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Soret and Dufour Effects on Mhd Heat And Mass Transfer Flow Over A Moving Non-Isothermal Vertical Plate With Thermal Stratification And Viscous Dissipation

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ABSTRACT

This paper analyses the Soret and Dufour effects on hydro magnetic mixed convection flow over a vertical semi-infinite plate with a convective surface boundary condition by taking viscous dissipation into account. The governing boundary layer equations have been transformed to a two-point boundary value problem in similarity variables and the resultant problem is solved numerically using the Runge-Kutta method with shooting technique. The effects of various governing parameters on the fluid velocity, temperature, concentration, skin-friction coefficient, Nusselt number and Sherwood number are shown in figures and tables and analyzed in detail.

Keywords: MHD, Soret and Dufour effects, Viscous Dissipation, vertical semi-infinite plate

1. INTRODUCTION

Magneto-hydrodynamic (MHD) boundary layers with heat and mass transfer over flat surfaces are found in a many engineering and geophysical applications such as geothermal reservoirs, thermal insulation, enhanced oil recovery, packed-bed catalytic reactors, cooling of nuclear reactors. Many chemical engineering processes like metallurgical and polymer extrusion processes involve cooling of a molten liquid being stretched into a cooling system; the fluid mechanical properties of the penultimate product depend mainly on the cooling liquid used and the rate of stretching. Some polymer fluids like Polyethylene oxide and polyisobutylene solution in cetane, having better electromagnetic properties, are normally used as cooling liquid as their flow can be regulated by external magnetic fields in order to improve the quality of the final product. A comprehensive review on the subject of the above problem has been made by many researchers (Yang et al., [1]; Trevisan and Bejan, [2]; Sparrow et al., [3]; Evans, [4]). The similarity solutions for hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through porous media as explained by Chamkha and Khaled [5].

In the context of space technology and in the processes involving high temperatures, the effects of radiation are of vital importance. Recent developments in hypersonic flights, missile re-entry, rocket combustion chambers, power plants for inter planetary flight and gas cooled nuclear reactors, have focused attention on thermal radiation as a mode of energy transfer, and emphasized the need for improved understanding of radiative transfer in these processes. Cess [6] presented radiation effects on the boundary

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layer flow of an absorbing fluid past a vertical plate, by using the Rosseland diffusion model. Makinde [7] carried out a numerical study on the effect of thermal radiation on boundary layer flow with heat and mass transfer past a moving vertical porous plate. Seddeek[8]studied the thermal radiation and buoyancy effects on MHD free convection heat generation flow over an accelerating permeable surface with temperature dependent viscosity. The effect of thermal radiation on heat and mass transfer flow of a variable viscosity fluid past a vertical porous plate permeated by a transverse magnetic field was reported in Makinde and Ogulu [9]. Recently Aziz [10] reported a similarity solution for laminar thermal boundary layer over a flat plate with a convective surface boundary condition.

In all these studies Soret / Dufour effects are assumed to be negligible. Such effects are significant when density differences exist in the flow regime. For example when species are introduced at a surface in fluid domain, with different (lower) density than the surrounding fluid, both Soret and Dufour effects can be significant. Also, when heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and the driving potentials are of more intricate nature. It has been found that an energy flux can be generated not only by temperature gradients but by composition gradients as well. The energy flux caused by a composition gradient is called the Dufour or diffusion-thermo effect. On the other hand, mass fluxes can also be created by temperature gradients and this is called the Soret or thermal-diffusion effect. The thermal-diffusion (Soret) effect, for instance, has been utilized for isotope separation, and in mixture between gases with very light molecular weight (H2, He) and of medium molecular weight (N2, air), the diffusion-thermo (Dufour) effect was found to be of a considerable magnitude such that it can not be ignored (Eckert and Drake [11]). In view of the importance of these above mentioned effects, Dursunkaya and Worek [12] studied diffusion-thermo and thermal-diffusion effects in transient and steady natural convection from a vertical surface, whereas Kafoussias and Williams [13] presented the same effects on mixed free-forced convective and mass transfer boundary layer flow with temperature dependent viscosity. Anghel et al. [14] investigated the Dufour and Soret effects on free convection boundary layer flow over a vertical surface embedded in a porous medium. Postelnicu [15] numerically studied the influence of magnetic field on heat and mass transfer by natural convection from vertical surfaces in porous media by considering the Soret and Dufour effects.

The problem of natural convection along a vertical isothermal or uniform flux plate is a classical problem. Gebhart [16] was the first who studied the problem taking into account the viscous dissipation. Copiello and Fabbri [17]studied the effect of viscous dissipation on the heat transfer in sinusoidal profile finned dissipaters; Alam *et al.* [18] considered the effect of viscous dissipation in natural convection over a sphere. Pantokratoras [19] studied the effect of viscous dissipation in natural convection in a new way. Ahmed and Liu [20] analyzed the effects of mixed convection and mass transfer of three-dimensional oscillatory flow of a viscous incompressible fluid past an infinite vertical porous plate in presence of transverse sinusoidal suction velocity oscillating with time and a constant free stream velocity. Recently, Tania et al [21] considered the effects of Radiation, Heat Generation and Viscous Dissipation on MHD Free Convection Flow along a Stretching Sheet. Gnaneswara Reddy and Bhaskar Reddy [22] reported a Soret and Dufour effects on steady MHD free convection flow past a semi-infinite moving vertical plate in a porous medium with viscous dissipation.

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The object of the present chapter is to analyze the Soret and Dufour effects on hydro magnetic mixed convection flow over a vertical semi-infinite plate with a convective surface boundary condition by taking viscous dissipation into account. The governing boundary layer equations have been transformed to a two-point boundary value problem in similarity variables and the resultant problem is solved numerically using the Runge-Kutta method with shooting technique. The effects of various governing parameters on the fluid velocity, temperature, concentration, skin-friction coefficient, Nusselt number and Sherwood number are shown in figures and tables and analyzed in detail.

2. MATHEMATICAL ANALYSIS

A steady two-dimensional laminar mixed convection flow of a viscous incompressible fluid along a vertical semi-infinite plate is considered. The fluid is assumed to be Newtonian, electrically conducting and its property variations due to temperature and chemical species concentration are limited to fluid density. The density variation and the effects of the buoyancy are taken into account in the momentum equation (Boussinesq's approximation). The x-axis is taken along the plate in the upward direction and the y-axis is taken normal to it. A uniform magnetic field is applied in the direction perpendicular to the plate. The transverse applied magnetic field and magnetic Reynolds number are assumed to be very small, so that the induced magnetic field and Hall effects are negligible. Now, under the above assumptions, the governing boundary layer equations of the flow field are

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}(u-U_\infty)+g\beta_T(T-T_\infty)+g\beta_c(C-C_\infty) \qquad (2)$$

Energy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2}+\frac{\nu}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 \qquad (3)$$

Species equation

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

The boundary conditions for the velocity, temperature and concentration fields are

$$u=v=0,\ -\kappa\frac{\partial T}{\partial y}=h[T-T_w],\ C_w=Ax^\lambda+C_\infty \quad \text{at} \quad y=0$$

$$u=U_\infty, T=T_\infty, C=C_\infty \quad \text{as} \quad y\to 0 \qquad (5)$$

where u, v, T and C are the fluid x-component of velocity, y-component of velocity, temperature and concentration respectively, ν is the fluid kinematics viscosity, ρ - the density, σ - the electric conductivity of the fluid, β_T and β_c - the coefficients of thermal and concentration expansions respectively, k - the thermal conductivity, C_∞ - the free stream concentration, B_0 - the magnetic induction, , U_∞ - t the free stream velocity , *D*- the mass diffusivity and g is the gravitational acceleration, h is the plate heat transfer coefficient, L is the plate characteristic length, T_w is the temperature of the plate, C_w is the species concentration at the plate, λ is the plate concentration exponent and κ is the thermal conductivity coefficient.

The mass concentration equation (1) is satisfied by the Cauchy-Riemann equations

$$u=\frac{\partial\psi}{\partial y}, v=-\frac{\partial\psi}{\partial x}. \qquad (6)$$

Where $\psi(x,y)$ is the stream function.

To transform equations (2) - (4) into a set of ordinary differential equations, the following similarity transformations and dimensionless variables are introduced.

$$\eta = y\sqrt{\frac{U_\infty}{\upsilon x}}, \quad \psi = \sqrt{\upsilon x U_\infty}\, f(\eta),$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \; \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty},$$

$$Ha = \frac{\sigma B_0^2 x}{\rho U_\infty}, \qquad Gr = \frac{g\beta_T (T_w - T_\infty)x}{U_\infty{}^2},$$

$$Gc = \frac{g\beta_c (C_w - C_\infty)x}{U_\infty^2}, \; Du = \frac{D_m k_T (C_w - C_\infty)}{c_s c_p (T_w - T_\infty)},$$

$$Sr = \frac{D_m k_T (T_w - T_\infty)}{\nu T_m (C_w - C_\infty)}, \qquad Ec = \frac{U_\infty^2}{c_p (T_w - T_\infty)},$$

$$Bi = \frac{h}{k}\sqrt{\frac{\upsilon x}{U_\infty}}, \; \Pr = \frac{\upsilon}{\alpha}, \; Sc = \frac{\upsilon}{D_m}. \qquad (7)$$

where η - similarity variable, f - dimensionless stream function, θ - dimensionless temperature, ϕ - dimensionless concentration, Ha - the Magnetic field parameter, Gr -the thermal Grashof number, Gc -the solutal Grashof number, Du -he Dufour number, Sr - the Soret number, Ec -the Eckert number, Bi -the convective heat transfer parameter, $\Pr$ -the Prandtl number and Sc -the Schmidt number.

In view of equations (6) and (7), equations (2) to (4) transform into

$$f''' + \frac{1}{2} ff'' - Ha(f' - 1) + Gr\,\theta + Gc\,\phi = 0 \qquad (8)$$

$$\theta'' + \frac{1}{2}\Pr f\theta' + \frac{1}{2}\Pr Du\phi'' + \frac{1}{2}\Pr Ecf''^2 = 0 \qquad (9)$$

$$\phi'' + \frac{1}{2} Scf\phi' + \frac{1}{2} ScSr\theta'' = 0 \qquad (10)$$

The corresponding boundary conditions are

$$f = 0, \; f' = 0, \theta' = Bi\,[\theta - 1], \phi = 1 \text{ at } \; y = 0$$

$$f' = 1, \theta = \phi = 0. \quad \text{as} \quad y = 0 \qquad (11)$$

where the prime symbol represents the derivative with respect to η.

It is noteworthy that the local parameters Bi, Ha, Gr and Gc in equations (8) - (9) are functions of x. However, in order to have a similarity solution all the parameters Bi, Ha, Gr, Gc, Du, Sr, Ec must be constant and we therefore assume

$$h = cx^{-\frac{1}{2}}, \sigma = ax^{-1}, \beta_T = bx^{-1} \text{ and } \beta_c = dx^{-1} \qquad (12)$$

where a, b, c, d are constants

Other physical quantities of interest for the problem of this type are the skin friction parameter $C_f = 2(\mathrm{Re})^{-\frac{1}{2}} f''(0)$, the plate surface temperature $\theta(0)$, Nusselt number $Nu = -(\mathrm{Re})^{\frac{1}{2}}\theta'(0)$ and the Sherwood number $Sh = -(\mathrm{Re})^{\frac{1}{2}}\phi'(0)$ (where Re = $\frac{Ut}{\nu}$ is the Reynolds number). For local similarity case, integration over the entire plate is necessary to obtain the total skin friction, total heat and mass transfer rates.

3. SOLUTION OF THE PROBLEM

The set of coupled non-linear governing boundary layer equations (8) - (10) together with the boundary conditions (11) are solved numerically by using Runge-Kutta fourth order technique along with shooting method. First of all, higher order non-linear differential Equations (8) - (10) are converted into simultaneous linear differential equations of first order and they are further transformed into initial value problem by applying the shooting technique (Jain *et al*[23]). The resultant initial value problem is solved by employing Runge-Kutta fourth order technique. The step size $\Delta\eta$ =0.05 is used to obtain the numerical solution with five decimal place accuracy as the criterion of convergence. From the process of numerical computation, the skin-friction coefficient, the Nusselt number and the Sherwood number, which are respectively proportional to $f''(0), -\theta'(0)$ and $-\phi'(0)$, are also sorted out and their numerical values are presented in a tabular form.

4. RESULTS AND DISCUSSION

The governing equations (8) - (10) subject to the boundary conditions (11) are integrated as described in section 3. Numerical results are reported in Tables 1-2. The Prandtl number is taken to be Pr=0.72 which corresponds to air, the value of Schmidt number (Sc) were chosen to be Sc=0.24,0.62, 0.78,2.62, representing diffusing chemical species of most common interest in air like H_2 , H_2O, NH_3 and Propyl Benzene respectively.

The effects of various parameters on velocity in the boundary layer are depicted in Figs. 1-8. It is observed that the velocity starts from a zero value at the plate surface and increase to the free stream value far away from the plate surface satisfying the far field boundary condition for all parameter values. In Fig. 1 the effect of increasing the magnetic field strength on the momentum boundary layer thickness is illustrated. It is now a well established fact that the magnetic field presents a damping effect on the velocity field by creating drag force that opposes the fluid motion, causing the velocity to decrease. However, in this case an increase in the *Ha* only slightly slows down the motion of the fluid away from the vertical plate surface towards the free stream velocity, while the fluid velocity near the vertical plate surface increases. Similar trend of slight increase in the fluid velocity near the vertical plate is observed with an increase in convective heat transfer parameter Bi (see in Fig.2). Fig.3 illustrates the effect of the thermal Grashof number (*Gr*) on the velocity field. The thermal Grashof number signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force. The flow is accelerated due to the enhancement in buoyancy force corresponding to an increase in the thermal Grashof number i.e. free convection effects. It is noticed that the thermal Grashof number (*Gr*) influence the velocity field almost in the boundary layer when compared to far away from the plate. It is seen that as the thermal Grashof number (*Gr*) increases, the velocity field increases. The effect of mass (solutal) Grashof number (*Gc*) on the velocity is illustrated in Fig.4. The mass (solutal) Grashof number (*Gc*) defines the ratio of the species buoyancy force to the viscous hydrodynamic force. It is noticed that the velocity increases with increasing values of the solutal Grashof number. Further as the mass Grashof number (*Gc*) increases, the velocity field near the boundary layer increases.

Fig.5 illustrates the effect of the Schmidt number (*Sc*) on the velocity. The Schmidt number (*Sc*) embodies the ratio of the momentum diffusivity to the mass (species) diffusivity. It physically relates the relative thickness of the hydrodynamic boundary layer and mass-transfer (concentration) boundary layer. It is noticed that as Schmidt number (*Sc*) increases the velocity field decreases. Fig. 6 shows the variation of the velocity boundary-layer with the Eckert number (Ec). It is noticed that the velocity boundary layer thickness increases with an increase in the Eckert number (Ec). Fig. 7 shows the variation of the velocity boundary-layer with the Dufour number (Du). It is observed that the velocity boundary layer thickness increases with an increase in the Dufour number (Du). Fig. 8 shows the variation of the velocity boundary-layer with the Soret number (*Sr*). It is found that the velocity boundary layer thickness increases with an increase in the Soret number (*Sr*).

As per the boundary conditions of the flow field under consideration, the fluid temperature attains its maximum value at the plate surface and decreases exponentially to the free stream zero value away from the plate. This is observed in Figs. 9-17. The effect of the magnetic parameter *Ha* on the temperature is illustrated in Fig.9. It is observed that as the magnetic parameter *Ha* increases, the temperature decreases. Fig.10 illustrates the effect of the convective heat transfer parameter (Bi) on the temperature. It is noticed that as convective heat transfer parameter (Bi) increases, the temperature increases. From Figs. 11 and 12, it is observed that the thermal boundary layer thickness decreases with an increase in the thermal or Solutal Grashof numbers (*Gr* or *Gc*). Fig. 13 illustrates the effect of Schmidt number (*Sc*) on the temperature. It is noticed that as the Schmidt number (*Sc*) increases an increasing trend in the temperature field is noticed. Much of significant contribution of Schmidt number (*Sc*) is noticed as we move far away from the plate.

Fig.14 illustrates the effect of the Eckert number (Ec) on the temperature. It is noticed that as the Eckert number (Ec) increases, the temperature increases. Fig. 15 shows the variation of the thermal boundary-layer with the Dufour number (Du). It is noticed that the thermal boundary layer thickness increases with an increase in the Dufour number (Du). Fig. 16 shows the variation of the thermal boundary-layer with the Soret number (*Sr*). It is observed that the thermal boundary layer thickness decreases with an increase in the Soret number (*Sr*). The effect of Prandtl number (*Pr*) on the temperature field is illustrated Fig.17. As the Prandtl number (*Pr*) increases the thermal boundary layer is found to be decreasing.

Figs. 18-24 depict chemical species concentration against span wise coordinate η for varying values physical parameters in the boundary layer. The species concentration is highest at the plate surface and decrease to zero far away from the plate satisfying the boundary condition. The effect of magnetic parameter *Ha* on the concentration field is illustrated Fig.18. As the magnetic parameter *Ha* increases the concentration is found to be decreasing. However, as we move away from the boundary layer, the effect is not significant. The effect of buoyancy parameters (Gr,Gc) on the concentration field is illustrated Figs. 19 and 20. It is noticed that the concentration boundary layer thickness decreases with an increase in the thermal or Solutal Grashof numbers (*Gr* or *Gc*). Fig. 21 illustrates the effect of Schmidt number (*Sc*) on the concentration. It is noticed that as the Schmidt number (*Sc*) increases, there is a decreasing trend in the concentration field. Not much of significant contribution of Schmidt number (*Sc*) is noticed as we move far away from the plate.

The influence of the Eckert number Ec on the concentration field is shown in Fig.22. It is noticed that the concentration decreases monotonically with the increase of the Eckert number Ec. Fig. 23 shows the variation of the concentration boundary-layer with the Dufour number (Du). It is observed that the concentration boundary layer thickness decreases with an increase in the Dufour number (Du). Fig. 24 shows the variation of the concentration boundary-layer with the Soret number (*Sr*). It is found that the concentration boundary layer thickness increases with an increase in the Soret number (*Sr*).

In order to benchmark our numerical results, the present results for the skin -friction, Nusselt number and Sherwood number in the absence of *Bi*, are compared with those of Gnaneswara Reddy and Bhaskar Reddy [22] and found them in excellent agreement as demonstrated in Table 1. From Table 2, it is obseved that the local skin-friction coefficient, local heat and mass transfer rates at the plate increases with an increase in the magnetic field or buoyancy forces. As the Eckert number increases, both the skin-friction and Sherwood number increase, whereas the Nusselt number decreases. It was found that the local skin-friction coefficient and local heat transfer rate at the plate increases but Sherwood number decreases with an increase in the Prandtl number. As the Dufour number increases, both the skin-friction and Sherwood number increase, whereas the Nusselt number decreases. The effect of the Soret number is to decrease the skin-friction and the Sherwood number, and to increase the Nusselt number.

5. CONCLUSIONS

The present chapter analyzes the Soret and Dufour effects on hydromagnetic mixed convection flow over a vertical semi-infinite plate with a convective surface boundary condition by taking viscous dissipation into account. The governing equations are approximated to a system of non-linear ordinary differential equations by similarity transformation. Numerical calculations are carried out for various values of the dimensionless parameters of the problem. A comparison with previously published work is performed and excellent agreement between the results is found. The results are presented graphically and the conclusion is drawn that the flow field and other quantities of physical interest are significantly influenced by these parameters. The results for the skin friction, local heat and mass transfer rates are presented in Tables and discussed. It is found that the local skin-friction coefficient, local heat and mass transfer rates at the plate increase with an increase in the magnetic field or buoyancy forces or convective heat exchange parameter. As the Eckert number increases, both the skin-friction and Sherwood number increase, whereas the Nusselt number decreases. It is observed that the local skin-friction coefficient and local heat transfer rates at the plate increase but Sherwood number decreases with an increase in the Prandtl number. As the Dufour number increases, both the skin-friction and Sherwood number increase, whereas the Nusselt number decreases. The effect of the Soret number is to decrease the skin-friction and the Sherwood number, and to increase the Nusselt number.

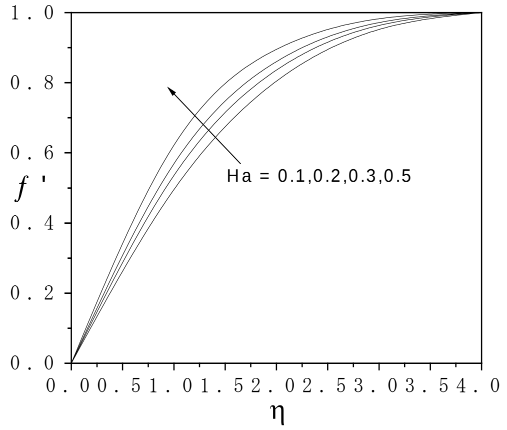

Fig.1 Velocity profiles for different values of *Ha*

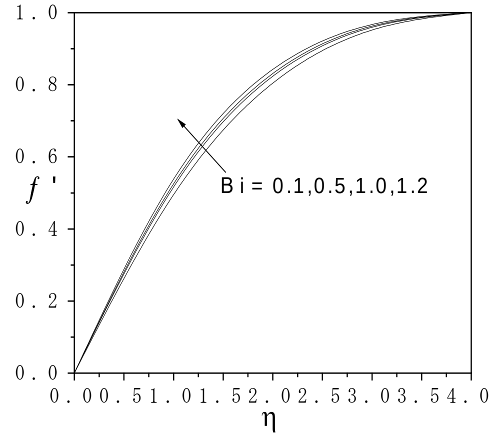

Fig.2: Velocity profiles for different values of *Bi*

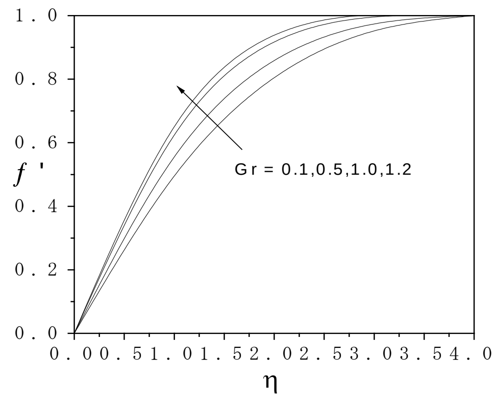

Fig.3: Velocity profiles for different values of *Gr*

ISSN 2348 – 7968

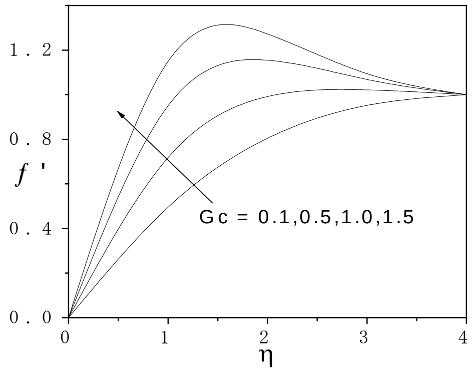

Fig.4: Velocity profiles for different values of Gc

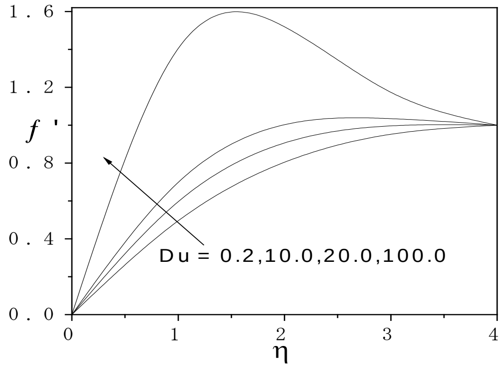

Fig.7: Velocity profiles for different values of *Du*

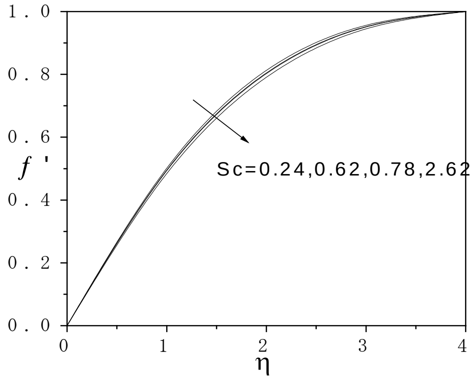

Fig.5: Velocity profiles for different values of Sc

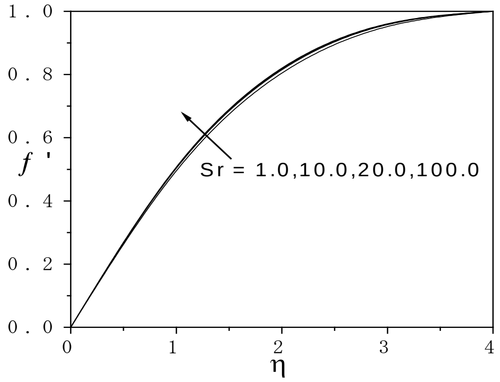

Fig.8: Velocity profiles for different values of *Sr*

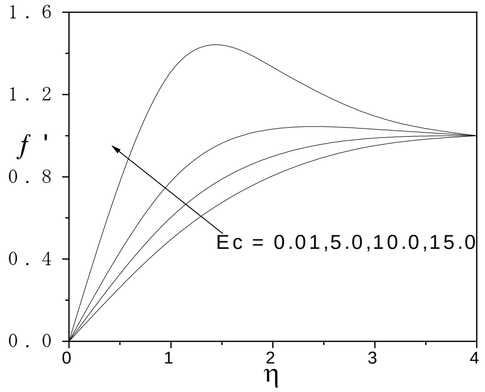

Fig.6: Velocity profiles for different values of *Ec*

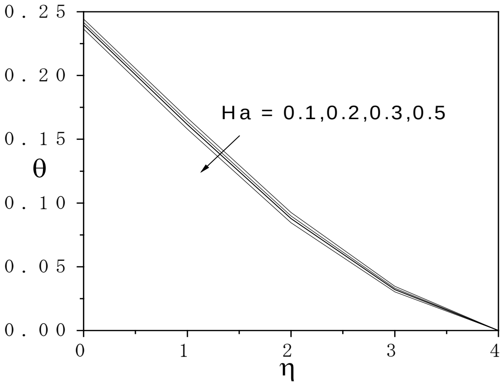

Fig.9: Temperature profiles for different values of *Ha*

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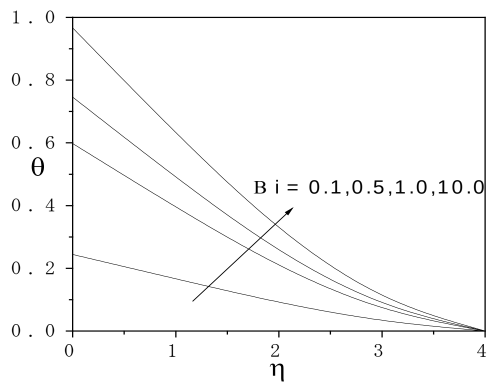

Fig.10: Temperature profiles for different values of *Bi*

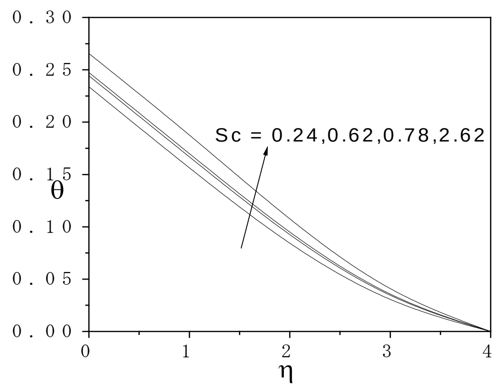

Fig.13: Temperature profiles for different values of *Sc*

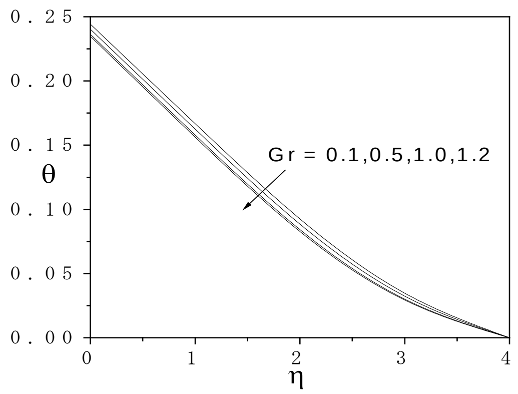

Fig.11: Temperature profiles for different values of *Gr*

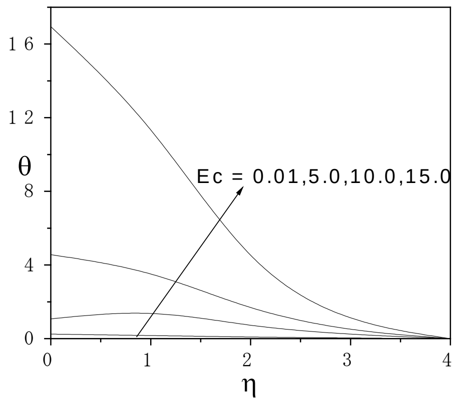

Fig.14: Temperature profiles for different values of *Ec*

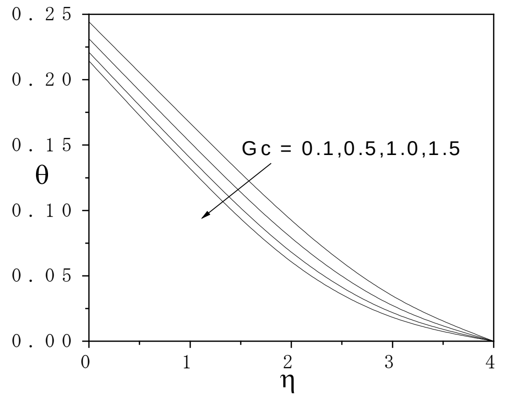

Fig.12: Temperature profiles for different values of *Gc*

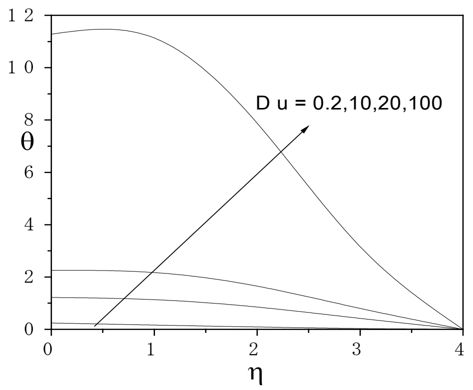

Fig.15: Temperature profiles for different values of *Gc*

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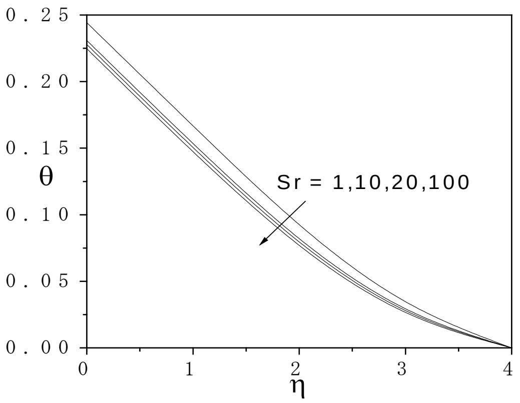

Fig.16: Temperature profiles for different values of Sr

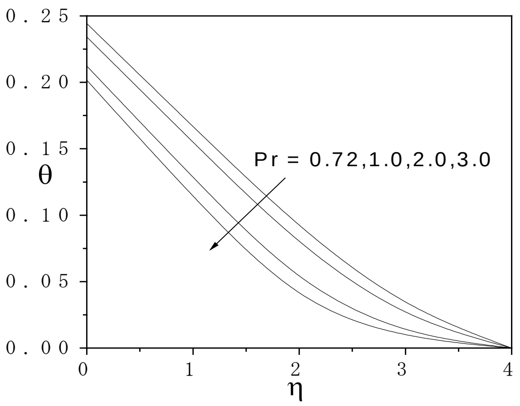

Fig.17: Temperature profiles for different values of *Pr*

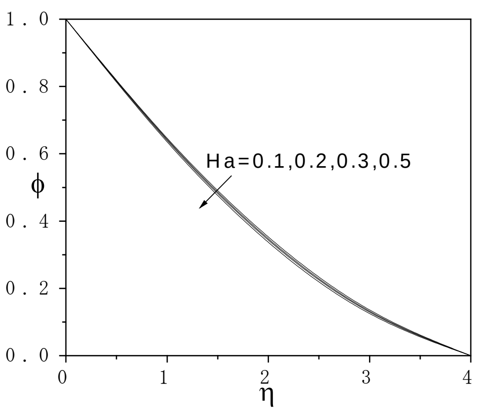

Fig.18: Concentration profiles for different values of *Ha*

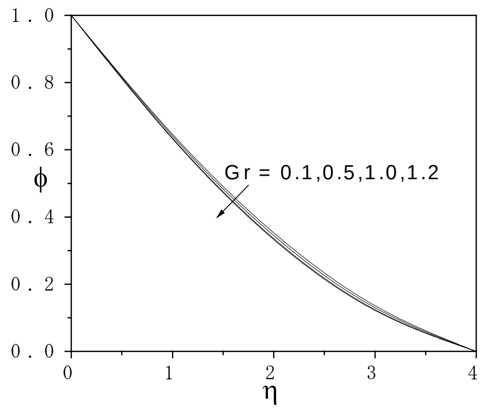

Fig.19: Concentration profiles for different values of *Gr*

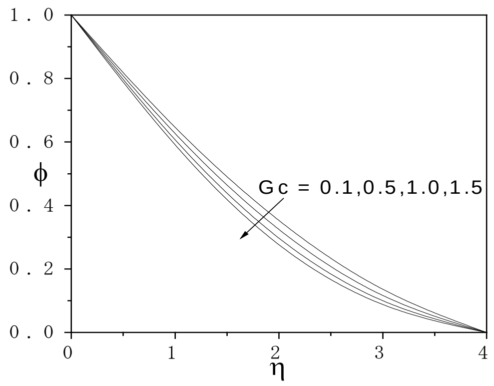

Fig.20: Concentration profiles for different values of *Gc*

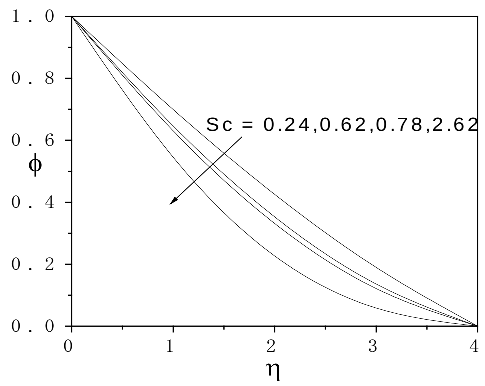

Fig.21: Concentration profiles for different values of *Sc*

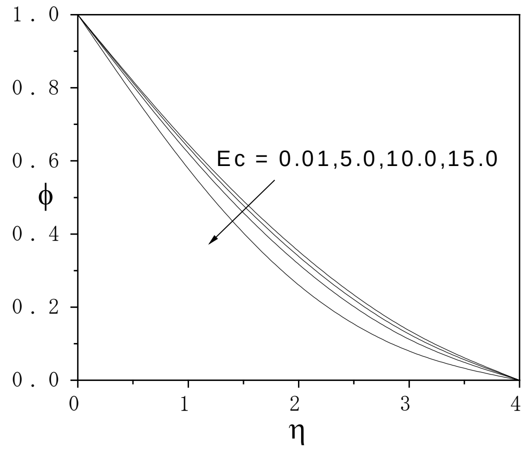

Fig.22: Concentration profiles for different values of *Ec*

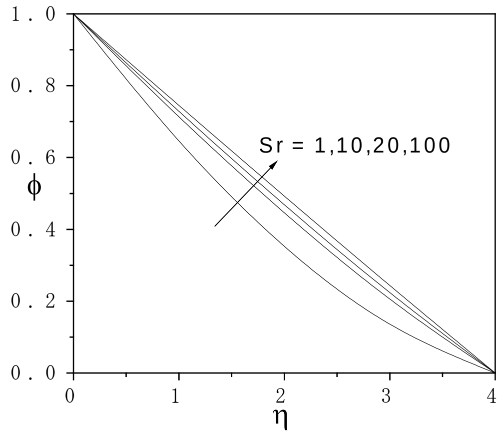

Fig.24: Concentration profiles for different values of *Sr*

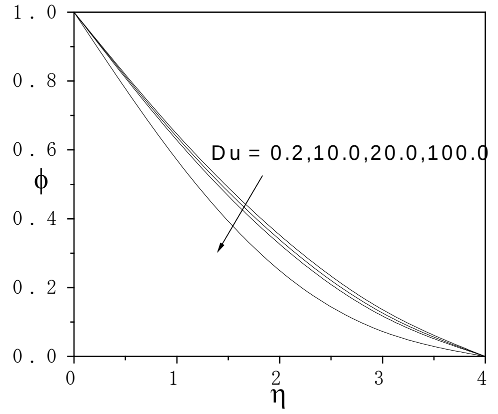

Fig.23: Concentration profiles for different values of *Du*

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Table 1 Comparison of the numerical values of the skin-friction coefficient C_f , Nusselt number *Nu* and Sherwood number *Sh* for *Gr* = 2.0, *Gc* = 2.0 , *Ha* = 0.5.

Pr	Ec	Du	Sc	Sr	Gnaneswar Reddy and Bhaskar Reddy [22]			Present work		
					C_f	*Nu*	*Sh*	C_f	*Nu*	*Sh*
0.71	0.01	0.2	0.6	1.0	0.82302	0.86186	0.43622	2.97496	0.23899	0.418769
1.0	0.01	0.2	0.6	1.0	0.75371	1.10872	0.29084	2.90242	0.253311	0.414998
0.71	0.02	0.2	0.6	1.0	0.82406	0.85906	0.43788	2.98881	0.234385	0.419263
0.71	0.01	0.4	0.6	1.0	0.84053	0.82924	0.45734	2.99899	0.234253	0.420044
0.71	0.01	0.2	0.78	1.0	0.77315	0.84694	0.49949	2.93998	0.237364	0.447626
0.71	0.01	0.2	0.6	2.0	1.00844	0.93303	0.29313	3.0091	0.240535	0.391731

Table 2 Variation of C_f **,** *Nu* and *Sh* at the plate with Bi , Ha , Gr , Gc , Sc , *Sr, Du, Ec* for *Pr*=0.71

Bi	Gr	Gc	Ha	*Sc*	*Sr*	*Du*	Ec	C_f	*Nu*	*Sh*
0.1	0.1	0.1	0.1	0.62	1.0	0.2	0.01	0.598376	0.0762841	0.331891
1.0	0.1	0.1	0.1	0.62	1.0	0.2	0.01	0.653245	0.256866	0.320825
10	0.1	0.1	0.1	0.62	1.0	0.2	0.01	0.677121	0.338045	0.315472
0.1	0.5	0.1	0.1	0.62	1.0	0.2	0.01	0.698351	0.0766069	0.33957
0.1	1.0	0.1	0.1	0.62	1.0	0.2	0.01	0.816094	0.0769505	0.348297
0.1	0.1	0.5	0.1	0.62	1.0	0.2	0.01	1.00085	0.0774128	0.381115
0.1	0.1	1.0	0.1	0.62	1.0	0.2	0.01	1.45005	0.0782785	0.389756
0.1	0.1	0.1	0.4	0.62	1.0	0.2	0.01	0.814697	0.0768279	0.345147
0.1	0.1	0.1	0.6	0.62	1.0	0.2	0.01	0.931282	0.0770551	0.351182
0.1	0.1	0.1	0.1	0.78	1.0	0.2	0.01	0.595819	0.0759924	0.351053
0.1	0.1	0.1	0.1	2.62	1.0	0.2	0.01	0.577713	0.0735124	0.517674
0.1	0.1	0.1	0.1	0.62	2.0	0.2	0.01	0.599112	0.07636	0.326933
0.1	0.1	0.1	0.1	0.62	3.0	0.2	0.01	0.599845	0.076438	0.321827
0.1	0.1	0.1	0.1	0.62	1.0	0.4	0.01	0.600373	0.0750642	0.333284
0.1	0.1	0.1	0.1	0.62	1.0	0.6	0.01	0.60241	0.0738055	0.334718
0.1	0.1	0.1	0.1	0.62	1.0	0.2	0.02	0.598684	0.076061	0.332147
0.1	0.1	0.1	0.1	0.62	1.0	0.2	0.04	0.599262	0.0756041	0.332658

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