Hall Current and Chemical Reaction Effects on MHD Free Convective Heat and Mass Transfer of a Viscous Incompressible Fluid over an Inclined Plate with Heat Source and Heat Absorption: A Biomedical Transport Modeling Study

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ABSTRACT

An attempt has been made to study the influence of Hall current and Chemical reaction effects on the Magneto hydrodynamic (MHD) natural convection boundary layer viscous incompressible fluid flow in the manifestation of transverse magnetic field near an inclined vertical permeable flat plate in the presence of Heat Source/absorption. It is assumed that the induced magnetic field is negligible compared with the imposed magnetic field. The governing boundary layer equations have been transferred into non-similar model by implementing similarity approaches. The coupled ordinary differential equations along with the boundary conditions are solved numerically by using Runge-Kutta method along with shooting technique. The physical effects of the various parameters on dimensionless primary velocity profile, secondary velocity profile, and temperature and concentration profile are discussed graphically. Moreover, the skin friction coefficient, Nusselt number and Sherwood number are shown in tabular form for various values of the parameters.

Keywords: *MHD, Heat and Mass Transfer, Hall Current, Inclined Plate, Chemical reaction and Heat Flux.*

I. INTRODUCTION

The influence of the magnetic field on a viscous incompressible flow of an electrically conducting fluid has its importance in many applications such as geophysics, metallurgy and aerodynamics, extrusion of plastics in the manufacture of rayon, nylon, purification of crude oil and other engineering processes such as in petroleum engineering, chemical engineering, composite or ceramic engineering and heat exchangers. The study of MHD viscous flows with Hall currents has important engineering applications in problems of MHD generators, Hall accelerators as well as in flight magneto hydrodynamics. The effect of Hall currents on a hydromagnetic flow near an accelerated plate was studied by Pop (1971) [01]. Rotation effects on a hydromagnetic free convective flow past an accelerated isothermal vertical plate were studied by Raptis and Singh (1981) [02]. Takhar et al. (1992) [03] studied the Hall effects on heat and mass transfer flow with variable suction and heat generation. Watanabe and Pop (1995) [04] studied the effect of Hall current on the steady MHD flow over a continuously moving plate, when the liquid is permeated by a uniform transverse magnetic field. Free convection flow of a conducting fluid permeated by a transverse magnetic field in the presence of the Hall effects and uniform magnetic field is analyzed by Pop and Watanabe [05].

Eichhorn [06] investigated the similarity solution by considering the power-law variations in the plate temperature and transpiration velocity. Vedhanayagam et al. [07] worked on the free convection flow along a vertical plate with the arbitrary blowing and wall temperature. Lin and Yu [08] investigated the free convection flow over a horizontal plate. Recently, Hossain et al. [09] investigated the natural convection flow from a vertical permeable flat plate with the variable surface temperature, considering the temperature and transpiration rates to follow the power-law variation. Saha et al. [10] studied the effect of Hall current on the steady laminar natural convection boundary layer flow of MHD viscous and incompressible fluids. Lately, Saha et al. [11] examined the effect of Hall current on MHD natural convection flow from vertical permeable flat plate with uniform surface heat flux. In recent years a number of studies of MHD convective heat and mass transfer boundary layer flow of viscous incompressible fluid were reported in the literature [12]-[24]. However, the effect of hall current and constant heat flux is still not getting promising attraction to the researchers. In this study MHD Free Convection and Mass Transfer Flow of Viscous Incompressible Fluid about an inclined Plate with Hall Current, Constant Heat Flux and Heat Absorption is investigated.

II. MATHEMATICAL ANALYSIS

Steady natural convection boundary layer flow of an electrically conducting and viscous incompressible fluid from a semi-infinite heated permeable inclined flat plate with a uniform surface heat flux and transverse magnetic field with the effect of the Hall current is considered. Here x axis is taken along the vertically upward direction and y axis is normal to it. The leading edge of the permeable surface is taken along z axis. The uniform heat is supplied from the surface of the plate to the fluid, which is maintained uniformly throughout the fluid flow. The temperature and concentration at the wall are T_w and C_w respectively. The temperature and concentration outside the boundary layer are T_∞ and C_∞ respectively. Uniform magnetic field of magnitude B_0 is imposed to perpendicular to the flow along the y axis. Let the angle of inclination of the plate is γ and the plate is semi finite. The x component momentum equation reduces to the boundary layer equation if and only if body force is made by gravity, then the body force per unit mass is $F_x = -\rho g_0 \cos\gamma$ where g_0 is the acceleration due to gravity. Further no body force exists in the direction of y and z, i.e. $\frac{\partial p}{\partial y} = 0, \ \frac{\partial p}{\partial z} = 0,$ and $F_y = 0 \ \ F_z = 0$. The x component of pressure gradient at any point in the boundary layer must equal to the pressure gradient in the region outside the boundary layer, in this region $u = 0,\ v = 0$. Hence x component of pressure gradient become $\frac{\partial p}{\partial x} = -\rho_\infty g_0 \cos\gamma$ where ρ_∞ is the density of the surrounding fluid at temperature T_∞. The quantity $\rho - \rho_\infty$ is related to the temperature difference $T - T_\infty$ and concentration (or mass) differences $C - C_\infty$ through the thermal volume expansion coefficient β and concentration volume expansion coefficient β^* by the relation, $\frac{\rho - \rho_\infty}{\rho} = -\beta(T - T_\infty) - \beta^*(C - C_\infty)$, therefore,

$$F_x - \frac{1}{\rho}\frac{\partial p}{\partial x} = g_0\beta(T - T_\infty)\cos\gamma + g\beta^*(C - C_\infty)\cos\gamma$$

We have the generalized ohm's law in the absence of electric field to the case of short circuit problem is of the form

$$\underline{J} + \frac{\omega_e \tau_e}{B_0}\underline{J} \times \underline{B} = \sigma(\underline{E} + \mu_e \underline{q} \times \underline{B}) \qquad \text{---------- (1)}$$

Where, μ_e is the magnetic permeability, τ_e is the electron collision time, σ is the electrical conductivity, ω_e is the cyclotron frequency, B_0 is the applied magnetic field. Since no applied or polarized voltage exist, so the effect of polarization of fluid is negligible, *i.e.* $\underline{E} = (0,0,0)$.

Therefore Equation (1) becomes $$\underline{J} + \frac{\omega_e \tau_e}{B_0}\underline{J} \times \underline{B} = \sigma\mu_e(\underline{q} \times \underline{B}) \qquad \text{---------- (2)}$$

If is assumed that induced magnetic field generated by fluid motion is negligible in comparison to the applied one *i.e.* $\underline{B} \equiv (0, B_0, 0)$. This assumption is valid because magnetic Reynolds number is very small for liquid metals and partially ionized fluids.

Since the Hall coefficient is $m = \omega_e \tau_e$, so the Equation (2) we can write

$$J_z = \frac{\sigma\mu_e B_0}{1 + m^2}(mw + u) \qquad \text{---------- (3)}$$

$$J_x = \frac{\sigma\mu_e B_0}{1+m^2}(mu - w) \quad \text{---------- (4)}$$

Where $J_y = 0$. The fundamental equations for the steady incompressible MHD flow with the generalized Ohm's law and Maxwell's equations, under the assumptions that the fluid is quasi-neutral, and the ion slip and thermoelectric effects can be neglected. Since the plate is semi-infinite and motion is steady, all physical equations will be the functions of x and y. Thus mathematically the problem reduces to a two dimensional problem given as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} = 0 \quad \text{---------- (5)}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = v\frac{\partial^2 u}{\partial y^2} + g_0\beta(T - T_\infty)\cos\gamma + g\beta^*(C - C_\infty)\cos\gamma - \frac{\sigma\beta_0^2}{\rho(1+m^2)}(u + mw) \quad \text{---------- (6)}$$

$$u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} = v\frac{\partial^2 w}{\partial y^2} + \frac{\sigma\beta_0^2}{\rho(1+m^2)}(mu - w) \quad \text{---------- (7)}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} + \frac{v}{c_p}\left[\left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial y}\right)^2\right] - \frac{Q_0^*}{\rho c_p}(T - T_\infty) + Q_1^*(C - C_\infty) \quad \text{---------- (8)}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_m\frac{\partial^2 C}{\partial y^2} - k_r^*(C - C_\infty) \quad \text{---------- (9)}$$

Subjected to the boundary conditions

$$\left.\begin{array}{ll} u = 0, v = 0, w = 0, \dfrac{\partial T}{\partial y} = -\dfrac{Q}{k}, C = C_w & at \;\; y = 0 \\ u \to 0, w \to 0, T \to T_\infty, C \to C_\infty & as \;\; y \to \infty \end{array}\right\} \quad \text{---------- (10)}$$

Where u, v, w are the velocity components in the x, y, z direction respectively, ν is the kinematics viscosity, ρ is the density. T, T_w and T_∞ are the temperature of the fluid inside the thermal boundary layer, the plate temperature and the fluid temperature in the free stream, respectively, while $C, C_{w,} C_\infty$ are the corresponding concentrations. Also, σ is the electric conductivity of the medium, k is the thermal conductivity of the medium, D_m is the coefficient of mass diffusivity, C_p is the specific heat at constant pressure, Q is the constant heat flux per unit area and other symbols have their usual meaning.

In order to solve the above system (**Figure 1**) of Equations (6)-(9) with the boundary conditions (10), we

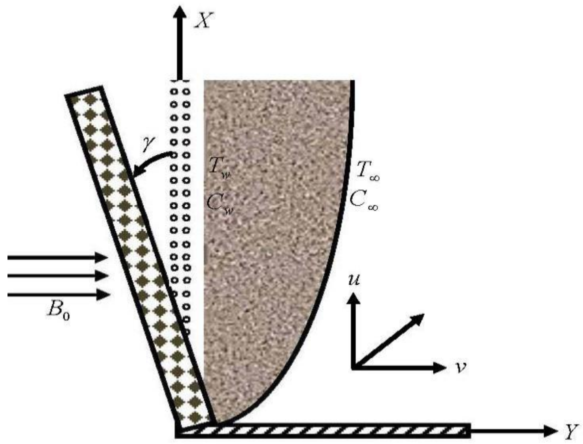

***Figure 1. Physical configuration and co-ordinate system*.**

adopt the well-defined similarity analysis to attain similarity solutions. For this purpose, the following similarity transformations are now introduced;

$$\eta = y\sqrt{\frac{U_0}{2\nu x}}\ ,\ g_0(\eta) = \frac{w}{U_0}\ ,\ \theta(\eta) = \frac{k(T-T_\infty)}{Q}\sqrt{\frac{U_0}{2\nu x}}\ ,\ \varphi(\eta) = \frac{C-C_\infty}{(C_0-C_\infty)}\ ,\ \psi = \sqrt{2\nu x U_0}\ f(\eta)\ ,$$

$$u = \frac{\partial \psi}{\partial y} = U_0 f'(\eta)\ \text{, and}\quad v = -\frac{\partial \psi}{\partial x} = \sqrt{\frac{U_0 \nu}{2x}}[\eta f'(\eta) - f(\eta)] \qquad \text{---------- (11)}$$

Thus, Equations (6)-(10) becomes;

$$f''' + ff'' + G_r \cos\gamma\theta + G_m \cos\gamma\varphi - \frac{M}{1+m^2}(f' + mg) = 0 \qquad \text{---------- (12)}$$

$$g'' + fg' + \frac{M}{1+m^2}(mf' + g) = 0 \qquad \text{---------- (13)}$$

$$\theta'' + P_r E_c[(f'')^2 + (g')^2] - P_r(f'\theta - f\theta') - P_r Q_0 \theta + P_r Q_1 \varphi = 0 \qquad \text{---------- (14)}$$

$$\varphi'' + Sc\varphi' f - Sck_r \varphi = 0 \qquad \text{---------- (15)}$$

The corresponding boundary conditions are

$$\left.\begin{array}{lllll} f'(\eta) = 0, & g(\eta) = 0, & \theta'(\eta) = -1, & \varphi(\eta) = 1 & at \quad \eta = 0 \\ f'(\eta) \to 0, & g(\eta) \to 0, & \theta(\eta) \to 0 & \varphi(\eta) \to 0 & as \quad \eta \to \infty \end{array}\right\} \qquad \text{---------- (16)}$$

Where $\Pr = \dfrac{\rho C_P \upsilon}{k}\ ,\ E_c = \dfrac{U_0^3 K}{C_p Q\sqrt{2\nu x U_0}}\ ,\ M = \dfrac{2x\sigma B_0^2}{\rho U_0}\ ,\ S_c = \dfrac{\nu}{D_m}\ ,\ G_r = \dfrac{g_0 \beta Q \sqrt{2x}}{kU_0\sqrt{\nu U_0}}$,

$$G_m = \frac{2g\beta^*(C_w - C_\infty)x}{U_0^2}\ ,\ Q_0 = \frac{2\ xQ_0^*}{U_0\ \rho C_P}\ ,\ Q_1 = \frac{k(C_0 - C_\infty)\sqrt{2x}}{Q\sqrt{U_0\ \upsilon}}Q_1^*\ ,\ Kr = \frac{2x}{U_0}Kr^*$$

III. SKIN-FRICTION COEFFICIENTS, NUSSELT NUMBER AND SHERWOOD NUMBER

The quantities of chief physical interest are the skin friction coefficients, the Nusselt number and the Sherwood number. The equation defining the wall skin frictions are $\tau_x = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0}$ and $\tau_z = \mu\left(\frac{\partial w}{\partial y}\right)_{y=0}$ which are proportional to $\left(\frac{\partial^2 f}{\partial \eta^2}\right)_{\eta=0}$ and $\left(\frac{\partial g}{\partial \eta}\right)_{\eta=0}$. The Nusselt number denoted by N_u is proportional to $-\left(\frac{\partial T}{\partial y}\right)_{y=0}$, hence we have N_u is proportional to $-\theta'(0)$. The Sherwood number denoted by S_h is proportional to $-\left(\frac{\partial C}{\partial y}\right)_{y=0}$, hence we have S_h is proportional to $-\varphi'(0)$. The numerical values of the skin friction coefficients, the Nusselt number and the Sherwood number are sorted in Tables 1-3.

IV. RESULTS AND DISCUSSIONS

In this study the MHD Free Convection and Mass Transfer Flow of Viscous Incompressible fluid about an inclined Plate with Hall Current and Constant Heat Flux have been investigated using the Nachtsheim-Swigert shooting iteration technique. To study the physical situation of this problem, we have computed the numerical values of the velocity, temperature, and concentration within the boundary layer and also find the skin friction coefficient, Nusselt number, Sherwood number at the plate. It can be seen that the solutions are affected by the parameters namely Grashof number (Gr), modified Grashof number (Gm), Magnetic parameter (M), Prandtl number (Pr), Eckert number (Ec), Schmidt number (Sc), γ, Hall current Parameter (m) and chemical reaction parameter (Kr).

The velocity profile for different values of Eckert number (Ec), γ, thermal Grashof number (Gr), modified Grashof number (Gm), Hall current Parameter (m), Magnetic parameter (M), Prandtl number (Pr), heat source parameter Q0, heat sink parameter (Q1) and Schmidt number (Sc) are shown in the figures (2) to (11) respectively. Fig (2) displays the effect of Eckert number (Ec) on velocity distribution. It is observed that the velocity increases with increasing values of Eckert number (Ec). Fig (3) shows the effect of γ on velocity distribution. It is observed that the velocity decreases with increasing values of γ. Fig (4) & (5) shows the effective of modified Grashof number (Gm) & thermal Grashof number (Gr) on velocity distribution. It is observed that the velocity increases with increasing values of both the numbers. This is due to the fact that the buoyancy which is acting on the fluid particles due to gravitational forces that enhances the fluid velocity. Fig (6) displays the effect of Hall current Parameter (m) on velocity distribution. It is observed that the velocity increases with increasing values of Hall current Parameter (m). Fig (7) shows the effect of Magnetic parameter (M) on velocity distribution. It is seen that the velocity decreases with increasing values of Magnetic parameter. It is known fact that the application transfers Magnetic field which is applied normal to the flow, result in a flow resistive force called the Lorentz force which acts in the opposite direction of the flow. This force has the effect of slowing the motion of the fluid. Fig (8) displays the effect of Prandtl number on velocity distribution. It is observed that the velocity decreases with increasing values of Prandtl number. It is due to the fact that fluids with high Prandtl number will have high viscosity and hence fluid moves slowly. Fig (9) shows the effective of heat source parameter (Qo) on velocity distribution. It is observed that the velocity decreases with increasing values of (Qo). Fig (10) shows the effective of heat sink parameter (Q1) on velocity distribution. It is observed that the velocity increases with increasing values of heat sink parameter (Q1). Fig (11) displays the effect of Schimidt number (Sc) on velocity distribution. It is seen that the velocity decreases with increasing values of Schimidt number (Sc).

The Secondary velocity profile for different values of Eckert number (Ec), γ, thermal Grashof number (Gr), modified Grashof number (Gm), Hall current Parameter (m), Magnetic parameter(M), Prandtl number (Pr), heat source parameter (Qo), heat sink parameter (Q1) and Schmidt number (Sc) are shown in the figures (12) to (21) respectively. Fig (13, 16, 17, 18, 19 and 21) shows the effect of γ, Magnetic parameter (M), hall current parameter (m), Prandtl number (Pr), heat source parameter (Qo) and Schmidt number (Sc) on secondary velocity distribution. It is observed that the secondary velocity increases with increasing values of γ, Magnetic parameter (M), hall current parameter (m), Prandtl number (Pr), heat source parameter (Qo) and Schmidt number (Sc). Fig (12, 14, 15 and 20) displays the effect of Eckert number (Ec), thermal Grashof number (Gr), modified Grashof number (Gm) and heat sink parameter (Q1) on secondary velocity distribution. It is observed that the secondary velocity decreases with increasing values of Eckert number (Ec), thermal Grashof number (Gr), modified Grashof number (Gm) and heat sink parameter (Q1).

Figures (22) to (31) show that the temperature profiles for different values of Eckert number (Ec), γ, thermal Grashof number (Gr), modified Grashof number (Gm), Magnetic parameter (M), hall current parameter (m), Prandtl number (Pr), heat source parameter (Qo), heat source parameter (Q1) and Schmidt number (Sc). Fig (22, 26 and 30) displays the effect of Eckert number (Ec), Magnetic parameter (M) and heat sink parameter (Q1) on temperature distribution. It is observed that the temperature increase with increasing values of Eckert number (Ec), Magnetic parameter (M) and heat sink parameter (Q1). Fig (23, 24, 25, 27, 29 & 31) shows the effect of γ, thermal Grashof number (Gr), modified Grashof number (Gm), hall current parameter (m), heat source parameter (Qo) and Schmidt number (Sc) on temperature distribution. It is observed that the temperature decreases with increasing values of γ, modified Grashof number (Gm), thermal Grashof number (Gr), hall current parameter (m), heat source parameter (Qo) and Schmidt number (Sc). Fig (28) shows the effect of Prandtl number on temperature distribution. It is observed that the temperature decrease with increasing values of Prandtl number. This occurs because reduced to velocity would mean that, is not conversed readily and hence surface temperature decreases.

The concentration profiles for different values of Prandtl number (Pr), Schmidt number (Sc), chemical reaction parameter (Kr), Magnetic parameter (M) thermal Grashof number (Gr) and modified Grashof number (Gm) are shown in figures (32) to (37). Fig (32 & 33) shows the effect of modified Grashof number (Gm), thermal Grashof number (Gr) on concentration distribution. It is observed that the concentration decreases with increasing values of modified Grashof number (Gm), thermal Grashof number (Gr). Fig (37) displays the effect of Schmidt number (Sc) on concentration distribution. It is noticed that as the Schmidt number increases there is a decreasing trend in the concentration field. Not much of significant contribution of Schmidt number is observed for away from the plate. Fig (34, 35 & 36) shows the effect of chemical reaction parameter (Kr), Magnetic parameter (M) and Prandtl number (Pr) on concentration distribution. It is observed that the concentration increases with increasing values of chemical reaction parameter (Kr), Magnetic parameter (M) and Prandtl number (Pr).

From Table 1 it is noticed that an increasing in thermal Grashaf number (Gr), modified Grashof number (Gm), Eckert number (Ec), heat source parameter (Qo), heat sink parameter (Q1), chemical reaction parameter (Kr) and hall current parameter (m) results on increasing skin friction, while it decreases with an increase in Prandtl number (Pr), magnetic parameter (M), Schmidt number (Sc) and γ respectively.

Table 2 shows the effects of thermal Grashaf number (Gr), modified Grashof number (Gm), Eckert number (Ec), heat source parameter (Qo), heat sink parameter (Q1), chemical reaction parameter (Kr), hall current parameter (m), Prandtl number (Pr), γ, Magnetic parameter (M) and Schmidt number (Sc) numerically on rate of heat transfer Nu. It is noticed that the rate of heat transfer decreases with increasing values of Magnetic parameter (M), Schmidt number (Sc), Eckert number (Ec), γ, heat source parameter (Qo), heat sink parameter (Q1) and chemical reaction parameter (Kr), while it decreases in the case of Prandtl number (Pr), thermal Grashaf number (Gr), modified Grashof number (Gm) and hall current parameter (m) respectively.

Table 3 shows the effects of chemical reaction parameter (Kr) and Schmidt number (Sc) on rate of mass transfer (Sh) numerically. It is observed that the rate of mass transfer increases with increasing values of chemical reaction parameter (Kr) and Schmidt number (Sc) on rate of mass transfer (Sh) respectively.

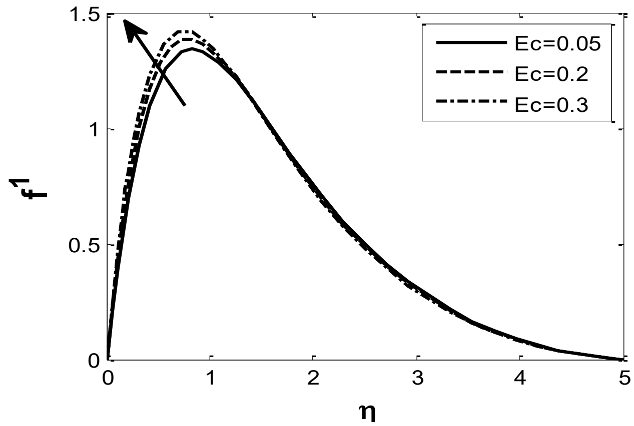

Fig.2: Velocity Profile for Ec

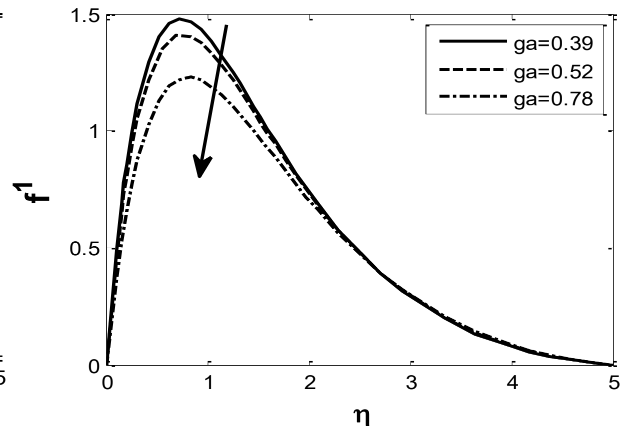

Fig.3: Velocity Profile for ga

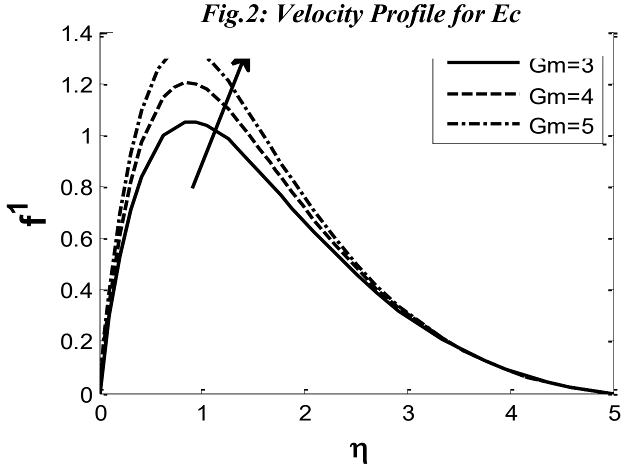

Fig.4: Velocity Profile for Gm

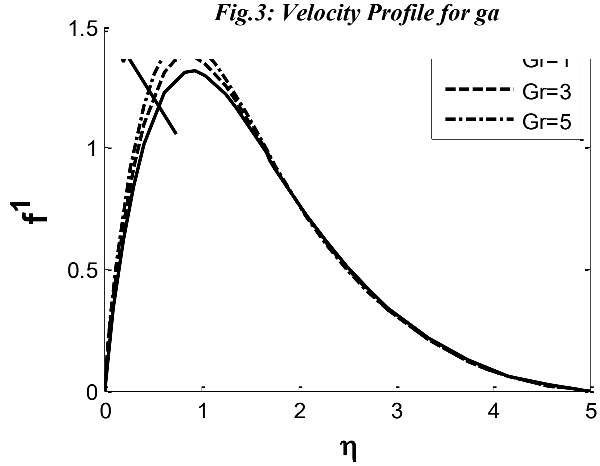

Fig.5: Velocity Profile for Gr

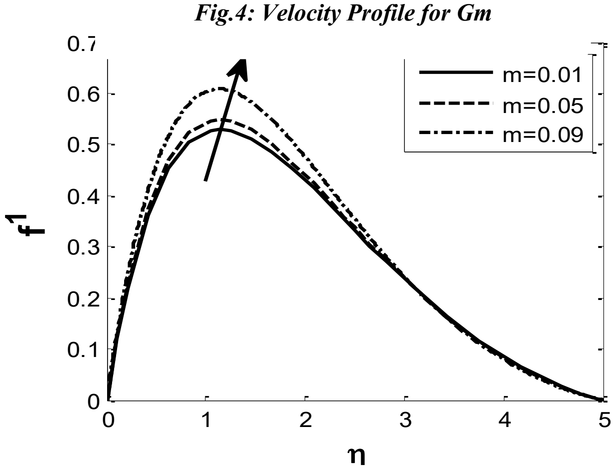

Fig.6: Velocity Profile for m

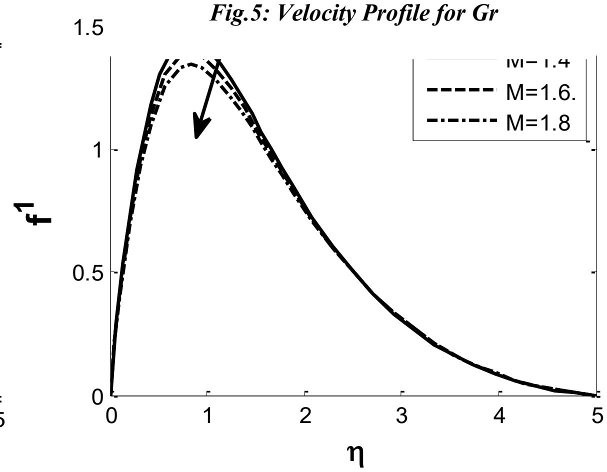

Fig.7: Velocity Profile for M

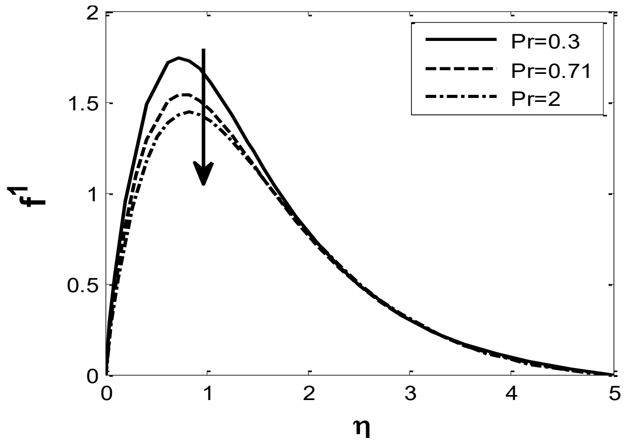

Fig.8: Velocity Profile for Pr

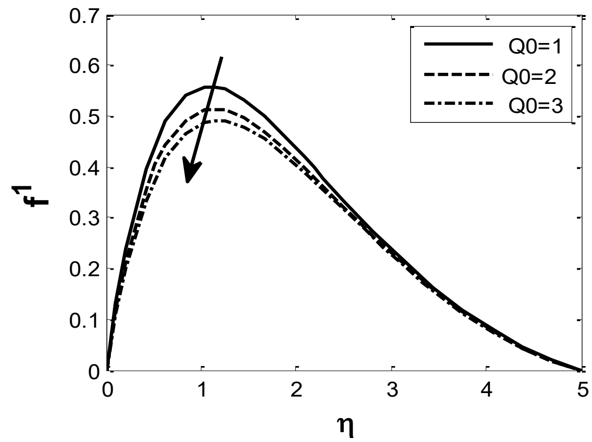

Fig.9: Velocity Profile for Q0

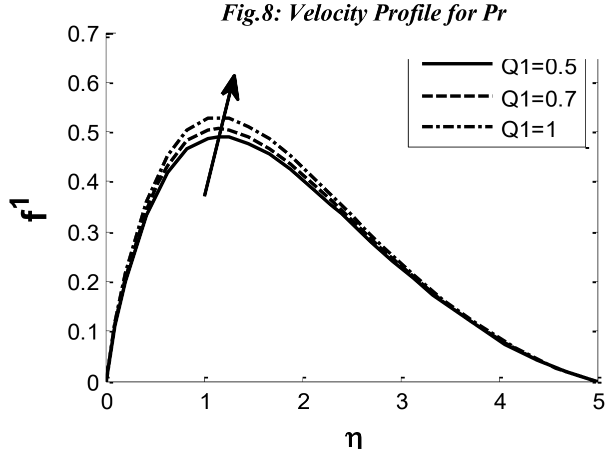

Fig.10: Velocity Profile for Q1

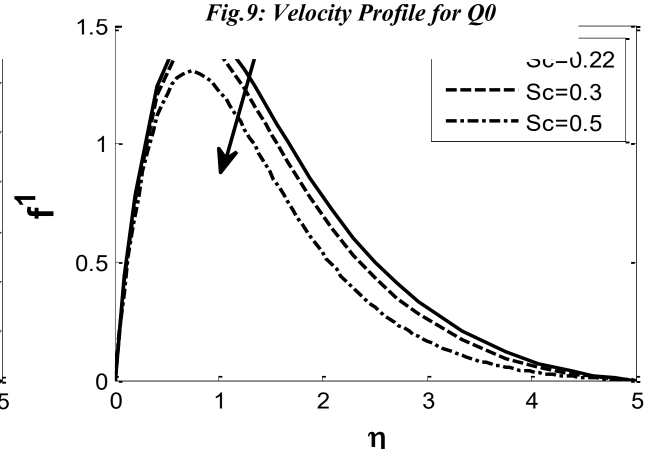

Fig11: Velocity Profile for Sc

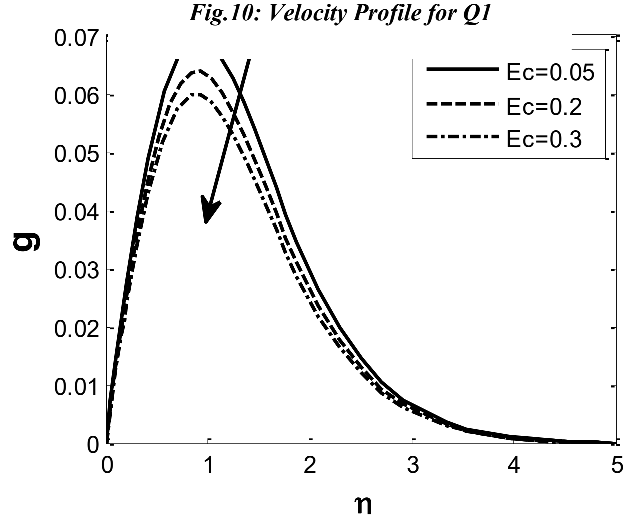

Fig12: Secondary Velocity Profile for Ec

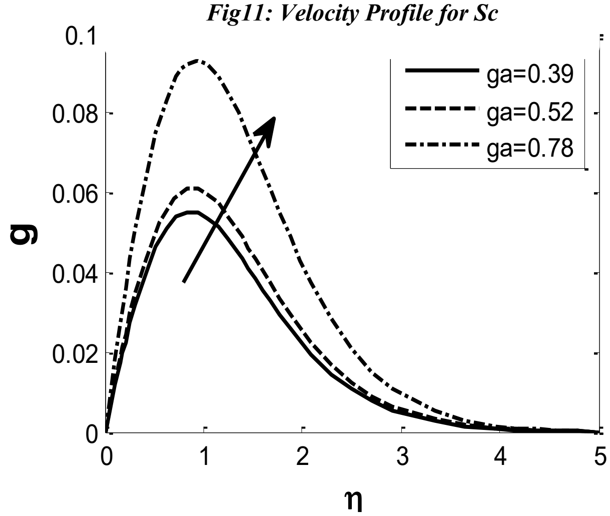

Fig13: Secondary Velocity Profile for ga

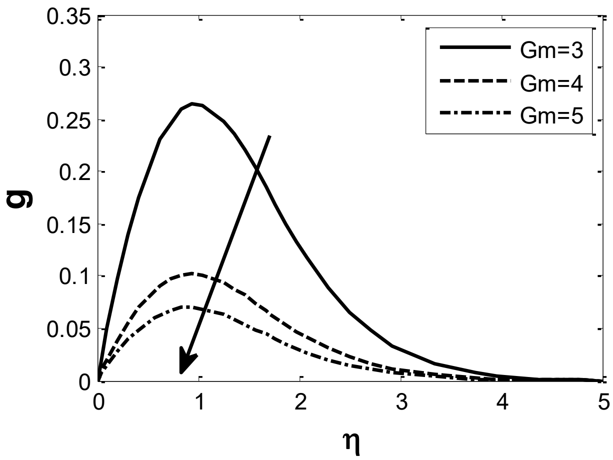

Fig14: Secondary Velocity Profile for Gm

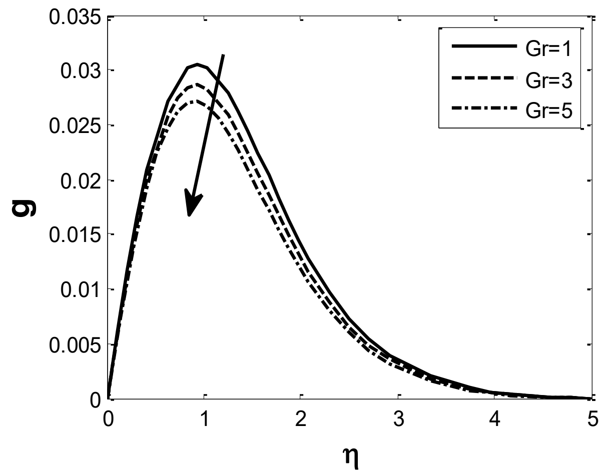

Fig15: Secondary Velocity Profile for Gr

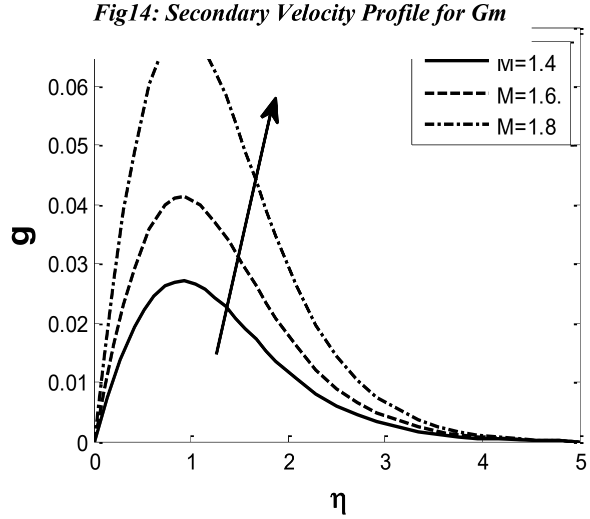

Fig16: Secondary Velocity Profile for M

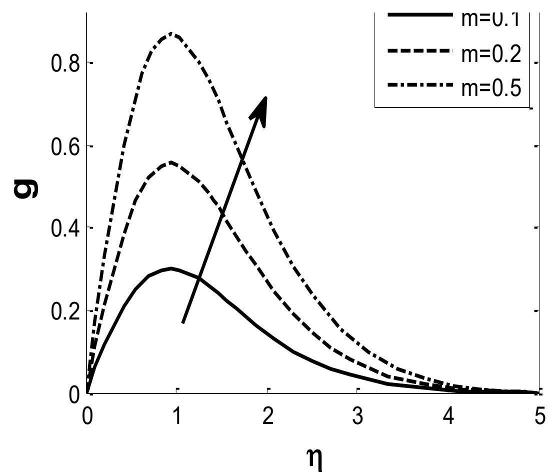

Fig17: Secondary Velocity Profile for m

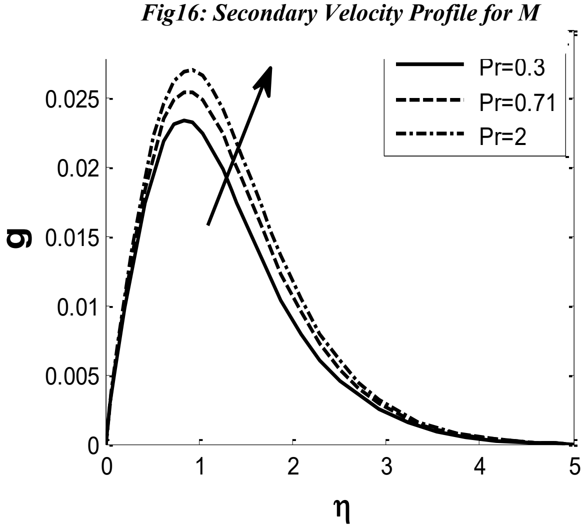

Fig.18: Secondary Velocity Profile for Pr

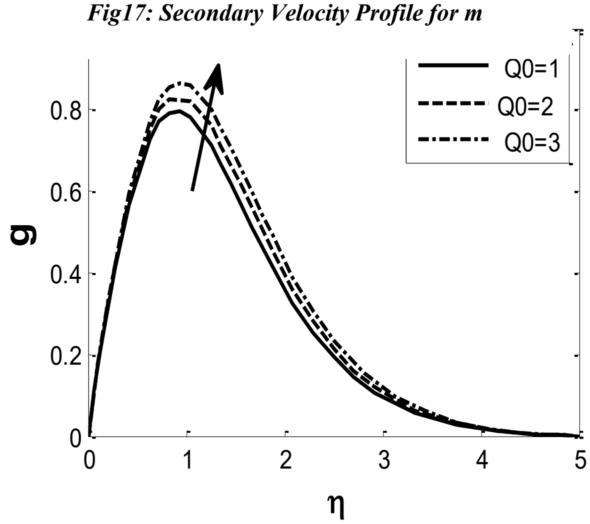

Fig.19: Secondary Velocity Profile for Q0

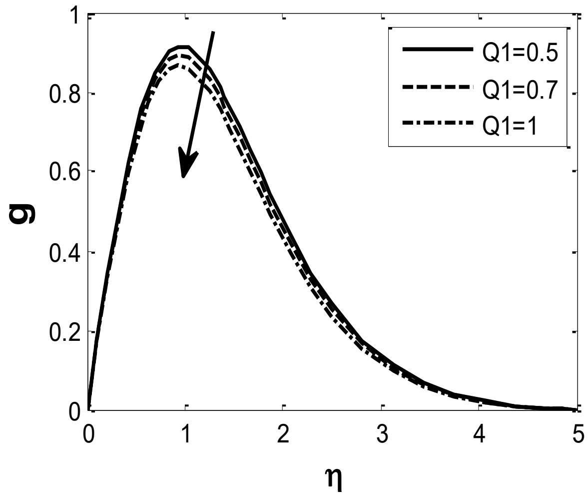

Fig.20: Secondary Velocity Profile for Q1

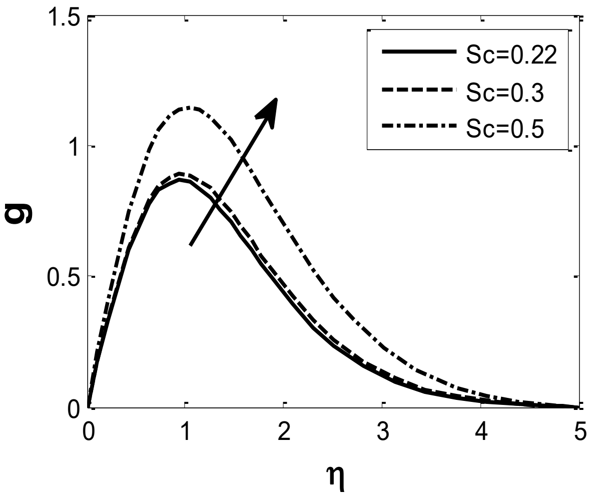

Fig.21: Secondary Velocity Profile for Sc

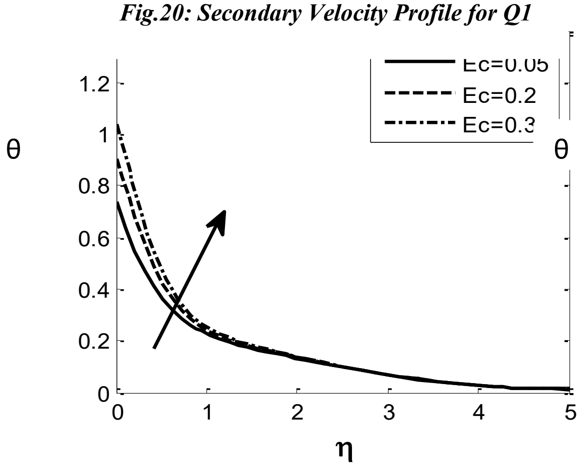

Fig.22: Temperature Profile for Ec

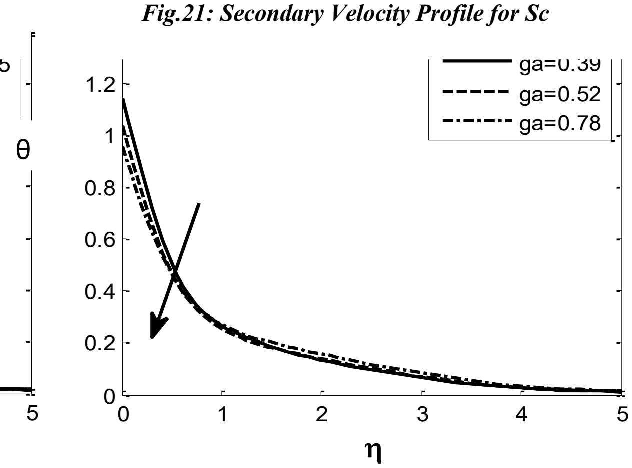

Fig.23: Temperature Profile for ga

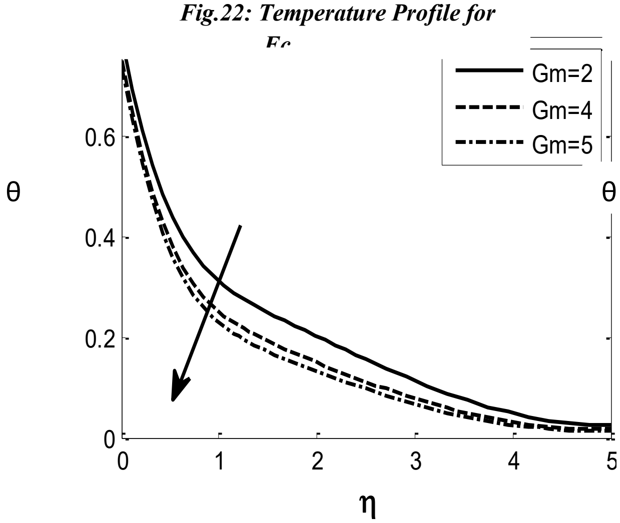

Fig.24: Temperature Profile for Gm

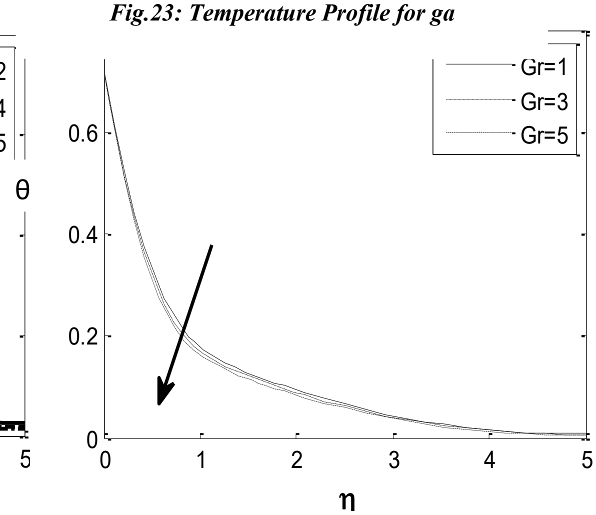

Fig.25: Temperature Profile for Gr

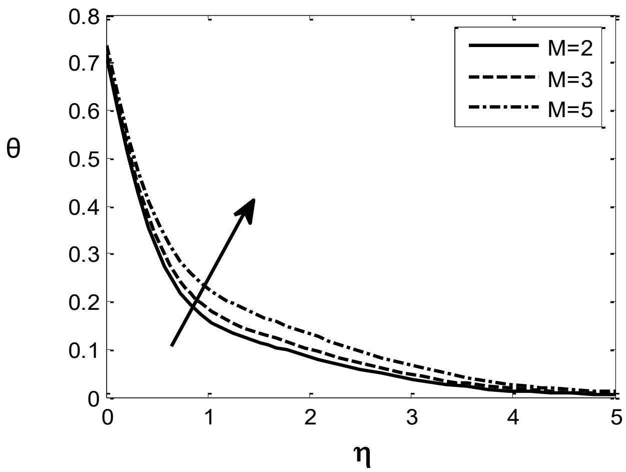

Fig.26: Temperature Profile for M

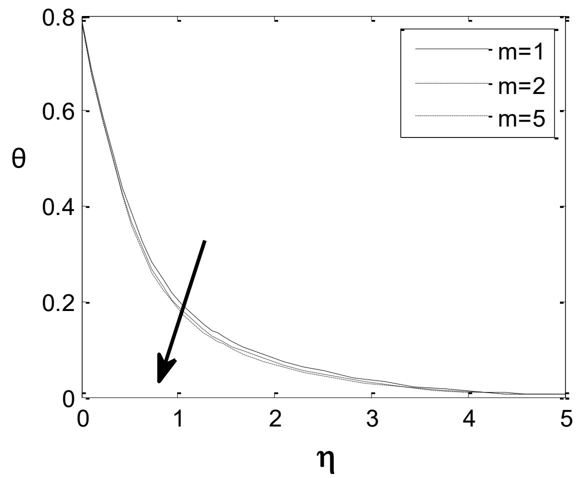

Fig.27: Temperature Profile for m

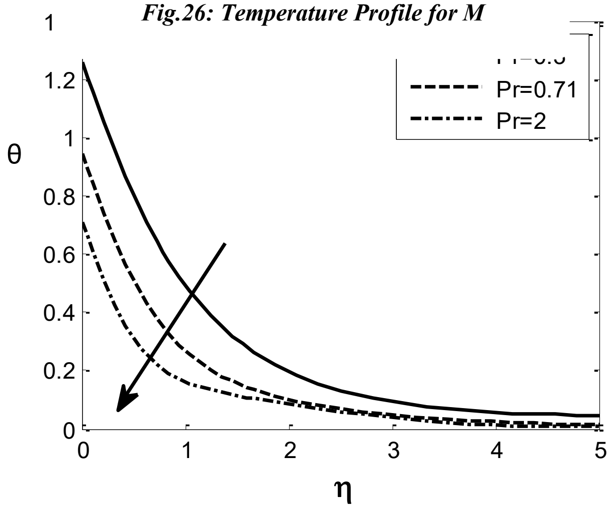

Fig.28: Temperature Profile for Pr

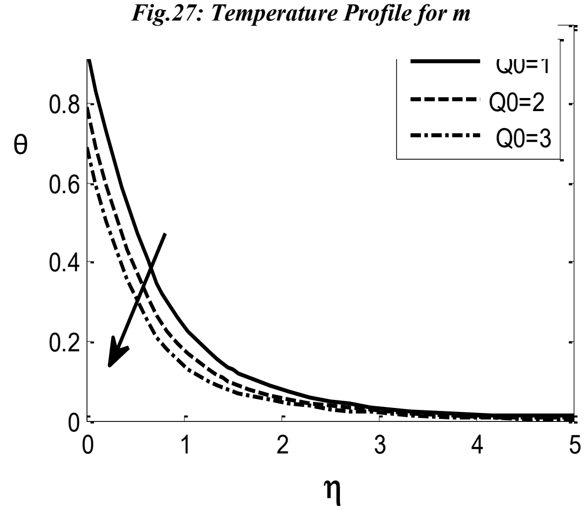

Fig.29: Temperature Profile for Q0

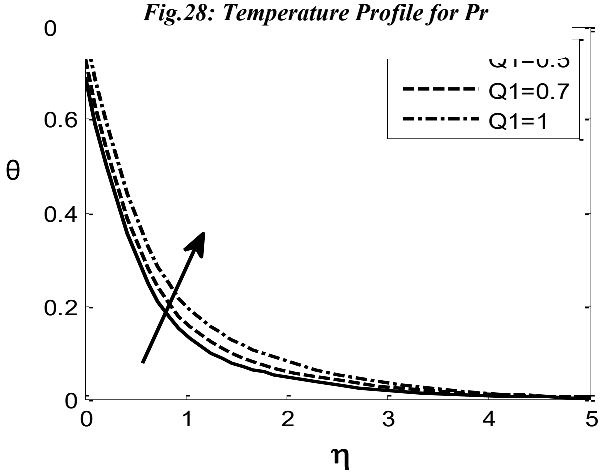

Fig.30: Temperature Profile for Q1

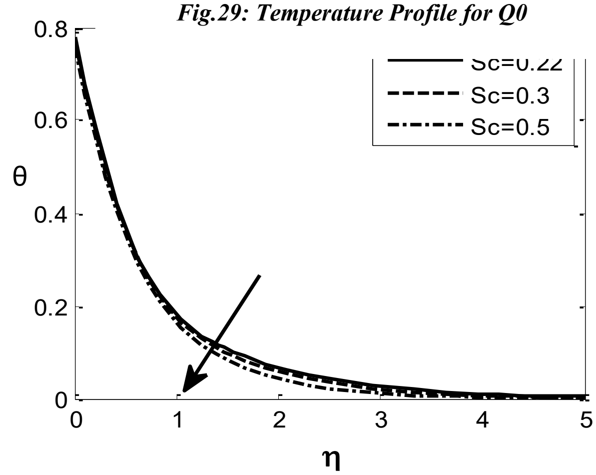

Fig.31: Temperature Profile for Sc

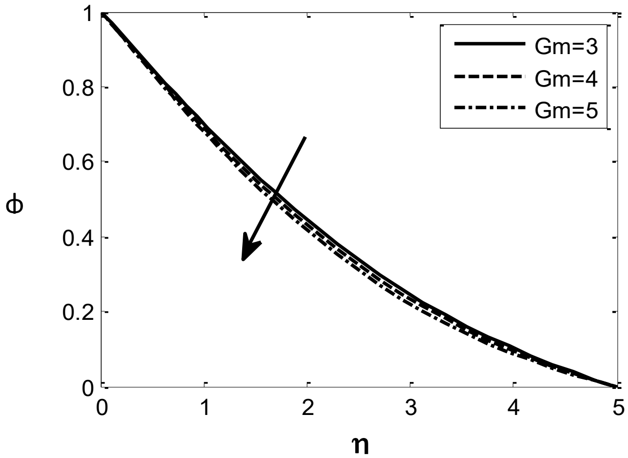

Fig.32: Concentration Profile for Gm

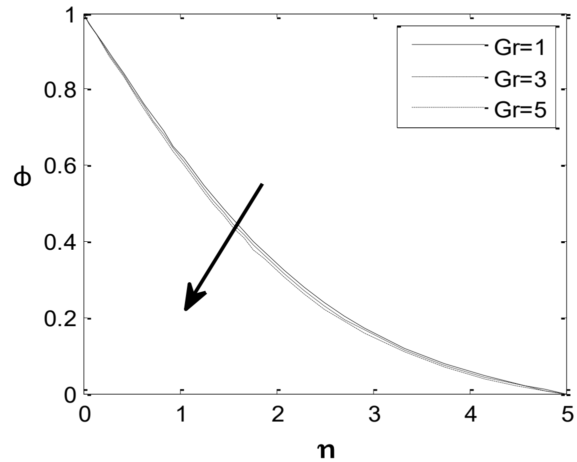

Fig.33: Concentration Profile for Gr

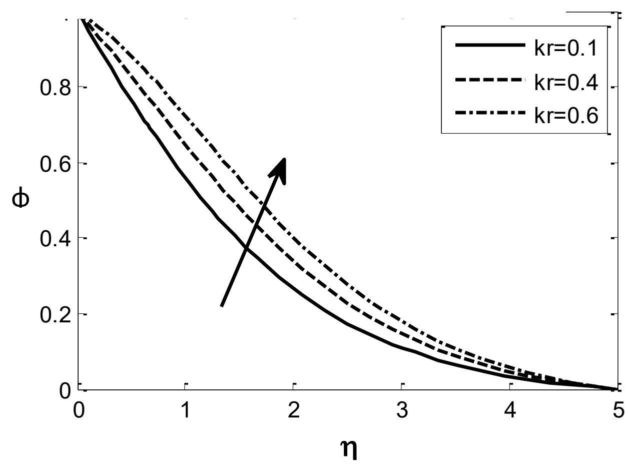

Fig.34: Concentration Profile for Kr

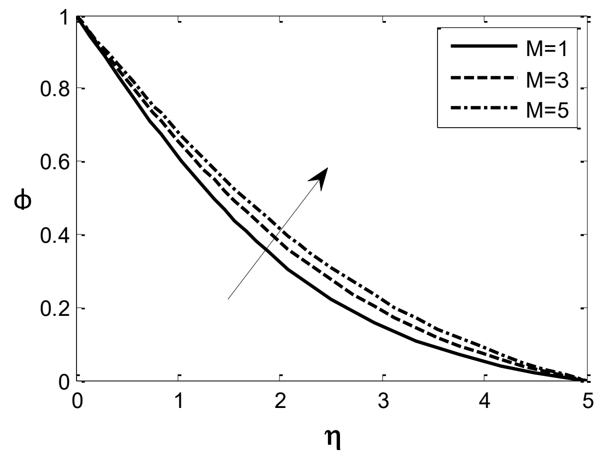

Fig.35: Concentration Profile for M

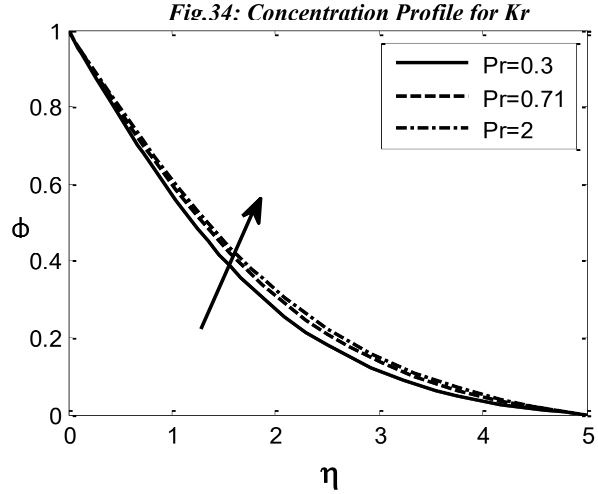

Fig.36: Concentration Profile for Pr

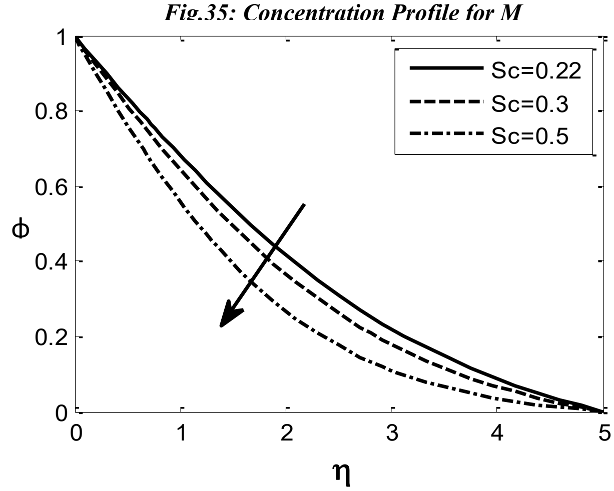

Fig.37: Concentration Profile for Sc

Table 1: Skin friction τ for different values of M, Pr, Sc, Gr, Gm, m, Kr, Q0, Q1 and γ

Pr	Gr	Gm	M	Sc	Ec	γ	Q0	Q1	Kr	m	Cf
0.71	2.00	2.00	0.50	0.22	0.05	0.52	1.00	0.50	1.00	0.01	3.91814
1.00	2.00	2.00	0.50	0.22	0.05	0.52	1.00	0.50	1.00	0.01	3.75508

0.71	**5.00**	2.00	0.50	0.22	0.05	0.52	1.00	0.50	1.00	0.01	5.63230
0.71	2.00	**5.00**	0.50	0.22	0.05	0.52	1.00	0.50	1.00	0.01	5.30166
0.71	2.00	2.00	**1.00**	0.22	0.05	0.52	1.00	0.50	1.00	0.01	3.72539
0.71	2.00	2.00	0.50	**1.00**	0.05	0.52	1.00	0.50	1.00	0.01	3.57246
0.71	2.00	2.00	0.50	0.22	**0.5**	0.52	1.00	0.50	1.00	0.01	5.16524
0.71	2.00	2.00	0.50	0.22	0.05	**0.79**	1.00	0.50	1.00	0.01	3.49655
0.71	2.00	2.00	0.50	0.22	0.05	0.52	**2.00**	0.50	1.00	0.01	5.44909
0.71	2.00	2.00	0.50	0.22	0.05	0.52	1.00	**1.00**	1.00	0.01	4.35199
0.71	2.00	2.00	0.50	0.22	0.05	0.52	1.00	0.50	**2.00**	0.01	5.78158
0.71	2.00	2.00	0.50	0.22	0.05	0.52	1.00	0.50	1.00	**0.50**	3.94287

Table 2: Nusselt number Nu for different values of Pr, Gr, Gm, M, m, Sc, Q0, Q1, Kr and γ

Pr	Gr	Gm	M	Sc	Ec	γ	Q0	Q1	Kr	m	Nu
0.71	2.00	2.00	0.50	0.22	0.05	0.52	1.00	0.50	1.00	0.01	0.51022
1.00	2.00	2.00	0.50	0.22	0.05	0.52	1.00	0.50	1.00	0.01	0.53320
0.71	**5.00**	2.00	0.50	0.22	0.05	0.52	1.00	0.50	1.00	0.01	0.60996
0.71	2.00	**5.00**	0.50	0.22	0.05	0.52	1.00	0.50	1.00	0.01	0.63326
0.71	2.00	2.00	**1.00**	0.22	0.05	0.52	1.00	0.50	1.00	0.01	0.47303
0.71	2.00	2.00	0.50	**1.00**	0.05	0.52	1.00	0.50	1.00	0.01	0.48082
0.71	2.00	2.00	0.50	0.22	**0.5**	0.52	1.00	0.50	1.00	0.01	0.28875
0.71	2.00	2.00	0.50	0.22	0.05	**0.79**	1.00	0.50	1.00	0.01	0.46613
0.71	2.00	2.00	0.50	0.22	0.05	0.52	**2.00**	0.50	1.00	0.01	0.29071
0.71	2.00	2.00	0.50	0.22	0.05	0.52	1.00	**1.00**	1.00	0.01	0.43144
0.71	2.00	2.00	0.50	0.22	0.05	0.52	1.00	0.50	**2.00**	0.01	0.17640
0.71	2.00	2.00	0.50	0.22	0.05	0.52	1.00	0.50	1.00	**0.5**	0.51392

Table 3: Sherwood number Sh for different values of Sc and Kr

Sc	kr	Sh
0.22	1.00	0.09704
1.00	1.00	0.25045
0.22	**2.00**	3.93633

REFERENCES

1. *Pop I. (1971): The effect of Hall currents on hydromagnetic flow near an accelerated plate. – J. Math. Phys. Sci. vol.5, pp.375-379.*
2. *Raptis A. and Singh A.K. (1981): MHD free convection flow past an accelerated vertical plate. – Letters in Heat and Mass Transfer, vol.8, pp.137-143.*
3. *Takhar H.S., Ram P.C. and Singh S.S. (1992): Hall effects on heat and mass transfer flow with variable suction and heat generation. – Astrophysics and Space Science, vol.191, No.1, pp.101-106.*
4. *T. Watanabe and I. Pop (1995): Hall effects on MHD boundary layer flow over a continuous moving flat plate. –Acta Mechanica, 108(1), 35-47, March 1995.*
5. *Pop, I. and Watanabe, T. (1994) Hall Effect on Magnetohydrodynamic Free Convection about a Semiinfinite Vertical Flat Plate. International Journal of Engineering Science, 32, 1903-1911. http://dx.doi.org/10.1016/0020-7225(94)90087-6*
6. *Eichhorn, R. (1960) The Effect of Mass Transfer on Free Convection. Journal of Heat Transfer, 82, 260-263. http://dx.doi.org/10.1115/1.3679928*
7. *Vedhanayagam, M., Altenkirch, R.A. and Echhorn, R.A. (1980) A Transformation of the Boundary Layer Equation for Free Convection Flow Past a Vertical Flat Plate with Arbitrary Blowing and Wall Temperature Variation. International Journal of Heat and Mass Transfer, 23, 1236-1288. http://dx.doi.org/10.1016/0017-9310(80)90059-9*
8. *Lin, H.T. and Yu, W.S. (1988) Free Convection on Horizontal Plate with Blowing and Suction. Journal of Heat Transfer, 110, 793-796. http://dx.doi.org/10.1115/1.3250564*
9. *Hossain, M.A., Alam, K.C.A. and Rees, D.A.S. (1997) MHD Free and Forced Convection Boundary Layer Flow along a Vertical Porous Plate. Applied Mechanics and Engineering, 2, 33-51.*

10. *Saha, L.K., Hossain, M.A. and Gorla, R.S.R. (2007) Effect of Hall Current on the MHD Laminar Natural Convection Flow from a Vertical Permeable Flat Plate with Uniform Surface Temperature. International Journal of Thermal Sciences, 46, 790-801. http://dx.doi.org/10.1016/j.ijthermalsci.2006.10.009*
11. *Saha, L.K., Siddiqa, S. and Hossain, M.A. (2011) Effect of Hall Current on MHD Natural Convection Flow from Vertical Permeable Flat Plate with Uniform Surface Heat Flux. Applied Mathematics and Mechanics, 32, 1127-1146. http://dx.doi.org/10.1007/s10483-011-1487-9*
12. *Bég, O.A., Khan, M.S., Karim, I., Alam, M.M. and Ferdows, M. (2013) Explicit Numerical Study of Unsteady Hydromagnetic Mixed Convective Nanofluid Flow from an Exponentially Stretching Sheet in Porous Media. Applied Nanoscience, 4, 943-957. http://dx.doi.org/10.1007/s13204-013-0275-0*
13. *Ferdows, M., Khan, M.S., Alam, M.M. and Sun, S. (2012) MHD Mixed Convective Boundary Layer Flow of a Nanofluid through a Porous Medium Due to an Exponentially Stretching Sheet. Mathematical Problems in Engineering, 2012, Article ID: 408528. http://dx.doi.org/10.1155/2012/408528*
14. *Ferdows, M., Khan, M.S., Bég, O.A. and Alam, M.M (2013) Numerical Study of Transient Magnetohydrodynamic Radiative Free Convection Nanofluid Flow from a Stretching Permeable Surface. Journal of Process Mechanical Engineering, 228, 181-196. http://dx.doi.org/10.1177/0954408913493406*
15. *Khan, M.S., Karim, I., Islam, M.S. and Wahiduzzaman, M. (2014) MHD Boundary Layer Radiative, Heat Generating and Chemical Reacting Flow Past a Wedge Moving in a Nanofluid. Nano Convergence, 1, 20. http://dx.doi.org/10.1186/s40580-014-0020-8*
16. *Khan, M.S., Alam, M.M. and Ferdows, M. (2013) Effects of Magnetic Field on Radiative Flow of a Nanofluid Past a Stretching Sheet. Procedia Engineering, 56, 316-322. http://dx.doi.org/10.1016/j.proeng.2013.03.125*
17. *Khan, M.S., Karim, I., Ali, L.E. and Islam, I. (2012) Unsteady MHD Free Convection Boundary-Layer Flow of a Nanofluid along a Stretching Sheet with Thermal Radiation and Viscous Dissipation Effects. International Nano Letters, 2, 24. http://dx.doi.org/10.1186/2228-5326-2-24*
18. *Khan, M.S., Karim, I. and Biswas, H.A. (2012) Heat Generation, Thermal Radiation and Chemical Reaction Effects on MHD Mixed Convection Flow over an Unsteady Stretching Permeable Surface. International Journal of Basic and Applied Science, 1, 363-377.*
    Khan, M.S., Karim, I. and Biswas, H.A. (2012) Non-Newtonian MHD Mixed Convective Power-Law Fluid Flow over a Vertical Stretching Sheet with Thermal Radiation, Heat Generation and Chemical Reaction Effects. Academic Research International, 3, 80-92.
19. *Khan, M.S., Karim, I. and Islam, M.S. (2014) MHD Buoyancy Flows of Cu, Al2O3 and Tio2Nanofluid near Stagnation-Point on a Vertical Plate with Heat Generation. Physical Science International Journal, 4, 754-767. http://dx.doi.org/10.9734/PSIJ/2014/9074*
20. *Khan, M.S., Karim, I. and Islam, M.S. (2014) Possessions of Chemical Reaction on MHD Heat and Mass Transfer Nanofluid Flow on a Continuously Moving Surface. American Chemical Science Journal, 4, 401-415. http://dx.doi.org/10.9734/ACSJ/2014/5422*
21. *Khan, M.S., Wahiduzzaman, M., Karim, I., Islam, M.S. and Alam, M.M. (2014) Heat Generation Effects on Unsteady Mixed Convection Flow from a Vertical Porous Plate with Induced Magnetic Field. Procedia Engineering, 90, 238-244. http://dx.doi.org/10.1016/j.proeng.2014.11.843*
22. *Wahiduzzaman, M., Khan, M.S. and Karim, I. (2015) MHD Convective Stagnation Flow of Nanofluid over a Shrinking Surface with Thermal Radiation, Heat Generation and Chemical Reaction. Procedia Engineering, 105, 398-405. http://dx.doi.org/10.1016/j.proeng.2015.05. 025*
23. *Wahiduzzaman, M., Khan, M.S., Karim, I., Biswas, P. and Uddin, M.S. (2015) MHD Flow of Fluid over a Rotating Inclined Permeable Plate with Variable Reactive Index. Physical Science International Journal, 6, 144-162.*