Determination of Characteristic Transport Coefficients of Porous Media: A Diffuse Interface approach

Fluid mechanics simulations of flow through porous media frequently use the Lattice Boltzmann Method (LBM) due to its compatibility with experimentally determined volumetric images of porous media. However, the use of the LBM does present challenges including accuracy of the fluid/solid interface and complexity of determining Lattice Boltzmann formulations for varying transport models. Traditional finite element-based methods require conformal meshes of porous domains that are able to accurately capture fluid/solid interfaces, but at the cost of significant computational complexity and user-interaction in order to create the mesh.

To address these challenges, this work presents the application of a diffuse-interface finite element method that approximates a phase-field from 3D tomography voxel images without user interaction and enables the use of a simple structured grid/mesh for traditional finite element-based fluid mechanics methods. The presented diffuse interface method is automated and non-iterative, enabling the direct calculation of three characteristic coefficients from an input tomogram: tortuosity, permeability, and inertial constant, optionally for each direction by simulating Fickian diffusion and single component incompressible Navier Stokes equation from low to high range of Reynolds numbers. The method is compared to traditional FEM implementation using conformal meshes with respect to the agreement with experimental determination of the characteristic coefficients, numerical accuracy, and computational requirements (time and memory). It was found that for comparable computational complexity, the diffuse interface method provides more accurate results than that of the conformal mesh approach. The developed method provides an automated and computationally feasible approach for computing effective transport properties from tomograms.