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Predictive Kinetics Model for Bioremediation of Crude Oil-Contaminated Soil in Arid Environment

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Background/Objectives. Over 25 years ago, Kuwait's oil wells were damaged and set on fire during the Iraqi invasion, resulting in millions of barrels of crude oil spilled throughout the 114 square kilometers of Kuwait landscape [1]. Contamination of the land occurred from oil gushing and spreading over the land surface and penetrating the soil to varying depths, forming wet and dry oil lakes in low-lying areas. The crude oil released had negative impacts on the physical and chemical characteristics of the soil and its ecosystem and has threatened existing limited fresh groundwater resources. Remediation of crude oil has been a challenge to oil and gas industries, especially in an arid environment such as Kuwait. Bioremediation of saturates and aromatic compounds of crude oil has been well documented in the environmental industries. However, very little is known about bioremediation of resins and asphaltenes due to their complex structures, which are difficult to analyze and quantify.

Approach/Field and Laboratory Activities. The study explores recent site data collected for soil characterization; past and recent field and laboratory enhanced bioremediation studies to identify the composition of oil contaminated-soil in Kuwait and elucidate the patterns of enhanced bioremediation of highly weathered crude oil. During 25 years of crude oil exposure to natural processes, it is clear that the soil physicochemical compositions have been altered and apparent little degradation has been observed in all crude oil constituents (e.g., aromatic, aliphatic and asphaltenes) with the exception of resins, which has increased slightly.

Results/Lessons Learned. The degree of biodegradation or decay constant rate (k) and half time life ($t_{1/2}$) are derived using a first order kinetics model using both linear and exponential functions. The derived biodegradation constant rate varies between 0.004/day and 0.008/day and longer half life time ($t_{1/2}$) ranges from 165 days to 86 days for both field and laboratory test data, respectively. These well correlated field and laboratory studies data are represented by correlation coefficients R^2 >0.95. This confirms that first-order kinetics is an appropriate model for highly weathered crude oil degradation. The degree of field and laboratory degradation is 78% and 36% for biostimulated and bioaugmented material, respectively, over the testing period. Therefore, weathered crude oil is a persistent contaminant in the impacted material. This indicates that enhanced natural attenuation will not suffice and may take decades to degrade the existing weathered oil constituents present in the soil matrix to acceptable cleanup levels.

The kinetic model plays an important role in understanding the behavior and scale-up for bioremediation strategies. The data derived by the kinetics model are used to predict the expected time to achieve pre-determined soil cleanup criteria under various scenarios for full-scale bioremediation schemes.