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Natural convection in wavy enclosures with volumetric heat sources

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ABSTRACT

In this paper, the effects of volumetric heat sources on natural convection heat transfer and flow structures in a wavy-walled enclosure are studied numerically. The governing differential equations are solved by an accurate finite-volume method. The vertical walls of enclosure are assumed to be heated differentially whereas the two wavy walls (top and bottom) are kept adiabatic. The effective governing parameters for this problem are the internal and external Rayleigh numbers and the amplitude of wavy walls. It is found that both the function of wavy wall and the ratio of internal Rayleigh number (Ra_I) to external Rayleigh number (Ra_E) affect the heat transfer and fluid flow significantly. The heat transfer is predicted to be a decreasing function of waviness of the top and bottom walls in case of $(Ra_I/Ra_E) > 1$ and $(Ra_I/Ra_E) < 1$.

1. Introduction

Natural convection heat transfer and fluid flow are widely studied topics in engineering due to their practical importance as reviewed by de Vahl Davis and Jones [1] and Ostrach [2]. Natural convection in enclosures with internal heat generation occurs in nuclear reactors and geothermal heat extraction processes. Studies on this topic were started nearly forty years ago by Kulacki and Goldstein [3] and Kulacki and Nagle [4].

Based on technological applications of internal heat generation problems in nuclear reactors and geothermal applications, Acharya and Goldstein [5] and Lee and Goldstein [6] obtained several solutions. Then, Shim and Hyun [7] reported a time-dependent solution of natural convection in a square cavity with internal heat generation. They indicated that the circulated cell number was strongly affected by the ratio of Ra_I/Ra_E. Fusegi et al. [8] numerically solved the governing equations of natural convection with internal heat generation at different Prandtl number to investigate the effects of aspect ratio of enclosure. Oztop and Bilgen [9] conducted a numerical analysis in a partially divided and volumetrically heated enclosure using the finite-volume method. They observed that for $(Ra_I/Ra_E) \ll 1$, the heat transfer was an increasing function of the external Rayleigh number with heat transfer direction as in the case of a differentially-heated cavity, from hot to cold wall. For $(Ra_I/Ra_E) \gg 1$, the heat transfer was an increasing function of the internal Rayleigh number and its direction was out from the cavity at both hot and cold walls. Ben-Nakhi and Chamkha [10] numerically studied steady, laminar, and conjugate natural convection around a finned pipe placed in the center of a square enclosure with uniform internal heat generation. In their work, four perpendicular thin fins of arbitrary and equal dimensions were attached to the pipe whose internal surface was isothermally cooled. They observed that the maximum temperature and extreme stream function difference could be controlled through the finned pipe inclination angle and fins length. Horvat et al. [11] investigated the turbulent natural convection heat transfer and fluid flow due to internal heat generation in a square cavity. In their study, the turbulent fluid motion was modeled using Large-Eddy Simulation (LES) technique. The obtained results were focused on the effects of Prandtl number on natural convection. The effects of volumetrically heat sources on a conjugate natural convection problem were studied by Liaqat and Baytas [12]. They made a comparison between conjugate and non-conjugate cases and observed that material of the cavity was an important parameter on heat and fluid flow.

Besides regular geometries such as square or rectangle, many studies on wavy-walled enclosures with or without internal heat generation were reported in the literature due to their application in many engineering problems related to geometrical design requirements. These studies can be classified in two categories as

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