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Two phase model for nanofluid heat transfer intensification in a rotating system under the effect of magnetic field

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ABSTRACT

In this paper, Buongiorno Model is applied for melting heat transfer effect on nanofluid heat transfer intensification between two horizontal parallel plates in a rotating system. Different shapes of nanoparticles are considered. Runge-Kutta method is selected to solve ODEs with are obtained from similarity transformation. Roles of Brownian motion, thermophoretic parameter, magnetic parameter, rotation parameter and Reynolds number are presented graphically. Results reveal that choosing Platelet shape leads to maximum Nusselt number. *Nu* enhances with enhance of Lorentz forces while it detracts with augment of melting parameters.

1. Introduction

Melting process has various uses such as application like in thermocouple, heat exchangers and heat engines. Various kinds of nanoparticles have been utilized by various researchers [1–3]. Sheikholeslami et al. [4] utilized MFD viscosity for simulating nanofluid natural convection in existence of magnetic field. Rashidi and Erfani [5] employed modified DTM for nanofluid flow over a plate. Sheikholeslami and Rokni [6] presented various papers which are about magnetic nanofluid in their review article. Modak et al. [7] examined an experimental procedure for alumina nanofluid heat transfer enhancement. Sheikholeslami and Rokni [8] investigated melting heat transfer inside a porous cavity under the effect of Lorentz forces. Hayat et al. [9] illustrated the melting of the plate in stagnation point flow. Sheikholeslami et al. [10] utilized CVFEM for ferrofluid thermal radiation inside a semi annulus cavity.

Wavy duct in existence of Brownian forces was examined by Shehzad et al. [11]. Sheikholeslami and Ganji [12] illustrated different uses of nanotechnology in their article paper. Sheikholeslami et al. [13] employed Buongiorno model for magnetic nanofluid forced convection heat transfer in existence of non- uniform magnetic field. Sheikholeslami et al. [14] presented MHD forced convection of nanofluid in an annulus. Chamkha and Rashad [15] reported the nanoparticle migration on porous cone. Bhanvase et al. [16] presented ethylene glycol based nanofluid convective heat transfer. They utilized TiO_2 nanopartilces. Sheikholeslami and Rashidi [17] investigated ferrofluid behavior in existence of magnetic field. Kandelousi [18] utilized the KKL model for nanofluid modeling in a porous channel. Sheikholeslami and Shehzad [19] utilized heat flux boundary condition for MHD nanofluid flow in a porous enclosure. Gurav et al. [20] presented the heat transfer improvement of polyaniline based nanofluid. They reported various applications of such nanofluid. Sheikholeslami et al. [21] reported the laminar nanofluid flow between two plates by means of two phase model. Srinivas and Vinod [22] investigated application of nanofluid in a heat exchanger. Sheikholeslami and Shamlooei [23] presented the effect of external magnetic source on nanofluid treatment in a porous cavity. Various uses of nanofluids were presented by different authors [24–61].

In this article, laminar nanofluid heat and mass transfer between two contracting and rotating plates is presented. Buongiorno model is selected in the simulation of the nanofluid. The impact of active parameter on hydrothermal behavior has been presented.

2. Problem definition

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

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Nomenclature

B_0	Magnetic induction [tesla]
D_B	Diffusion coefficient
Ec	Eckert number
Ha	Hartmann number
T_0	Initial temperature
T_m	Melting temperature
Nt	Thermophoretic parameter
Nb	Brownian motion parameter
Sc	Schmidt number
c_s	Surface heat capacity
Pr	Prandtl number
T	Fluid temperature [K]
v,u	Y and x directions velocity [m/s^2]

Greek symbols

η	Similarity independent variable
ϕ	Volume fraction of nanofluid
	Dynamic viscosity
α	Thermal diffusivity [m^2/s]
σ	Electrical conductivity
δ	Melting parameter

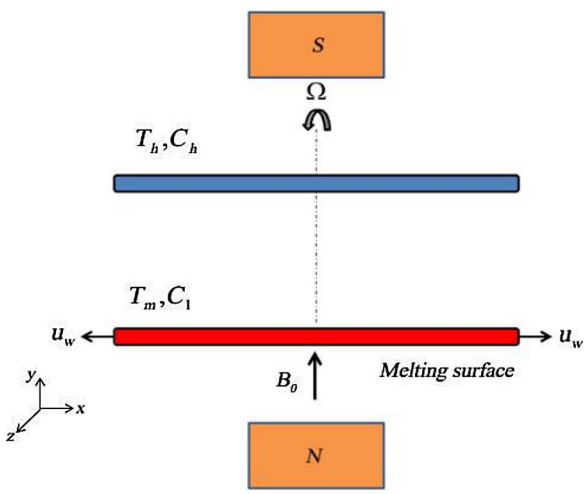

Fig. 1. Geometry of the problem.

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 [62]:

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

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

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

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

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{(\rho c_P)_p}{(\rho c_P)_f}\left[\begin{array}{l} D_B\left\{\frac{\partial C}{\partial x}.\frac{\partial T}{\partial x} + \frac{\partial C}{\partial y}.\frac{\partial T}{\partial y} + \frac{\partial C}{\partial z}.\frac{\partial T}{\partial z}\right\} \\ +(D_T/T_c)\left\{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2\right\}\end{array}\right], \tag{5}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = D_B\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right) + \left(\frac{D_T}{T_0}\right)\left\{\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right\} \tag{6}$$

Here u, v and z are the velocities in the x, y and z directions respectively, T is the temperature, C is the concentration, $\rho_f$is the base fluid's density, μ is the dynamic viscosity, k is the thermal conductivity, $c_P$is the specific heat of nanofluid, $D_B$is the diffusion coefficient of the diffusing species. Also p^* is the modified fluid pressure. The absence of $\frac{\partial p^*}{\partial z}$in Eq. (4) implies that there is a net cross-flow along the z-axis. The relevant boundary conditions are:

$$\begin{aligned} u = ax,\ k\left(\frac{\partial T}{\partial y}\right)\Big|_{y=0} &= \rho_f(L + c_s(T_m - T_0))v,\ w = 0,\ T \quad at\ \ y = 0 \\ = T_m,\ C = C_0 & \\ u = 0,\ v = 0,\ w = 0,\ T = T_h,\ C = C_h & \qquad at\ \ y = +h \end{aligned} \tag{7}$$

L is the non-uniform latent heat of the fluid and c_s is the heat capacity of the solid surface. The boundary condition (8) shows that the heat conducted to the melting surface is equal to the heat of melting plus the sensible heat required raising the solid temperature T_0 to its melting temperature T_m. ([63])

The following non-dimensional variables are introduced:

$$\begin{aligned} &\eta = \tfrac{y}{h}, \qquad u = axf'(\eta), \qquad v = -ahf(\eta),\ \ w = ax\,g(\eta) \\ &\theta(\eta) = \tfrac{T - T_m}{T_m - T_0},\ \ \phi(\eta) = \tfrac{C - C_0}{C_h - C_0} \end{aligned} \tag{8}$$

where a prime denotes differentiation with respect to η.

Substituting (7) in Eqs. (1)–(4), we have:

$$-\frac{1}{\rho h}\frac{\partial p^*}{\partial \eta} = a^2x\,[f' - ff'' - \frac{f'''}{R} + \frac{M}{R} + \frac{2Kr}{R}g], \tag{9}$$

$$-\frac{1}{\rho h}\frac{\partial p^*}{\partial \eta} = a^2\,h\,[ff' + \frac{1}{R}f''], \tag{10}$$

$$g'' - R(f'g - fg') + 2\,Kr\,f' - Mg = 0 \tag{11}$$

and the non-dimensional quantities are defined through in which R is the viscosity parameter, M is the magnetic parameter, and K_r is the rotation parameter.

$$R = \frac{ah^2}{\upsilon},\ \ M = \frac{\sigma\,B_0{}^2\,h^2}{\rho\upsilon},\ \ Kr = \frac{\Omega h^2}{\upsilon} \tag{12}$$

Eq. (7) with the help of (8) can be written as:

$$f''' - R[f'^2 - ff''] - 2Kr^2g - M^2f' = A \tag{13}$$

Differentiation of Eq. (11) with respect to η gives:

$$f^{iv} - R(f'f'' - ff'') - 2\,Kr\,g' - M\,f'' = 0 \tag{14}$$

Therefore, the governing equations and boundary conditions for this case in non-dimensional form are given by:

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