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Flow Behavior of Sheared Foam in Porous Media: An Experimental Investigation on the Effects of Stabilizing Agents and Oil Presence

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In enhanced oil recovery, foam is used for its inherent capability to act as a mobility control agent. Compared to conventional displacement fluids, such as surfactant and polymer solutions, foams contain up to about 95% less water, have tunable rheological characteristics, and leave behind less residue. However, foams are thermodynamically unstable, especially when exposed to hydrocarbons, and must therefore be treated with stabilizing agents.

This study focuses on the systematic characterization of nitrogen-foam rheology using steady-state and oscillatory shear measurements as well as core flooding tests. We investigate the effects of surfactant and salt concentration as well as additives, such as polymers and nanoparticles. Furthermore, the effects of different oils (n-Decane; Soltrol 170; and Ekofisk crude oil) are investigated. In this study, foam is made by either sparging gas through a porous frit into aqueous surfactant solution or co-injecting gas and surfactant into a novel foam generator. The foam generator creates fresh, homogeneous foam by co-injection of up to three phases with highly controllable flow rates. This allows for the characterization of generative and destructive foam dynamics (by co-injecting an oil phase) inside porous media. Berea sandstone with average porosity and permeability of 21.03% and 449.6 mD is used for the core flooding tests.

We find that higher concentrations of surfactant and/or salt containing monovalent counterions could enhance foam rheology, most likely due to a change in the rate of surfactant adsorption at the liquid-vapor interface. Furthermore, for a constant gas-volume fraction (91%), we show that a polymer additive could boost foam rheology if the gas phase is well dispersed in the surfactant/polymer solution and the bubble size that is produced decreases, thereby increasing the total surface area and multiplying the effects of enhanced film elasticity. Likewise, for the core flooding tests, we notice that polymer-enhanced foam increases the mobility reduction factor over polymer solution as injection rate increases and average bubble size decreases; though this corollary in porous media is better explained by the injection of pre-generated foam and elimination of any region of net foam generation inside the core. Moreover, contrary to reported observations of CO2-foam, nanoparticles have no appreciable effect on nitrogen-foam rheology, a discrepancy we believe to be a consequence of gas solubility and a slower rate of inter-bubble gas diffusion for N2 compared to CO2. On the other hand, as expected, oil has a considerably destructive effect on foam, and different oils lead to varying degrees of destabilization. In agreement with previous observations, foam is generally more stable in heavy oil than in light oil. However, a slight reversal of this trend in the three-phase core flooding tests as compared to the standard rheological measurements at atmospheric conditions hints at the added complexity of the fourth (solid) phase and the dynamic effects that arise during flooding in porous media. We believe the novel method of foam generation is more representative of the foam flooding process in oil reservoirs and could help in better understanding the dynamics of foam generation, destruction, and regeneration in porous media.

References

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