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ScienceDirect

Procedia Engineering 194 (2017) 463 – 470

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Conference on Marine Technology, MARTEC 2016

Mixed Magneto Convection in a Lid Driven Square Enclosure with a Sinusoidal Vertical Wall and Joule Heating

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Abstract

The problem of mixed convection flow in the presence of magnetic field in a lid-driven square cavity with a sinusoidal vertical wall and Joule heating were investigated numerically. The horizontal bottom and top walls are adiabatic. The left and right vertical walls are of temperature T_h and T_c respectively with $T_h > T_c$. The governing equations along with appropriate boundary conditions for the present problem are first transformed into a non-dimensional form and the resulting non linear system of partial differential equations are then solved numerically using Galerkin's finite element method. Parametric studies of the fluid flow and heat transfer in the enclosure are performed for magnetic parameter Hartmann number Ha, Joule heating J, Reynolds number Re and Richardson number Ri. The streamlines, isotherms, average Nusselt number at the hot wall and average temperature of the fluid in the enclosure are presented for the parameters. The numerical results indicate that the Hartmann number, Reynolds number and Richardson number have strong influence on the streamlines and isotherms. On the other hand, Joule heating parameter has little effect on the stream line and isotherm plots. Finally, the mentioned parameters have significant effect on average Nusselt number at the hot wall and average temperature of the fluid in the enclosure.

Peer-review under responsibility of the organizing committee of the 10th International Conference on Marine Technology.
Keywords: Magnetohydrodynamic; Finite element method; Mixed convection; Lid driven enclosure; Joule heating

1. Introduction

Mixed convection flow and heat transfer in lid-driven cavities occurs as a result of two competing mechanisms. The first is due to shear flow caused by the movement of one of the walls in the enclosure, while the second is due to buoyancy flow produced by thermal non homogeneity of the enclosure boundaries. Analysis of mixed convective flow in a lid driven enclosure are applied in materials processing, flow and heat transfer in solar ponds, dynamics of lakes, reservoirs and cooling ponds, crystal growing, float glass production, metal casting, food processing, galvanizing, and metal coating, among others. Many authors have recently studied heat transfer in enclosures with partitions, which influence the convection flow phenomenon. Aydin [1] conducted a numerical study to investigate the transport mechanism of laminar mixed convection in a shear and buoyancy driven cavity. Two orientations of thermal boundary conditions at the cavity walls were considered to simulate the aiding and opposing buoyancy mechanism. Rahman et al.[2] conducted finite element analysis of mixed convection in a rectangular cavity with a heat-conducting horizontal circular cylinder. The present study demonstrates the capability of the finite element formulation that can

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Peer-review under responsibility of the organizing committee of the 10th International Conference on Marine Technology.
doi:10.1016/j.proeng.2017.08.172

provide insight to steady-state incompressible conjugate effect of mixed convection and conduction problem. Saha et al. [3] studied numerically steady state two-dimensional mixed convection problem in a square enclosure where they observed increasing heat transfer rate with dominant internal heat generation. Nasrin and Parvin [4] analyzed the hydrodynamic effect on mixed convection in a lid driven cavity with sinusoidal wavy bottom surface. They observed the highest heat transfer rate at the lowest magnetic effect. Rabienataj Darzi et al. [5] investigated mixed convection simulation of inclined lid driven cavity using lattice boltzmann method. They investigated laminar mixed convection for three Richardson numbers that present forced convection dominating, mixed convection and natural convection dominating are investigated using lattice Boltzmann method for various inclination angles of lid-driven cavity. Finite element analysis of magneto-hydrodynamic (MHD) mixed convection flow on a triangular cavity was formulated by Akhi Farhana et al. [6]. Dawood and Teamah [7] performed hydro-magnetic mixed convection double diffusive in a lid driven square cavity.Ahmed et al.[8] investigated mixed convection flow and heat transfer behaviour inside a vented enclosure in the presence of heat generating obstacle. Hydro-magnetic mixed convection flow in a lid-driven cavity with wavy bottom surface was conducted by Saha et al.[9] where they fund that the variation in the Reynolds number affects significantly the flow and thermal current activities. Hussein & Hussein [10] studied characteristics of magnetohydrodynamic mixed convection in a parallel motion of two-sided lid- driven differentially heated parallelogrammic cavity with various skew angles. Recently Saha et al. [11] analyzed the effect of internal heat generation or absorption on MHD mixed convection flow in a lid driven cavity. Heat transfer rate decreases with increasing of Hartmann number and heat generation parameter whereas increases for the increasing values of heat absorption parameter. Thus, magnetic field plays an important role to control heat transfer and fluid flow. Very recently Malleswaran and Sivasankaran [12] investigated numerically MHD mixed convection in alid-driven cavity with corner heaters. They concluded that cavity with corner heaters is completely different from differentially heated cavity in which the thermal boundary layer occurs near both hot and cold walls whereas no such boundary layer exist in the cavity with corner heaters at forced convection mode.

To the best of the author's knowledge, attention has not been paid to the problem of mixed magneto convection in a lid driven square enclosure with a sinusoidal left vertical wall and Joule heating. The objective of the present study is to examine the momentum and energy transport processes in a lid-driven cavity with wavy surface. The results are shown in terms of parametric presentation of streamlines and isotherms for various pertinent dimensionless parameters such as Rayleigh number Ra, magnetic parameter Ha and undulations λ offered by the wavy surface. Finally, the implications of the above parameters are also depicted on the velocity, temperature, local Nusselt number, average fluid temperature and temperature of body centre.

Nomenclature

B_0	magnetic field strength (Wbm^{-2})
C_p	specific heat at constant pressure ($JKg^{-1}K^{-1}$)
g	acceleration due to gravity (ms^{-2})
Gr	Grashof number
Ha	Hartmann number
K	thermal conductivity of fluid ($Wm^{-1}K^{-1}$)
L	length of the cavity (m)
Nu	Nusselt number
p	dimensional pressure (Nm^{-2})
P	non-dimensional pressure
Pr	Prandtl number
Re	Reynolds number
Ri	Richardson number
T	dimensional temperature of fluid (K)
T_c	dimensional temperature of lid (K)
av	average
T_h	dimensional temperature of wavy wall (K)
u, v	velocity components (ms^{-1})
U, V	non-dimensional velocity components
U_0	lid velocity (ms^{-1})
V	cavity volume (m^3)
x, y	cartesian coordinates (m)
X, Y	non-dimensional Cartesian coordinates

Greek symbols

α	thermal diffusivity (m^2s^{-1})
β	thermal expansion coefficient (K^{-1})
θ	non-dimensional temperature
μ	dynamic viscosity of the fluid ($Kgm^{-1}s^{-1}$)
ν	kinematic viscosity of the fluid (m^2s^{-1})
σ	electrical conductivity of the fluid ($\Omega^{-1}m^{-1}$)
ρ	density of the fluid (Kgm^{-3})