Improved micro-continuum approach for pore-scale simulation of capillary dominated multiphase flow with reduced spurious velocity
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Abstract:
Multiphase reactive flow in porous media is fundamental in many areas of subsurface science and engineering, such as mineral dissolution by acidic injection and hydrate decomposition. Pore scale simulation is an effective method to deeply investigate the mechanism of reactive mass transfer in porous media. Soulain presented a micro-continuum approach to simulate reactive flow at pore scale in the presence of multiple fluid phases[1]-[2]. The micro-continuum approach avoids mesh generation and dynamic update for complex geometry of porous media. However, large spurious velocities in simulation of capillary dominated flow can cause adversely affect the prediction of concentration distribution and reaction rate[3]. On the basis of existing research on the spurious velocity problem, we improved Soulain's method to reduce the spurious velocities for multi-phase flow with Capillary Number less than 10^{-3}.
Firstly, the comparison of different numerical schemes calculating the interfacial curvature during the surface tension force model shows that different numerical schemes can lead to the magnitude of spurious velocities with at least two orders of magnitude difference. We discussed the underlying reasons for the reduction of the spurious velocity. For interpolating cell saturation gradient (widely used in OpenFoam multi-phase flow solvers, e.g *interFoam*[4]), the magnitude of the spurious velocity is about 0.1 m/s. While interpolating cell unit normal (used in Maes's *GeoChemFoam*[5]), the magnitude of the spurious velocity can be reduced to 0.01 m/s. Secondly, we find that the saturation in the solid region causes wrong gradient near the solid wall, which increases the spurious velocity. We proposed a gradient correction method for the solid wall region. Finally, we improved the smoothing method of the solid wall to obtain more accurate unit normal of the solid-fluid interface and prevent the smoothed interface thickening.
The improved method is validated by three multiphase flow cases for Capillary Numbers from 10^{-4} to 10^{-3}. The stationary bubble cases show that the interpolating cell unit normal method reduce spurious velocity by at least two magnitude, far better than the reduction of the Sharp Surface Force (SSF) model. The capillary rise cases show that the capillary rise height predicted by the improved method is very consistent with theoretical height. The porous media cases show that the spurious velocities of the improved method can reduce near one magnitude. The improved method provides more accurate simulation for multi-phase reactive flow with Capillary Number less than 10^{-3}.

Reference

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