**Flow Rate Dependency of Steady-State Two-Phase Flows in Pore Networks: Universal, Relative Permeability Scaling Function and System-Characteristic Invariants.**

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**Abstract.**

*The phenomenology of steady-state two-phase flow in porous media is recorded in the well-known relative permeability curves. Conventionally, relative permeabilities are considered as functions of saturation. Yet, this has been put into challenge by theoretical, numerical and laboratory studies of flow in artificial pore network models and natural porous media, that have revealed a significant dependency on the flow rates -especially when the flow regime is capillary to capillary/viscous and part of the disconnected non-wetting phase remains mobile. These studies suggest that relative permeability models should include the functional dependence on flow intensities.*

*In the present work, a systematic dependence of the pressure gradient (and of the relative permeabilities) on the local flow rate intensities is revealed. It is based on the outcome of extensive simulations of steady-state two-phase flow within a typical 3D model pore network, implementing the DeProF mechanistic-stochastic hybrid model algorithm, across flow conditions spanning 5 orders of magnitude, both in the capillary number, Ca, and the flow rate ratio, r, and for different favourable /unfavourable viscosity ratio systems. The revealed systematic dependence can be described analytically by a universal scaling functional form along the entire domain of the true independent variables of the process, Ca and r. In addition, we will see that this universal scaling comprises a kernel function of the capillary number, Ca, that describes the asymmetric effects of capillarity across the entire flow regime – from capillarity-dominated to mixed capillarity/viscosity-dominated to viscosity-dominated flow regimes. We will also see that the afore mentioned kernel function, together with the locus of the cross-over values of relative permeabilities, both in terms of the capillary number, form two viscosity ratio invariants of the system. These can be correlated to the structure of the pore network, the correlation being associated to the wettability characteristics of the system.*

*By revealing a consistent, universal, true-to-mechanism scaling of the process, new possibilities emerge in improving SCAL protocols, in rock typing, etc. The structural/analytical form of the associated flow-dependent relative permeability maps can also be integrated into macroscopic-scale simulators for improved performance.*