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Using the blocking effect of the foam for remediation of high permeability contaminated aquifers

Liquid foam has been studied as a blocking agent in porous media, especially for Enhanced Oil Recovery applications [1]. The goal of foam injection is to block high-permeability layers in the media in order to reach the oil in low-permeability layers. This technique can also be used for remediation [2]. However, contrary to oil industry, soils are non-consolidated porous media with high permeability as well as low pressure and temperature operational conditions. Foams can also be used to desorb pollutant thanks to the low surface tension of surfactant or push the pollutant to a recovery well thanks to foam high viscosity. In both cases, the benefits of using foam instead of monophasic surfactant solution is to create a homogeneous high viscous fluid that limits fingering.

In this study, we assume that groundwater velocity is too high (10 m/day) to use conventional in situ remediation techniques like oxidation/reduction because of short contact time. That is why the main goal is to create a foam barrier upstream to temporarily divert the groundwater flow away from the treatment area downstream. While the pollution is isolated from the groundwater flow, other techniques can be used to actually remediate more efficiently the polluted aquifer. Moreover, the pilot polluted aquifer soil is heterogeneous with a very high hydraulic conductivity (10^{-4} – 10^{-2} m/s).

Two different experimental setups were used to obtain the results. The first one is composed of a column of sand or glass beads, instrumented with pressure sensors to monitor the pressure gradient during foam flow. Mass balance was also conducted to measure the water saturation in the column. The second one is composed of a thin 1 m large and 50 cm high tank to model a 2D flow. The tank is instrumented with pressure and water saturation sensors. In addition, an imaging technique is used to measure the evolution of foam volumes, streamlines and water saturations. During the experiments, foam is injected from the bottom of the tank and water is injected from left to right to model a groundwater flow. Finally, the experimental results are compared with numerical models in order to validate them. The validated model can be then used to simulate foam injection for field scale studies.

The surfactant has been chosen based on low toxicity, foamability and foam stability tests. Then, thanks to the column experiments, a specific behavior of foam in high permeable porous media was identified with two successive different regimes of foam flow (“weak” and “strong” foam) as well as necessary injection conditions for its generation. Finally, the influence of injection parameters on the foam blocking properties, such as the “Resistance Factor”, the residual water saturation, the radius of influence or the stability under a groundwater flow, has been investigated. The parameters studied are the injection method (gas and surfactant co-injection, Surfactant-Alternating-Foam (SAF), foam pre-generation), the flow rates, and the foam quality. The results show the applicability of this technique and its limits for a field usage.

[1] R. Farajzadeh, A. Andrianov, and P. L. J. Zitha, Investigation of immiscible and miscible foam for enhancing oil recovery, Industrial & Engineering chemistry research, 49.4, 1910-1919 (2009).
[2] G. J. Hirasaki et al., Surfactant/foam process for aquifer remediation, International symposium on oilfield chemistry, Society of Petroleum Engineers (1997).