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Three dimensional heat and mass transfer in a rotating system using nanofluid

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ABSTRACT

In this study, three dimensional nanofluid flow and heat transfer in a rotating system in the presence of magnetic field is investigated. The important effects of Brownian motion and thermophoresis have been included in the model of nanofluid. The basic partial differential equations are reduced to ordinary differential equations which are solved numerically using the fourth-order Runge–Kutta method. The numerical investigation is carried out for different governing parameters namely: Reynolds number, Rotation parameter, Magnetic parameter, Schmidt number, Thermophoretic parameter and Brownian parameter. Results indicate that skin friction parameter increases with augment of Reynolds number, Rotation parameter and Magnetic parameter. Also it can be found that Nusselt number has a direct relationship with Reynolds number while it has a reverse relationship with Rotation parameter, Magnetic parameter, Schmidt number, Thermophoretic parameter and Brownian parameter.

1. Introduction

A recent way of improving the performance of thermal systems is to suspend metallic nanoparticles in the base fluid. Rashidi et al. [1] 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. Sheikholeslami et al. [2] analyzed the magnetohydrodynamic nanofluid flow and heat transfer between two horizontal plates in a rotating system. Their results indicated that, for both suction and injection, Nusselt number has a direct relationship with nanoparticle volume fraction. Ellahi [3] studied the magnetohydrodynamic (MHD) flow of non-Newtonian nanofluid in a pipe. He observed that the MHD parameter decreases the fluid motion and the velocity profile is larger than that of temperature profile even in the presence of variable viscosities. Squeezing unsteady nanofluid flow and heat transfer has been studied by Sheikholeslami and Ganji [4]. They showed that for the case in which two plates are moving together, the Nusselt number increases with increase of nanoparticle volume fraction and Eckert number while it decreases with growth of the squeeze number. Free convection heat transfer in a concentric annulus between a cold square and heated elliptic cylinders in the presence of magnetic field was investigated by Sheikholeslami et al. [5]. They found that the enhancement in heat transfer increases as Hartmann number increases but it decreases with the increase of Rayleigh number. This field of science became very popular for several authors [6–17].

All the above studies assumed that there aren't any slip velocities between nanoparticles. It is believed that in natural convection of nanofluids, the nanoparticles could not 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 [18] studied the natural convection in a horizontal layer of a porous medium. Their analysis revealed 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. Khan and Pop [19] published a paper on boundary-layer flow of a nanofluid past a stretching sheet. They indicated that the reduced Nusselt number is a decreasing function of each dimensionless number. Sheikholeslami et al. [20] 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. Hassani et al. [21] investigated the problem of boundary layer flow of a nanofluid past a stretching sheet. They found that the reduced Nusselt number decreases with the increase in Prandtl number for many Brownian motion numbers.

In recent years the effect of magnetic field in different engineering applications such as the cooling of reactors and many metallurgical processes involved in the cooling of continuous tiles has been more

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Nomenclature

B	constant applied magnetic field
C	nanofluid concentration
$Cf, \tilde{C}_f$	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
p^*	modified fluid pressure
Pr	Prandtl number
R	Reynolds number
u v, w	velocity components along x, y, z axes, respectively
$u_w(x)$	velocity of the stretching surface

Greek symbols

α	thermal diffusivity
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

Subscripts

h	Hot
o	Cold

considerable. Also, in several engineering processes, materials manufactured by extrusion processes and heat treated materials traveling between a feed roll and a wind up roll on convey belts possess the characteristics of a moving continuous surface. Chakrabarti and Gupta [22] studied the MHD flow of Newtonian fluids initially at rest, over a stretching sheet at a different uniform temperature. Several papers have been published about the effect of magnetic field on flow and heat transfer [23–36].

Table 1
Comparison of the Nu for different grid resolutions, at $Pr = 10, R = 0.5, K_r = 0.5, Sc = 1, M = 1$ and $Nt = Nb = 0.1$.

Mesh size	50	100	150	200	250	300
Nu	1.15096563	1.15096576	1.15096587	1.15096595	1.15096601	1.15096609

The main purpose of this work is to apply two phase model for simulating nanofluid flow and heat transfer in a rotating system in the presence of magnetic field. The reduced ordinary differential equations are solved numerically. The effects of Reynolds number, Rotation parameter, Magnetic parameter, Schmidt number, Thermophoretic parameter and Brownian parameter on flow, heat and mass transfer are examined.

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 the y-axis about which the system is rotating. The governing equations in a rotating frame of reference are:

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

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

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

$$\rho_f\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}-2\ \Omega w\right)=\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}\right)-\sigma {B_0}^2 w, \tag{4}$$

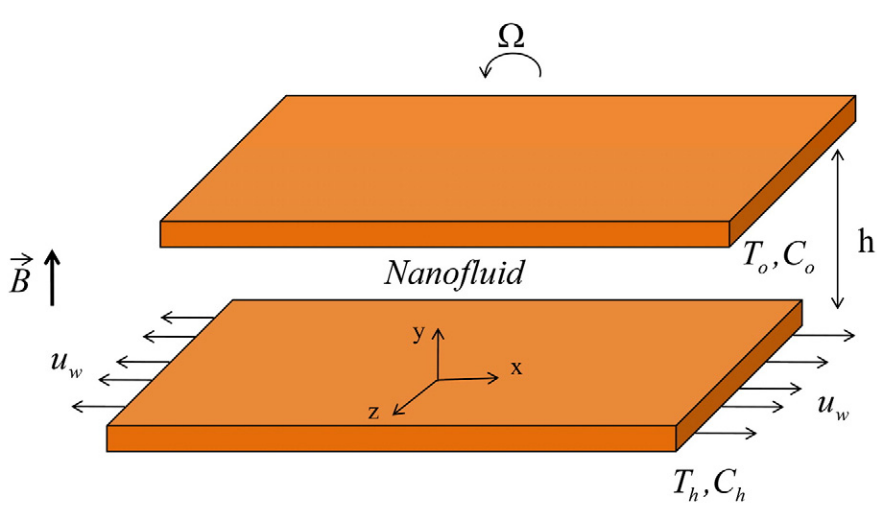

Fig. 1. Geometry of problem.