Flow regimes of natural convection in a horizontal magnetic field

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Direct numerical simulations in three dimensions have been conducted to explore the features of natural convection in a rectangular container of low width-to-height aspect ratio (0.2), filled with GaInSn alloy having a low Prandtl number of 0.0321. The study examines the flow state and global transport properties for a range of parameters defined by Rayleigh numbers (Ra) up to 2×10^7 and Hartmann numbers (Ha) up to 1000, in the presence of a horizontal magnetic field. With increasing magnetic field strength, four primary flow modes are observed in the thermal convection system, as shown in Figure1: (I) classic large-scale circulation, (II) antisymmetric three-rolls, (III) three & two-rolls transition, and (IV) steady two-rolls. The findings indicate that the heat transport efficiency of the system increases as the flow field symmetry improves, and that plume coverage is a critical determinant of this efficiency. Furthermore, it was observed that the elliptical instability dominates the multiple states occurring in the transition regime, which is characterized by the fracture of a two-dimensional plane flow with elliptical streamlines. The probability density function at the cell center gradually evolved from a Gaussian-like shape to a multi-peak structure corresponding to a characteristic mode with an increase in the magnetic field.

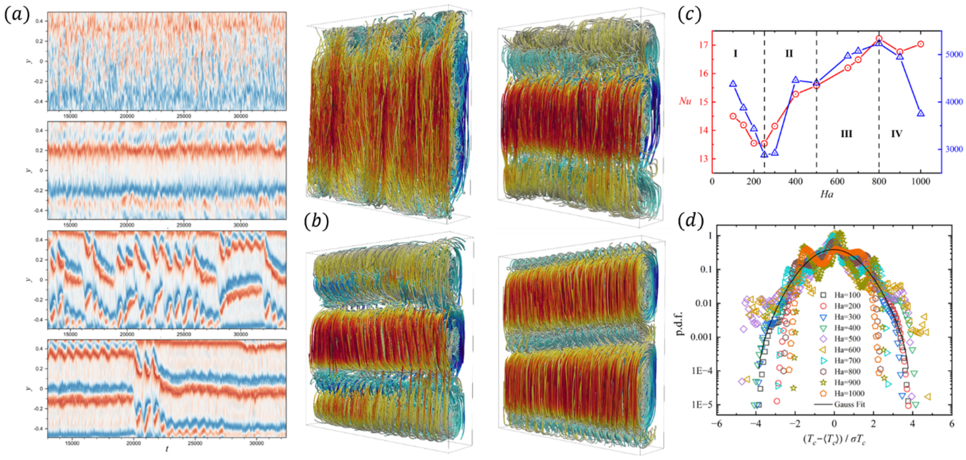

Figure 1: (a) Spatiotemporal distribution of horizontal velocity along the central vertical axis. (b) Instantaneous flow patterns observed through trajectories of passive tracer particles. (c) The evolution of Nusselt number and Reynolds number as the magnetic field is increased, normalized by characteristic modes. (d) The probability density distribution of temperature fluctuations at the center of the cell.

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