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Steady and oscillatory laminar opposing mixed convection in a vertical channel of finite length subjected to symmetrical isothermal discrete heat sources

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Transient laminar opposing mixed convection in a gravity driven downward flow confined inside a vertical rectangular channel has been investigated, with both walls suddenly subjected to symmetrical isothermal heat sources over a finite portion of the channel walls. The unsteady two-dimensional Navier-Stokes and energy equations have been solved numerically for a wide parametric set. Studies are carried out for Reynolds numbers of 100 and 200 and several values of buoyancy strength or Richardson number. The effect of Reynolds number and opposing buoyancy on the temporal evolution of the overall flow structure, temperature field, and Nusselt number from the heated surfaces is investigated using fixed geometrical parameters and considering heat losses to the channel walls. In this parameter space, for a given Reynolds number and relatively small values of the buoyancy parameter, the transient process leads to a final symmetric or asymmetric steady-state. However, as the value of buoyancy strength increases, the flow and temperature fields become more complex and an oscillatory flow with a fundamental frequency sets in when a critical value of the Richardson number is reached. Numerical predictions show that the critical value of the Richardson number between the two regimes strongly depends on the value of the Reynolds number, and the time scales, natural frequencies, and phase-space portraits of flow oscillation are presented and discussed in detail. Stability of the symmetric response has been analyzed. The results include the effects of Prandtl number and heat losses to the channel walls on the evolution of the final flow and thermal responses. © *2015 AIP Publishing LLC.* [http://dx.doi.org/10.1063/1.4922647]

I. INTRODUCTION

Mixed convection studies are important for many industrial applications where buoyant forces are comparable to pumping forces. The problem of laminar fully developed mixed convection in vertical channels when buoyancy opposes the flow has been extensively studied in the past.[1,2] Much work, both theoretical and experimental, has been done on mixed convection heat transfer in symmetrically and asymmetrically heated vertical channels with boundary conditions of uniform wall temperature or uniform heat flux, as is evident in the reviews conducted by Incropera,[3] Aung,[4] and Gebhart *et al.*[5] Recently, studies on mixed convection heat transfer in vertical channels where the duct walls are heated discretely have become a subject of increased interest due to its relevance

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