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Effect of thermal radiation on magnetohydrodynamics nanofluid flow and heat transfer by means of two phase model

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ABSTRACT

In this study, effect of thermal radiation on magnetohydrodynamics nanofluid flow between two horizontal rotating plates is studied. The significant effects of Brownian motion and thermophoresis have been included in the model of nanofluid. By using the appropriate transformation for the velocity, temperature and concentration, the basic equations governing the flow, heat and mass transfer are reduced to a set of ordinary differential equations. These equations, subjected to the associated boundary conditions are solved numerically using the fourth-order Runge–Kutta method. The effects of Reynolds number, magnetic parameter, rotation parameter, Schmidt number, thermophoretic parameter, Brownian parameter and radiation parameter on heat and mass characteristics are examined. Results show that Nusselt number has direct relationship with radiation parameter and Reynolds number while it has reverse relationship with other active parameters. It can also be found that concentration boundary layer thickness decreases with the increase of radiation parameter.

1. Introduction

Thermal radiation has a significant role in the overall surface heat transfer when the convection heat transfer coefficient is small. Thermal radiation effect on mixed convection from vertical surface in a porous medium was studied by Bakier [1]. He applied fourth-order Runge–Kutta scheme to solve the governing equations. Effect of MHD flow with mixed convection from radiative vertical isothermal surface embedded in a porous medium was numerically analyzed by Damseh [2]. He used an implicit iterative tri-diagonal finite difference method in order to solve the dimensionless boundary-layer equations. It is well known that the effect of thermal radiation is important in space technology and high temperature processes. Thermal radiation also plays an important role in controlling heat transfer process in polymer processing industry. The effect of radiation on heat transfer problems have been studied by Hossain and Takhar [3]. Zahmatkesh [4] has found that the presence of thermal radiation makes temperature distribution nearly uniform in the vertical sections inside the enclosure and causes the streamlines to be nearly parallel with the vertical walls. Thermal analysis of the mixed convection-radiation of an inclined flat plate embedded in a porous medium was conducted by Moradi et al. [5]. Later, Pal and Mondal [6] have investigated radiation effects on combined convection over a vertical flat plate embedded in a porous medium of variable porosity. In critical technological applications like in nuclear reactor cooling, the reactor bed can be modeled as a heat generating porous medium, quenched by a convective flow.

The performances of thermal systems with common base fluid are relatively poor. A recent way of improving the performance of these systems is to suspend metallic nanoparticles in the base fluid. Free convection heat transfer in a concentric annulus between cold square and heated elliptic cylinders in the presence of magnetic field was investigated by Sheikholeslami et al. [7]. They showed that the enhancement in heat transfer increases as Hartmann number increases but it decreases with increase of Rayleigh number. Rashidi et al. [8] considered the analysis of the second law of thermodynamics applied to an electrically conducting incompressible nanofluid fluid flowing over a porous rotating disk. They concluded that using magnetic rotating disk drives has important applications in heat transfer enhancement in renewable energy systems. Some relevant studies on the topic can be seen from the list of references [9–38].

All the above studies assumed that there are not any slip velocities between nanoparticles and fluid molecules and assumed that the nanoparticle concentration is uniform. It is believed that in natural convection of nanofluids, the nanoparticles could not

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Nomenclature

B	constant applied magnetic field
C	nanofluid concentration
$C_f, \tilde{C}_f$	skin friction coefficients
C_p	specific heat at constant pressure
h	distance between the plates
k	thermal conductivity
Kr	rotation parameter
M	magnetic parameter
Nu	Nusselt number
Nb	Brownian motion parameter
Nt	thermophoretic parameter
Sc	Schmidt number
p^*	modified fluid pressure
q_r	radiation heat flux
Pr	Prandtl number
Rd	radiation parameter$(=4\sigma_e T_c^3/(\beta_R k))$
R	Reynolds number
u, v, w	velocity components along x, y, and z axes, respectively
$u_w(x)$	velocity of the stretching surface

Greek symbols

α	thermal diffusivity$(=k/(\rho c)_f)$
ϕ	dimensionless concentration
η	dimensionless variable
μ	dynamic viscosity
υ	kinematic viscosity
θ	dimensionless temperature
ρ	fluid density
σ	electrical conductivity
τ_w	skin friction or shear stress along the stretching surface
Ω	constant rotation velocity
σ_e	Stefan–Boltzmann constant
β_R	mean absorption coefficient

Subscripts

h	Hot
o	Cold

accompany fluid molecules due to some slip mechanisms such as Brownian motion and thermophoresis. So, the volume fraction of nanofluids may not be uniform anymore and there would be a variable concentration of nanoparticles in a mixture. Nield and Kuznetsov [39] studied the natural convection in a horizontal layer of a porous medium. The analysis reveals that for a typical nanofluid (with large Lewis number), the prime effect of the nanofluids is via a buoyancy effect coupled with the conservation of nanoparticles, the contribution of nanoparticles to the thermal energy equation being a second-order effect. Sheikholeslami et al. [40] used heatline analysis to simulate two phase simulation of nanofluid flow and heat transfer. Their results indicated that the average Nusselt number decreases as buoyancy ratio number increases until it reaches a minimum value and then starts increasing. MHD effect on natural convection heat transfer in an enclosure filled with nanofluid was studied by Sheikholeslami et al. [41]. Their results indicated that Nusselt number is an increasing function of buoyancy ratio number but it is a decreasing function of Lewis number and Hartmann number. Free convection heat transfer in an enclosure filled with nanofluid was investigated by Sheikholeslami et al. [42]. They found that Nusselt number is an increasing function of buoyancy ratio number while it is a decreasing function of Lewis number and angle of turn.

Magnetohydrodynamic has many industrial applications such as crystal growth, metal casting and liquid metal cooling blankets for fusion reactors. Sheikholeslami et al. [43] studied the magnetic field effect on CuO–water nanofluid flow and heat transfer in an enclosure which is heated from below. They concluded that effect of Hartmann number and heat source length is more pronounced at high Rayleigh number. Sheikholeslami et al. [44] studied the problem of MHD free convection in an eccentric semi-annulus filled with nanofluid. They showed that Nusselt number decreases with increase of position of inner cylinder at high Rayleigh number. Sheikholeslami and Ganji [45] studied the Magnetohydrodynamic flow in a permeable channel filled with nanofluid. They showed that velocity boundary layer thickness decreases with increase of Reynolds number and nanoparticle volume fraction and it increases as Hartmann number increases. Recently, several authors studied the magnetohydrodynamic flow and heat transfer [46–69].

A careful review of the literature reveals that no efforts are devoted to examine the effect of thermal radiation on magnetohydrodynamics nanofluid flow and heat transfer by means of two phase model yet. Motivated by these facts, the present work has been undertaken to analyze the fully developed flow of an incompressible nanofluid flow between two horizontal rotating plates in the presence of thermal radiation and magnetic field. The reduced ordinary differential equations are solved numerically. The calculations are performed and examined for different governing parameters such as Reynolds number, magnetic parameter, rotation parameter, Schmidt number, thermophoretic parameter, Brownian parameter and radiation parameter on heat and mass characteristics through graphs and in the tabular form. After the introduction in Section 1, the outlines of this paper are as follows. Section 2 contains mathematical formulation and solution of the problem. Results and discussion are given in Section 3. Finally Section 4 summarizes the concluding remarks.

2. Governing equations

Consider the steady nanofluid flow between two horizontal parallel plates when the fluid and the plates rotate together around the y-axis which is normal to the plates with an angular velocity. A Cartesian coordinate system is considered as followed: 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 plates are located at $y=0$ and $y=h$. The lower plate is being stretched by two equal and opposite forces so that the position of the point $(0,0,0)$ remains unchanged. A uniform magnetic flux with density B_0 is acting along y-axis about which the system is rotating. The governing equations in a rotating frame of reference are:

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

$$\rho_f\left(u\frac{\partial u}{\partial x}+\nu\frac{\partial u}{\partial y}+2\,\Omega\,w\right)=-\frac{\partial p^*}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\sigma {B_0}^2 u, \tag{2}$$

$$\rho_f\left(u\frac{\partial v}{\partial y}\right)=-\frac{\partial p^*}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right), \tag{3}$$