International Journal of Heat and Mass Transfer 51 (2008) 5991–6005

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Transient laminar opposing mixed convection in a differentially and asymmetrically heated vertical channel of finite length

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ARTICLE INFO

Article history:
Received 29 October 2007
Received in revised form 12 April 2008
Available online 21 June 2008

Keywords:
Mixed convection
Opposed flows
Unsteady convective flows
Asymmetrical heating

ABSTRACT

Transient laminar mixed convection in an asymmetrically and differentially heated vertical channel of finite length subject to an opposing buoyancy is investigated by solving the unsteady two-dimensional Navier–Stokes and energy equations. Results illustrate the effects of buoyancy strength or Richardson number $Ri = Gr/Re^2$ and Reynolds number Re on the overall flow structure and the nondimensional heat flux (Nusselt number) from the heated surface. Final steady or oscillatory flow response is obtained depending on the value of the Reynolds and Richardson numbers. The critical value of the buoyancy strength between the two regimes strongly depends on the value of the Reynolds number.

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1. Introduction

Buoyant effects in fluid flow in channels have been studied extensively due to its practical applications including the design of compact heat exchangers, solar collectors, nuclear reactors and the cooling of electronic equipment. The subject of forced and mixed convection in rectangular ducts with uniform heating conditions has been widely treated in the literature, as can be seen in the review on this subject by Hartnett and Kostic [1]. The study by Aung and Worku [2] provided theoretical results for mixed convection flows between parallel plate channels with unequal wall temperatures and showed that when the parameter Gr/Re exceeds a certain threshold value, flow reversal occurs. In further studies for vertically upward flow in a parallel plate channel, the same authors [3] presented criteria for the occurrence of flow reversal and showed that buoyancy dramatically increases the hydrodynamic development length and diminishes the thermal development distance. Sparrow et al. [4] performed experiments that revealed the presence of a pocket of downflow and recirculation in a buoyancy-driven flow in a heated vertical channel, where one of the principal walls was maintained at a uniform temperature above that of the ambient, while the other principal wall was not heated. Elpidorou et al. [5] reported numerical results for two-dimensional, steady mixed convection from a flush-mounted, isoflux heat source on one side of a vertical channel with adiabatic walls, reporting the effect of opposite wall boundary conditions in the velocity and temperature fields. The unsteady laminar aiding and opposing mixed convection heat transfer in a vertical flat duct was numerically investigated for an initially fully developed flow by Lin et al. [6], obtaining correlation equations for the time variations of local Nusselt numbers with wall-to-fluid heat capacity ratios. In [7], Lin et al. numerically investigated the transient laminar opposing mixed convection in a vertical plane channel subject to a symmetric heat input, reporting periodic flow and thermal evolution in space and time along with detailed flow and thermal characteristics. Yao [8] obtained an analytical solution for the fluid flow and the heat transfer in the entry region of a heated vertical channel for constant wall temperature and constant wall heat flux conditions, suggesting that moving periodic and recirculating cells are generated if natural convection is a dominant mode. Chang and Lin [9] numerically investigated the buoyancy and inertia effects on a low Prandtl fluid flowing through a symmetrically and uniformly heated vertical plane channel subject to an opposing buoyancy, pointing out that an oscillatory flow with a single fundamental frequency is found when the buoyancy parameter or Richardson number, which is a function of the Reynolds number, exceeds a critical value. The linear stability of mixed convection in a differentially heated vertical channel for various Prandtl numbers was studied by Chen and Chung [10], indicating that the flow can become unstable under appropriate conditions. In [11], Cheng et al. made numerical predictions of buoyancy assisted flow reversal and convective heat transfer in the entrance region of a vertical rectangular duct, investigating cases with various

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doi:10.1016/j.ijheatmasstransfer.2008.04.055