Quasi-two-dimensional convection in a 3D laterally heated box in a strong magnetic field normal to main circulation

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ABSTRACT

Convection in a laterally heated three-dimensional box affected by a strong transverse magnetic field is considered in the quasi-two-dimensional formulation. It is assumed that the magnetic field is strong enough to turn the flow into almost independent on the transverse coordinate everywhere except the Hartmann boundary layers developing near the boundaries normal to the field. Assuming that the flow in the transverse direction is described by the Hartmann boundary layer profiles the averaging procedure is applied. This results in a quasi-two-dimensional model that describes the flow far from the boundaries. Steady state flow patterns and stability of the resulting quasi 2D flow is then studied for two values of the Hartmann number *Hd* scaled by a half of the width ratio, 100 and 1000, and for either thermally insulating or perfectly conducting horizontal boundaries.

We observe that multiple many-cell steady flow states characteristic for flows in long horizontal cavities are suppressed by the magnetic field, so that only single-cell steady flows are observed. Along with the instability of the bulk flow observed in the absence of the magnetic field, these single cell flows can be destabilized by two additional instability mechanisms. The first one is characterized by appearance of cold and hot spots near the vertical boundaries that are advected into the central part of the flow where they dissipate. This mechanism is observed at $Hd=100$ for all aspect ratios in the case of perfectly conducting horizontal boundaries and for $Hd=100$ and $L<5.6$ for perfectly insulated horizontal boundaries.

The second mechanism, characteristic for stronger magnetic fields ($Hd=1000$), as well as for $L>5.6$, $Hd=100$ and perfectly insulated horizontal boundaries, exhibits some features similar to what was already observed in flows affected by vertical or transverse magnetic field, as well as convective flows of fluids with a larger Prandtl number. The strong transverse magnetic field stabilizes the flow by suppressing perturbations in the central part of the cavity. The instability sets in thin thermal and Shercliff boundary layers located near the heated, cooled and horizontal boundaries. The perturbation pattern and the resulting oscillation frequency depend on the ratio of boundary layer thickness and the cavity length. The boundary layers tend to become thinner with the increase of the Hartmann number and to elongate with the increase of the aspect ratio. The thinning and elongation, in their turn, change the perturbation pattern, which can remain qualitatively the same but contains different number of small structures. The latter is most strongly emphasized at large Hartmann numbers, $Hd = 1000$ and beyond, and for the thermally insulating horizontal boundaries.