Solutal Convection in Layered Sorbing Porous Media

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We study convective instability in the vertically layered porous media saturated with mixture. The mixture consists of a carrier fluid and solid nanoparticles. The nanoparticles are considered as solute within the continuous approach. The porous media are two horizontal sublayers with different permeabilities. The solute concentration is maximal near the upper boundary and is zero near the lower boundary of the superposed sublayers. Thus, one has suitable conditions for the onset of solutal convection in the gravitational field.

The porous sublayers are reactive media, which can absorb nanoparticles. The mixture transport here is accompanied by immobilization. It is described by the mobile/immobile media model. The mobile phase is carried by fluid flow, while the immobile phase is absorbed by porous matrix. The linear kinetic equation for the mixture redistribution between the phases is applied. The Boussinesq approximation is used in the equations for convection in each of the sublayers. Numerical simulation is performed by the shooting method.

We apply a linear stability theory to find the threshold Rayleigh-Darcy number for the onset of solutal convection. This similarity criterion is determined through the average permeability and porosity of uncontaminated porous sublayers. For the first time, we introduce a solutal pore shrinkage coefficient, which is analogous to the thermal expansion coefficient for thermal natural convection. This coefficient shows that porosity decreases as the concentration of immobile phase grows in the presence of sorption. Particles in this case join the surface of pores and shrink the void space.

Firstly, we find the permeability ratios for bimodal marginal stability curves in the uncontaminated sublayers. Here, the sublayer permeabilities differ by approximately 100 times. The bimodal curves demonstrate the competition between two convective instabilities. One of them is for the local convective rolls that generate within the more permeable layer and the other is for the large-scale rolls penetrating both layers. The rolls are similar to thermal natural convection in the multi-layered porous media studied by McKibbin and O’Sullivan (1980). For sorbing porous media, the type of convective rolls strongly depends on the solutal pore shrinkage coefficient. Even a small change in its value can produce a large variation of flow streamlines from the convective rolls localized within the upper highly permeable sublayer to the rolls covering both the upper and lower sublayers. The observed sorption effect on the transition from local to large-scale convection is due to the fact that the permeability ratio depends on the solutal pore shrinkage...
coefficient. It is also found that sorption effect delays the onset of solutal convection. The work was supported by the Russian Science Foundation (Grant No. 20-11-20125).