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Upscaling Multiphase Fluid Flow in Naturally Fractured Reservoirs

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Hydrocarbon recovery from fractured porous reservoirs is difficult to predict as it depends on the focusing of the flow and the local balance of viscous, gravitational, and capillary forces. Hecto-metre scale sub-volumes of fractured oil reservoirs contain thousands of fractures with highly variable flow properties, dimensions and orientations. This complexity precludes direct geometric incorporation into field scale multiphase flow models. Macroscopic laws of their integral effects on multiphase flow are required. These can be investigated by DFM (discrete fracture and matrix) numerical simulations based on discrete fracture models representing fractured reservoir analogues.

Here we present DFM results indicating that hecto-metre-scale relative permeability, the time to water break-through, and the subsequent water cut primarily depend on the fracture-to-rock matrix flux ratio, qf/qm, quantifying the proportion of the cross-sectional flux that occurs through the fractures. Relative permeability during imbibition runs is best approximated by a rate-dependent new model taking into account capillary fracture-matrix transfer. The up-scaled fractional flow function fo(sw) derived from this new kri formulation is convex with a near-infinity slope at the residual water saturation. This implies that the hector-metre scale spatially averaged Buckley-Leverett equation for fractured porous media does not contain a shock, but a long leading edge in the averaged profile of the invading phase. This dispersive behaviour marks the progressively widening saturation front and an early water breakthrough observed in the discrete fracture reservoir analogues. Since fracture porosity f is usually only a fraction of a percent, a cross-over from krw < kro to krw/kro ≈ qf/qm occurs after the first few percent of recovery, and because qf/qm ranges between 10-1,000, sweep efficiency ignoring the positive influence of counter-current imbibition is extremely low.

The accuracy of reservoir performance predictions by the proposed fo(sw) up-scaling methodology depends on how well f , qf/qm and a new parameter termed fraction of fracture matrix interface area in contact with the invading fluid, XA,if(si) can be constrained under in situ conditions.