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Effects of Radiation and Chemical Reaction on Mhd Boundary Layer Flow over A Moving Vertical Porous Plate with Heat Source

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ABSTRACT

We analyze the effects of radiation and chemical reaction on MHD boundary layer flow over a moving vertical porous plate with heat source. The partial differential equations governing the flow are solved numerically using the shooting technique. The influence of various parameters on velocity, temperature and concentration profiles, as well as Nusselt number and skin-friction coefficient are examined and presented graphically and through tables. We observed that rate of heat transfer are more influenced by radiation and chemical reaction parameters.

Key Words: Radiation, Chemical Reaction, Heat Source, MHD, Porous medium.

1 INTRODUCTION

The process of heat and mass transfer is encountered in aeronautics, fluid fuel nuclear reactor, chemical process industries and many engineering applications in which the fluid is the working medium. Bejan and Khair (1985) have investigated the vertical free convective boundary layer flow embedded in a porous medium resulting from the combined heat and mass transfer. Cheng and Minkowycz (1977) studied the problem of natural convection from a vertical flat plate embedded in a saturated porous medium where the wall temperature is a power function of the heat of the plate. The heat and mass transfer effects on a flow along a vertical plate in the presence of a magnetic field was investigated by Elbashbeshy (1997). Mass transfer effects on the flow past an exponentially accelerated vertical plate with constant heat flux was studied by Jha et al. (1991). Das et al. (1999) have studied effects of mass transfer on flow past an impulsively started vertical infinite plate with constant heat flux and chemical reaction. The influence of magnetic field on an electrically conducting viscous incompressible fluid is extensively used in many applications. Because of its application for MHD natural convection flow in the nuclear engineering where convection aids the cooling of reactors, the natural convection boundary layer flow of an electrically fluid up a hot vertical wall in the presence of strong magnetic field has been studied by several authors such as Sparrow and Cess (1961), Riley (1964) and Kuiken (1970). Simultaneous occurrence of buoyancy and magnetic field forces up a hot vertical flat plate in the presence of a strong cross magnetic field was studied by Singh and Cowling (1963) who have shown that regards of strength of applied magnetic field there will always be a region in the neighborhood of the leading edge of the plate where electromagnetic forces are unimportant. The investigation of boundary layer flow and mass transfer past a vertical plate in a porous medium with constant heat flux in presence of transverse magnetic field has been done by Makinde (2009). The effects of transversely applied magnetic field on the flow of an electrically conducting fluid past an impulsively started isothermal vertical plate was studied by Soundalgekar et al. (1979). MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field were studied by Soundalgekar et al. (1981). The dimensionless governing equations were solved using Laplace transform technique.

Radiative heat and mass transfer play an important role in manufacturing industries for the design of reliable equipment. Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering applications. If the temperature of surrounding fluid is rather high, radiation effects play an important role and this situation does not exist in space technology. In such cases one has to take into account the effect of thermal radiation and mass diffusion. Influence of thermal radiation on transient magneto hydrodynamic coutte flow through a porous medium by using finite difference method discussed by Baoku et al. (2012). The effect of radiation on MHD flow and heat transfer must be considered when high temperatures are reached. Ghaly (2002) employed symbolic computation software Mathematica to study the effect of radiation on heat and mass transfer over a stretching sheet in the presence of a magnetic field. Raptis et al. (2003) studied the effect of radiation on 2D steady MHD optically thin gray gas flow along an infinite vertical plate taking into account the induced magnetic field.

The study of heat and mass transfer in a moving fluid is important in view of several physical problems, such as fluids undergoing exothermic and endothermic chemical reaction. Kandasamy et al. (2005) studied the effects of chemical reaction heat and mass transfer along a wedge with heat source and concentration in the presence of suction or injection. Das et al (1994) have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. Mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction studied by Das et al. (1999). Al-Qadat and Al-Azab (2007) studied the influence of chemical reaction on transient MHD free convection flow over a moving vertical plate. Chamka and Ahmed (2011) found the similarity solution for an unsteady magneto hydrodynamic flow near a stagnation point of a three-dimensional porous body with heat and mass transfer, heat generation/absorption and chemical reaction.

The present study is of immediate application to all those processes which are highly affected with heat enhancement concept. It is pertinent to mention here that some researchers have pursued their investigations with heat source but the effects of radiation, chemical reaction, magnetic field on MHD boundary layer flow over a moving vertical porous plate is presented in this paper clearly.

2 MATHEMATICAL ANALYSYS

We analyze the effects of two-dimensional free convection flow on the steady incompressible laminar MHD heat and mass transfer characteristics of a linearly started porous vertical plate. The velocity of the fluid which is assumed to be zero far away from the plate surface. For a quiescent state fluid, the surface temperature and concentration are taken to be linear. All the fluid properties are assumed to be constant except for the density variations in the buoyancy force term. For the linear momentum equation because of the magnetic Reynolds number is assumed to be small. So that the induced magnetic field is neglected. No electrical field is assumed to exist and both viscous and magnetic dissipations are neglected. Here we neglect the Hall effects, the viscous dissipation and the joule heating terms. With these assumptions, along with Boussinesq approximations, the boundary layer equations are described as

Continuity equation:

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

Momentum equation:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)+g\beta(C-C_\infty)-\frac{\sigma B_0^2}{\rho}u-\frac{\upsilon}{k^{'}}u \tag{2}$$

Energy equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y}+\frac{Q}{\rho C_p}(T-T_\infty) \tag{3}$$

Species diffusion equation:

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-K_l^{'}C \tag{4}$$

The corresponding boundary conditions are

$$\begin{aligned}&u=Bx,\ v=V,\ T=T_w=T_\infty+ax, C=C_w=C_\infty+bx \qquad \text{at}\quad y=0\\&u\to 0,\ T\to T_\infty,\ \ C\to C_\infty \qquad as\quad y\to\infty\end{aligned} \tag{5}$$

where x and y represent the coordinate axes along the continuous moving vertical surface in the direction of motion and normal to it respectively, u and v are the velocity components along the x and y axes respectively, υ is the kinematic viscosity, β, β^* are the thermal and concentration expansion coefficients respectively, σ is the electric conductivity, B_0 is the uniform magnetic field, ρ is the density, $k^{'}$ is the permeability of the porous medium, T is the temperature inside the boundary layer, T_∞ is the temperature far away from the plate, C is the species concentration in the boundary layer, C_∞ Species concentration of the ambient fluid, D is the is the molecular diffusivity of the species concentration, $K_l^{'}$ is the chemical reaction parameter, K_l is the dimensionless chemical reaction parameter, B is a constant, a and b denotes the stratification rate of the gradient of ambient temperature and concentration profiles.

By using Roseland approximation, the Radiative heat flux q_r is given by

$q_r = -\dfrac{4\sigma^*}{3k^*}\dfrac{\partial T^4}{\partial y}$ Where σ^* is the Steffen Boltzmann constant and k^* is the mean absorption coefficient.

Considering the temperature differences within the flow sufficiently small such that T^4 may be expressed as the linear function of temperature. Then expanding T^4 in Taylor series about T_∞ and neglecting higher-order terms, we get $T^4 \cong 4T_\infty^3 T - 3T_\infty^4$.

We introduce the following non-dimensional quantities as:

$$M = \frac{\sigma B_0^{\,2}}{\rho B},\ H = \frac{Q}{B\rho C_p},\ \Pr = \frac{\mu C_p}{k},\ K = \frac{\upsilon}{k^{'}B},\ Sc = \frac{\upsilon}{D},$$

$$Gr = \frac{g\beta(T_w - T_\infty)}{xB^2}, Gc = \frac{g\beta^*(C_w - C_\infty)}{xB^2},\ \theta = \frac{T - T_\infty}{T_w - T_\infty}, \tag{6}$$

$$\phi = \frac{C - C_\infty}{C_w - C_\infty}, R = \frac{16T_\infty^3\sigma^*}{3kk^*}, K_l = \frac{K_l^{'}}{B}$$

$$\eta = \sqrt{\frac{B}{v}}\,y,\ f(\eta) = \frac{\psi}{x\sqrt{Bv}} \tag{7}$$

where $F(\eta)$ is a dimensionless stream function, $\theta(\eta)$ is a dimensionless temperature of the fluid in the boundary layer region, $\phi(\eta)$ is a dimensionless species concentration of the fluid in the boundary layer region and η is the similarity variable. The velocity components u and v are defined as follows

$$u = \frac{\partial\psi}{\partial y} = xBf^{'},\quad v = -\frac{\partial\psi}{\partial x} = -\sqrt{B\upsilon}\,f \tag{8}$$

where $f_w = \dfrac{V}{\sqrt{\upsilon B}}$ is the suction parameter.

In view of the equations (6), (7) and (8) the Equations (2) to (4) takes the form as below

$$f''' + ff'' - (f')^2 + Gr\theta + Gc\phi - (M + K)f' = 0 \tag{9}$$

$$(1+R)\theta'' - \Pr\left[\left(f' - H\right)\theta - f\theta'\right] = 0 \tag{10}$$

$$\phi'' - Sc\left[\left(f' + K_l\right)\phi - f\phi'\right] = 0 \tag{11}$$

where the primes denote the differentiation with respect to η, M is the magnetic parameter, K is the permeability parameter, Gr is the local temperature (Grashof number), Gc is the local concentration (modified Grashof number), $\Pr$ is the Prandtl number, R is the Radiative parameter and Sc is the Schmidt number.

The corresponding boundary conditions are

$$\begin{aligned} &f' = 1, f = -f_w,\ \theta = 1,\ \phi = 1 \quad \text{at} \quad \eta = 0 \\ &f' = 0,\ \theta = 0,\ \phi = 0 \quad \text{as} \quad \eta \to \infty \end{aligned} \tag{12}$$

Numerical Procedure:

The set of equations (9) to (11) under the boundary conditions (12) have been solved numerically using the shooting method. We consider $f = x_1,\ f' = x_2,\ f'' = x_3,\ \theta = x_4,\ \theta' = x_5,\ \varphi = x_6,\ \varphi' = x_7$. Equations (9) t0 (11) are transformed into systems of first order differential equations as follows:

$$\left.\begin{aligned} x_1' &= x_2 \\ x_2' &= x_3 \\ x_3' &= -x_1x_3 + x_2^{\ 2} + Mx_2 - Grx_4 - Gcx_6 \\ x_4' &= x_5 \\ x_5' &= -\Pr x_1x_5 + \Pr x_2x_4 \\ x_6' &= x_7 \\ x_7' &= -Scx_1x_7 + Scx_2x_6 \end{aligned}\right\} \tag{13}$$

Subject to the following initial conditions

$$\begin{aligned} &x_1(0) = -f_w,\ x_2(0) = 1,\ x_3(0) = s_1 \\ &x_4(0) = 1,\ x_5(0) = s_2,\ x_6(0) = 1,\ x_7(0) = s_3 \end{aligned} \tag{14}$$

In shooting method, we assume the unspecified initial conditions $s_1,\ s_2\ and\ s_3$ in equation (14). Equation (13) is then integrated numerically as an initial valued problem to a given terminal point. We can check the accuracy of the assumed missing initial condition. By comparing the calculated value of the different variable at the terminal point with the given value by the existence of the difference in improved values the missing initial conditions must be obtained. The calculations are carried out the program by using MATLAB.

3 SOLUTION OF THE PROBLEM

The governing boundary layer equations (9) to (11) subject to boundary conditions (12) are solved numerically by using shooting method. First of all higher order non-linear differential equations (9) to (11) are converted into simultaneous linear differential equations of first order and they are further transformed into initial value problem by applying the shooting technique. From the process of numerical computation, the skin-friction coefficient, the Nusselt number and 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.

The Skin – Friction and the rate of heat and mass transfer are the most important characteristics of the flow which are defined as

The coefficient of skin-Friction

$$C_f = \frac{\tau_w}{\mu B x \sqrt{\frac{B}{\upsilon}}} = f^{''}(0) \tag{15}$$

where $\tau_w = \mu(\partial u/\partial y)_{y=0} = \mu B x \sqrt{\frac{B}{\upsilon}} f^{''}(0)$

The coefficient of rate of heat transfer

$$Nu = -\frac{q_w}{k\sqrt{\frac{B}{\upsilon}}(T_w - T_\infty)} = -\theta^{'}(0) \tag{16}$$

where $q_w = -k(\partial T/\partial y)_{y=0} = -k\sqrt{\frac{B}{\upsilon}}(T_w - T_\infty)\theta^{'}(0)$

The coefficient of rate of mass transfer

$$Sh = -\frac{m_w}{D\sqrt{\frac{B}{\upsilon}}(C_w - C_\infty)} = -\phi^{'}(0) \tag{17}$$

Where $m_w = -D(\partial C/\partial y)_{y=0} = -D\sqrt{\frac{B}{\upsilon}}(C_w - C_\infty)\phi^{'}(0)$

4 RESULTS AND DISCUSSION

The velocity, temperature and concentration profiles for different parameters like Magnetic field parameter M , Grashof number Gr ,modified Grashof number Gc , Schmidt number Sc , Radiation parameter R , Prandtl number $\Pr$, Heat source H and Suction parameter f_w are shown in figures 1 to 21.

Effect of Magnetic parameter M on velocity profiles is shown in figure 1. It is observed that the velocity decreases with an increase of M. Figures 2 and 3 shows the influence of Magnetic parameter M on temperature and concentration profiles. It is noticed that an increase in M contributes the increase of temperature and concentration of the fluid medium respectively. Figure 4 shows that the effect of Grashof number on velocity profiles. It is seen that the velocity increases with the increase of Grashof number. Figures 5 & 6 illustrate the temperature and concentration profiles for different values of Grashof number. It is clear that the temperature and concentration are decreases with an increase of Grashof number. Figures 7 and 8 shows the variation of velocity and temperature for different values of Radiation parameter R. It is observed that the velocity and temperature increases with an increase of Radiation parameter. Figures 9 to 11 shows the effect of velocity, temperature and concentration for different values of Schmidt number Sc . It is clear that the velocity and concentration decreases with an increase of Sc but temperature increases with an increase of Sc . The velocity and temperature profiles for different values of Heat source parameter H is represented in figures 12 and 13. It is clear that the velocity and temperature increases with an increase of H . Figures 14 to 16 represents the velocity, temperature and concentration profiles for different values of suction parameter f_w . It is noticed that the velocity, temperature and concentration increases with an increase of Suction parameter f_w . The velocity profiles for different values of modified Grashof number Gc are shown in figure 17. It is observed that the velocity increases when modified Grashof number Gc is increased but after $y = 2$ we notice the reversal effect. Figures 18 and 19 shows the temperature and concentration profiles for different values of modified Grashof number Gc . It is clear that with an increase in Gc the temperature and concentration decreases. The effect of Prandtl number $\Pr$ on velocity and temperature profiles is shown in figures 20 and 21. It is noticed that the Pr increases, the velocity and temperature increases. The velocity and temperature profiles for different values of chemical reaction parameter are represented in Figures 22 to 24. From figures 22 and 23 it is observed that the velocity and concentration decreases with an increase of chemical reaction parameter but from figure 24 we found that increase in chemical reaction parameter causes the increase in temperature. From table 1 it is observed that the Skin-friction coefficients, Nusselt number and Sherwood number are more influenced by radiation and chemical reaction parameter.

TABLE-1**:** Numerical values of the Skin-friction coefficients, Nusselt number and Sherwood number for M, Gr, Gc, R, K, Pr, Sc, H, f_w and K_l

M	Gr	Gc	R	K	f_w	K_l	$\Pr$	Sc	H	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
1	3	2	2	0.1	0.1	0.5	0.71	0.60	0.1	0.673588	0.541506	1.081608
2	3	2	2	0.1	0.1	0.5	0.71	0.60	0.1	0.212206	0.504806	1.039830
1	5	2	2	0.1	0.1	0.5	0.71	0.60	0.1	1.430087	0.590041	1.138076
1	3	4	2	0.1	0.1	0.5	0.71	0.60	0.1	1.286949	0.568367	1.118264
1	3	2	4	0.1	0.1	0.5	0.71	0.60	0.1	0.743634	0.429851	1.093810
1	3	2	2	0.5	0.1	0.5	0.71	0.60	0.1	0.479238	0.525987	1.064018
1	3	2	2	0.1	0.5	0.5	0.71	0.60	0.1	0.720468	0.504587	0.969380
1	3	2	2	0.1	0.1	1	0.71	0.60	0.1	0.647709	0.538477	1.209094
1	3	2	2	0.1	0.1	0.5	3	0.60	0.1	0.390740	1.097804	1.032124
1	3	2	2	0.1	0.1	0.5	0.71	0.78	0.1	0.638061	0.536999	1.230682
1	3	2	2	0.1	0.1	0.5	0.71	0.60	0.5	0.723759	0.452899	1.090096

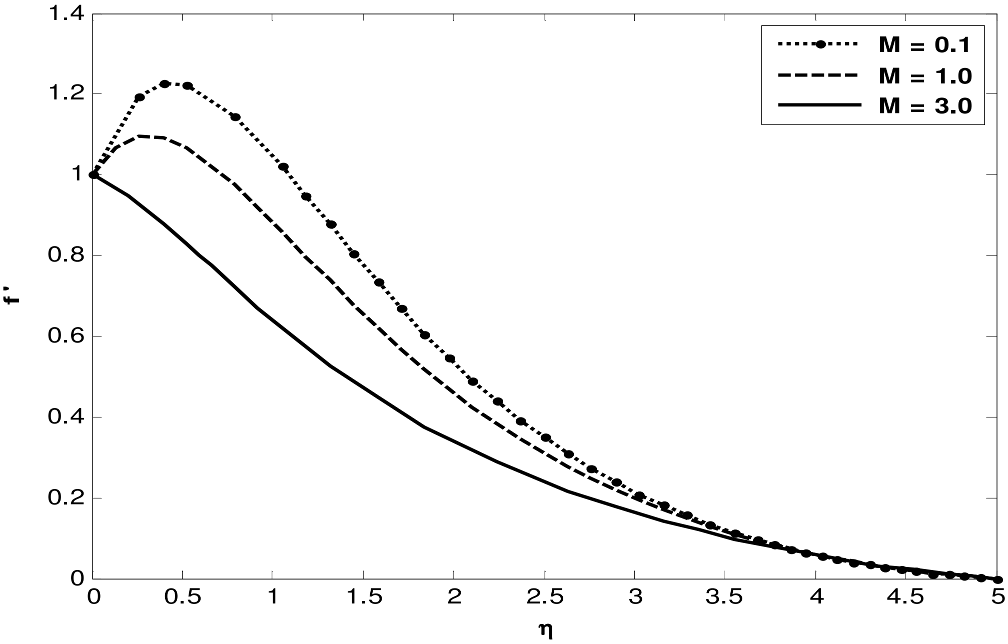

Fig.1: Velocity profiles for different values of M when $\Pr$ =0.71,

Gr =3, Gc =2, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

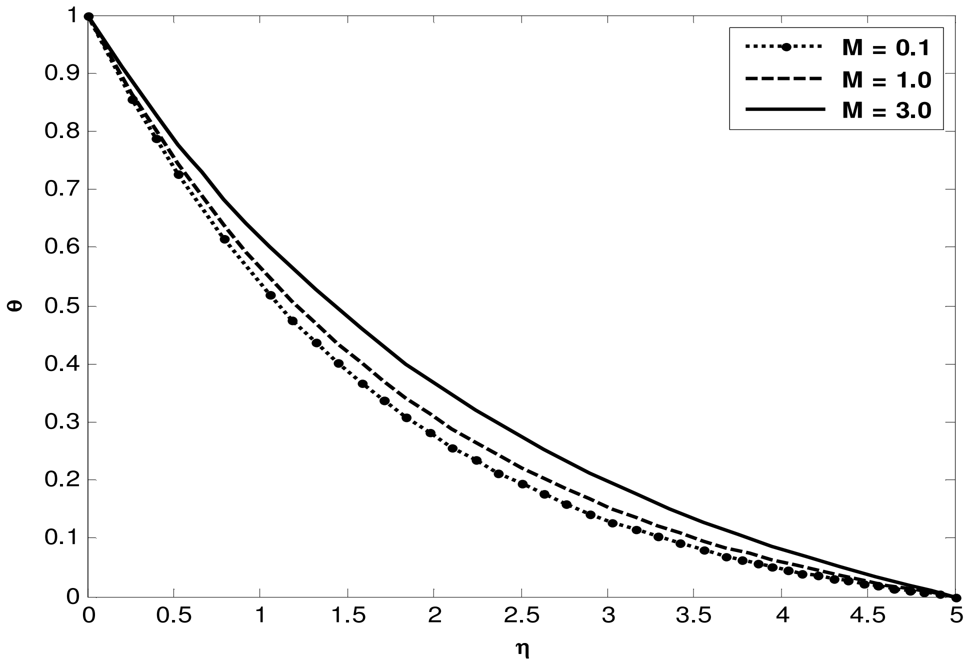

Fig.2: Temperature profiles for different values of M when $\Pr$ =0.71,

Gr =3, Gc =2, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

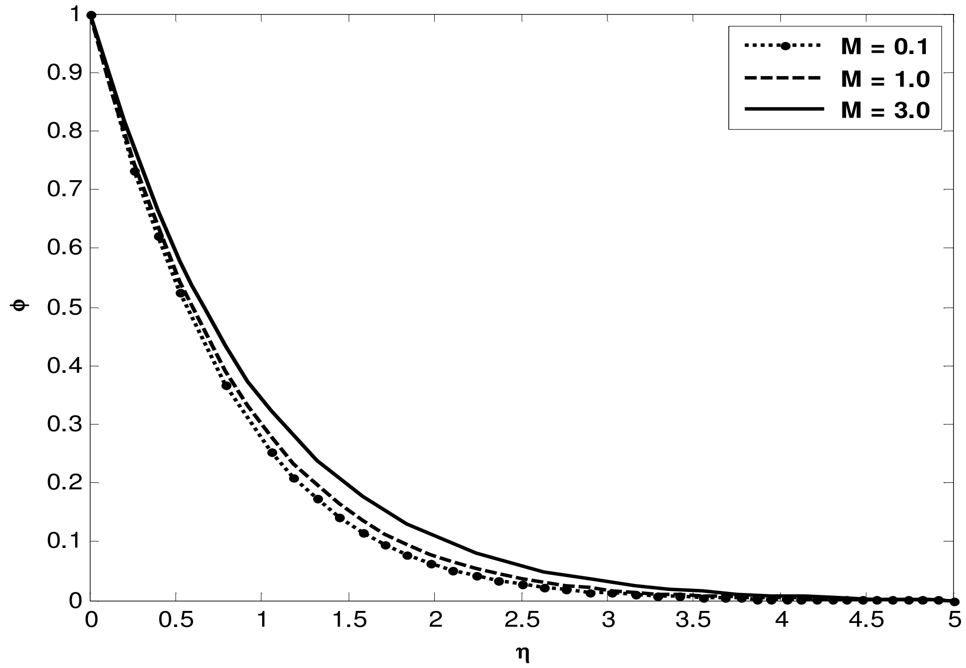

Fig.3: Concentration profiles for different values of M when $\Pr = 0.71$,

$Gr = 3$, $Gc = 2$, $R = 2$, $K = 0.1$, $Sc = 0.60$, $H = 0.1$, $f_w = 0.1$, $K_l = 0.5$.

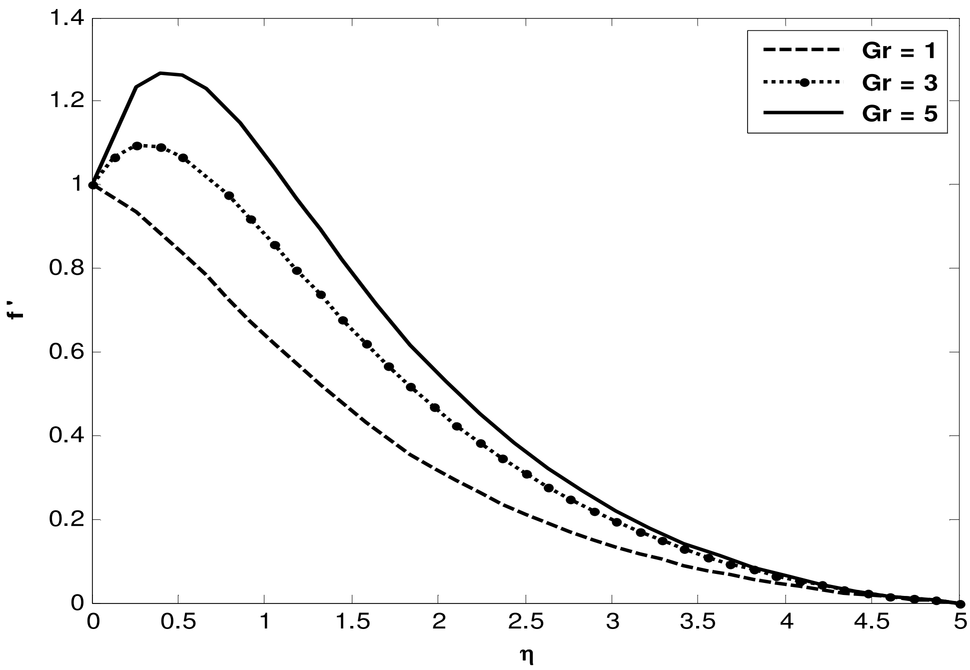

Fig.4: Velocity profiles for different values Gr of when $\Pr = 0.71$,

$M = 1$, $Gc = 2$, $R = 2$, $K = 0.1$, $Sc = 0.60$, $H = 0.1$, $f_w = 0.1$, $K_l = 0.5$.

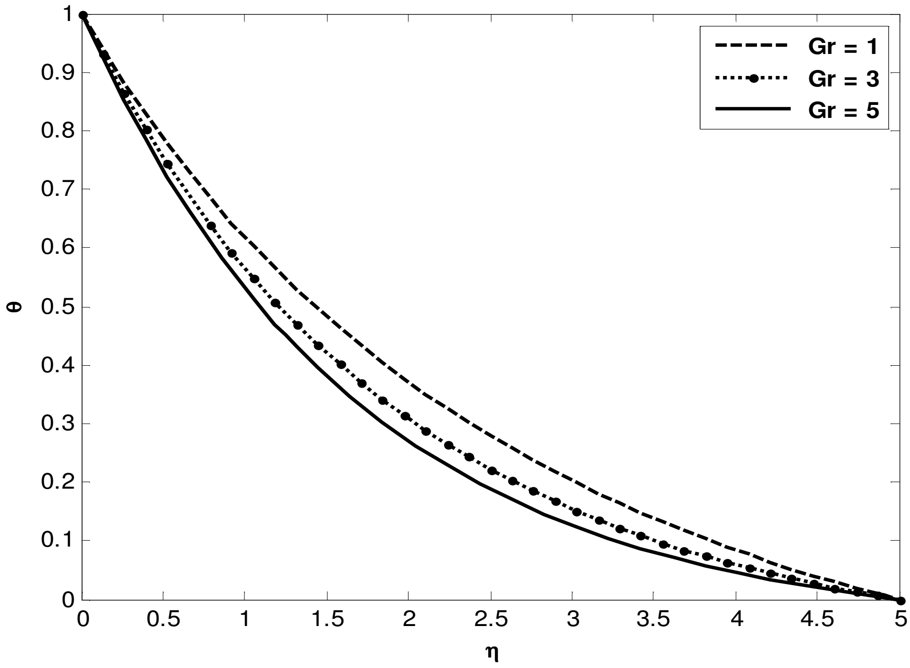

Fig.5: Temperature profiles for different values of Gr when M =1, $\Pr$ =0.71, Gc =2, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

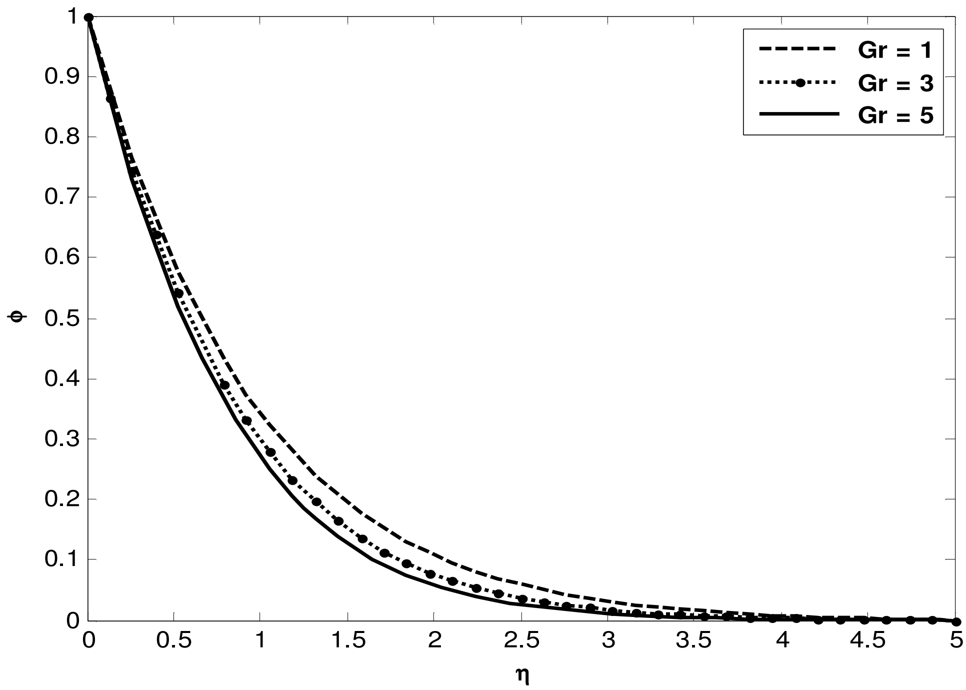

Fig.6: Concentration profiles for different values Gr of when $\Pr$ =0.71, M =1, Gc =2, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

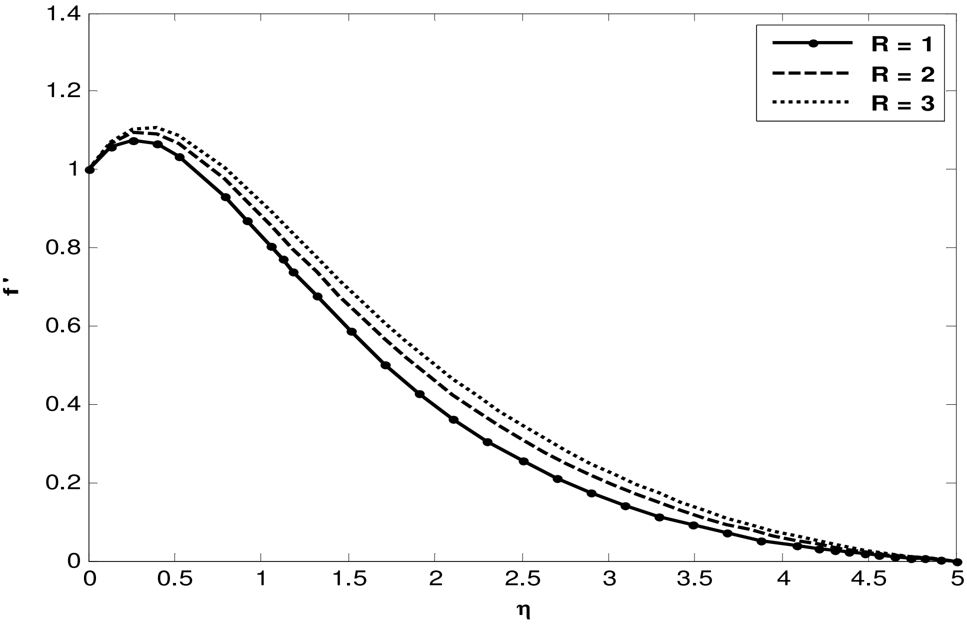

Fig.7: Velocity profiles for different values R of when $\Pr$ =0.71,

Gr =3, Gc =2, M =1, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

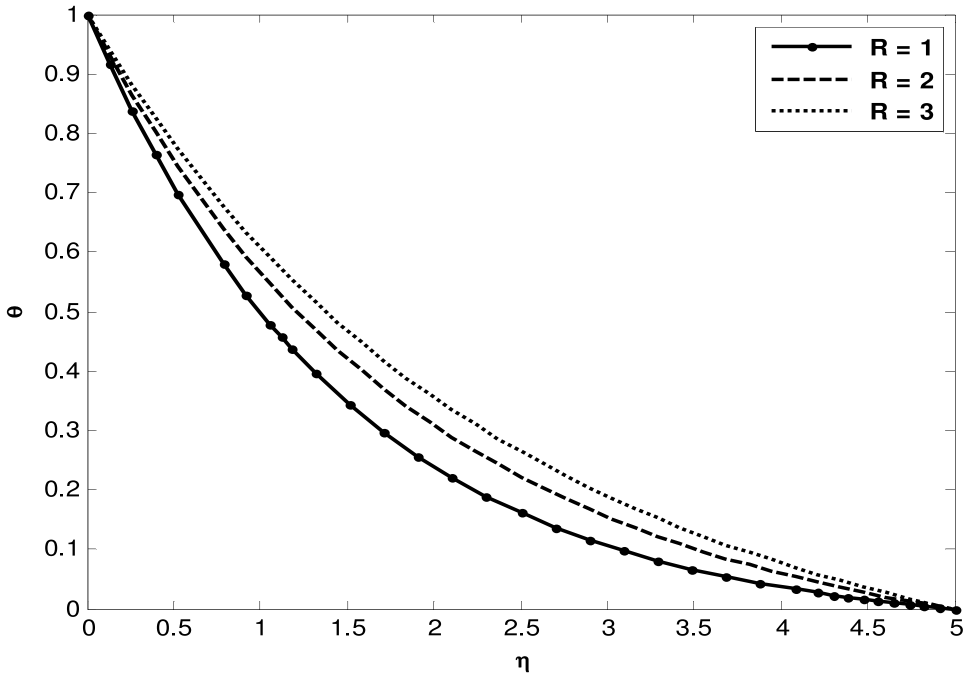

Fig.8: Temperature profiles for different values of R when M =1,

Gr =3, Gc =2, $\Pr$ =0.71, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

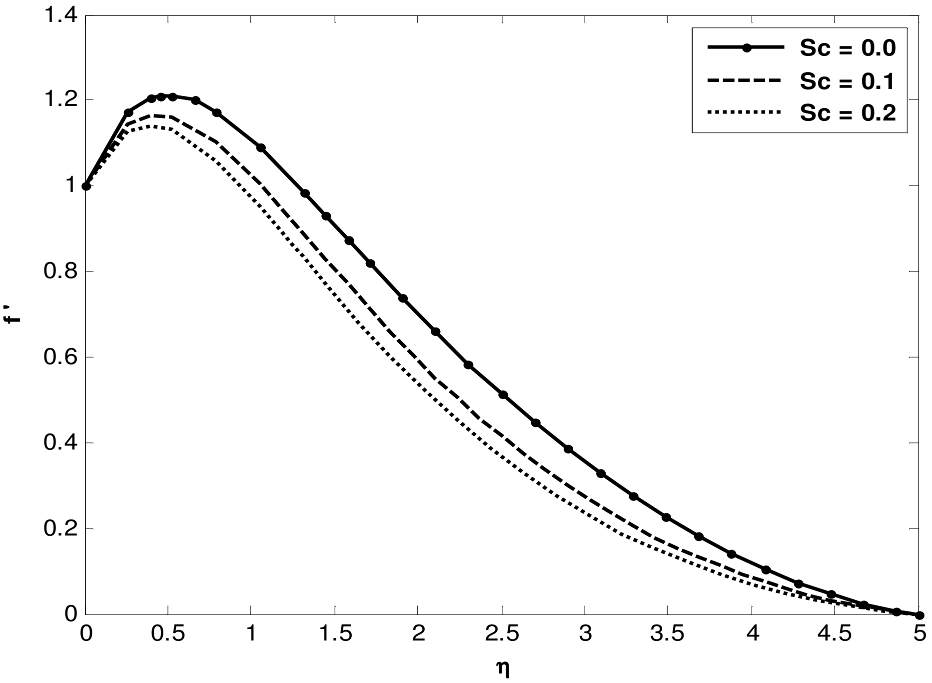

Fig.9: Velocity profiles for different values Sc of when $\Pr = 0.71$,

$Gr = 3$, $Gc = 2$, $R = 2$, $K = 0.1$, $M = 1$, $H = 0.1$, $f_w = 0.1$, $K_l = 0.5$.

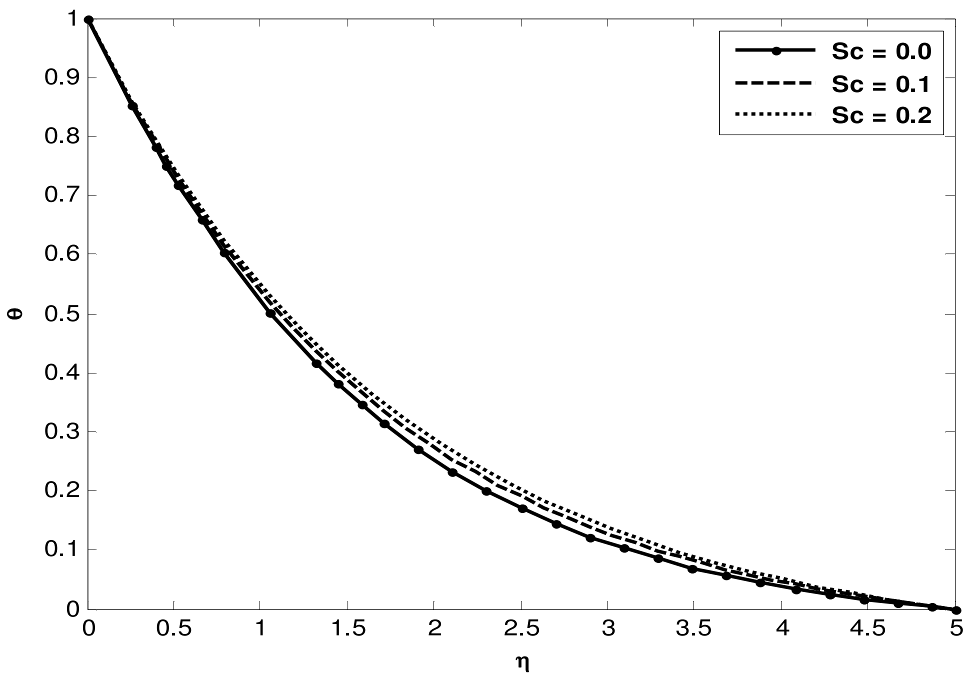

Fig.10: Temperature profiles for different values of Sc when $M = 1$,

$Gr = 3$, $Gc = 2$, $R = 2$, $K = 0.1$, $\Pr = 0.71$, $H = 0.1$, $f_w = 0.1$, $K_l = 0.5$.

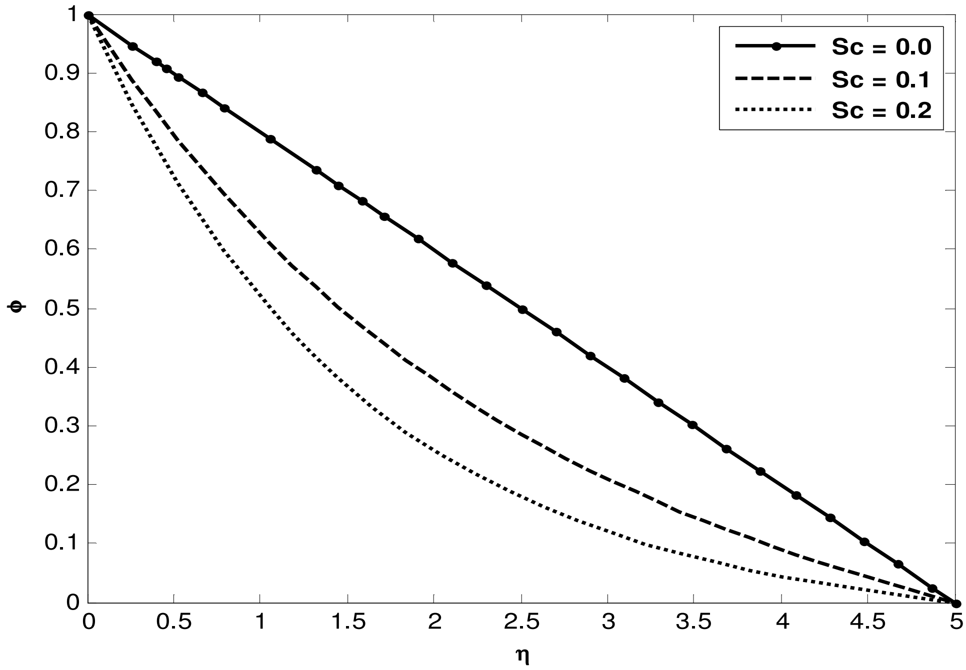

Fig.11: Concentration profiles for different values Sc of when $\Pr$ =0.71, Gr =3, Gc =2, R =2, K =0.1, M =1, H =0.1, f_w =0.1, K_l =0.5.

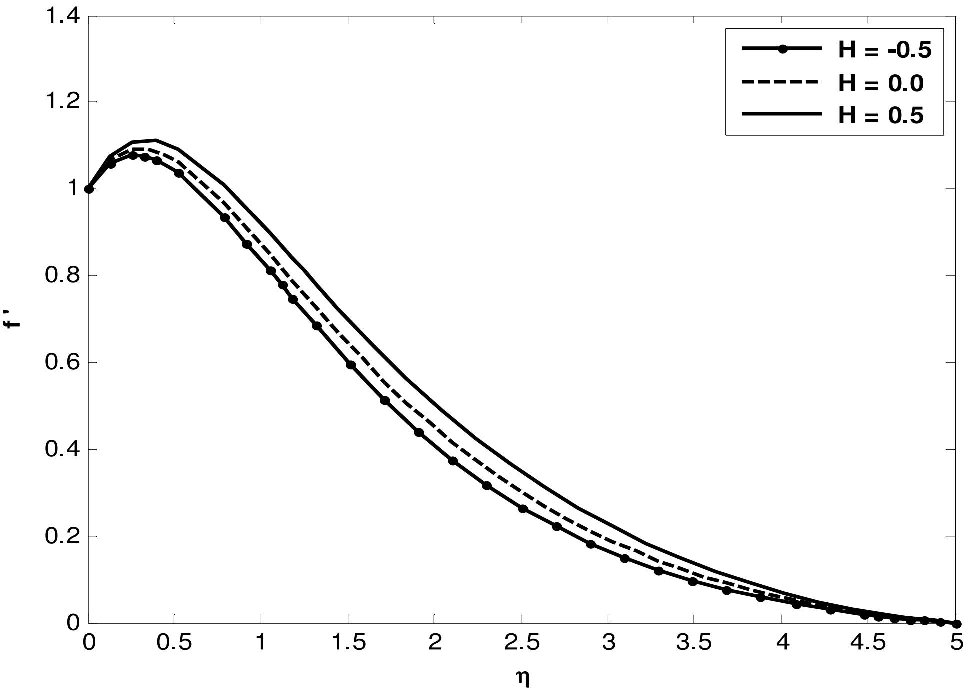

Fig.12: Velocity profiles for different values H of when $\Pr$ =0.71, Gr =3, Gc =2, R =2, K =0.1, Sc =0.60, M =1, f_w =0.1, K_l =0.5.

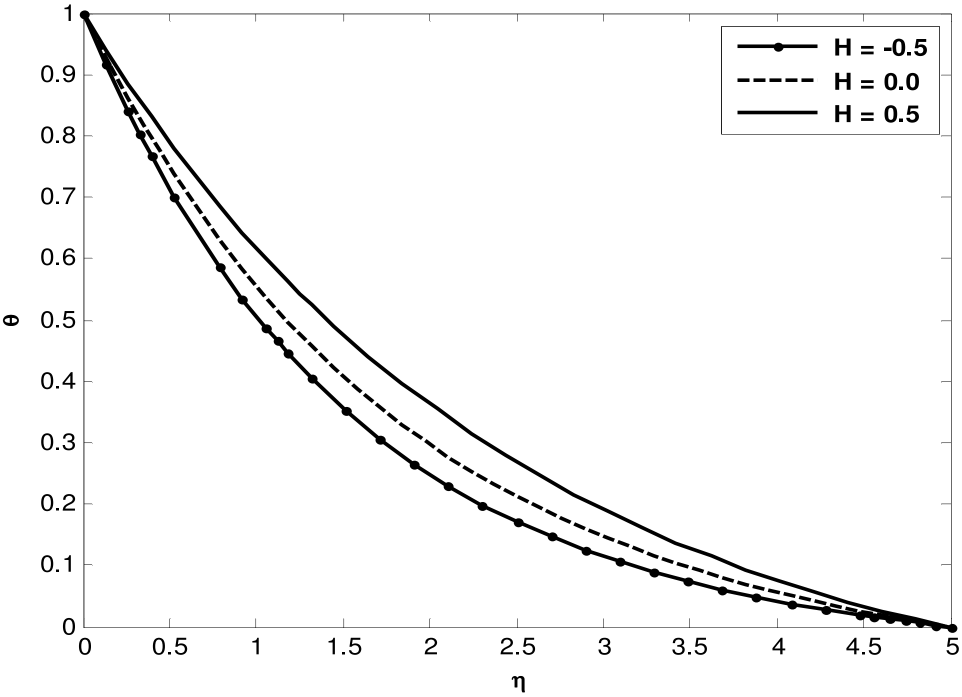

Fig.13: Temperature profiles for different values H of when M =1, Gr =3, Gc =2, R =2, K =0.1, Sc =0.60, $\Pr$ =0.71, f_w =0.1, K_l =0.5.

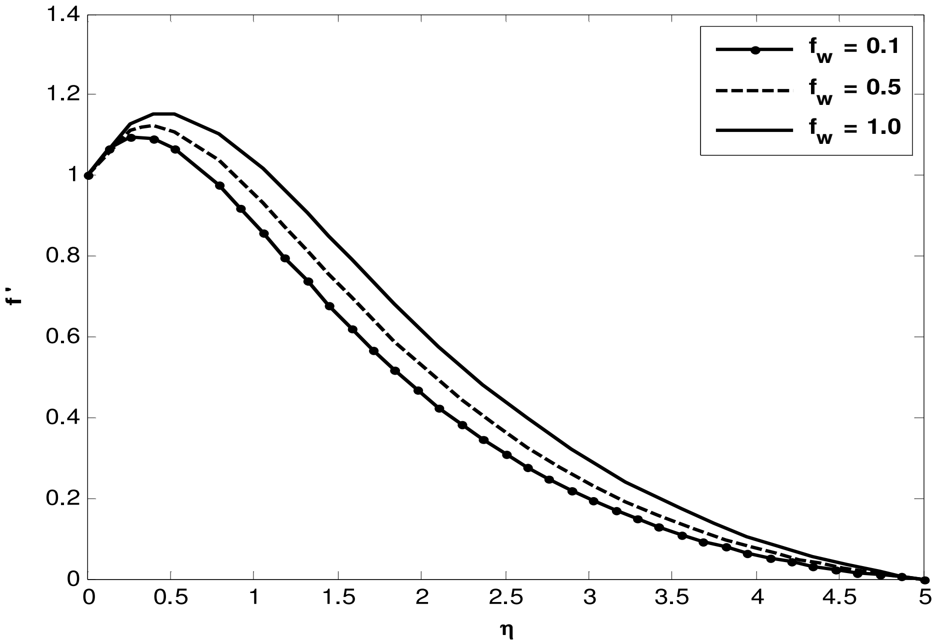

Fig.14: Velocity profiles for different values f_w of when $\Pr$ =0.71, Gr =3, Gc =2, R =2, K =0.1, Sc =0.60, H =0.1, M =1, K_l =0.5.

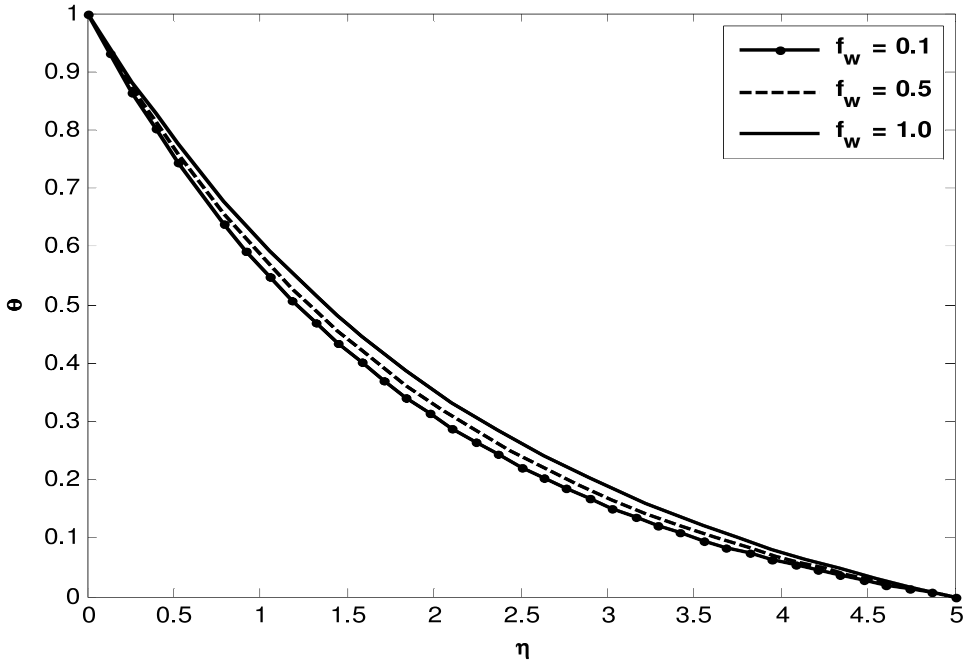

Fig.15: Temperature profiles for different values of f_w when M =1,

Gr =3, $\Pr$ =0.71, R =2, K =0.1, Sc =0.60, H =0.1, Gc =0.1, K_l =0.5.

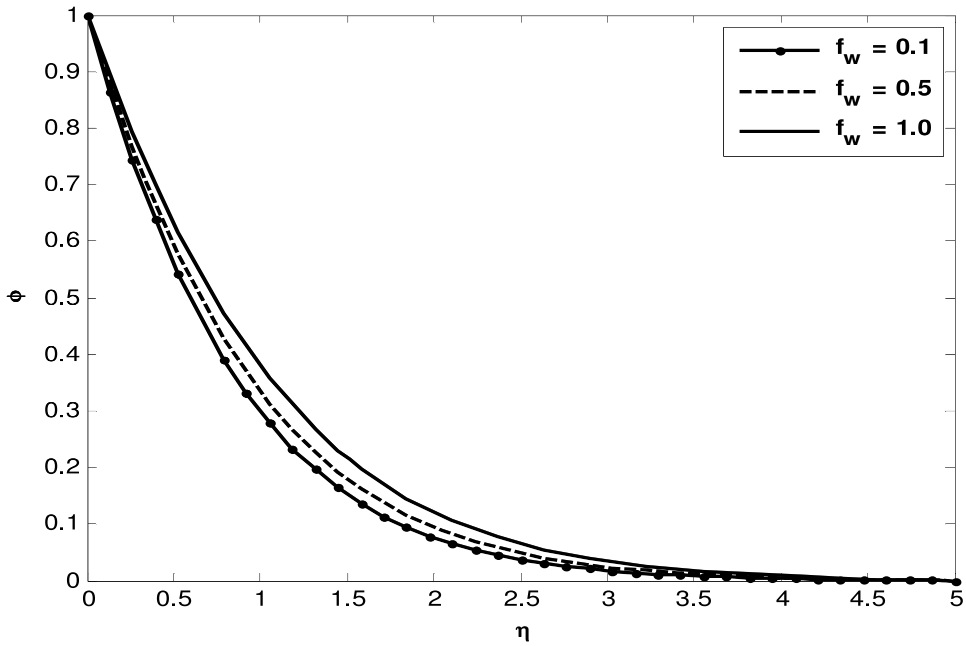

Fig.16: Concentration profiles for different values of f_w when $\Pr$ =0.71,

Gr =3, Gc =2, R =2, K =0.1, Sc =0.60, H =0.1, M =1, K_l =0.5.

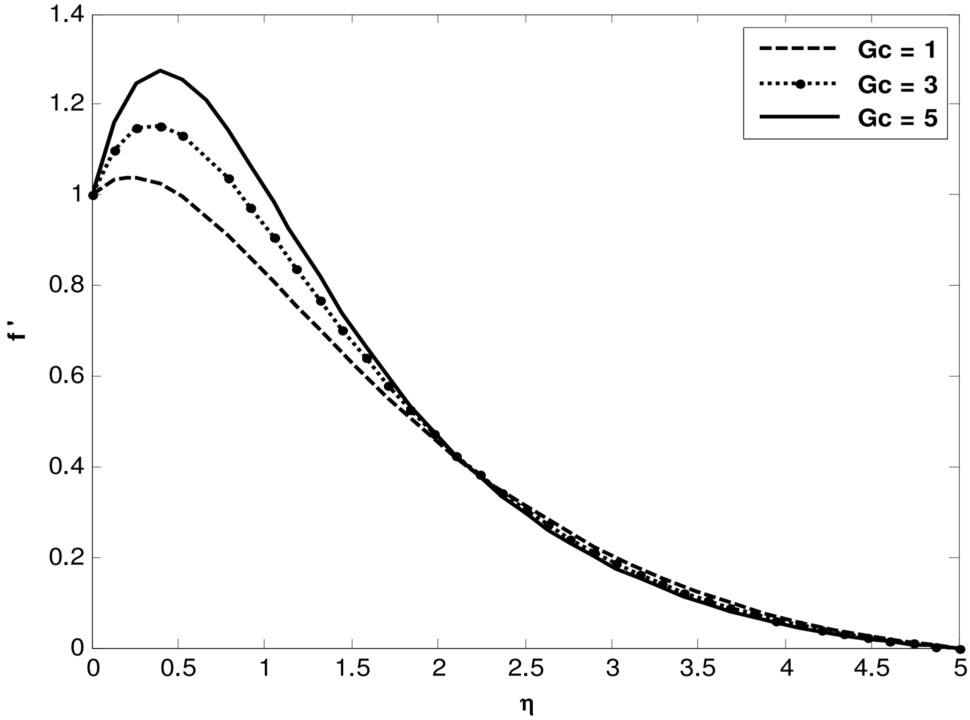

Fig.17: Velocity profiles for different values Gc of when $\Pr$ =0.71,

Gr =3, M =1, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

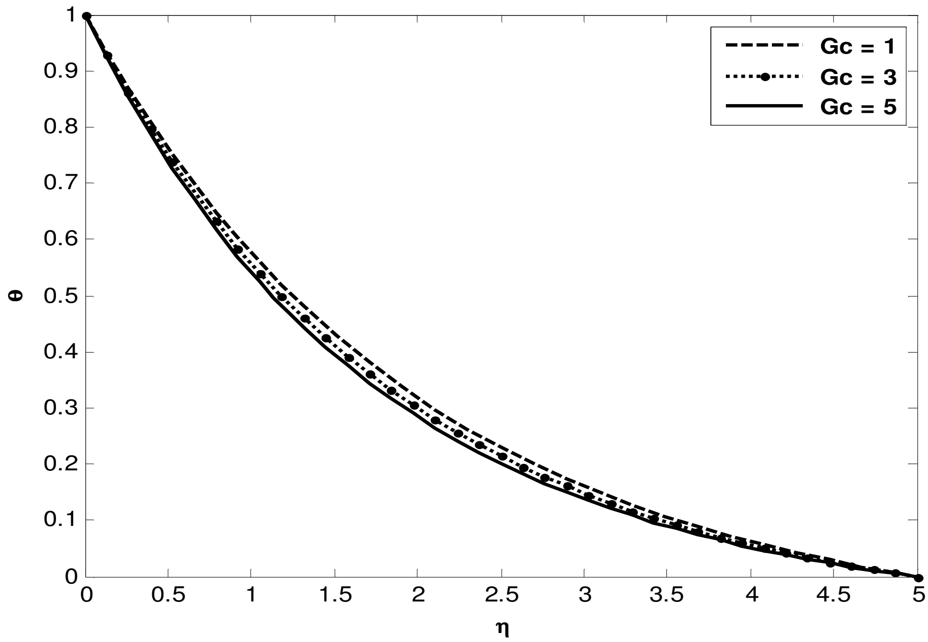

Fig.18: Temperature profiles for different values of Gc when M =1,

Gr =3, $\Pr$ =0.71, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

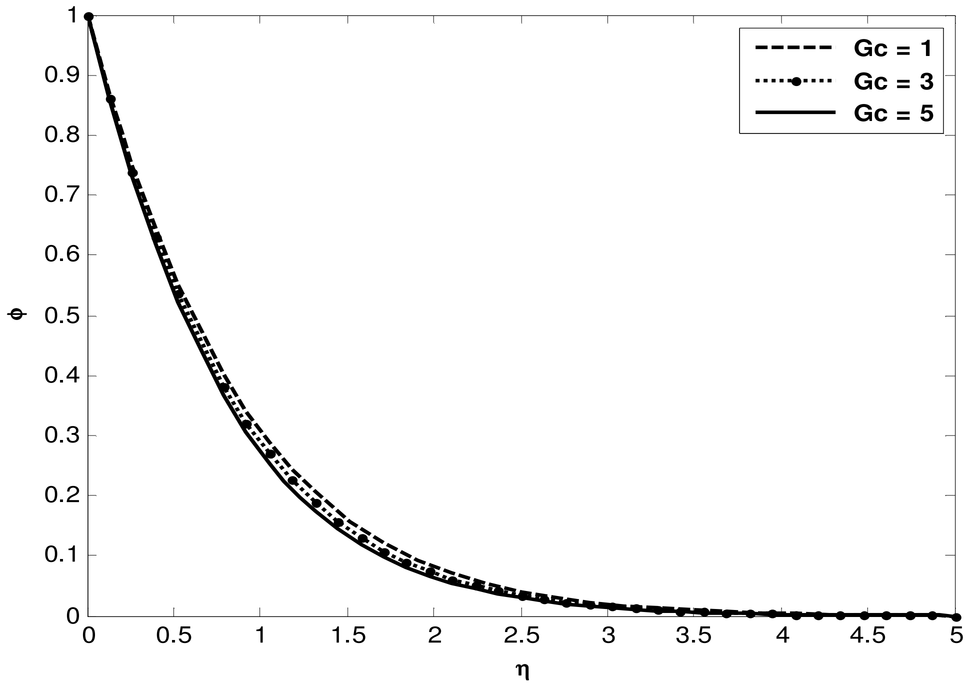

Fig.19: Concentration profiles for different values Gc of when $\Pr$ =0.71,

Gr =3, M =1, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

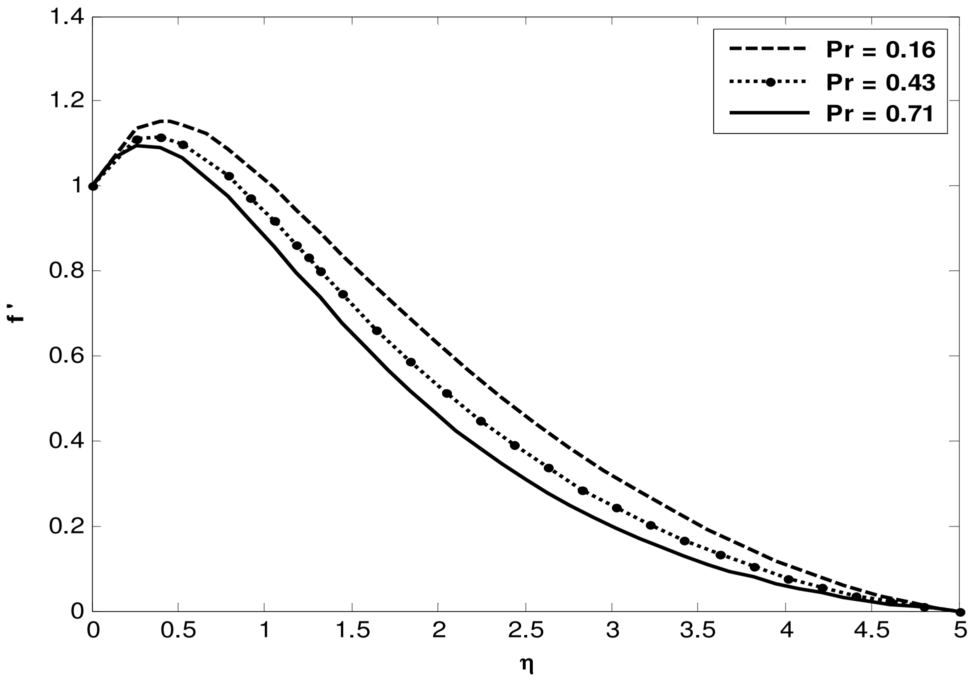

Fig. 20: Velocity profiles for different values $\Pr$ of when M =1,

Gr =3, Gc =2, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

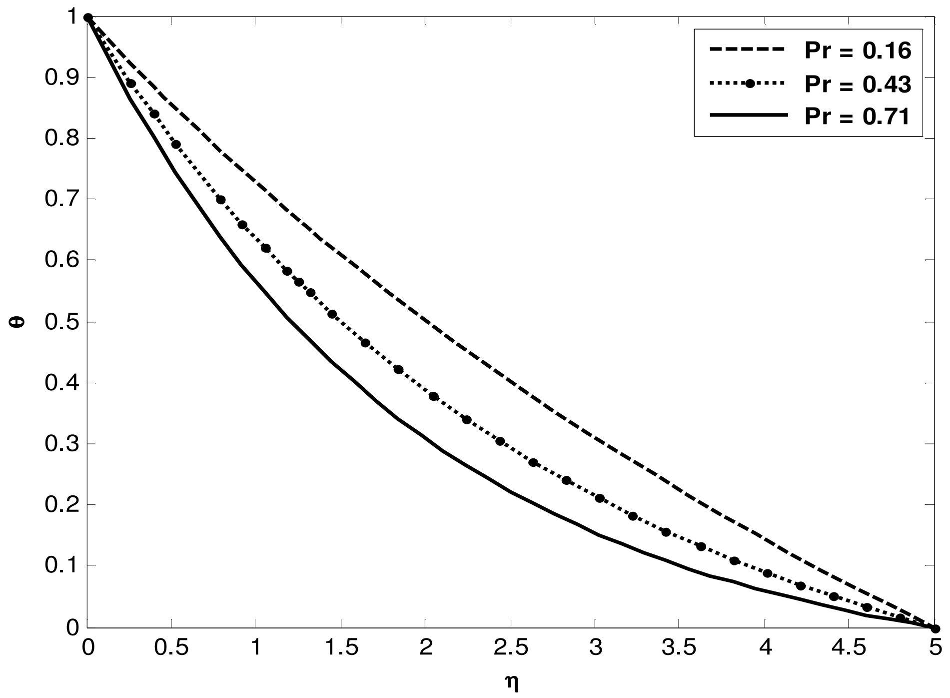

Fig. 21: Temperature profiles for different values of $\Pr$ when M =1, Gr =3, Gc =2, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, K_l =0.5.

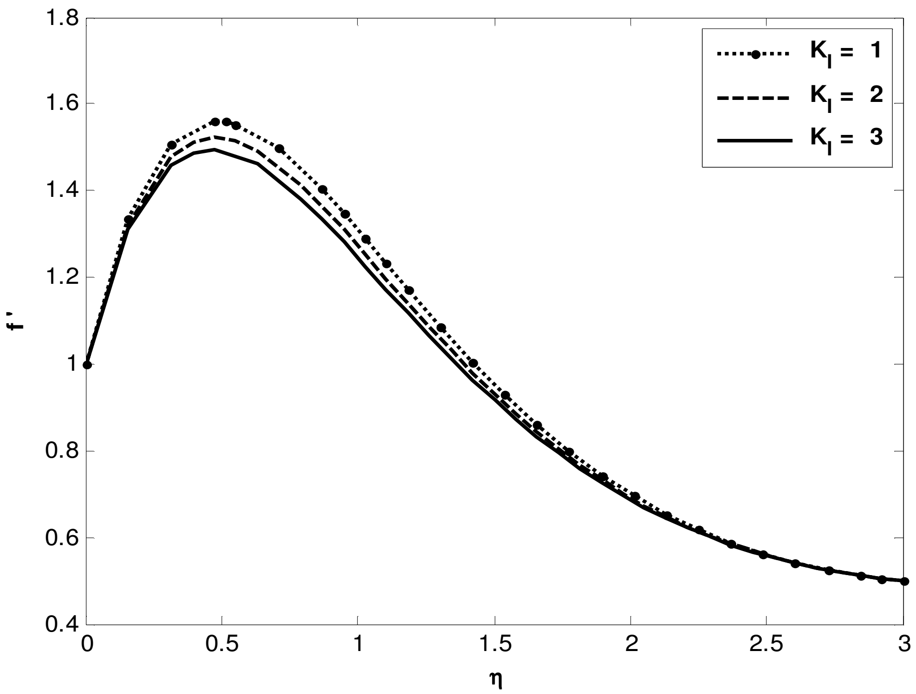

Fig.22: Velocity Profiles for different values of K_l when Pr=0.71, Sc=0.60, R=1=M, H=0.1, Gr=5= Gc, s=0, c=0.5, K=1.

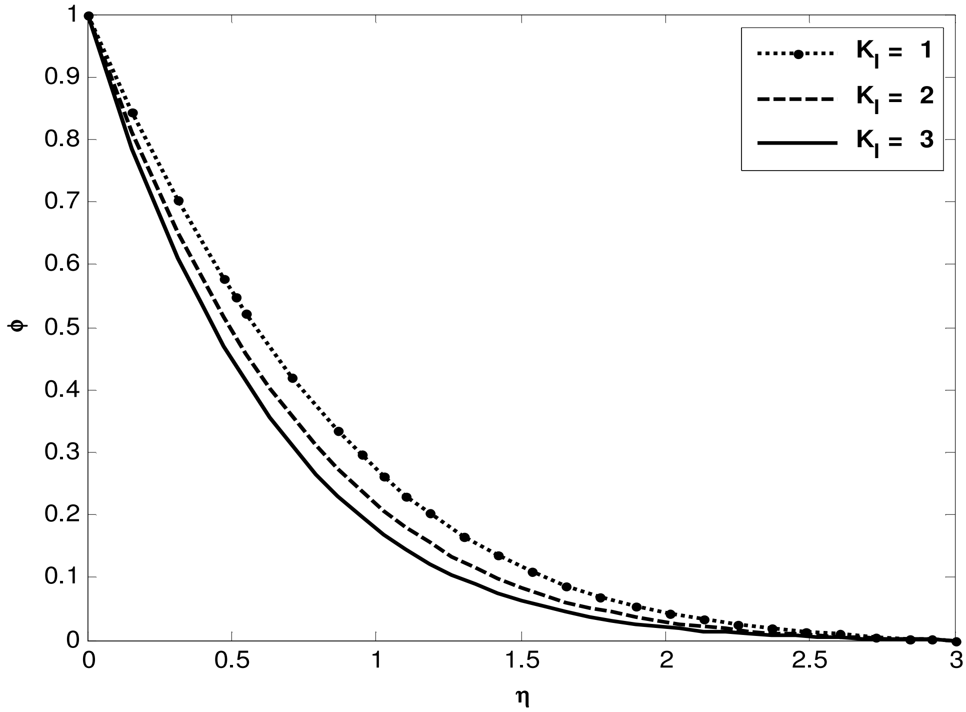

Fig.23: Concentration Profiles for different values of K_l when Pr=0.71,

Sc=0.60, R=1=M, Gr=5= Gc, s=0, c=0.5, K=0.1, H=0.1.

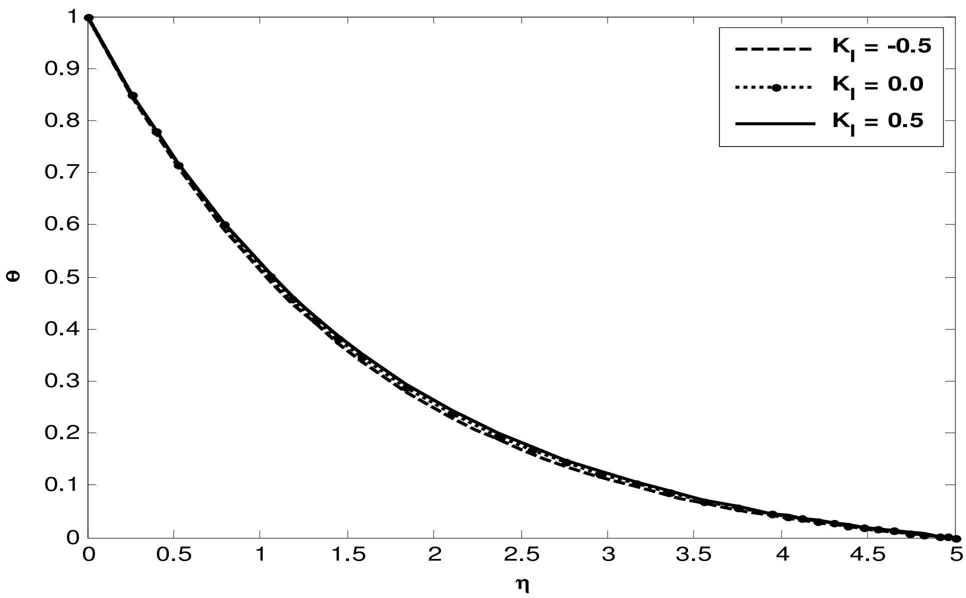

Fig. 24: Temperature profiles for different values of K_l when M =1,

Gr =3, Gc =2, R =2, K =0.1, Sc =0.60, H =0.1, f_w =0.1, Pr =0.71.

6 CONCLUSIONS

The effects of radiation and chemical reaction on MHD boundary layer flow over a moving vertical porous plate with heat source were analysed. The partial differential equations governing the flow are solved numerically using the shooting technique. The influence of various parameters on velocity, temperature and concentration profiles, as well as Nusselt number and skin-friction coefficient are examined.

The conclusions are as follows:

1. The variations of Skin-friction coefficient, Nusselt number and Sherwood number are more influenced by radiation and chemical reaction parameter, which is increase in radiation and chemical reaction parameter causes the slight increase in Skin-friction coefficient, Nusselt number and Sherwood number.
2. The dimensionless surface velocity of the flow is decreases by increase in magnetic field, decrease in Grashof number and radiation parameter.
3. The increase in radiation parameter, magnetic field parameter increases the fluid temperature, which leads to an increase in rate of heat transfer.
4. The velocity and concentration profiles decreases with an increase of chemical reaction parameter but it is reverse in case of temperature profiles.

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