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Jet A fuel recovery using micellar flooding: Design and implementation

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HIGHLIGHTS

- LNAPL mobilization has not been used as a recovery mechanism at the field-scale.
- Ultra-low interfacial tension is achieved using the surfactant formulation.
- The phase behavior data is indispensable to design the field implementation.

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ABSTRACT

Surfactants offer two mechanisms for recovering NAPLs: 1) to mobilize NAPL by reducing NAPL/water interfacial tension, and; 2) to increase the NAPL's aqueous solubility—called *solubilization*—as an enhancement to pump & treat. The second approach has been well-studied and applied successfully in several pilot-scale and a few full-scale tests within the last 15 years, known as Surfactant Enhanced Aquifer Remediation (SEAR). A useful source of information for this second approach is the "Surfactant-enhanced aquifer remediation (SEAR) design manual" from the U.S. Navy Facilities Engineering Command. Few attempts, however, have been made at recovering NAPLs using the mobilization approach presented in this paper. Now, a full-scale field implementation of the mobilization approach is planned to recover an LNAPL (Jet A fuel) from a surficial sand aquifer located in Denmark using a smaller amount of surfactant solution and fewer PVs of throughput compared with the SEAR approach. The approach will rely on mobilizing the LNAPL so that it is recovered ahead of the surfactant microemulsion, also known as a micellar flood.

This paper will review the laboratory work performed as part of the design for a full-scale implementation of a micellar flood. Completed lab work includes screening of surfactants, phase behavior and detailed salinity scans of the most promising formulations, and generating a ternary diagram to be used for the numerical simulations of the field application. The site owners and regulators were able to make crucial decisions such as the anticipated field results based on this work.

1. Introduction

It is widely accepted amongst environmental practitioners that contamination of soil from non-aqueous phase liquids (NAPLs) is a serious problem for groundwater bodies, affecting human health and the ecosystem in general. NAPLs are classified as either LNAPLs or DNAPLs regarding to their density (lighter or denser than water). Petroleum products contaminate soil through spills and the need for remediation of contaminated areas is urgent both for their economic value but also for the environmental problems they create.

Contamination by jet fuel (EPA, 1995, 2010; ETC, 2001; Ritchie et al., 2003) is an environmental problem that is commonly encountered in areas near airports or in fuel repositories. A number of remediation technologies such as the use of surfactants solutions (Mulligan et al., 2001; Schramm et al., 2003; Paria, 2008; Mao et al., 2015) were examined and used the last two decades for recovering NAPLs from soil (Chu and Kwan, 2003). Surfactants could be used for recovering NAPLs from the subsurface through two mechanisms: 1) to mobilize NAPL by reducing NAPL/water interfacial tension, and; 2) to increase the NAPL's apparent aqueous solubility—called 'solubilization'—as an enhancement to pump & treat (P&T). The second approach has been well-studied and applied successfully in several pilot-scale and a few full-scale tests within the last 15 years, known as Surfactant Enhanced Aquifer Remediation (SEAR) (NAVFAC, 2002).

Surfactants have been studied to recover spilled coal tar (Link, 2000; Yoon et al., 2002; Kostarelos et al., 2013), ethylene dichloride tar (EDC-

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tar) (Liang and Hsieh, 2015); trichloroethylene (TCE) (Dwarakanath et al., 1999), tetrachloroethylene (PCE) (Dwarakanath et al., 1999; Taylor et al., 2001; Childs et al., 2006), jet fuel (Dwarakanath et al., 1999; Wu et al., 2000; Gallego et al., 2011), diesel (Lee et al., 2005; Couto et al., 2009; Khalladi et al., 2009), gasoline (Lee et al., 2005), kerosene (Lee et al., 2005), polycyclic aromatic hydrocarbons (PAHs) (Guha et al., 1998; Kim et al., 2001; Prak and Pritchard, 2002; Lopez et al., 2004; Mohamed and Mahfoodh, 2006; Ghosh, and Tick, 2013).

As mentioned above, most of these studies focused on the *solubilization* or *SEAR* approach to recover the NAPL which requires many pore volumes (PVs) of throughput. The throughput that is used in this approach is the selected surfactant formulation that is used to achieve an increase in the apparent solubility of the NAPL components that is an order of magnitude higher than their solubility limits. While the use of SEAR is a significant improvement over conventional P&T, the *mobilization* approach could recover the NAPL with even fewer PVs of throughput, which should translate into significant cost savings over both P&T and SEAR since the project duration is reduced. Moreover, the throughput used in the mobilization approach consists of only a small amount of the selected surfactant formulation (typically 1PV or less) so that the overall costs for materiel are lower compared to the SEAR approach as well.

The primary goal of this research was to find the most suitable surfactant formulation that could be used at the field scale to recover an LNAPL using the mobilization approach, having the advantage of requiring a relatively small number of PVs of throughput and a smaller amount of surfactant compared to the solubilization approach. In addition, a secondary objective of this study was to collect data for numerical simulations (using the UTChem simulator) so that the field application of this approach could be designed. Although this paper does not discuss the numerical simulations for the field applications, we briefly describe UTChem (University of Texas Chemical Compositional Simulator, copyright owned by The University of Texas at Austin) here: UTChem is a three-dimensional, multiphase, multicomponent, compositional, variable temperature, finite-difference numerical simulator and can be run on a variety of Unix workstations and Windows PCs. The computation scheme solves for pressure implicitly and concentrations are solved for explicitly, similar to an IMPES model (Implicit Pressure-Explicit Saturation). Phase saturations and concentrations are then solved in a flash routine. More details can be found at http://www.cpge.utexas.edu/?q=UTChem_GI.

The field application is being planned to recover an LNAPL, Jet A fuel, from a surficial sand aquifer located at a tank facility in western Jutland, Denmark (see Fig. 1). The spill of jet fuel from a leaking pipeline near the northern end of the manifold building was observed in 2003; the total spill of jet-fuel was not recorded at that time. In the following years, investigations were performed using boreholes. From 2002 to 2005, LNAPL was recovered by skimming the groundwater table. The operation removed a total of 24 m^3 of LNAPL from the subsurface. The skimming was stopped in 2005, when the flow of LNAPL to the skimming wells was reduced to minimal amount. During subsequent groundwater monitoring in May, June, and August 2010, an oil film was observed in a series of wells centrally located within the source area. Studies showed that the area of LNAPL (primarily at residual saturation) represents an areal extent of 950 m^2. Laser induced fluorescence measurements were used to delineate the location of LNAPL (see Fig. 2). Central within the NAPL area is an area of 65 m^2, where contamination is widespread in the vadose zone from 2 to 3 m below ground level (bgl), and underlying in the smear zone and in top of the aquifer to a depth of 6 m bgl. Generally, LNAPL is prevalent in the smear zone from 3 to 4 m bgl and the top of the aquifer to a depth of 5.5 m bgl. The main part for the residual LNAPL (78%) is found from the top of the groundwater aquifer 4–5 m bgl.

Investigations carried out in 2010 have shown hydrocarbons in concentrations up 20,000 mg/kg (dry soil weight). Based on the survey results, the amount of residual LNAPL is estimated to be about 25–40 m^3, indicating that about half of the original spill volume is still in the subsurface.

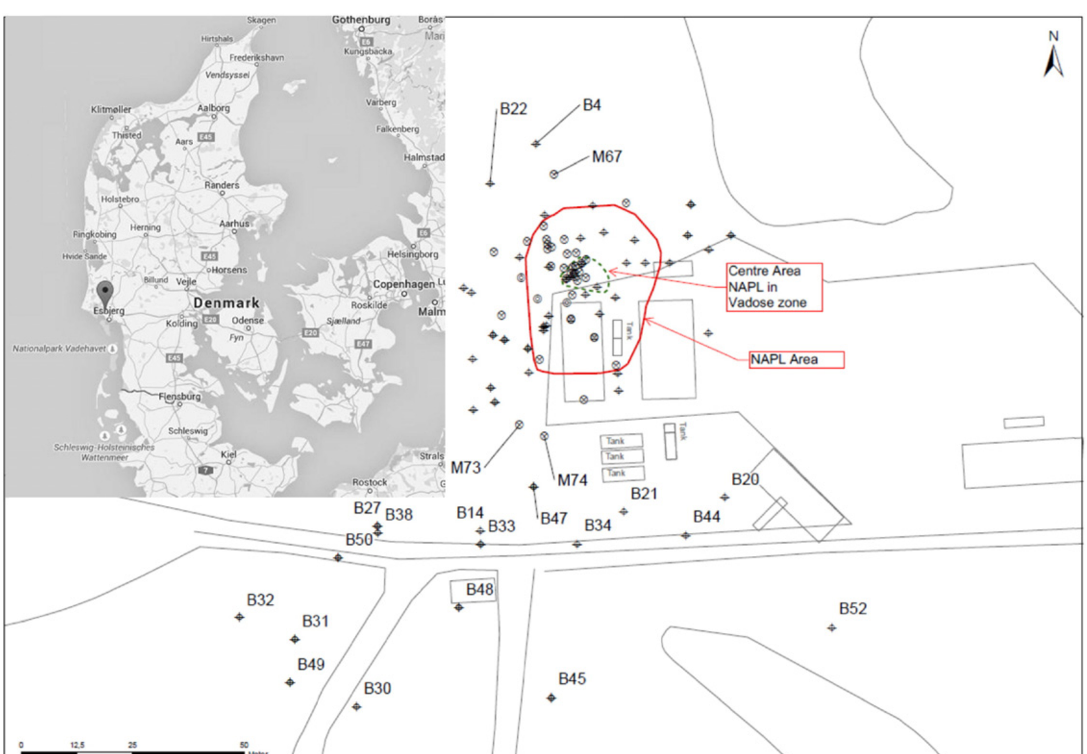

Fig. 1. Site location in western Jutland, Denmark (see inset map) where a leak of Jet A fuel was detected and the NAPL area to be remediated is shown encircled.

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