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KINETIC THEORY OF TRANSFER PROCESSES

CALCULATION OF FILTRATION CHARACTERISTICS OF POROUS MEDIA BY THEIR DIGITIZED IMAGES WITH THE USE OF LATTICE BOLTZMANN EQUATIONS

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We have investigated the features of using STR and MTR models of lattice Boltzmann equations for calculating the filtration characteristics of porous media with the use of their digital images. The results of calculations performed on the basis of these models were compared with the results of analytical calculations made with the use of stationary Navier–Stokes equations and continuity equations. Calculations of the laminar flow in a pipe with the use of the MTR model had a much higher accuracy as compared to analogous calculations by the SRT model and showed independence of the relaxation parameter. It has been established that for fluid flow in pore channels the MRT model and the Navier–Stokes equations give comparable results, whereas in using the SRT model the numerical solution depends on the relaxation parameter.

Keywords: *mathematical modeling, lattice Boltzmann equations, x-ray microtomography, porous media.*

Introduction. The x-ray microtomography technique used to construct a digital three-dimensional image of the internal structure of a porous medium with a submicron resolution has proved to be successful in investigating the filtration-volume properties of rocks. Computer processing of digital images of a porous medium permits distinguishing in them two phases corresponding to fluid-saturated pores and the mineral skeleton of the medium, which makes it possible to calculate the volume properties of the medium and specify the necessary boundary conditions for computational experiments on the fluid flow in pore channels. The application of the given technique for investigating the properties of porous media was considered in detail in [1–4]. The use of digital images of porous media is especially topical in investigating their filtration characteristics [5–7]. Modeling the fluid flow in a porous medium on lattices associated with its digital image permits determining all components of the absolute permeability tensor, which is difficult to realize under laboratory conditions, as well as investigating the question on the representability of the chosen volume of the image [8–10].

In the present paper, the single-phase fluid flow was investigated mainly by the lattice Boltzmann method (LBM) [11–13]. This method gained popularity because of the relative ease of its numerical realization, for example, compared to Navier–Stokes equations. One of the stages in solving the problem with the use of the LBM method is the use of the operation of particle collision, as a result of which the state of the system tends to equilibrium [14]. To describe this phenomenon, models of lattice Boltzmann equations SRT (single relaxation time) [11] and MRT (multirelaxation time) were used [15, 16]. The main goal of the investigation was to reveal the features of using these models to calculate the filtration characteristics of porous media, as well as to estimate the reliability of modeling the fluid flow in the pore channel.

Mathematical Model. ***Solution of the Boltzmann equation.*** In the LBM, the medium flow is considered from the viewpoint of dynamics of an ensemble of particles with a given finite number of possible velocities. The flow region is split by a lattice with cells of quadratic or cubic form. An aggregate of such cells forms a lattice. In a time step Δt the particles can perform, without interacting with one another, one act of transition between neighboring lattice points. The state of the system at each lattice point is described by the velocity distribution of particles $f(r, \mathbf{u}, t)$ defined so that $f(r, \mathbf{u}, t)\cdot\Delta r\cdot\Delta u$ shows

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