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Wettability control on multiphase flow in porous media: A benchmark study on current pore-scale modeling approaches

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Multiphase flow in porous media is important in many natural and industrial processes, including geologic CO_2 sequestration, enhanced oil recovery, and water infiltration into soil. Although it is well known that the wetting properties of porous media can vary drastically depending on the type of media and pore fluids, certain aspects of wettability control on multiphase flow continue to challenge our microscopic and macroscopic descriptions. The gap in our understanding could be bridged by pore-scale modeling, which has seen rapid development in recent years and is becoming a useful predictive tool in both academic and industrial applications. The goal of this work is to validate and improve different pore-scale modeling methodologies by comparing the modeling results from various leading researchers with a benchmark experimental dataset on patterned microfluidic cells.

As part of the benchmark study, we received submissions from over 10 research groups from around the world, whose modeling approaches include Lattice Boltzmann methods (LBM), smoothed particle hydrodynamics (SPH), Cahn-Hilliard phase-field models, volume of fluid (VoF) methods, level-set methods (LSM), and pore-network models. For each submission, we conduct both qualitative and quantitative comparisons between the modeling results and the experimental results. Qualitatively, we compare the macroscopic fluid-fluid displacement patterns for a given wettability condition and capillary number. Quantitatively, we compare the fractal dimension of the displacement pattern, the median saturation, and the displacement efficiency of the invading fluid.

Despite the high computational demand of simulating the fluid-fluid displacement process at the pore-scale, the modeling results have shown impressive agreement with the experiments. In particular, most modeling approaches are able to capture the increasingly compact displacement pattern in the transition from strong drainage (i.e. highly non-wetting invading fluid) to weak imbibition (i.e. weakly wetting invading fluid). However, capturing the flow behavior in strong imbibition (i.e. highly wetting invading fluid) proves to be much more challenging. This is because strong imbibition is dominated by capillary-assisted corner flow, where the 3D configuration of the fluid-fluid interface is important. The present study highlights the need to develop alternative pore-scale modeling methodologies capable of accounting for the 3D nature of interfacial flows in a computationally efficient manner.

References

B. Zhao, C. W. MacMinn, and R. Juanes, Wettability control on multiphase flow in patterned microfluidics, Proc. Natl. Acad. Sci. U.S.A., 111(37), 10251-10256 (2016).

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Primary authors: JUANES, Ruben (MIT); ZHAO, Benzhong (U. Toronto); MACMINN, Christopher (Oxford U.)

Presenter: JUANES, Ruben (MIT)

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