

CHEMICALLY REACTING MHD FLOW PAST AN OSCILLATING INCLINED PLATE WITH VARIABLE TEMPERATURE

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Abstract

This paper presents the perturbation analysis of the effects of MHD free convection flow on convective heat and mass transfer flow past an oscillating inclined plate in the presence of chemical reaction. The governing partial differential equations are solved by using perturbation method. The results are obtained for the velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number. The effects of various parameters on flow variables are illustrated graphically, and the physical aspects of the problem are discussed.

Keywords: Magnetic field, Chemical reaction, Inclined porous plate

Introduction

Free convection arises in the fluid when temperature changes cause density variation leading to buoyancy forces acting on the fluid elements. In recent years, the problems of free convective heat and mass transfer flows through a porous medium under the influence of a magnetic field have attracted the attention of a number of researchers because of their possible applications in many branches of science and technology, such as applications in cooling of re-entry vehicles and rocket booster, cross-hatching on ablative surfaces and film vaporization in combustion chambers. The simplest physical model of such a flow is the two dimensional laminar free convection flows along a vertical flat plate and various aspects of this type of flow have been investigated by many researchers [1-20]

The study of heat and mass transfer with chemical reaction is of great practical importance to engineers and scientist because of its almost universal occurrence in many branches of science and engineering. Possible applications of this type of flow can be found in many industries such as the power industry and chemical process industries. In many chemical engineering processes, there does occur the chemical reaction between a foreign mass and the fluid in which plate is moving. These processes take place in numerous industrial applications viz., polymer production, manufacturing of ceramic or glassware and food processing. In view of the above application some of the authors studies on this regarding [21-40].

Hence, the objective of this paper is the effects of MHD free convection flow on convective heat and mass transfer flow past an oscillating inclined plate in the presence of chemical reaction. The governing partial differential equations are solved by using perturbation method. The results are obtained for the velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number. The effects of various parameters on flow variables are illustrated graphically, and the physical aspects of the problem are discussed.

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

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

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

$$\frac{\partial T}{\partial t} = \frac{\kappa}{\rho C_p} \frac{\partial^2 T}{\partial z^2} - \frac{Q_0}{\rho C_p} (T - T_\infty) \quad (3)$$

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

The initial and boundary conditions are:

$$\left. \begin{aligned} u = 0, v = 0, T = T_\infty, C = C_\infty, \quad t \leq 0 \\ u = u_0 \cos \omega t, v = 0, T = T_\infty + \frac{(T_w - T_\infty) u_0^2 t}{\nu}, C = C_\infty + \frac{(C_w - C_\infty) u_0^2 t}{\nu} \quad z = 0 \\ u \rightarrow 0, v \rightarrow 0, T \rightarrow T_\infty, C \rightarrow C_\infty \quad \text{as } z \rightarrow \infty \end{aligned} \right\}, t > 0 \quad (5)$$

Here u – is the primary velocity, v – the secondary velocity, g – the acceleration due to gravity, β – volumetric coefficient of thermal expansion, t – time, $m (= \omega_e \tau_e)$ 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, ν – kinematic viscosity, ρ – the density, C_p – the specific heat, κ – 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, σ – 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

$$\left. \begin{aligned} z^* = \frac{z u_0}{\nu}, \quad u^* = \frac{u}{u_0}, \quad v^* = \frac{v}{v_0}, \quad t^* = \frac{t u_0^2}{\nu}, \quad \omega^* = \frac{\omega \nu}{u_0^2}, \quad T = \frac{T - T_\infty}{T_w - T_\infty} \\ C = \frac{C - C_\infty}{C_w - C_\infty}, Gr = \frac{\nu \beta g (T_w - T_\infty)}{u_0^3}, Gc = \frac{\nu \beta^* g (C_w - C_\infty)}{u_0^3}, Pr = \frac{\mu C_p}{\kappa} \\ M = \frac{\sigma B_0^2 \nu}{\rho u_0^2}, \quad K^* = \frac{K u_0^2}{\nu^2}, \quad Kr^* = \frac{K r \nu}{u_0^2}, \quad Q = \frac{Q_0 \nu}{\rho C_p u_0^2}, \quad Sc = \frac{\nu}{D} \end{aligned} \right\} \quad (6)$$

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 form and dropping the stars (*) as

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

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

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

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

The initial and boundary conditions in dimensionless form are

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

Combining the equations (10) and (11), the model becomes

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

Finally the boundary becomes

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

where $q = u + iv$

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:

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

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

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

The corresponding boundary conditions can be written as

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

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

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

$$\theta_0 = t e^{-\beta_2 z}$$

$$q_0 = G_1 e^{-\beta_2 z} + G_2 e^{-\beta_1 z} + G_3 e^{-\beta_3 z}$$

In view of the equation (17) becomes

$$q = e^{i\omega t} \{ G_1 e^{-\beta_2 z} + G_2 e^{-\beta_1 z} + G_3 e^{-\beta_3 z} \}$$

$$\theta = t e^{-\beta_2 z}$$

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

Coefficient of Skin-Friction

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

$$C_f = \left(\frac{\partial q}{\partial z} \right)_{z=0} = e^{i\omega t} \{ G_1 \beta_2 + G_2 \beta_1 + G_3 \beta_3 \}$$

Coefficient of Heat Transfer

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

$$N_u = \left(\frac{\partial \theta}{\partial z} \right)_{z=0} = e^{i\omega t} \{ t \beta_2 \}$$

Sherwood number

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

Results and discussions

Figure (1) shows the results of the permeability on the velocity profiles and the velocity decreases with the increasing dimensionless porous parameter. Figure (2) depicts the results of the Hall current parameter (m) on the velocity profiles, it is ascertained that for lower values of Hall current parameter, the velocity will decrease for increasing Hall current parameter. Figure (3) 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 α . The effect of thermal Grashof number (Gr) on the velocity is exposed in figure (4). 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 (5), 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 (6) signifies the velocity outlines for various principles of magnetic parameter (M) in the figure; it ascertained 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 decreases. This decrease in temperature produces a decrease in the flow field due to the buoyancy effect which couples the flow and thermal field. Figure (9) 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. The velocity profiles for different values angle of inclination (ω) is shown in figure (10). It is noticed that the velocity decreases with the progression of ω . Variation of velocity profiles for different values of dimensionless time parameter (t) is shown in figure (11). It is noticed that the velocity decreases with the progression of time. Figure (12) 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. Figure (13) 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. The effects of time parameter (t) and angle of inclination (ω) shown in figures (14) and (15), it is observed that the increases in time parameter the temperature decreases in both the parameters. The effect of chemical reaction parameter (Kr) on the concentration (ϕ) is shown in figure (16). 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 (17), 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 different values of angle of inclination parameter (ω), it is clear that the concentration decreases with increases values of angle of inclination parameter, the same effect was observed for the time parameter (t) are shown in figure (19). Skin friction is a measure of shearing stress experienced at the solid surface. Figure (20) exhibit the effect of permeability of porous medium (K), it is observed that an increasing permeability of the porous medium the skin friction was decreased. From figure (21) it is observed that the absolute values of the rate of heat transfer decreases as the time parameter (t) increases versus different values with heat source parameter. From figure (22) it is observed that the absolute values of the rate of mass transfer decreases as the angle of inclination parameter (ω) increases versus different values with chemical reaction parameter.

Appendix

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

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

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

$$G_1 = -\frac{Gr t \cos \alpha}{m_4^2 - \beta_3^2} e^{i\omega t}, G_2 = -\frac{Gct e^{-i\omega t} \cos \alpha}{\beta_1^2 - \beta_3^2}, G_3 = (e^{-i\omega t} \cos \omega t - G_1 - G_2)$$

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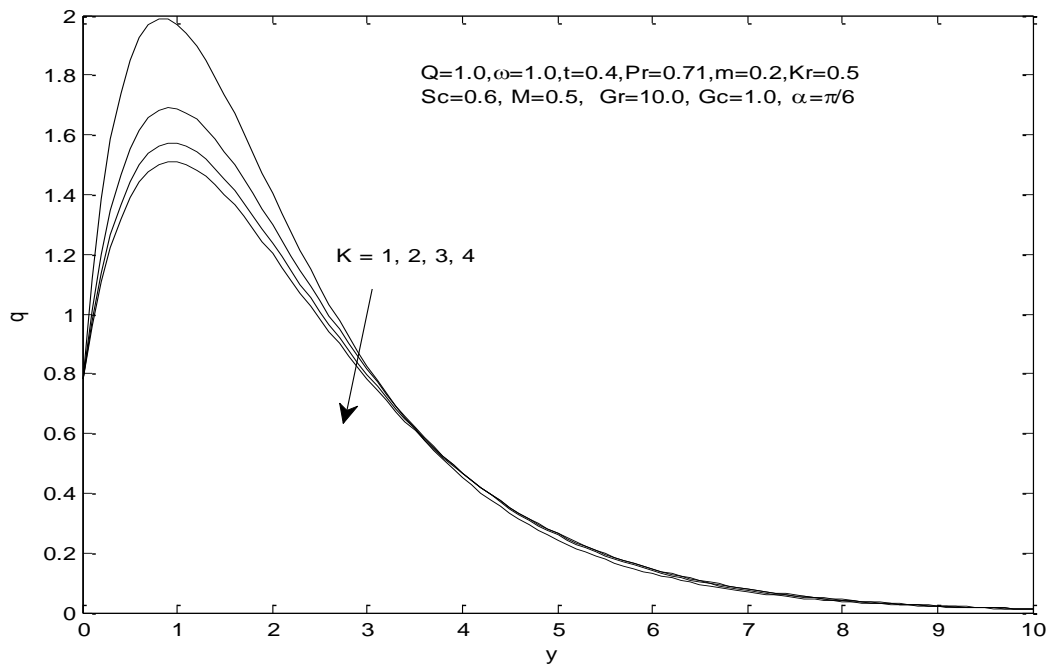


Figure (1): Velocity profiles for different values of K

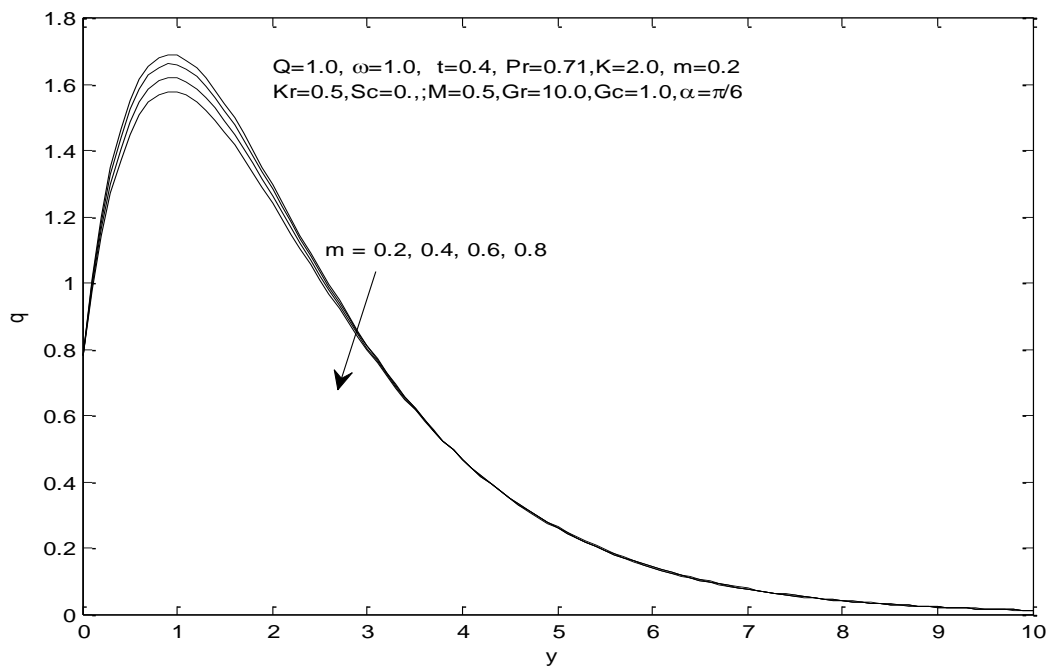


Figure (2): Velocity profiles for different values of m

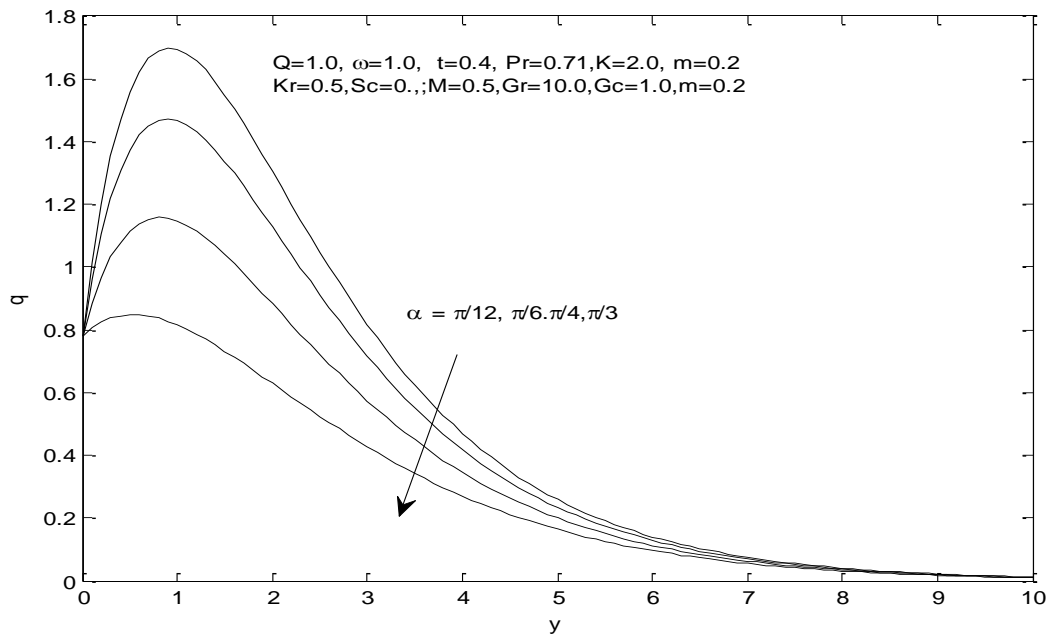


Figure (3): Velocity profiles for different values of α .

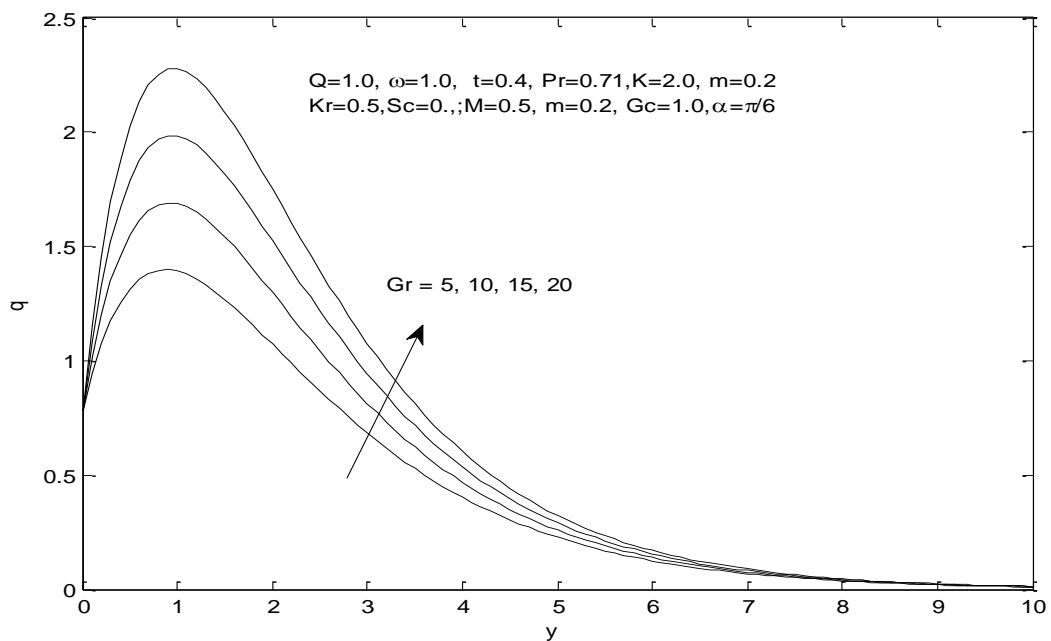


Figure (4): Velocity profiles for different values of Gr .

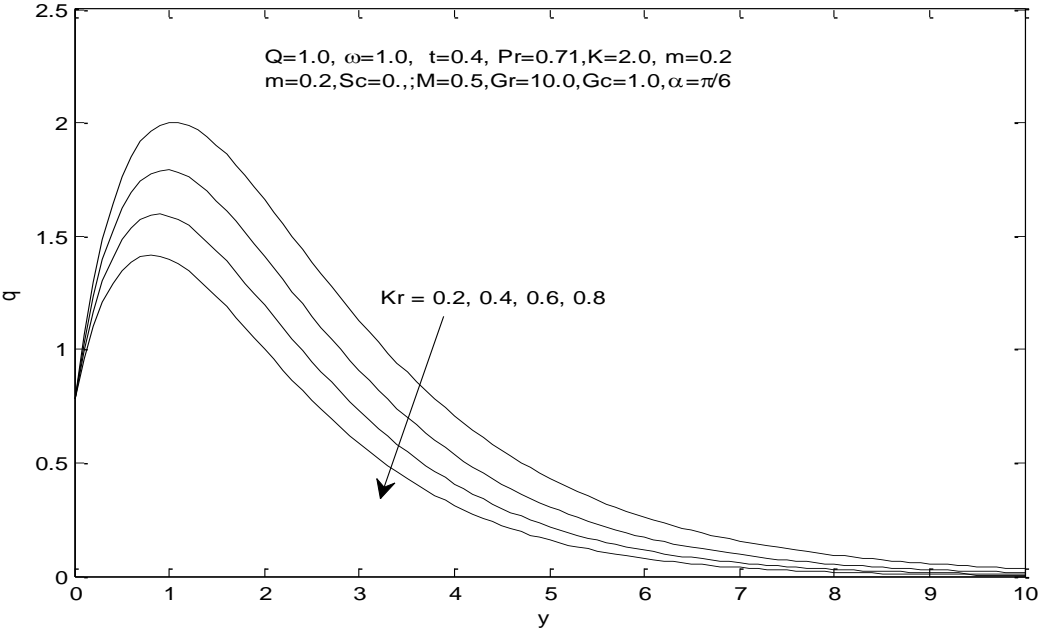


Figure (5): Velocity profiles for different values of Kr

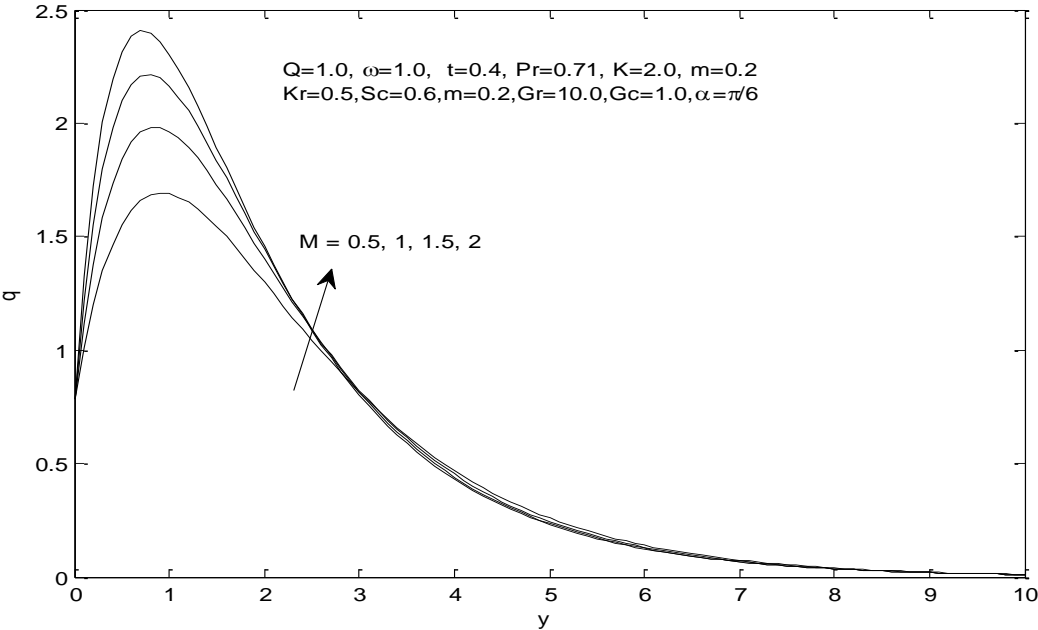


Figure (6): Velocity profiles for different values of M

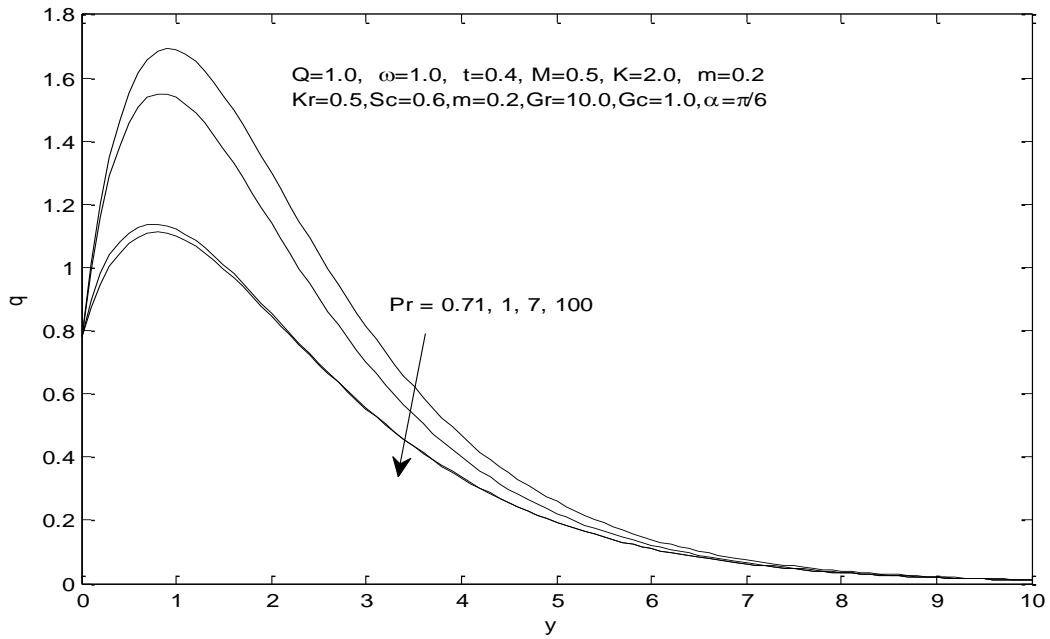


Figure (7): Velocity profiles for different values of Pr

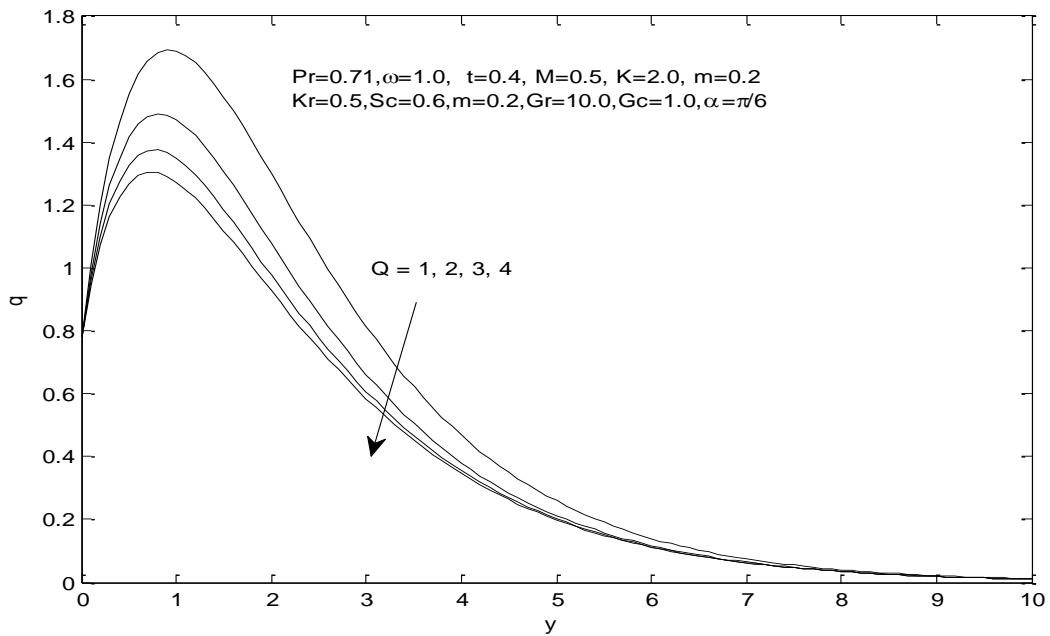


Figure (8): Velocity profiles for different values of Q

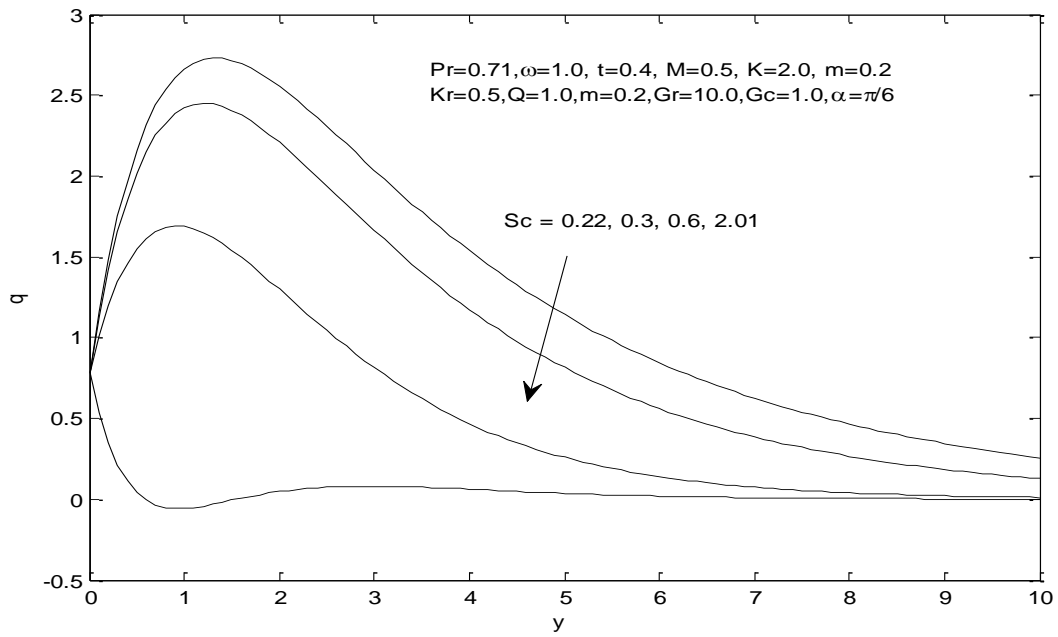


Figure (9): Velocity profiles for different values of Sc

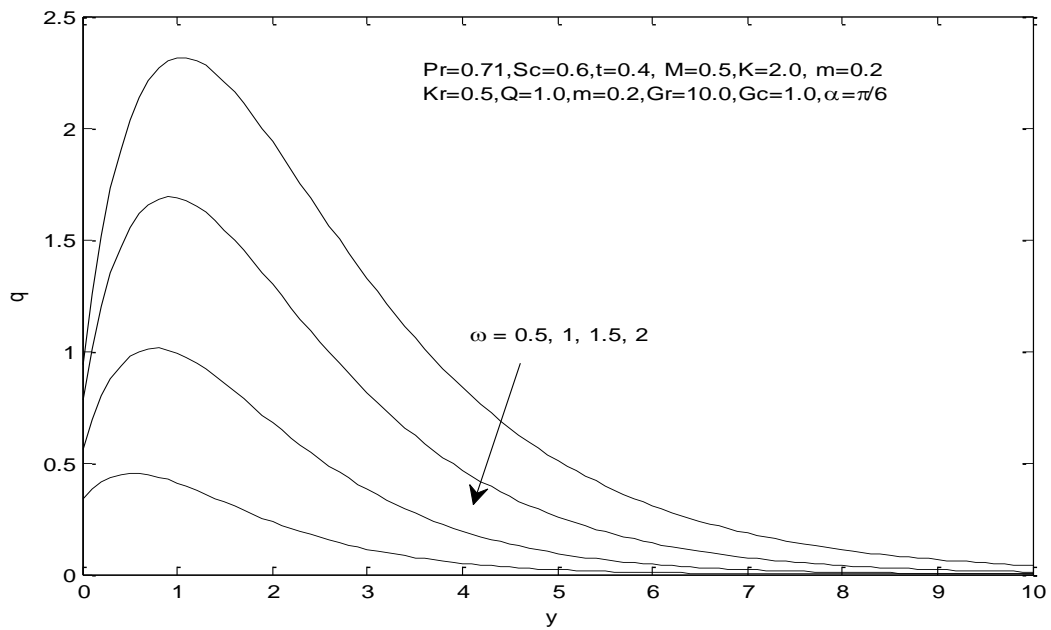


Figure (10): Velocity profiles for different values of ω

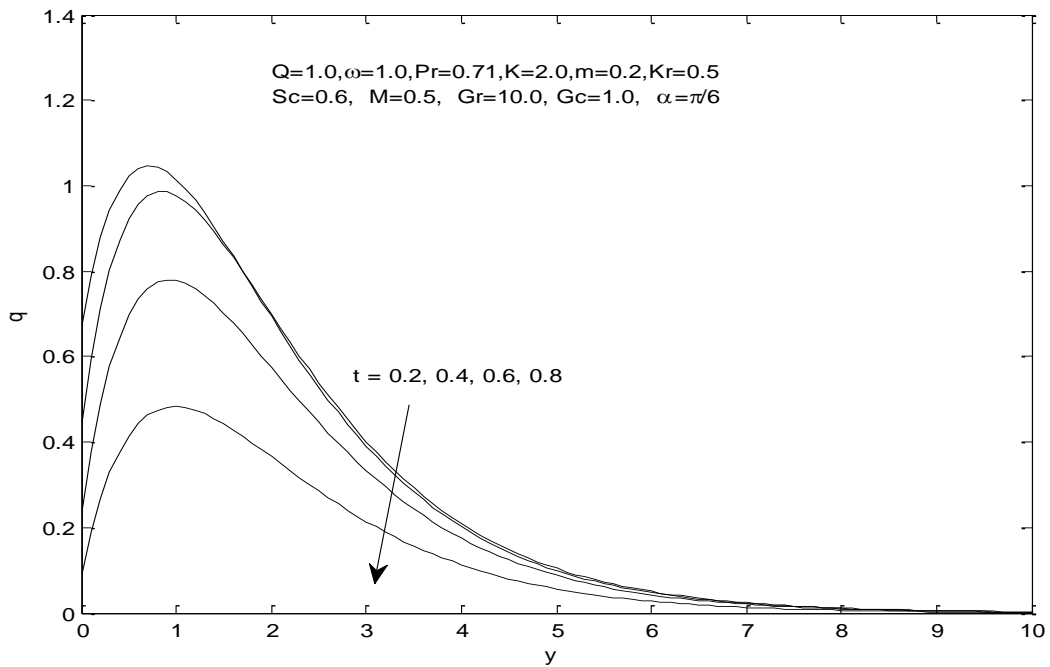


Figure (11): Velocity profiles for different values of t

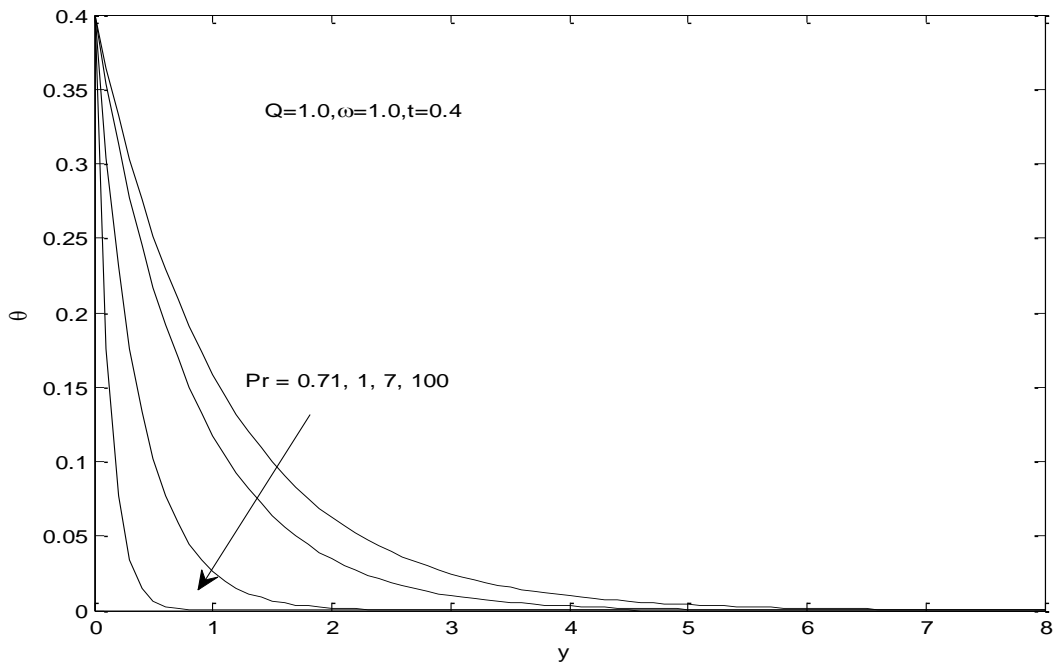


Figure (12): Temperature profiles for different values of Pr

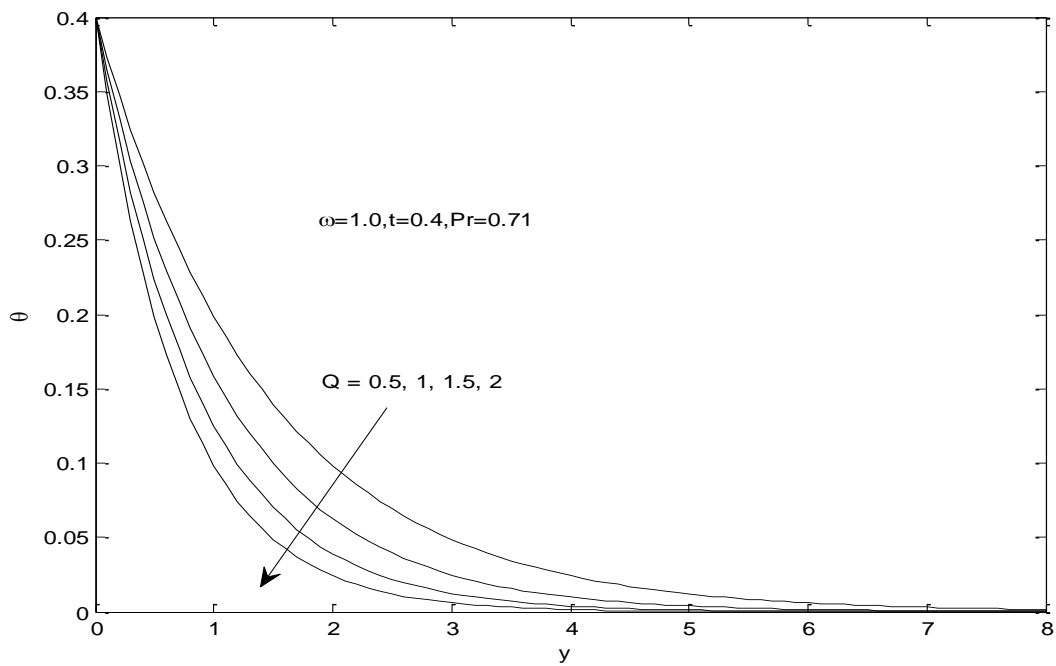


Figure (13): Temperature profiles for different values of Q

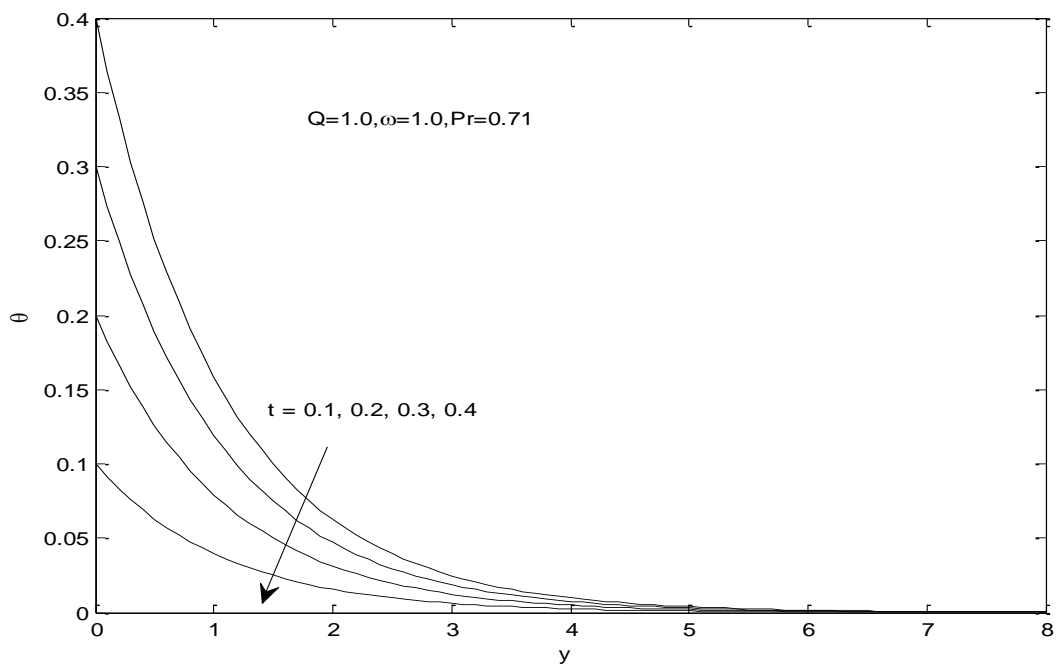


Figure (14): Temperature profiles for different values of t

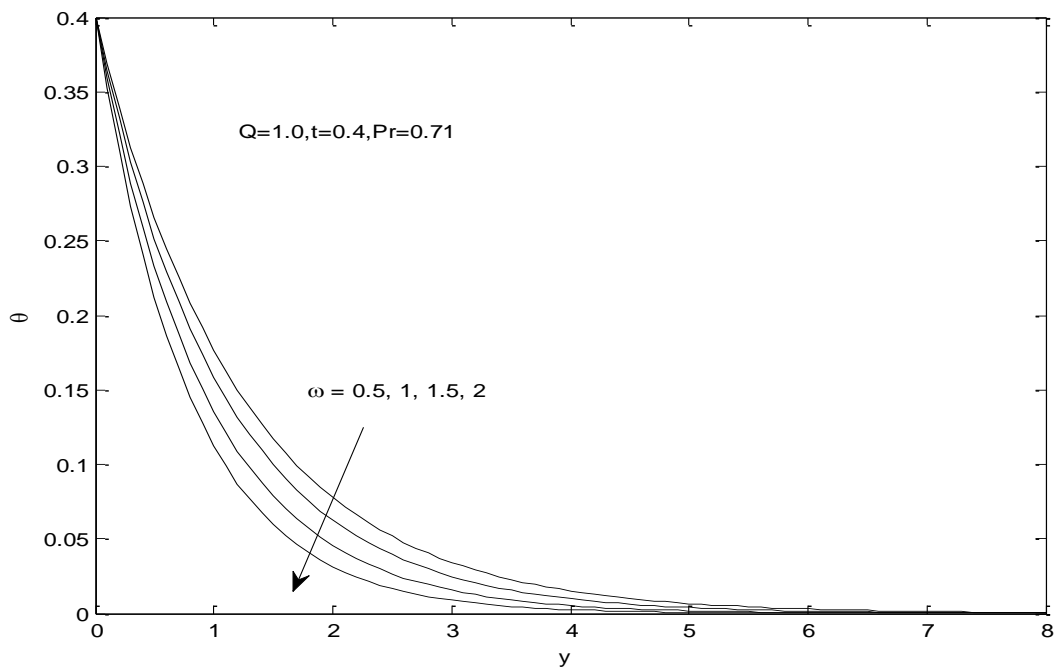


Figure (15): Temperature profiles for different values of ω

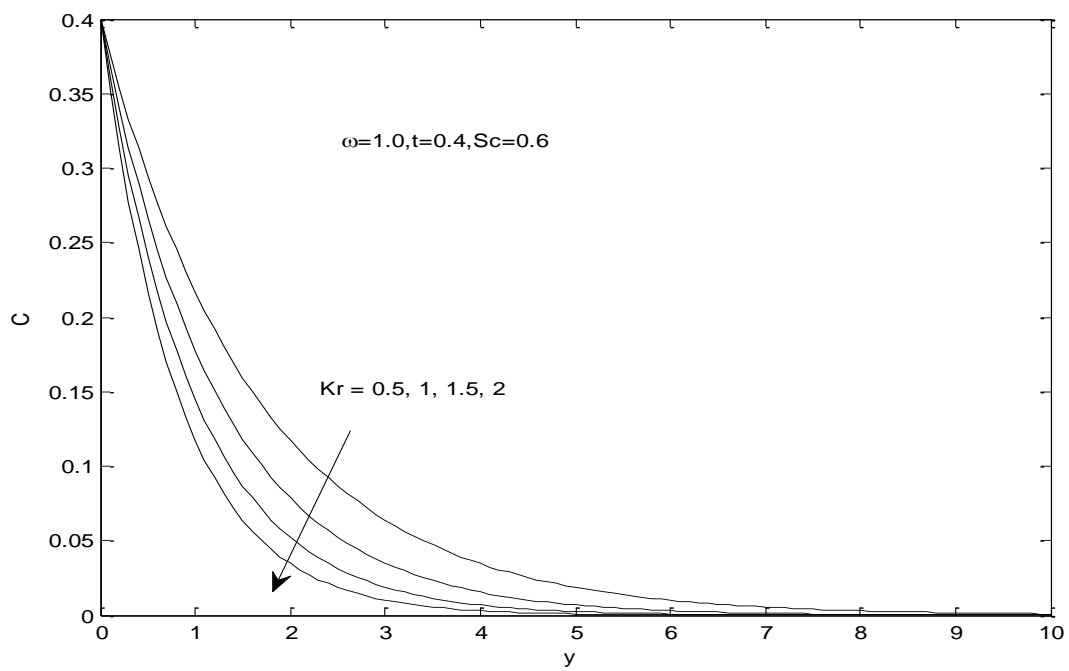


Figure (16): Concentration profiles for different values of Kr

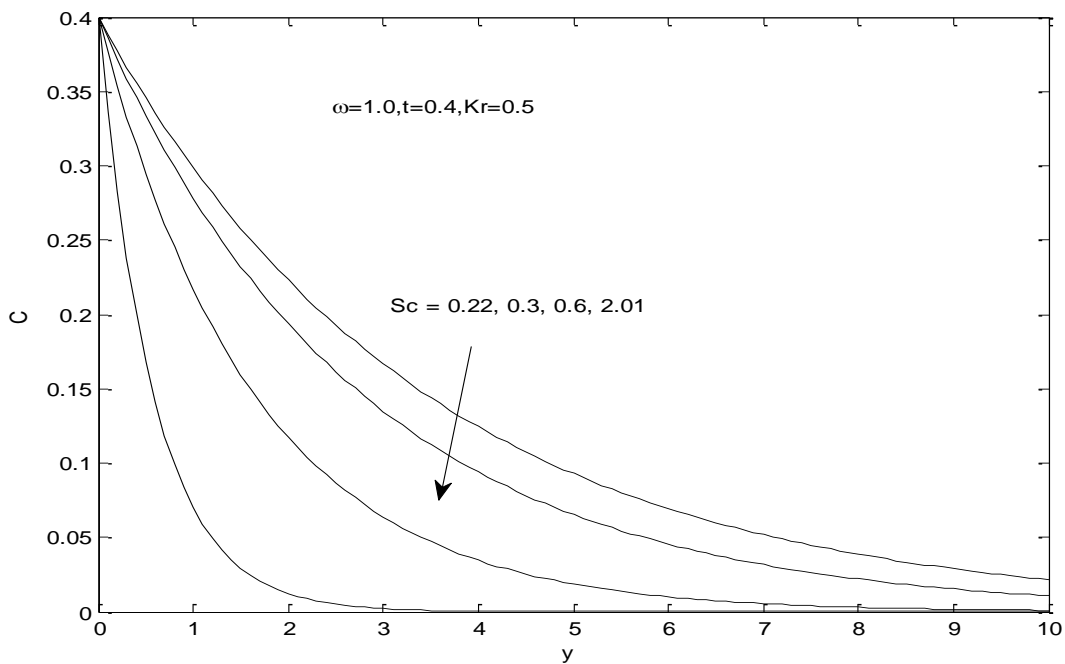


Figure (17): Concentration profiles for different values of Sc

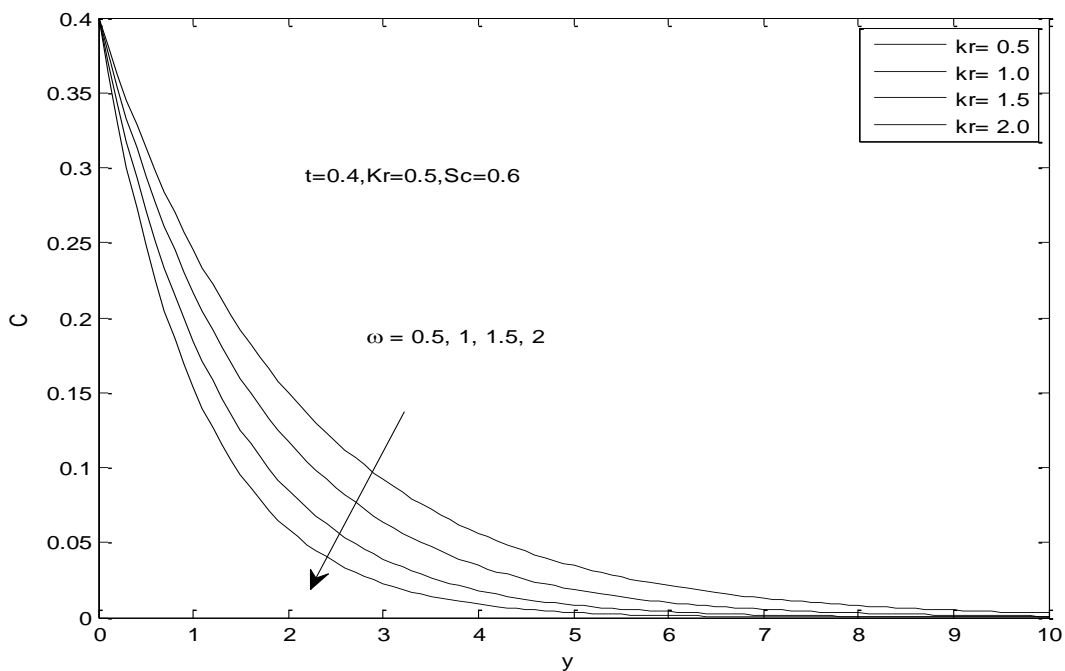
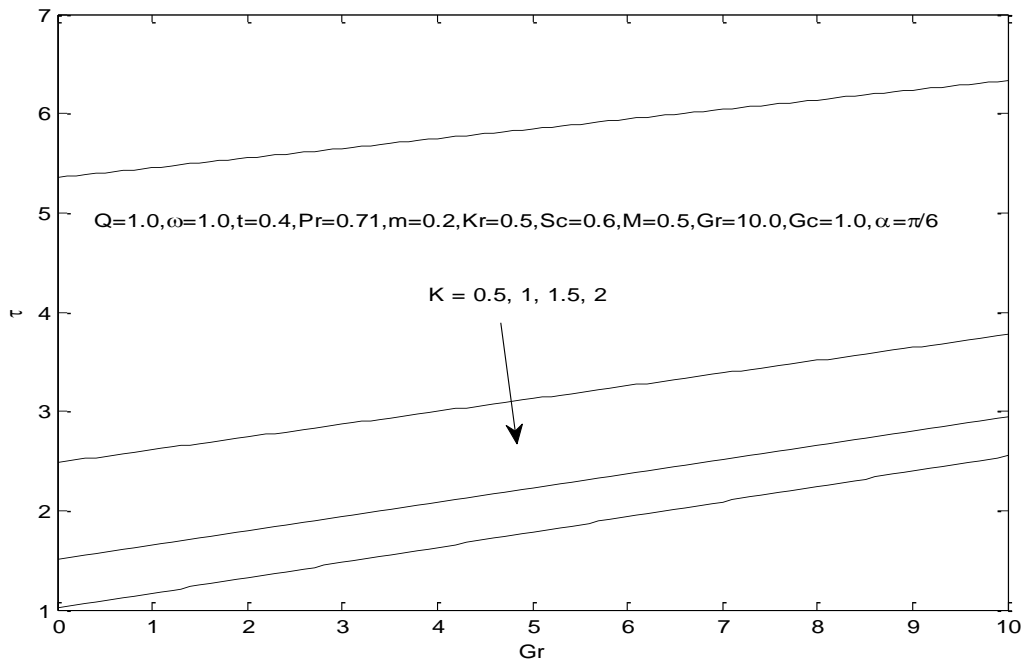
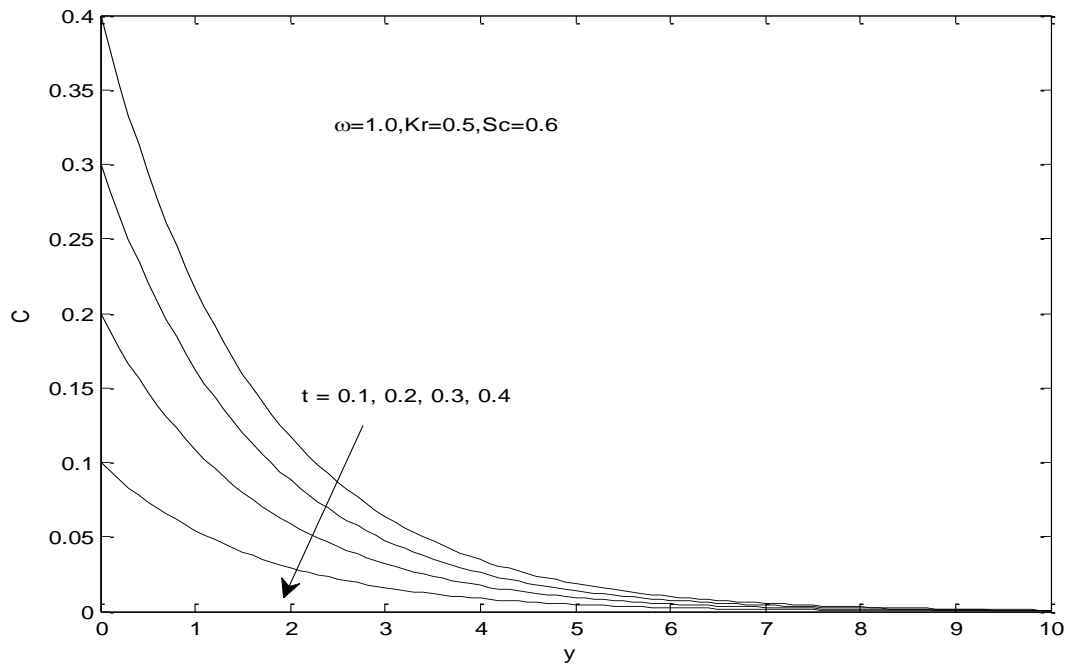


Figure (18): Concentration profiles for different values of ω



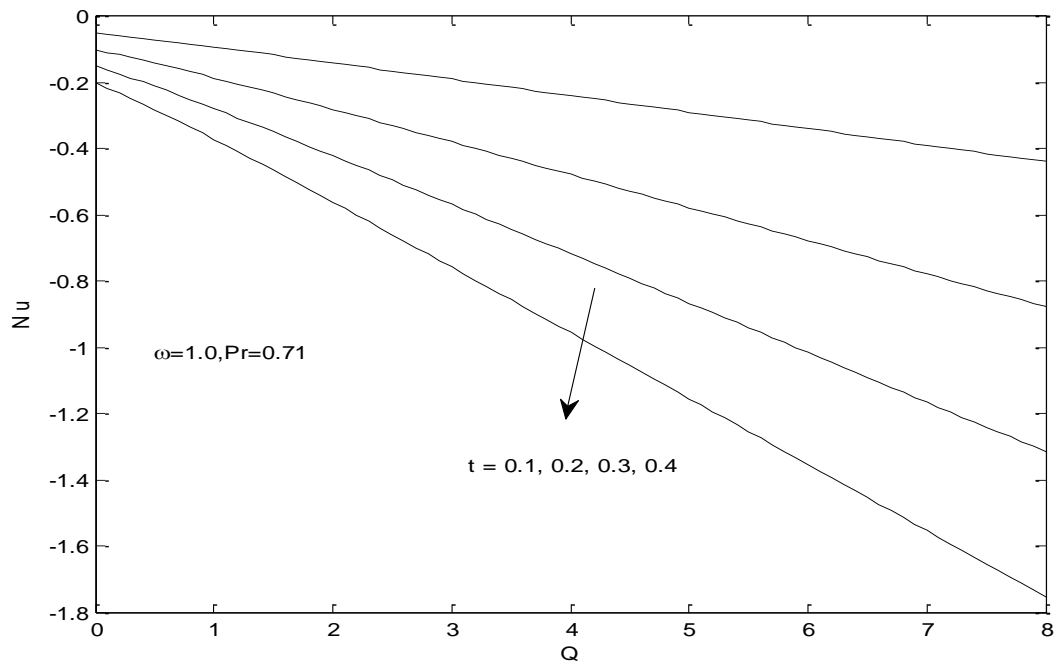


Figure (21): Nusselt number for different values of t

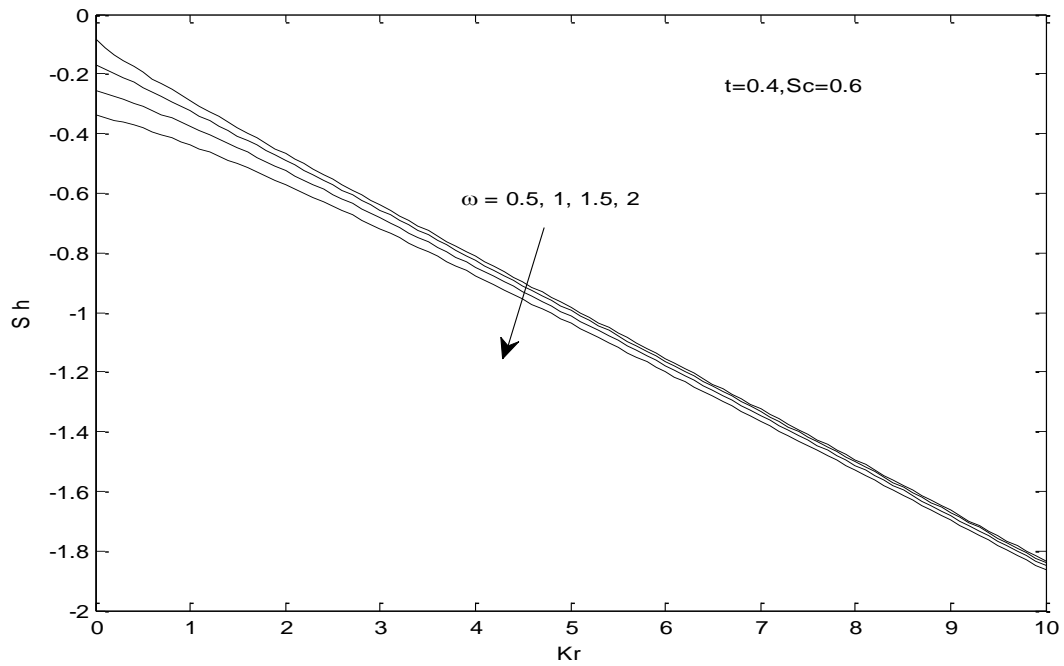


Figure (22): Sherwood number for different values of ω