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Transient mixed convection heat transfer for opposing flow from two discrete flush-mounted heaters in a rectangular channel of finite length: Effect of buoyancy and inclination angle

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An experimental investigation in a vertical rectangular channel using water as the working fluid is carried out to study the transient laminar opposing mixed convection heat transfer from two flush-mounted, symmetric and discrete heat sources subjected to a constant wall heat flux boundary condition while the other bounding walls are insulated and adiabatic. The experiments are done under different values of buoyancy strength or modified Richardson number $Ri^* = Gr^*/Re^2$, Reynolds number of $300 \le Re \le 900$ and channel inclination of $0^\circ \le \gamma \le 90^\circ$. From experimental measurements, surface temperature distributions and averaged Nusselt number for each heat source are obtained. In general, for a fixed value of the buoyancy parameter, the averaged Nusselt number increases for increasing values of the Reynolds number. In the vertical channel configuration, it is observed that for fixed values of Re and high Ri^* number, because buoyancy acts directly against convective flow, higher heat transfer rates are achieved. As the duct approaches the horizontal configuration, buoyancy strength is reduced and the averaged Nusselt number decreases for decreasing values of the inclination angle with marked variations. Here, the effect on the heat transfer rates is more pronounced at $\gamma = 60^\circ$ for low Ri^*. For the horizontal configuration, because buoyancy only acts indirectly, higher threshold values of Ri^* are required to induce instability. The results show that for relatively large values of buoyancy strength, the surface temperature presents strong spanwise and axial variations, and for all of the inclination angles considered in this study, the values of the surface temperatures achieve higher values at the middle spanwise positions of both heaters than those registered at other spanwise locations. This indicates that because of the secondary three-dimensional flow, heat transfer augmentation takes place close to the channel corners while the higher surface temperatures and hence, lower heat transfer rates are achieved at the centerline of the discrete heat sources.

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. The outcome of advances in electronic systems miniaturization is that increased heat flux densities are obtained, which has generated and increased need for dependable and efficient cooling technologies. Because the reliability and durability of electronic devices depends on their capability to dissipate excessive heating, numerous theoretical and experimental investigations aimed to increase power dissipation of these systems are available in the literature. However, although mixed convection flow in vertical ducts is inherently three-dimensional (3D), the majority of the studies available are analyzed in two dimensions [1–9], and relatively few investigations of flow reversal of 3D flow and heat transfer have been reported [10–15]. Dogan et al. [16] investigated experimentally the mixed convection heat transfer from discrete

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