Long-wave and short-wave instabilities in a two-layered air-porous system with vertical throughflow and internal heat source depending on solid volume fraction

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The convective instability of vertical throughflow in a two-layered system made up of a horizontal air layer partially filled with a heat-generating porous matrix is studied. The system consists of an air sublayer free from porous matrix at the top and a granular porous sublayer saturated with air at the bottom. The volumetric heat source is placed in the porous sublayer. Its strength is proportional to solid volume fraction. The values of thermal conductivities and volumetric heat capacities are chosen typical for a biologically active porous medium, which solid elements contain water in their compositions. The two-layered system is bounded by solid air-permeable plates with equal fixed temperatures. The air is pumped uniformly through one plate with a constant velocity and sucked out through the other plate with the same velocity.

A two-domain model accounting for the Navier-Stokes equation in the air sublayer and Darcy equation in the porous sublayer is applied. Explicit expressions for temperature are found in each of the sublayers. The study concerning a maximum over the basic thermal profile versus the Peckle number has shown that temperature in the porous medium reaches its highest value at a sufficiently low velocity of the upward throughflow. A decrease in temperature is observed with increasing velocity. On the contrary, basic temperature grows as the solid volume fraction of porous sublayer and depth of air sublayer increase.

The linear stability analysis carried out for the basic air throughflow with respect to the small normal perturbations periodic along the horizontal axis has revealed that different types of the convective rolls corresponding to distinct minima of marginal stability curves can be most dangerous, depending on the values of control parameters. The rolls are either local short-wave flows, which are form mainly within the air sublayer, or large-scale long-wave convective flows, which cover both sublayers. The evolution of the former ones do not practically affect heat transfer in the porous sublayer, while that of the latter ones causes a more efficient heat removal from this sublayer. It has been found that basic throughflow velocity has a stabilizing effect predominantly. It means that high heat release in the porous medium is required for the basic flow to lose its stability with respect to both types of rolls. A destabilizing effect is for the air sublayer depth and solid volume fraction. The critical Rayleigh-Darcy number decreases as these parameters increases. There is a transition from the large-scale to local convection with the variation of Pecle number, air sublayer depth and solid volume fraction. It is accompanied by a
discontinuous growth of the wave number of critical rolls by a factor of tens. Moreover, wave number can reach a minimum at low Peclet numbers. Its value is comparable to that of large-scale convection at a sufficiently high depth of the air sublayer, despite the localization of critical flows within the air sublayer.

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