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Impact of water table fluctuations on the redistribution of light hydrocarbons in heterogeneous porous media and remediation efficiency using non-Newtonian fluid flushing

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Contamination of subsurface environments by light petroleum hydrocarbons is a significant environmental issue caused by the widespread use of such products. These hydrocarbons, characterized by their toxicity and low water solubility, pose serious risks to ecosystems and human health. Understanding the transport and fate of these pollutants in the subsurface is crucial for developing effective remediation strategies. Upon release, the pollutants migrate through the subsurface and eventually reach the groundwater table, where significant redistribution occurs due to fluctuations in the water table. Accounting for these fluctuations is critical for effective management of contaminated sites.

This study investigates the redistribution of light petroleum hydrocarbons at the interface between saturated and unsaturated zones under varying water table conditions. Laboratory experiments were conducted to explore the effects of water table fluctuations, soil heterogeneity, and hydrocarbon type on contaminant behavior. The study employed geophysical sensors, image analysis, and remediation testing to characterize these processes.
The experimental setup consisted of a one-dimensional column made of polyvinylidene fluoride (PVDF), measuring 65 cm in height and 10 cm in inner diameter, with a transparent front panel for visual monitoring. The column was equipped with four Time Domain Reflectometers (TDRs) positioned at different heights to measure relative permittivity, and paired pressure ports to simultaneously record pressure data. Relative permittivity values were converted into saturation data using the Complex Refractive Index Model (CRIM) for three-phase fluid flow analysis.

The experiments utilized a heterogeneous porous medium composed of two silica sand grain sizes: fine sand (0.6–0.8 mm) and coarse sand (1–1.25 mm). This setup simulated three subsurface zones: a water-saturated aquifer, a hydrocarbon layer floating above the water table, and an unsaturated soil zone. Diesel oil, representing a typical light hydrocarbon pollutant, was used in the experiments.

The study focused on the effects of imbibition (displacement of non-wetting phases by wetting phases) and drainage cycles, followed by remediation attempts using surfactant and polymer-based flushing agents. Sodium dodecyl sulfate (5 g/L) and xanthan gum bio-polymer (1 g/L) were tested for their effectiveness in displacing the residual hydrocarbons. Experiments included various heterogeneity configurations, such as horizontal and vertical layering, to replicate field-like conditions. Additionally, a complex mixture of degraded hydrocarbons from a pilot site was tested to expand the applicability of the findings.
Preliminary results revealed significant residual diesel saturation in the smear zone, attributed to the hysteresis effects observed during three-phase flow processes. Capillary forces, stronger in smaller pores due to higher entry pressures, played a major role in redistributing hydrocarbons toward zones with higher permeability. This redistribution resulted in lower residual saturation levels in the medium.

Soil heterogeneity was identified as a critical factor affecting hydrocarbon redistribution during imbibition and drainage. These findings underscore the necessity of incorporating heterogeneity into the design of remediation strategies. Additionally, ongoing tests aim to evaluate the behavior of more viscous fluid mixtures and their redistribution pathways, which differ significantly from diesel. Results from these experiments will

provide further insights into the dynamics of hydrocarbon behavior and will be presented in the presentation.

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References

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