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Effect of Magnetic Field on Natural Convection flow in a Prism Shaped Cavity Filled with Nanofluid

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Abstract

The paper executes the laminar natural convection flow and heat transfer inside a prismatic enclosure with non-uniform temperature distribution maintained at the bottom wall. The side walls are insulated and the remaining walls are cooled at temperature T_c. A magnetic field of strength B_0 is applied horizontally normal to the side walls. The water-Al_2O_3 nanofluid is used as the heat transfer medium through the enclosure. Finite Element Method of Galerkin's weighted residual scheme is used to solve the transport equations with appropriate boundary conditions. The effect of Hartman number Ha (0 to 50) for nanofluid as well as for the base fluid on isotherms, streamlines and heat lines, local and average heat transfer are presented graphically. The calculations have been performed for Prandtl number $Pr = 6.2$. Results indicate that the heat transfer rate is significantly affected by increasing the mentioned parameter.

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Keywords: Moonpool; Piston mode; Sloshing mode; Explicit Algebraic Stress model (EASM)

1. Introduction

Magnetohydrodynamic (MHD) flow of nanofluid and especially when associated with heat transfer have received considerable attention recent years because of their wide variety of application in industry, science & engineering areas. Parvin and Nasrin [1] have studied the analysis of the flow and heat transfer characteristics for MHD free convection in an enclosure with a heated obstacle. They showed that the influence of Magnetic parameter on streamlines and isotherms are remarkable. Ellahi [2] studied magnetohydrodynamic (MHD) flow of non-Newtonian nanofluid in a pipe and observed that the MHD parameter decreases the fluid motion and the velocity profile is larger than that of the temperature profile even in the presence of variable viscosities. Free convection heat transfer in a concentric annulus between a cold square and heated elliptic cylinders in the presence of a magnetic field was investigated by Sheikholeslami et al. [3]. They found that enhancement in heat transfer increases as the Hartmann number increases but it decreases with increase of Rayleigh number.

Nanofluid, which is a mixture of nanosized particles (nanoparticles) suspended in a base fluid, is used to enhance the rate of heat transfer via its higher thermal conductivity compared to the base fluid. Nanofluids have been widely used in industry, because of the growing use of these smart fluids. Many studies [4–9] explained that nanofluids clearly exhibit enhanced thermal conductivity, which goes up with increasing volumetric fraction of nanoparticles. The heatline method is the way of visualizing the heat recovery system. Sheikholeslami et al. [10] studied the magnetic

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field effect on CuOwater nanofluid flow and heat source length is more pronounced at high Rayleigh number. Recently, Yaseen [11] has studied and analyzed numerically the steady natural convection flow in a prismatic enclosure with strip heater on bottom wall. Recently Ahmed et.al [12] performed numerical analysis for natural convection flows within prismatic enclosures based on heatline approach.

The objective of this work is to study natural convection in a prism shaped enclosure filled with a water based nanofluid (water with Al_2O_3) in the presence of a horizontal magnetic field effect with non-uniform (sinusoidal) temperature distribution maintained at the bottom wall. The study focuses specifically on the effects of the magnetic field on the streamlines, isotherm distribution, heatlines and average Nusselt number for nanofluid as well as water.

Nomenclature

C_p	specific heat $[Jkg^1K^1]$
g	acceleration due to gravity $[ms^{-2}]$
k	thermal conductivity $[Wm^{-1}K^{-1}]$
L	length of the base and height [m]
Nu	Nusselt number
p	dimensional pressure [Pa]
P	dimensionless pressure
Pr	Prandtl number
Ra	Rayleigh number
Ha	Hartmann number
T	temperature [K]
u, v	velocity components $[ms^{-1}]$
U, V	dimensionless velocity components
x, y	distance along x- and y- coordinates
X, Y	dimensionless distance along x- and y- coordinates

Greek symbols

α	thermal diffusivity $[ms^2]$
ν	kinematic viscosity of the fluid$[m^2s^{-1}]$
q	dimensionless temperature
χ	nanoparticle volume fraction
ρ	density $[kgm^3]$
ψ	Stream function

2. Governing Equations

The physical domain consists of laminar natural convection flow of water-based nanofluid in a prism shaped enclosure of length L (Figure 1). The enclosure is heated from the bottom wall with a non-uniformly-distributed temperature $T = (T_h - T_c) \times \sin(\pi x/L) + T_c$. The side walls are insulated and the remaining walls are cooled at temperature T_c. A magnetic field of strength B_0 is applied horizontally normal to the side walls. Under Boussinesq approximations, the governing equations for steady two dimensional laminar incompressible flows can be written in dimensionless form as:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0$$

$$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\rho_f}{\rho_{nf}}\frac{\partial P}{\partial X} + Pr\frac{\nu_{nf}}{\nu_f}\Big(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\Big)$$

$$U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{\rho_f}{\rho_{nf}}\frac{\partial P}{\partial X} + Pr\frac{\nu_{nf}}{\nu_f}\Big(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\Big) + RaPr\frac{(1-\chi)\rho_f B_f + \chi\rho_s B_s}{\rho_{nf}B_f}\theta - Ha^2PrV$$

$$U\frac{\partial \theta}{\partial X} + V\frac{\partial \theta}{\partial Y} = \frac{\alpha_{nf}}{\alpha_f}\Big(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}\Big)$$

where, $\rho_{nf} = (1-\chi)\rho_f + \chi\rho_s$ is the density, $(\rho C_P)_{nf} = (1-\chi)(\rho C_p)_f + \chi(\rho C_s)_f$ is the heat capacitance, $\beta_{nf} = (1-\chi)\beta_f + \chi\beta_s$ is the thermal expansion coefficient, $\alpha_{nf} = k_{nf}/(\rho C_p)_{nf}$ is the thermal diffusivity, $\mu_{nf} = \mu_f(1-\chi)^{-2.5}$ is dynamic viscosity and $k_{nf} = k_f\frac{k_s + 2k_f - 2\chi(k_f - k_s)}{k_s + 2k_f + \chi(k_f - k_s)}$ is the thermal conductivity