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Numerical study of natural convection in an open cavity considering temperature-dependent fluid properties

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ABSTRACT

In this work the numerical results of heat transfer calculations in an open cavity considering natural convection and temperature-dependent fluid properties are presented. The overall continuity, momentum, and energy equations in terms of primitive variables were solved numerically using the finite-volume method. Numerical calculations were conducted for Rayleigh number (*Ra*) values in the range of 10^4–10^7. The temperature difference between the hot wall and the bulk fluid (ΔT) was varied between 10 and 500 K, and was represented as a dimensionless temperature difference (ε) for the purpose of generalization of the trends observed. The results show that the thickness of the hydrodynamic boundary layer in the vicinity of the hot wall increases as ε increases from 0.03 to 1.6. The average Nusselt number in the cavity (*Nu*) was found to increase by 807% ($\varepsilon = 0.03$) and 1105% ($\varepsilon = 1.6$) as the *Ra* number varied from 10^4 to 10^7. Likewise, the average *Nu* number in the cavity decreased by 39% ($Ra = 10^4$) and 18% ($Ra = 10^6$) as ε was varied from 0.03 to 1.6.

1. Introduction

Natural convection in open cavities is relevant in several thermal engineering applications. Some examples include the cooling of electronic devices and the design of solar concentrators receivers, among others. For the latter, the temperature difference between the receiver wall and the ambient air is very high. However over the last forty years, a large number of numerical studies to describe the natural convection in open cavities have been reported in the literature [1–33]. These studies can be categorized as: (a) natural convection in an open cavity with isothermal walls [1,2,5,14,29,30], (b) natural convection in an open cavities with adiabatic walls and isothermal at the wall facing the aperture [3,4,10,13,16,20,28,32], (c) combined natural convection with conduction or surface thermal radiation in two-dimensional open cavities [9,11,12,21,22,24–26], (d) natural convection in partially open cavities [6,15,23,27] and (e) natural convection in a cavity with two open sides (using a symmetry plane) [7,8,17–19,31,33].Next the studies of natural convection in open cavities are briefly described.

(a) Natural convection in an open cavity with isothermal walls.

Le Quere P. et al. [1] studied natural convection under laminar conditions inside a rectangular cavity with isothermal walls with variable properties. The effect of the Grashof number (10^4–10^7), inclination angle of the cavity (0–45°), aspect ratio (0.5, 1 and 2) and ΔT (50 K and 500 K) on the flow pattern, temperature field and heat transfer behavior are reported. Penot [2] obtained numerical results of natural convection inside an isothermal open square cavity using the Boussinesq approach. The effects of Grashof number and inclination of the cavity are analyzed, observing unsteady solutions for Grashof number larger than 10^5 and cavity aperture facing upward. Humphrey et al. [5] conducted a numerical study on natural and mixed convection in a rectangular cavity with isothermal walls under turbulent conditions considering variable properties. The authors analyzed the effects of the inclination angle (90°–135°), aspect ratio (0.5 and 1) and Rayleigh number (4.8×10^7–1.3×10^9) on the fluid patterns, temperature fields and heat transfer in the cavity.

Angirasa et al. [14] reported numerical simulations for natural convection in a square isothermal open cavity using the vorticity–stream function formulation with improvised boundary conditions at the window of the cavity and applying the Boussinesq approximation. It is observed that the flows at moderate and high Rayleigh numbers are periodic or unsteady with plume formation

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