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Mixed convection in a nanofluid filled-cavity with partial slip subjected to constant heat flux and inclined magnetic field

Muneer A. Ismael [a], M.A. Mansour [b], Ali J. Chamkha [c,d], A.M. Rashad [e,*]

[a] Mechanical Engineering Department, Engineering College, University of Basrah, Basrah, Iraq
[b] Department of Mathematics, Assuit University, Faculty of Science, Assuit, Egypt
[c] Mechanical Engineering Department, Prince Mohammad Bin Fahd University, Al-Khobar 31952, Saudi Arabia
[d] Prince Sultan Endowment for Energy and Environment, Prince Mohammad Bin Fahd University, Al-Khobar 31952, Saudi Arabia
[e] Department of Mathematics, Aswan University, Faculty of Science, Aswan 81528, Egypt

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ABSTRACT

Mixed convection in a lid-driven square cavity filled with Cu-water nanofluid and subjected to inclined magnetic field is investigated in this paper. Partial slip effect is considered along the lid driven horizontal walls. A constant heat flux source on the left wall is considered, meanwhile the right vertical wall is cooled isothermally. The remainder cavity walls are thermally insulted. A control finite volume method is used as a numerical appliance of the governing equations. Six pertinent parameters were studied these; the orientation of the magnetic field (Φ=0–360°), Richardson number (Ri=0.001–1000), Hartman number (Ha=0–100), the size and position of the heat source (B=0.2–0.8, D=0.3–0.7, respectively), nanoparticles volume fraction (ϕ=0.0–0.1), and the lid-direction of the horizontal walls ($\lambda = \pm 1$) where the positive sign means lid-driven to the right while the negative sign means lid-driven to the left. The results show that the orientation and the strength of the magnetic field can play a significant role in controlling the convection under the effect of partial slip. It is also found that the natural convection decreases with increasing the length of the heat source for all ranges of the studied parameters, while it is do so due to the vertical distance up to Hartman number of 50, beyond this value the natural convection decreases with lifting the heat source narrower to the top wall.

1. Introduction

The developments in electronic technology, industry, environmental applications such as lubrication technologies, food processing and nuclear reactors have became more pronounced in the recent years [1–5]. These continually developments are cumulative accompanied with progress in heat rejection (cooling) methods. Mixed convection has been and will continue to be pivotal in improving the performance of the heat rejection in electronic sources contained in enclosures. Mixed convection flow and heat transfer in enclosures can also encountered in many other industrial applications such as, float glass manufacturing, solidification of ingots, coating or continuous reheating furnaces, and any application under goes to a solid material motion inside a chamber. The mixed convection flow in lid-driven cavity or enclosure is raised from two mechanisms. The first is due to shear flow caused by the movement of one (or two) of the cavity wall(s) while the second is due to the buoyancy flow induced by the non-homogeneous thermal boundaries. The contribution of shear force caused by movement of wall and the buoyancy force by temperature difference make the heat transfer mechanism complex. Cavity flow simulation was introduced in early works of Torrance et al. [6] and Ghia et al. [7]. Recently, lid-driven cavities are found studied in various situations such as pure or nanofluid-filled cavities, and pure or nanofluid saturated porous medium cavities. Selective studies of lid-driven cavities filled with pure fluids can be referred to Koseff [1], Mohamad and Viskanta [8], Mekroussi et al. [9], Sivasankaran et al. [10], or in nanofluid filled cavities as in Tiwari and Das [11], Talebi et al. [12], Abu-Nada and Chamkha [13], Chamkha and Abu-Nada [14]. The effect of uniform magnetic field was found to have considerable effect on the rate of heat transfer [15]. The role of magnetic field on natural convection in nanofluid filled cavities is addressed in Sheikholeslami et al. [16] and Sheikholeslami and Rashidi [17]. Lid-driven pure fluid filled cavities as in Oztop et al. [18], Muthtamilselvan et al. [19]. Lid-driven porous cavity as in Khanafer and Chamkha [20], lid-driven nanofluid saturated porous cavities as in Sun and Pop [21], Chamkha and Ismael [22], and Bourantas et al. [23].

In some applications like fluoroplastic coating (e.g. Teflon) which resists adhesion, the no-slip boundary condition imposed

* Corresponding author.
E-mail address: am_rashad@yahoo.com (A.M. Rashad).

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Nomenclature

B	heat source (m)
D	heat source position (m)
g	gravitational field (m s^{-2})
Gr	Grashof number $Gr = g\,\beta\,\Delta T\,H^3/\nu^2$
H	cavity width (m)
Ha	Hartman number
N	slip constant (m^2 s kg^{-1})
Nu_s	local Nusselt number
Nu_m	average Nusselt number
p	pressure (N/m^2)
Pr	Prandtl number $Pr = \nu/\alpha$
Re	Reynolds number $Re = U_0\,H/\nu$
Ri	Richardson number $Ri=(Gr/Re^2)$
S	dimensionless partial slip parameter $S_t=S_b=N\mu_f/H$
T	temperature (K)
u	velocity component along x-direction (m s^{-1})
U	dimensionless velocity component along x-direction
Uo	velocity of the moving wall (m/s)
v	velocity component along y-direction (m s^{-1})
V	dimensionless velocity component along y-direction
x,y	Cartesian coordinates (m)
X,Y	dimensionless Cartesian coordinates

Greek symbols

α	thermal diffusivity (m^2 s^{-1})
β	thermal expansion coefficient (K^{-1})
ϕ	nanoparticles volume fraction
Φ	inclination angle of the magnetic field (degree)
λ	constant moving parameter
μ	dynamic viscosity (Pa s)
ν	kinematic viscosity (m^2 s^{-1})
θ	dimensionless temperature
ρ	density (kg m^{-3})
σ	electrical conductivity (S m^{-1})
ψ, Ψ	stream function (m^2 s^{-1}), dimensionless stream function

Subscripts

b	bottom
c	cold
f	fluid
h	hot
m	average
nf	nanofluid
p	porous
t	top

on the tangential velocity cannot be held. Moreover, some surfaces are rough or porous such that equivalent slip occurs (Wang [24]). Also, there existsa hydrodynamic boundary slip regime for rarefied gases when the Knudsen number is small (Sharipov and Seleznev [25]). Dealing with such problems is strictly embargo to consider Navier's slip-boundary condition [26] along these surfaces. Generally, the physical interpretation of the velocity slip on solid boundary arises from the unequal wall and fluid densities, the weak wall-fluid interaction, and the high temperature [27]. However, the studies dealing with slip boundary conditions may be achieved in order to simulate engineering problems Fang et al. [28] and Yoshimura and Prudhomme [29], or to solve the problem of non-physical singularity resulting from meeting stationary and moving walls, Navier [26], Koplik & Banavar [30], Qian and Wang [31], Nie et al. [32], and Ismael et al. [33] have considered the partial slip condition along two horizontal isothermal moving walls under steady laminar mixed convection inside lid-driven square cavity. Their results have showed that there were critical values of the partial slip parameter at which the convection is declined. These non-zero critical slips where found to be sensitive to both Richardson number and the lid direction. Alternatively, Soltani and Yilmazer [34] have reported that the wall slip can occur in the working fluid contains concentrated suspensions. Convective heat transfer of nanofluids in circular concentric pipes under the influence of partial velocity slips on the surfaces and the resulting anomalous heat transfer enhancement were investigated by Turkyilmazoglu [35]. Recently, there are some studies consider slip boundary condition in nanofluid fill cavity, as in Malvandi and Ganji [36], and Mabood and Mastroberardin [37].

The present literature survey has led us to confirm that there is, relatively, a very little published works regarding the slip boundary condition in the lid-driven cavities. Moreover, the topics of nanofluids and magnetic field with partial slip have not clearly arisen yet. Accordingly, the present work is prepared as an attempt to continue in developing the mixed convection aspects. The present geometry is a square cavity filled with Cu-Water nanofluid subjected to an inclined magnetic field. The horizontal walls are thermally insulted (adiabatic) and lid-driven with partial slip, the vertical left wall is also adiabatic but contains a segment of heat source. The right wall is isothermally cooled. It is sought that this work will contribute in finding new parameters arrangements those govern the performance of the lid driven cavities especially those hold very high temperature difference where the partial slip is inevitably exist.

2. Mathematical modeling

Consider a steady two-dimensional mixed convection flow inside a square cavity of side length H filled with Cu-water nanofluid, as depicted in Fig. 1. The coordinates x and y are chosen such that x measures the distance along the bottom horizontal wall,

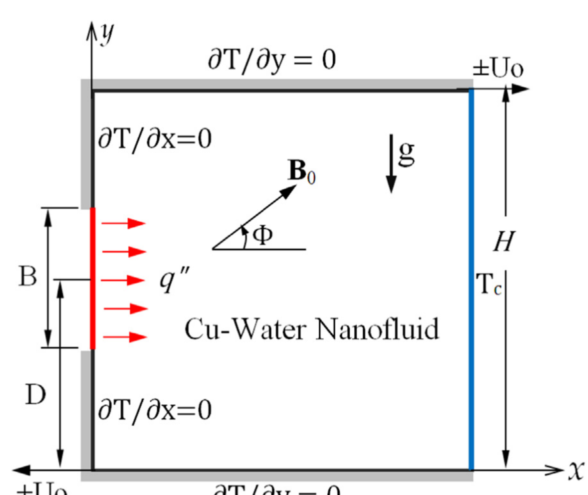

Fig. 1. Schematic diagram and boundary conditions.