Statistical Mechanics of Two-Phase, Steady-State Flow in Porous Media

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The study of two-phase flow in porous rocks is relevant to several fluid flow problems encountered in nature; from the study of diffusion of pollutants in water, to enhanced oil recovery from hydrocarbon reservoirs. Regarding two-phase immiscible flow, not much attention has been given to the steady-state case, in which average flow properties, like the velocity of fluids, remain unchanged [1]. The system under consideration is dissipative, with entropy production due to viscous flow, while all liquid-liquid interfaces are assumed to be in equilibrium. Once the oil- water system has reached steady-state, important relations like the fractional-flow *vs* saturation can be studied. The aim is to predict the effective and relative permeability of the porous material in addition to finding relations between the macroscopic parameters characterizing the flow: saturation, fractional flow rates, pressure gradients and total flow rates. The standard pore-scale numerical modeling of this problem has been to follow the motion of the fluid interfaces by time integration: one solves the Washburn equation, which is a generalisation of the Darcy's equation to take capillary pressures due to the interfaces into account [2]. We report evidence that the whole system, under prevalent flow conditions, (flow rate = 50 mm^3/sec, dP/dx = 1000 Pa, dT/dx = 0 K), can be regarded to be in local equilibrium. Monte Carlo simulations have been used to evolve samples or sub-parts of the system till the whole system reaches steady-state, the result being independent of the size of the samples of the system above a certain length scale. We find that the system reaches steady state much faster with the Monte Carlo approach, as compared to its evolution using time integration. Besides speeding up the algorithm to a great degree, the thus established equivalence between time averaging and ensemble averaging, enables us to use statistical mechanics to characterize the flow in terms of local flow parameters, like pressure differences and flow composition.

References

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