MULTISCALE NUMERICAL MODELING OF THREE-PHASE FLOW IN POROUS MEDIA

R. Juanes

Department of Petroleum Engineering
Stanford University
65 Green Earth Sciences Building
Stanford, California 94305–2220

We propose the development of stabilized finite element methods for the numerical solution of two-phase and three-phase flow in porous media. The key idea of the proposed methodology is a multiscale decomposition into resolved (or grid) scales and unresolved (or subgrid) scales [1]. In the context of subsurface flow and transport, the term multiscale usually refers to subgrid heterogeneity and upscaling. In contrast, here we deal with unresolved physics: multiple scales are present in the solution even if the medium is homogeneous.

We use the fractional flow approach for the mathematical description of the three-phase flow equations, which leads to a global pressure equation of elliptic type, and a system of conservation laws (the saturation equations). Numerical difficulties in solving these equations include: high nonlinearity, advection-dominated flow, degenerate diffusion, sharpening near-shock solutions, boundary layers, and convergence to the entropy solution.

The multiscale formalism allows one to split the original mathematical problem into a grid-scale problem and a subscale problem. The effect of the subgrid scales are then incorporated —in integral form— into the grid-scale equations. Specific original contributions of the methodology proposed herein are: (1) the formulation is applied for the first time to the three-phase flow equations; (2) nonlinearity of the equations is retained at the time of invoking the multiscale split; (3) several definitions of the matrix of intrinsic time scales are tested and compared; and (4) a novel expression of a discontinuity-capturing technique is proposed and compared with existing formulations.

The proposed methodology is applied to the simulation of an oil-filtration problem in a relatively dry medium, and to water/gas injection in a hydrocarbon reservoir. These representative numerical simulations show that the multiscale formalism yields exceptionally accurate and stable numerical solutions to the system of saturation equations on very coarse grids. Preliminary results suggest that this framework is also uniquely suited for the solution of the pressure equation, as it provides means to handle both the small-scale heterogeneity and the instabilities associated with equal-order interpolations of pressure and velocity.

References

[1] T. J. R. Hughes, "Multiscale phenomena: Green's functions, the Dirichlet-to-Neumann formulation, subgrid scale models, bubbles and the origins of stabilized methods," *Computer Methods in Applied Mechanics and Engineering*, v. 127, p. 387–401, 1995.