A Three-Dimensional Model of Two-Phase Flows in a Porous Medium Accounting for Motion of the Liquid–Liquid Interface

A new three-dimensional hydrodynamic model for unsteady two-phase flows in a porous medium, accounting for the motion of the interface between the flowing liquids, is developed. In a minimum number of interpretable geometrical assumptions, a complete system of macroscale flow equations is derived by averaging the microscale equations for viscous flow. The macroscale flow velocities of the phases may be non-parallel, while the interface between them is, on average, inclined to the directions of the phase velocities, as well as to the direction of the saturation gradient. The last gradient plays a specific role in the determination of the flow geometry. The resulting system of flow equations is a far generalization of the classical Buckley–Leverett model, explicitly describing the motion of the interface and velocity of the liquid close to it. Apart from propagation of the two liquid volumes, their expansion or contraction is also described, while rotation has been proven negligible. A detailed comparison with the previous studies for the two-phase flows accounting for propagation of the interface on micro- and macroscale has been carried out. A numerical algorithm has been developed allowing for solution of the system of flow equations in multiple dimensions. Sample computations demonstrate that the new model results in sharpening the displacement front and a more piston-like character of displacement. It is also demonstrated that the velocities of the flowing phases may indeed be non-collinear, especially at the zone of intersection of the displacement front and a zone of sharp permeability variation.

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