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Dufour and Soret Effects on Steady MHD free convection and Mass Transfer flow past a vertical porous plate in a porous medium

KEYWORDS: Free convection, MHD, vertical plate

M. N. Raja Shekar

Department of Mathematics, JNTUH CEJ, Nachupally, Karimnagar – 505501

ABSTRACT *The effects of Dufour and Soret on a steady two dimensional MHD free convection flow past a semi-infinite vertical porous plate embedded in a porous medium have been studied numerically. The governing non-linear partial differential equations are dimensionless form and transformed by a similarity transformation into a system of ordinary differential equations. The resulting non-linear coupled equations are solved under appropriate transformed boundary conditions using the Crank-Nicolson method. The dimensionless velocity, temperature and concentration profiles are displayed graphically showing the effects for the different values of the involved parameters of the problem.*

Introduction

The study of Magnetohydrodynamic (MHD) flows have stimulated extensive attention due to its significant applications in three different subject areas, such as astrophysical, geophysical and engineering problems. Free convection in electrically conducting fluids through an external magnetic field has been a subject of considerable research interest of a large number of scholars for a long time due to its diverse applications in the fields such as nuclear reactors, geothermal engineering, liquid metals and plasma flows, among others. Fluid flow control under magnetic forces is also applicable in magnetohydrodynamic generators and a host of magnetic devices used in industries. Steady and transient free convection of an electrically conducting fluid from a vertical plate in the presence of magnetic field was studied by Gupta[1]. Lykoudis[2] investigated natural convection of an electrically conducting fluid with a magnetic field. Takhar et al.[3] computed flow and mass transfer on a stretching sheet under the consideration of magnetic field and chemically reactive species. They focused that the energy flux can be produced by both of the temperature gradient and concentration gradient. The energy flux caused by concentration gradient is called Dufour effect and the same by temperature gradient is called the Soret effect. These effects have a vital role in the high temperature and high concentration gradient. The significant Soret effects in convective transport in clear fluids have been found in the work of Bergaman and Srinivasan[4] and Zimmerman et al.[5]. The effect of magnetic field on heat and mass transfer from vertical surfaces in porous media considering Soret and Dufour effects have been performed by Postelnicu[6]. Alam et al.[7] analyzed the Dufour and Soret effects on steady MHD combined free forced convective and mass transfer flow past a semi-infinite vertical plate. Jha et al.[8] included Soret effects free convection and mass transfer flow in the Stokes problem for an infinite vertical plate. An analysis of the steady two-dimensional flow of an incompressible viscous and electrically conducting fluid over a non-linearly semi-infinite stretching sheet in the presence of a chemical reaction and under the influence of a magnetic field have been carried out by Raptis and Perdikis[9]. Acharya et al.[10] studied heat and mass transfer over an accelerating surface with heat source in the presence of suction and blowing. Anghel et al.[11] investigated the Dufour and Soret effects on free convection boundary layer over a vertical surface embedded in a porous medium. Mohammadein et al.[12] found the result of heat transfer in a micropolar fluid over a stretching sheet with viscous dissipation and internal heat generation. Helmy[13] presented the effects of the magnetic field on a non-Newtonian conducting fluid past a stretching plate. The goal of the present work is to investigate the effects of Dufour number and Soret number in the presence of magnetic field for MHD free convection flow and mass transfer along a stretching sheet. However, the interaction of Soret and Dufour effects on steady MHD free convection flow in a porous medium has received a little attention. Hence, the object of the present problem is to analyze the Soret and Dufour effects on steady MHD free convection boundary layer flow past a semi-infinite moving vertical plate embedded in a porous medium. The governing equations are transformed by similarity transformation and the resultant dimensionless equations are solved numerically using the Crank-Nicolson method. The effects of various governing parameters on the velocity, temperature, concentration are shown in figures and analyzed in details.

Flow Analysis

A steady two dimensional flow of an incompressible and electrically conducting viscous fluid, along a semi infinite vertical porous flat plate embedded in a porous medium is considered. The x- axis is taken on the infinite plate, and parallel to the free-steam velocity which is vertical and the y-axis is taken normal to the plate. A magnetic field β_0 of uniform strength is applied transversely to the direction of the flow. Initially the plate and the fluid are at same temperature T_∞ in stationary condition with concentration level C_∞ at all points. For t>0, the plate starts moving impulsively in its own plane with a velocity U_0, its temperature is raised to T_w and the concentration level at the plate is raised to C_w.

The flow is assumed to have constant properties except that the influence the density variations with temperature and concentration, which are considered only in the body force term. Under the above assumptions, the physical variables and functions of ψ and τ only. Assuming that the Boussinesq and boundary-layer approximation hold and using the Darcy-Forchheimer model, the basic equation which govern the problem are given by

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad \text{......1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y} = v\frac{\partial^2 v}{\partial y^2} + g\beta(T - T\infty) + g\beta^*(C - C\infty) - \frac{u}{k} \qquad \text{...2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2} \qquad \text{.....3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = Dm\frac{\partial^2 C}{\partial y^2} + \frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2} \qquad \text{.......4}$$

The appropriate boundary conditions for the above problem are as follows

$$\left.\begin{array}{l} u=0,\ v=0,\ T=T_w,\ C=C_w, \quad at \quad y=0 \\ u\to 0,\ T\to T_\infty,\ C\to C_\infty, \quad at \quad y\to\infty \end{array}\right\} \qquad \text{.....5}$$

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We now introduce the following dimensionless variables:

$$\left.\begin{aligned} \eta &= y\sqrt{\frac{U_\infty}{\nu x}} \\ \psi &= \sqrt{\nu x U_\infty}\, f(\eta) \\ \theta(\eta) &= \frac{T-T_\infty}{T_w-T_\infty} \\ \phi(\eta) &= \frac{C-C_\infty}{C_w-C_\infty} \end{aligned}\right\} \qquad \ldots\ldots.6$$

From the continuity equation (1), we have

$$\frac{\partial v}{\partial y} = -\frac{\partial u}{\partial x} \qquad \ldots\ldots.7$$

Integrating both sides of (7) with respect to y, we get

$$v = -\frac{1}{2}\sqrt{\frac{U_\infty \upsilon}{x}}\,\left[f(\eta)-\eta f'(\eta)\right] \qquad \ldots\ldots.8$$

Introducing the relations (6) and (8) into the equations (2) – (4), we get the following dimensionless equations which are locally similar:

$$f''' + \frac{1}{2} ff'' + g_t\theta + g_c\phi - \frac{1}{Da\mathrm{Re}^2} f' = 0 \ldots\ldots 9$$

$$\theta'' + \frac{1}{2}\Pr f\theta' + \Pr D\phi'' = 0 \qquad \ldots\ldots 10$$

$$\phi'' + \frac{1}{2} Scf\phi' + ScSr\theta'' = 0 \qquad \ldots\ldots 11$$

The relevant boundary conditions in dimensionless form are:

$$\left.\begin{aligned} &f=f_w,\ f'=1,\ \theta=1,\ \phi=1 \quad at \quad \eta=0 \\ &f'=0,\ \theta=0,\ \phi=0 \quad as \quad \eta\to\infty \end{aligned}\right\} \qquad \ldots\ldots 12$$

where primes denote differentiation with respect to the variable η and the dimensionless parameters introduced in the above equations are defined as follows:

Pr = $\frac{\upsilon}{\alpha}$ is the Prandtl number, Sc = $\frac{\upsilon}{D_m}$ is the Schmidt number, $\mathrm{Re}_x = \frac{U_\infty x}{\upsilon}$ is the local Reynolds number, M = $\frac{\sigma B_0^2 x}{\rho U_\infty}$ is the Magnetic field parameter, Sr = $\frac{D_m k_T}{T_m \upsilon}\frac{(T_w-T_\infty)}{(C_w-C_\infty)}$ is the Soret number, D = $\frac{D_m k_T}{c_s c_p \upsilon}\frac{(C_w-C_\infty)}{(T_w-T_\infty)}$ is the Dufour number, Da = $\frac{k}{x^2}$ is the local Darcy number, $Gr_t = \frac{g\beta(T_w-T_\infty)x^3}{\upsilon^2}$ is the local temperature Grashof number, $Gr_m = \frac{g\beta^*(C_w-C_\infty)x^3}{\upsilon^2}$ is the local mass Grashof number, $g_t = \frac{Gr_t}{\mathrm{Re}_x^2}$ is the temperature buoyancy parameter and $g_c = \frac{Gr_m}{\mathrm{Re}_x^2}$ is the mass buoyancy parameter, $f_w = -\left[\frac{2x\,v_0(x)}{\upsilon}\right]\mathrm{Re}_x^{-\frac{1}{2}}$ is the suction velocity.

Solution of the Problem

The set of coupled non-linear governing boundary layer equations (9) – (11) together with the boundary conditions (12) are solved numerically by using finite-difference technique. First of all higher order non-differential equations (9) – (11) are converted into simultaneous linear equations and the resultant equations are solved by Guass-Seidel iterative method using C- Program. The step size Δη = 0.05 is used to obtain the numerical solution with five decimal place accuracy as the criterion of convergence.

Result and Discussion

As a result of the numerical calculations, the dimensionless velocity, temperature and concentration distributions for the flow under consideration are obtained and their behavior have been discussed for variations in the governing parameters .

The effects of suction parameter on the velocity field are shown in Fig. 1. It is seen from this figure that the velocity profiles decrease monotonically with an increase of suction parameter indicating the usual fact that suction stabilizes the boundary layer growth. The effect of Soret and Dufour numbers on the velocity field are shown in Fig.2. We observe that quantitatively when η = 1.5 and Sr decreases from 1.6 to 1.2 there is 6.25% decrease in the velocity value, whereas the corresponding decrease is 5.87%, when Sr decreases from 0.8 to 0.4.

The effect of suction parameter on the temperature is displayed in Fig.3. From this figure we see that the temperature decreases with an increase of suction parameter. The effects of Soret and Durour numbers on the temperature field are shown in Fig.4. We observe that quantitatively when η = 0.80 and Sr decreases from 1.6 to 1.2 there is 27.56% increase in the temperature value, whereas the corresponding decrease is 23%, when Sr decreases from 0.8 to 0.4.

The effect of suction parameter on the temperature is displayed in Fig.5. From this figure we see that the temperature decreases with an increase of suction parameter. The effects of Soret and Durour numbers on the temperature field are shown in Fig.6. We observe that quantitatively when η = 1.0 and Sr decreases from 1.6 to 1.2 there is 7.64% decrease in the concentration value, whereas the corresponding decrease is 8.90%, when Sr decreases from 0.8 to 0.4.

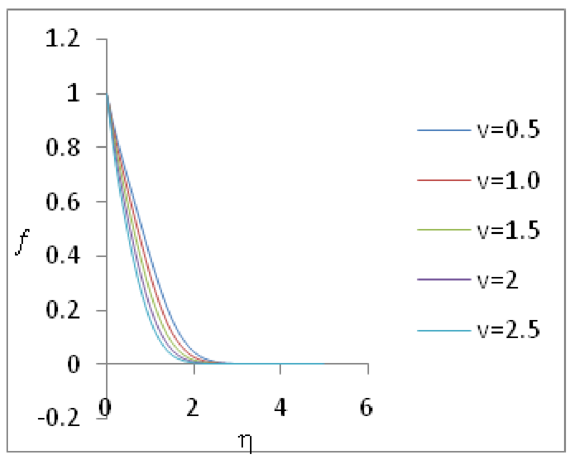

Fig.1 Velocity Profiles for different of v

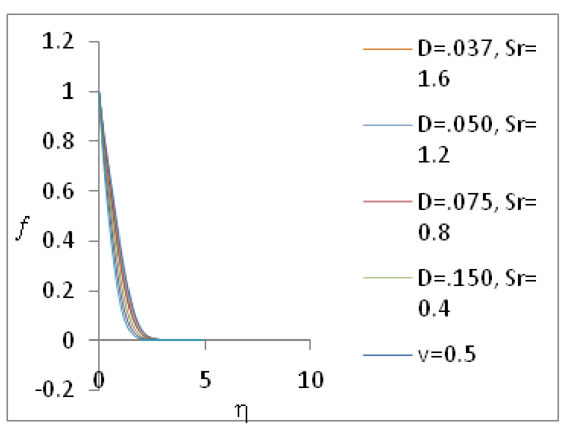

Fig. 2 Velocity profiles for different D and Sr.

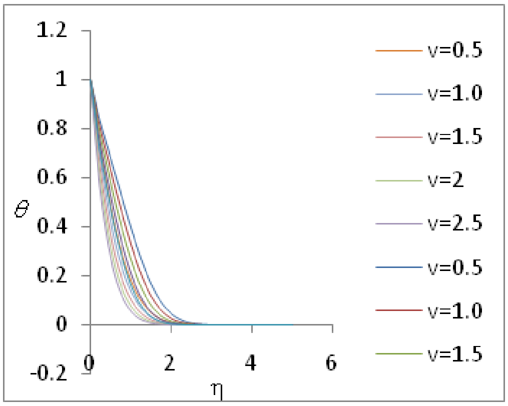

Fig.3 Temperature profiles for different of v

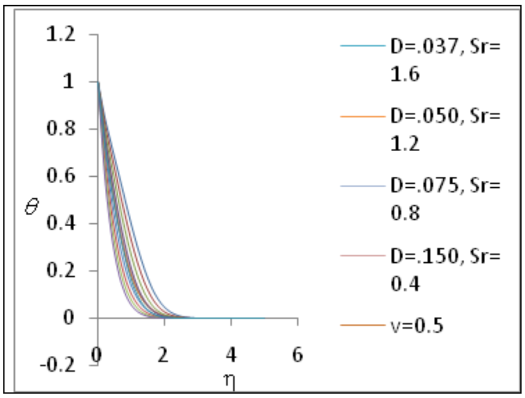

Fig. 4 Temperature profiles for different D and Sr.

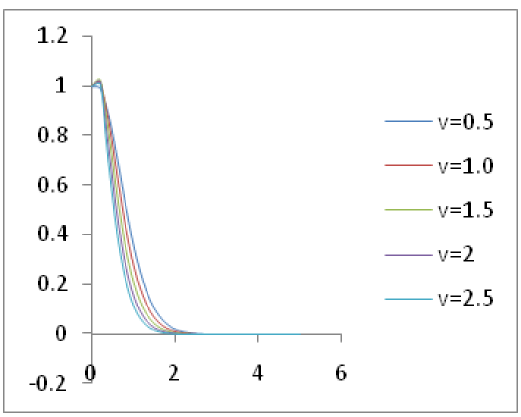

Fig.3 Concentration profiles for different of v

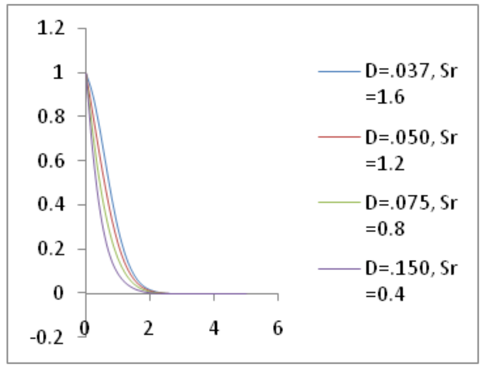

Fig. 4 Concentration profiles for different D and Sr.

Conclusions

In this paper we have studied numerically the Dufour and Soret effects on an on steady MHD free convection and mass transfer flow past a vertical porous plate in a porous medium. From the present numerical study the following conclusion can be drawn.

- Velocity profiles increase with the increase of Darcy number.
- Magnetic field retards the motion of the fluid.
- Suction stabilizes the hydrodynamic, thermal as well as concentration boundary layers growth.

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