



## Oil Spill Remediation Efforts in the Middle East

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The Persian Gulf war brought about some of the worst environmental pollution ever recorded as the result of oil spills. From August 1990 to February 1991, 240 million gallons of oil were spilled into the Arabian and Persian Gulfs and in the Kuwait Desert making this the largest oil spill in history (Purvis, 1999). After a brief history of this incident, techniques for remediation of contaminated soils will be discussed.

Seven hundred kilometers of Kuwait and Saudi Arabian coastline were severely polluted as well as an area of approximately 49 square kilometers in the Kuwait Desert (Al- Hasan et al., 1994). These oil spills were the result of deliberate damage done by Iraqi forces during their invasion of Kuwait. Crude oil was deliberately dumped into the gulfs and oil production, storage, and refining facilities were destroyed and torched. The oil leaking from the well heads, storage tanks, and pipelines formed huge oil lakes as deep as 2 meters. Many of the oil wells were also set on fire and this resulted in the aerial deposition of partially combusted oil particles and associated non-combusted products of the oil fires, which also polluted large areas. Along with this the oil quality was also degraded due to long exposure to harsh atmospheric conditions which caused it to lose volatile hydrocarbons and experience other physical and chemical changes making its sale less profitable (Al-Hashash et al., 1998).

Initial cleanup efforts in the desert involved extinguishing fires, clearing the contaminated areas of mines and unexploded ammunition and pumping the oil from the oil lakes. Thousands of trucks, bulldozers, and cranes were required to reduce the size of the oil lakes (Green Cross International, 1998). Ninety-five percent of the oil was removed and exported. Five percent continues to pollute the desert with a high risk of contaminating the ground water that is so limited in the region (Green Cross International, 1998). In order to restore the soil for use in animal and plant production practices and to guard against long-term health threats to humans and other species, the oil content of the soil must be further reduced. There are many techniques that have been developed just for this purpose. Some of the techniques that will be discussed in further detail will include doing nothing, self-cleaning with cyanobacteria, phytoremediation, and several kinds of bioremediation with fungi. These efforts are still in the experimental stages of being developed and have not yet been applied in the field (Al-Hashash et al., 1998). Research has been done and continues to be done by the Kuwait Institute For Scientific Research and the Japan Petroleum Energy Center (Al-Awadhi et al., 1998a).

The first option for remediation would be to deliberately choose to do nothing. This option could be made for several reasons, including lack of money and the difficulty associated with implementing techniques on a large scale. The choice to do nothing can lead to some very serious consequences. After many of the oil lakes were pumped by the Kuwait Oil Company the area was abandoned (Al-Awadhi et al., 1998a). The outcome of doing nothing in the oil lakes after initial remediation was that after five years of weathering in the very hot climate, any oil that remained turned into a semi-solid mass. This semi-solid mass is very difficult to remove. It is estimated that there was 1.55 million tons of oil remaining in the lakebeds. The presence of

such a large amount of oil spread over such a large area poses a serious environmental hazard to air, land, and ground water resources as well as to humans (Al-Hashash et al., 1998). As these lakebeds dry out their hazard potential increases. Heavily contaminated soil in the dry lakebed may eventually erode, become suspended in the air column, and transported to populated areas during dust storms, which are common in Kuwait. Thus there is an urgent need to address the issue of oil lakes seriously in order to minimize the hazard to public health and to the environment.

In contrast to the desert oil lakes, the choice to do nothing in the gulf turned out to be beneficial. When polluted gulf areas are left alone, extensive mats of blue-green algae appear on the oil layers (Al-Hasan et al., 1992). The mats are only associated with the oiled areas and the oil-free areas are free of the cyanobacterial mats. The microbial mats appear to be the only living things in the area. The microorganisms are both photosynthetic and non-photosynthetic. Included in the mats is an organophilic bacteria which is capable of utilizing crude oil as a sole source of carbon and energy (Al-Hasan et al., 1992). It is believed that cyanobacteria can at most initiate the biodegradation of hydrocarbons in oil by oxidizing them only to the corresponding alcohols (Al-Hasan et al., 1994). Bacteria, yeast and fungi can then consume hydrocarbons by initially oxidizing them to alcohols, aldehydes, and finally to fatty acids, then degrading them further by beta oxidation to acetyl coenzyme A which can be used for the production of cell material and energy (Al-Hasan et al., 1994).

A second alternative is phytoremediation. Initial observations of moderate to weakly contaminated areas showed that plants belonging to the family Compositae that were growing in black, oil polluted sand always had white clean roots (El-Nemr et al., 1995). The soil immediately adjacent to the roots was also clean while sand nearby was still polluted. Studies showed that hundreds of millions of oil-utilizing microorganisms are associated with roots. The microorganisms take up and metabolize hydrocarbons quickly, which helps detoxify and remediate the soil. Remediation can be done then by densely cultivating oil-polluted desert areas with selected crops that tolerate oil and whose roots are associated with oil degrading microorganisms. This would work well in moderate and weakly contaminated areas, but heavily contaminated areas would first have to be mixed with clean sand to dilute the oil to tolerable levels for plants (El-Nemr et al., 1995).

The third and final group of alternatives involves several techniques that use fungi in bioremediation of the soil. The techniques include land farming, windrow composting piles and static bioventing piles. There are forty fungal types or strains that have been shown to grow on crude oils (Davies and Westlake, 1979). Some of the more common species that have been isolated include *Aspergillus*, *Penicillium*, and *Verticillium*. The chemical composition of the oil, namely the number of n-alkanes present, determines whether fungi can grow on the oil. The exact role the fungi play in the decomposition of oil in the soil is not clearly known. It is thought that since they can grow in low pH and poor nutrient conditions that they can interact synergistically with bacteria and yeast which can then degrade twice as much of the oil (Davies and Westlake, 1979). Some of the white rot fungi like *Phanerochaete*, *Pleurotus*, and *Coriolus* have the fastest degradation rates and may be good alternatives for further study (Al-Awadhi et al., 1998c). During studies in an oil lake in the Kuwait desert Al-Zarban and Obuekwe (1998) observed that stones and other solid materials lifted from the oil-soaked soil in the oil lake

had completely clean surfaces. Evidently oil-degrading microorganisms attached to the surfaces that developed in crevices of stones and other solid materials (Al-Zarban and Obuekwe, 1998).

Several large-scale experiments were conducted on soil remediation techniques using fungi. The contaminated soil was very dark brown in color, had an oily aroma and a very sticky texture. Normal, unpolluted Kuwaiti soil is calcareous sand with a silt concentration of less than 6%. The pH is generally 7.5-8.0, organic matter is less than .02% and each gram of soil contains 105-6 bacteria and 101-2 fungi. Water holding capacity is generally around 6% (El-Nawawy, 1992). In the contaminated soil salt concentrations were high due to the large volumes of seawater used to extinguish the oil well fires and the subsequent evaporation of the water. These high salt levels influenced the selection of an appropriate bioremediation technique. For example phytoremediation would probably not work well on soils with high salt concentrations unless salt tolerant plants were used.

Soil removal was the first step in the remediation project (Al-Awadhi et al., 1998a). Due to the high viscosity of the material it was impossible to get the equipment into the oil lake during the day. Therefore work had to be done in the early morning when temperatures were cold enough to make working with the sludge possible. In this example, the contamination was thought to only reach a depth of 50 centimeters but after digging began it was discovered that the oil contamination reached 100 centimeters in places. The soil was excavated and taken to a specially designed containment area where it was screened to remove tarry material and large stones. The soil was then amended with fertilizer and a mixture of compost and wood chips to improve water-holding capacity and to provide microorganisms with sufficient carbon and nutrients. When the soil was thoroughly mixed, the three bioremediation techniques were initiated (Al-Awadhi et al., 1998a).

The land farming method involved spreading the soil mixture to a thickness of 30 centimeters in four land farming plots. The plots were irrigated with fresh water from a pivot irrigation system. The soil water content was maintained in the optimal range of 8 to 10 %. A mixed microbial culture was isolated from a local oil-contaminated soil. Every soil plot was inoculated individually through the irrigation system using a sprinkler connected to a pump. The soil was tilled at least twice a week with a rototiller to maintain aeration and mixing (Al-Awadhi et al., 1998a).

For the second bioremediation approach, eight windrow composting piles were constructed of the same soil mixture as was used in land farming with the fertilizer and the wood chips added (Al-Awadhi et al., 1998a). The soil was also inoculated with the fungi Phanerochaete chrysosporium by adding it to the water running through the irrigation system. All the piles were 1.5 meters tall, 20 meters long and 3 meters wide. The piles had leaky pipes buried inside them at different heights and spacings to supply constant water and nutrients. Once a month the soil piles were turned using front-end loaders for mixing and aerating. One pile was covered with plastic to study the effect of increasing water retention (Al-Awadhi et al., 1998a, 1998b).

Finally, four static soil piles were also constructed in much the same way as the windrow piles except that the piles were fitted with perforated plastic pipes laid on the ground in the piles (Al-

Awadhi et al., 1998a). The pipes were hooked to an air compressor that provided a continuous supply of air to the pile. The leaky pipes were also used to provide soil, fertilizer and the fungal inoculum and the same mix of soil was used (Al-Awadhi et al., 1998a).

All sites were monitored on a monthly basis for one year (Al-Awadhi et al., 1998a). Soil tests were performed to analyze for oil content and other key factors like nutrient concentrations and microbial counts. In general all treatments reduced the oil concentration compared to doing nothing or passive bioremediation which was the experimental control. The highest oil degradation rate was observed in the soil that was landfarmed where oil content was reduced by 82.5%, then the windrow piles, 74.2% and the static bioventing, 64.2%. Using large volumes of fresh water to leach out the salts also reduced soil salinity levels. Although landfarming and windrow soil pile methods resulted in more oil degradation than soil bioventing, soil bioventing was deemed the better method to use. This was based on the high operation and maintenance costs associated with landfarming and windrow piles. The costs were high because of the amount and intensity of labor and the heavy field equipment needed for operation. Soil bio-venting also required a much smaller area for operation compared to the other two methods (Al-Awadhi et al., 1998a).

After oil contaminated soil has been bioremediated, it can either potentially be used in construction projects or it goes to a hazardous waste dump (Aiban, 1998). The use of these soils in construction is considered a creative way to minimize the environmental impacts even though it has not yet been implemented on a practical scale (Aiban, 1998). Some alternatives include the use of contaminated soils in embankments with the proper linings to minimize their spread to other areas (e.g. the ground water). They can also be used in making parking lots, roads, and in backfilling. This will reduce the cost of the projects because contaminated soil is nearly an endless resource in Kuwait and is readily available in both the north and the south. Several aspects of soil quality must be considered before it can be used in construction such as the effects of heat and water on their strength and compressibility. It was found that oil-contaminated soils would meet the minimum strength requirement under extreme temperature and moisture conditions. However, their dependence on environmental and loading conditions needs to be further investigated and understood before they are used (Aiban, 1998). If these materials are not used in construction activities they must either be treated further to make them safer or they must be disposed of. Both of these alternatives greatly increase the economic and environmental costs.

In conclusion there are many techniques that are being developed for bioremediation of oil contaminated soils. None are currently being used as they are still in the experimental stages. However, with proper funding, they could become very useful tools in the future. As of now it is not known when these techniques will be practically applied nor what the cost associated with implementation will be. It is only clear that remediation can not be put off much longer if the diminishing groundwater supply is to be salvaged. It is hoped that funding will become available in the next several years to make these projects feasible.

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