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► To cite this version:

Adil Baigadilov, Stéfan Colombano, Sagyn Omirbekov, Maxime Cochenne, Dorian Davarzani, et al.. Evaluation of stability and performance of foam composed of complex mixtures of surfactant, nanoparticles and polymer for in-situ remediation of LNAPL. AquaConSoil 2023, AquaConSoil, Sep 2023, Prague, Czech Republic. hal-04375348

HAL Id: hal-04375348

<https://hal.science/hal-04375348>

Submitted on 5 Jan 2024

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Evaluation of stability and performance of foam composed of complex mixtures of surfactant, nanoparticles and polymer for in-situ remediation of LNAPL

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Keywords: foam, foam stability, polymer, nanoparticles, soil remediation, LNAPL, porous media

Purpose of study:

Light Non-Aqueous Phase Liquids (LNAPL: gasoline, diesel, motor oil, etc.) - immiscible organic liquids which are one of the most common sources of groundwater pollution, particularly in France they represent 37.22% of polluted sites. The presence of LNAPL in subsurface is mostly associated with accidental spills and leaks during storage and transportation. As a result of the low mass removal efficiency of the pump and treat *in-situ* environmental remediation (ER) methods are receiving more attention thanks to the lower risk of contaminant migration and higher sustainability. Moreover, due to the heterogeneity of the soil, even the more advanced recovery methods like *in-situ* surfactant flushing reach their technical limits. Injected fluid preferentially flows in highly permeable areas caused by differences in viscosity.

Among the increasing interest in shear-thinning fluids for *in-situ* ER, foam (being 60-99% of gas in a continuous liquid phase) is a promising displacing agent. However, it is worth noting the main challenge of using foam for ER. When foam gets in contact with organic compounds, its stability deteriorates dramatically, which leads to poor sweeping efficiency. A current focus among many foam stability studies is on methods to enhance foam using a variety of additives, such as co-surfactants, polymers, and nanoparticles (NPs). It should be noted that the majority of these studies are focused on foam applications in EOR. Thus, our study focuses on (i) determining the destructive effect of LNAPL on foam properties, (ii) examining the stability of foam generated by two or more additives in the presence of a contaminant, both in bulk form and in porous medium, (iii) evaluating the recovery yields of each of the foaming formulations.

Methodology:

All foaming components used in our study were environmentally friendly. Diesel oil was used as the source of LNAPL. Two biodegradable surfactants (sodium dodecyl sulfate (SDS) and cocamidopropyl hydroxysultaine (CAHS)), and their mixture were used for the main foaming components. Silica (SiO₂) NPs and Xanthan Gum (XG) biopolymer were employed as foam-enhancing additives. All prepared foaming formulations were experimentally investigated for their foaming ability and stability (half-life) in the presence of diesel oil using the bulk and bubble scale foam screening method. The rheological properties of the foaming liquids were also studied using a rheometer.

Two decimetric 1D columns filled with sand and connected in series (i.e. foam generator and highly permeable diesel saturated sandpack) were utilized to (i) generate a fully developed foam flow and (ii) assess foam Resistance Factor (RF) (i.e. foam strength) and removal efficiency of diesel initially at residual saturation. Each injection experiment involved monitoring the pressure drop along the sandpack and collecting the effluents.

Results:

Our results showed significant destruction effect of diesel oil on foam stability. For instance, the half-life of the bulk SDS foam decreased 8 times in the presence of LNAPL, while the Resistance Factor decreased by more than 2.2 times in the porous medium. However stability assessments clearly demonstrated improved performance in the presence of diesel oil both in bulk and porous medium, when

complex foaming solutions were employed. The bulk foam analysis showed that in contrast to SDS alone, the mixture of SDS and CAHS (SC), SC+NPs and SC+XG enhanced foam stability more than 7.5 times. From 1D sand column experiments, we found foam enhancement of 2.2, 2.5, and 2.8 times for SC, SC+NPs, and SC+XG, respectively. Moreover, for all these complex foaming solutions there was a significant recovery efficiency of more than 90%.

Conclusion/contributions of study:

Additional studies are being carried out to deeply characterize how the presence of NPs and polymer impacts the diesel oil recovery. Nevertheless, based on our results we can conclude that advanced foam formulations clearly exhibited promising perspectives to develop an efficient in-situ remediation technique for highly permeable soils contaminated by LNAPL.