Abstract

Thermal convection is omnipresent in many natural phenomena and technological applications. An idealised model for the study of turbulent thermal convection is Rayleigh-Bénard (RB) convection, where a fluid layer is heated from below and cooled from above. Due to the buoyancy, fluid moves upward and carries the heat flux if the applied temperature difference across the fluid layer is higher than a critical value. To enhance heat transfer in an enclosure various techniques have been proposed like inserting surface roughness or protrusions on the conducting plates, varying the fluid properties, using multi-phase working fluids, changing the geometry of the enclosure, and inserting adiabatic partitions. These techniques significantly affect the system's large-scale circulation structure; thus, we observe notable variation in heat and momentum transport. The dissertation focused on the numerical studies of several heat transport enhancement techniques.

In the first study, we have explored the flow reversal and heat transport phenomena in octagonal shaped enclosure. Flow-reversal phenomena in a classical two-dimensional (2D) square Rayleigh-Bénard convection enclosure are usually explained through growth and merging of diagonally opposite counter-rotating corner rolls. To probe further the corner roll growth dynamics, we have altered the square enclosure edges by additional slanted conduction walls, so that the enclosure resembles an octagonal shape. We have performed a series of 2D numerical simulations by varying the slanted wall inclination angle (α) from 0° to 45°, to construct a detailed flow map in thermal convection in a range $5 \times 10^5 \leq Ra \leq 10^8$ and $0.8 \leq Pr \leq 2.0$, where Ra is the Rayleigh number, and Pr is the Prandtl number. Depending on Ra, Pr and α, flow features in the octagonal enclosure can exist in the form of uniform circulation, two-roll, mixed, periodic, quasiperiodic, or multiple flow states superimposed on each other. We have uncovered the mechanism responsible for the observed engulfments due to the increase in turbulence production in the core bulk region by the buoyancy. As a result, we have observed that total heat transport also increases up to 14% when α is varied from 0° to 45°.

In the second study, we have analyzed the effect of protrusions in the top and bottom conduction walls of a square RB convection enclosure to understand the flow pattern and heat transport for $10^6 \leq Ra \leq 10^8$, and $Pr = 1$. Protrusions are in the form of a parallelepiped base and triangular top with vertex angle 90^o. We have varied the protrusion

height from 10% to 25% of enclosure height and found an increase in heat flux approximately up to 37% compared to classical square RB convection. We observe a monotonic increase in heat flux approximately up to 20% increase in protrusion height. Further, increase in protrusion height, the heat flux decreases. As protrusion height increases, the large-scale circulation can not thoroughly wash out the cavity between two consecutive protrusions. The flow is viscosity-dominated in the cavity region due to the generation of small-scale secondary vortices; as a result, the overall heat transport of the system impedes.

In the third study, we have investigated the effect of adiabatic partitions in a square RB convection enclosure on flow topology and heat transport. We performed $2D$ numerical simulations in a square enclosure with equally spaced four vertical adiabatic partitions for $10^6 \leq Ra \leq 10^9$, and $Pr = 1$. When the partition boards are inserted into the enclosure with gaps left open between the partition boards and the cooling/heating plates, it is observed that the convective flow becomes more organized and leading to a remarkable heat transport enhancement. The maximum heat transport enhancement in the partitioned RB case is approximately up to 3.5 times of classical square RB. The increase in heat transport is due to strong horizontal flow through the gap between the conduction plate and partition board, which reduces the thickness of the thermal boundary layer locally. The partition boards perturb the thermal boundary layer locally; thus, we observe ejecting, impacting, and shearing zones in the top and bottom conduction walls. We address the heat flux contribution from different zones and found a crossover between the shearing to impacting zone dominant heat transport by varying the height of the partition boards.

In the final study, we have probed the influence of the regular roughness of heated and cooled plates and adiabatic partition boards on the mean heat transport in a square RB convection enclosure by $2D$ numerical simulations. The roughness is in the form of isothermal protrusions with a rectangular base and triangular tip. The protrusion height varies from 10% to 25% of enclosure height. With increased protrusion height, the large-scale circulation can not wash out the cavity between two consecutive protrusions. Thus, the overall heat transport of the enclosure impedes. We have inserted the partition boards between two successive protrusions with a gap between the conduction plate and the partition board to wash out the cavity. The partition board height varies from 20% to 99.8% of enclosure height. We have performed the simulations for the range of Rayleigh number 10^6 to 10^8 and at a fixed Prandtl number of 1. The tip of the triangular protrusion acts as an active plume-emitting spot. We observe a single large-scale elliptical roll with counter-rotating corner rolls for small partition board height.

With an increase in partition board height, an elliptical large-scale roll breakdown into the number of large-scale rolls horizontally placed one beside the other. Finally, we observe multiple rolls stacked vertically when the partition boards almost touch the conduction walls. Heat flux enhancement strongly depends on large-scale flow structures. We found a maximum heat flux enhancement in protrusion with partitioned RB case approximately up to 4.7 times classical square RB for an optimal gap between conduction plate and partition board. The maximum heat transport enhancement is due to the strong horizontal flow through the gap between the conduction plate and partition board, which locally reduces the thermal boundary layer's thickness. The interaction between the horizontal jets and the thermal boundary layers enhances heat transport.

Keywords: Rayleigh-Bénard convection, Heat transfer, Turbulence