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RADIATION EFFECTS ON AN UNSTEADY MHD VERTICAL POROUS PLATE IN THE PRESENCE OF HOMOGENEOUS CHEMICAL REACTION

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ABSTRACT

The objective of this paper is to study the on an unsteady MHD flow, radiation and mass transfer of a viscous incompressible conducting fluid past on impulsively started infinite vertical porous plate with variable temperature in the presence of homogeneous chemical reaction is studied. The governing equations are solved by using the finite element method. The expression for velocity, temperature and concentration has been obtained. Some important applications of physical interest for different type motion of the plate are discussed. The results obtained have also been presented numerically through graphs to observe the effects of various parameters and the physical aspects of the problem.

Keywords: radiation, MHD, homogenous chemical reaction, finite element method.

NOMENCLATURE

B_0 External magnetic field
C' Species concentration in the fluid
C'_w Concentration of the plate
C'_∞ Concentration in the fluid far away from the plate
C Dimensionless concentration
C_p Specific heat at constant pressure
g Acceleration due to gravity
G_Γ Thermal Grashof number
Gc Mass Grashof number
R Radiation parameter
k Thermal conductivity of the fluid
K_τ Chemical reaction parameter
M Magnetic field parameter
D Mass diffusivity
P_Γ Prandtl number
S_C Schmidt number fluid near the plate
T'_w Temperature of the plate
T'_∞ Temperature of the fluid far away from the plate
t' Time
t Dimensionless time
u' Velocity of the fluid in the x-direction
u_o Velocity of the plate
u Dimensionless velocity
y' Coordinate axis normal to the plate
y Dimensionless coordinate axis normal to the plate

Greek symbols

α Thermal conductivity
β Volumetric coefficient of thermal expansion
β^* Volumetric coefficient of expansion with concentration
μ Coefficient of viscosity
ν Kinematic viscosity
ρ Density of the fluid
σ Electric conductivity
θ Dimensionless temperature
η Similarity parameter

INTRODUCTION

Natural convection in a fluid saturated porous medium is of fundamental importance in many industrial and natural problems. Few examples of the heat transfer by natural convection can be found in geophysics and energy related engineering problems such as natural circulation in geothermal reservoirs, aquifers, porous insulations, solar power collectors, spreading of pollutants etc. Natural convection occurs due to the spatial variations in density, which is caused by the non-uniform distribution of temperature or/and concentration of a dissolved substance. Kandaswamy *et al.*, [1] were presented to investigate the effects of thermo physic and variable viscosity on MHD mixed convective heat and mass transfer of viscous, incompressible and electrically conducting fluid past a porous wedge in the presence of chemical reaction. Also Anjali devi and Kandaswamy [2] studied an approximate solution for the steady laminar flow along a semi- infinite horizontal plate in the presence of species concentration and chemical reaction. The effects of thermal radiation on unsteady free convective flow over a moving vertical over a moving vertical plate with mass transfer in the presence of homogeneous first order chemical reaction analyzed by Muthukumara swamy *et al.*, [3]. MHD effects on moving vertical plate with homogeneous chemical reaction studied by Nield and Bejan [4], Cheng and Minkowyez [5], Prasad and Kulacki [6] and Angirasa and Peterson [7] in which natural convection caused by immersing a hot surface in a fluidsaturate porous medium at constant ambient temperature has been considered. Also a few studies are found when the porous medium is thermally stratified, i.e., the ambient temperature is not uniform and it varies as a linear function of stream wise direction. This phenomena on has its applications in hot dike complexes in volcanic region for heating of ground water, development of advanced technologies for nuclear waste management, separation process in chemical engineering etc. Rees and Lage [8],

Takhar and Pop [9], Tewari and Singh [10] analytically analyzed free convection from a vertical plate immersed in a thermally stratified porous medium under boundary layer assumptions. On the other hand, Angirasa and Peterson [11], Rathish Kumar *et al*., [12] and Rathis Kumar and Singh [13] have numerically investigated the natural convection process in a thermally stratified porous medium.

Stewartson [14] presented analytic solution to the viscous flow past an impulsively started semi-infinite horizontal plate whereas Hall [15] solved the problem of Stewartson [14] by finite-difference method. Soundalgekar [16] first presented an exact solution to the flow of a viscous incompressible fluid past a impulsively started infinite vertical plate by the Laplace transform technique. The fluid considered in this study was pure air or water. However, in nature, availability of pure air or water is very difficult. It is usually a very complicated phenomenon; however, by introducing suitable assumptions, the governing equations can be simplified. These simplified equations were derived by Gebhart [17] by assuming the concentration level to be very low. This enabled us to neglect Soret-Dufur effects. The solution to this problem governed by coupled linear differential equations was derived by the Laplace-transform technique. Free convection flow with mass-transfer past a semi-infinite vertical plate was presented by Gebhart and Pera [18]. Similarity solutions were presented by Gebhart [17]. In all these studies the concentration level at the plate was assumed to be constant and at low level, which is true in some cases. Many times, mass is supplied at the plate at constant rate in the presence of species concentration and such a situation has not been studied in case of an impulsively started infinite vertical isothermal plate. Such a study will be found useful in chemical, aerospace and other engineering applications. Raptis [19] investigate the steady flow of a viscous fluid through a very porous medium bounded by a porous plate subject to a constant suction velocity by the presence of thermal radiation. Abdus Sattar and Hamid Kalim [20] investigated the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate.

Chambre and Young [21] have analyzed a first order chemical reaction in the neighborhood of a horizontal plate. Boundary layer flow on moving horizontal surfaces was studied by Sakiadis [22]. The effects of transversely applied magnetic field, on the flow of an electrically conducting fluid past an impulsively started infinite isothermal vertical plate was studied by Soundalgekar *et al*., [23]. MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field studied by Soundalgekar *et al*., [24].

In the present paper, effect of thermal radiation on an unsteady MHD vertical porous plate in the presence of homogeneous chemical reaction has been studied. The problem is governed by the system of coupled non-linear partial differential equations whose exact solutions are difficult to obtain, if possible. So, Galerkin finite element method has been adopted for its solution, which is more economical from computational point of view.

MATHEMATICAL ANALYSIS

MHD flow of a viscous incompressible fluid past an impulsively started infinite vertical plate with variable temperature and uniform mass diffusion in the presence of homogeneous chemical reaction is studied. Here the x' -axis is taken along the plate in vertically upward direction and the y'-axis is taken normal to the plate. Initially, the plate and fluid are at the same temperature and concentration. At time t'>0. The plate is given an impulse motion in the vertical direction against gravitational field with constant velocity u_o . The plate temperature is raised linearly. With time and the concentration level near the plate is also raised to c_w . A transverse magnetic field of uniform strength B_o is assumed to be applied normal to the plate. The induced magnetic field and viscous dissipation is assumed to be negligible. It is also assumed that there exists a homogeneous first order chemical reaction between the fluid and species concentration.

The governing equations are :

$$\frac{\partial u'}{\partial t'} = g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) + \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma\beta_o^2}{\rho}u' - \frac{\nu}{K}u' \quad (1)$$

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\left[\frac{\partial^2 T'}{\partial y'^2} + \frac{1}{k}\frac{\partial q}{\partial y}\right] \quad (2)$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} - K_l\left(C' - C'_\infty\right) \quad (3)$$

With the following initial and boundary conditions

$$\left.\begin{array}{l} t' \le 0 : u' = 0, T' = T'_\infty \\ \qquad C' = C'_\infty \; forall \;\; y' \\ t' > 0 : u' = u_o, T' = T'_\infty + (T'_w - T'_\infty)At' \\ \qquad C' = C'_w \; at \; y' = 0 \\ u' = 0, T' \to T'_\infty \\ \qquad C' \to C'_\infty \; as \; y' \to \infty \end{array}\right\} \quad (4)$$

On introducing the following non -dimensional quantities:

$$\left.\begin{array}{l} u = \dfrac{u'}{u_o}, t = \dfrac{t' u_o^2}{\nu}, y = \dfrac{y' u_o}{\nu}, C = \dfrac{(C' - C'_\infty)}{(C'_w - C'_\infty)}, \\ G_\Gamma = \dfrac{g\beta\nu(T'_w - T'_\infty)}{u_o^3}, G_C = \dfrac{\nu g\beta^*(C'_w - C'_\infty)}{u_o^3}, \\ P_\Gamma = \dfrac{\mu C_p}{k}, \quad \theta = \dfrac{(T' - T'_w)}{(T'_w - T'_\infty)}, \quad S_C = \dfrac{\nu}{D}, \\ K_\Gamma = \dfrac{\nu K_l}{u_o^2}, \quad N = \dfrac{\sigma B_o^2 \nu}{\rho u_o^2} + \dfrac{1}{K}, A = \dfrac{u^2}{\nu} \\ R = \dfrac{16a^* \upsilon^2 \sigma T_\infty^3}{k u_o^2}, \quad \dfrac{\partial q}{\partial y} = 4\alpha^2 (T - T_\infty) \end{array}\right\} \quad (5)$$

By using non-dimensional variables the governing equations (1) to (4) leads to:

$$\frac{\partial u}{\partial t} = G_\Gamma \theta + G_C C + \frac{\partial^2 u}{\partial y^2} - Nu \qquad (6)$$

$$\frac{\partial \theta}{\partial t} = \frac{(1+R)}{P_\Gamma} \frac{\partial^2 \theta}{\partial y^2} \qquad (7)$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_C} \frac{\partial^2 C}{\partial y^2} - K_\tau C \qquad (8)$$

The last term in (8) represents homogeneous first order chemical reaction, K_τ being the dimensionless reaction rate constant.

The initial and boundary condition in dimensionless form are:

$$\left.\begin{array}{ll} u = 0, \theta = 0, C = 0 & for \; all \;\; y, t \le 0 \\ t > 0 : u = 1, \theta = t, C = 1 & at \;\; y = 0 \\ u = 0, \theta \to 0, C \to 0 & as \;\; y \to \infty \end{array}\right\} \qquad (9)$$

METHOD OF SOLUTION

The Galerkin expansion for the differential equation (6) becomes:

$$\int_{y_J}^{y_K} N^{(e)^T} \left(\frac{\partial^2 u^{(e)}}{\partial y^2} + \frac{\partial u^{(e)}}{\partial t} - Nu^{(e)} + R_1 \right) dy = 0 \quad (10)$$

Where

$$R_1 = G_\Gamma \theta + G_C C, N = M + \frac{1}{K}, \quad A = \frac{(1+R)}{\Pr}$$

Let the linear piecewise approximation solution be:

$$u^{(e)} = N_j(y)u_j(t) + N_k(y)u_k(t) = N_j u_j + N_k u_k$$

Where

$$N_j = \frac{y_k - y}{y_k - y_j}, \qquad N_k = \frac{y - y_j}{y_k - y_j}$$

$$N^{(e)^T} = \begin{bmatrix} N_j & N_k \end{bmatrix}^T = \begin{bmatrix} N_j \\ N_k \end{bmatrix}$$

$$N^{(e)^T} \frac{\partial u^{(e)}}{\partial y} \Bigg\}_{y_j}^{y_k} - \int_{y_j}^{y_k} \left\{ \frac{\partial N^{(e)^T}}{\partial y} \frac{\partial u^{(e)}}{\partial y} - N^{(e)^T} \left(\frac{\partial u^{(e)}}{\partial t} + Nu^{(e)} - R_1 \right) \right\} dy = 0 \qquad (11)$$

Neglecting the first term in equation (11), we get:

$$\int_{y_j}^{y_K} \left\{ \frac{\partial N^{(e)^T}}{\partial y} \frac{\partial u^{(e)}}{\partial y} + N^{(e)^T} \left(\frac{\partial u^{(e)}}{\partial t} + Nu^{(e)} - R_1 \right) \right\} dy = 0$$

$$\frac{1}{l^{(e)}} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} u_j \\ u_k \end{bmatrix} + \frac{l_{(e)}}{6} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} \dot{u}_j \\ \dot{u}_k \end{bmatrix} + \frac{Nl^{(e)}}{6} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} u_j \\ u_k \end{bmatrix} = R_1 \frac{l_{(e)}}{2} \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

Where $l^{(e)} = y_k - y_j = h$ and dot denotes the differentiation with respect to *t*.

We write the element equations for the elements $y_{i-1} \le y \le y_i$ and $y_j \le y \le y_k$ assemble three element equations, we obtain:

$$\frac{1}{l^{(e)^2}} \begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} + \frac{1}{6} \begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix} \begin{bmatrix} \dot{u}_{i-1} \\ \dot{u}_i \\ \dot{u}_{i+1} \end{bmatrix} + \frac{N}{6} \begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix} \begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} = \frac{R_1}{2} \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} \qquad (12)$$

Now put row corresponding to the node *i* to zero, from Equation (12) the difference schemes is:

$$\frac{1}{l^{(e)^2}} \left[-u_{i-1} + 2u_i - u_{i+1} \right] + \frac{1}{6} \left[\dot{u}_{i-1} + 4\dot{u}_i + \dot{u}_{i+1} \right] + \frac{N}{6} \left[u_{I-1} + 4u_i + u_{i+1} \right] = R_1$$

Applying Crank-Nicholson method to the above equation then we gets:

$$A_1 u_{i-1}^{j+1} + A_2 u_i^{j+1} + A_3 u_{i+1}^{j+1} = A_4 u_{i-1}^j + A_5 u_i^j + A_6 u_{i+1}^j + R^* \qquad (13)$$

Where

$$A_1 = 2 - 6r + Nk \quad A_2 = 8 - 12r + 4Nk$$

$$A_3 = 2 - 6r + Nk \quad A_4 = 2 + 6r - Nk$$

$$A_5 = 8 - 12r - 4Nk \quad A_6 = 2 + 6r - Nk$$

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$$R^* = 12(G_\Gamma)k\theta_i^j + 12(G_C)kC_i^j$$

Applying similar procedure to equation (11) and (12) then we gets:

$$B_1\theta_{i-1}^{j+1} + B_2\theta_i^{j+1} + B_3\theta_{i+1}^{j+1} = B_4\theta_{i-1}^j + B_5\theta_i^j + B_6\theta_{i+1}^j \quad (14)$$

$$C_1C_{i-1}^{j+1} + C_2C_i^{j+1} + C_3C_{i+1}^{j+1} = C_4C_{i-1}^j + C_5C_i^j + C_6C_{i+1}^j \quad (15)$$

Where

$B_1 = 1 - 3Ar \qquad B_2 = 4 + 6rA$

$B_3 = 1 - 3Ar \qquad B_4 = 1 + 3Ar$

$B_5 = 4 - 6Ar \qquad B_6 = 1 + 3Ar$

$C_1 = 2S_C - 6r + S_C kK_\Gamma$

$C_2 = 8S_C + 12r + 4S_C kK_\Gamma$

$C_3 = 2S_C - 6r + S_C kK_\Gamma$

$C_4 = 2S_C + 6r - S_C kK_\Gamma$

$C_5 = 8S_C - 12r - 4S_C kK_\Gamma$

$C_6 = 2S_C + 6r - S_C kK_\Gamma$

Here $r = \frac{k}{h^2}$ and h, k are the mesh sizes along y-direction and t -direction, respectively. Index i refers to the space and j refers to the time. In Equations (13)-(15), taking i = 1(1) n and using initial and boundary conditions (9), the following system of equations are obtained:

$$A_i X_i = B_i \qquad i = 1(1)3 \quad (16)$$

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

RESULTS AND DISCUSSIONS

As a result of the numerical calculations, the dimensionless velocity, temperature and concentration distributions for the flow under consideration are obtained and their behavior have been discussed for variations in the governing parameters viz., the thermal Grashof number G_Γ Mass Grashof number G_C, Radiation parameter R, Magnetic field parameter *M*, permeability parameter *K*, Prandtl number P_Γ, Schmidt number S_C, and Chemical reaction parameter K_τ Here we fixed t = 0.2.

The influence of the Magnetic field parameter M thermal on the velocity is presented in Figure-1. Magnetic field parameter signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force in the boundary layer. As expected, it is observed that, while all other participating parameters are held constant and Magnetic field parameter M is increased it is seen that velocity decreases in general. Further, it is noticed that we move far away from the plate, the fluid velocity goes down.

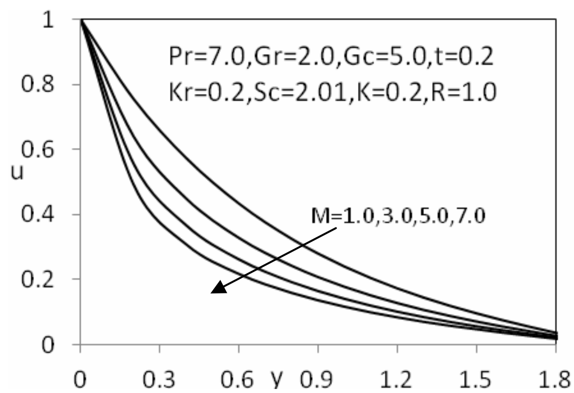

Figure-1. Effects of M on velocity.

The influence of the Mass Grashof number Gc on the velocity is presented in Figure-2. It is observed that, while all other parameters are held constant and velocity increases with an increase in Mass Grashof number Gc.

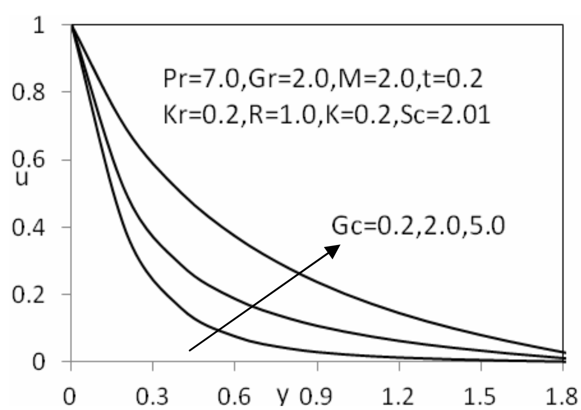

Figure-2. Effects of G_C on velocity.

The influence of the Grashof number G_Γ on the velocity is presented in Figure-3. Increase in the Grashof number G_Γ contributes to the increase in velocity when all other parameter that appears in the velocity field are held constant.

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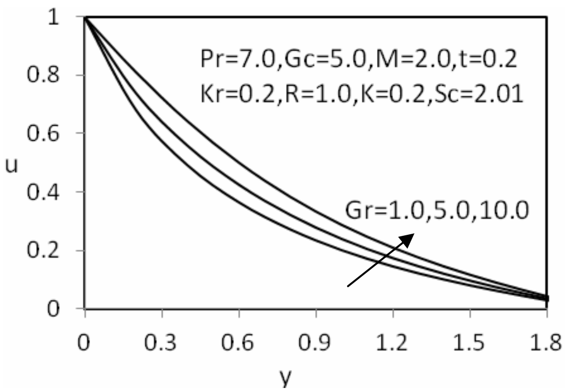

Figure-3. Effects of G_C on velocity.

Figure-4 shows the velocity profiles for different permeability parameters *K*. It is clearly seen that, as *K* increases, the peak values of the velocity tend to increase. While all other participating parameters are held constant.

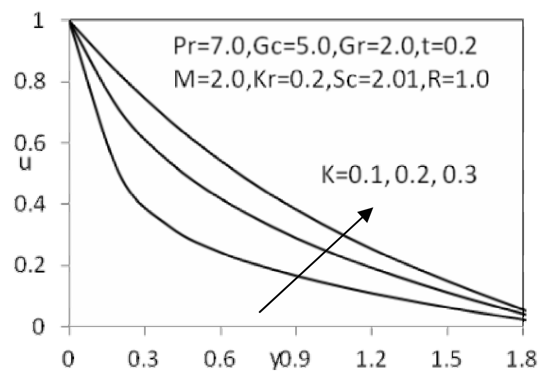

Figure-4. Effects of *K* on velocity.

The influence of the Schmidt number Sc on the velocity is presented in Figure-5. It is observed that, while all other participating parameters are held constant and the increases schmidth number S_C contributes the decrease in the velocity.

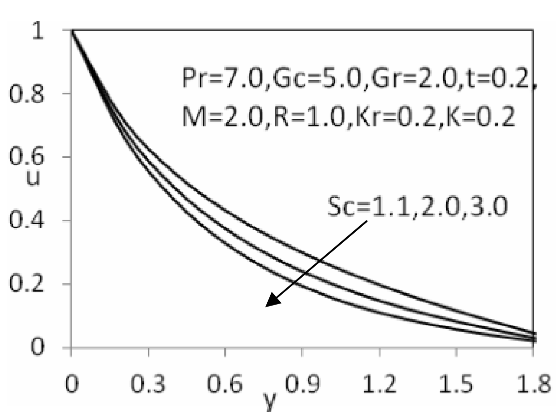

Figure-5. Effects of S_C on the velocity.

Influence of the Schmidth number S_C on the concentration is presented in Figure-6. It is observed that, while all other participating parameters are held constant and the increases schmidth number S_C contributes the decrease in the concentration.

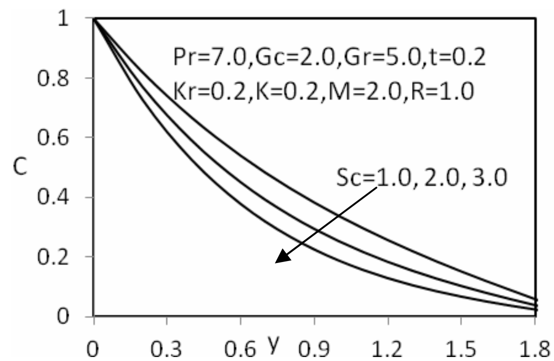

Figure-6. Effects of S_C on the concentration.

The influence of dimensionless chemical reaction parameter K_τ on the velocity of the fluid medium has been shown in Figure-7. It is absorb that increase in chemical reaction contributes to the decrease in velocity when all other parameters that appears in the velocity field are held constant.

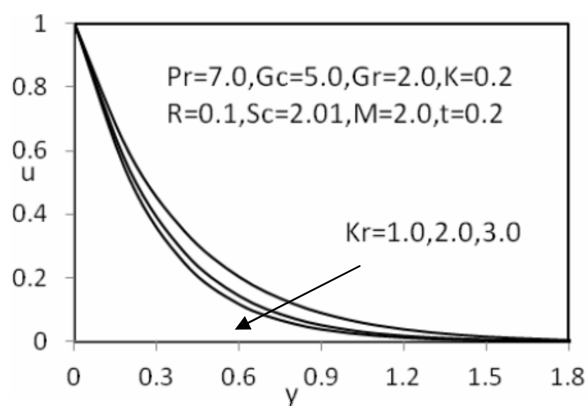

Figure-7. Effects of K_τ on velocity.

The influence of dimensionless chemical reaction parameter K_τ on the concentration is shown in Figure-8. It is absorb that increase in chemical reaction contributes to the decrease in concentration while all other parameters that appears in the concentration field are held constant.

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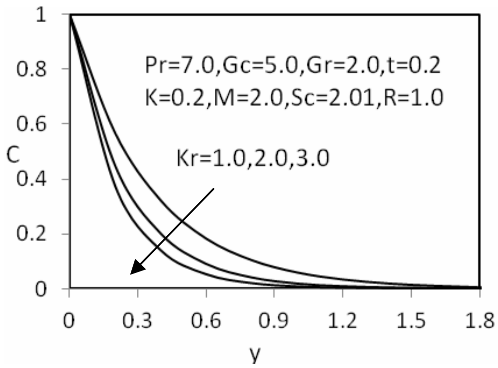

Figure-8. Effects of K_{τ} on the concentration.

The Effect of Prandtle number P_r on the velocity field has been illustrated in Figure-9. It observed that the velocity field increase with decreasing Prandtle number P_r while all other parameter that appears in the velocity field are held constant.

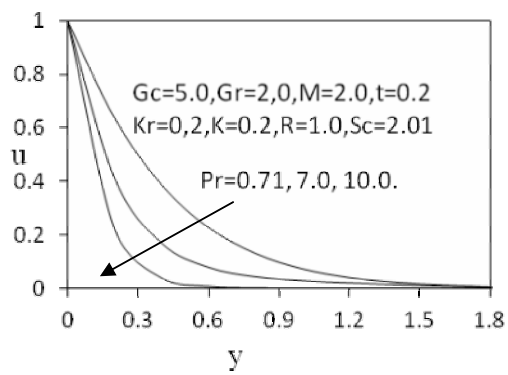

Figure-9. Effect of P_r on the velocity.

The Effect of Prandtle number P_r on the temperature field has been illustrated in Figure-10. It is observed that the temperature field decrease with increasing Prandtle number P_r while all other parameters that appear in the temperature field are held constant.

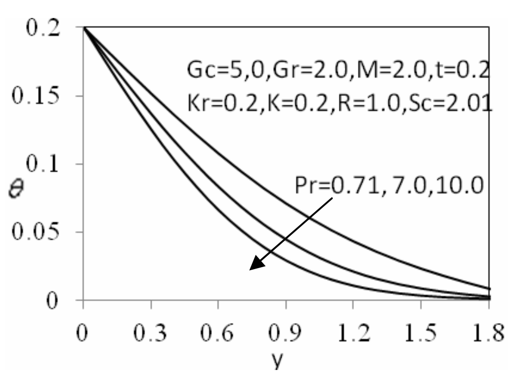

Figure-10. Effect of P_r on the temperature.

The influence of the Radiation Parameter R on the velocity is presented in Figure-11. Increase in the Radiation Parameter R contributes to the increase in velocity when all other parameter that appears in the velocity field is held constant.

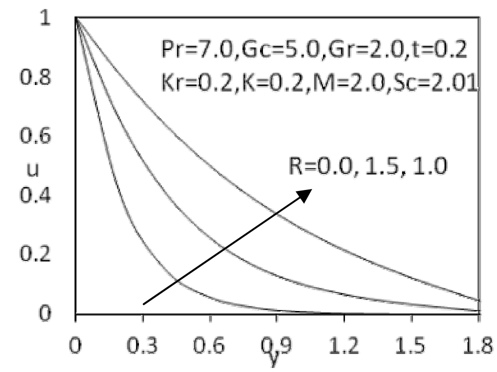

Figure-11. Effect of R on velocity.

The influence of the Radiation Parameter R on the temperature is presented in Figure-12. Increase in the Radiation Parameter R contributes to the increase in temperature when all other parameter that appears in the velocity field is held constant.

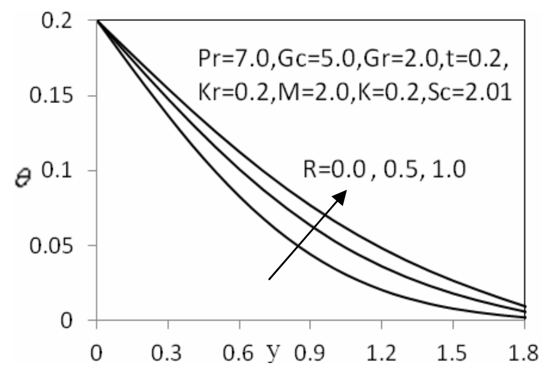

Figure-12. Effect of R on the temperature.

CONCLUSIONS

In this paper, the governing equation for the radiation effects on an unsteady MHD vertical porous plate in the presence of homogeneous chemical reaction has been studied. Employing the highly efficient finite element method, the leading equations are solved numerically. The results illustrate the flow characteristics for the velocity, temperature, concentration, it is found that when the Grashof numbers increase, the concentration buoyancy effects enhance, and thus the fluid velocity increases. The velocity as well as the temperature increase s with as increase in the Radiation parameter. The velocity as well as the concentration decreases with an increase in the chemical reaction parameter. Also, when the Schmidt number increases, the concentration level decreases the fluid velocity. When the Schmidt number or the chemical reaction parameter increases, the velocity decreases. The velocity as well as the temperature decreases with an increase in Prandtle number.

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