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Fluid Distributions for Drainage in Open Rough-walled Fractures with Smoothly Varying Aperture

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Displacement of a wetting by a non-wetting fluid in fractured media is a process with relevance for many applications, such as fluid storage in the subsurface or oil and gas exploitation. Numerical modeling of flow processes in fractured media is challenging due to the very small length scales needed to resolve fracture geometries of large fracture networks. It is highly questionable if the two-phase flow equations can be simplified to continuum approaches, such as established for porous media, which would allow for coarse spatial resolutions of a model. For this reason, it is necessary to develop a good understanding of how flow conditions (in particular, the capillary number and viscosity contrast) and fracture geometry control the two-phase flow regimes, and in particular the spatial distributions of the two fluids during the displacement process. These patterns play a key role in determining the macroscopic behavior. One key properties of the flow patterns are, for example, the amount and spatial distribution of wetting fluid that is immobilized behind the displacement front. While there has been extensive investigation of this question in the context of porous media, studies on rough fractures are relatively scarce.
It is well established that in horizontal settings, the displacement is governed by capillary and viscous forces, resulting in the emergence of various displacement patterns (compact, viscous fingering or capillary fingering, and various intermediate regimes between them). For porous media flow in uniform packings and flow between parallel plates, these patterns are well quantified. If the fracture is, however, rough, i.e., with rough walls resulting in a spatially-varying aperture field, patterns can be controlled by both the structure and the flow conditions. It is not well understood, under which conditions patterns are controlled by the flow conditions or by the geometrical properties of the aperture field.
In this contribution, we perform Direct Numerical Simulation (DNS) to analyze the drainage process by solving the Navier–Stokes equations within the fracture's space, employing the Volume of Fluid (VOF) method to track the evolution of fluid-fluid interfaces. We consider a wide range of Capillary numbers (10-5 –10-2), as well as three distinct viscosity ratios (0.8, 0.05 and 0.01), and address realistic synthetic fracture geometries characterized by their Hurst exponent, the ratio of the roughness amplitude to the mean aperture, and the correlation scale of the investigated fracture domain.
We evaluate the displacement patterns based on morphological properties, such as Euler number, cluster size distribution or interfacial length, as well as on macroscopic (averaged) properties, such as volumetric fluid content. The focus is on the question, for which conditions the fracture behaves macroscopically 'smooth', meaning that the features are dominated by the flow conditions, and for which conditions the geometry of the aperture field influences these properties. As an example, we look for the geometric conditions that maximize trapping of the displaced fluid.

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References

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