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Role of micro-fractures on displacement of immiscible fluids in fractured porous media: a pore-scale perspective

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Displacement of immiscible fluids in heterogeneous porous media is extensively found in many underground applications, such as groundwater remediation, underground hydrogen storage (UHS), and geological carbon storage (GCS). Natural fractures are widely distributed in the subsurface system and likely to induce a channeling effect that makes the flow within fractured porous media very distinct from that in conventional ones. In pursuit of enhanced displacement efficiencies in the aforementioned applications, the mechanisms of flow phenomena within fractured porous media needs to be better known by accounting of the channeling effect. Here, based on a numerical phase-field method (PFM), the spatial and temporal evolution of the phases and their interface during a multiphase flow in a fractured porous media are investigated under various fracture morphologies (i.e., aperture, length, dip angle, and tortuosity). The results show that the absolute permeability of the porous medium is all increased in the studied cases due to the presence of microfractures. This increase in permeability is largely attributed to the reduced fluid tortuosity in the flow direction. Yet the ultimate displacement efficiency shows a non-linear dependence on the absolute permeability. Micro-fractures serve as a main displacement pathway in view of the varying topology of the local pores, and thus play a key role in controlling the ultimate displacement efficiency. Among the above four characteristic parameters, aperture has the most significance in regulating the fluid displacement. The ultimate displacement efficiency reaches a maximum value (51.14%) as the aperture of the micro-fracture is twice the mean pore diameter and can be 1.2 times larger than that of the model without micro-fractures. The relative permeability of the displacing fluid, which is proportional to its saturation, shows a higher growth rate under presence of micro-fractures. It is also demonstrated that the ultimate displacement efficiency is negatively correlated to the growth rate of relative permeability.

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