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Dynamic permeability of porous media by the lattice Boltzmann method

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The main objective of our work is to determine the dynamic permeability of three dimensional porous media by means of the Lattice Boltzmann method (LBM).
The Navier-Stokes equation can be numerically solved by LBM which is widely used to address various fluid dynamics problems. Space is discretized by a three-dimensional cubic lattice and time is discretized as well. The generally accepted notation for lattice Boltzmann models is DdQq where D stands for space dimension and Q for the number of discrete velocities. The present model is denoted by D3Q19. Moreover, the Two Relaxation Times variant of the Multi Relaxation Times model is implemented. Bounce back boundary conditions are used on the solid-fluid interfaces.
The porous medium is spatially periodic. Reconstructed media were used; they are obtained by imposing a porosity and a correlation function characterized by a correlation length. Real samples can be obtained by MicroCT.
In contrast with other previous contributions, the dynamic permeability K(omega) which is a complex number, is derived by imposing an oscillating body force of pulsation omega on the unit cell and by deriving the amplitude and the phase shift of the resulting time dependent seepage velocity.
The influence of two limiting parameters, namely the Knudsen number Kn and the discretization for high frequencies, on K(omega) is carefully studied for the first time.
Kn is proportional to nu/(c_s H) where nu is the kinematic viscosity, c_s the speed of sound in the fluid and H a characteristic length scale of the porous medium. Several porous media such as the classical plane Poiseuille flow and the reconstructed media are used to show that it is only for small enough values of Kn that reliable results are obtained. Otherwise, the data depend on Kn and may even be totally unphysical. However, it should be noticed that the limiting value of Kn could not be derived in general since it depends very much on the structure of the medium.
Problems occur at high frequencies since the discretization of the oscillating seepage velocity can be too poor to get the amplitude and the phase shift B with a sufficient precision. Errors in B may be considerably amplified especially when B is close to -pi/2.
Once these validation tests are made, calculations of K(omega) were systematically performed for reconstructed porous media of porosities varying between 0.15 and 0.40 and of correlation lengths equal to 16a, 24, and 32a where a is the size of the elementary cube. The Johnson length Lambda which is an intrinsic measure of the interconnected pore size, is calculated by solving the Laplace equation in the pore space when a macroscopic electric field is imposed onto the porous medium. The real and the imaginary parts of K(omega) are shown to follow a universal curve when dimensionless quantities are plotted as functions of a dimensionless pulsation.
Finally, a real sandstone was discretized by Micro CT. Calculations are performed on a unit cell formed by the sample and its mirror image along the direction where the oscillating body force is imposed. When plotted in dimensionless terms, the results for this sample follow the universal behaviour already followed by the reconstructed media.