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Experiment and simulation of quasistatic fluid invasion resulting in pressure-saturation (p-s) hysteresis

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During imbibition, fluid-fluid interface at the inlet of a constriction experiences an increase in capillary force that results in rapid fluid invasion known as Haines jump (Haines, 1930). During drainage, the interface gets pinned at the end of the constriction, which causes p-s trajectories to follow different paths during imbibition and drainage resulting in p-s hysteresis. In this work, we performed quasistatic two-phase flow experiments and simulations of cyclic imbibition and drainage to have a quantitative understanding of pore-scale processes resulting in pressure-saturation (p-s) hysteresis. We considered two different 2D Hele-Shaw cell setups: a capillary tube with a horizontal constriction (ink-bottle) and a heterogeneous porous media randomly populated by cylindrical obstacles. In both setups, drainage and imbibition are driven by quasitatically changing the pressure gradient between the inlet and the outlet of the domain. The experimental results were compared with the results from numerical model in OpenFOAM, which solves the Navier-Stokes equations employing volume of fluid (Hirt and Nichols, 1981) method to calculate the position of the interface and the continuum surface force (Brackbill et al., 1992) model to describe surface tension. For the ink-bottle setup, we observed that multiphase flow through a single constriction displayed the signature trait of p-s hysteresis, which depends innately on the cross-section gradient. The steeper the cross-section gradient, the more pronounced the p-s hysteresis, moreover, p-s hysteresis did not occur below a critical gradient. We derived an analytical solution to calculate the critical gradient and compared it with the critical gradient obtained from experiments and simulations. In heterogeneous porous media setup, we observed rapid fluid invasion and retention patterns in small pores during imbibition-drainage cycles, which give rise to hysteretic p-s trajectories. This comparative study will allow us to quantitatively link the pore-scale capillary physics to large-scale p-s hysteresis.

Participation

In-Person

References

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