Thermodynamic Basis of Capillary Pressure in Porous Media

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Important features of multiphase flow in porous media that distinguish it from single-phase flow are the presence of interfaces between the fluid phases and of common lines where three phases come in contact. Despite this fact, mathematical descriptions of these flows have been lacking in rigor, consisting primarily of heuristic extensions of Darcy's law that include a hysteretic relation between capillary pressure and saturation and a relative permeability coefficient. As a result, the standard capillary pressure concept appears to have physically unrealistic properties. The present paper employs microscopic mass and momentum balance equations for phases and interfaces to develop an understanding of capillary pressure at the microscale. Next, the standard theories and approaches that define capillary pressure at the macroscale are described and their shortcomings are discussed. Finally, an approach is presented whereby capillary pressure is shown to be an intrinsic property of the system under study. In particular, the presence of interfaces and their distribution within a multiphase system are shown to be essential to describing the state of the system. A thermodynamic approach to the definition of capillary pressure provides a theoretically sound alternative to the definition of capillary pressure as a simple hysteretic function of saturation.