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Sub-Phase Approach to Model Hysteretic and Non-Equilibrium Two-Phase Flow in Porous Media

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Several existing models for immiscible two-phase flow identify trapping as the major cause of non-wetting relative permeability hysteresis. These models usually assume that relative permeability is a non-hysteretic function of the connected saturation. However, existing pore-network simulations indicate that the relative permeability is a non-hysteretic function of the backbone saturation, but not necessarily of the connected saturation. The latter is supported by experimental relative permeability measurements of sandpacks (unconsolidated media), which show that the relative permeability of the non-wetting phase is higher during imbibition than during drainage. Hence, while existing models can capture the correct hysteresis behaviour in consolidated porous media, they cannot be applied for unconsolidated porous media.

In order to bridge this gap, we present a novel relative permeability hysteresis model for immiscible two-phase flow. An important aspect of this model is the subdivision of the non-wetting phase into dendritic, backbone and trapped sub-phases. This distinction provides a physical link between pore-scale flow dynamics and macroscopic, average flow behaviour. The closure problem now consists in modeling the sub-phase transfer terms. In principle this framework allows to describe hysteretic and non-equilibrium multi-phase phenomena in consolidated as well as unconsolidated media. The proposed model has been calibrated and validated for different porous media using pore-network simulation results.