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INFLUENCE OF PRANDTL NUMBER ON INSTABILITY OF BUOYANCY INDUCED FLOWS AT MODERATE RAYLEIGH NUMBER

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Numerical investigations are carried out for steady and unsteady natural convection flows within square enclosure with embedded heated circular cylinder by using an immersed-boundary method[1, 2]. The method is first validated with steady flows induced by natural convection in an air-filled annulus for different Rayleigh numbers (Ra) within the range of $10^4 - 3 \times 10^6$. Computations are further conducted to explore the influence of the Prandtl numbers ($0.07 \le Pr \le 7$) on the dynamic and thermal fields at different Rayleigh numbers ($2\times10^5 \le Ra \le 2\times10^6$). In general, the reduction of Prandtl number thickens the thermal boundary layer, and hence the decrease of predicted Nusselt number[3]. However, the dynamic boundary layer becomes thin and this leads to the increase of internal counter rotating vortex pairs, and further to the breakdown of vortex symmetry and hence the eventual instability[4]. During the increase of vortex pairs, the Nusselt number rises, but again decreases in tandem with the decrease of Prandtl number. In the unsetady regime, the shedding frequency of the Nusselt number is as expected twice of other flow variables and increases in pace with the reduction of Prandtl number. However, for the Rayleigh number investigated, the unsteady-regime is dominated by the growth of thermal boundary layer and hence the averaged Nusselt number decreases accordingly. Finally, different scaling laws for the Nusselt number exist due to the change of vortex structures in the steady and unsteady regions. In the steady regimes with single thermal plume and triple plume, and unsteady regime, the respective averaged Nusselt numbers scale with $Ra^{1/4}$, $Ra^{1/4}Pr^{0.08}$ and $(RaPr)^{1/4}$. As the Prandtl number further decreases, the scaling law shows enhanced influence of the Prandtl number on the heat transfer. Thus, Rayleigh number and Boussinesq number are the proper functional dependence in the respective steady and unsteady regions with higher and lower Prandtl numbers.

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