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Effects of Thermal Boundary Conditions on Natural Convection Flow Within a Square Cavity: Review

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ABSTRACT

Effects of Natural Convection within a Square Cavity is Studied for Steady Laminar Flow, With Different heating Method. Numerical results are obtained for various values of Rayleigh number (Ra) (103 ≤Ra ≤ 105) and Prandtl number (Pr) (0.7 ≤Pr ≤10).The Galerkin Finite element method is used to solve various Governing equations Mass, Momentum and Energy into Simplied form.

Keywords : Finite Element Method; Natural Convection; Steady Laminar flow; Uniform and Non-Uniform Heating

INTRODUCTION

Natural convection is a mechanism or type of heat transport in which the fluid motion is not generated by any external source (like a pump, fan, suction device, etc.) but only by density differences in the fluid occurring due to temperature gradients. In natural convection, fluid surrounding a heat source receives heat, becomes less dense and rises.

Natural convection is a type of heat transfer wherein non-human forces influence the cooling and heating of fluids, such as gasses and liquids. Heat transfer creates a cycle called convection current where a warm fluid is replaced by a cooler one. All fluids and matter are made out of tiny building blocks called atoms, which group together in molecules.

Mathematical Formulation

The flow model is based on the assumptions that the fluid is Newtonian and that the properties are constant with the exception of the density in the body force term of the momentum equation. The Boussinesq approximation is invoked for the fluid properties to relate density changes to temperature changes, and so to couple in this way the temperature field to the flows field. The governing equations for natural convection flows using conservation of mass, momentum and energy can be written as:

A schematic diagram of two-dimensional drive square cavity with the physical dimensional as shown in fig. The bottom wall of the cavity is maintained at a uniform or non uniform temperature and the upper wall is adiabatic. The two vertical walls are maintained at cold temperature. It may be noted that the bottom wall is maintained at a higher temperature to induce buoyancy effect. The top wall is assumed to slide from left to right with a constant speed.

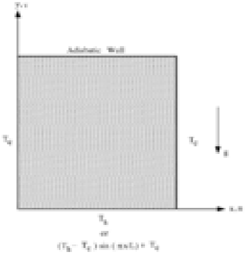

Figure 1: Schematic diagram of the physical system.

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \quad (2)$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+v\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+g\beta(T-T_c) \quad (3)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad (4)$$

LITERATURE REVIEW

In this section the research papers related with the present work has been discussed. Among the papers published the related articles are highlighted in the subsequent section.

Tanmay Basak et al. [1] presented the effects of thermal boundary conditions on natural convection flows within a square cavity. The system of equations of motion is derived by using the governing mass, momentum and energy equations.

The buoyancy driven force convection in a sealed cavity with differentially heated isothermal walls in a prototype of much industrial application such as energy design of buildings and rooms, operation and safety of nuclear reactors and convective heat transfer associated with boilers by using finite element method. The present study is to investigate natural convection in a square cavity by putting bottom wall is heated uniformly and non-uniformly and top wall insulated.

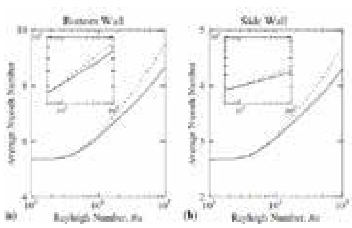

Figure 2: Variation of average Nusselt number with Rayleigh number for uniform heating (a) & (b).

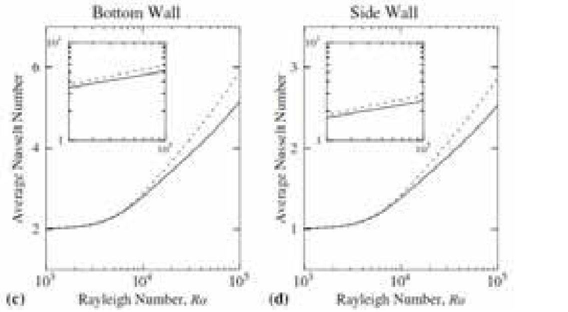

Figure 3: (c) and (d) with Pr = 0.7; (—) and Pr = 10; (- - -). The insets show the log–log plot of average Nusselt number versus Rayleigh number for convection dominant regimes.

M. Sathiyamoorthy et al. [2] Presented the Steady natural convection flows in a square cavity with linearly heated side wall(s). Results are presented in the form of streamlines, isotherm contours, local Nusselt number and the average Nusselt as a function of Rayleigh number.

The penalty finite element method helps to obtain smooth solutions in terms of stream function and isotherm contours for a range of Pr and Ra. In case of linearly heated side walls, for large values of Ra the presence of a pair of symmetric strong secondary circulations enhances the local mixing process in the lower half of the cavity and the local Nusselt numbers (Nu_s) are found to be oscillating in nature at the lower half of the side walls with an usual increasing trend in the upper half of the side walls due to the insulated top wall.

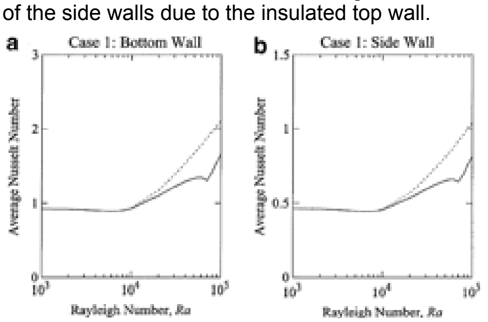

Figure 4: Variation of average Nusselt number for linearly heated left sided walls. (a) & (b).

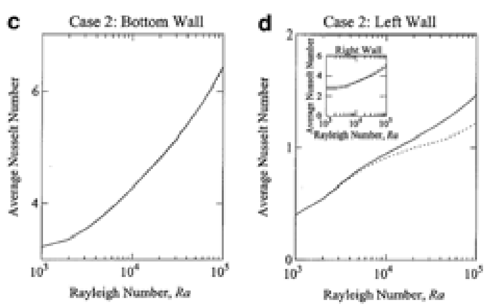

Figure 5: Variation of average Nusselt number for linearly cooled right sided walls (c) & (d).with Pr = 0.7 (—) and Pr = 10 (- - -). The inset of (d) shows plot of average Nusselt number vs. Rayleigh number for right wall.

H. Oztop et al. [3] presented Natural convection in differentially heated and partially divided square cavities with internal heat generation. There is a renewed interest in energy conservation and energy storage systems using fundamental principles of heat transfer in enclosures with volumetric heat generating fluids.

The presence of a partial divider in a differentially heated enclosures containing heat generating fluid adds an additional dynamic to overall convection characteristics, which we will study in the present work. Generally in the presence of a cold partition the heat transfer is reduced and the heat reduction is gradually increased with increasing partition height and thickness.

H.N. Dixit et al. [4] studied the Simulation of high Rayleigh number natural convection in a square cavity using the lattice Boltzmann method. A thermal lattice Boltzmann method based on the BGK model has been used to simulate high Rayleigh number natural convection in a square cavity. The traditional lattice Boltzmann method on a uniform grid has unreasonably high grid requirements at higher Rayleigh numbers which renders the method impractical.

In this work, the interpolation supplemented lattice Boltzmann method has been utilized. This is shown to be effective even at high Rayleigh numbers. The numerical results are in very good Agreement with the benchmark results available in the literature. The highlight of the calculations is that no turbulence model has been employed.

Jae Ryong Lee et al. [5] assumed that the Numerical simulation of natural convection in a horizontal enclosure with a heat-generating conducting body. The fluid flow, heat transfer and time and surface-averaged Nusselt number is investigated for various ranges of Rayleigh number, thermal conductivity ratio and dimensionless temperature difference ratio.

The results for the case of conducting body with heat generation are also compared to those without heat generation to see the effects of heat generation from the conducting body on the fluid flow and heat transfer in the enclosure. The detailed analysis for the distribution of streamlines, isotherms and Nusselt number as a function of time in order to investigate the effect of unsteadiness and the presence of heat-generating conducting body with different thermal conductivity.

M.R. Safaei et al. [6] assumed that the Simulation of Fluid Flow and Heat Transfer in the Inclined Enclosure. A computer code was developed to investigate laminar mixed convection processes in shallow two dimensional rectangular cavities. The effects of inclination were investigated and the following results were achieved: The local Nusselt number at the heated moving wall starts with a high value and decreases to a small value. Maximum stream function has more differences in the dominant natural convection case than the dominant forced convection at the different cavity inclinations.

With increasing the cavity inclination the power of natural convection would increases (especially in the dominant natural convection). In order to find a position of the cavity to have the most mixed convection heat transfer we should select an appropriate inclination according to the range of Richardson number. With variation of the cavity inclination, the average Nusselt number changes a little for the dominant forced convection but it increases considerably for the dominant natural convection.

Ali Chamkha et al. [7] presented the effect of magnetic field on natural convection flow in a liquid gallium filled square cavity for linearly heated side wall(s). The present paper investigates the effect of magnetic field on natural convection flow within a square cavity filled with an electrically conducting liquid gallium when the bottom wall is heated uniformly, left vertical wall is linearly heated and right vertical wall is linearly heated or cooled while the top wall is well insulated. The present study considered steady, laminar, two-dimensional MHD natural convection within a liquid gallium filled square enclosure in the presence of inclined magnetic field for different thermal boundary conditions. The governing equations are developed and the solved by the penalty finite element method with Bi-quadratic rectangular elements for the cases of linearly heated side walls and linearly heated left wall with cooled right wall. In both cases, the bottom wall of the enclosure was heated uniformly while the upper wall was kept insulated.

Mohamed Hasnaoui et al. [8] presented the vertical, including different kinds of boundary conditions. Results of these studies show that radiation affects the dynamical and thermal structures of the fluid, reduces the natural-convective heat transfer component, and contributes to increasing the total amount of heat exchanged in the configurations considered. Most of the works conducted in the past on natural convection coupled with radiation inside rectangular enclosures has been substantially oriented to study unidirectional heat flows resulting from imposing heat flux or temperature gradients either parallel or normal to gravity.

CONCLUSIONS

The prime objective of the current investigation is to study the effect of continuous boundary conditions on the flow and heat transfer characteristics due to natural convection within a square enclosure. The finite element helps to obtain smooth solutions in terms of stream functions and isotherm in the form of Pr and Ra with uniform and non-uniform heating. Each case exhibited different behavior on the temperature distribution and flow field. Heat transfer increase with increasing of Rayleigh Number and each case differ with their heating conditions and different boundary layer.

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