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Pore Scale Dynamics of Gravity-Stable Surfactant Flooding

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Surfactants can drastically reduce the water/oil interfacial tension (IFT) to mobilize residual oil. However, surfactant flooding is viscously unstable inherently because of its large mobility ratio. Alkaline/surfactant/polymer (ASP) flooding has been serving as a conventional solution, where polymer plays a vital role in increasing viscosity for a more stable oil bank. Recently, a gravity-stable surfactant (GSS) flooding was proposed as a promising alternative to stabilize the displacement front without mobility control.
In comparison with the sandpack/coreflood experiments, glass-etching model provides a powerful visualization means to examine both static occurrence and flow dynamics of the fluids from a micro perspective. Based on pore network patterns, conceptual models were etched to study the basic mechanism; while actual water-wet models were etched to investigate the effectiveness in heterogeneous scenarios. After the model was vacuumed and NaCl brine-saturated, we took advantage of the gravity, therefore, oil injection (from the top), initial brine injection and surfactant flooding (from the bottom) were vertically performed in turn. Using computer image preprocessing technique, microscopic residual oil in the model is automatically recognized and extracted.
After injecting surfactant solution, microemulsion phase was generated between the oil bank and surfactant slug. Their movement and interaction was visualized and recorded. Firstly, we compared the results among brine at under-optimum, optimum, and over-optimum salinities. Besides, under the condition of optimum salinity, formulation was tuned to reduce microemulsion viscosity to obtain higher critical velocity. Results show that a significant enhanced oil recovery was achieved; and the displacement front was sufficiently maintained with collected oil bank moving ahead under high critical velocity. This validates the modified stability theory and corresponding reservoir simulation. Specifically, according to topological structures, we classify the residual oil into five types for a detailed discussion: membranous flow, droplet flow, columnar flow, multi-porous flow, and clustered flow. And their ratio were calculated through shape recognition. During water flooding, the clustered flow (continuous phase) was mainly transformed into multi-porous flow and columnar flow (non-continuous phase). After the surfactant flooding, yet some reversion occurred due to the in situ emulsification. Moreover, in the follow-up experiments, a less surfactant slug size with a brine post-flush could also realize the desired result, saving more chemical cost.
The novelty of the paper lies in 1) applying microfluidics to the newly designed GSS flooding for microscopic investigation; and 2) quantitatively charactering the residual oil during the flooding. This approach illustrates the phenomena and analyzes the mechanism of the GSS flooding at pore scale, which offers guidance for further effective optimization and economical implementation of the flooding.

References

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