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Evaluating the Potential of Nanoparticles for Foam Generation and Stability at High Temperatures: Steam Foam Application

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Steam injection has been implemented with residual oil saturation in swept zones being as low as 10% in the case of Steam Assisted Gravity Drainage (SAGD) processes. The primary difficulty with a gas injection of any kind is conformance due to low density and viscosity of the gas. Therefore, gases tend to form channels and pathways through oil rather than displacing the oil. Traditionally foam-forming additives such as surfactants have been added to reduce gas mobility. However, the surfactants ability to perform under harsh conditions (e.g. temperature and salinity) are limited. Nanoparticles can be a promising enhancer/stabilizer for foam additives at reservoir condition. This is promising for EOR processes with steam (i.e. SAGD) since the increased mobility control and the transport stability, can improve the conformance control and consequently sweep efficiency.
In this study, the foam height tests (Nitrogen as the gas phase) were performed with the surfactants, nanoparticles, and combinations of the two with the help of high-pressure high-temperature (HPHT) visual cell. Foams generated with surfactant were treated as a baseline and effect of nanoparticle addition on foam behavior was studied. Dynamic light scattering was used to characterize all nanofluid solutions before and after foam height tests to ensure nanoparticle-surfactant compatibility and stability in solution at HPHT condition. After screening the various foaming agents, the dynamic flow experiments were performed with a specially configured core flood apparatus designed for steam foam flooding. Propagation of the nitrogen foam was measured using four differential pressure taps located along the length of the porous media (100 °C and 500 psig). In addition, steam foam flow experiments were also performed in the presence of nitrogen as a non-condensable gas (500 psig and 250 °C). Effluent samples were analyzed for nanoparticle and surfactant effective concentrations using high accuracy inductively coupled plasma triple quadrupole mass spectrometry that yielded retention and adsorption.
In initial foam height tests (500 psig and 100 °C) it was observed that the combination of a studied coated silica nanoparticle and sodium dodecylbenzenesulfonate surfactant produced foam with a better texture, and a longer retention of foam height compared to foam generated with the only surfactant. In addition, the foam produced with a proprietary nanoparticle alone outlasted the surfactant stabilized foam at HPHT condition. The increase in foam half-life was also correlated with higher mobility reduction and faster foam propagation in nitrogen and steam foam flow experiments. Effluent composition profiles and tracer composition profiles developed by ICP-QQQ analysis yielded mass balance data in addition to providing detailed information about the throughput of injection fluid. Dynamic flow experiments revealed the synergy between nanoparticle and surfactant in steam foam application (i.e. mobility control) compare to that of the steam-surfactant system.
The results obtained through this study yielded data regarding multiphase transport of nanostructured foams through porous media at high temperatures, such as propagation through porous media, nanoparticle stability in harsh conditions, retention and adsorption of surfactant, nanoparticles, and their combinations. The knowledge obtained from this study significantly improves our understanding of nanoparticles as an additive in steam foam application.

References

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