Available online at www.sciencedirect.com

ScienceDirect

Journal of Computational Design and Engineering 3 (2016) 330–336

www.elsevier.com/locate/jcde

Heat and mass transfer of a second grade magnetohydrodynamic fluid over a convectively heated stretching sheet

Kalidas Das[a,*], Ram Prakash Sharma[b], Amit Sarkar[c]

[a]Department of Mathematics, A.B.N. Seal College, Cooch Behar 736101, W.B., India
[b]Department of Mathematics, JECRC University, Jaipur 303905, Rajasthan, India
[c]Ramnagar High School, Nadia 741502, W.B., India

Received 17 March 2016; received in revised form 12 June 2016; accepted 16 June 2016
Available online 22 June 2016

Abstract

The present work is concerned with heat and mass transfer of an electrically conducting second grade MHD fluid past a semi-infinite stretching sheet with convective surface heat flux. The analysis accounts for thermophoresis and thermal radiation. A similarity transformations is used to reduce the governing equations into a dimensionless form. The local similarity equations are derived and solved using Nachtsheim-Swigert shooting iteration technique together with Runge–Kutta sixth order integration scheme. Results for various flow characteristics are presented through graphs and tables delineating the effect of various parameters characterizing the flow. Our analysis explores that the rate of heat transfer enhances with increasing the values of the surface convection parameter. Also the fluid velocity and temperature in the boundary layer region rise significantly for increasing the values of thermal radiation parameter.

Keywords: Thermophoresis; Thermal radiation; Convective boundary condition; Second grade fluid

1. Introduction

The study of heat and mass transfer of non-Newtonian fluid has been increased due to their applications in many branches of science and engineering, such as metallurgical process, polymer extrusion, glass blowing, crystal growing and so on. The boundary layer flow of a non-Newtonian viscous fluid has drawn the attention of many researchers [1–5]. Pal and Mondal [6] discussed MHD non-Darcian mixed convection heat and mass transfer over a non-linear stretching sheet. Heat and mass transfer past a stretching surface in a MHD micropolar fluid through a porous medium was studied by Pal and Chatterjee [7]. Pal and Mondal [8] extended their work [6] by considering Soret and Dufour effects on MHD non-Darcian in presence of non-uniform heat source/sink. Kandelousi [9] investigated the effect of spatially variable magnetic field on ferrofluid flow. Sheikholeslami et al. [10] discussed the impact of non-uniform magnetic field on forced convection heat transfer of Fe_3O_4–water nanofluid. Sheikholeslami and Rashidi [11] developed the work of Sheikholeslami et al. [10] by considering the space dependent magnetic field. Effect of electric field on hydro-thermal behavior of nanofluid in a complex geometry was investigated by Sheikholeslami et al. [12]. Sheikholeslami et al. [13] worked on forced convection heat transfer in a semi annulus under the influence of a variable magnetic field.

MHD flow problem in presence thermal radiation has become more important in industry at high temperature. So the knowledge of the radiation heat transfer becomes very important. Cogley et al. [14] observed that in the optically thin limit the fluid does not absorb its own emitted radiation but absorb radiation emitted by the boundaries. The effect of thermal radiation on heat transfer problems have studied by Makinde [15], Ibrahim et al. [16] Pal and Chatterjee [17], Olajuwon [18] and Zheng et al. [19]. Pal and

*Corresponding author.
E-mail addresses: kd.kgec@gmail.com (K. Das), ramprakash0808@gmail.com (R.P. Sharma), amitfor.math@gmail.com (A. Sarkar).
Peer review under responsibility of Society of CAD/CAM Engineers.

http://dx.doi.org/10.1016/j.jcde.2016.06.001

Mondal [20] examined the effect of chemical reaction and thermal radiation on mixed convection heat and mass transfer over a stretching sheet in Darcian porous medium. Sheikholeslami et al. [21] examined numerically MHD free convection of Al_2O_3–water nanofluid in presence of thermal radiation. Ferrofluid flow and heat transfer in a semi annulus enclosure in the presence of thermal radiation was studied by Sheikholeslami et al. [22]. Sheikholeslami et al. [23] considered the effect of thermal radiation on two phase model of nanofluid flow and heat transfer.

Thermophoresis, a physical phenomenon in which aerosol particles move from hot surface to cold surface, has attracted considerable attention for collection of sub-micrometer and nanometer particles. The force experienced by the suspended particles due to the temperature gradient is termed as thermophoretic force which is used in commercial precipitators. In this occurrence, the repulsion of particles from hot objects takes place and so a layer is obtained around hot bodies which is particle free (Goldsmith and May [24]). This phenomenon has many applications: to remove small particles from gas particle trajectories from combustion devices and to study the particulate material deposition turbine blades. The effect of thermophoresis particle deposition on boundary layer flow under different situation was discussed by many researchers (Selim et al. [25], Chamkha and Pop [26], Chamkha et al. [27] , Zucco et al. [28]). Pal and Mondal [29] discussed the effect of thermophoresis on magnetohydrodynamic heat and mass transfer over a non-Isothermal wedge. KKL correlation for simulation of nanofluid flow and heat transfer in a permeable channel was examined by Sheikholeslam [30]. Sheikholeslami and Ganji [31] studied nanofluid flow and heat transfer between parallel plates using DTM.

In the study of boundary layer flow problems, the boundary conditions are either a specified surface temperature or a specified surface heat flux [32]. But there are many problems in which surface heat transfer depends on the surface temperature. Newtonian heating arises in the situation where the heat is supplied to the convective fluid through a bounding surface with a finite heat capacity. Recently, boundary layer heat transfer problems concerning with a convective boundary condition were investigated by Makinde and Aziz [33], Ishak [34] and Rahman [35]. Recently Das [36] studied the effect of chemical reaction on MHD mixed convection second grade fluid flow passing through a semi-infinite stretching sheet.

Motivated by the above investigations present paper deals with the second grade fluid flow passing through a semi-infinite stretching sheet with convective surface heat flux. The impact of thermophoresis and thermal radiation on heat and mass transfer are included in the present model. The Nachtsheim and Swigert shooting iteration technique together with Runge-Kutta sixth-order integration scheme is used to solve the problem numerically.

2. Mathematical formulation of the problem

Consider the steady boundary layer flow of an incompressible and electrically conducting second grade fluid over a stretching sheet coinciding with the plane $y=0$ and the flow being confined to $y>0$ in the presence of viscous dissipation and joule heating as depicted in Fig. 1. The flow is generated, due to the stretching of the sheet caused by the simultaneous action of two equal and opposite forces along the x-axis. The sheet is then stretched with a velocity $u_w(x)=ax$, where a is a constant and x is the coordinate measured along the stretching surface from the slit. The thermal radiation is taking place in the flow and the effect of thermophoresis is being taken into account to help in understanding of the mass deposition variation on the surface. A uniform transverse magnetic field of strength B_0 is applied parallel to the y-axis. The applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and the Hall effect are negligible. It is assumed that there is no applied voltage which implies the absence of an electric field. The stretching surface is maintained at constant temperature T_w higher than the constant temperature T_∞ of the ambient fluid. Due to the boundary layer behavior the temperature gradient along y-direction is much more than that along x-direction and hence only the thermophoretic velocity component which is normal to the surface is of importance.

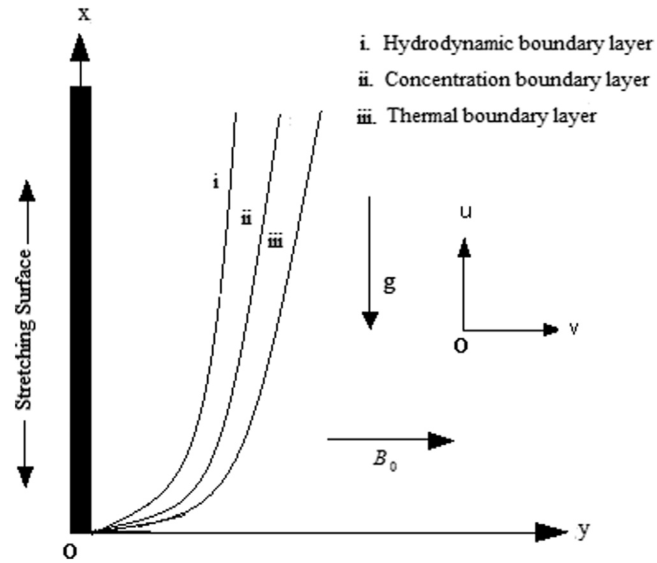

Fig. 1. Physical model and coordinate system.

Under these assumptions, the governing boundary layer equations for a second grade fluid flow can be written as [18,36]

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+\frac{\alpha_1}{\rho}\left[\frac{\partial}{\partial x}\left(u\frac{\partial^2 u}{\partial y^2}\right)-\frac{\partial u}{\partial y}\frac{\partial^2 u}{\partial x\partial y}+v\frac{\partial^3 u}{\partial y^3}\right]$$
$$-\frac{\sigma B_0^2 u}{\rho}+g\beta(T-T_\infty)+g\beta^*(C-C_\infty), \tag{2}$$

$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\kappa\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y}+\mu\left(\frac{\partial u}{\partial y}\right)^2$$
$$+\alpha_1\frac{\partial u}{\partial y}\left[\frac{\partial}{\partial y}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)\right]+\sigma {B_0}^2u^2, \tag{3}$$