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Numerical study on buoyancy and inclination effects on transient laminar opposing mixed convection in rectangular channels with symmetric and discrete heating

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ABSTRACT

Detailed numerical simulations are carried out for transient laminar opposing mixed convection in a rectangular inclined channel with both walls suddenly subjected to discrete isothermal flush-mounted heat sources simulating electronic components. Using the vorticity-stream function formulation of the unsteady two-dimensional Navier–Stokes and energy equations, the governing equations are solved numerically using the control volume method. Simulations are performed for fixed values of the geometrical parameters, Reynolds number of $Re = 500$, Prandtl number of $Pr = 7$ and channel inclination of $0^\circ \leqslant \gamma \leqslant 90^\circ$. Results illustrate the effects of buoyancy strength or Richardson number $Ri = Gr/Re^2$ and channel inclination angle on the overall flow structure and nondimensional heat flux (Nusselt number) from the heated slabs. It is found that for the horizontal configuration ($\gamma = 0^\circ$), due to the indirect effect of buoyancy, much higher threshold values of buoyancy strength are required for the appearance of the recirculation flows that take place downstream of the heated slabs. However, for increasing values of the inclination angle, vortex migration to higher positions inside the channel occurs and higher heat transfer rates are obtained. In addition, transition from steady to time-periodic flow takes place for values of the buoyancy parameter larger than a critical one, and the threshold value between the two regimes strongly depends on the value of the Reynolds number and channel orientation. The results include the effects of Reynolds and Prandtl numbers along with heat losses to the channel walls on the evolution of the final flow and thermal response.

1. Introduction

Mixed convection studies in ducts are important for many industrial applications where buoyant forces are comparable to pumping forces. Most studies found in the literature have focused on the horizontal or vertical configuration for different channel geometries, boundary and operating conditions [1–3]. However, in many practical situations in the design of compact heat exchangers, solar collectors, electronic cooling systems, nuclear reactors and other thermal devices, the duct is inclined with respect to the horizontal. Although the inclination angle effect in mixed convection has received relatively less attention, it is well known that the flow and heat transfer are relatively sensitive to duct orientation and a great deal of research efforts have been devoted to this topic. Guimarães and Menon [4] numerically studied mixed convection in an inclined rectangular channel with three discrete heat sources placed on the bottom surface. Their results show that the inclination angle has a stronger influence on the flow and heat transfer for low Reynolds numbers and that in general, cases which show the lowest temperature distribution on the modules are those where the inclination angles are 45° and 60°. Choi and Ortega [5] numerically investigated the effects of inclination angle during mixed convection for a parallel plane channel with a discrete heat source. Their results indicate that the overall Nusselt number strongly depends on the inclination angle when the latter is larger than 45°, while the changes in the maximum surface temperature and Nusselt number are negligible when the

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