Research Paper Engineering

Effects of Thermal Boundary Conditions on Mixed Convection flow within a Square Cavity: Review

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ABSTRACT

Effects of Thermal Boundary Condition on Mixed Convection flow within a Square Cavity is Studied for Steady, laminar mixed Convection flow in square cavity with uniformly or non-uniformly heated bottom wall, two walls maintained at cold temperature and a top wall is kept at adiabatic condition. The Galerkin Finite element method is used to solve various Governing equations Mass, Momentum and Energy into Simple form.

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

INTRODUCTION

The flow of a liquid or a gas through a heat exchangers, two phase flow in the boilers and condensers, cooling of electronics chips, heat removal from the condenser of a refrigerator are some common examples of convection heat transfer.

The principle of convection is to give basic understanding of physics of convection heat transfer and to present them in the form of general equations, which are applied in subsequent problems for the particular cases.

The understanding of convection should start with basic knowledge of fluid dynamics, momentum transfer, energy transfer, shear stress, pressure drop, friction coefficient, velocity and thermal boundary layers, and the nature of fluid flow like laminar or turbulent.

MATHEMATICAL FORMULATION

A schematic diagram of two-dimensional lid drive square cavity with the physical dimensional as shown in figure. The bottom wall of the cavity is maintained at a uniform or non uniform temperature and the upper wall is insulated. 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.

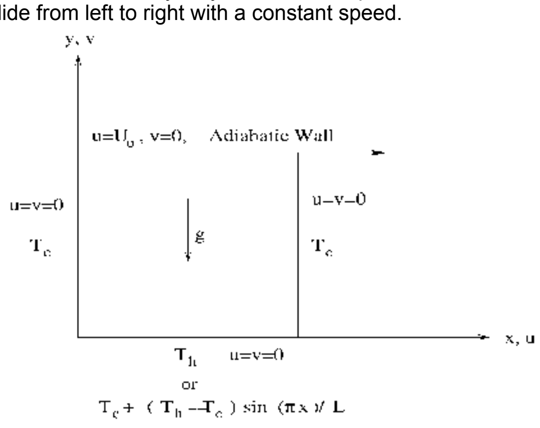

Figure 1: Schematic diagram of the physical system

The flow is assumed to be laminar and fluid properties are assumed to follow Boussinesq approximation while viscous dissipation terms are considered to be negligible. The viscous incompressible flow and the temperature distribution inside the cavity are governed by the Navier-Stokes and the energy equations, respectively. The governing equations for steady mixed convection flow in square cavity using conservation of mass, momentum and energy can be written as:

Continuity equation:

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

Momentum equation:

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

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

Energy equation:

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

LITERATURE REVIEW

D.Ramakrishna et al. [1] presented mixed convection heat transfer within square cavities for various thermal boundary condition on bottom and side walls based on thermal aspect ratio (A) on the flow and heat transfer characteristics due to lid-drive mixed convection flows within a square cavity for various Prandlt numbers (=0.015, 0.7, 10), (= 1, 10, 100) for = - with thermal aspect ratio (A= 0.1-0.9).

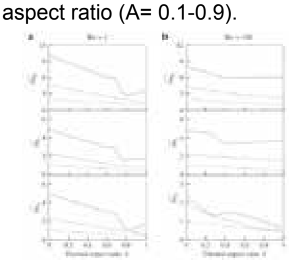

Figure 2: Variation of average Nusselt number with thermal aspect ratio for (a) $Re = 1$ (b) $Re = 100$ with $Gr = 10^5$; $Pr = 0.015(\ldots)$, $Pr = 0.7(---)$, $Pr = 10(- - -)$ respectively.

The governing equations are solved using Galerkin finite element method with penalty formulation in terms of heat lines, streamlines and isotherms. The study of mixed convection heat transfer within closed cavities has been regarded as one of the most important research topic due to its wide spectrum of scientific and engineering application such as chemical vapor deposition process, electronic cooling devices, polymer processing, green-house covering, energy extraction, manufacturing processes, material processing, wedge flow processing, stretching sheet extraction process.

Tanmay Basak et al. [2] presented a convection situation involving both natural and forced convection is commonly referred as mixed convection. The bottom wall is uniformly and non-uniformly heated while the two vertical walls are maintained at constant cold temperature and the top wall is well insulated and moving with uniform velocity.

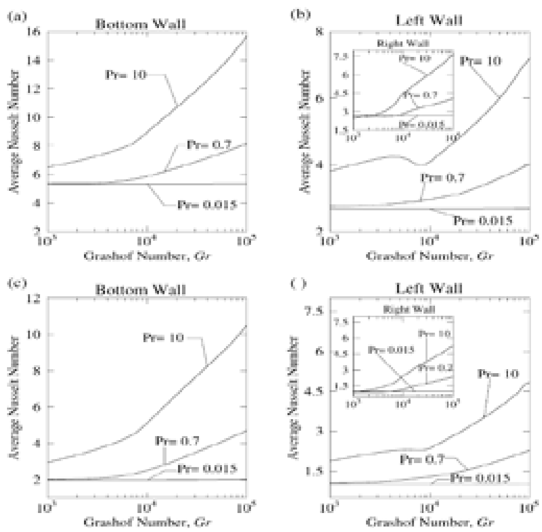

Figure 3: Variation of average Nusselt number plot with Grashof number for uniform heating [a and b] and for non-uniform heating [c and d].

The flow is assumed to be laminar and the fluid properties are constant except for the density variation which is modeled according to Boussinesq approximation while viscous dissipation effects are considered to be negligible. The governing equations are solved using Galerkin finite element method with penalty formulation in terms of Stream function and temperature counters. A complete study on the effect of G show that the strength of circulation increases with the increase in the value of G respective of R and P.

M. M. Rahman et al. [3] presented mixed convection heat transfer, temperature distribution and flow field in a channel with a cavity heated from different sides. Flow inlets to the channel are uniform. Constant magnetic field is applied to the channel as Hartmann =10, Prandlt number is chosen as =0.7 and Reynolds number is fixed at =100. Finite element method is used to solve governing equations. There are three different cases were considered based on heater position in the cavity at the left vertical side (Case 1), bottom side (Case 2) and right vertical side (Case 3). It is found that the highest heat transfer is obtained when the isothermal heater is located at the right vertical wall.

S. Sivasankaran et al. [4] presented mixed convection heat transfer of lid-driven cavity with sinusoidal temperature distribution on both vertical walls. They are assumed that unsteady, laminar, incompressible combined convective flow. A finite volume method is used to solve numerically the non-dimensional governing equation. Results are analyzed over a range of the Richardson numbers, amplitude rations and the phase derivation.

B. V. Rathish Kumar et al. [5] presented mixed convection in a non-Darcian fluid saturated square porous enclosure under multiple suction effects. They are consider 2-D enclosure filled with a fluid saturated porous medium with the left vertical wall at the constant temperature, right wall at ambient temperature and two other walls are adiabatic, excluding the inlet/outlet portions at the top/bottom.

The mixed convection process is computationally investigated by finite element method. For different values of the flow governing parameters like Grashof number (), Reyleigh number (), injection/suction velocity (a), and injection/suction window slit width (D/H). The computed flow and temperature fields are analyzed through streamlines, isotherms and cumulative heat flux plots.

R. A. Bortolozzi et al. [6] presented the theoretical and phenomenological understanding of how the temperature and velocity field are generated either by natural and mixed convection in the RPC (Rectangular Porous Cavity) and APC (Annular Porous Cavity) with thermal spots.

The 2-D model uses the balance equations of momentum and energy to study natural and mixed convection in a porous medium saturated with Newtonian fluid. The model assumed that steady-state movement of the fluid phase and includes a variable porosity near the wall containing the porous medium. Also, the model considers dispersion phenomena due to fluid convection fluctuations in the interstices of the solid matrix, which are assumed isotropic. The energy balanced for a both solid and fluid phases, an exchange of heat between phases is included. The results are founded in terms of isotherms and streamlines.

CONCLUSIONS

The prime objective of the current investigation is to study of different boundary condition on mixed convection flow and heat transfer characteristics due to mixed convection within a square enclosure. The Galerkin finite element method with bi-quadratic rectangular element used to solve the governing equation in terms of continuity equation, momentum equation and energy equation. The penalty finite element method helps to obtain smooth solution in terms of Stream function, Temperature, and Heat function. Thermal intensities together with configuration of thermal spot control the fluid movement in the porous cavity. Each case exhibited different behavior on the temperature distribution and flow field. It is found that, the overall heat transfer rate is high at A = 0.1 compared to that of A=0.5 and A=0.9 irrespective of R_e and P_r. The variation of average Nus- selt number with thermal aspect ratio exhibits that, overall heat transfer rate decreases as thermal aspect ratio (A) increases from 0 to 1 for P_r = 0.015 and 0.7 irrespective of R_e. Heat transfer in- crease with increasing of Ray- leigh Number and higher fluid temperature is formed for the highest value of Rayleigh Number. The velocity of fluid is increased as increasing the Richardson number. The heat transfer rate is very high at the edge of the bottom wall and it decreases at the center for the uniform heating which is in contrast with lower heat transfer rate at the edges for the non-uniform heating of the bottom wall. The local Nusselt number plot for the side wall show that the heat transfer rate for uniform heating is always more as compared to the non-uniform heating.

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