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Salinity Effects During Two-Phase Flow in Porous Media: Electrokinetic Control of Viscous Fingering

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Pattern formation is ubiquitous in many physical or chemical processes and has been at the center of attention for the past couple of decades. In many instances, interfacial instabilities play a central role in creating these patterns and controlling their spatiotemporal evolution. Perhaps one of the most well-known examples is the striking figures generated when a high-viscosity fluid is displaced by a low-viscosity fluid. This "viscous fingering"phenomenon was originally described by Saffman and Taylor in the context of Hele-Shaw flows but is also observed in porous media flows, where it leads to residual trapping during secondary or tertiary oil recovery and reduces extraction efficiency.

In the classical theory, the onset of instability is only controlled by a single parameter, i.e. the viscosity ratio. However, coupling with other physiochemical processes could enhance or suppress viscous fingering. For instance, many rock formations contain chemically active surface groups that dissociate in the presence of water and lead to the formation of surface charge. These surface charges interact electro-statically with mobile ions in the solution and can affect the flow behavior through the so-called electrokinetic coupling.

Here, we use linear stability theory as well as nonlinear numerical simulations to study the role of electrokinetic coupling and salinity effects on the interface stability. Our results indicate that viscous fingering may be controlled, and even suppressed, by applying external electric fields. Furthermore, even in the absence of electric fields, strong electrokinetic coupling (present in nanopores where the electric double layers overlap) can reduce viscous fingering by enhancing the "effective viscosity" of the injected fluid through the electro-viscous effect.

Our findings can have implications for electrically enhanced oil recovery application, as well as low salinity water flooding, and might help with understanding other similar multi-field driven interfacial instabilities.

References

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