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Effects of buoyancy and inclination for opposing mixed convection in a symmetrical heated duct with a plane symmetric sudden contraction–expansion

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ABSTRACT

In this work, transient laminar opposing mixed convection is studied experimentally in an open vertical rectangular channel configuration with plane symmetric forward–backward facing steps located at the middle of the test section with uniform heat flux imposed to the lateral walls of each step while the other bounding walls are treated as adiabatic surfaces. The effect of opposing buoyancy and the geometrical configuration of partial blockage on the heat transfer behavior for the double stepped wall is analyzed for a Reynolds number of $300 \leqslant Re \leqslant 900$, channel inclination of $0° \leqslant \gamma \leqslant 90°$, and different values of buoyancy strength or modified Richardson number. From experimental measurements, space-averaged surface temperatures and overall Nusselt number of each simulated electronic chip are obtained for a wide range in the parametric space. Also, phase-space plots of the self-oscillatory system, characteristic times of temperature oscillations and spectral distribution of the fluctuating energy are presented. Results show that for relatively large values of buoyancy strength, strong three-dimensional secondary flow oscillations develop in the axial and spanwise directions. The temperature measurements show that for a fixed value of the modified Richardson number, there is not a linear dependence between the duct orientation and the heat transfer rates achieved. Also, when the duct is inclined with respect to the horizontal, the right (upper) and left (lower) oscillating vortical structures present large and small amplitude thermal fluctuations, respectively. In addition, it is pointed out that the highest flow reversal takes place at the channel corners of the upper heater block, and that higher surface temperatures are reached at the centerline of the latter. The analysis brings out the significance of the three-dimensional configuration of the vortical structure and how the buoyancy induced secondary flow is affected by the partial blockage.

1. Introduction

Mixed convection heat transfer in the presence of finite-size heat sources has become a subject of increased interest because of advances in the electronics industry and heat exchanger technology. As higher flux densities are obtained due to advances in electronic systems miniaturization and because of the presence of protruding heaters, the flow features around partially blocked geometries are of fundamental interest in the implementation of passive thermal control mechanisms aimed towards increasing the capability of these electronic devices to dissipate excessive heating. As a result, a considerable amount of literature work has been devoted to evaluate the thermal performance of rectangular channels with various forms of partially blocked geometries. One of the most frequently investigated configurations on laminar mixed convection in flow passages with an abrupt change in geometry are backward and forward-facing steps [1–7], as these geometries generate detachment and reattachment of flows and develop recirculation regions which result in a higher heat transfer performance. Abu-Mulaweh [8] presented an extensive review on the topic along with a detailed summary of the effects of several parameters such as step height, expansion ratio, inclination angle, Reynolds and Prandtl numbers, and buoyancy force (Richardson number) on the flow and thermal fields. There have also been considerable numerical and experimental investigations of incompressible laminar flow in ducts with plane symmetric sudden contractions [9–14] and plane sudden expansions [15–21] in flow

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