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The synergistic role of pore geometry and wettability in governing immiscible displacement and entry capillary pressure

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Immiscible multi-phase flow within porous structures plays a crucial role in a variety of natural and industrial processes and is governed by several forces such as viscous, capillary, and buoyancy forces and pore geometry. Understanding the interplay of these factors is critical in controlling the behaviour of fluid-fluid interfaces in multi-phase flow in porous media. This interplay determines the resistance to fluid entry into pores and directly impacts the displacement efficiency. Entry capillary pressure is the capillary pressure that the nonwetting phase must overcome to enter a pore occupied entirely with the wetting phase. The effect of pore geometry and wettability on immiscible two-phase flow has been emphasised in recent research studies. However, the conventional entry capillary pressure equations neglect the three-dimensional (3D) details of pore structures and wettability, which results in deviations between analytical and practical results.

In this study, we adopted volume-of-fluid (VOF) method to explore the synergistic role of pore geometry and wettability in governing interfacial morphology, entry capillary pressure, and residual trapping. Numerical simulations were performed in four idealised constricted capillaries and two real pores extracted from rock sample. The numerical predictions were compared with analytical solutions and findings from other studies. The results show that entry capillary pressure temporarily decreases and even turns negative under intermediate wettability conditions during the drainage process when the interface initially enters the converging segment. Through the analysis of the evolution of interface morphology and the detailed distribution of curvatures on the interface, the role of net force rearrangement and pore geometry on evolution of curvature and displacement characteristics was investigated. Moreover, it was shown that intermediate wettability improves displacement efficiency due to curvature reversal (suction effect), which is also verified in core-scale experiments. This work highlights the importance of considering the corner flow in controlling immiscible two-phase flow dynamics in pore network modelling research.

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References

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