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Electrohydrodynamic nanofluid flow and heat transfer between two plates

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ABSTRACT

In this paper electro-magneto-hydrodynamics effects on nanofluid flow and heat transfer characteristics in a rotating system are studied. The fourth-order Runge–Kutta method is used in order to solve the governing equations. Effects of electric parameter, magnetic parameter, Reynolds number and rotation parameter on the magnitude of the skin friction coefficient and rate of heat transfer have been considered. Results show that the Nusselt number increases with an increase of the magnetic parameter, electric parameter and Reynolds number but it decreases with an increase of the rotation parameter.

1. Introduction

The study of magnetic field effects has important applications in physics, chemistry and engineering. Industrial equipment, such as magnetohydrodynamic (MHD) generators, pumps, bearings and boundary layer control is affected by the interaction between the electrically conducting fluid and a magnetic field. The work of many investigators has been studied in relation to these applications. One of the basic and important problems in this area is the hydromagnetic behavior of boundary layers along fixed or moving surfaces in the presence of a transverse magnetic field. MHD boundary layers are observed in various technical systems employing liquid metal and plasma flow transverse of magnetic fields [1]. Magnetohydrodynamics treats the phenomena that arise in fluid dynamics from the interaction of an electrically conducting fluid with the electromagnetic field [2]. The study of an electrically conducting fluid flow under a transversely applied magnetic field has become the basis of many scientific and engineering applications [3]. Sheikholeslami and Ellahi [4] studied three dimensional mesoscopic simulation of magnetic field effect on natural convection of nanofluid. They found that thermal boundary layer thickness increases with an increase of Lorentz forces. Onyejekwe [5] has analyzed the problem of unsteady magnetohydrodynamic flow of an electrically conducting, laminar, incompressible, Newtonian, viscous fluid through a tube exposed to screen electrodes placed centrally in the flow field and at the two ends of the tube. The governing differential equations which comprise such effects as the electric field, the magnetic and flow fields are non-dimensionalized and solved numerically. Force convective heat transfer of magnetic nanofluid in a lid driven semi-annulus enclosure has been investigated by Sheikholeslami et al. [6]. Their results showed that the Nusselt number has a direct relationship with the Reynolds number and nanoparticle volume fraction while it has a reverse relationship with the Hartmann number. Magnetohydrodynamic squeezing flow of nanofluid over a porous stretching surface was investigated by Hayat et al. [7]. Sheikholeslami et al. [8] simulated electric field effect on nanofluid flow and heat transfer. They proved that the effect of the electric field on heat transfer is more pronounced at low Reynolds number. Mahmoudi et al. [9] investigated the natural convection in a square enclosure filled with a water–Al_2O_3 nanofluid in the presence of a magnetic field and uniform heat generation/absorption. They observed that adding nanoparticle reduces the entropy generation. The nanoparticle effect is more intense for high Hartmann number. Recently several authors investigated about the effect of magnetic and electric fields on flow style [10–28].

From an energy saving perspective, improvement of heat transfer performance in systems is a necessary subject. Low thermal conductivity of conventional heat transfer fluids such as water and oils is a primary limitation in enhancing the performance and the compactness of systems. Solids typically have a higher thermal conductivity than liquids. For example, copper (Cu) has a thermal conductivity 700 times greater than water and 3000 times greater than engine oil. An innovative and novel technique to enhance heat transfer is to use solid particles in the base fluid (i.e. nanofluids) in the range of sizes 10–50 nm. Sheikholeslami and Abelman [29] used two phase simulation of nanofluid flow and heat transfer in an annulus in the presence of an axial magnetic field. The MHD steady flow of viscous nanofluid flow over a stretching sheet was studied by Sandeep et al. [30]. They

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Nomenclature

A_1,A_2,A_3,A_4,A_5	Dimensionless constants
B_0	Magnetic field
C_p	Specific heat at constant pressure
$C_f, \tilde{C}_f$	Skin friction coefficients
E_h	Electric parameter
$f(\eta)$,$g(\eta)$	Similarity functions
h	Distance between the plates
k	Thermal conductivity
K_r	Rotation parameter
Nu	Nusselt number
P^*	Modified fluid pressure
Pr	Prandtl number
q_w	Heat flux at the lower plate
R	Reynolds number
u, v, w	Velocity components along x, y, z axes, respectively
u_w	Velocity of the stretching surface

Greek symbols

α	Thermal diffusivity
η	Dimensionless variable
θ	Dimensionless temperature
ρ	Density
ϕ	Nanoparticle volume fraction
σ	Electrical conductivity
μ	Dynamic viscosity
υ	Kinematic viscosity
τ_w	Skin friction or shear stress along the stretching surface
Ω	Constant rotation velocity

Subscripts

∞	Condition at infinity
nf	Nanofluid
f	Base fluid
s	Nano-solid-particles

observed that the heat and mass transfer rate in Oldroyd-B nanofluid is significantly high compared with the Jeffery and Maxwell nanofluids. Sheikholeslami et al. [31] investigated the effect of a variable magnetic field on force convection heat transfer. Their results indicated that the effects of Kelvin forces are more pronounced for high Reynolds number. The turbulent forced convection of nanofluids in shallow cavity heated from sides with uniform temperature was analyzed by Abdellahoum et al. [32]. Their obtained results show that the heat transfer is enhanced with the studied parameters for all models of thermal conductivity. Squeezing unsteady nanofluid flow and heat transfer have been studied by Sheikholeslami et al. [33].They showed that for the case in which two plates are moving together, the Nusselt number increases with an increase of nanoparticle volume fraction and Eckert number while it decreases with growth of the squeeze number. Recently several authors investigated about nanofluid flow and heat transfer [34–68].

The objective of the present paper is to study nanofluid flow and heat transfer between two horizontal parallel plates in a rotating system in the presence of both electrical field and magnetic field. The reduced ordinary differential equations are solved numerically using the fourth-order Runge–Kutta method. The effects of the parameters governing the problem are discussed.

2. Problem statement

Consider steady flow of nanofluid between two horizontal parallel plates when the fluid and the plates rotate together with a constant angular velocity Ω around the axis which is normal to the plates. A Cartesian coordinate system (x,y,z) is considered as follows: the x-axis is along the plate, the y-axis is perpendicular to it and the z-axis is normal to the x–y plane (see Fig. 1). The origin is located at the lower plate, and the plates are located at $y = 0$ and $y = h$. The lower plate is being stretched by two equal opposite forces so that the position of the point (0,0,0) remains unchanged. A uniform magnetic flux with densityB_0 acts along the y-axis. Also an electrical field $(E = E_0 xy)$ acts along the z-axis. Under these assumptions, the Navier–Stokes and energy equations are:

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

$$\rho_{nf}\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + 2\Omega w\right) = -\frac{\partial p^*}{\partial x} + \mu_{nf}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \sigma_{nf} B_0 (u B_0 + E), \tag{2}$$

$$\rho_{nf}\left(u\frac{\partial v}{\partial y}\right) = -\frac{\partial p^*}{\partial y} + \mu_{nf}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \tag{3}$$

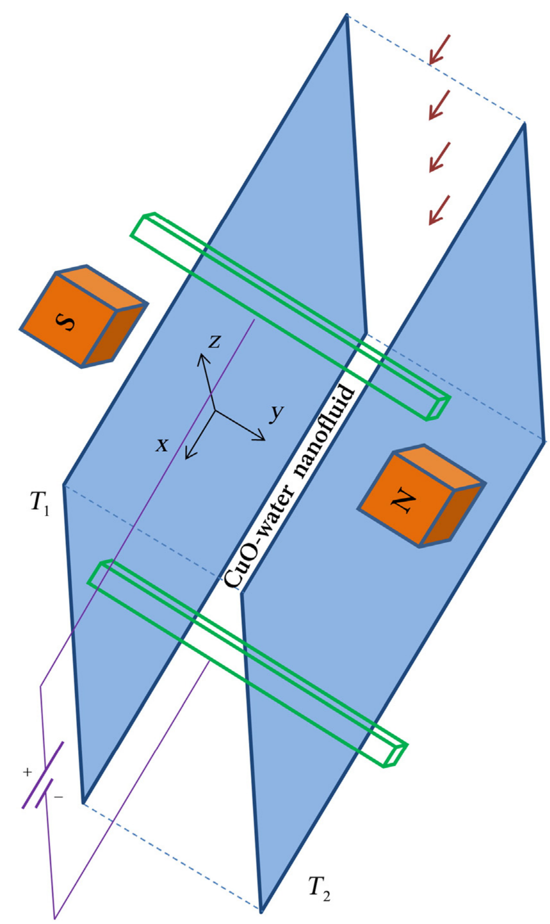

Fig. 1. Schematic theme of the problem geometry.

Table 1
Thermo-physical properties of water and nanoparticles.

	ρ (kg/m^3)	C_p(j/kg·k)	k (W/m×k)	$\beta \times 10^5$(K^{-1})	$\sigma(\Omega \times \text{m})^{-1}$
Water	997.1	4179	0.613	21	0.05
Cu	8933	385	401	1.67	5.96×10^7