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Robust determination of viscosity of surfactant-polymer solution for enhanced oil recovery using microfluidics approach

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Objective:
It is believed that viscous oil-displacement fluids enhance oil recovery (EOR) by modulating the mobility ratio between displacement fluid and oil. According to classical mobility control theory, a lower viscosity ratio of the defending fluid and the invading fluid would allow for better incremental oil recovery. However, core-scale experiments have shown that the viscosity ratio is not always monotonically related to incremental oil recovery. Instead, there is an optimal viscosity. The determination of viscosity for non-Newtonian fluids, which are the primary composition of chemical flooding, is inherently elusive. This has become an important issue in the application of chemical oil-displacement agents to reservoirs. While core-scale experiments can aid in viscosity design, extensive experimental work can impede research progress. Microfluidic is an advanced technique that enables in-situ visualization within porous media. In this study, we propose a microfluidic approach to enable rapid decision-making on the viscosity of viscous chemical oil-displacement agents.
Method:
Microfluidic experiments using PDMS chips were conducted to perform surfactant-polymer (SP) experiments at different polymer molecular weights and concentrations. The experimental results were analyzed using our previously proposed image algorithm (Gao,2021) for multi-scale pore recovery coupling with z-score method, which allows for characterization of the viscosity matching degree in different planar pore radii. Finally, the hydraulic radius approach is applied to upscale the planar pore radius in microfluidics to permeability of the reservoir. This enables the graphical plotting of matching degree between reservoir permeability and apparent viscosity.
Results：
The microfluidic experimental results confirm that higher viscosity does not lead to better incremental recovery. Instead, there exists an optimal viscosity. The viscosity of the displacement agent and the pore have a matching relationship, and a higher matching degree corresponds to a higher recovery. For HPAM-based SP solutions, a lower viscosity is observed at lower pore radii. With average pore radius in the range of 3-14μm, the most appropriate viscosity is in the range of 9-42cP. In same viscosity SP solutions, a high concentration of low molecular weight was found to be more effective in EOR than a low concentration of high molecular weight. The reason for this is that higher concentration gradients are conducive to the mobilization of residual oil in the smaller pore spaces.
Novel：
This work provides new insights into the microfluidic applications for EOR. Compared to extensive core experiments, microfluidics offers the advantage of characterizing mobilization in multi-scale pores simultaneously. This approach requires only a few experiment to achieve the same results as more than a dozen core-scale experiments, thus significantly reducing the effort and time required. On the other hand, microfluidics has the advantage of allowing in-situ visualization in porous media, which facilitates the understanding of the performance and mechanism of chemical oil-displacement agent, and has the potential to replace core-scale experiment to some extent in phenomenological research.

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