and ex-situ field demonstration trial tests. In order to evaluate viability, performance effectiveness, and efficiency in a variety of treatments, field proven technologies and/or other innovative technology approaches will be field demonstrated either single or in treatment train. Treatment objective will be focused on treating the heavily oil-contaminated soil and/or recovery of oil to achieve soil remediation target goal of (5,000 mg.kg-1TPH as reference in KEPA). Performance monitoring will be implemented for each technology via defined parameters in order to assess remediation effectiveness and efficiency. Depending on the remediation progress, outcomes for each soil remediation technology or solution will be evaluated and determined. In general, the evaluation will be conducted based on the following considerations:

A. At both stages, demonstration as well as full-scale remediation applicability and suitability with respect to the site specific conditions to effectively treat the heavily oil contaminated soils.

B. Soil Risk-based objective of TPH (5,000 mg.kg-1 as reference in KEPA) to be established.

C. The scalability and time period in which the established remediation target can be met.

D. The actual cost of the remediation technology demonstration and total cost for proposed for full scale remediation;

E. Quality of the remediated soil.

F. Overall consumption of energy (fuel, electricity), water, and other plant operating requirements with a focus on sustainable and remediation methodologies.

G. Indication of net environmental gains.

H. No excessive long term monitoring and/or minimal by- products or wastes generated from remediation solutions.

## 5. Conclusion

Since the Gulf War in 1990, highly oil contaminated oil forming dry or wet lakes and soil piles are still present in large desert areas of Kuwait. As a result of the presence weathered crude oil; soil physical, chemical and geochemical properties were negatively affected. The persistence of extremely highly weathered oil and TPH levels suggest that the oil contaminated soils would require to be remediated in order to reduce the adverse environmental impacts to Kuwait's desert. Therefore, a remediation demonstration strategy is developed to assess and field test various remediation technologies in restoring the oil contaminated soil areas. The results of this demonstration strategy will provide valuable information on specific single technology treatment or train of technologies applicable for each contamination type to the existing site conditions. Depending on the outcome of the demonstration strategy results; full scale remediation action plans will be devised and implemented to restore the impaired land areas.

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