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Nanofluid flow and heat transfer in a rotating system in the presence of a magnetic field

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ABSTRACT

In this paper the magnetohydrodynamic (MHD) nanofluid flow and heat transfer between two horizontal plates in a rotating system is analyzed. The lower plate is a stretching sheet and the upper one is a solid permeable plate. The basic partial differential equations are reduced to ordinary differential equations which are solved numerically using the fourth-order Runge–Kutta method. Different types of nanoparticles such as copper, silver, alumina and titanium oxide with water as their base fluid have been considered. Velocity and temperature profiles as well as the skin friction coefficient and the Nusselt number are determined numerically. The influence of pertinent parameters such as nanofluid volume fraction, magnetic parameter, wall injection/suction parameter, viscosity parameter and rotation parameter on the flow and heat transfer characteristics is discussed. The results indicate that, for both suction and injection the Nusselt number has a direct relationship with the nanoparticle volume fraction. The type of nanofluid is a key factor for heat transfer enhancement. The highest values are obtained when titanium oxide is used as a nanoparticle. Also it can be found that the Nusselt number decreases with the increase of the magnetic parameter due to the presence of Lorentz forces.

1. Introduction

Fluid flow over a stretching surface has many important applications in the polymer industry. For instance a number of technical processes concerning polymers involve the cooling of continuous strips extruded from a die by drawing them through a quiescent fluid with a controlled cooling system and in the process of drawing, these strips are sometimes stretched. Furthermore glass blowing, continuous casting of metals and spinning of fibers involve the flow due to a stretching surface. In all these cases, the quality of the final product depends on the rate of heat transfer at the stretching surface. Dutta et al. [1] studied the temperature field in the flow over a stretching surface subjected to uniform heat flux. Gupta [2] investigated the heat and mass transfer on a stretching sheet with suction or blowing.

Effects of a magnetic field in different engineering applications such as the cooling of reactors and many metallurgical processes involving the cooling of continuous tiles has been more 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 conveyor belts possess the characteristics of a moving continuous surface. Chakrabarti and Gupta [3] studied the MHD flow of Newtonian fluids initially at rest, over a stretching sheet at different uniform temperatures. Borkakoti and Bharali [4] studied the two dimensional channel flows with heat transfer analysis of a hydromagnetic fluid where the lower plate was a stretching sheet. The flow between two rotating disks has many important applications such as in lubrication. Keeping this fact in mind Vajravelu and Kumar [5] studied the effect of rotation on the two dimensional channel flows. They solved the governing equations numerically. It is worth mentioning that in recent years, the interest in flow and heat transfer through porous media has grown considerably, due largely to the demands of such diverse areas such as geophysics, chemical and petroleum industries, building construction, nuclear reactors, etc.

Taking into account the rising demands of modern technology, including chemical production, power stations, and microelectronics, there is a need to develop new types of fluids that will be more effective in terms of heat exchange performance. The term 'nanofluid' is envisioned to describe a fluid in which nanometer-sized particles are suspended in conventional heat transfer basic fluids [6]. Convectional heat transfer fluids, including oil, water, and ethylene glycol mixtures are poor heat transfer fluids, while the thermal conductivity of these fluids plays an important role in the heat transfer coefficient between the heat transfer medium and the heat transfer surface [7]. A theory based model for the viscosity of nanofluids was presented by Hosseini and Ghader [8]. The MHD effect on natural convection heat transfer in an inclined L-shaped enclosure filled with nanofluid was studied by Sheikholeslami et al. [9]. They found that an enhancement in heat transfer has a reverse relationship with the Hartmann number and the Rayleigh number. Sheikholeslami et al. [10] used heatline analysis to investigate a two

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Nomenclature

A, A_1, A_2, A_3, A_4,	dimensionless constants
B_0	constant applied magnetic field
$C_f, \tilde{C}_f$	skin friction coefficients
C_p	specific heat at constant pressure
$f(\eta), g(\eta)$	similarity functions
h	distance between the plates
k	thermal conductivity
Kr	rotation parameter
M	magnetic 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
$u_w(x)$	velocity of the stretching surface
v_0	suction/injection velocity

Greek symbols

α	thermal diffusivity
ϕ	nanoparticle volume fraction
η	Dimensionless variable
λ	dimensionless suction/injection parameter
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

nf	nanofluid
f	base fluid
s	nano-solid-particles

phase simulation of nanofluid flow and heat transfer. Their results indicated that the average Nusselt number decreases as the buoyancy ratio number increases until it reaches a minimum value and then starts increasing. Rashidi et al. [11] considered the analysis of the second law of thermodynamics applied to an electrically conducting incompressible nanofluid fluid flowing over a porous rotating disk. Free convection heat transfer in a concentric annulus between a cold square and heated elliptic cylinders in the presence of a magnetic field was investigated by Sheikholeslami et al. [12]. They found that the enhancement in heat transfer increases as the Hartmann number increases but it decreases with the increase of the Rayleigh number. Yousefi et al. [13] used diffusional neural networks for modeling the viscosity of nanofluids. Their predicted relative viscosities of suspensions using diffusional neural networks (DNNs) are in accordance with the literature values. Sheikholeslami et al. [14] applied GMDH to investigate the heat transfer of a Cu–water nanofluid over a stretching cylinder in the presence of a magnetic field. Their results indicated that a GMDH type NN in comparison with a fourth-order Runge–Kutta integration scheme. The problem of laminar nanofluid flow in a semi-porous channel in the presence of a transverse magnetic field was investigated analytically by Sheikholeslami et al. [15]. Their results showed that the velocity boundary layer thickness decreases with the increase of the Reynolds number and it increases as the Hartmann number increases. Recently several authors investigated nanofluid flow and heat transfer [16–28].

The main aim of this work is to present the effects of the nanoparticle volume fraction, different types of nanofluids, magnetic parameter, wall injection/suction parameter, viscosity parameter and rotation parameter on the heat and mass transfer of nanofluid flow between two horizontal plates in a rotating system, where the lower plate is a stretching sheet and the upper one is a solid porous plate in the presence of a magnetic field. The nanofluid model proposed by Tiwari and Das [29] is used. The reduced ordinary differential equations are solved numerically. The variation distribution of the shear stress and heat transfer rates with the parameters that govern the problem are presented.

2. Flow analysis

2.1. Governing equations

Consider the steady flow of an electrically conducting nanofluid between two horizontal parallel plates when the fluid and the plates rotate together around the axis which is normal to the plates with a constant angular velocity Ω. 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 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 density B_0 is acting along the y-axis about which the system is rotating. The upper plate is subjected to a constant wall suction velocity v_0 (<0) or a constant wall injection velocity v_0 (>0), respectively. The fluid is a water based nanofluid containing different types of nanoparticles: Cu (copper), Al_2O_3 (alumina), Ag (silver) and TiO_2 (titanium oxide). The nanofluid is a two component mixture with the following assumptions: (i) incompressible; (ii) no-chemical reaction; (iii) negligible viscous dissipation; (iv) negligible radiative heat transfer and (v) nano-solid-particles and the base fluid are in thermal equilibrium and no slip occurs between them. The thermo physical properties of the nanofluid are given in Table 1 [30]. Under these assumptions, the governing equations of motion in a rotating frame of reference are:

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

$$u\frac{\partial u}{\partial x}+\nu\frac{\partial u}{\partial y}+2\Omega w=-\frac{1}{\rho_{\mathrm{nf}}}\frac{\partial p^*}{\partial x}+\upsilon_{nf}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{\sigma_{nf}B_0^2}{\rho_{nf}}u \tag{2}$$

$$u\frac{\partial v}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p^*}{\partial y}+\upsilon_{nf}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 sv}{\partial y^2}\right) \tag{3}$$

$$u\frac{\partial w}{\partial x}+\nu\frac{\partial w}{\partial y}-2\Omega w=\upsilon_{nf}\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}\right)-\frac{\sigma_{nf}B_0^2}{\rho_{nf}}w \tag{4}$$

where u, v and w denote the fluid velocity components along the x, y and z directions, P^* is the modified fluid pressure and the physical meanings

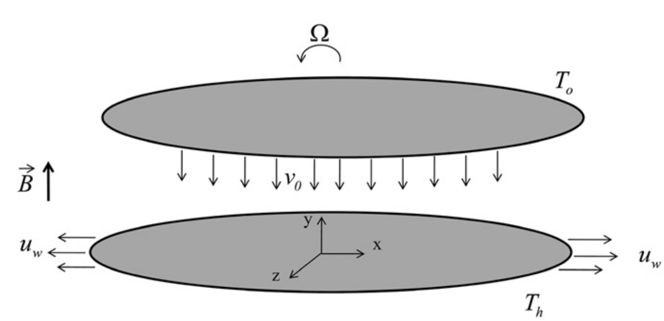

Fig. 1. Physical model along with the coordinate system.