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An Improved MCMP Pseudopotential Model for Immiscible Fluids Flow in Porous Media

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Extreme viscosity ratios emerge in many important applications such as carbon dioxide geological sequestration (CO2 is much less viscous than formation fluids), natural gas production and hydrogen storage (gas is much less viscous than water), and heavy oil reservoir recovery (oil is much more viscous than water). Clearly understanding the immiscible two-phase flow with extreme viscosity ratio can provide guidance for practical production.
Lattice Boltzmann method (LBM) has recently been widely applied for numerical simulation of pore-scale two-phase flow. However, prior LBM approaches on two phase porous media flow [1-4] present major limitation in modeling extreme viscosity ratio and low capillary number. It mainly stems from the large spurious currents[5,6] when dealing with multiphase flow problems in complex media due to insufficient isotropic, which results in poor stability and accuracy of the prevailing multiphase LB model. Consequently, genuine flow velocities, particularly under conditions of low capillary numbers or high viscosity ratios, become tainted with these unwarranted velocities. Such interferences significantly hinder a comprehensive understanding of two-phase flow mechanisms within porous media.
To address this challenge, we integrate interaction forces using a higher-order difference approach[7], building upon Porter et al.'s multi-relaxation MCMP pseudopotential model[8] with an explicit forcing format. Our findings point that adjustable parameters related to the non-conserved quantities within the multi-relaxation matrix offer a distinct advantage in diminishing spurious currents. Furthermore, by employing the color gradient model for the diffusive mixing of two-phase systems, we successfully achieve higher viscosity ratios. Notably, our improved model dramatically reduces maximum spurious currents in porous media by two orders of magnitude (from 1e-3 to 1e-5) compared to its predecessor. Based on this improvement, we simulate two-phase flow in porous media, spanning a broad capillary number range (4e-5 to 1e-2), extreme wetting conditions (0° to 180°), and high viscosity ratios (up to 100). We are therefore able to extract more accurate velocity distribution for diverse analysis on multiphase flow in porous media.
In general, we propose a novel MCMP pseudopotential model, that extends our capacity to numerically investigate immiscible fluid flow in porous media with low capillary number and extreme viscosity ratio flow.

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