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A microfluidics investigation of the impact of microfractures on flow patterns in porous media during imbibition

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The imbibition in porous media plays a critical role in various natural and engineering processes, such as rainfall infiltration, hydrocarbon recovery, geological CO2 storage, and environmental remediation. Microfractures and discontinuities are naturally presented and purposely induced in natural rocks and soils. The interaction between these heterogeneities and the matrix increases the complexity of multiphase flow behavior in porous media.
This study aims to investigate the impact of microfractures on flow patterns in porous media during imbibition and understand the pore-scale fluid interaction between microfracture and matrix via microfluidics experiments. Polydimethylsiloxane (PDMS) micromodels of fracture-matrix porous media with various fracture widths are designed and fabricated using the soft lithography technique. The width of the matrix channels follows a lognormal pore-size distribution with a mean size of 30 and a standard deviation of 0.4. The width of the fracture varies from 4 to 40 times the mean pore size (120 μm to 1200 μm). The depth of the channel is around 110 μm. We inject ethanol as the wetting phase to displace air at various flow conditions (constant flow and constant pressure). A pressure transducer at the inlet monitors the pressure change, and a fluorescent microscope records the flow behavior. The effect of different microfracture geometries on flow patterns during imbibition at various flow conditions is analyzed.
Results show that the flow pattern is matrix-prefer when the injection flow rate is low. The ethanol prefers to invade the matrix, and the fracture acts as a capillary barrier. The flow pattern transfers from matrix-prefer to the transitional stage as the flow rate increases. The liquid equally invades the matrix and fracture area. The interaction between fracture flow and matrix flow is observed. Eventually, the fracture becomes a preferential channel at high flow rates. The capillary barrier and preferential channel phenomena are less salient for narrow fractured porous media, whereas they become more significant as the width of the fracture increases. The recorded pressure signatures reveal that the interplay between capillary and viscous forces results in different flow patterns during imbibition. The capillary force dominates the flow behavior at low capillary numbers and imbibes the wetting phase into the matrix. Fractures act as capillary barriers when the fluid pressure is smaller than the entry pressure. The viscous force dominates the flow behavior as the capillary number increases. The wetting phase invades the low-viscous drag fracture and the cross flow between fracture and matrix is limited.
In conclusion, we observe three flow patterns in fractured porous media during imbibition and identify two thresholds for these patterns. The interaction between fracture flow and matrix flow is analyzed at the pore-scale, Results presented in this study are relevant to the understanding of multiphase flow phenomena in fracture-matrix systems at various flow conditions.

Keywords: Microfracture, heterogeneity, imbibition, microfluidics, flow pattern, porous media

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