Fluid-Fluid Displacement in Mixed-Wet Porous Media

Fluid-fluid displacement in porous media occurs in many natural and engineering processes such as water infiltration into soil, geological carbon dioxide storage, and enhanced oil recovery. It has long been recognized that wettability plays an important role in the displacement process. For instance, the displacement pattern of a viscous ambient fluid by a less viscous invading fluid becomes more compact as the invading fluid becomes more wetting to the porous medium. Thanks to decades of research, we now have a fairly good understanding of fluid-fluid displacement in porous media with uniform wettabilities. In contrast, our knowledge of fluid-fluid displacement in porous media with heterogeneous wettabilities (i.e., mixed-wet) is much less complete, even though mixed-wet conditions are common in many subsurface processes.

Here, we study the impact of mixed-wettability on fluid-fluid displacement in simple porous media. Experimentally, we perform constant-rate displacement of a viscous ambient fluid by a less viscous invading fluid in microfluidic flow cells patterned with vertical posts. We image the system at high resolution, providing simultaneous visualization of both the physics of wetting at the pore scale and the impact of wetting on the macroscopic displacement pattern. By tuning the surface energy of the flow cell locally, we achieve clusters of posts that are distinctly more wetting to the invading fluid compared to the rest of the flow cell. We vary the wettability of the clusters, as well as their size and distribution. We find that they both exert important control over the displacement pattern. Numerically, we simulate the experiments using a novel pore network model (Primkulov *et al.*, 2019). We achieve excellent agreement between the modeling results and the experiments. Our work provides an experimental and numerical platform to systematically investigate fluid-fluid displacement in mixed-wet porous media.