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The effect of pore-scale geometry and wettability on two-phase relative permeabilities within elementary cells

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We study the relative role of the complex pore space geometry and wettability of the solid matrix on the quantification of relative permeabilities characterizing steady state immiscible two-phase flow in porous media. We do so by considering elementary cells, which are typically employed in upscaling frameworks based on, e.g., homogenization or volume averaging. In this context one typically relies on the solution of pore-scale physics at a scale which is much smaller than that of an investigated porous system. Pressure-driven two-phase flow following simultaneous co-current injection of water and oil is numerically solved for a suite of regular and stochastically generated two-dimensional explicit elementary cells with fixed porosity and sharing main topological/morphological features. We show that relative permeabilities of the randomly generated elementary cells are significantly influenced by the formation of preferential percolation paths (principal pathways), giving rise to a strongly nonuniform distribution of fluid fluxes. These pathways are a result of the spatially variable resistance that the random pore structures exert on the fluid. The overall effect on relative permeabilities of the diverse organization of principal pathways, as driven by a given random realization at the scale of the unit cell, is significantly larger than that of the wettability of the host rock. In contrast to what can be observed for the random cells analyzed, relative permeabilities of regular cells display a clear trend with contact angle at the investigated scale. Our findings suggest the need to perform systematic upscaling studies in a stochastic context, to propagate the effects of uncertain pore space geometries to a probabilistic description of relative permeability curves at the continuum scale.