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Evaluation of foam stability in bulk and core-scale with CO₂-rich gas mixture and zwitterionic surfactants

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Foam-assisted water-alternating-gas is a promising technology to control gas mobility in carbonate reservoirs. Maintaining the stability of the foam since its generation is key to achieve this goal. It has been widely demonstrated that the high water-solubility of the carbon dioxide (CO₂) favors coarsening and coalescence phenomena, negatively affecting the stability of foams formed with this gas (Farajzadeh et al., 2012). CO₂-foam stability can be improved by mixing the CO₂ with other less-soluble gases, such as nitrogen (N₂) or methane (CH₄), generating stronger foams, also improving mobility control (Siddiqui and Gajbhiye, 2017). The choice for a suitable surfactant is also fundamental for the generation of stable foams. Zwitterionic surfactants such as cocamidopropyl betaine (CAPB) and cocamidopropyl hydroxysultaine (CAHS) are good candidates for their strong tolerance to salinity and temperature, and lower adsorption on carbonate rock surface in high-salinity conditions compared to anionic surfactants. The aim of this work was to evaluate the potential of two zwitterionic surfactants (betaine and sultaine) to generate strong foams in bulk and at core-scale using CO₂-rich gas mixture. Experiments were carried out under high-pressure and high-temperature (HPHT) conditions (65°C and 10MPa) using 0.5wt% of surfactant (active matter) and 40mol% CO₂ mixture with nitrogen. We evaluated foam texture and stability in bulk by sparging the gas from the bottom of the surfactant solution, and foam apparent viscosity at core-scale by co-injecting the fluids through low- and high-permeability Indiana limestone cores. Core flood experiments were performed from top-to-bottom at 3.5 x10⁻⁶ m/s Darcy velocity at varied foam qualities (fg). Bulk foam experiments showed that foams formed at HPHT were highly stable (decay of less than 10% of foam height) throughout the experiment (7200 s), suggesting that both surfactants stabilized foam despite having 40mol% concentration of CO₂ in the gas phase. It was also observed that the coarsening rate obtained in bulk were similar for CAPB (6.3 mm²/s) and CAHS (6.4 mm²/s). Regarding the core flood experiments, we demonstrated that CAPB and CAHS surfactants were able to generate strong foam at HPHT using a CO₂-N₂ gas mixture. For CAPB surfactant, maximum foam apparent viscosity was 83 mPa.s (at fg=0.6) for the high-permeability core and 35 mPa.s (at fg=0.5) for the low-permeability core. The same parameters for the CAHS surfactant were 80 mPa.s (fg=0.6) and 13 mPa.s (fg=0.4). The formation of strong foam in porous media corroborates with the high foam stability and low coarsening rate obtained in bulk. These results confirm our observations in micromodel experiments, where we showed that using a gas mixture would improve foam texture and strength (Lopes et al., 2021) and slow down coarsening (Façanha et al., 2022). Our results suggest that the presence of CO₂ as a contaminant in the gas phase would not completely destabilize foam at 10MPa and 65°C, and good mobility control could be achieved for projects with similar gas streams. Additionally, we showed that bulk experiments at HPHT correlated well with pore- and core-scale experiments, indicating that foam physical behavior could be understood across scales using these techniques.

Participation

In-Person

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