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Investigation of drainage and imbibition fronts by direct numerical simulations

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The dynamics of an invading front during drainage or imbibition of a porous medium depend on the particular flow regime, which is determined by the interplay between different forces. The large-scale behavior is affected by the presence of small-scale instabilities, which can give raise to dynamic effects or irreversible transitions.
Numerical investigation of this complex behavior requires employing an accurate description of the sub-pore physics in order to limit the number of ad-hoc model assumptions. At this end, we numerically solve the full Navier-Stokes equations (including inertia) in synthetic pore geometries and we investigate the effects of the different dimensionless numbers affecting the flow and the front morphology. The Volume of Fluid (VOF) method is used to capture the evolution of the interface. This approach is able to resolve the sub-pore physics and can serve as benchmark to validate both pore-network models and theoretically derived macroscopic models.
We present simulations of drainage and imbibition cycles under quasi-static and dynamic conditions. We analyze the numerical results to investigate the most appropriate definition of macroscopic viscous and capillary pressure and to link the latter to its physical origin: surface free energy.