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SIMULATION OF MULTIPHASE FLOWS IN POROUS MEDIA WITH THE FLUX RELAXATION

Marina Trapeznikova[1]*, Natalia Churbanova[1] and Anastasia Lyupa[2]

[1] Keldysh Institute of Applied Mathematics RAS
4 Miusskaya Square, Moscow 125047, Russia, mtrapez@yandex.ru
[2] Moscow Institute of Physics and Technology (State University)
9 Institutsky Lane, Dolgoprudny, Moscow Region 141700, Russia, anastasiya.lyupa@gmail.com

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The work deals with the development of explicit algorithms for the simulation of multiphase fluid flow in the subsurface. Interest in explicit schemes is explained by the fact that some problems (e.g., oil recovery with combustion fronts or phase transitions) require calculations with very small space steps constraining the time step strictly. Then explicit schemes can surpass implicit ones. Besides explicit methods are preferable for HPC systems.

An original model of slightly compressible fluid flow in a porous medium [1] is developed in accordance to this trend. The phase continuity equation gets a regularizing term and a second order time derivative with small parameters via the principle of minimal sizes and the differential approximation technique. The equation type is changed from parabolic to hyperbolic. An explicit scheme with a mild stability condition can be used for approximation.

The present paper reports another approach to deriving hyperbolized equations. The continuity equation includes the Darcy flux: $\mathbf{Q}_\alpha^D = \rho_\alpha \mathbf{u}_\alpha$, α denotes a phase (water or NAPL for two-phase fluid). Let us introduce the flux relaxation: $\mathbf{Q}_\alpha = \mathbf{Q}_\alpha^D - \tau \dfrac{\partial \mathbf{Q}_\alpha}{\partial t}$, τ is the time of eqilibrium establishing in the system. The modified continuty equation is written as follows:

$$\tau \frac{\partial^2 (\phi \rho_\alpha S_\alpha)}{\partial t^2} + \frac{\partial (\phi \rho_\alpha S_\alpha)}{\partial t} + \operatorname{div} \mathbf{Q}_\alpha^D = q_\alpha + \tau \frac{\partial q_\alpha}{\partial t}.$$

Here ϕ is the porosity, ρ_α is the density, S_α is the saturation, $\mathbf{u}_\alpha$ is the Darcy velocity, q_α is the source of fluid. Applying the technique like [2] the modified model turns into the "average pressure – water saturation" formulation. Both the pressure and saturation equations contain the second time derivative with small parameter τ and are approximated by a three-level explicit scheme. Test predictions confirm the accuracy and efficiency of this approach. The three-level scheme allows increasing the time step at least by an order of magnitude in comparison with two-level schemes for the classical model. The new approach demonstrates some advantages over the algorithm proposed in [1].

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