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# Effect of Chemical Reaction and Thermal Radiation on MHD free Convective flow of a Semi-Infinite Porous Plate Moving Vertically

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**ABSTRACT**

This paper focuses on the effects of thermal radiation and chemical reaction on MHD convective heat and mass transfer flow of a viscous incompressible fluid past a semi-infinite vertical permeable plate with time dependent suction. The governing boundary layer equations are solved by a finite element method. The effect of various thermo-physical parameters like radiation parameter ***N,*** Magnetic parameter ***M,*** Permeability parameter ***K,*** chemical reaction parameter **γ,** Schimdt number ***Sc,*** radiation absorption coefficient $Q_1$ heat absorption coefficient $\varphi$ and time $t$ on the velocity, temperature and concentration, rates of heat and mass transfer are obtained numerically and discussed in detail. It is found that the rate of heat transfer at the plate increases with increasing in values of the radiation parameter and the mass transfer rate increases with increasing in values of the chemical reaction parameter.

***Key words:*** *Thermal radiation, chemical reaction, MHD, porous medium, heat absorption, radiation absorption, Finite element method.*

## INTRODUCTION:

Porous bearings are used where non-porous bearings are impracticable owing to lack of space or inaccessibility for lubrication. The application of porous bearings in mounting horsepower motors include vacuum cleaners, coffee grinders, hair driers, saving machines, sewing machines, water pumps, record players, tape recorders, generators and distributors, gravitational body force. Combined heat and mass transfer (or double-diffusion) in fluid-saturated porous media finds applications in a variety of engineering processes such as heat exchanger devices, petroleum reservoirs, chemical catalytic reactors and processes, geothermal and geophysical engineering, moisture migration in a fibrous insulation and nuclear waste disposal and others. Due to recent advances in space technology and nuclear energy the study of natural convection still continues to be a major area of interest. The natural convection in fluids with microstructure has been an important area of research. Flows in which buoyancy forces are dominant are called natural and the respective heat transfer being known as natural convection. This occurs at very small velocity of motion in the presence of large temperature differences. These temperature differences cause density gradients in the fluid medium and in the presence of gravitational body force, free convection effects become important. In forced convection case, the natural convection effects are also present because of the presence of Porous bearings have the features of simple structure and low cost.

Magnetohydrodynamic flows have applications in meteorology, solar physics, cosmic fluid dynamics, astrophysics, geophysics and in the motion of earth's core. In addition from the technological point of view, 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 (Huges and Young1966). Raptis(Raptis1986) 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 (Helmy1998) analyzed MHD unsteady free convection flow past a vertical porous plate embedded in a porous medium. Elabashbeshy (Elabashbeshy1997) studied heat and mass transfer along a vertical plate in the presence of magnetic field. Chamkha (Chamkha 2004) analyzed an unsteady, MHD convective, viscous incompressible, heat and mass transfer along a semi-infinite vertical porous plate in the presence of transverse magnetic field, thermal and concentration buoyancy effects.

Lai and Kulacki (Lai and Kulacki1990) used the series expansion method to investigate coupled heat and mass transfer in natural convection from a sphere in a porous medium. The suction and blowing effects on free convection coupled heat and mass transfer over a vertical plate in a saturated porous medium were studied by Raptis et al. (Raptis et al. 1981) and Lai and Kulacki (Lai and Kulacki1991), respectively.

In the context of space technology and in the process involving high temperatures, the effects of radiation are of vital importance. Rapid 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 from improved understanding of radiative transfer in these process. Rapits (Rapits 1998) discussed the steady flow of two dimensional free convection bounded by a vertical infinite porous plate in the presence of thermal radiation effects. Makinde (Makinde 2005) analyzed the free convection flow with thermal radiation and mass transfer past a moving vertical porous plate. Mahdy (Mahdy 2008) described the numerical solutions for the effects of radiation on a MHD convective heat transfer past a semi-infinite porous plate with a magnetic field. Gnaneswara Reddy and Bhaskar Reddy (Gnaneswara Reddy and Bhaskar Reddy 2011) analyzed the unsteady heat and mass transfer MHD flow of a chemically reacting fluid past an impulsively started vertical plate with radiation. Suneetha and Bhaskar Reddy (Suneetha and Bhaskar Reddy 2011) studied Radiation effects on MHD flow of a chemically reacting fluid past a vertical plate with viscous dissipation.

The study of heat generation or absorption in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions. In many chemical engineering processes, there does occur the chemical reaction between a foreign mass and the fluid in which the plate is moving .These take place in numerous industrial applications viz., polymer production, manufacturing of ceramics or glass ware and food processing. Sharma et al. (Sharmaetal. 2008) have discussed in detail the effect of variable thermal conductivity in MHD fluid flow over a stretching sheet considering heat source and sink parameter. Chamkha and Khaled (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. Vajravelu and Hadjinicolaou (Vajravelu and Hadjinicolaou 1997) studied the heat transfer characteristics in the laminar boundary layer of a viscous fluid over a stretching sheet with viscous dissipation or frictional heating and internal heat generation.

In many chemical engineering processes a chemical reaction between a foreign mass and the fluid does occurs. These processes take place in numerous industrial applications, such as the polymer production, the manufacturing of ceramics or glassware, the food processing and so on. Singh et al. (Singh et al. 2011) analyzed the effects of chemical reaction and radiation absorption on MHD free convective heat and mass transfer flow past a semi-infinite vertical moving plate with time dependent suction. Ibrahim et al. (Ibrahim et al. 2008) presented the effect of chemical reaction and radiation absorption on MHD flow past a continuously moving permeable surface with heat source and time dependent suction. Rajeshwari et al. (Rajeshwari et al. 2009) included the effects of chemical reaction on heat and mass transfer in non-linear MHD boundary layer flow with vertical porous surface in the presence of suction. An approximate numerical solution of chemical reaction, heat and mass transfer on MHD flow along a vertical stretching surface over a wedge with heat source and concentration in the presence of suction or injection was studied by Kandhaswamy et al. (Kandhaswamyetal.2005). Chamkha (Chamkha 2003) studied the analytical solutions for MHD flow of a uniformly stretched vertical permeable surface with effect of heat generation/absorption and chemical reaction. Recently Bala Siddulu Malga et al. (Bala Siddulu Malga et al. 2013) studied Effects of Hall Current on an Unsteady MHD Flow of Heat and Mass Transfer along a Porous Flat Plate with Chemical Reaction and Viscous Dissipation.

To the best of authors' knowledge, the interaction between thermal radiation and chemical reaction in the presence of heat absorption and radiation absorption has received little attention. Hence, an attempt is made to study the effects of thermal radiation and chemical reaction on MHD free convective flow of a semi-infinite porous plate moving vertically, in the presence of heat absorption and radiation absorption. The expressions for the velocity, temperature and concentration have been obtained and the effects of various parameters have been computed numerically and discussed in detail.

**MATHEMATICAL ANALYSIS**

An unsteady, laminar, two dimensional free convection flow of a viscous, incompressible electrically conducting and radiating fluid past a semi-infinite vertical porous moving plate embedded in a porous medium is considered. The fluid is considered to be a gray, absorbing emitting radiation but non-scattering medium .The $x^*$- axis is taken in the upward direction along the plate and $y^*$- axis normal to it .The plate is maintained at a constant temperature *Tw* and concentration *Cw* which are higher than the ambient temperature $T_\infty$ and ambient concentration $C_\infty$ ,respectively. A uniform magnetic field is applied in the transverse direction to the flow. The fluid is assumed to be slightly conducting, so that the magnetic Reynolds number is much less than unity and hence the induced magnetic field is negligible in comparison with the applied magnetic field. The level of concentration of foreign mass is assumed to be low, so that the Soret and Dufour effects are negligible .Since the plate is of infinite length, all the physical variables are functions of $y^*$ and time $t^*$only. It is also assumed that all the fluid properties are constant except that the influence of the density variation with temperature and concentration in the body force term (Boussinesq's approximation).Then, under the above assumptions, in the absence of input electric field, the governing equations are

Continuity: $$\frac{\partial v^*}{\partial y^*} = 0 \qquad (1)$$

Linear momentum:

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = g\beta(T^* - T^*_\infty) + g\beta^*(C^* - C^*_\infty) + v\frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\sigma}{\rho}B_0^2 u^* - v\frac{u^*}{K^*}$$

(2)

Energy:

$$\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{Q_0}{\rho C_p}(T^* - T^*_\infty) + Q_1^*(C^* - C^*_\infty) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y}$$

(3)

Diffusion: $$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} + k_1(C^* - C^*_\infty) \qquad (4)$$

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

$$\left.\begin{array}{l} u^* = u_p^*, T^* = T_w, C^* = C_w, \text{ at } y^* = 0 \\ u^* \to U^*(t^*), T^* \to T_\infty, C^* \to C_\infty, \text{ at } y^* \to \infty \end{array}\right\} \qquad (5)$$

where $u_p^*$- the wall dimensional velocity, $T^*$, $C^*$- dimensional temperature and concentration, $u^*$,$v^*$- Velocity component in $x^*$and $y^*$ direction, respectively, $K^*$- permeability parameter, $T_\infty$, $C_\infty$-free stream temperature and concentration respectively, *g*- acceleration due to gravity, $v$ -kinematics viscosity, *ρ*-density, *σ*-the electric conductivity of the fluid, *β*, $\beta^*$- the coefficients of thermal and concentration expansions respectively, $k^*$-thermal conductivity, *Cp*-the specific heat at constant pressure, $B_0$-magnetic induction, $Q_0$-the heat absorption coefficient, $Q_1^*$- the radiation absorption parameter, *D*-the mass diffusivity coefficient , $k_1$-chemical reaction parameter and $q_r$- the radiative heat flux.

The first and second terms on the right hand side of the momentum equation (2) denote the thermal and concentration buoyancy effects, respectively. Also the second, third and fourth terms on the right hand side of the energy equation (3) represent the heat absorption, radiation absorption and thermal radiation respectively. The last term of the concentration equation (4) represents the chemical concentration buoyancy effects. It is assumed that the permeable plate moves with a constant velocity in the direction of fluid flow and the free stream velocity follows the exponentially increasing small perturbation law. In addition, it is assumed that the temperature and concentration at the wall as well as the suction velocity are exponentially varying with time.

By using the Rosseland approximation (Brewster1992), the radiative heat flux $q_r$ is given by

$$q_r = -\frac{4\sigma_s}{3k_e}\frac{\partial T^4}{\partial y} \quad (6)$$

where $\sigma_s$ is the Stephen Boltzman constant and $k_e$-the mean absorption coefficient.

It should be noted that by using the Rosseland approximation, the present analysis is limited to optically thick fluids .If the temperature differences within the flow are sufficiently small,

then equation (3) can be linearized by expanding $T^4$ into the Taylor series about $T_\infty$ , which after neglecting higher order terms takes the form

$$T^4 = 4T_\infty^3 T - 3T_\infty^4 \quad (7)$$

In view of equations (5) and (6), equation (3) reduces to

$$\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{Q_0}{\rho C_p}(T^* - T_\infty^*) + Q_1^*(C^* - C_\infty^*) + \frac{16T_\infty^{*3}}{3k_e\rho C_p}\frac{\partial^2 T}{\partial y^2}$$

(8)

From the continuity equation (1), it is obvious that the suction velocity is a constant or function of time. Hence it is assumed that

$$v^* = -V_0\left(1 + \varepsilon e^{\omega t}\right) \quad (9)$$

where $V_0$ is the mean suction velocity and ε is a small quantity less than unity. The negative sign indicates that the suction velocity is directed towards the plate.

In order to write the governing equations and the boundary conditions in the dimensionless form, the following dimensionless quantities are introduced.

$$\left.\begin{array}{c}
u = \frac{u^*}{V_0}, V = \frac{v^*}{V_0}, y = \frac{y^* V_0}{v}, U(t) = \frac{U^*(t^*)}{V_0}, u_p = \frac{u_p^*}{V_0}, t = \frac{t^* V_0^2}{v}, \\
\theta = \frac{(T^* - T_\infty)}{(T_w - T_\infty)}, C = \frac{(C^* - C_\infty)}{(C_w - C_\infty)}, \gamma = \frac{k_1 v}{V_0^2}, K = \frac{K^* V_0^2}{v^2}, \varphi = \frac{Q_0 v}{\rho C_p V_0^2}, N = \frac{k_e k}{4\sigma_s T_\infty^3}, \\
Sc = \frac{v}{D}, \text{is the Schmidth number}, P_r = \frac{\mu C_p}{k} \text{ is the Prandtl number}, \\
G_r = \frac{vg\beta(T_w - T_\infty)}{V_0^3}, \text{is the Grashof number for heat transfer}, \\
G_c = \frac{vg\beta(C_w - C_\infty)}{V_0^3}, \text{is the Modified Grashof number for mass transfer}, \\
M = \frac{\sigma B_0^2 v}{\rho V_0^2} \text{ is the Magnetic field parameter} \\
Q_1 = \frac{vQ_1^*}{V_0^2}\frac{(T_w - T_\infty)}{(C_w - C_\infty)} \text{ is the thermal diffusion parameter}
\end{array}\right\} \quad (10)$$

In the view of the above, the governing equations (2),(4) and (8) reduce to the following dimensionless form:

$$\frac{\partial u}{\partial t} - (1 + \varepsilon e^{wt})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{K}\right)u + G_r\theta + G_c C \quad (11)$$

$$\frac{\partial \theta}{\partial t} - (1 + \varepsilon e^{wt})\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\left(1 + \frac{4}{3N}\right)\frac{\partial^2 \theta}{\partial y^2} - \varphi\theta + Q_1 C \quad (12)$$

$$\frac{\partial C}{\partial t} - (1 + \varepsilon e^{wt})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - \gamma C \quad (13)$$

The boundary conditions are:

$$\left.\begin{array}{l}
u = u_p, \ \theta = 1, \ C = 1 \quad at\ y = 0 \\
u \to U(t), \ \theta \to 0, \ C \to 0 \ \ as \ \ y \to \infty
\end{array}\right\} \quad (14)$$

**METHOD OF SOLUTION:**

In order to reduce the above system of partial differential equations the velocity, temperature and concentration in the neighborhood of the porous plate are assumed by applying the Galerkin finite element method for equation (11) over a typical two-nodded linear element $(e)$ $(y_j \le y \le y_k)$ is

$$u = N.\emptyset, N = [N_j, N_k], \quad \emptyset = \begin{bmatrix} u_j \\ u_k \end{bmatrix}, N_j = \frac{y_k - y}{l}, \qquad N_k = \frac{y - y_j}{l}, l = y_k - y_j = h,$$

$$\int_{y_j}^{y_k} N^T \left[ \frac{\partial^2 u}{\partial y^2} + (1 + \varepsilon e^{wt}) \frac{\partial u}{\partial y} - \frac{\partial u}{\partial t} - \left(M + \frac{1}{K}\right) u + (G_r \theta + G_c C) \right] dy$$

(15)

$$\int_{y_j}^{y_k} \left[ \frac{\partial N}{\partial y} . \frac{\partial u}{\partial y} - N^T \left( (1 + \varepsilon e^{wt}) \frac{\partial u}{\partial y} - \frac{\partial u}{\partial t} - \left(M + \frac{1}{K}\right) u + (G_r \theta + G_c C) \right) \right] dy = 0$$

$$\int_{y_j}^{y_k} \left[ \frac{\partial N}{\partial y} . \frac{\partial u}{\partial y} - N^T \left( (1 + \varepsilon e^{wt}) \frac{\partial u}{\partial y} - \frac{\partial u}{\partial t} - \left(M + \frac{1}{K}\right) u + R \right) \right] dy = 0$$

(16)

$$where \;\; R = (G_r \theta + G_c C)$$

The element equation given by

$$\int_{y_j}^{y_k} \begin{bmatrix} N_j' N_j' & N_j' N_k' \\ N_k' N_j' & N_k' N_k' \end{bmatrix} \begin{bmatrix} u_j \\ u_k \end{bmatrix} dy - (1 + \varepsilon e^{wt}) \begin{bmatrix} N_j N_j' & N_j N_k' \\ N_k N_j' & N_k N_k' \end{bmatrix} \begin{bmatrix} u_j \\ u_k \end{bmatrix} dy + \begin{bmatrix} N_j N_j & N_j N_k \\ N_k N_j & N_k N_k \end{bmatrix} \begin{bmatrix} \dot{u}_j \\ \dot{u}_k \end{bmatrix} dy + \left(M + \frac{1}{K}\right) \begin{bmatrix} N_j N_j & N_j N_k \\ N_k N_j & N_k N_k \end{bmatrix} \begin{bmatrix} u_j \\ u_k \end{bmatrix} dy - R \begin{bmatrix} N_j \\ N_k \end{bmatrix} dy = 0$$

$$\int_{y_j}^{y_k} (S + A)\, dy = \int_{y_j}^{y_k} R^* \, dy \qquad (17)$$

Where

$$S = \begin{bmatrix} N_j' N_j' & N_j' N_k' \\ N_k' N_j' & N_k' N_k' \end{bmatrix} \begin{bmatrix} u_j \\ u_k \end{bmatrix} - (1 + \varepsilon e^{wt}) \begin{bmatrix} N_j N_j' & N_j N_k' \\ N_k N_j' & N_k N_k' \end{bmatrix} \begin{bmatrix} u_j \\ u_k \end{bmatrix} + \left(M + \frac{1}{K}\right) \begin{bmatrix} N_j N_j & N_j N_k \\ N_k N_j & N_k N_k \end{bmatrix} \begin{bmatrix} u_j \\ u_k \end{bmatrix}$$

$$A = \begin{bmatrix} N_j N_j & N_j N_k \\ N_k N_j & N_k N_k \end{bmatrix} \begin{bmatrix} \dot{u}_j \\ \dot{u}_k \end{bmatrix} \;\; and \; R^* = R \begin{bmatrix} N_j \\ N_k \end{bmatrix}$$

Here the prime and dot denote differentiation with respect to y and t. we obtain

$$S = \frac{1}{l}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} - \frac{(1+\varepsilon e^{wt})}{2}\begin{bmatrix} -1 & 1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} + \left(M + \frac{1}{K}\right)\frac{l}{6}\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix}$$

$$A = \frac{l}{6}\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} \dot{u}_j \\ \dot{u}_k \end{bmatrix} \text{ and } R^* = R\frac{l}{2}\begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

We write the element equation for the elements $y_{i-1} \le y \le y_i$ and $y_i \le y \le y_{i+1}$. Assembling these element equations, we get

$$\frac{1}{l}\begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} - \frac{(1+\varepsilon e^{wt})}{2}\begin{bmatrix} -1 & 1 & 0 \\ -1 & 0 & 1 \\ 0 & -1 & 1 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} +$$

$$\left(M + \frac{1}{K}\right)\frac{l}{6}\begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} +$$

$$\frac{l}{6}\begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix}\begin{bmatrix} \dot{u}_{i+1} \\ \dot{u}_i \\ \dot{u}_{i+1} \end{bmatrix} = R\frac{l}{2}\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$$

(18)

Now put row corresponding to the node i to zero, from equation (18) the difference schemes with $l = h$ is

$$\frac{h}{6}(\dot{u}_{i-1} + 4\dot{u}_i + \dot{u}_{i+1}) + \frac{1}{h}(-u_{i-1} + 2u_i - u_{i+1}) - \frac{(1+\varepsilon e^{wt})}{2}(-u_{i-1} + u_{i+1}) +$$

$$\frac{\left(M+\frac{1}{K}\right)h}{6}(u_{i-1} + 4u_i + u_{i+1}) = R^* \quad (19)$$

Using the Cranck-Nicolson method to the equation (19), we obtain:

$$A_1 u_{i-1}^{j+1} + A_2 u_i^{j+1} + A_3 u_{i+1}^{j+1} = A_4 u_{i-1}^{j} + A_5 u_i^{j} + A_6 u_{i+1}^{j} + R^* \quad (20)$$

Similarly, the equations (12) & (13) are becoming as follows:

$$B_1 \theta_{i-1}^{j+1} + B_2 \theta_i^{j+1} + B_3 \theta_{i+1}^{j+1} = B_4 \theta_{i-1}^{j} + B_5 \theta_i^{j} + B_6 \theta_{i+1}^{j} + R^{**} \quad (21)$$

$$C_1 C_{i-1}^{j+1} + C_2 C_i^{j+1} + C_3 C_{i+1}^{j+1} = C_4 C_{i-1}^{j} + C_5 C_i^{j} + C_6 C_{i+1}^{j} \quad (22)$$

$$A_1 = \left(1 - 6r + 3pV + \left(M + \frac{1}{K}\right)k\right),\ A_2 = \left(4 + 12r + 4\left(M + \frac{1}{K}\right)k\right),$$

$$A_3 = \left(1 - 6r - 3pV + \left(M + \frac{1}{K}\right)k\right),\ A_4 = \left(1 + 6r - 3pV - \left(M + \frac{1}{K}\right)k\right),$$

$$A_5 = \left(4 - 12r - 4\left(M + \frac{1}{K}\right)k\right),\ A_6 = \left(1 + 6r + 3pV - 4\left(M + \frac{1}{K}\right)k\right)$$

$$B_1 = \left(1 - 6r\frac{1}{P_r}\left(1+\frac{4}{3N}\right) + 3pV - \varphi k\right),\ B_2 = \left(4 + 12r\frac{1}{P_r}\left(1+\frac{4}{3N}\right) - 4\varphi k\right),$$

$$B_3 = \left(1 - 6r\frac{1}{P_r}\left(1+\frac{4}{3N}\right) - 3pV - \varphi k\right), B_4 = \left(1 + 6r\frac{1}{P_r}\left(1+\frac{4}{3N}\right) - 3pV + \varphi k\right),$$

$$B_5 = \left(4 - 12r\frac{1}{P_r}\left(1+\frac{4}{3N}\right) + 4\varphi k\right),\ B_6 = \left(1 + 6r\frac{1}{P_r}\left(1+\frac{4}{3N}\right) + 3pV + 4\varphi k\right)$$

$$C_1 = \left(1 - 6r\frac{1}{S_c} + 3pV - \gamma k\right),\ C_2 = \left(4 + 12r\frac{1}{S_c} - 4\gamma k\right), C_3 = \left(1 - 6r\frac{1}{S_c} - 3pV - \gamma k\right)$$

$$C_4 = \left(1 + 6r\frac{1}{S_c} - 3pV + \gamma k\right), C_5 = \left(4 - 12r\frac{1}{S_c} + 4\gamma k\right), C_6 = \left(1 + 6r\frac{1}{S_c} + 3pV + 4\gamma k\right)$$

$$R^{**} = Q_1 C$$

Here $r = \frac{k}{h^2}$ where k, h is mesh sizes along y direction and time direction respectively. Index i refers to space and j refers to time. The mesh system consists of h=0.05 for velocity profiles and concentration profiles and k=0.025 has been considered for computations. In equation (20)-(22), taking i=1(1) n and using initial and boundary conditions (14), the following system of equation are obtained.

$$A_i X_i = B_i\ ,\ i = 1,2,3\ \ldots. \qquad (23)$$

Where $A_i$'s are matrices of order n and $X_i$ and $B_i$'s are column matrices having n-components. The solution of above system of equations are obtained using Thomas algorithm for velocity, angular velocity, temperature and concentration. Also, numerical solutions for these equations are obtained by MATLAB-Program. In order to prove the convergence and stability of Galerkin finite element method, the same Mat lab-program was run with slightly changed values of h and k, no significant change was observed in the values of $u, w, \theta, C$. Hence, the Galerkin finite element method is stable and convergent.

**RESULTS AND DISCUSSION:**

In order to get a physical insight of the problem, the numerical calculations are carried out to illustrate the influence of various physical parameters viz., thermal radiation, magnetic parameter, chemical reaction parameter and permeability parameter on the velocity, temperature, concentration and presented graphically in Figures (1)-(11). Throughout the calculations, the parametric values are chosen as, ε=0.2, ω=0.1 $u_p$ =0.5, Pr =0.71, t =1, Gr = 4,Gc = 2, $Q_1$ = 2, K = 2, M = 2, $\phi$ = 2, $\gamma$ = 0.2 and Sc = 0.2.All the graphs therefore correspond to these values unless specifically indicated on the appropriate graph.

The velocity profiles for different values of permeability parameter, magnetic parameter, thermal Grashof number and solutal Grashof number are depicted in Figures (1)-(4), respectively. It is observed that ,the velocity increases as the permeability parameter K increases (Figure1).The parameter K is directly proportional to the actual permeability K* of the porous medium. Hence an increase in K will decrease the resistance of the porous medium which will tend to accelerate the flow and increase the velocity. It is observed that, the velocity decreases with an increase in the magnetic parameter (Figure2). This is because, the application of the transverse magnetic field will result in a resistive type force (Lorentz force) similar to drag force which tends to resist the fluid flow and thus reduces its velocity. From Figure 3 and 4, it is noticed that there is a rise in the velocity within the boundary layer due to the enhancement of thermal buoyancy force or species buoyancy force. Here, the positive values of Gr correspond to cooling of the plate.

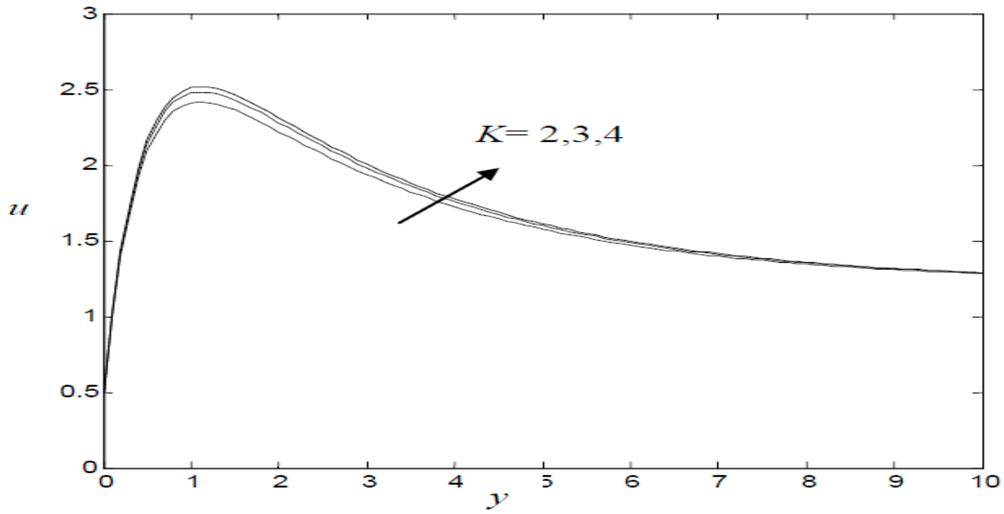


Figure1: Velocity profiles for different values of K.

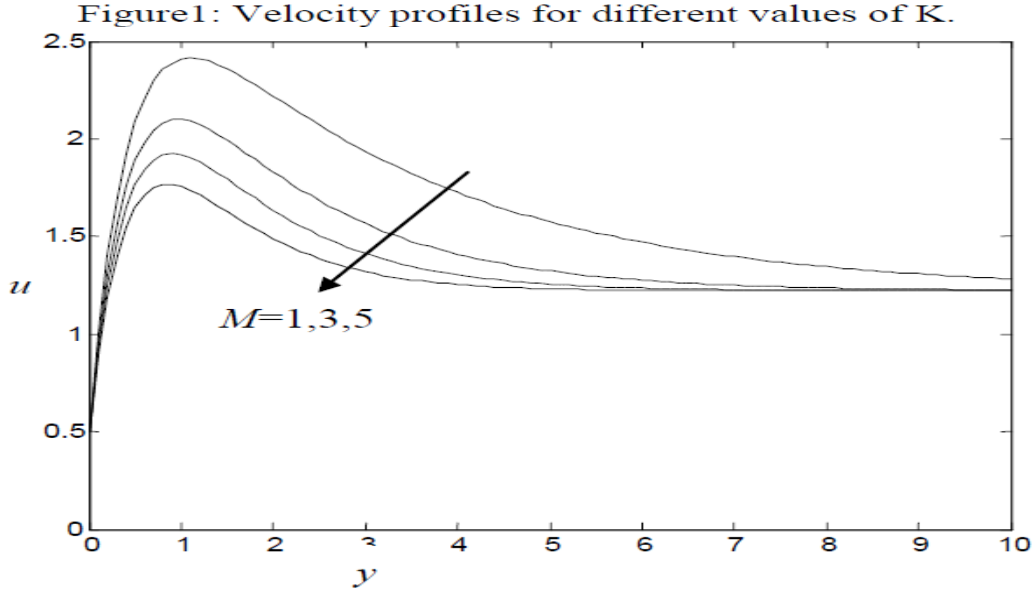


Figure 2: Velocity Profiles for different values of M

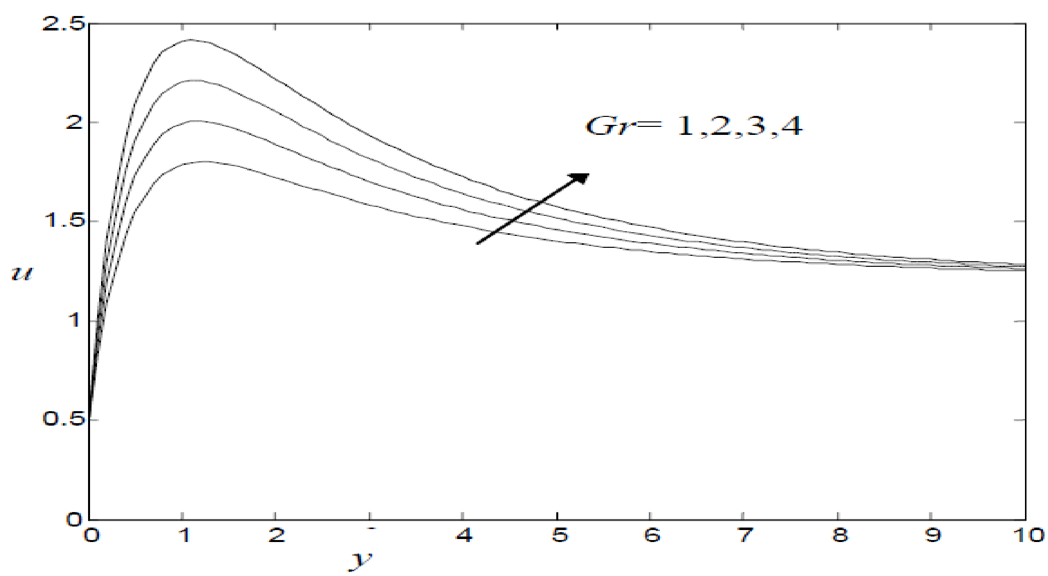


Figure 3: Velocity Profiles for different values of Gr

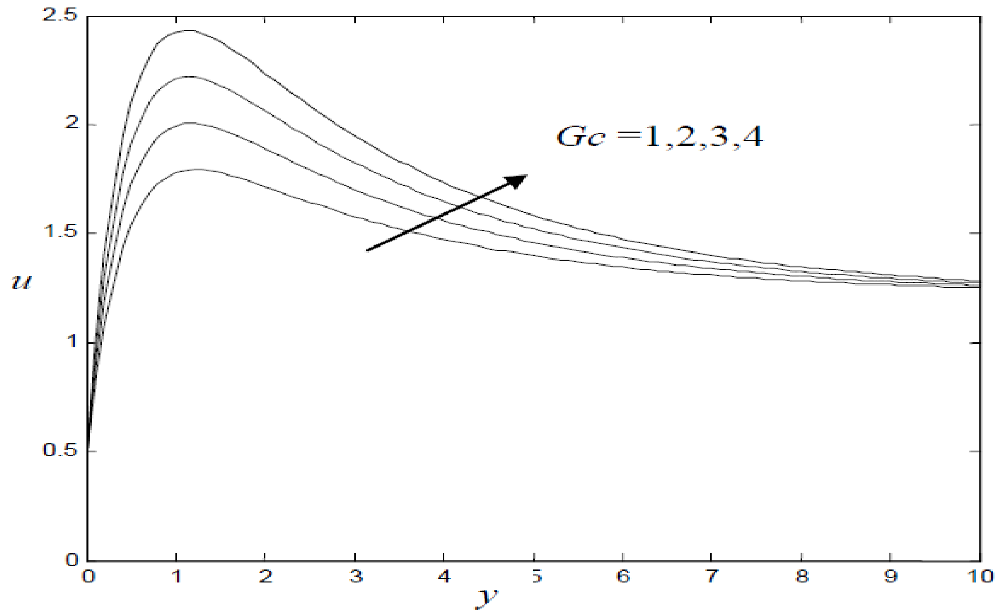


Figure 4: Velocity profiles for differentvalues of Gc

Figures (5)-(8) show the effects of the radiation parameter, radiation absorption parameter, Prandtl number and heat absorption parameter on the temperature, respectively. The radiation parameter defines the relative contribution of conduction heat transfer to thermal radiation transfer. It is observed that with an increase in the radiation parameter, the temperature decreases within the boundary layer (Figure5).It is observed that with an increase in the radiation absorption parameter, the temperature increases (Figure 6). From Figure(7),it is noticed that an increase in the Prandtl number results in a decrease of the thermal boundary layer thickness and in general, lower average temperature within the boundary layer. The reason is that for smaller values of Pr are equivalent to increase the thermal conductivities, and therefore heat is able to diffuse away from the heated surface more rapidly than for a higher value for Pr. It is observed that an increase in the heat absorption parameter decreases the temperature field (Figure.8).

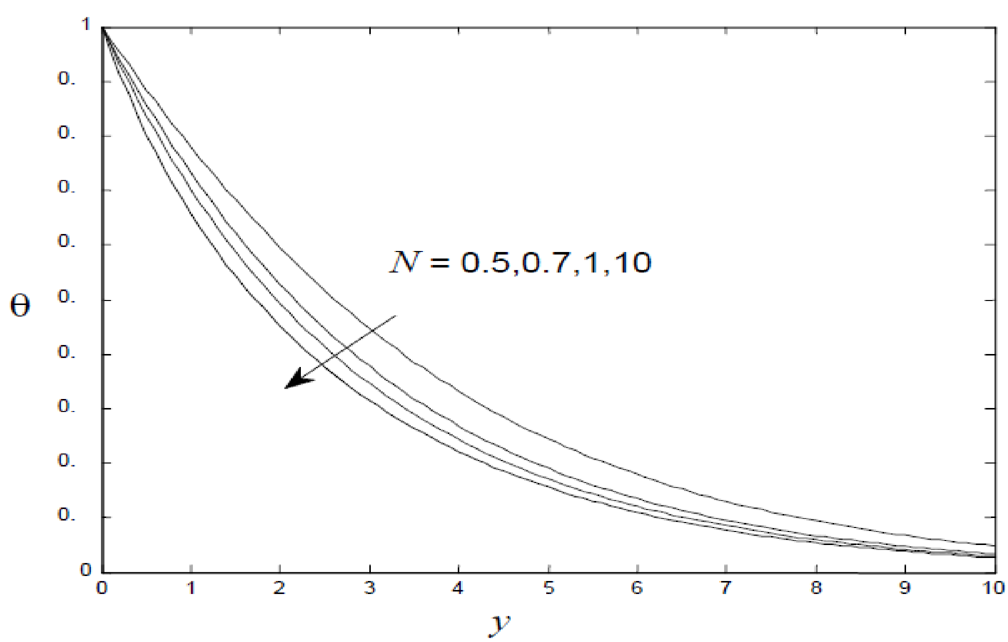


Figure 5: Temperature profiles for differentvalues of N

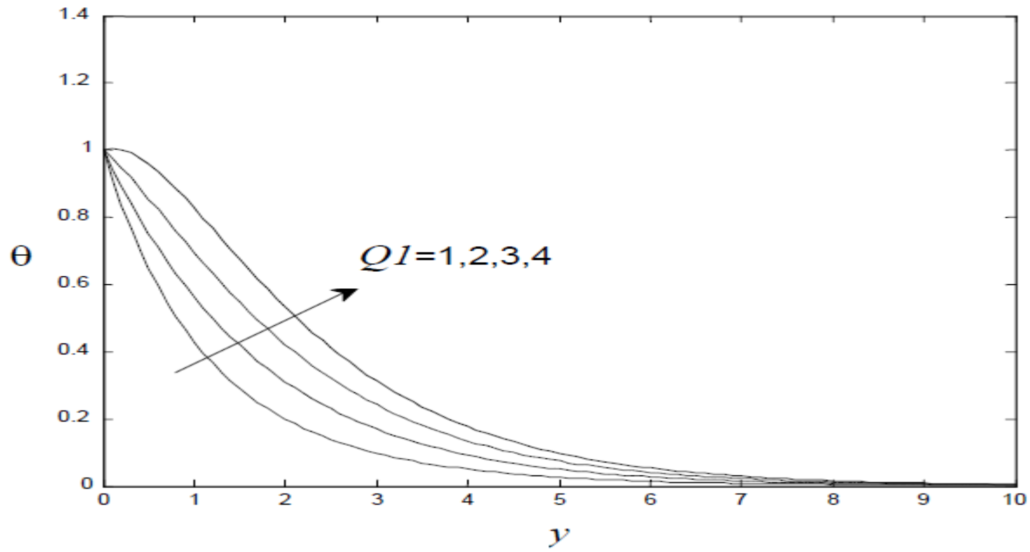


Figure 6: Temperature profile for different values of $Q_1$

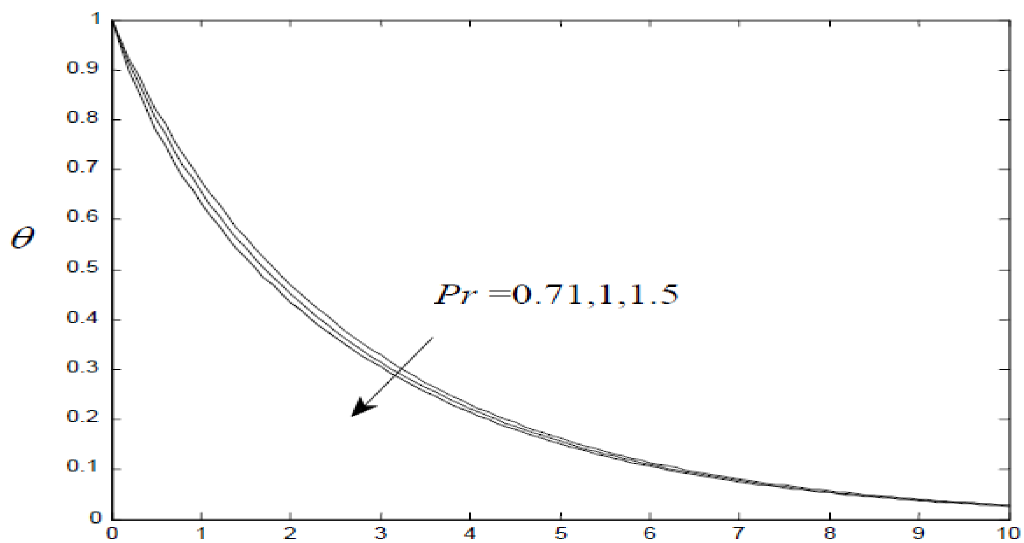


Figure 7: Temperature profile for different Pr values

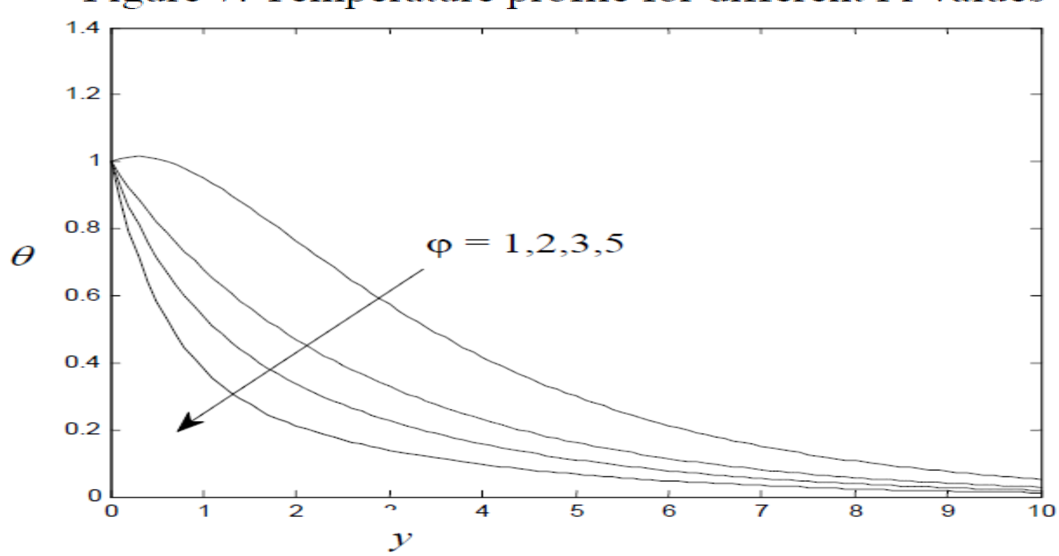


Figure 8: Temperature profiles for different φ values

The concentration profiles for different values of the chemical reaction parameter are presented in Figure (9). As, the chemical reaction parameter γ increases, the concentration decreases. The effect of Schmidt number on the velocity, temperature and concentration are shown in Figures (10) and (11). The Schmidt number embodies the ratio of momentum to mass diffusivity. The Schmidt number quantifies the relative effectiveness of momentum and mass transport by diffusion in the hydrodynamic (velocity) and concentration (species) boundary layers. As the Schmidt number increases the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reductions in the velocity and concentration profiles are accompanied by simultaneous reduction in the velocity and concentration boundary layer thicknesses.

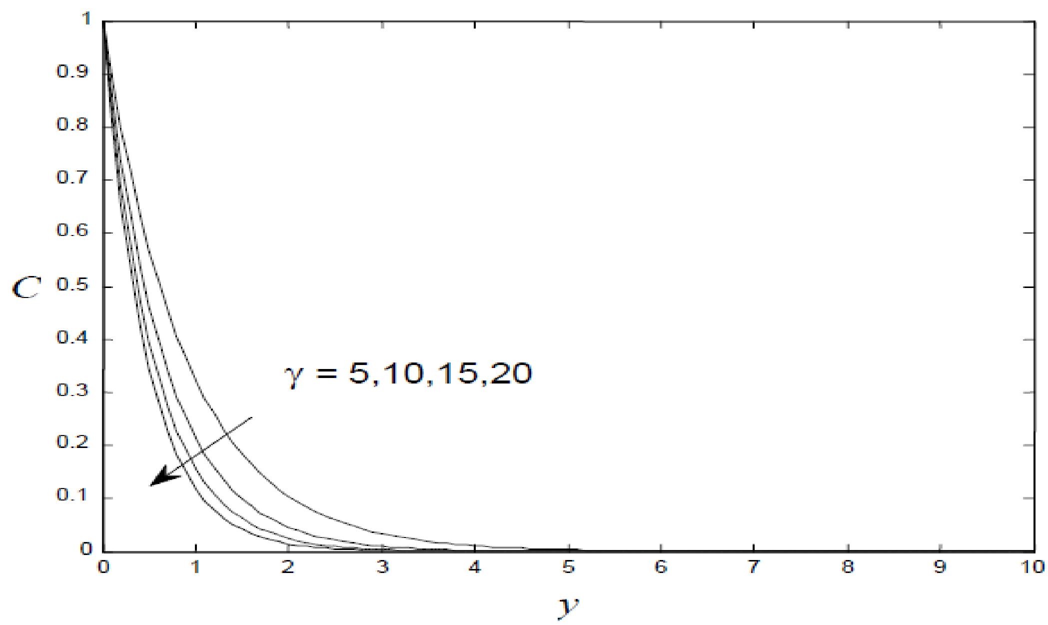


Figure 9: Concentration Profiles for different $\gamma$ values

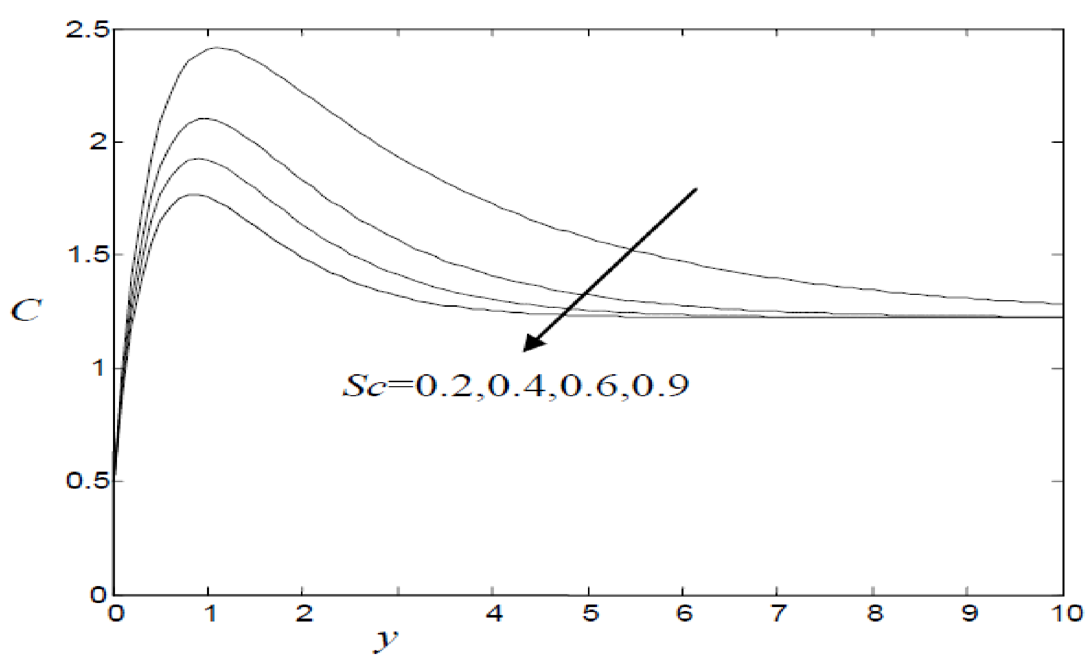


Figure 10: Velocity profiles for differentvalues of Sc

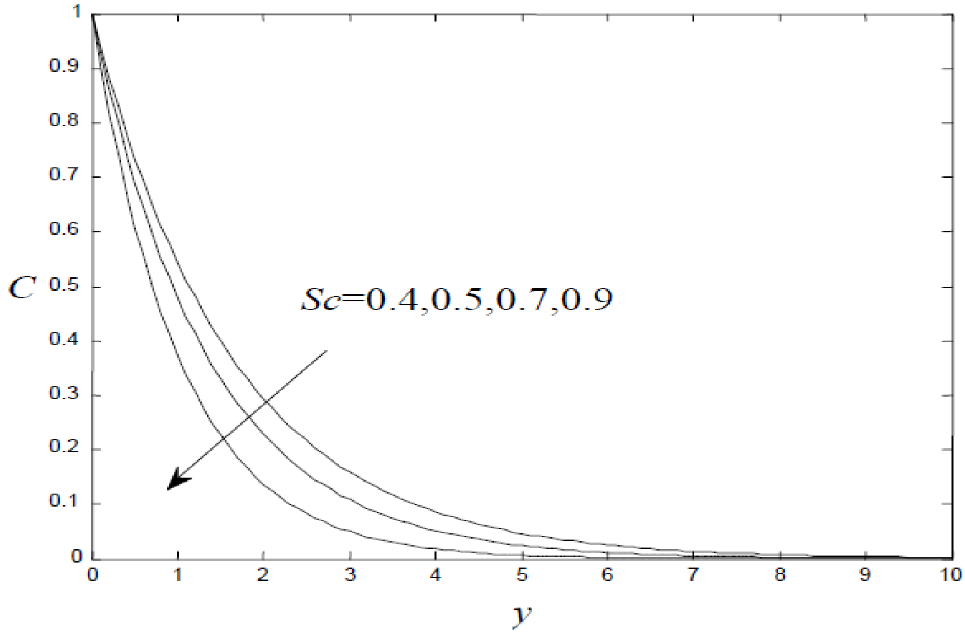


Figure 11: Concentration profiles for differentvalues of Sc

**CONCLUSIONS:**

This paper analyses the effect of thermal radiation on MHD free convective flow past a semi infinite vertical porous moving plate, in the presence of heat absorption and radiation absorption. The results and discussion of the present study leads to the following observations.

• It is interesting to note that the velocity increases near the plate and then decreases smoothly away from the plate, in all the cases.

• An increase in the Schmidt number leads to a decrease in the velocity as well as concentration, and an increase in the rate of mass transfer coefficient.

• The presence of magnetic field reduces the velocity as well as the skin friction coefficient.

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