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Pore-Scale Modeling and Relative Permeability Upscaling in Stress-Sensitive Fractured Porous Media

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We investigate multiphase flow in rough-walled fractures within stress-sensitive rocks, addressing the complexities introduced by rock deformation and fracture geometry. At the pore scale, we employ a Lattice-Boltzmann formulation to simulate flow under various conditions, parametrized by fracture aperture, joint roughness coefficient (JRC), contact angle, and viscosity ratio. The simulations capture detailed physical processes at the fracture scale, enabling the generation of a family of relative permeability curves. These curves deviate significantly from traditional correlations for 3D porous media, reflecting the unique dynamics of flow in fractured systems. Through an upscaling process, we derive robust parametrization for the relative permeability curves. Additionally, we explore the Barton-Bandis law, which models the hyperbolic relationship between normal stress and fracture closure, to examine the effective stress influence upon the flow patterns. Perturbation analyses reveal stress-induced variations in the relative permeability curves, highlighting their sensitivity to mechanical deformation. To extend these insights to larger scales, we consider an idealized fracture arrangement within a coarse computational cell and perform steady-state, flow-based upscaling. This approach yields homogenized macroscopic relative permeability curves that capture the interplay between capillary forces and viscosity contrasts across various regimes. The proposed methodology provides a framework for analyzing the stress-sensitive behavior of these curves under realistic geological conditions. Finally, numerical simulations demonstrate the predictive capability and versatility of the model in capturing complex multiphase flow phenomena in fractured, stress-sensitive rocks. These results underscore the importance of incorporating fracture mechanics and detailed pore-scale physics into macroscopic flow models for improved characterization of fractured reservoirs.

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References

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