Project Number: 54576

Project Title: On The Inclusion of the Interfacial Area Between Phases in the Physical and Mathematical Description of Subsurface Multiphase Flow

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Currently Supported Graduate Students: 0

Research Objective

The scientific motivation for conducting this research lies in an assessment of the current state of modeling in the subsurface, where "modeling" refers to a any systematic framework used to gain understanding of a system. At present, subsurface modeling addresses only the phases present, and even there considers the modeling process to be an extension of single phase flow. The shortcoming of this approach is that the governing flow equations do not account for some of the important physical phenomena. Therefore accurate simulation is more of an art than a scientific exercise. Experimental and field programs designed to measure data in support of these equations may actually be seeking curve fitting coefficients rather than information characteristic of physical phenomena. By providing a more general framework, we can contribute to improving the knowledge base related to important processes in the subsurface. We are convinced that such an improvement can be gained only by integrating various approaches to describing subsurface problems. Here, we are assessing and implementing the extended description of system physics by the following procedures: i) development of equations of mass, momentum, and energy transport for phases, interfaces between phases, and the common lines where interfaces meet; ii) provision of a consistent thermodynamic framework at the core scale that accounts for the interaction among the system elements; iii) derivation of needed closure conditions that describe the dynamics of the geometric elements (volume fractions, interfacial areas per volume, and common line length per volume); iv) development of state equations for capillary pressure as a function of saturation and area densities based on lattice Boltzmann simulations; v) implementation of the lattice Boltzmann procedure to determine core scale parameters from simulations at the pore scale; vi) extension of numerical simulators to account for the physics of the interfacial and common line processes. Integration of these elements relies on fundamental scientific inquiry to improve assessment capabilities of the multiphase flow situation. This work will impact both the study of flow of organic phases introduced into the natural environment and the study of natural multiphase systems such as air-water interactions in the vadose zone.

Research Progress and Implications

This report summarizes progress after 3.4 years of our work. The underpinning of this work is the development of a set of core scale continuum equations. These equations have been derived and are reported in As its underpinning, this research requires a set of macroscale continuum equations. These equations have been derived and are contained in reference [1]. To complete the general forms of the equations, the entropy inequality is applied as in [2]. The problem of closure of the system of equations is complicated by the need for dynamic descriptions of the changes in the geometric variables. Insight into the needed relations is obtained from a variational analysis of the equilibrium conditions [3, 4]. We have been able to develop a consistent thermodynamic description of multiphase flow at the core scale and to identify and overcome the need for closure relations. Building on these results, we have obtained equations for the geometric quantities and are in the process of writing up this information. Thus, we have a closed set of equations that accounts for the interfacial areas in a systematic manner. The mathematical and experimental complexities of our approaches need to be made accessible to those who might wish to apply our results. We have made a significant effort to transfer our technology through organization of a workshop [5], presentation of our work in a simplified form that emphasizes physical over mathematical considerations [6, 7]. We are also engaged in research directed at gaining insight into the parameters that arise in the theory and at relating those parameters to physical problems. The approach employed relies on lattice Boltzmann modeling and some results are provided in references [8-11].

The results that we have developed challenge current understanding and approaches to modeling hysteresis in multiphase flow. Addition of the area per volume as an independent variable has shown promise for elimination, or at least dramatic reduction, of hysteresis in the capillary pressure vs. saturation relationship. Furthermore, the area per volume is a crucial parameter for developing models of mass transfer between phases and biological processes occurring at phase interfaces. These results will provide improved description of remediation processes at contaminated sites.

Planned Activities

Although not reported in the publications, additional work has been initiated to develop a reduced set of the balance equations and closure relations for a simplified core-scale physical system. These will be used in the development of the continuum scale model and for the identification of constitutive parameters from the lattice model simulations.

Information Access

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