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Numerical Challenges in Numerical of Foam Displacements in Porous Media

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We review challenges to accurate simulation of processes of foam injection into geological formations for CO2 storage, aquifer remediation and enhanced oil recovery, with a focus on numerical issues (Rossen, 2013). Foam responds in an abrupt, nonlinear way to changes in water saturation, surfactant concentration, and oil saturation, in ways that cause fluxes to fluctuate in time and space. For instance, in simulations of foam with oil, consecutive grid blocks can lie on opposite sides of a strong foam/weak foam boundary on the composition diagram. The fluctuations can be suppressed by including capillary diffusion in the simulation. In addition, difficulty in representing shock fronts can lead to an increase in the foam-swept zone in simulations. As the grid is refined these effects have smaller impact on the overall process but execution of the simulation slows. Consideration of the 1D fractional-flow solution for the same displacement can determine whether the increase in foam sweep is a numerical artifact (Lyu et al., 2021a,b).

The representation of near-well effects on injectivity can require an impractical level of grid resolution near an injection well (Gong et al., 2020a,b). In addition, some near-well effects are not yet represented in foam simulators. An imperfect solution is to refine the grid to the extent practical and simply disregard the rise in injection-well pressure predicted by the Peaceman in the injection-well grid block.

Because by definition foam is an interaction between gas and water, the naming of phases (gas or oil) in a compositional simulation of a miscible EOR process can have significant effect on the simulation of a foam displacement. Numerical dispersion of surfactant concentration is also a problem, but attempts to minimize its effect can lead to other numerical artifacts. Because foam is so sensitive to water saturation and capillary pressure, capillary effects are important, especially in finely laminated formations.

"Population-balance" foam simulators, which represent the complex dynamics of bubble creation and destruction along with the effect of foam on gas mobility, face additional challenges with instability and slow run times, especially for models that represent the multiple steady states seen in the laboratory. A minimum velocity for foam generation in co-injection of gas and liquid can be represented by at least two simulation models (Yu and Rossen, 2022), but the implications for foam propagation may not be fully resolved.

We collect and review the various numerical challenges to foam simulation. Some of these problems are largely cosmetic, giving for instance fluctuating fluxes and pressure gradient but no significant effect on sweep and final recovery. Others do severely influence the whole progress of the flood. We discuss the origin of the challenges, how to recognize them, how they can be mitigated, and whether they arise from a correct representation of foam physics or the unintended result of attempts to solve other numerical problems.

Participation

In-Person

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