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Radiation Absorption and Chemical Reaction Effects on MHD Flow Through Porous Medium Past an Exponentially Accelerated Inclined Plate with Variable Temperature

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The present paper investigates an unsteady MHD free convection flow heat and mass transfer past an exponentially accelerated inclined plate embedded in a saturated porous medium with uniform permeability, variable temperature and concentration has been studies. The effect of angle of inclination on the flow phenomena in the presence of heat source or sink and destructive reaction. The governing partial differential equations are solved by using regular perturbation technique. The present study has an immediate application in understanding the drag experienced at the heated or cooled and inclined surfaces in a seepage flow.
Keywords: Radiation absorption, Chemical reaction, MHD, Variable temperature.

1. Introduction

Form the scientific point of observation, flow arising from temperature and material difference is applied in chemical engineering, geothermal reservoirs, aeronautics and astrophysics. In some applications, magnetic forces are present and at other times the flow is further complicated by the presence of radiation absorption, an excellent paradigm of this is in the planetary atmosphere where there is radiation absorption form near by the stars [1-15].

The current development of magnetodydrodynamics application is toward a strong magnetic field (so that the influence of electromagnetic force is noticeable) and toward a low density of the gas (such as in space flight and in nuclear fusion research). Under this condition, the Hall current become important. The rotating flow of an electrically conducting fluid in the presence of a magnetic field is encountered in geophysical, cosmical fluid dynamics, medicine and biology. Application in biomedical engineering includes cardiac MRI, ECG, ect. Several engineering applications in areas of hall accelerator as well as in flight [16-30].

They have considered four different types of plate motion such as (i) flow induced by an impulsively motion of the plate, (ii) flow due to acceleration of the plate (iii) flow due to non uniform acceleration of the plate, (iv) flow due to highly non uniform acceleration of the plate. In the present analysis we have considered the heat generation (absorption) of the type $Q = Q'\left(T' - T'_\infty\right)$, where $\dfrac{Q'}{\rho C_p}$ is the volumetric rate of heat generation (absorption) [31-45].

The present paper consist of free convective flow of an electrically conducting as well as radiating absorption viscous fluid past an exponentially accelerated inclined plate embedded in a porous medium with variable surface temperature and concentration in the presence of transverse magnetic field, heat source and chemical reaction has been studied.

Formulation of the problem

We consider an unsteady uniform MHD free convective flow of a viscous, incompressible and radiation absorption fluid past an exponentially accelerated inclined infinite plate with variable temperature embedded in a saturated porous medium. The x – axis is taken along the plate and y –axis is normal to the plate. Magnetic field intensity B_0 is applied in the direction perpendicular to the plate. The plate is inclined to vertical direction by an angle c. the induced magnetic field is neglected as the magnetic Reynolds number of the flow is very small. Initially, it is assumed that the plate and the surrounding fluid are at the same temperature T_∞' and the concentration C_∞'.

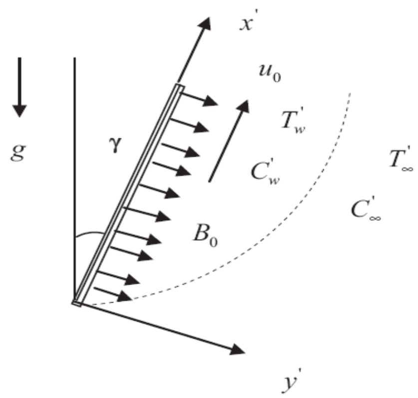

Figure (1): Flow geometry

At time t' the plate is exponentially accelerated with a velocity $u' = u_0 \exp(a't')$ in its own plate. At the same time the temperature and concentration level are also raised or lowered linearly with time t. The physical model is represented in figure (1). Following Kumar and Varma [46], Schlichting and Gersten [47], Bansal [48], the boundary layer equations of flow, heat and mass transfer past an exponentially accelerated inclined plate are given by

$$\frac{\partial u'}{\partial t'} = g\beta\left(T' - T_\infty'\right)\cos\gamma + g\beta'\left(C' - C_\infty'\right)\cos\gamma + \frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_0^2}{\rho}u' - \frac{\nu}{K_p'}u'$$

(1)

$$\rho C_p \frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial y'^2} - Q'\left(T' - T_\infty'\right) + Q_l'\left(C' - C_\infty'\right)$$

(2)

$$\frac{\partial C'}{\partial t'} = \kappa \frac{\partial^2 C'}{\partial y'^2} - K_r'\left(C' - C_\infty'\right)$$

(3)

The initial and boundary conditions are:

$$u' = 0, T' = T_\infty', C' = C_\infty' \quad for\ all \quad y', t' \le 0$$

$$u' = u_0 \exp(a't'), T_\infty' + \frac{(T_w' - T_\infty')u_0^2 t'}{\nu}, C' = C_\infty' + \frac{\left(C_w' - C_\infty'\right)u_0^2 t'}{\nu} at \quad y' = 0,, t' > 0$$

$$u' = 0, T' \to T_\infty', C' \to C_\infty' \qquad as \quad y' \to \infty$$

(4)

The boundary conditions for the temperature at the plate impose a linearity relation between temperature and time with a residual temperature T_∞' and having a constant slope $\frac{u_0^2}{\nu}$ which depends upon square of the characteristic velocity and material property. Similar explanation holds for concentration at the plate.

On introducing the following non – dimensional quantities

$$y = \frac{u_0 y'}{\nu}, U = \frac{u'}{u_0}, \quad t = \frac{t' u_0^2}{\nu}, \quad a = \frac{a'\nu}{u_0^2}, \quad T = \frac{T' - T_\infty'}{T_w' - T_\infty'}, \quad C = \frac{C' - C_\infty'}{C_w' - C_\infty'}$$

$$Gr = \frac{\nu\beta g\left(T_w' - T_\infty'\right)}{u_0^3}, \quad \Pr = \frac{\mu C_p}{\kappa}, \quad Gc = \frac{\nu\beta^* g\left(C_w' - C_\infty'\right)}{u_0^3}, M = \frac{\sigma B_0^2 \nu}{\rho u_0^2} \qquad (5)$$

$$K_p = \frac{u_0^2 K_p'}{\nu^2}, Kr = \frac{Kr'\nu}{u_0^2}, Q = \frac{Q'\nu}{\rho C_p u_0^2}, Sc = \frac{\nu}{D}, Q_l = \frac{Q_l' \nu^2\left(C_w' - C_\infty'\right)}{\rho C_p u_0^2\left(T_w' - T_\infty'\right)}$$

In equations (1), (2), (3) and (4)

$$\frac{\partial U}{\partial t}=\frac{\partial^2 U}{\partial y^2}-M\ U-\frac{1}{K_P}U+Gr\,T\ \cos\gamma+Gc\ C\cos\gamma$$
(6)

$$\frac{\partial T}{\partial t}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2}-QT+Q_l\,C \qquad (7)$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-Kr\ C \qquad (8)$$

The initial and boundary conditions in dimensionless form are

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

where u' is the velocity of the fluid along the plate in the x' - direction, t' is the time, g is the acceleration due to gravity, β is the coefficient of volume expansion, β^* is the coefficient of thermal expansion with concentration, T'_∞ is the temperature of the fluid near the plate, T'_w is the temperature of the fluid far away from the plate, T'_w is the temperature of the fluid, C' is the species concentration in the fluid near the plate, C'_∞ is the species concentration in the fluid far away from the plate, ν is the kinematic viscosity, K_0 is the coefficient of kinematic visco-elastic parameter, σ is the electrical conductivity of the fluid, B_0 is the strength of applied magnetic field, ρ is the density of the fluid, C_p is the specific heat at constant pressure, K is the thermal conductivity of the fluid, μ is the viscosity of the fluid, D is the molecular diffusivity, u_0 is the velocity of the plate, Gr is the thermal Grashof number, Gc is modified Grashof Number, $\Pr$ is Prandtl Number, M is the magnetic field, Sc is Schmidt number, Kr is Chemical Reaction, K is Porous Permeability, S is Heat source parameter respectively.

Solution of the problem

Equation (6) – (8) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (9). However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. This can be done by representing the velocity, temperature and concentration of the fluid in the neighbourhood of the fluid in the neighbourhood of the plate as

$$U = U_0(y) + \varepsilon e^{at} U_1(y)$$
$$T = T_0(y) + \varepsilon e^{at} T_1(y)$$
$$C = C_0(y) + \varepsilon e^{at} C_1(y)$$
(10)

Substituting (10) in Equation (6) – (8) and equating the harmonic and non – harmonic terms, we obtain

$$U_0'' - \beta_4 U_0 = -Gr\, T_0 \cos\gamma - Gc C_0 \cos\gamma$$
(12)

$$U_1'' - \beta_3 U_1 = -Gr\, T_1 \cos\gamma - Gc C_1 \cos\gamma$$
(13)

$$T_0'' - Q \Pr T_0 = -Q_l \Pr C_0$$
(14)

$$T_1'' - \beta_2 T_1 = -Q_l \Pr C_1$$
(15)

$$C_0'' - Sc\, Kr\, C_0 = 0$$
(16)

$$C_1'' - \beta_1 C_1 = 0$$
(17)

The corresponding boundary conditions can be written as

$$U_0 = 0, U_1 = 1,\ \theta_0 = 1, \theta_1 = 0, C_0 = 1, C_1 = 0 \qquad at\ \ y = 0$$
$$U_0 = 0, U_1 = 0,\ \theta_0 = 0, \theta_1 = 0, C_0 = 0, C_1 = 0 \qquad as\ \ y \to \infty$$
(18)

Where $\beta_1 = Sc(Kr + at), \beta_2 = (Q - at)\Pr, \beta_3 = \left(M + \frac{1}{K_p} + at\right)$

Solving Equations (12) - (17) under the boundary conditions (18) and we obtain the velocity, temperature and concentration distributions in the boundary layer as

$$C_0 = t\ e^{m4y}; C_1 = 0$$

$$T_0 = A_1 e^{m4y} + A_2 e^{m8y}; T_1 = 0$$

$$U_0 = L_1 e^{m8y} + L_2 e^{m4y} + L_3 e^{m12y}; U_1 = 0$$

In view of the equation (10) becomes

$$U = L_1 e^{m4y} + L_2 e^{m8y} + L_3 e^{m4y} + L_4 e^{m12y}$$

$$T = A_1\, e^{m4y} + A_2\, e^{m8y}$$

$$C = t\; e^{m4y}$$

Coefficient of Skin-Friction

The coefficient of skin-friction at the vertical porous surface is given by

$$C_f = \left(\frac{\partial U}{\partial y}\right)_{y=0} = m_4 L_1 + m_8 L_2 + m_4 L_3 + m_{12} L_4$$

Coefficient of Heat Transfer

The rate of heat transfer in terms of Nusselt number at the vertical porous surface is given by

$$N_u = \left(\frac{\partial T}{\partial y}\right)_{y=0} = A_1\, m_4 + A_2 m_8$$

Sherwood number

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = t\; m_4$$

Appendix

$$\beta_4 = \left(M + \frac{1}{K_p}\right), m_4 = -KrSc$$

$$m_8 = -Q\,\mathrm{Pr}, m_{12} = \beta_4, L_1 = -\frac{A_1 Gr \cos\gamma t}{m_4{}^2 - \beta_4}, L_2 = -\frac{A_2 Gr \cos\gamma t}{m_8{}^2 - \beta_4}, L_3 = -\frac{Gc \cos\gamma t}{m_4{}^2 - \beta_4}$$

$$L_4 = \left(e^{at} - L_1 - L_2 - L_3\right), A_1 = -\frac{Q_l\,\mathrm{Pr}\,t}{m_4{}^2 - Q\,\mathrm{Pr}}, A_2 = \left(t - A_1\right)$$

2. Results and discussions

The analysis of the graphical representation of flow, heat and mass transfer phenomena brings out the effects of various parameters governing the flow. The effect of inclined plate on flow characteristics has been also discussed. Moreover assigning zero to the angle of inclination, the case of vertical plate can be derived as a particular case. Further for $a = 0$ in the boundary condition (9), the plate is set to a constant motion. It is also evident from boundary condition that elapse of time induces higher start – up for $a > 0$ in velocity temperature and concentration distribution. In order to substantiate the exactitude of our consequence, we have contrasted results with those obtained by Jyotsna Rani Pattnaik et.al [6] and found that they are in better concord, as revealed in table (1) – (3). The impact of several prevailing physical parameters such as convection parameters Gr is the thermal Grashof number, Gc is modified Grashof Number, γ is inclination angle, $\Pr$ is Prandtl Number, M is the magnetic field, Sc is Schmidt number, Kr is Chemical Reaction, K is Porous Permeability, Q is Heat source parameter, $\Pr$ is Prandtl number are elucidated through figures and tables. The effects of distinct governing parameters on velocity, temperature and concentration are revealed in figures (2) – (16). Velocity profiles plotted in figure (2) for various values of magnetic parameter. We notice that the velocity profiles decreasing with increasing values of magnetic parameter. Figure (3) are plotted for different values of Prandtl number $(\Pr)$ against velocity profiles. In this figure we can seen that an increment in Prandtl number $(\Pr)$ produces a marked increase in the velocity. Figure (4) and (5) show that the velocity profiles for different values of inclination angle (γ) and acceleration parameter (a), it is observed that increases in inclination angle the velocity decreases, but the reverse effect observed in acceleration parameter. Figure (6) represent the influence of chemical reaction parameter (Kr) on the velocity profiles respectively. Increasing the chemical reaction parameter (Kr) the velocity decreases. Figure (7) is plotted for velocity profiles against different values of heat generation coefficient (Q). It can be observed from this figure when heat generation coefficient $(Q > 0)$ the velocity profiles increases. Effects of radiation absorption (Q_l) parameter in figure (8). As increases radiation absorption parameter increases the thickness of the momentum boundary layer decreases for velocity. Figure (9) – (10) shows the influence of the thermal buoyancy force parameter Grashof number (Gr) and modified Grashof number (Gc), it is observed that increases Gr, Gc in the velocity increases. This is due to the fact that buoyancy forces enhance fluid velocity and increase the boundary layer thickness with increase in the values of Gr, Gc. Figure (11) are plotted for different values of Prandtl number $(\Pr)$ against temperature profiles. In this figure we can seen that an increment in Prandtl number $(\Pr)$ produces a marked increase in the temperature. Higher values of Prandtl number $(\Pr)$ are relevant to lower thermal diffusivity and different kinds of fluid that contain lower thermal diffusivity have very low temperature. Such type of lower thermal diffusivity represents the decrement in temperature distribution. Figure (12) is plotted for temperature profiles against different values of heat generation coefficient (Q). It can be observed from this figure when heat generation coefficient $(Q > 0)$ the temperature profiles decreases, however when heat generation coefficient $(Q < 0)$ then the temperature increases. The temperature profiles for radiation absorption parameter (Q_l) shown in figure (13). It is found that with the increase radiation absorption parameter (Q_l), the temperature increases. Figure (14) display the effects of Schmidt number Sc on temperature profiles respectively. As the Schmidt number increases the temperature decreases. Figure (15) shows the chemical reaction parameter (Kr) on concentration profiles. It is noticed here that the chemical reaction parameter (Kr) decreases with increase in the Kr. Figure (16) display the effects of Schmidt number Sc on concentration profiles respectively. As the Schmidt number increases the concentration decreases. The reductions concentration profiles are accompanied by simultaneous reductions in the velocity and concentration boundary layers.

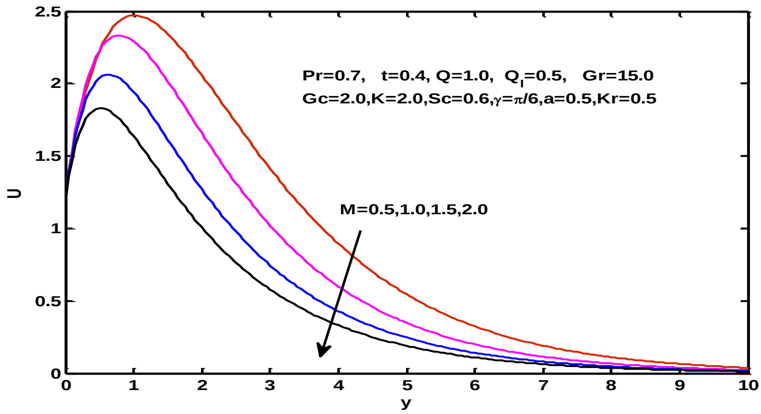

Figure (2): Velocity profiles for different values of M

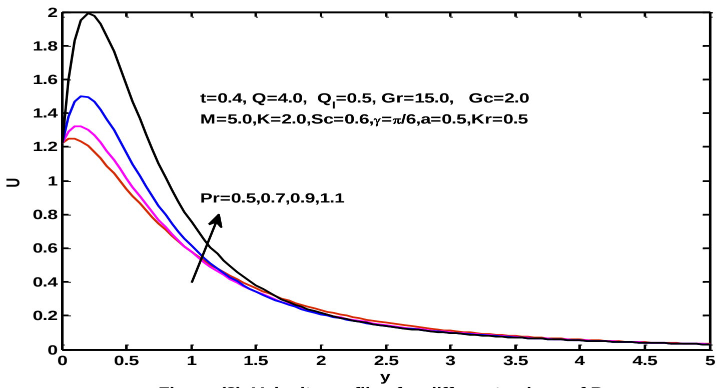

Figure (3): Velocity profiles for different values of Pr

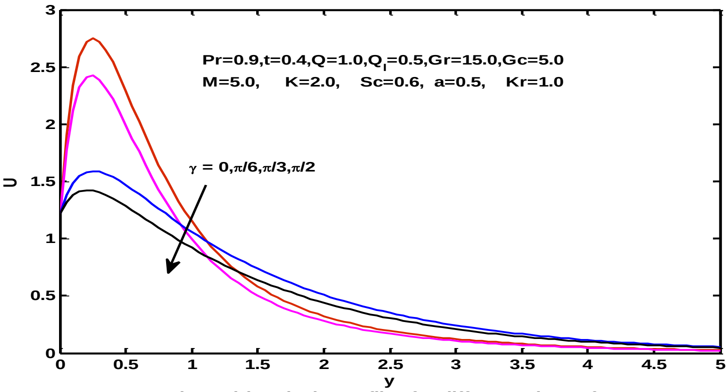

Figure (4): Velcoity profiles for diffeent values of γ

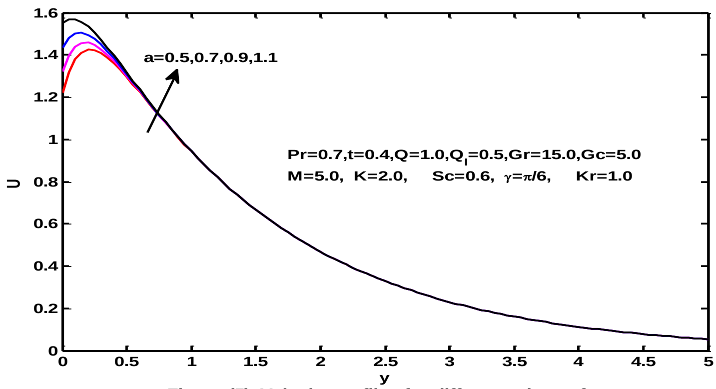

Figure (5): Velcoity profiles for diffeent values of a

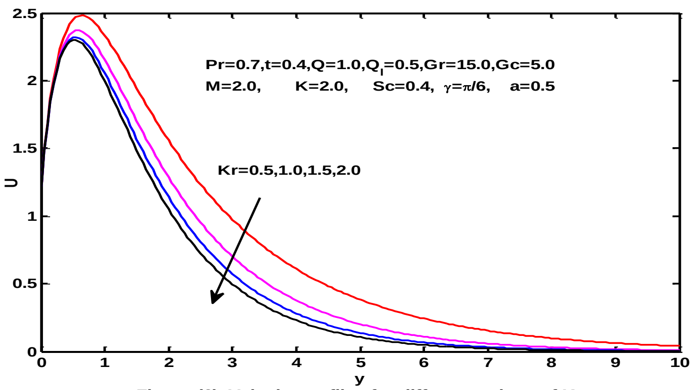

Figure (6): Velocity profiles for different values of Kr

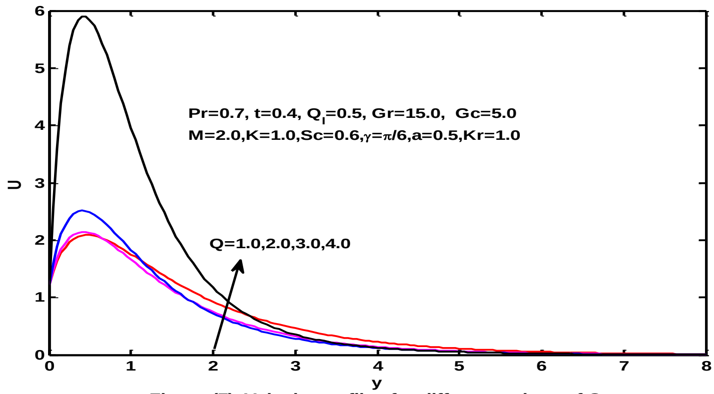

Figure (7): Velocity profiles for different values of Q

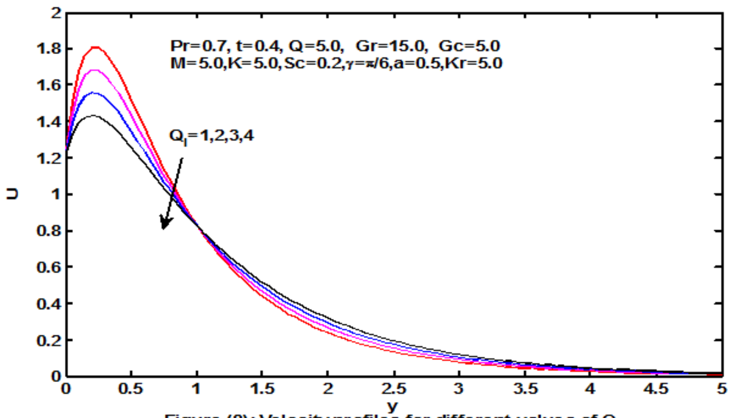

Figure (8): Velocity profiles for different values of Q_l

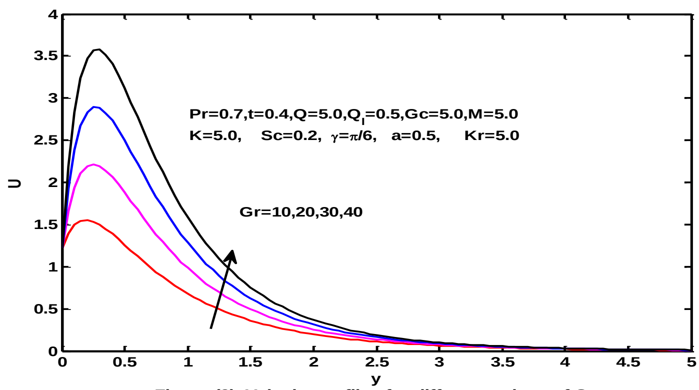

Figure (9): Velocity profiles for different values of Gr

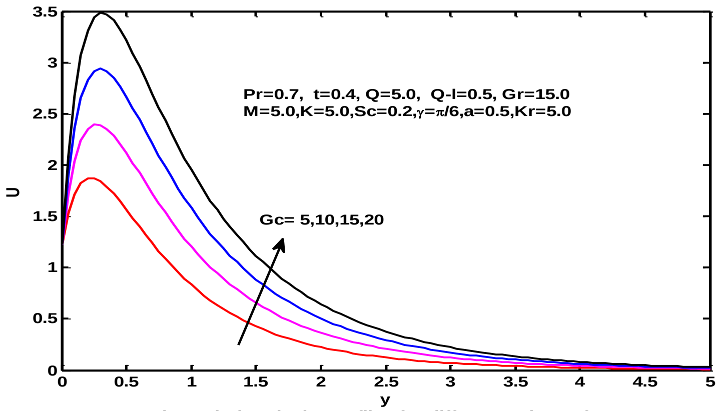

Figure (10): Velocity profiles for different values of Gc

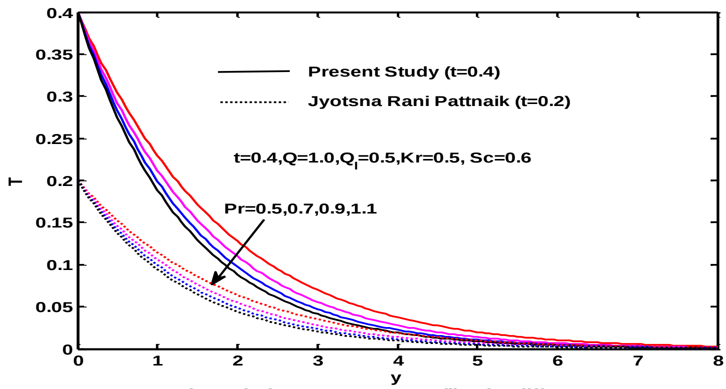

Figure (11): Temperature profiles for different Pr

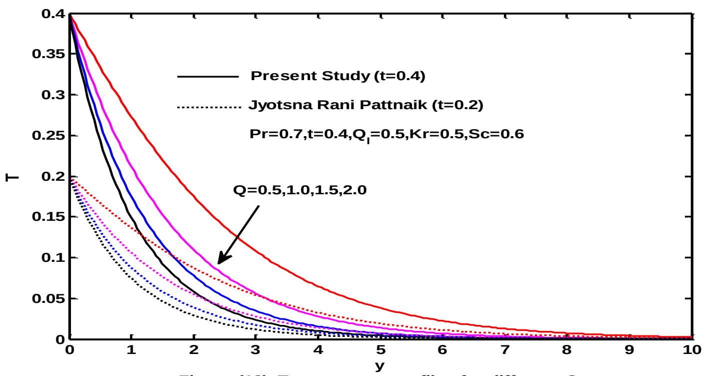

Figure (12): Temperature profiles for different Q

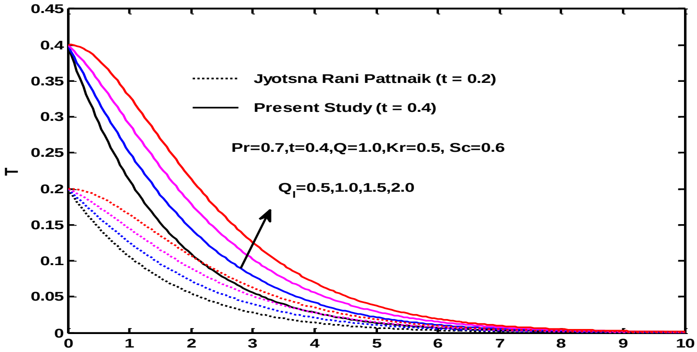

Figure (13): Temperature profiles for different Q_l

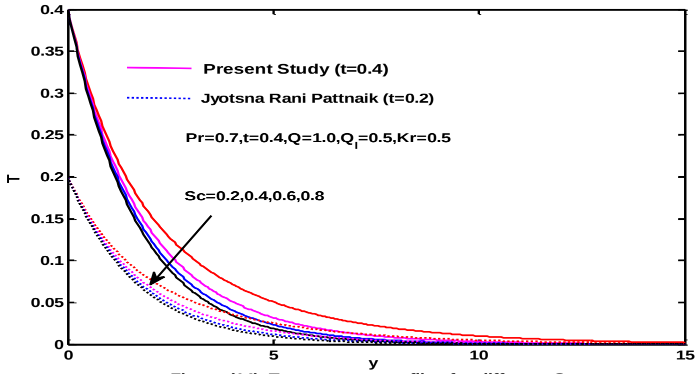

Figure (14): Temperature profiles for different Sc

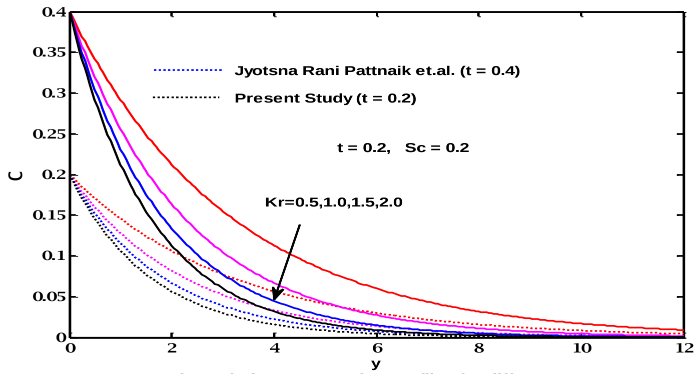

Figure (15); Concentration Profiles for different Kr

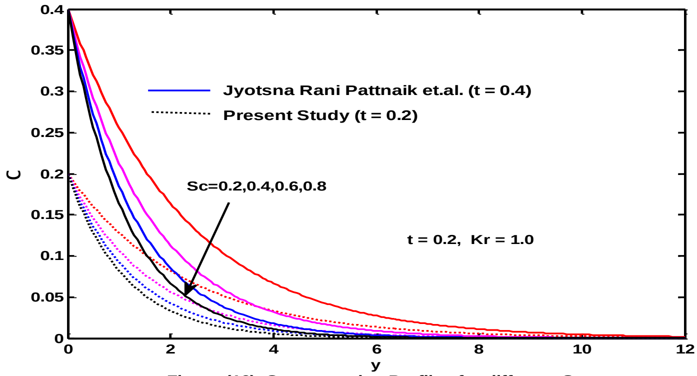

Figure (16); Concentration Profiles for different Sc

Table 1: Variation of Skin friction		
M	τ(Ref. [4])	τ(Present Stduy)
0	0.9254	0.7809
1	1.2387	0.8614
5	2.3617	0.9463

On careful study of table (1) with the values of $Gr = 10, Gc = 5, K = 0.5, Kr = 0.2,$ $t = 0.4, \Pr = 0.71, Sc = 0.6, \gamma = \frac{\pi}{6}, a = 0.5, Q = 2.0, Q_l = 1.0$ it is observed that skin friction increase with an increase in the values of magnetic parameter.

Table 2: Variation of Nusselt number						
Sc	t	Kr	Pr	Q	Q_l	Nu
0.6	0.2	0.5	0.71	2.0	0.5	0.2549
0.6	0.2	0.5	0.71	2.0	1.0	0.2715
0.6	0.2	0.5	0.71	2.0	1.5	0.2881
0.6	0.2	0.5	0.71	2.0	2.0	0.3047

From table (2), it is seen that Nusselt number increases with increases in Q_l. Thus it is concluded that the fluid with low thermal diffusivity and higher radiative property favours higher rate of heat transfer at the surface shown in the table (3).

Table 3: Variation of Sherwood number				
Sc	t	Kr	Sh(Ref. [4])	Sh (Present study)
0.6	0.4	0.2	0.5674	0.9212
3.0	0.4	0.2	1.2688	2.0600
0.6	0.4	2.0	0.6896	0.6350

0.6	0.8	0.2	0.8228	1.8420

From table (3), it is observed that Sherwood number, which determines the rate of Solutal concentration at the surface of the wall, increases with an increase in Sc, Kr and t. Thus heavier species with higher rate of chemical reaction increases the rate of solutal concentration at the surface.

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