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Viscous fingering with partially miscible fluids

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Viscous fingering–the fluid-mechanical instability that takes place when a low-viscosity fluid displaces a high-viscosity fluid–has traditionally been studied under either fully miscible or fully immiscible fluid systems. In practice, however, the miscibility between two fluids can change appreciably with temperature and pressure and often falls into the case of partial miscibility, where two fluids have limited (but nonzero) solubility in each other (e.g. CO_2 and water). Following our recent work for miscible systems [1, 2] and immiscible systems [3, 4], here we study the impact of partial miscibility on the pattern forming dynamics of viscous fingering [5, 6]. Through a careful design of the thermodynamic free energy of a binary mixture, we develop a phase-field model of fluid-fluid displacements in a Hele-Shaw cell for the general case in which the two fluids have limited (but nonzero) solubility into one another [5]. We show, by means of high-resolution numerical simulations, that partial miscibility exerts a powerful control on the degree of fingering: fluid dissolution hinders fingering while fluid exsolution enhances fingering. We also show that, as a result of the interplay between compositional exchange and the hydrodynamic pattern-forming process, stronger fingering promotes that the system approach thermodynamic equilibrium faster.

References

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