Variable temperature, radiation absorption and chemical reaction effects on unsteady MHD flow through porous medium past an oscillating inclined plate

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ABSTRACT
An analytical study on the effects of chemical reaction on unsteady flow of a viscous, incompressible and electrically conducting fluid past an oscillating inclined plate and radiation absorption through a porous medium with variable temperature and heat source in the presence of transversely applied uniform magnetic field, because of its widespread application in chemical engineering and manufacturing industries. The plate temperature and concentration level near the plate increase linearly with time. The equations of momentum, thermal and as well as species concentration were solved used by the perturbation technique. The visual representation of changes in fluid velocity, temperature and concentration, results obtained are discussed with the help of graphs drawn for different parameters.

Keywords: Variable temperature, Radiation, Magnetic field, Chemical reaction, Inclined Porous plate

1. INTRODUCTION

The study of heat generation or absorption in moving fluids is important in problems dealing with chemical reactions dissociating fluids. Since some fluids can also emit and absorb thermal radiation, it is of interest to study the effects of magnetic field on the temperature distribution vis-à-vis heat transfer when the fluid is not only an electrical conductor but also it is capable of emitting and absorbing radiation. With its broad range of applications in physics and engineering, especially for equipment design, processes of high-temperature, and space technology, radiation on natural convection has become more prominent. Nuclear power plants, hypersonic aircraft, space vehicles, and other recent advancements in these fields include gas-cooled nuclear reactors. Chemical reactions in the context of collective heat and mass transfer flow issues have received tremendous attention in a variety of chemical engineering processes. Chemical reaction consequences are critical in the dispersion of temperature and moisture across agricultural regions, the manufacture and dispersion of fog, cooling tower designs, configurations of chemical process apparatuses and more application in industrial [1-15].

The problem of free convection and mass transfer flow of an electrically conducting fluid past an inclined heated surface under the influence of magnetic field has attracted interest in view of its applications to geophysics, astrophysics and many engineering problems, such as cooling of nuclear reactors, boundary layer control in aerodynamics and cooling towers. The MHD flow with heat and mass transfer plays an important role in different areas of science and technology like chemical engineering, mechanical engineering, biological science, petroleum engineering, biomechanics, irrigation engineering and aerospace technology. Study of radiation with heat transfer and mass diffusion is essential in describing several fluid models. In view of the above some of the authors studied [16-31].

Numerous researchers have been intrigued by the unsteady free convection MHD heat and mass transfer flow associated with radiation, despite enormous uses in the engineering environment and industrial processes. Additional uses for MHD flow include metrology, solar physics, MHD generators, MHD pumps, fluid fuel nuclear reactors, aeronautics, and the chemical process sector, which have been used recently. Very recently, a research article entitled effects of wall shear stress on MHD conjugate flow over an inclined plate in porous medium with ramped wall temperature is reported, the data analyzed by [32-43]. This research seek to discover the role of radiation absorption and chemical reaction effect on unsteady MHD flow through porous medium past an oscillating inclined plate with variable temperature and mass diffusion with heat source. The results are shown with the help of graphs.

2. Formulation of the problem

We consider an unsteady uniform MHD free convective flow of a viscous, incompressible and radiating fluid past an exponentially accelerated inclined 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_∞ .

In view of the above the boundary layer equations of flow, heat and mass transfer past an exponentially accelerated inclined plate are given by

$$\frac{\partial u}{\partial t}=\nu\frac{\partial^2 u}{\partial z^2}+g\,\beta\left(T-T_\infty\right)\cos\alpha+g\,\beta^*\left(C-C_\infty\right)\cos\alpha-\frac{\sigma B_0^2\left(u+mv\right)}{\rho\left(1+m^2\right)}-\frac{\nu}{K}u \tag{1}$$

$$\frac{\partial v}{\partial t}=\nu\frac{\partial^2 v}{\partial z^2}+\frac{\sigma B_0^2\left(mu-v\right)}{\rho\left(1+m^2\right)}-\frac{\nu}{K}v \tag{2}$$

$$\frac{\partial T}{\partial t}=\frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial z^2}-\frac{Q_0}{\rho C_p}\left(T-T_\infty\right)+\frac{Q_l'}{\rho C_p}\left(C-C_\infty\right) \tag{3}$$

$$\frac{\partial C}{\partial t}=\kappa\frac{\partial^2 C}{\partial z^2}-K_r\left(C-C_\infty\right) \tag{4}$$

The initial and boundary conditions are:

$$u=0,v=0,T=T_\infty,C=C_\infty \quad ,\ t\le 0$$

$$\left.\begin{array}{ll} u=u_0\cos\omega t,v=0,T=T_\infty+\dfrac{\left(T_\omega-T_\infty\right)u_0^2t}{\nu},C=C_\infty+\dfrac{\left(C_w-C_\infty\right)u_0^2t}{\nu}\,at & z=0 \\ u\to 0,v\to 0,T\to T_\infty,C\to C_\infty & as\ z\to\infty \end{array}\right\},t>0 \tag{5}$$

Here $u-$ is the primary velocity, $v-$ the secondary velocity, $g-$the acceleration due to gravity, $\beta-$volumetric coefficient of thermal expansion, $t-$time, $m\left(=\omega_e\tau_e\right)$ the hall current parameter with ω_e cyclotron frequency of electrons and electron collision of time, $T-$temperature of the fluid, β^*-volumetric coefficient, $C-$spices concentration, $\nu-$kinematic viscosity, $\rho-$the density, C_p- the specific heat, $\kappa-$thermal conductivity of the fluid, $D-$the mass diffusion coefficient, $K-$the permeability parameter, T_w- temperature of the plate at $z=0$, C_w species concentration at $z=0$, B_0 the plate the uniform magnetic field, $\sigma-$electrical conductivity.

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

$$z^* = \frac{zu_0}{\nu}, u^* = \frac{u}{u_0}, v^* = \frac{v}{v_0}, t^* = \frac{tu_0^{\ 2}}{\nu}, \omega^* = \frac{\omega\nu}{u_0^2}, T = \frac{T - T_\infty}{T_w - T_\infty}, C = \frac{C - C_\infty}{C_w - C_\infty}$$

$$Gr = \frac{\nu\beta g\left(T_w - T_\infty\right)}{u_0^{\ 3}}, \quad \Pr = \frac{\mu C_p}{\kappa}, \quad Gc = \frac{\nu\beta^* g\left(C_w - C_\infty\right)}{u_0^{\ 3}}, \quad M = \frac{\sigma B_0^{\ 2}\nu}{\rho u_0^{\ 2}} \tag{6}$$

$$K^* = \frac{Ku_0^{\ 2}}{\nu^2}, \quad Kr^* = \frac{Kr\,\nu}{u_0^{\ 2}}, \quad R = \frac{16a^*\nu^2\sigma T_\infty}{\kappa u_0^{\ 2}}, \quad Q = \frac{Q_0\nu}{\rho C_p u_0^{\ 2}}, \quad Sc = \frac{\nu}{D}$$

where $Gr-$thermal Grashof number, $Gc-$mass Grashof number, $K-$the dimensionless permeability parameter, $\Pr-$the Prandtl number, $Sc-$the Schmidt number, $R-$radiation parameter, $M-$the magnetic parameter and $Q-$ is heat source/sink parameter

The basic field equations (1) – (4) can be expressed in the non – dimensional from and dropping the starts $(*)$ as

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial z^2} + Gr\cos\alpha\ \theta + Gc\ \cos\alpha\ \theta - \frac{M\left(u + mv\right)}{1 + m^2} - \frac{1}{K}u \tag{7}$$

$$\frac{\partial v}{\partial t} = \frac{\partial^2 v}{\partial z^2} + \frac{M\left(mu - v\right)}{1 + m^2} - \frac{1}{K}v \tag{8}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - Q\theta + Q_l\,C \tag{9}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} - Kr\ C \tag{10}$$

The initial and boundary conditions in dimensionless form are

$$\begin{aligned} &u = 0, v = 0, \theta = 0, C = 0 \qquad t \le 0 \quad for\ all\ \ z \\ &\left.\begin{aligned} &u = \cos\omega t, v = 0, \theta = t, C = t, && at\ \ z = 0 \\ &u = 0, v \to 0, \theta \to 0, C \to 0 && as\ \ z \to \infty \end{aligned}\right\} \ t > 0 \end{aligned} \tag{11}$$

Combining the equations (7) and (8), the model becomes

$$\frac{\partial q}{\partial t} = \frac{\partial^2 q}{\partial z^2} + Gr\cos\alpha\ \theta + Gc\ \cos\alpha\ \theta - \left(\frac{M\left(1 - im\right)}{1 + m^2} + \frac{1}{K}\right)q \tag{12}$$

Finally the boundary becomes

$$\begin{aligned} &q = 0,, \theta = 0, C = 0 \qquad t \le 0 \quad for\ all\ \ z \\ &\left.\begin{aligned} &q = \cos\omega t, \theta = t, C = t, && at\ \ z = 0 \\ &q \to 0, \theta \to 0, C \to 0 && as\ \ z \to \infty \end{aligned}\right\} \ t > 0 \end{aligned} \tag{13}$$

wehre $q = u + iv$

3. Solution of the problem

Equation (9), (10) and (12) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (13). 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

$$\begin{aligned} q\left(z,t\right) &= q_0\left(z\right)\ e^{i\omega t} \\ \theta\left(z,t\right) &= \theta_0\left(z\right)e^{i\omega t} \\ C\left(z,t\right) &= C_0\left(z\right)e^{i\omega t} \end{aligned} \tag{14}$$

Substituting (14) in Equation (9), (10), (12) and equating the harmonic and non – harmonic terms, we obtain

$$q_0'' - \beta_3^2 q_0 = -Gr\cos\alpha\ \theta_0 - Gc\cos\alpha\, C_0 \tag{15}$$

$$\theta_0'' - \beta_2^2\,\theta_0 = 0 \tag{16}$$

$$C_0'' - \beta_1^2 C_0 = 0 \tag{17}$$

here the summits denote the differentiation w. r. t. y

where $\beta_1^2 = (Kr + i\omega)Sc, \beta_2^2 = (Q\,\mathrm{Pr} + i\omega\,\mathrm{Pr}), \beta_3^2 = \left[\frac{M(1-im)}{1+m^2} + \frac{1}{K}\right]$

The corresponding boundary conditions can be written as

$$\begin{aligned} &q_0 = e^{-i\omega t}\cos\omega t, \quad \theta_0 = t\,e^{-i\omega t}, C_0 = t\,e^{-i\omega t} \qquad at\ z = 0 \\ &q_0 \to 0, \qquad \theta_0 \to 0, \quad C_0 \to 0 \qquad\qquad as\ z \to \infty \end{aligned} \tag{18}$$

Solving Equations (15) - (17) under the boundary conditions (18) and we obtain the velocity, temperature and concentration distributions in the boundary layer as

$$C_0 = t\ e^{-i\omega t} e^{-\beta_1 z}$$

$$\theta_0 = K_1 e^{-\beta_1 z} K_2 e^{m_4 z}$$

$$q_0 = L_1 e^{m_4 z} + L_2 e^{-\beta_1 z} + L_3 e^{-\beta_1 z} + L_4 e^{-\beta_3 z}$$

In view of the equation (17) becomes

$$q = e^{i\omega t}\left\{L_1 e^{m_4 z} + L_2 e^{-\beta_1 z} + L_3 e^{-\beta_1 z} + L_4 e^{-\beta_3 z}\right\}$$

$$\theta = e^{i\omega t}\left\{K_1 e^{-\beta_1 z} K_2 e^{m_4 z}\right\}$$

$$C = t\ e^{-\beta_1 z}$$

Coefficient of Skin-Friction

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

$$C_f = \left(\frac{\partial q}{\partial z}\right)_{z=0} = e^{i\omega t}\left\{L_1 m_4 + L_2\beta_1 + L_3\beta_1 + L_4\beta_3\right\}$$

Coefficient of Heat Transfer

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

$$N_u = \left(\frac{\partial \theta}{\partial z}\right)_{z=0} = e^{i\omega t}\left\{K_1\beta_1 + K_2 m_4\right\}$$

Sherwood number

$$Sh = \left(\frac{\partial C}{\partial z}\right)_{z=0} = e^{i\omega t}\left\{t\ \beta_1\right\}$$

4. RESULTS AND DISCUSSIONS

Figure (1) displays the consequences of angle of disposition (α) on the velocity profiles. It is pragmatic that the velocity reduces for positive change in the angle of inclination of α. Figure (2) shows the results of the permeability of the porous medium (K) on the velocity profiles and the velocity increases with the increasing dimensionless porous parameter. The effect of thermal Grashof number (Gr) on the velocity is exposed in figure (3). The thermal Grashof number shows the qualified result of the thermal buoyancy force to the viscous hydraulics force. The flow is quicker as a result of the event in buoyancy force matching to a growth within the thermal Grashof number. Heat is so conducted aloof from the vertical plate into the fluid will increase the temperature and thereby enhance the buoyancy force. Additionally, it is seen that the values of the velocity improve quickly close to the plate as thermal Grashof number will increase so disintegrates swimmingly to stream velocity. Figure (4), plotted the behaviour velocity profiles for various values of chemical reaction parameter (Kr), it is ascertained that a rise in results in a decrease in each the values of velocity. A definite velocity increase happens close to the wall when that profiles decay swimmingly to the stationary price in free stream. Hence the chemical action accelerates the flow. Figure (5) depicts the results of the Hall current parameter (m) on the velocity profiles, it is determined that for lower values of Hall current parameter, the velocity increases for increasing Hall current parameter. Figure (6) signifies the velocity outlines for various principles of magnetic parameter (M); it found that the velocity decrease with improvement of the magnetic parameter. Figure (7) illustrate the characteristic of velocity profiles for various values of Prandtl number $(\Pr)$. It is noticed that a rise within the Prandtl number results in reduction of the thermal thickness. This is due to the fact that fluid with large Prandtl number has high viscosity and small thermal conductivity, which make the fluid thick and causes a decrease in fluid velocity. The influence of presence of the heat source parameter (Q) on the velocity distribution in the boundary layer is presented in figure (8). It is obvious that increasing the values of heat source parameter produces a decrease in the velocity distribution of the fluid. This is expected since the presence of a heat sink in the boundary layer absorbs energy. Which in turn cause the temperature of the fluid to decrease. This decrease in temperature produces a decrease in the flow field due to the buoyancy effect which couples the flow and thermal field. The consequences of radiation absorption parameter (Q_l) on velocity are unit shown in figure (9) respectively. It is seem that the velocity increases with a growing the radiation absorption parameter. Figure (10) shows the effect of Schmidt number on the velocity profiles for $Sc = 0.16$ (hydrogen), $Sc = 0.3$ (helium), $Sc = 0.6$ (water vapour), $Sc = 2.01$ (ethyl Benzene). It is observed that the velocity decreases with increasing Schmidt number values due to the decrease in the molecular diffusivity, which results in a decrease in the concentration and velocity boundary layer thickness. Variation of velocity profiles for different values of dimensionless time parameter (t) is shown in figure (11). It is noticed that the velocity increases with the progression of time. The velocity profiles for different values angle of inclination parameter (ω) is shown in figure (12). It is noticed that the velocity decreases with the progression of angle of inclination parameter. The effects of time parameter (t) and angle of inclination parameter (ω) shown in figures (13) and (14), it is observed that the increases in time parameter the temperature increases, but increase in angle of inclination resulted in the decrease of the temperature. The temperature variations for different values of Schmidt number (Sc) shown in figure (15); it is clear that the temperature decreases with increasing values of Schmidt number. It is observed in figure (16) that the temperature increases as the radiation absorption parameter (R) increases in the temperature. Figure (17) has been plotted to depict the variation of temperature profiles against y for different values of heat source parameter (Q) by fixing other parameter. It is observed from this graph that temperature decrease with increasing heat source parameter. Figure (18) illustrate the characteristic of temperature profiles for various values of Prandtl number $(\Pr)$. It is noticed that a rise within the Prandtl number results in reduction of the thermal thickness and generally lower average temperature among the physical phenomenon, the reason for that smaller values of area unit admire increase within the thermal conduction of the fluid and thus, heat will diffuse aloof from the heated surface earlier for higher values of Prandtl number. Increasing the chemical reaction parameter (Kr) the temperature profiles decreases as observed in the figure (19). The effect of chemical reaction parameter (Kr) on the concentration (ϕ) is shown in figure (20). It is noticed from this figure that there is a marked effect of increasing values of on concentration distribution in the boundary layer. It is clearly observed from this figure that increasing values of decrease the concentration of species in the boundary layer. This happens because large values of chemical reaction parameter reduce the solutal boundary layer thickness and increase the mass transfer. The concentration profiles is shown in figure (21), increase in Schmidt number (Sc) shows that the concentration profiles reduce. This cause the concentration buoyancy effects to reduce yielding a reduction within the fluid velocity; reduction within the concentration distribution area unit in the simultaneous reduction within the concentration boundary layers. For different values of time parameter (t) are shown in figure (22), it is clear that the concentration decreases with increases in time parameter. Skin friction is a measure of shearing stress experienced at the solid surface. Figure (23) exhibit the effect of permeability of the porous medium(K), it is observed that an increasing permeability of the porous medium the skin friction increases versus thermal Grashof number. From figure (24) it is observed that the absolute values of the rate of heat transfer decreases as the Prandtl number$(\Pr)$ increases versus different values of heat source parameter. From figure (25) it is observed that the absolute values of the rate of mass transfer decreases as the Schmidt number(Sc) increases versus different values with chemical reaction parameter.

Appendix

$$\beta_1 = \text{Real part of } \sqrt{(Kr + i\omega)Sc} = \sqrt{\frac{KrSc + Kr^2Sc^2 + \omega^2 Sc^2}{2}}$$

$$\beta_2 = \text{Real part of } (Q\Pr + i\omega\Pr) = \sqrt{\frac{(Q\Pr) + (Q\Pr)^2 + \omega^2\Pr^2}{2}}$$

$$\beta_3 = \text{Real part of } \left[\frac{M(1-im)}{1+m^2} + \frac{1}{K}\right] = \sqrt{\frac{\frac{KM+1+m^2}{K(1+m^2)} + \left(\frac{KM+1+m^2}{K(1+m^2)}\right)^2 + \left(\frac{KMm}{K(1+m^2)}\right)^2}{2}}$$

$$K_1 = \frac{Q_l te^{-i\omega t}}{\beta_1{}^2 - \beta_2{}^2}, K_2 = te^{-i\omega t} - K_1, L_1 = -\frac{Gr\,K_2\cos\alpha}{m_4{}^2 - \beta_3{}^2}, L_2 = -\frac{Gr\,K_1\cos\alpha}{\beta_1{}^2 - \beta_3{}^2}, L_3 = -\frac{Gc\,te^{-i\omega t}\cos\alpha}{\beta_1{}^2 - \beta_3{}^2}$$

$$L_4 = \left(e^{-i\omega t}\cos\omega t - L_1 - L_2 - L_3\right)$$

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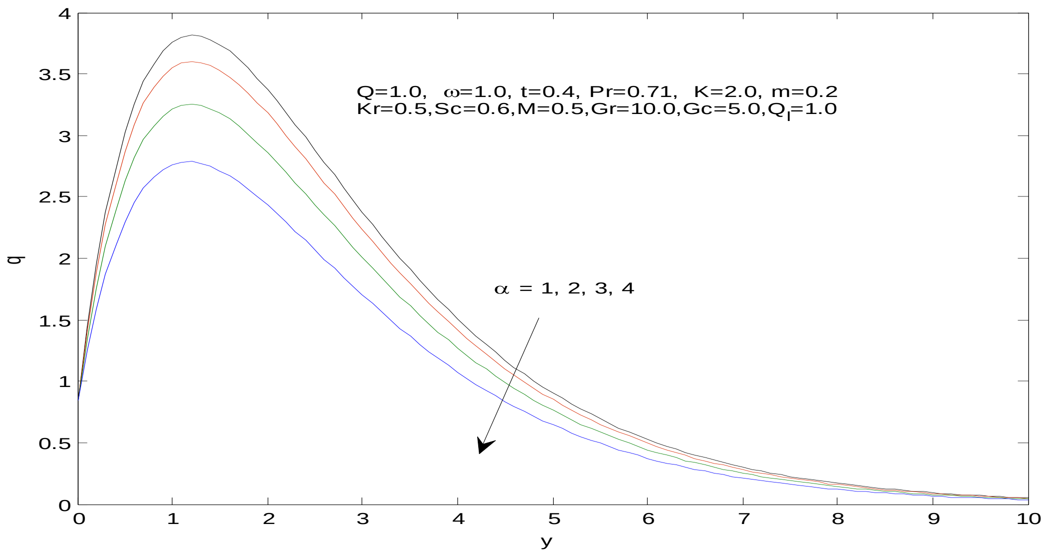

Figure (1): Velocity profiles for different values of α

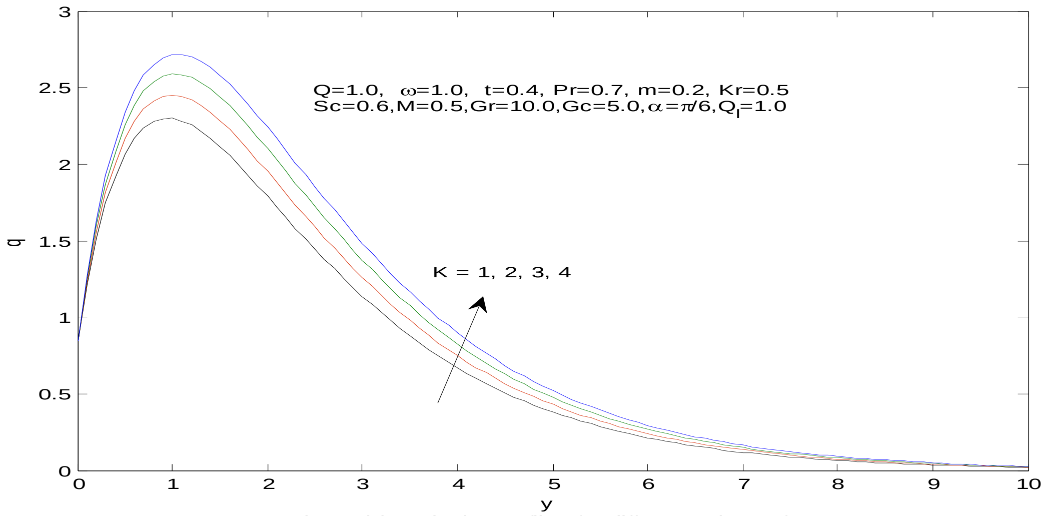

Figure (2): Velocity profiles for different values of K

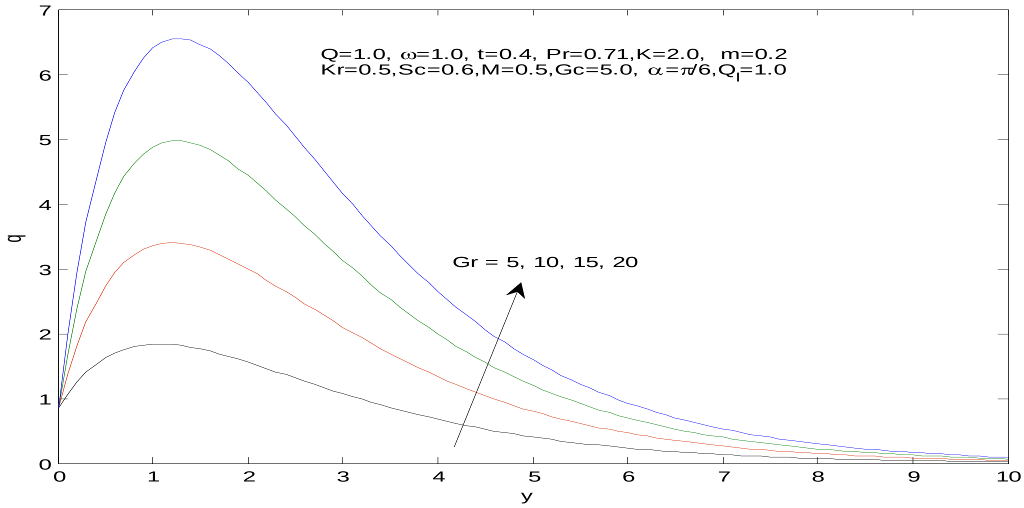

Figure (3): Velocity profiles for different values of Gr

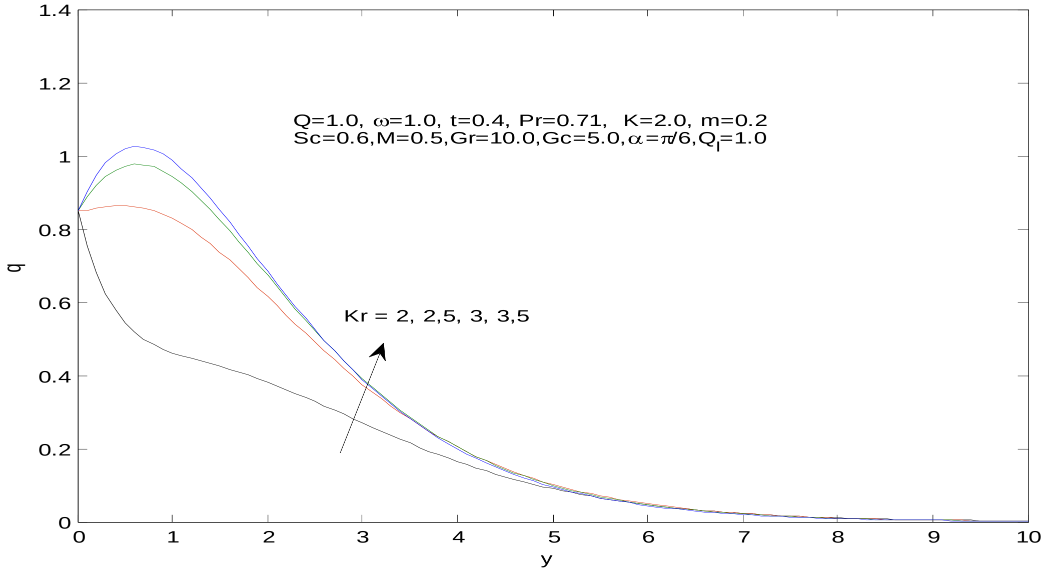

Figure (4): Velocity profiles for different values of Kr

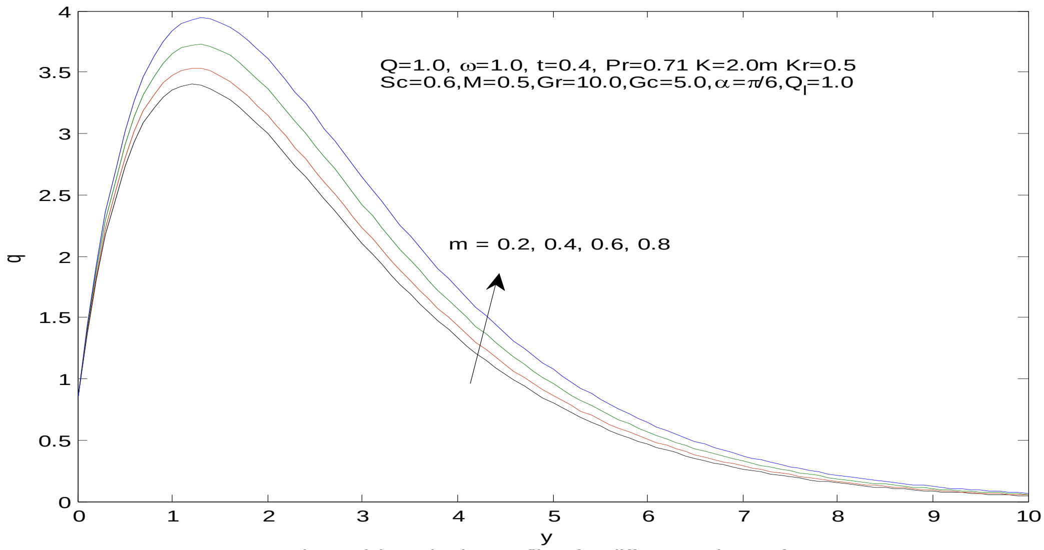

Figure (5): Velocity profiles for different values of m

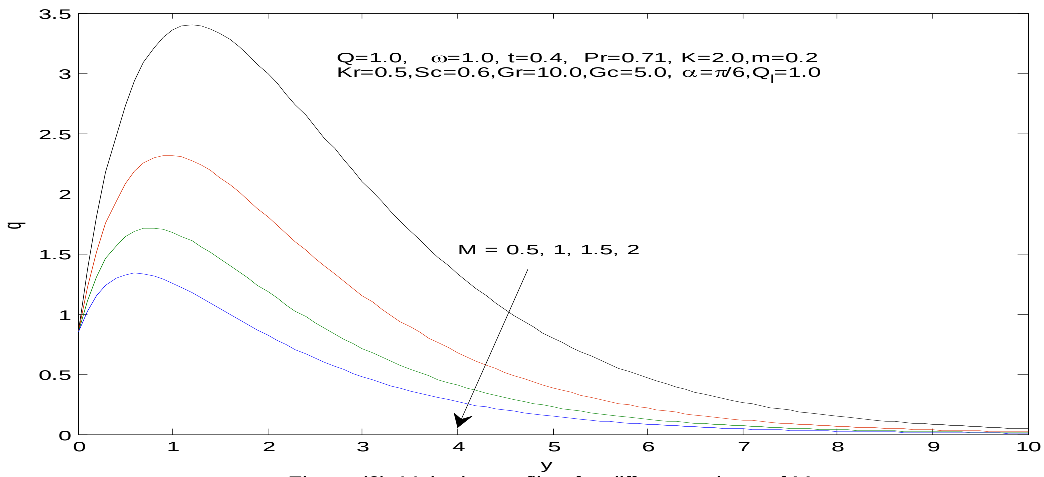

Figure (6): Velocity profiles for different values of M

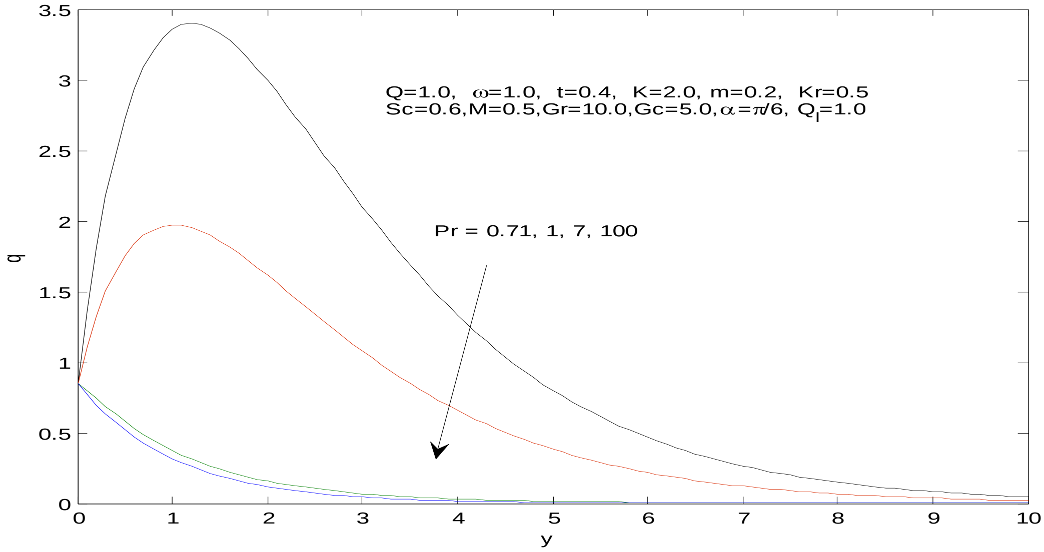

Figure (7): Velocity profiles for different values of Pr

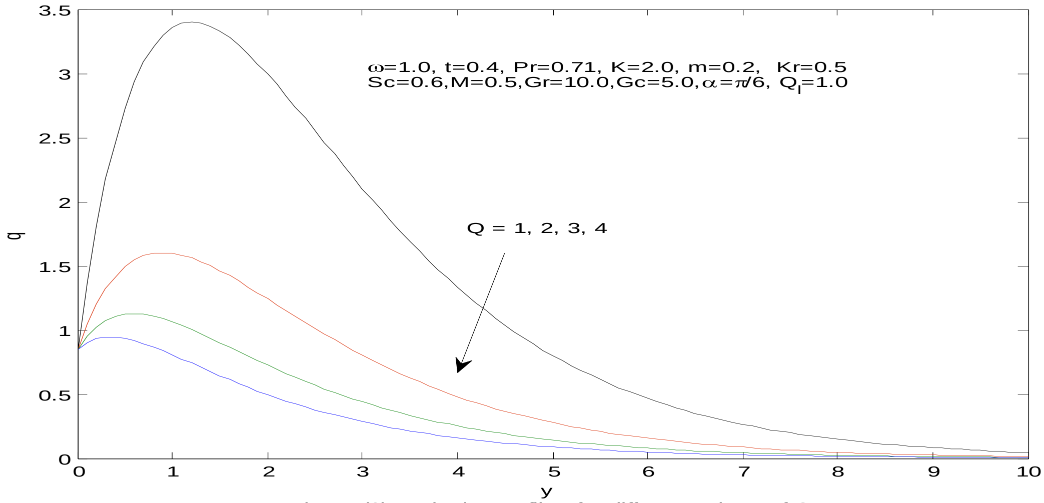

Figure (8): Velocity profiles for different values of Q

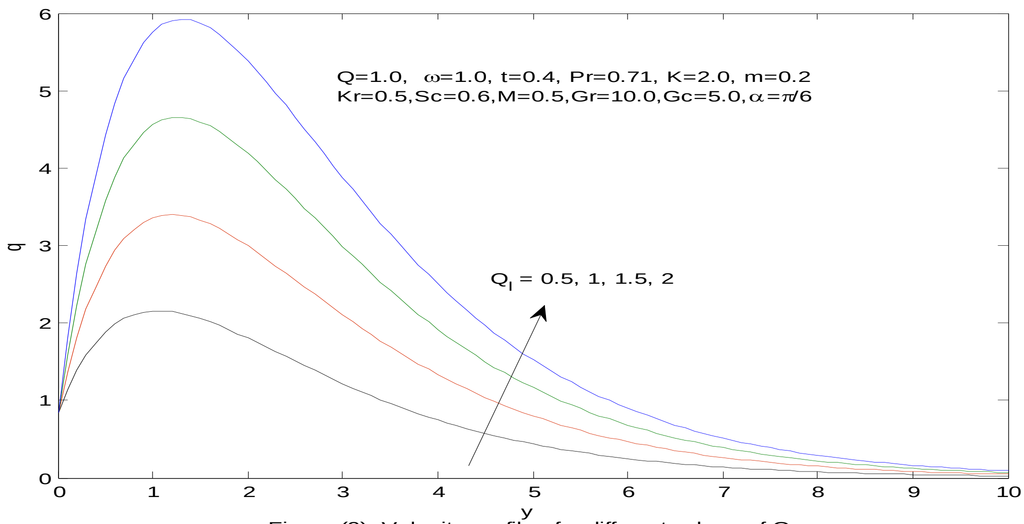

Figure (9): Velocity profiles for different values of Q_l

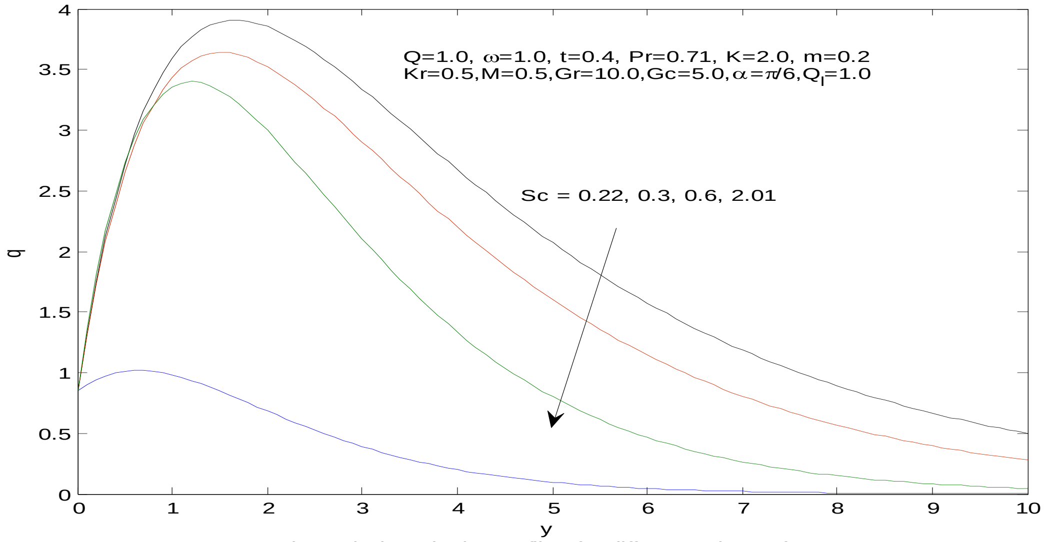

Figure (10): Velocity profiles for different values of Sc

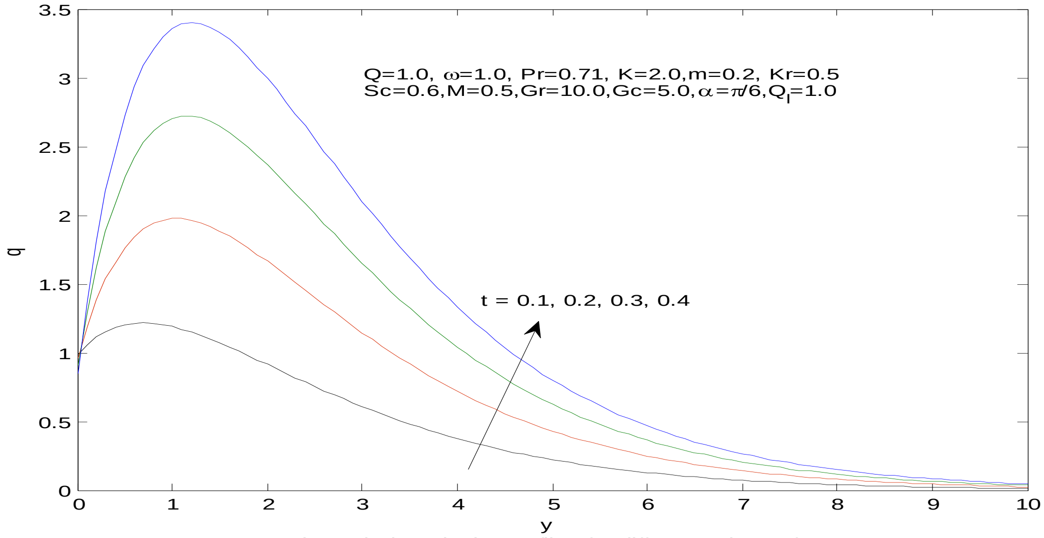

Figure (11): Velocity profiles for different values of t

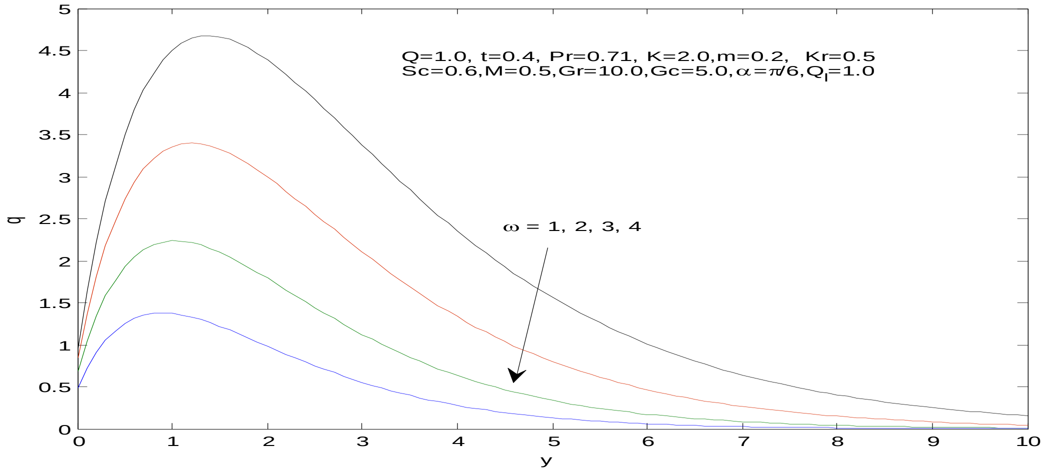

Figure (12): Velocity profiles for different values of ω

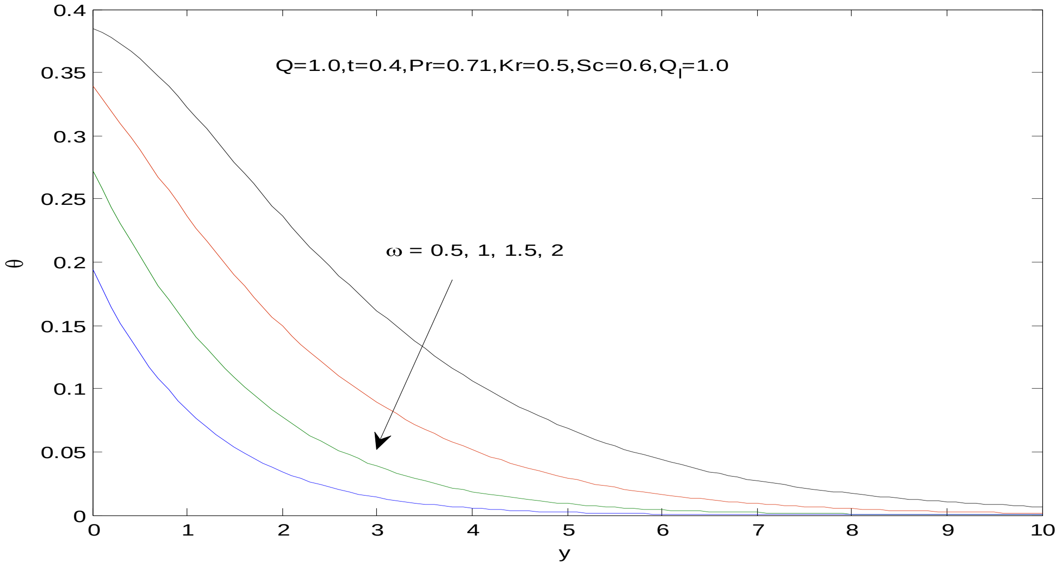

Figure (13): Temperature profiles for different values of ω

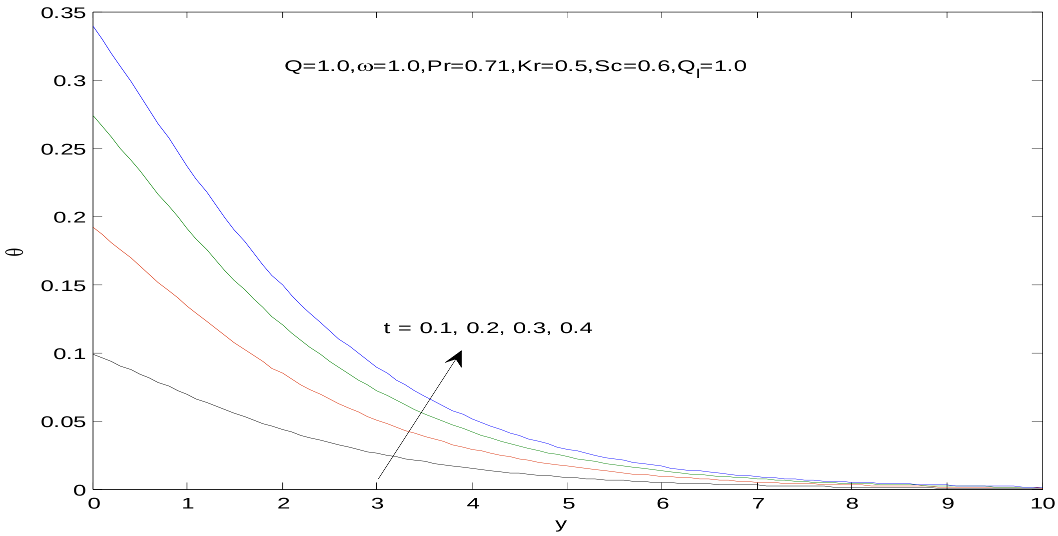

Figure (14): Temperature profiles for different values of t

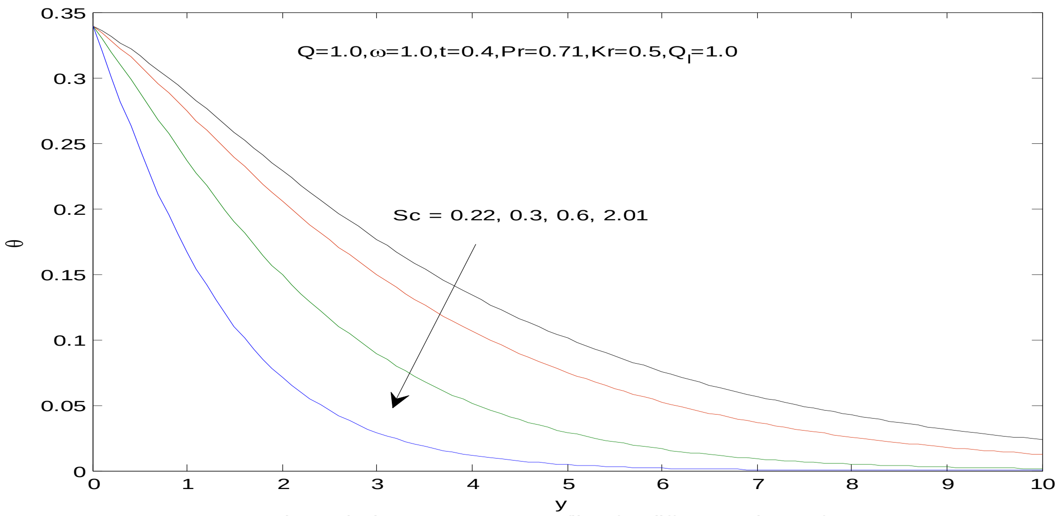

Figure (15): Temperature profiles for different values of Sc

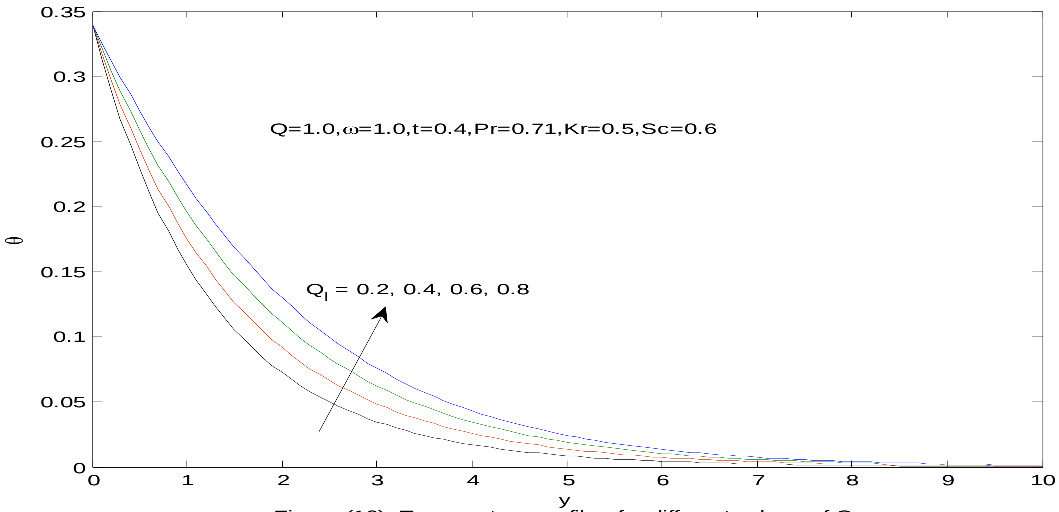

Figure (16): Temperature profiles for different values of Q_l

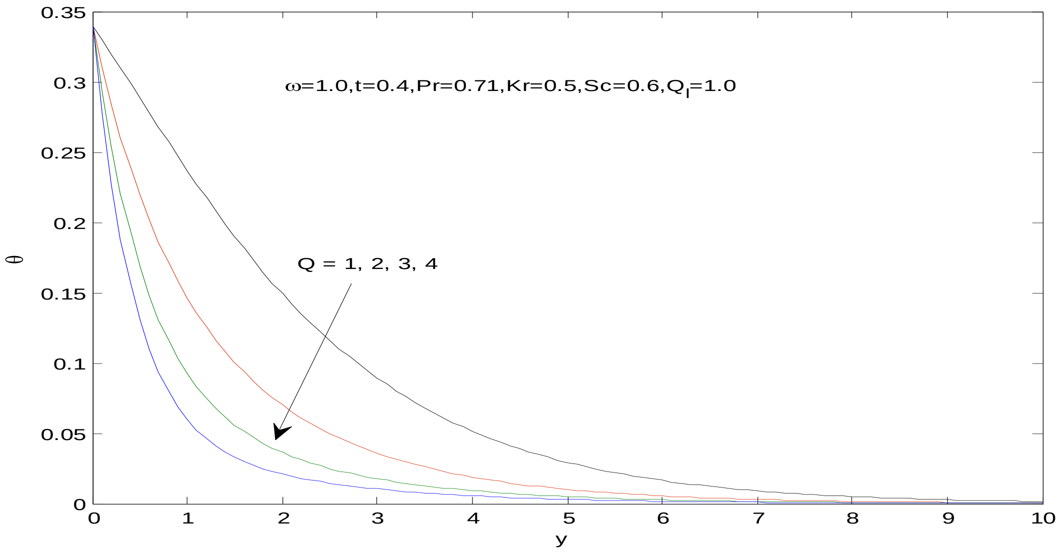

Figure (17): Temperature profiles for different values of Q

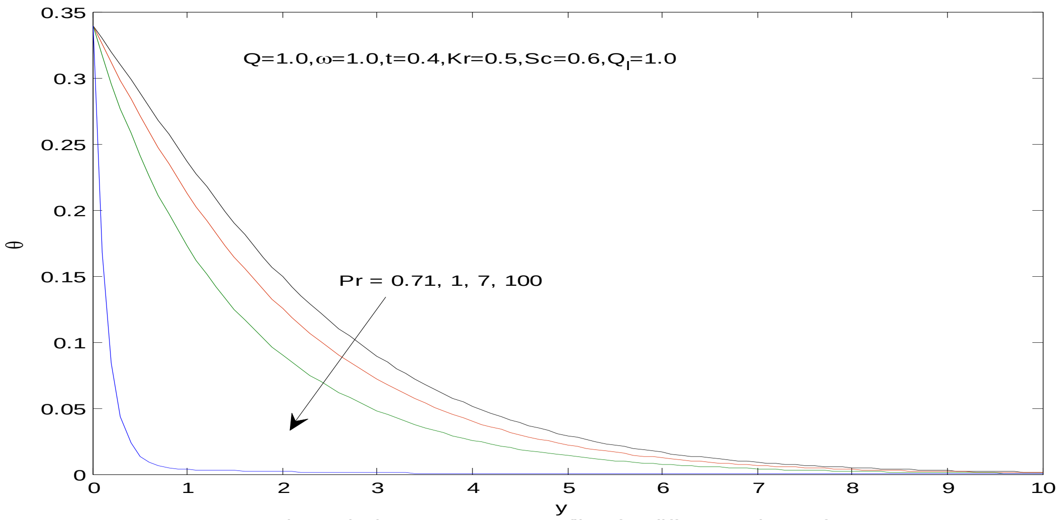

Figure (18): Temperature profiles for different values of Pr

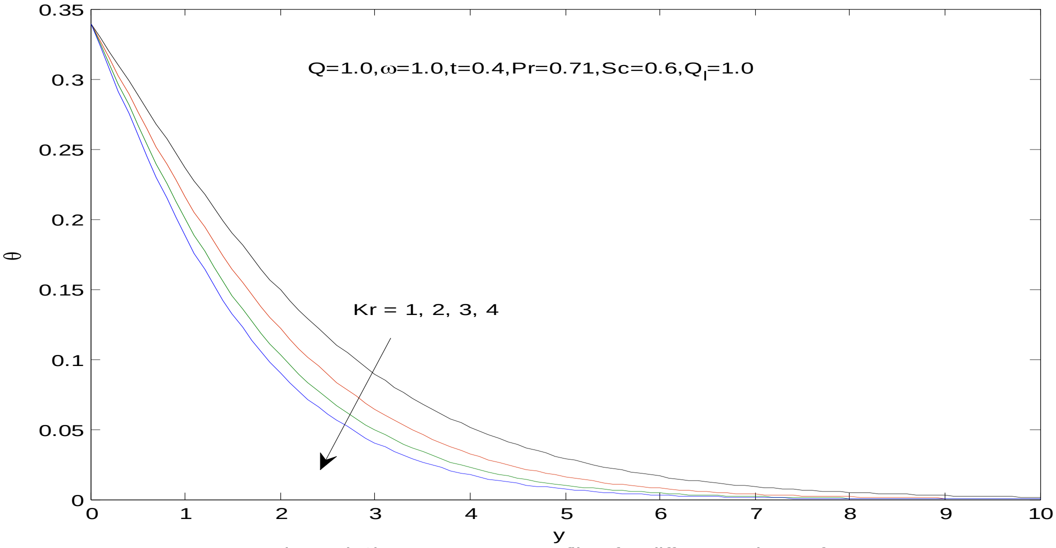

Figure (19): Temperature profiles for different values of Kr

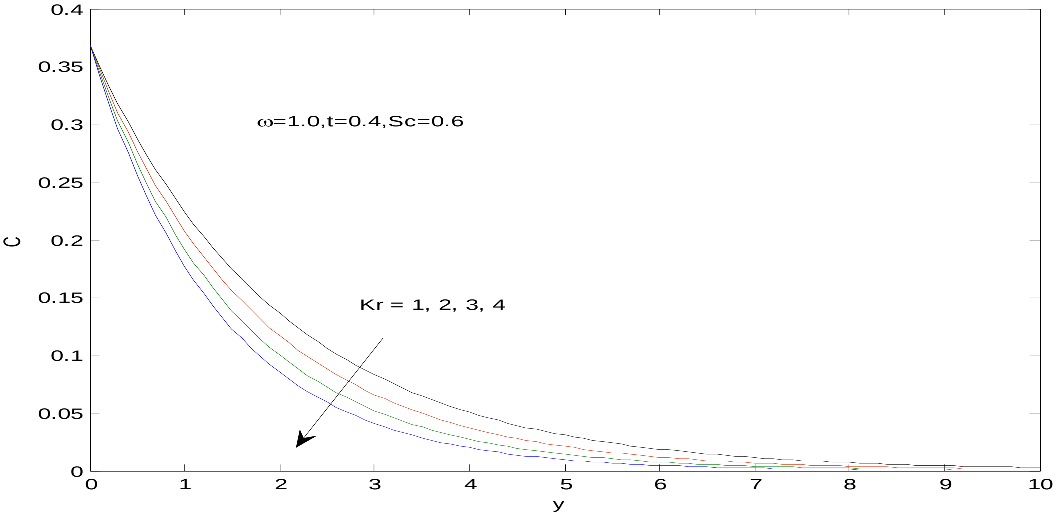

Figure (20): Concentration profiles for different values of Kr

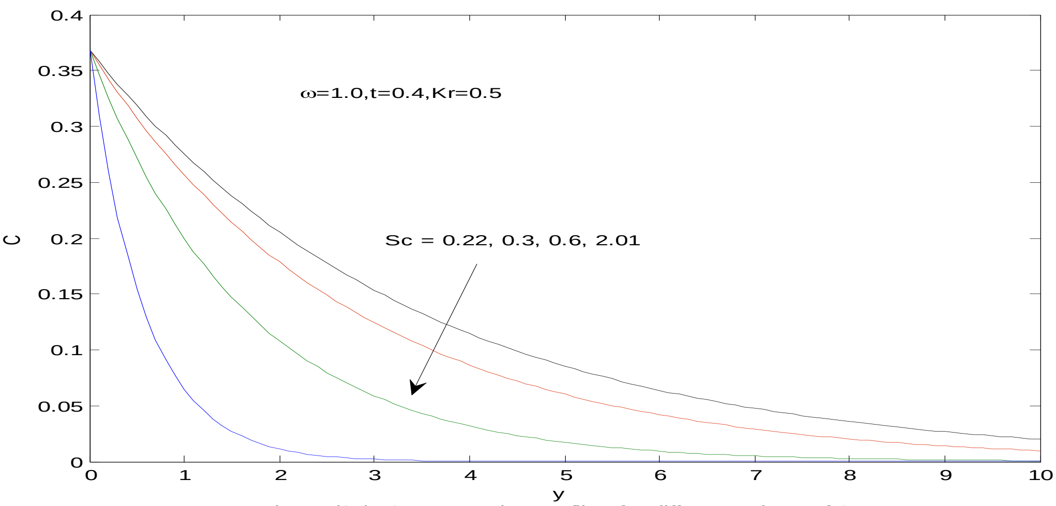

Figure (21): Concentration profiles for different values of Sc

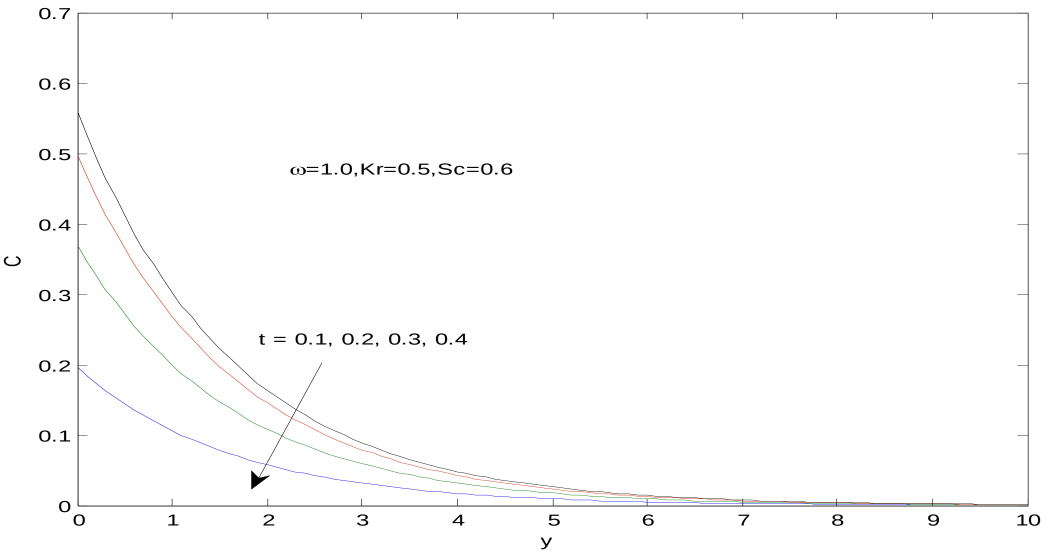

Figure (22): Concentration profiles for different values of t

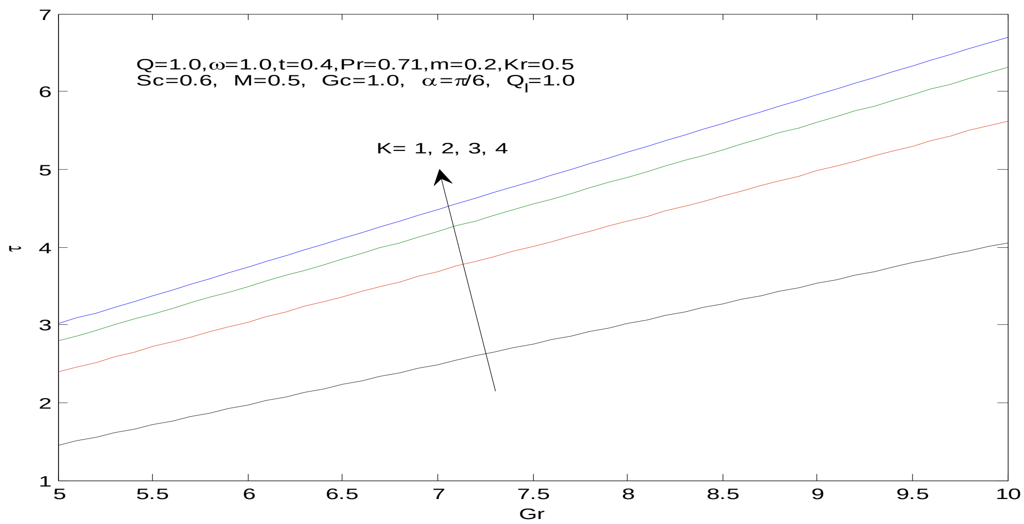

Figure (23): Velocity profiles for different values of K

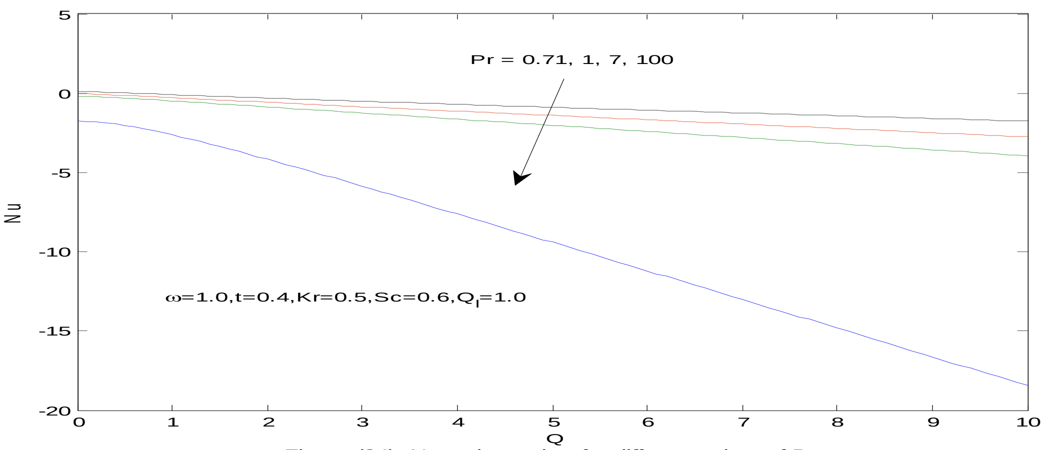

Figure (24): Nusselt number for different valuesof Pr

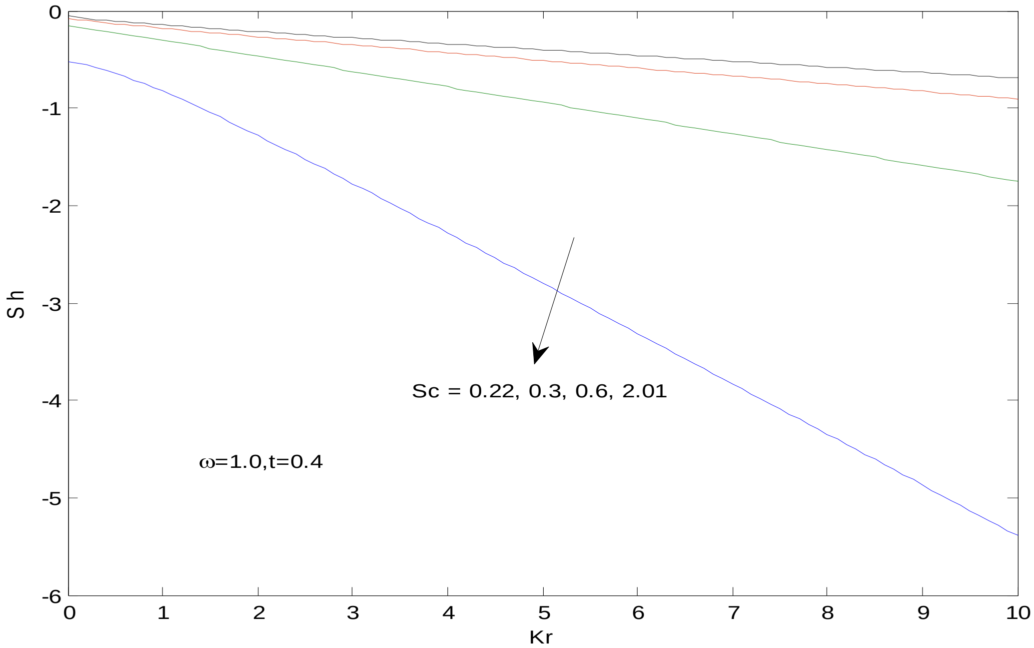

Figure (25): Sherwood number for different values of Sc