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Immiscible displacements in rough fracture: phase diagram and localized flow channel

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Fluid-fluid immiscible displacement in fractured media plays an important role in various subsurface processes, including enhanced oil recovery and geological carbon sequestration. The displacement patterns range from viscous to capillary fingering to compact displacement owing to the competition between capillary and viscous forces. Although has been profoundly studied for porous media, the phase diagram as well as the displacement efficiency in different displacement patterns was rarely reported for rough fractures. Here we studied immiscible displacements in a horizontal transparent rough fracture under a wide range of capillary number Ca and viscosity ratio M. We performed drainage experiments of water-glycerol mixture displacing silicone oil to visualize the displacement processes under favorable conditions (1≤log10M≤3). Based on qualitative and quantitative analyses of the dynamic invasion morphologies, we for the first time proposed a full phase diagram for rough fracture, showing the domains of pattern formations (viscous fingering, capillary fingering and compact displacement) and the corresponding displacement efficiency as a function of Ca and M. The phase diagram indicates that the displacement efficiency decreases with the increase of Ca in the domain of compact-displacement. We can show that this efficiency reduction is attributed to the onset of localized flow channel induced by the spatial variability of fracture aperture. In this zone, the front is stable at initial stage until approaching a critical location, after which a finger is initiated and advances toward the outlet along the center of the fracture space with much higher velocity, demonstrating the important role of the heterogeneity of fracture geometry in the displacement processes. This study not only extends the phase diagram from porous media to rough fractures but also improves our understanding of the dynamics of displacement processes jointly governed by the viscous/capillary forces and the fracture geometry under favorable conditions.

References

Chen, Y. F., Fang, S., Wu, D. S., and Hu, R. (2017), Visualizing and quantifying the crossover from capillary fingering to viscous fingering in a rough fracture, Water Resources Research, 53(9), 7756-7772.

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