Influence of chemical reaction and thermal radiation effects on MHD boundary layer flow over a moving vertical porous plate

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Abstract: ***In the present paper we have studied the flow, heat and mass transfer on MHD boundary layer flow over a moving vertical porous plate, the velocity of the fluid far away from the plate surface is assumed zero for a quiescent state fluid. The problem of flow, heat and mass transfer is studied by taking into consideration of chemical reaction and thermal radiation effects. Governing boundary layer equations are first transformed into ordinary differential equations and are solved by using MATLAB's built in solver bvp4c. Velocity, temperature and concentration profiles are shown graphically for different values of parameters involved in the dimensionless equations and discussed in detail.***

Key Words: *Porous medium, MHD, Heat transfer and Mass transfer, Vertical plate, Thermal radiation, Chemical reaction.*

1. INTRODUCTION

In many areas like meteorology, solar physics, cosmic fluid dynamics, astrophysics, geophysics etc., Magnetohydrodynamic (MHD) flows have play an important rule. MHD free convection flows have significant applications in the field of stellar and planetary magnetospheres, aeronautical plasma flows, chemical engineering and electronics. An excellent summary of applications is given by Huges and Young (1996). Raptis (1986) studied mathematically the case of time varying two dimensional natural convective flow of an incompressible, electrically conducting fluid along an infinite vertical porous plate embedded in a porous medium. Helmy (1998) analyzed MHD unsteady free convection flow past a vertical plate embedded in a porous medium. Elabashbeshy (1997) studied heat and mass transfer along a vertical plate in the presence of magnetic field. Chamkha and Khaled (2001) investigated the problem of coupled heat and mass transfer by Magnetohydrodynamic free convection from an inclined plate in the presence of internal heat generation or absorption. Transport processes through porous media play important roles in diverse applications, such as in geothermal operations, petroleum industries, thermal insulation, design of solid-matrix heat exchangers, chemical catalytic reactors, and many others. Bejan and Khair (1985) reported on the natural convection boundary layer flow in a saturated porous medium with combined heat and mass transfer. Vafai and Tien (1981) have discussed the importance of inertia effects for flows in porous media. Makinde (2009) considered the MHD boundary-layer flow and mass transfer past a vertical plate in a porous medium with constant heat flux. Raptis *et al.* (1981) constructed similarity solutions for boundary layer near a vertical surface in a porous medium with constant temperature and concentration. Many transport processes exist in nature and in industrial applications in which the simultaneous heat and mass transfer occur as a result of combined buoyancy effects of thermal diffusion and diffusion of chemical species. A few representative fields of interest in which combined heat and mass transfer plays an important role are designing of chemical processing equipment, formation and dispersion of fog, distribution of temperature and moisture over a agricultural fields and groves of fruit trees, crop damage due to freezing, and environmental pollution. In this context, Soundalgekar (1979) studied the effects of mass transfer and free convection on the flow past an impulsively started vertical flat plate. Erickson *et al.* (1966) have discussed the effects of heat and Mass transfer in the laminar boundary layer flow of a moving flat surface with constant surface velocity and temperature focusing on the effects of suction/injection.

Callahan and Marner (1976) considered the transient free convection flow past a semi-infinite vertical plate with mass transfer. Unsteady free convective flow on taking into account the mass transfer phenomenon past an infinite vertical plate was studied by Soundalgekhar and Wavre (1977). Yih (1999) studied free convection effect on MHD coupled heat and mass transfer of a moving permeable vertical surface. Ibrahim and Makinde (2010) have discussed the chemically reacting MHD boundary layer flow of heat and mass transfer over a moving vertical plate with suction.

The objective of this paper is to study the effects of chemical reaction and thermal radiation on MHD boundary layer flow over a moving vertical porous plate.

2. MATHEMATICAL FORMULATION

Consider a two-dimensional free convection effects on the steady incompressible laminar MHD heat and mass transfer characteristics of a linearly started porous vertical plate, the velocity of the fluid far away from the plate surface is assumed zero for a quiescent state fluid. The variations of surface temperature and concentration are linear. All the fluid properties are assumed to be constant except for the density variations in the buoyancy force term of the linear momentum equation. 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. The Hall effects, the viscous dissipation and the joule heating terms are also neglected. The effects of chemical reaction and thermal radiation on flow, heat and mass transfer are taken into account. Under these assumptions, along with Boussinesq approximations, the boundary layer equations describing this flow as:

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

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

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} \tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - k_1(C - C_\infty) \tag{4}$$

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

$u = Bx$, $v = V$, $T = T_w = T_\infty + ax$, $C = C_w = C_\infty + bx$ at $y = 0$

$$u \to 0,\ T \to T_\infty,\ C \to C_\infty \quad \text{as } y \to \infty \tag{5}$$

where x and y represent the coordinate axes along the continuous stretching 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, ν is the kinematics viscosity, β, β^* are the thermal and concentration expansion coefficient respectively, σ electric conductivity, B_0 is the uniform magnetic field, ρ is the density, κ' is the permeability of the porous medium, T is the temperature inside the boundary layer, T_∞ is the temperature for away from the plate, C is the species concentration in the boundary layer, C_∞ Species concentration of the ambient fluid, α is the thermal diffusivity, k_1 is the rate constant of first order chemical reaction, C_p is the specific heat at constant pressure, q_r is the relative heat flux, D is the is the molecular diffusivity of the species concentration, B is a constant, a and b denotes the stratification rate of the gradient of ambient temperature and concentration profiles.

By using Rosseland approximation of the radiation for an optically thick boundary layer, the radiative heat flux q_r is expressed as: $q_r = -\frac{4\sigma^*}{3\kappa^*}\frac{\partial T^4}{\partial y}$ (6)

where σ^* is the Stefan-Boltzmann constant and κ^* is the mean absorption coefficient. The above radiative heat flux q_r is effective at a point away from boundary layer surface in an intensive absorption flow. Considering that the temperature variation within the flow is very small, then T^4 may be expressed as a linear function of temperature T. Expanding T^4 by Taylor's series about temperature T_∞ and neglecting higher-order terms, hence

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{7}$$

Using Equation (6) and (7), equation (3) is reduced to:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{16\sigma^* T_\infty^3}{3\kappa^* \rho C_p}\frac{\partial^2 T}{\partial y^2} \tag{8}$$

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 06 | Sep-2015 www.irjet.net p-ISSN: 2395-0072

We introduce the following non-dimensional variables:

$$\eta = \sqrt{\frac{B}{\nu}}\, y,\ u = \frac{\partial \psi}{\partial y} = xBf',\ v = -\frac{\partial \psi}{\partial x} = -\sqrt{B\nu}\, f,\ \theta = \frac{(T - T_\infty)}{(T_w - T_\infty)},$$

$$\phi = \frac{(C - C_\infty)}{(C_w - C_\infty)}$$

M(magnetic parameter) = $\frac{\sigma B_0^2}{\rho B}$, K(Permeability parameter) = $\frac{\nu}{\kappa' B}$, Gr(Temperature Grashof number) = $\frac{g\beta\,(T_w - T_\infty)}{xB^2}$, Gc(Concentration Grashof number) = $\frac{g\beta^*(C_w - C_\infty)}{xB^2}$, Pr(Prandtl number) = $\frac{\nu}{\alpha}$, Sc(Schmidt number) = $\frac{\nu}{D}$, γ(Chemical reaction parameter) = $\frac{k_1(C_w - C_\infty)}{bxB}$ and R(Radiation parameter) = $\frac{\alpha\kappa^*\rho C_p}{\sigma^* T_\infty^3}$ (9)

Using (9), the Equations (2), (4) and (8) reduced to the form

$$f''' + ff'' - f'^2 + Gr\theta + Gc\phi - (M+K)f' = 0 \qquad (10)$$

$$\left(1 + \frac{16}{3R}\right)\theta'' + Pr[\, f\theta' - f'\theta\,] = 0 \qquad (11)$$

$$\phi'' + Sc\,[\, f\phi' - f'\phi\,] - Sc\,\gamma\phi = 0 \qquad (12)$$

Where the prime denote the differentiation with respect to η.

The corresponding boundary conditions are

$$f' = 1,\ f = -f_w,\ \theta = 1,\ \phi = 1 \quad \text{at } \eta = 0$$

$$f' = 0,\ \theta = 0,\ \phi = 0 \quad \text{as } \eta \to \infty \qquad (13)$$

where $f_w = \frac{V}{\sqrt{\nu B}}$ is the suction parameter.

3. NUMERICAL ANALYSIS AND DISCUSSIONS

The non-linear coupled ordinary differential equations (10) to (12) are solved numerically by using MATLAB's built in solver bvp4c by taking into consideration the boundary conditions equations (13). Graphical representations are shown below for various values of Parameters.

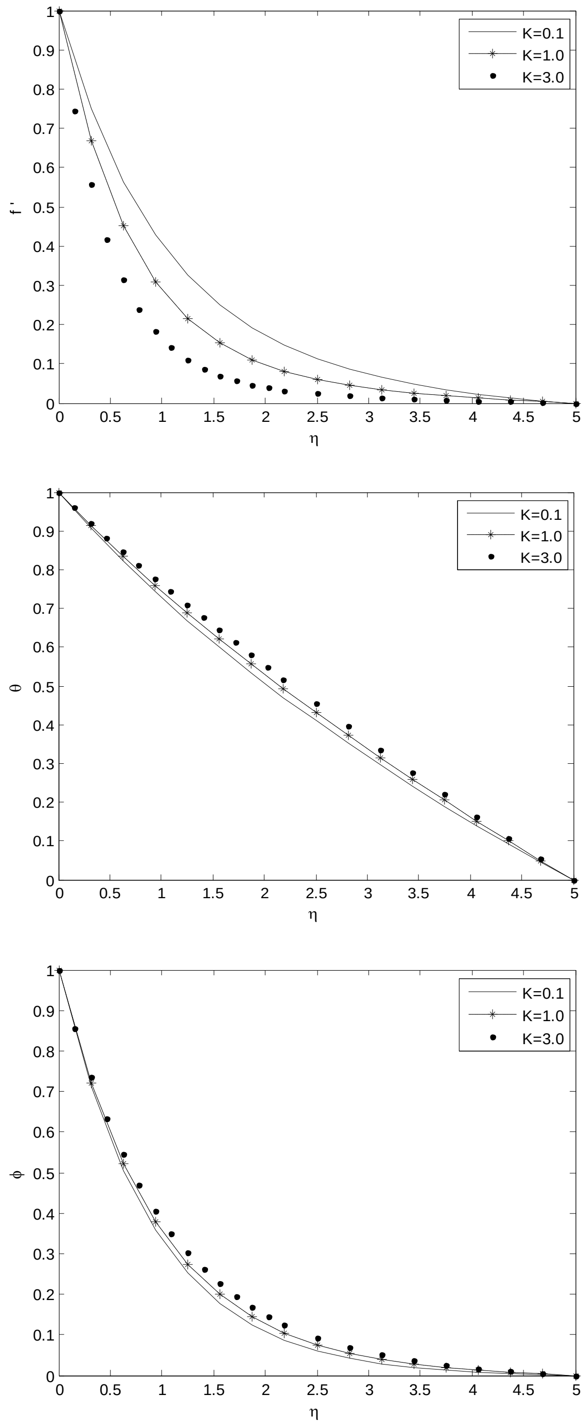

Fig1,2,3: Velocity, Temperature and Concentration Profile for different values of K when M = Gr = Gc = f_w = 0.1, Pr = 0.72, Sc = 0.60 and R = γ = 1

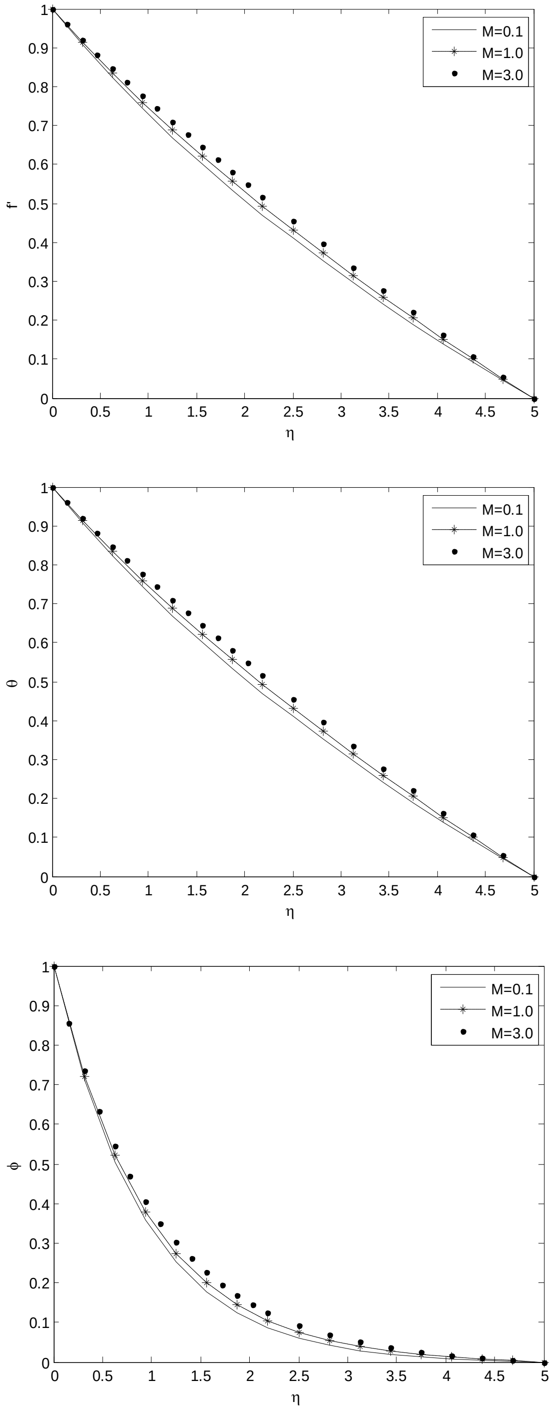

Fig4,5,6: Velocity, Temperature and Concentration Profile for different values of M when K = Gr = Gc = f_w = 0.1, Pr = 0.72, Sc = 0.60 and R = γ = 1

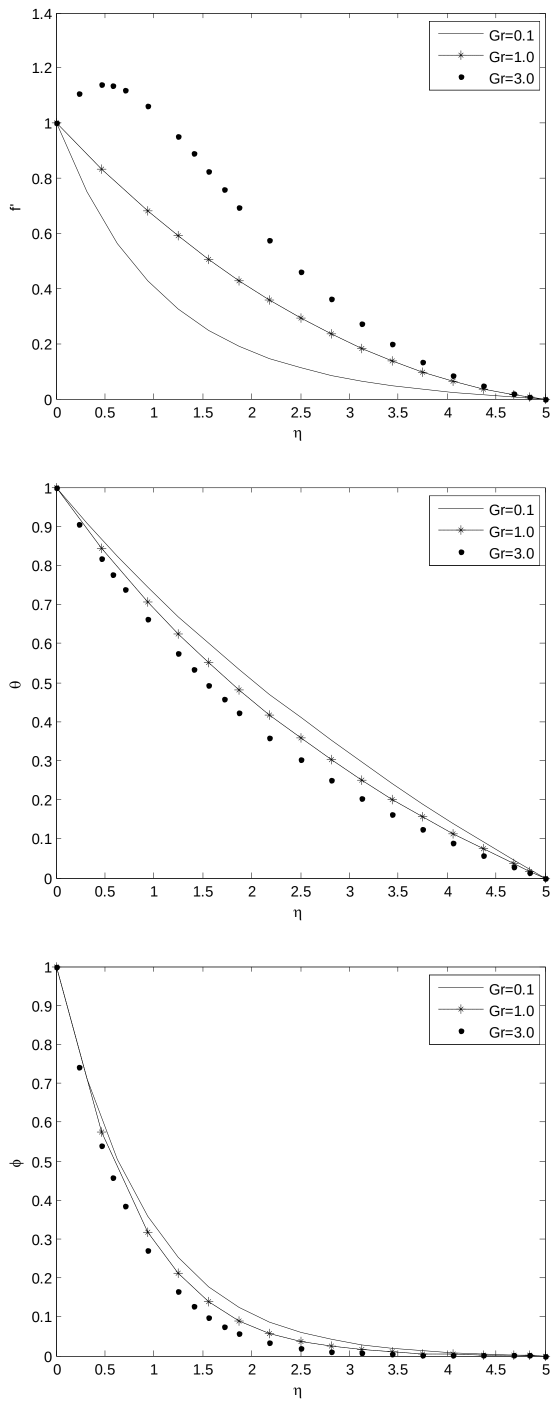

Fig7,8,9: Velocity, Temperature and Concentration Profile for different values of Gr when K = M = Gc = f_w = 0.1, Pr = 0.72, Sc = 0.60 and R = γ = 1

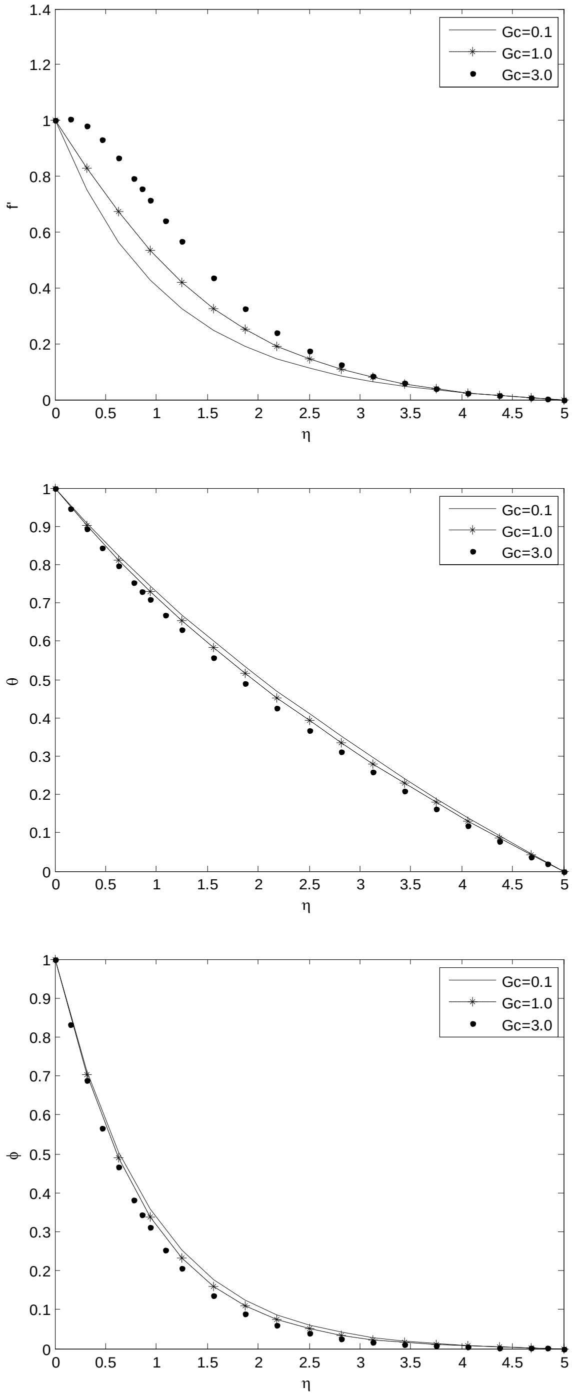

Fig10,11,12: Velocity, Temperature and Concentration Profile for different values of Gc when K = M = Gr = f_w = 0.1, Pr = 0.72, Sc = 0.60 and R = γ = 1

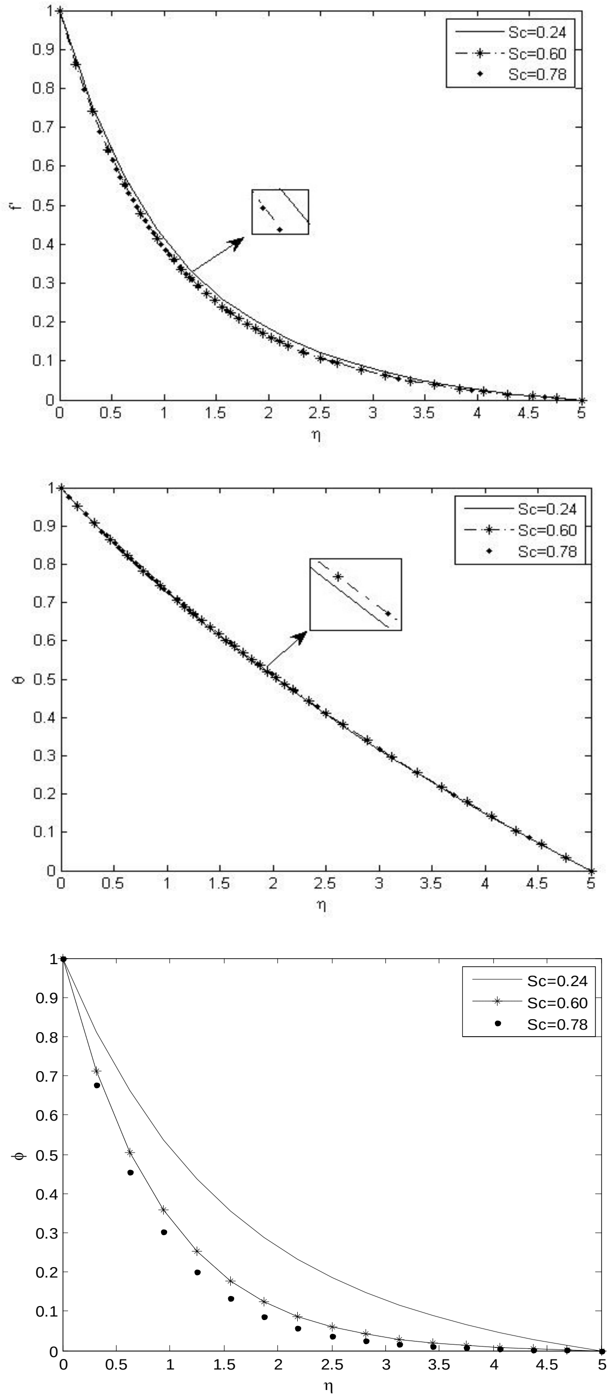

Fig13,14,15: Velocity, Temperature and Concentration Profile for different values of Sc when K = M = Gr = Gc = f_w = 0.1, Pr = 0.72 and R = γ = 1

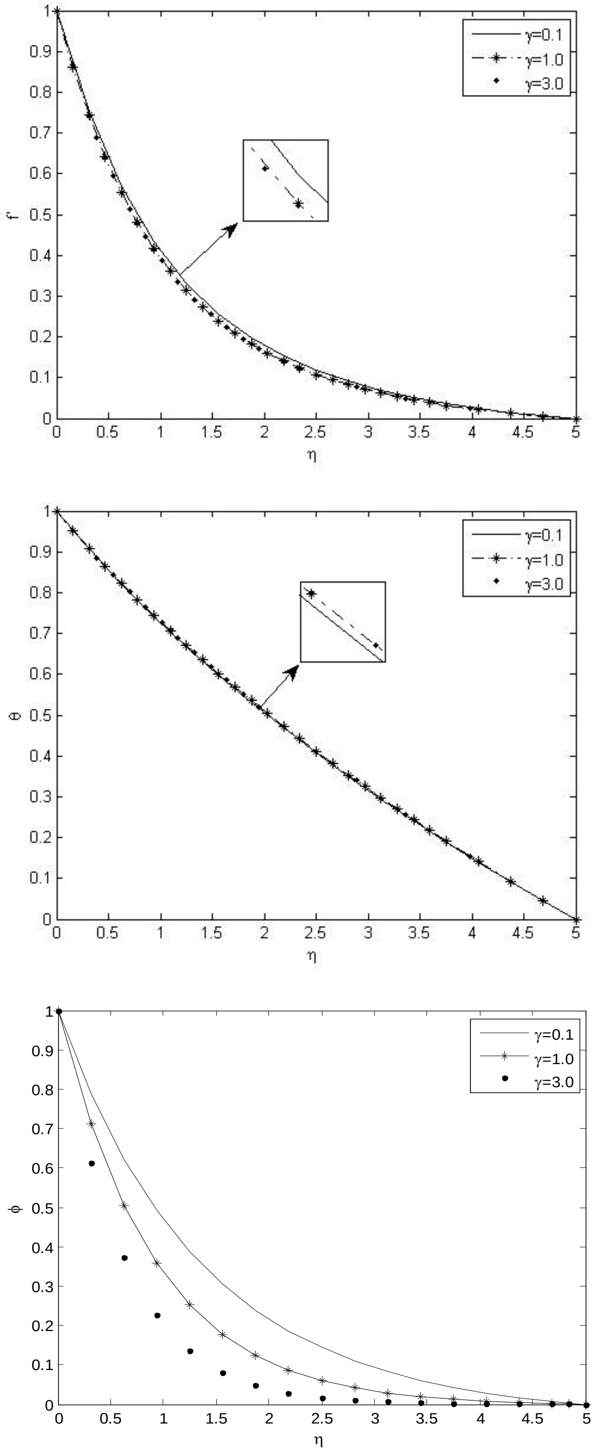

Fig16,17,18: Velocity, Temperature and Concentration Profile for different values of γ when K = M = Gr = Gc = f_w = 0.1, Pr = 0.72, Sc = 0.60 and R = 1

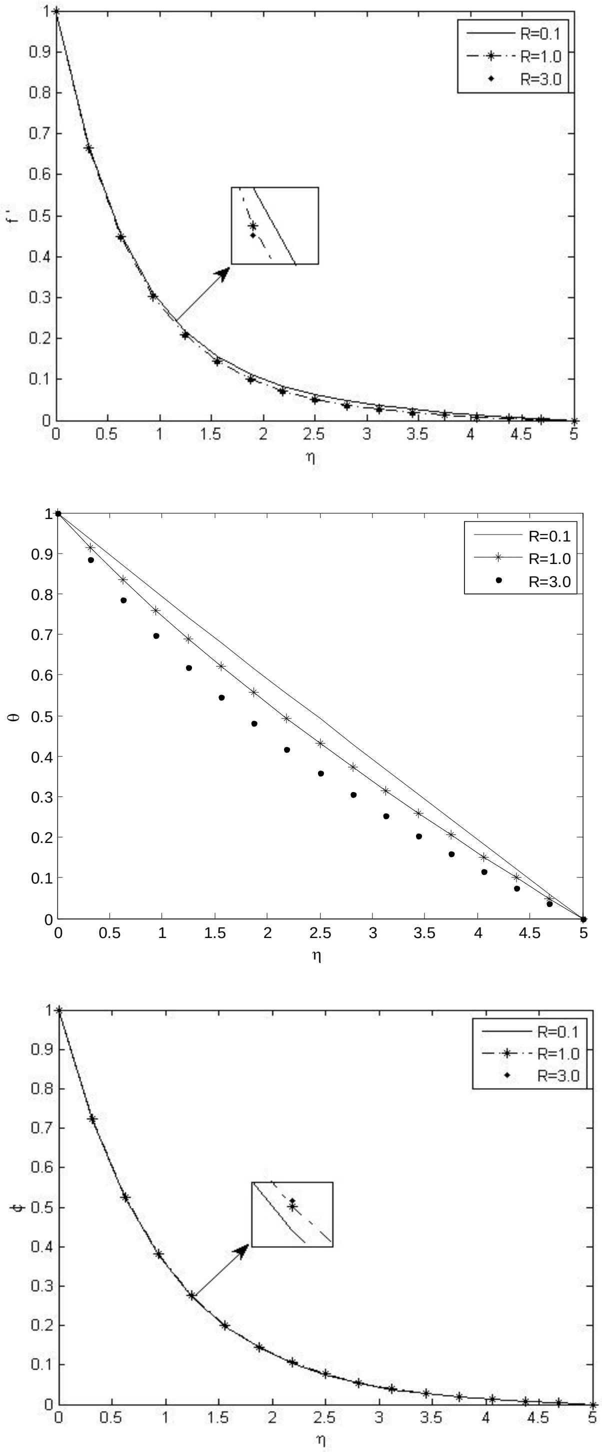

Fig19,20,21: Velocity, Temperature and Concentration Profile for different values of R when K = M = Gr = Gc = f_w = 0.1, Pr = 0.72, Sc = 0.60 and γ = 1

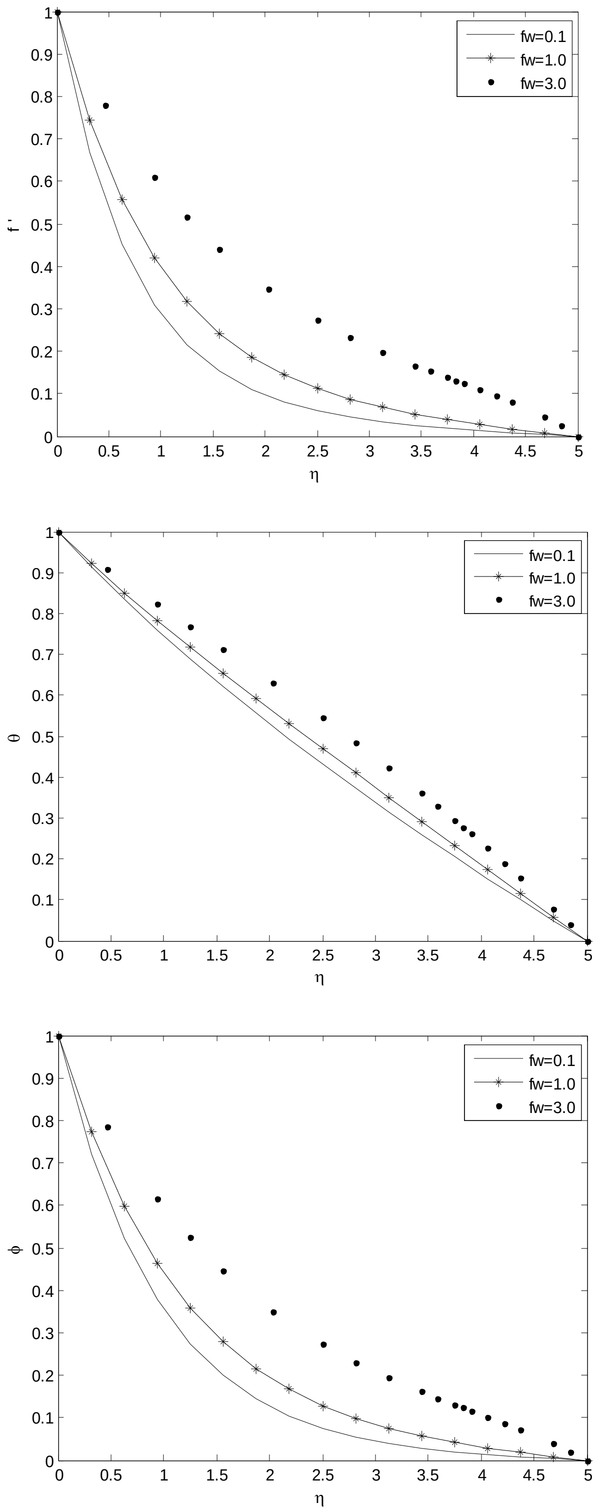

Fig22,23,24: Velocity, Temperature and Concentration Profile for different values of f_w when K = M = Gr = Gc = 0.1, Pr = 0.72, Sc = 0.60 and R = γ = 1

4. CONCLUSIONS

In this paper we study the Heat and mass transfer effects on MHD boundary layer flow over a moving vertical porous plate in the presence of chemical reaction and thermal radiation. The expressions for the velocity, temperature and concentration distributions are the equations governing the flow are numerically by using MATLAB built in solver bvp4c. The conclusions of this study are as follows:

(1) The effect of increase in the value of parameters M, Gr, Gc and f_w is to increase the velocity and decreases for the value of parameters K, Sc, γ and R.
(2) The effect of increase in the value of parameters M, K, Sc, γ and f_w is to increase the temperature and decreases for the value of parameters Gr, Gc and R.
(3) The effect of increase in the value of parameters K, M, f_w and R is to increase the concentration and decreases for the value of parameters Gr, Gc, Sc and γ.

ACKNOWLEDGEMENT

The second author is thankful to his parents to give all types of support during this research paper.

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BIOGRAPHIES

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