Direct numerical simulation of pore-scale flow in a bead pack: Comparison with magnetic resonance imaging observations

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A significant body of current research is aimed at developing methods for numerical simulation of flow and transport in porous media that explicitly resolve complex pore and solid geometries, and at utilizing such models to study the relationships between fundamental pore-scale processes and macroscopic manifestations at larger (i.e., Darcy) scales. A number of different numerical methods for pore-scale simulation have been developed, and have been extensively tested and validated for simplified geometries. However, validation of pore-scale simulations of fluid velocity for complex, three-dimensional (3D) pore geometries that are representative of natural porous media is challenging due to our limited ability to measure pore-scale velocity in such systems. Recent advances in magnetic resonance imaging (MRI) offer the opportunity to measure not only the pore geometry, but also local fluid velocities under steady-state flow conditions in 3D and with high spatial resolution. In this paper, we present a 3D velocity field measured at sub-pore resolution (tens of micrometers) over a centimeter-scale 3D domain using MRI methods.We have utilized the measured pore geometry to perform 3D simulations of Navier?Stokes flow over the same domain using direct numerical simulation techniques. We present a comparison of the numerical simulation results with the measured velocity field. It is shown that the numerical results match the observed velocity patterns well overall except for a variance and small systematic scaling which can be attributed to the known experimental uncertainty in the MRI measurements. The comparisons presented here provide strong validation of the pore-scale simulation methods and new insights for interpretation of uncertainty in MRI measurements of pore-scale velocity. This study also provides a potential benchmark for future comparison of other pore-scale simulation methods.

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