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Experimental techniques and computational methods toward the estimation of the effective two-phase flow coefficients and multi-scale heterogeneities of soils

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A hierarchical, network-type, dynamic simulator of the immiscible displacement of water by oil in heterogeneous porous media is developed to simulate the rate-controlled displacement of two fluids at the soil column scale. A cubic network is constructed, where each node is assigned a permeability which is chosen randomly from a distribution function. The intensity of heterogeneities is quantified by the width of the permeability distribution function. The capillary pressure at each node is calculated by combining a generalized Leverett J-function with a Corey type model.

Information about the heterogeneity of soils at the pore network scale is obtained by combining mercury intrusion porosimetry (MIP) data with back-scattered scanning electron microscope (BSEM) images [1]. In order to estimate the two-phase flow properties of nodes (relative permeability and capillary pressure functions, permeability distribution function) immiscible and miscible displacement experiments are performed on undisturbed soil columns. The transient responses of measured variables (pressure drop, fluid saturation averaged over five successive segments, solute concentration averaged over three cross-sections) are fitted with models accounting for the preferential flow paths at the micro- (multi-region model) and macro-scale (multi flowpath model) because of multi-scale heterogeneities [2,3].

Simulating the immiscible displacement of water by oil (drainage) in a large netork, at each time step, the fluid saturation and pressure of each node are calculated formulating mass balances at each node, accounting for capillary, viscous and gravity forces, and solving the system of coupled equations. At each iteration of the algorithm, the pressure drop is so selected that the total flow rate of the injected fluid is kept constant. The dynamic large-scale network simulator is used (1) to examine the sensitivity of the transient responses of the axial distribution of fluid saturation and total pressure drop across the network to the permeability distribution function, spatial correlations of permeability, and capillary number, and (2) to estimate the effective (up-scaled) relative permeability functions at the soil column scale.

In an attempt to clarify potential effects of the permeability distribution and spatial permeability correlations on the transient responses of the pressure drop across a soil column, signal analysis with wavelets is performed [4] on experimental and simulated results. The transient variation of signal energy and frequency of pressure drop fluctuations at the wavelet domain are correlated with macroscopic properties such as the effective water and oil relative permeabilities of the porous medium, and microscopic properties such as the variation of the permeability distribution of oil-occupied nodes. Toward the solution of the inverse problem, a general procedure is suggested to identify macro-heterogeneities from the fast analysis of pressure drop signals.

References

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