

Variably saturated flow described by Lattice Boltzmann advection and anisotropic dispersion models

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Richards' equation describes water flow in variably saturated soils under the assumptions that the air phase is continuous and at atmospheric pressure, and that velocity and pressure are linked through Darcy law. Pressure head and moisture content are related by non-linear retention functions, where pressure head reaches its air entry value at the unsaturated/saturated interface and moisture content, under incompressibility assumption, holds its saturated value within the saturated zone. The numerical method should couple the parabolic type equation with the elliptic one on the interface and maintain the continuity of the velocity and pressure head, which implies moisture content discontinuity, on the boundaries between different soils.

We design a pressure formulation for steady flows and a mixed formulation for transient flows, using pressure head and moisture content as conserved quantities, accordingly. Using a linear extrapolation of the retention curves beyond air entry, the mixed formulation describes the saturated flow in pseudo compressible manner, matching the Darcy law in local steady state. Without resorting to eigenvalues of the collision operator, expanded equilibrium functions (E-Model) match all components of anisotropic diffusion tensors, defined as a function of the conserved quantity. In particular, for any choice of the relaxation parameter, the BGK model can run advection anisotropic dispersion and even pure advection equations. Degrees of freedom are still expanded due to coupling of the extended equilibrium functions and link-wise collision operators, introduced as an alternative to the “hydrodynamic” (multi-relaxation-times) ones. Full F-model covers dispersion tensors either with the help of the equilibrium coefficients, the eigenvalues corresponding to anti-symmetric link vectors, or both.

Numerical examples in homogeneous and heterogeneous soils illustrate the developments based on expanded “multi-reflexion” technique to fit pressure head, specified flux conditions or switch between them on static and seepage boundaries. In current study, anisotropic diffusion tensors appear from the coordinate transformations corresponding to distinct physical spacings within different layers. Variably saturated flow on orthorhombic non-uniform physical grids is described then with the LB method on cuboid grids.