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Quasi-3D pore-scale simulation of wettability heterogeneity in porous media

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Wettability plays a crucial role in multiphase flow and fluid displacement in porous media [1,2] and it is generally classified as homogeneous and heterogeneous.[3] For homogeneous wettability, the whole rock surface has a uniform molecular affinity for the fluids in contact. In contrast, for heterogeneous wettability, variation in affinities for the fluids at different regions is expected.[3] Most reservoirs display heterogeneous wettability which can be categorized as either fractional or mixed-wet.[4] In the fractional-wet group, oil- and water-wet regions are random with respect to pore size, but in mixed-wet group water- and oil-wet pores are sorted based on their size.[5]

In order to understand the effect of wettability heterogeneity at the macroscopic level on flow functions, e.g. relative permeability and capillary pressure, it is essential to understand its role at microscale/pore level. Limited micromodel studies have been performed on microscale wettability heterogeneity mainly due to fabrication challenges.[1,6] Significant impacts on fluid displacement and level of residual saturation have been observed in the system with non-uniform wettability.[1] Although fabrication of porous media replicas with several spatial configurations for wettability heterogeneities is not practical, pore-scale numerical simulations are very useful to study different scenarios and optimize the experimental design for further investigation.

To the best of our knowledge, most of the numerical simulation studies investigated the effect of different uniform wettability on fluid flow dynamics, however, most rocks display heterogeneous wettability (fractional or mixed-wet). In this work, we have used direct numerical simulations (DNS) to investigate wettability heterogeneity at pore-scale. DNS studies were conducted using the Phase Field method using a commercial computational fluid dynamics (CFD) software (COMSOL Multiphysics).[7] We have built Quasi-3D pore-scale models and simulated homogenous and heterogeneous types of wettability and investigated the effect of uniform and non-uniform wettability on the two-phase flow in porous media.

Two-phase flow displacements are compared at different uniform and non-uniform contact angles distributions. We observed that non-uniform wettability has a significant effect on the evolution of fluid interface, pressure drop across the system, displacement efficiency and trapped saturation. A porous media with equal surface areas of two different contact angles e.g., 60^{o} and 120^{o} does not simply behave similar to a media with a uniform contact angle of 90^{o}. Simulation results showed that certain spatial configurations of wettability heterogeneity at microscale assist the stability of displacement, while other configurations promote flow instability for the same pore-scale geometry. The results of these DNS studies are of interest to different subsurface processes involving wettability alteration and reactive transport.

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