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Influence of inclined Lorentz force on micropolar fluids in a square cavity with uniform and nonuniform heated thin plate

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ABSTRACT

In the present study, the effect of inclined magnetic field on natural convection of micro-polar fluid in a square cavity with uniform and nonuniform heated thin plate built in centrally is investigated numerically. The vertical walls are cooled while the top and bottom walls are insulated. The thin plate is assumed to be isothermal with a linearly varying temperature. The governing equations were solved by finite volume method using second order central difference scheme and upwind differencing scheme. The numerical investigation is carried out for different governing parameters namely, the Hartmann number, inclination angle of magnetic field, Rayleigh number, vortex viscosity and source non-uniformity parameters. The result shows that the heat transfer rate is decreased when increasing Hartmann number, inclination angle of magnetic field and vortex viscosity parameter. It is found that the non-uniformity parameter affects the fluid flow and temperature distribution especially for the high Rayleigh numbers. Finally, the overall heat transfer rate of micro-polar fluids is found to be smaller than that of Newtonian fluid.

1. Introduction

The model of micropolar fluids introduced by Eringen [1,2]. Analysis of the flow and heat transfer of micro-polar fluid in a square cavity has been of great interest because of the Navier - Stokes Navier–Stokes equations for Newtonian fluids cannot successfully describe the characteristics of fluid with suspended particles. This study is expected to successfully distinguish the non-Newtonian $(k \neq 0)$ behavior of certain real fluids. The importance of natural convection in cavities can be found in many engineering applications, such as ventilation of living space, cooling in nuclear reactors and electronic packaging and energy transfer in solar collectors. Therefore, natural convection in cavities has been extensively investigated over the past several decades. A brief review of some valuable studies on natural convection in an enclosures is outlined below. Natural convection in a rectangular cavity with differentially heated side walls and insulated horizontal surfaces was investigated numerically and experimentally by Davis [3] and Keyhani et al. [4] respectively. Ganzarolli and Milanez [5] performed a numerical study of steady natural convection in rectangular enclosure heated from below and symmetrically cooled from the sides. They observed that for the square cavity, the flow and thermal fields are not strongly affected by the isothermal or constant heat flux boundary condition at the bottom heat source. However, distinct differences were observed between the isothermal and constant heat flux conditions for the shallow cavity. Aydin and Yang [6] numerically investigated natural convection of air in a cavity with localized isothermal heating from below and symmetrical cooling from sidewalls. The average Nusselt number at the heated part of the bottom wall is shown to increase with increasing Rayleigh number as well as with increasing length of the heat source. Free convection fluid flow and heat transfer of various water based nanofluids in a square cavity with an inside thin heater has been investigated numerically by Mahmoodi [7]. They found that at high Rayleigh number, the Ag-water nanofluid is more effective to enhance the heat transfer rate while at low Rayleigh number the type of nanofluids does not affect the heat transfer rate. Natural convection heat transfer in a square cavity with a heated palate built in vertically and horizontally by Oztop and Dagtekin [8]. They showed that heat transfer rate increase at both vertical and horizontal position of the plate as Rayleigh number increases. Eulerian - Lagrangian Eulerian–Lagrangian modeling of solid particle behavior in a square cavity with several pairs of heaters and coolers inside is investigated by Garoosi et al. [9]. They found that at lower Rayleigh numbers the particle distribution is strongly non-uniform. Furthermore, the results of this study showed by increasing the number of coolers and splitting HAC into smaller segments, the deposition rate of the solid

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Nomenclature

Alphabetics

L	length of the cavity (m)
l	length of the heat source (m)
g	gravitational acceleration (m/s^2)
h	local heat transfer coefficient (W/m^2 K)
P	pressure (N/m^2)
p	dimensionless pressure (N/m^2)
k	thermal conductivity(W/mk)
Nu	Nusselt number $(Nu = hH/k)$
N	angular velocity $\left(s^{-1}\right)$
Pr	Prandtl number (ν/α)
q_w	heat flux $\left(W/m^2\right)$
Ra	Rayleigh number $(g\beta L^3 \Delta T/\nu\alpha)$
Ha	Hartmann number $\left(B_0 L\sqrt{\frac{\sigma}{\mu}}\right)$
t	time (s)
T	temperature (K)
x, y	dimensional coordinates
u, v	dimensional velocity components (m/s)
U, V	dimensionless velocity components
X, Y	dimensionless coordinates

Greek Symbolssymbols

α	thermal diffusivity (m^2/s)
β	thermal expansion coefficient $\left(K^{-1}\right)$
λ	source non-uniformity parameter $((T_{h1} - T_{h2})/2\Delta T)$
ν	kinematic viscosity (m^2/s)
μ	dynamic viscosity (kg/ms)
σ	electrical conductivity (W/m K)
θ	dimensionless temperature
ρ	density (kg/m^3)
τ	dimensionless time
ϵ	dimensionless length of the heat source (l/L)
ω	dimensional vorticity $\left(s^{-1}\right)$
ψ	dimensional stream function (m^2/s^1)
Ψ	dimensionless stream function
Ω	dimensionless vorticity

Subscripts

avg	average
c	cold wall
h	hot wall

particles and heat transfer rate changes significantly.

A numerical study to investigate the free convection micropolar fluid flow in an square cavity with boundary element method is performed by Zadravec et al. [10]. They observed that the micropolar fluid flow produces lesser heat transfer rate compared to the Newtonian fluids. Sathiyamoorthy et al. [11] numerically investigated steady natural convection flows in a square cavity with linearly heated side walls. They found that average Nusselt numbers smoothly increase as Ra increases with an exception for $Pr=10$ at the left wall due to the presence of a strong secondary cell near the top edge of the left wall. Natural convection in tilted rectangular enclosures with a vertically situated hot plate inside is studied by Altac and Kurtul [12]. They found that the heat transfer rate increases with an increase in the aspect ratio for all tilt angles and Rayleigh numbers.

Laminar natural convection in a two dimensional square cavity filled with micropolar fluid and differentially heated on the vertical sidewalls is numerically investigated by Aydin and Pop [13]. They found that, when the Rayleigh number and Prandtl number increases the heat transfer is increased. Obviously, an increase of material parameter condensed the heat transfer rate. Saleem et al. [14] numerically investigated steady two-dimensional natural convection flow of micropolar fluid in a rectangular cavity heated from below with cold sidewalls. It is found the heat transfer rate from heated surface, in the case of micropolar fluid is less than that of the Newtonian fluid under the same physical conditions. The effects of both rotation and magnetic field of a micro-polar fluid through a porous medium induced by sinusoidal peristaltic waves traveling down the channel walls are studied analytically and computed numerically by Abd-Alla et al. [15]. MHD free convection in an inclined enclosure filled with a micropolar nanofluid numerically investigated by BourantasBourants and Loukopoulos [16]. It can be observed that the average Nusselt number of micropolar nanofluid is smaller compared with that of a pure nanofluid model. Transient buoyancy-opposed double diffusive convection of micropolar fluids in a square enclosure investigated by Jena et al. [17]. They revealed that the flow field and rotation velocities increases with an increase in the Rayleigh number. The presence of the vortex viscosity parameter leading monotonic decrease in the flow strength and heat transfer rate. A numerical study of MHD mixed convection with the influence of inclined magnetic fields on nanofluid filled lid driven cavity is presented by Selimefendigil et al. [18]. They found that as the Hartmann number and magnetic angle of the upper triangle are increased, the overall heat transfer rate decreases as to compare with the lower triangular domain.

On the basis of the literature review, it appears that no work was reported on the natural convection flow of micropolar fluids in enclosure with nonuniform heat source placed inside. Therefore, due to its practical interest in the engineering fields, the topic needs to be further explored. Hence, the aim of this study is to investigate the effect of inclined Lorenz force on natural convection of micropolar fluid in a square cavity with horizontally/vertically localized heat plate.

2. Mathematical formulation

Consider a two dimensional square cavity of sides of length L as shown in Fig. 1. The top and bottom walls of the cavity are adiabatic and two vertical walls have constant temperature T_c. A thin horizontal/vertical plate of height $L/2$ is placed at the center of the cavity. The temperature of the plate T_h is varying linearly from T_{h1h1} to T_{h2h2}. The cartesian coordinates (x,y) with the corresponding velocity components (u,v) are chosen. The gravity g acts downward normal to the x direction.

The flow is assumed to be laminar incompressible and the fluid properties are assumed to be constant except the density in the buoyancy term following the Boussinesq approximation. Then the governing equations for unsteady natural convection flow, using conservation of mass, linear momentum, angular momentum and energy can be written as

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} = 0 \tag{1}$$