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Laminar natural convection heat transfer in a differentially heated cavity with a thin porous fin attached to the hot wall

Khalil Khanafer [a,b,*], Abdalla AlAmiri [c], Joe Bull [b]

[a] Mechanical Engineering Department, Australian College of Kuwait, Safat 13015, Kuwait
[b] Biomedical Engineering Department, University of Michigan, Ann Arbor, MI 48109, USA
[c] Mechanical Engineering Department, United Arab Emirates University, P.O. Box 17555, AlAin, United Arab Emirates

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ABSTRACT

Laminar natural convection heat transfer in a differentially heated square cavity with a thin porous fin attached to the hot wall is studied numerically under steady state condition. Various pertinent parameters were employed, such as the Rayleigh number, Darcy number, fin inclination angle, length and position of the fin. Three different fin lengths (L = 0.2, 0.35, and 0.5) and positions (S = 0.25, 0.5, and 0.75) are considered. The inclination fin angle is varied between 30° and 150°. The left wall of the cavity, to which the fin is attached, is assumed uniformly heated while the right wall is kept at a lower temperature. In addition, the horizontal walls of the cavity were considered insulated. Furthermore, the governing transport equations within the porous media are treated according to the volume-average theory while the Navier–Stokes equations were employed to represent the transport phenomena in the rest of the cavity. Moreover, the governing equations are solved using a finite element formulation based on the Galerkin method of weighted residuals. The results of this investigation showed that the presence of a porous fin increases the average Nusselt number when compared with the differentially heated cavity for various lengths, positions, and inclination angle of the fin. To achieve optimum heat transfer, the present results suggests that the porous fin should be placed either close to the bottom surface or in the middle of the vertical hot surface and an angle of 90°. Finally, a numerical correlation for the average Nusselt number was developed as a function of the employed range of the Rayleigh number, Darcy number, fin's length and position.

1. Introduction

Buoyancy-driven natural convection in a differentially heated square cavity is a classical problem which has received great attention in various fundamental and engineering applications such as electronic cooling devices, nuclear reactor design, solar thermal collector systems, and others [1–5]. Heat transfer enhancement in cavities due to incorporation of obstacles and fins attached to the walls has also received significant consideration in recent years [6–10]. Oosthuizen and Paul [11] studied numerically an air-filled rectangular cavity with a horizontal plate on the cold wall. They found an increase in heat transfer characteristics when the plate was either adiabatic or perfectly conducting. Further, a finite-volume-based numerical study of steady laminar natural convection (using Boussinesq approximation) within a differentially-heated square cavity due to the presence of a single thin fin was investigated by Shi and Khodadadi [12]. They reported augmentation in heat transfer performance when the thin fin attached to the hot wall was positioned closer to the insulated walls. Meanwhile, Nag et al. [9] had studied natural convection heat transfer phenomenon in a differentially heated square cavity with a horizontal partition plate being placed on the hot left wall. The plate was alternated to examine both infinite thermal conductivity and insulated conditions. The range of the Rayleigh number employed was between 10^3 and 10^6 while three partition lengths placed at three prescribed positions were analyzed. It was concluded that for a partition of infinitely high thermal conductivity, the Nusselt number on the cold wall was greater than the case with no partition regardless the position of the partition on the hot wall. In addition, Bilgen [13] analyzed natural convection in differentially heated square cavities with a thin fin attached on the hot wall. A parametric study was carried out using the following parameters: Rayleigh number between 10^4 and 10^9, dimensionless fin length between 0.10 and 0.90, dimensionless fin position between 0 and 0.90, and

* Corresponding author at: Mechanical Engineering Department, Australian College of Kuwait, Safat 13015, Kuwait. Tel.: +965 2537 6111; fax: +965 2537 6222.
E-mail address: khanafer@umich.edu (K. Khanafer).

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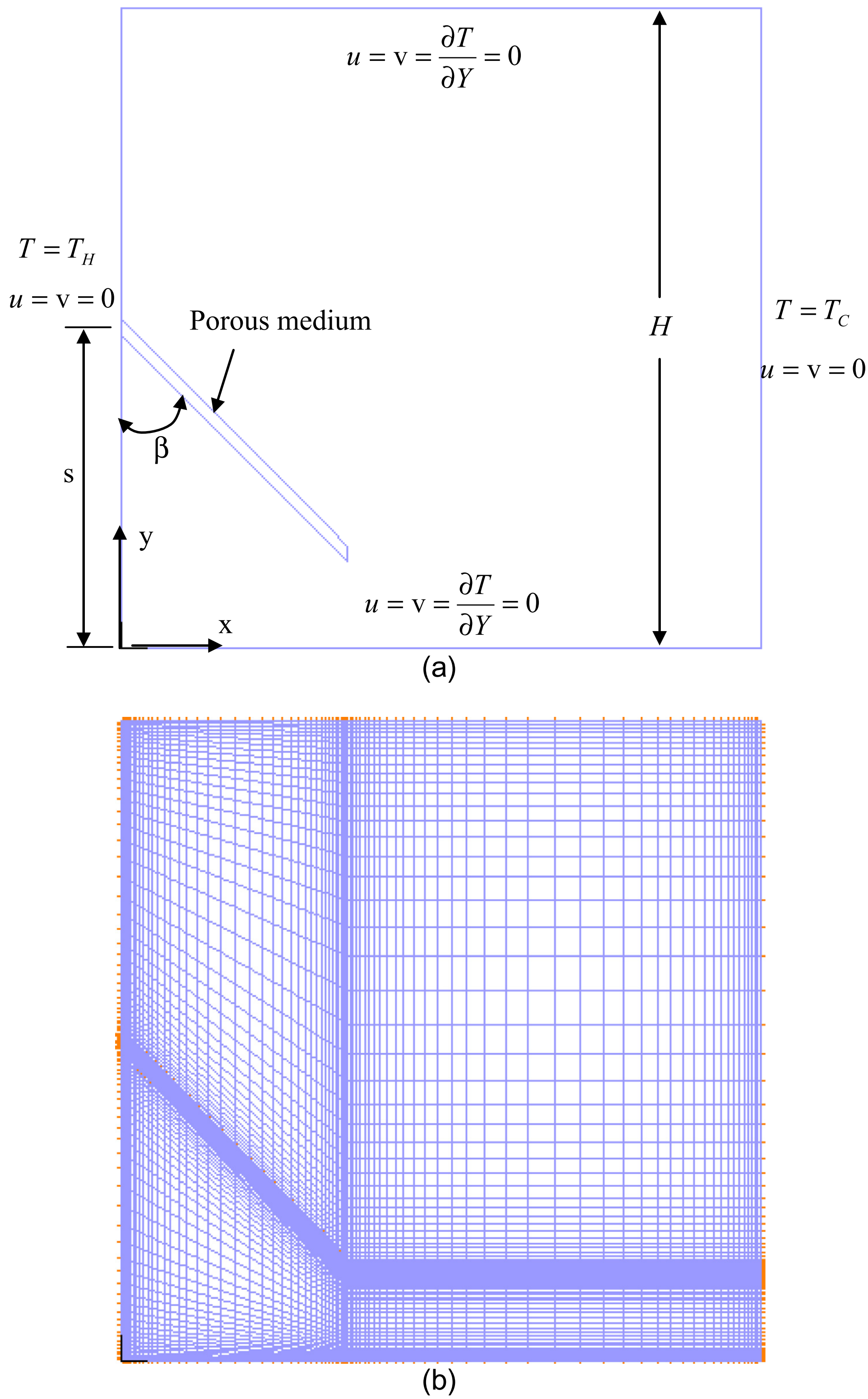

Fig. 1. (a) Schematic diagram of the problem under consideration, (b) mesh.

dimensionless thermal conductivity ratio of fin between 0 (perfectly insulating) and 60. The results of the investigation indicated that the average Nusselt number was an increasing function of Rayleigh number and a decreasing function of fin length and relative thermal conductivity ratio. Heat transfer was enhanced when the fin length was short and positioned near the insulated horizontal boundaries for the case with relative conductivity of one.

Other studies in the literature showed reduction in heat transfer within closed enclosures in the presence of thin fins. Heat transfer reduction capabilities of vertical or horizontal adiabatic partial partitions (baffles) fixed in a differentially heated cavity with insulated top and bottom walls were analyzed numerically by Haghighi and Vafai [14]. The effects of length and location of the partition was taken into account for cavity aspect ratios from 1