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Pore-scale Experimental Investigation of Displacement Mechanisms during Flow of Non-Newtonian Fluids in Natural Porous Media

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A large number of applications in science and engineering involve the flow of non-Newtonian fluids in naturally-occurring and synthetic porous media. Examples include flow processes that are related to enhanced oil recovery, underground waste disposal, and groundwater contamination. In the recent years, a growing number of studies have been dedicated to investigate a wide variety of viscoelastic fluids for use in enhanced oil recovery (EOR) from underground reservoirs. Pioneering field trials have indicated that the injection of viscoelastic fluids into a reservoir may provide sufficient increase in the capillary number to improve non-wetting phase mobilization and sweep efficiency compared to those of the traditional waterflooding. However, the pore-scale displacement mechanisms responsible for this improvement and the transport of fluids in porous media during viscoelastic fluid injection are poorly understood partly due its complex rheology. To the best of our knowledge, the current body of the literature has not distilled a clear image of the underlying displacement physics and essential physical relationships such as capillary desaturation curve during viscoelastic fluid injection. Hence, in this study, we address the trapping and mobilization of non-wetting phase during the flow of immiscible viscoelastic fluids.

We perform several sets of two-phase flow experiments on miniature water-wet Berea sandstone core samples at the microscale and using various Newtonian and viscoelastic aqueous phases. The experiments are performed on vertically oriented core samples at 4.12 MPa pore pressure and 5.52 MPa overburden pressure. The core initially saturated with water was subjected to a primary oil drainage (to establish Swi) followed by a waterflood during which the brine flow rate is increased stepwise. The core sample is scanned after each flood when no changes are observed in fluid configurations.

We use a two-phase miniature core-flooding apparatus integrated with a micro-CT scanner to directly visualize the complex morphologies of non-wetting fluid ganglia within natural porous media. This information is then used to study the effect of flow rate on oil mobilization over a wide range of flow rates corresponding to different regimes of the bulk viscoelastic flow behavior (i.e. shear flow and elongation dominated flow). Furthermore, pore-scale fluid occupancy maps during different flooding scenarios along with pore space characteristics, local fluid saturations, oil cluster size distributions, and in-situ wettability obtained from the tomography images are used to explain the observed capillary desaturation trends and shed light on the dominant displacement mechanisms under two-phase flow conditions.

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