Time-Correlation Functions of Immiscible Two-Phase Flow in Porous Media

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In a steady state of immiscible two-phase flow in porous media, the instantaneous flow rate undergoes fluctuations around a steady mean. These fluctuations are due to the constantly changing saturation in the individual pores of the porous media and the random distribution of pore sizes. Such a situation has much in common with equilibrium and steady states in atomistic statistical mechanics where fluctuations around the steady mean arise from random thermal motion.

Linear response theory implies that the decay of such microscopic fluctuations is governed by the same physics as the relaxation of a macroscopic system driven out of equilibrium. Thus, one can calculate transport coefficients from time-correlation functions of the equilibrium system via the Green-Kubo method. The latter finds application in not only equilibrium and steady state situation but can be extended to stationary systems with slowly decaying power law correlations and even to aging system [1]. It appears that time-correlation functions of multiphase flow in porous media have not been studied in this context, which may open a novel route to determine transport properties of such flows.

In this study, we use a periodic network model [2] to investigate the behavior of time-correlations function of the flow rates and velocity in steady state. We show that such time-correlation functions do indeed converge and that the transport matrix is symmetric, thus obeying the Onsager relations. These findings imply that the assumption of local equilibrium is valid and that the framework of non-equilibrium thermodynamics applies to steady state immiscible two-phase flow. The findings therefore support a recent effort to extend non-equilibrium thermodynamics to flow in porous media [3].

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