Chemical Reaction And Radiation Effects On Magnetohydrodynamic Convective Flow In Porous Medium With Heat Generation

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ABSTRACT

The present paper focus on simultaneous effects of thermal and concentration diffusions in unsteady magnetohydrodynamic free convection flow past a moving plate maintained at constant heat flux and embedded in a viscous fluid saturated porous medium is presented. The transported model employed includes the effects of thermal radiation, heat source and chemical reaction. Te fluid is considered as a gray absorbing – emitting but non-scattering medium and the Rosseland approximation in the energy equation is used to describe the radiative heat flux for optically thick fluid. The dimensionless coupled linear partial differential equations are solved by suing perturbation technique. The solution for the velocity, temperature and concentration as well as the skin friction coefficient and the rates of heat and mass transfer are shown graphically for different values of physical parameters involved.

Keywords: *Magnetic field, Free convection, Porous medium, Heat flux, Chemical reaction*

1. INTRODUCTION

Study of flow with heat and mass transfer play an important role in engineering sciences. Effect of heat and mass transfer plays vital role, in space craft design, in the cooling of liquid metal of nuclear reactors, pollution of environment etc. Radiative heat and mass transfer play an important role in manufacturing industries for the design of fins, steel rolling, nuclear power plants, gas turbines and various propulsion devices for aircraft, combustion and furnace design. Ahmmed et al. [1] have analyzed radiation and mass transfer effects on MHD free convection flow past a vertical plate with variable temperature and concentration. Amit and Srivastava Saraswat [2] studied heat and mass transfer on flow past an exponentially accelerated infinite vertical plate with variable temperature and mass diffusion through a porous medium. Kaprawi [3] explains analysis of transient natural convection flow past an accelerated infinite vertical plate. Kumar and Verma [4] discussed radiation effects on MHD flow past an impulsively started exponentially accelerated vertical plate with variable temperature in the presence of heat generation. Muthucumarasamy and Visalakshi [5] investigated radiative flow past an exponentially accelerated vertical plate with variable temperature and mass diffusion in the presence of magnetic field. Okedoye and Lamidi [6] have considered analytical solution of mass transfer effects unsteady flow past an accelerated vertical porous plate with suction. Sathappan and Muthucumaraswamy [9] rendered radiation effects on exponentially accelerated vertical plate with uniform mass diffusion. Rajput and Sahu [7] discussed effects of rotation and magnetic field on the flow past an exponentially vertical plate with constant temperature. Sanatan Das et al. [8] investigated radiation effects on free convection MHD couette flow started exponentially with variable wall temperature in presence of heat generation. Thamizhsudar and Pandurangan [10] explain combined effects of radiation and Hall current on MHD flow past an exponentially accelerated vertical plate in the presence of rotation. Uwanta and Sarki [11] presented heat and mass transfer with variable temperature and exponential mass diffusion.

The study of convective flow with heat and mass transfer under the influence of magnetic field and chemical reaction with heat source has practical applications in many areas of science and engineering. This phenomenon plays an important role in chemical industry, petroleum industry, cooling of nuclear reactors, and packed-bed catalytic reactors. Natural convection flows occur frequently in nature due to temperature differences, concentration differences, and also due to combined effects. The concentration difference may sometimes produce qualitative changes to the rate of heat transfer. The study of heat generation in many fluids due to exothermic and endothermic chemical reactions and natural convection with heat generation can be added to combustion modelling. Ch Kesavaiah et.al [12] investigated effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, Chenna Kesavaiah and Satyanarayana [13] studied MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, Srinathuni Lavanya and Chenna Kesavaiah [14] analyzed Heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction. Karunakar Reddy et. al. [15] considered MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, Mallikarjuna Reddy et. al. [16] investigated effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, Bhavana and Chenna Kesavaiah [17] analyzed perturbation solution for thermal diffusion and chemical reaction effects on MHD flow in vertical surface with heat generation, Chenna Kesavaiah and Venkateswarlu [18] has been studied chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, Srinathuni Lavanya et. al. [19] worked out radiation effect on unsteady free convective MHD flow of a viscoelastic fluid past a tilted porous plate with heat source.

The chemical reaction within nanofluid flow has important effects on transport phenomena due to the formation of new species and then affects the criteria of the production. These effects are investigated by many researchers. Ramesh Babu et. al. [21] explained in detailed information on radiation effect on MHD free convective heat absorbing Newtonian fluid with variable temperature, Chenna Kesavaiah et. al. [22] motivated study on heat and mass transfer effects over isothermal infinite vertical plate of Newtonian fluid with chemical reaction, recently a numerous studies on Influence of joule heating and mass transfer effects on MHD mixed convection flow of chemically reacting fluid on a vertical surface by Chenna Kesavaiah et. al. [23], Bal Reddy et. al. [24] explained A note on heat transfer of MHD Jeffrey fluid over a stretching vertical surface through porous plate, Chenna Kesavaiah et. al. [25] expressed their ideas on radiation and mass transfer effects on MHD mixed convective flow from a vertical surface with heat source and chemical reaction, Chenna Kesavaiah et. al. [26] expressed radiation, radiation absorption, chemical reaction and hall effects on unsteady flow past an isothermal vertical plate in a rotating fluid with variable mass diffusion with heat source,

2. FORMULATION OF THE PROBLEM

Consider an unsteady one-dimensional flow of an incompressible, electrically conducting and viscous fluid past an infinite vertical plate embedded in a porous medium with constant heat flux at $y^* = 0$. The $x^* -$axis is measured along the plate in the upward direction and $y^* -$ axis is measured normal to the plate in the outward direction. A uniform magnetic field B_0 is acting in the transverse direction to the flow.

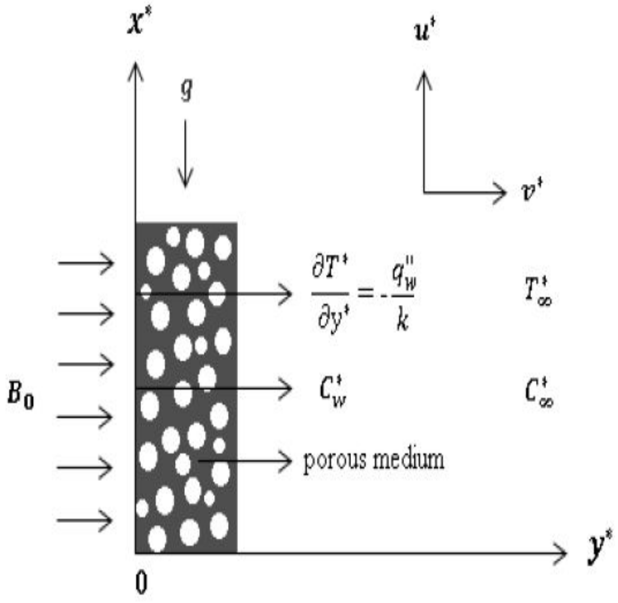

Figure (1): Flow geometry and physical coordinate system

The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and the Hall Effect are negligible. The Soret and thermal buoyancy effects are also considered. The plate is infinite in length, so all the field quantities become functions of space coordinate y^* and time t^*. Initially, the plate and the fluid are at same temperature $T_\infty{}^*$ and concentration $C_\infty{}^*$. Subsequently, at time $t^* > 0$, the plate begins to move in its own plane and accelerates against the gravitational field with uniform acceleration $f\left(t^*\right)$ in $x^* -$direction. Simultaneously, heat is supplied form the surface of the plate to the fluid, which is maintained throughout the fluid flow at the uniform rate $\frac{q_w''}{k}$ and concentration level is raised to C_w'' as shown in figure (1). Under the above assumptions and invoking the Boussinesq approximation, the governing equations of momentum, energy and concentration are derived as follows:

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

$$\rho c_p \frac{\partial T^*}{\partial t^*} = \kappa \frac{\partial^2 T^*}{\partial y^{*2}} - Q_0\left(T^* - T_\infty^{\ *}\right) \qquad (2)$$

$$\frac{\partial C^*}{\partial t^*} = \kappa \frac{\partial^2 C^*}{\partial y^{*2}} - Kr^*\left(C^* - C_\infty^{\ *}\right) \qquad (3)$$

The initial and boundary conditions are:

$$\begin{aligned}
&u^* = 0, T^* = T_\infty^*, C^* = C_\infty^* && \text{for all} \quad y^* \geq 0,\ t^* \leq 0 \\
&u^* = f\left(t^*\right), \frac{\partial T^*}{\partial y^*} = -\frac{q_w{}''}{k}, C^* = C_\infty^* && at \quad y^* = 0,\ t^* > 0 \qquad (4) \\
&u^* \to 0, T^* \to T_\infty^*, C^* \to C_\infty^* && as \quad y^* \to \infty
\end{aligned}$$

in which $f\left(t^*\right)$ is the uniform acceleration of the plate, x^* and y^* are the distances along and perpendicular to the plate, t^* is the dimensional time, u^* is the fluid velocity in the x^*-direction, T^* is the temperature of the fluid, T_∞^* is the free stream temperature, C^* is the concentration, C_w^* is the surface concentration, C_∞^* is the free stream concentration, Q_0 is the dimensional heat absorption coefficient, κ is the thermal conductivity, q_r^* is the radiative heat flux in x^*-direction, $q_w{}''$ is the constant heat flux per unit area at the plate, β is the volumetric coefficient of thermal expansion, β^* is the volumetric coefficient of expansion for concentration, ν is the kinematic viscosity, μ is the fluid viscosity, ρ is the fluid density, c_p is the specific heat capacity, σ is the electrical conductivity of the fluid, K^* is the permeability of the porous medium, T_m is the mean fluid temperature, K_T is the thermal-diffusion ratio, Kr^* is the chemical reaction constant and D is the mass diffusivity.

Now, we take $f\left(t^*\right) = At^*$ and define the following non-dimensional variables

$$y = y^* 3\sqrt{\frac{A}{\nu^2}},\ u = \frac{u^*}{3\sqrt{\nu A}},\ t = t^* 3\sqrt{\frac{A^2}{\nu}},\ \theta = \frac{T^* - T_\infty^{\ *}}{\frac{q_w{}''}{k} 3\sqrt{\frac{\nu^2}{A}}},\quad C^* = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*} \qquad (5)$$

where A denotes the uniform acceleration of the plate in $x-$direction, u is the dimensionless velocity, y is dimensionless coordinate perpendicular to the plate, t is the dimensionless time, θ is the dimensionless temperature and ϕ is the dimensionless concentration.

Substituting equations (5) into equation (1), (3) gives the governing equations in dimensionless form

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} - H\ Gr\,\theta + Gm\phi \qquad (6)$$

$$F^* \frac{\partial \theta}{\partial t} = \frac{1}{\Pr} \frac{\partial^2 \theta}{\partial y^2} - Q\theta \qquad (7)$$

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

with dimensionless initial and boundary conditions

$$\begin{aligned}
&u=0,\theta=0,\phi=0 \quad for\ all \quad y\ge 0,\ t\le 0\\
&u=t,\frac{\partial \theta}{\partial y}=-1,\ \ \phi=1 \quad at \quad y=0,\ t>0 \qquad (9)\\
&u\to 0,\theta\to 0,\phi\to 0 \quad as \quad y\to\infty
\end{aligned}$$

where

$$\begin{aligned}
&M=\frac{\sigma B_0{}^2\, 3\sqrt{\nu A}}{\rho A},Gr=\frac{\beta g q_w{}''\sqrt{\nu A}}{\rho A},Gm=\frac{\beta^* g\left(C_w^*-C_\infty^*\right)}{A}\\
&\frac{1}{K}=\frac{\nu\sqrt{\nu A}}{AK^*},\quad H=M+\frac{1}{K},\quad \Pr=\frac{\nu\rho c_p}{k},R=\frac{16a^*T^{*3}_\infty}{3kk^*} \qquad (10)\\
&Q=\frac{Q_0}{\rho c_p 3\sqrt{\frac{A^2}{\nu}}},\quad Sc=\frac{\nu}{D},\quad Kr=Kr^*\sqrt{\frac{\nu}{A^2}}\ ,\ L=\Pr Q
\end{aligned}$$

where 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 respectively.

Solution of the problem

The well-posed problems defined by (6) – (8) will be solved by suing the perturbation technique. Exact analytical expression for dimensionless velocity, temperature and concentration fields will be separately obtained for $Sc\ne 1$, $Sc=1$. Therefore the fluid in the neighbourhood of the fluid in the neighbourhood of the plate as

$$\begin{aligned}
&u=u_0\left(y\right)+\varepsilon\, e^{at}u_1\left(y\right)\\
&\theta=\theta_0\left(y\right)+\varepsilon\, e^{at}\theta_1\left(y\right) \qquad (11)\\
&\phi=\phi_0\left(y\right)+\varepsilon\, e^{at}\phi_1\left(y\right)
\end{aligned}$$

Substituting (14) in Equation (6) – (8) and equating the harmonic and non – harmonic terms, we obtain

$$u_0''-Hu_0=-Gr\,\theta_0-Gm\,\phi_0 \qquad (12)$$

$$u_1''-\beta_3 u_1=-Gr\,\theta_1-Gm\phi_1 \qquad (13)$$

$$\theta_0''-L\theta_0=0 \qquad (14)$$

$$\theta_1''-\beta_1\theta_1=0 \qquad (15)$$

$$\phi_0''-KrSc\ \phi_0=0 \qquad (16)$$

$$\phi_1'' - \beta_2 \phi_1 = 0 \qquad (17)$$

The corresponding boundary conditions can be written as

$$\begin{aligned}
&u = 0, \theta = 0, \phi = 0 && \textit{for all} \quad y \geq 0,\ t \leq 0 \\
&u_0 = t, u \ \ = 0, \frac{\partial \theta_0}{\partial y} = -1, \frac{\partial \theta_1}{\partial y} = 0 \ \ \phi_0 = 1,\ \phi_0 = 0 && at \quad y = 0,\ t > 0 \qquad (18) \\
&u_0 \to 0, \theta_0 \to 0, \phi_0 \to 0, u_1 \to 0, \theta_1 \to 0, \phi_1 \to 0 && as \ \ y \to \infty
\end{aligned}$$

Case (i): For $Sc \neq 1$

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

$$u_0 = L_1 e^{-\sqrt{L}y} + L_2 e^{-\sqrt{KrSc}\ y} + L_3 e^{-\sqrt{H}\,y}; u_1 = 0$$

$$\theta_0 = \frac{1}{\sqrt{L}} e^{-\sqrt{L}\,y}; \theta_1 = 0$$

$$\phi_0 = e^{-\sqrt{KrSc}\ y}; \phi_1 = 0$$

In view of the equation (14) becomes

$$u = L_1 e^{-\sqrt{L}y} + L_2 e^{-\sqrt{KrSc}\ y} + L_3 e^{-\sqrt{H}\,y}$$

$$\theta = \frac{1}{\sqrt{L}} e^{-\sqrt{L}\,y}$$

$$\phi = e^{-\sqrt{KrSc}\ y}$$

Coefficient of Skin-Friction

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

$$C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0} = -\sqrt{L}\,L_1 - \sqrt{KrSc}\ L_2 - \sqrt{H}\ L_3$$

Coefficient of Heat Transfer

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

$$N_u = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -1$$

Sherwood number

$$Sh = \left(\frac{\partial \phi}{\partial y}\right)_{y=0} = -\sqrt{KrSc}$$

Case (ii): For $Sc = 1$

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

$$u_0 = L_1 e^{-\sqrt{L}y} + L_2 e^{-\sqrt{\gamma}\,y} + L_3 e^{-\sqrt{H}\,y}; u_1 = 0$$

$$\theta_0 = \frac{1}{\sqrt{L}} e^{-\sqrt{L}\,y}; \theta_1 = 0$$

$$\phi_0 = e^{-\sqrt{\gamma}\,y}; \phi_1 = 0$$

In view of the equation (14) becomes

$$u = L_1 e^{-\sqrt{L}y} + L_2 e^{-\sqrt{Kr}\,y} + L_3 e^{-\sqrt{H}\,y}$$

$$\theta = \frac{1}{\sqrt{L}} e^{-\sqrt{L}\,y}$$

$$\phi = e^{-\sqrt{Kr}\,y}$$

Coefficient of Skin-Friction

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

$$C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0} = -\sqrt{L}\,L_1 - \sqrt{Kr}\;L_2 - \sqrt{H}\,L_3$$

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Sherwood number

$$Sh = \left(\frac{\partial \phi}{\partial y}\right)_{y=0} = -\sqrt{Kr}$$

3. RESULTS AND DISCUSSIONS

In order to get the physical insight into the problem the numerical values of the velocity, temperature and concentration fields are studied for different physical parameters such as Grashof number for heat transfer and mass transfer (Gr, Gm), permeability of the porosity parameter (K), chemical reaction parameter (Sc), magnetic parameter (M), Prandtl number $(\Pr)$, Schmidt number (Sc), heat source parameter (Q), and time (t) upon the nature of flow and transport. The value of the Schmidt number (Sc) is taken to be $(Sc = 0.6)$ which corresponds to water-vapor, also the value of Prandtl number Pr are chosen such that they represent air $(\Pr = 0.71)$. The effect of Prandtl number $(\Pr)$ is important in temperature profiles. The effect of heat transfer is more in the presence of air than in water. Numerical evaluation of the analytical results is in terms of an exponential and complementary error function and a representative a set of results is reported graphically. Figure (2) and (3) shows the influence of thermal buoyancy force parameter and the modified buoyancy force parameter on the velocity while all other parameters are kept at some fixed values. It is clear from figure

(2) and (3) that the velocity increases with increasing thermal Grashof number and mass Grashof number. Figure (4) the velocity profiles are shown for different values of the Schmidt number for aiding flows in the presence of foreign mass and constant mass flux respectively. It is observed that the velocity decreases with increasing Schmidt number. The velocity profiles of chemical reaction parameter are noticed in figure (5). It is observed that the velocity decreases as chemical reaction parameter increases. Figure (6) reveal that the velocity profiles for various values of magnetic parameter. Due to an increase in the magnetic parameter, the velocity decreases. It is because that the application of transverse magnetic field will result a resistive type force (Lorentz force) similar to drag force which tends to resist the fluid flow and thus reducing its velocity. Effects of Prandtl number are studied through figure (7) on velocity. From this figure it is observed that the velocity decrease with increasing values of Prandtl number. It is noticed from figure (8) that and decrease on increasing. This implied that heat source parameter tends to retard fluid flow in the velocity. The variation of velocity for different values of dimensionless time is shown in figure (9). It is noticed that the velocity increases with increasing values of t near the plate and then decays to zero asymptotically. Typical variation of the temperature along the span wise coordinate y is shown in figure (10) for different values of the Prandtl number. It is observed that as Prandtl number increases, the temperature distribution across the boundary layer decreases. Figure (11) shows that the temperature profiles for different values of the heat source parameter. It is observed that the temperature decreases with increasing heat source parameter. For different values of the chemical reaction parameter, the concentration profiles are plotted in figure (12). It is observed that as the chemical reaction parameter increases, the concentration distribution across the boundary layer decreases. Figure (13) represents the effect of concentration profiles for different Schmidt number. It is observed that the wall concentration increases with decreasing values of the Schmidt number. Variation of skin friction coefficient $\left(\tau\right)$ are plotted in figure (14) for various values of heat source parameter. It is revealed form this figure that τ decreases as heat source parameter increase. It can be seen from figure (15) that the Sherwood number $\left(Sh\right)$ is reduced with an increase of for all values of Schmidt number $\left(Sc\right)$. Also, this figure illustrates that with increasing values of Sc, Sh increasing when $Kr \le K_0$ □ 0.1 and it is decreasing when $Kr > K_0$.

Appendix

$$\beta_1 = (1 + Q\,Pr\,at), \beta_2 = (Kr + at)Sc, \beta_3 = (H + at)$$

$$L_1 = -\frac{Gr}{\sqrt{L}(L-H)}, L_2 = -\frac{Gc}{KrSc - H}, L_3 = (t - L_1 - L_2)$$

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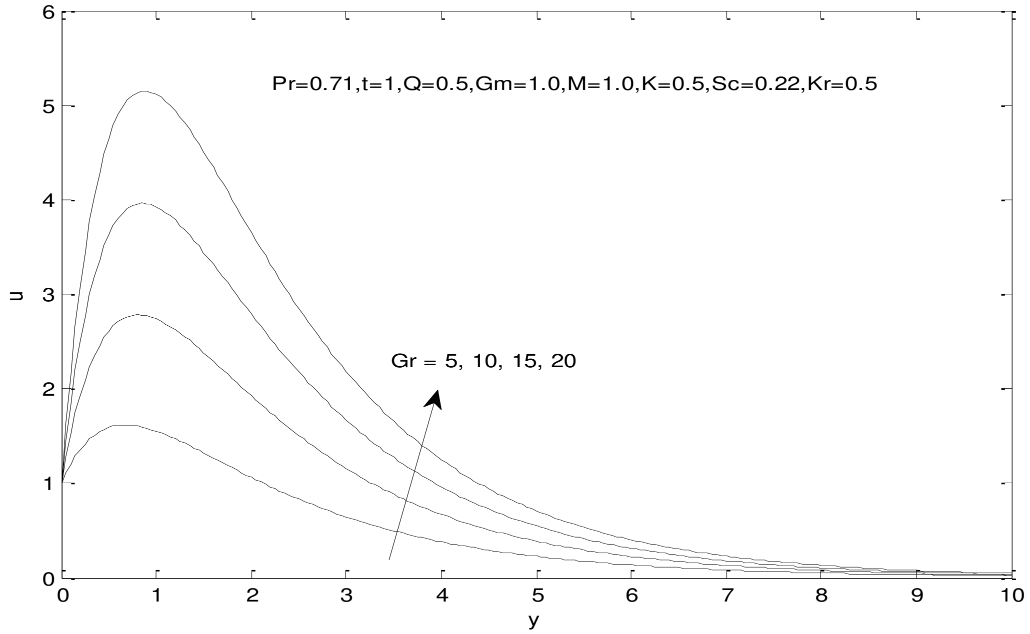

Figure (2): Velocity profiles for Gr

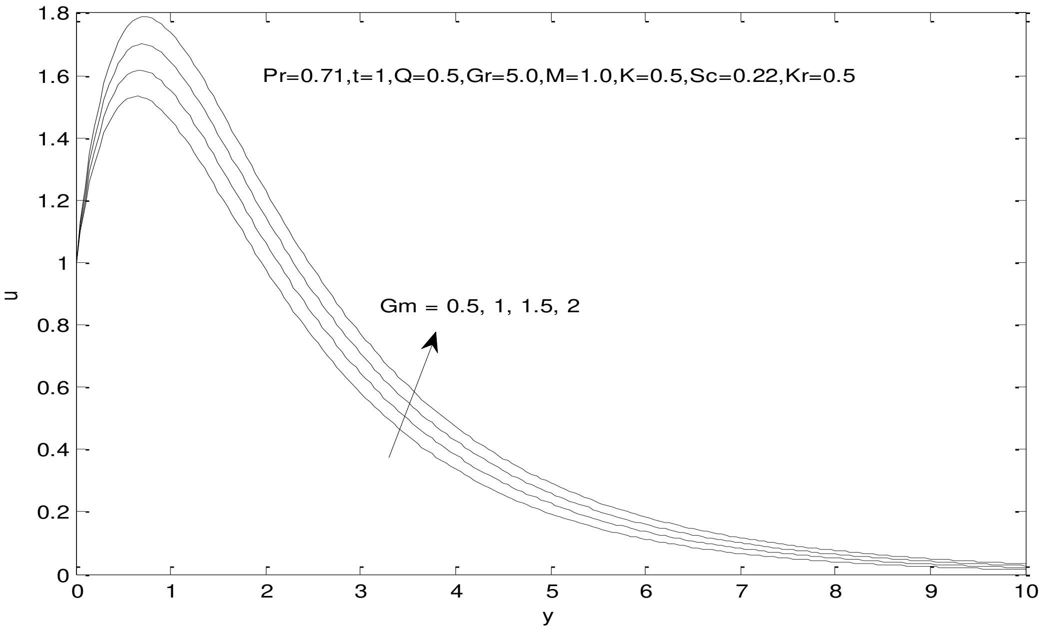

Figure (3): Velocity profiles for Gm

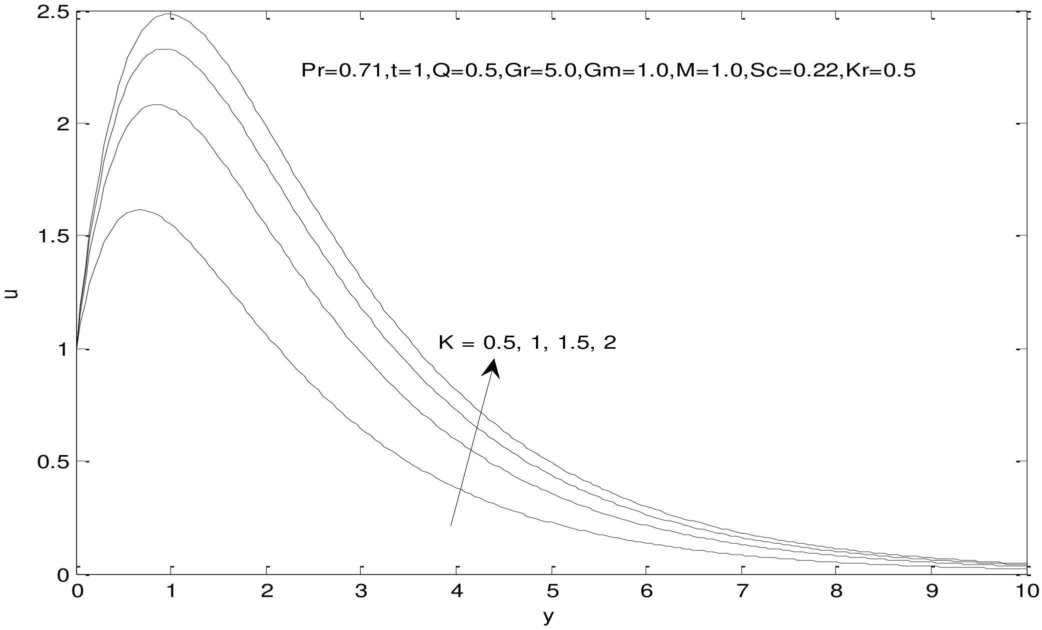

Figure (4): Velocity profiles for K

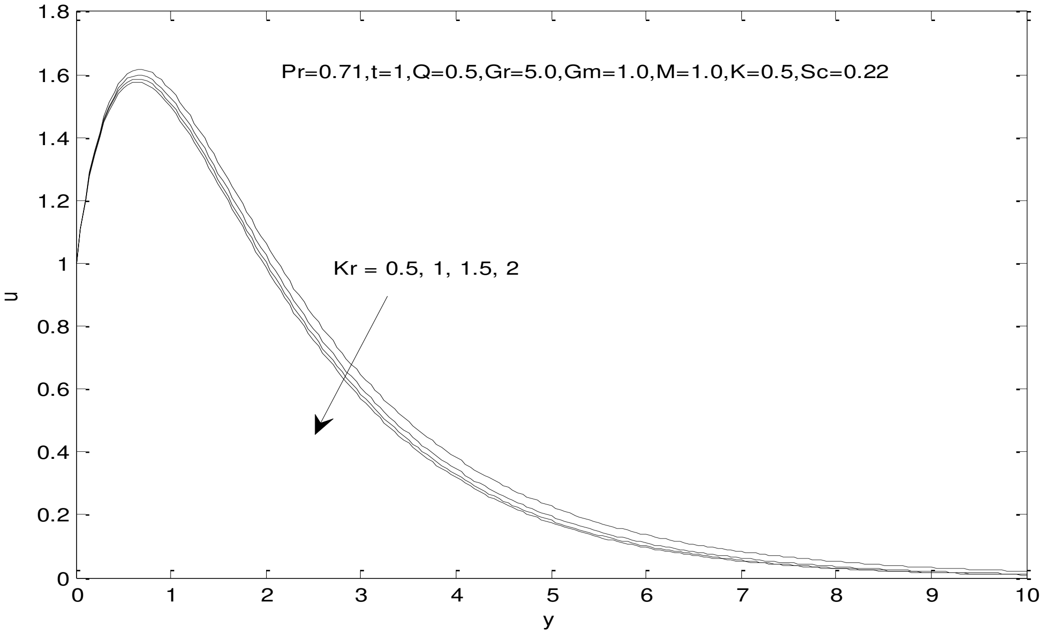

Figure (5): Velocity profiles for Kr

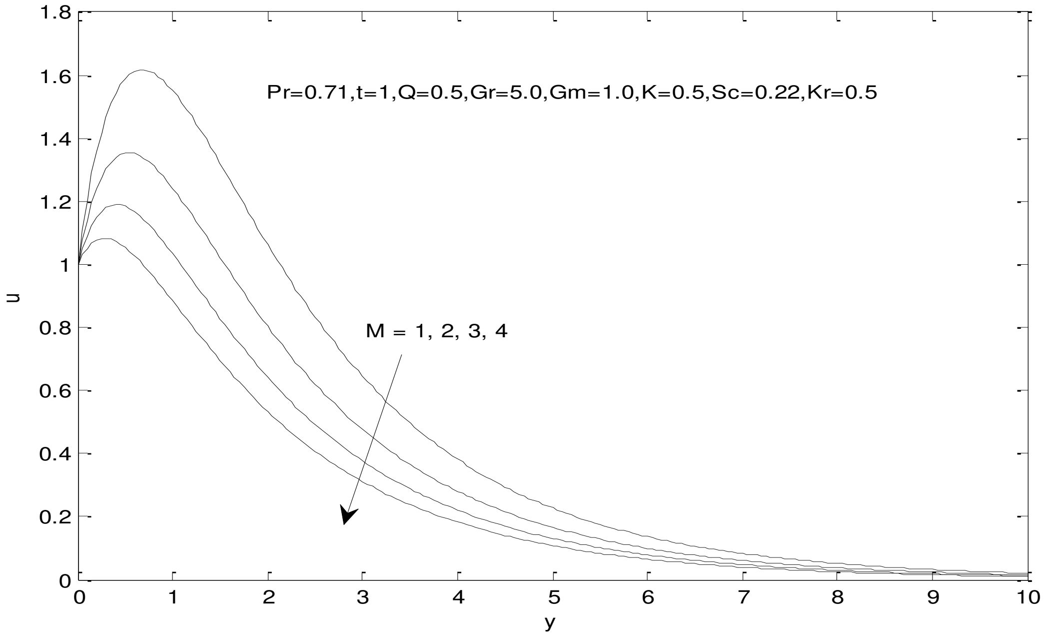

Figure (6): Velocity profiles for M

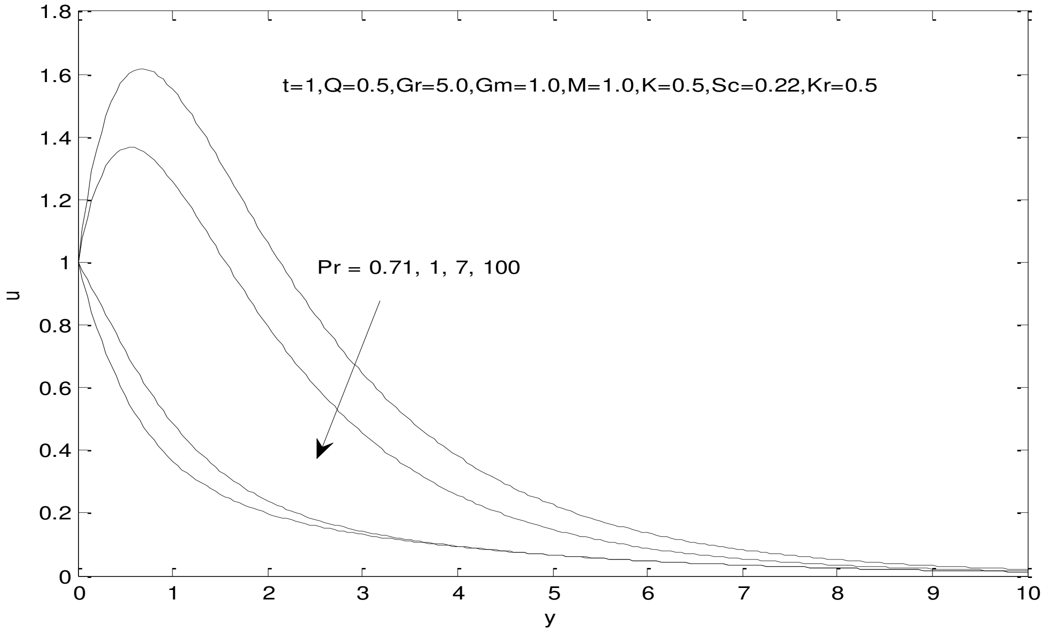

Figure (7): Velocity profiles for Pr

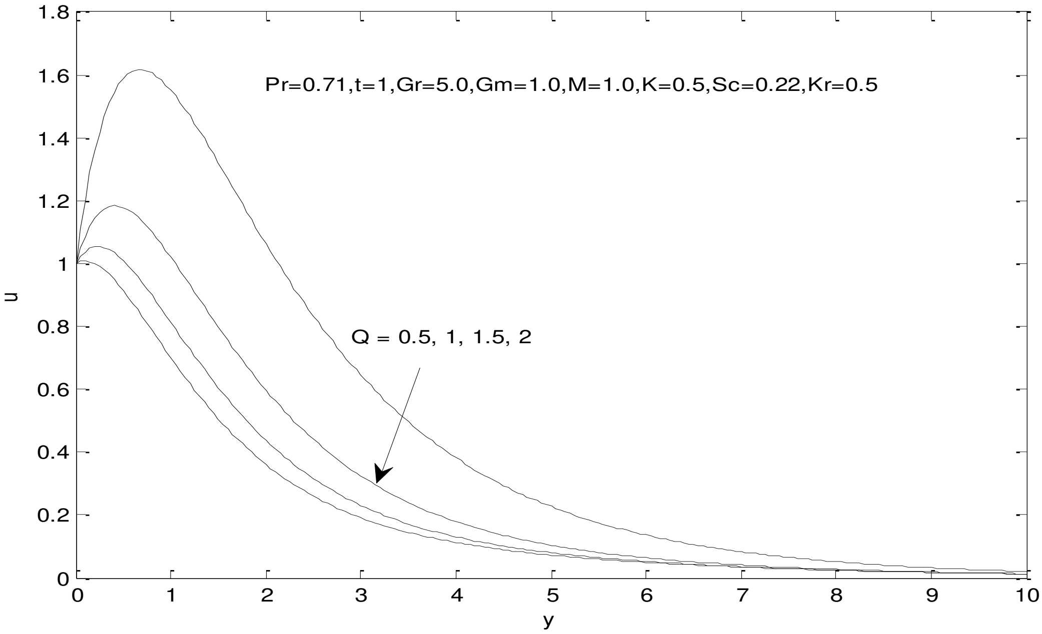

Figure (8): Velocity profiles for Q

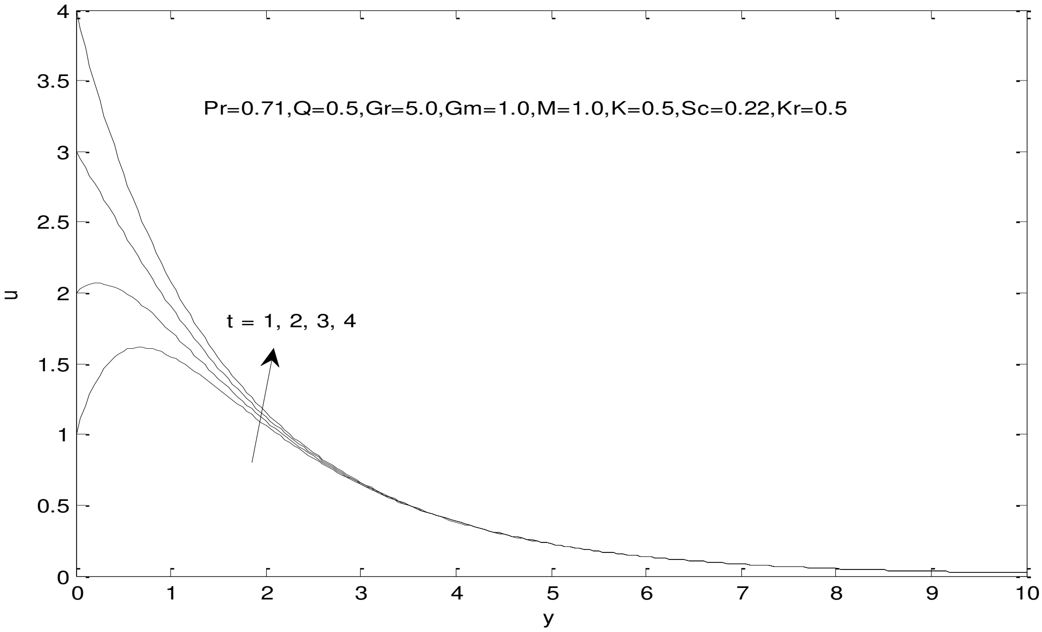

Figure (9): Velocity profiles for t

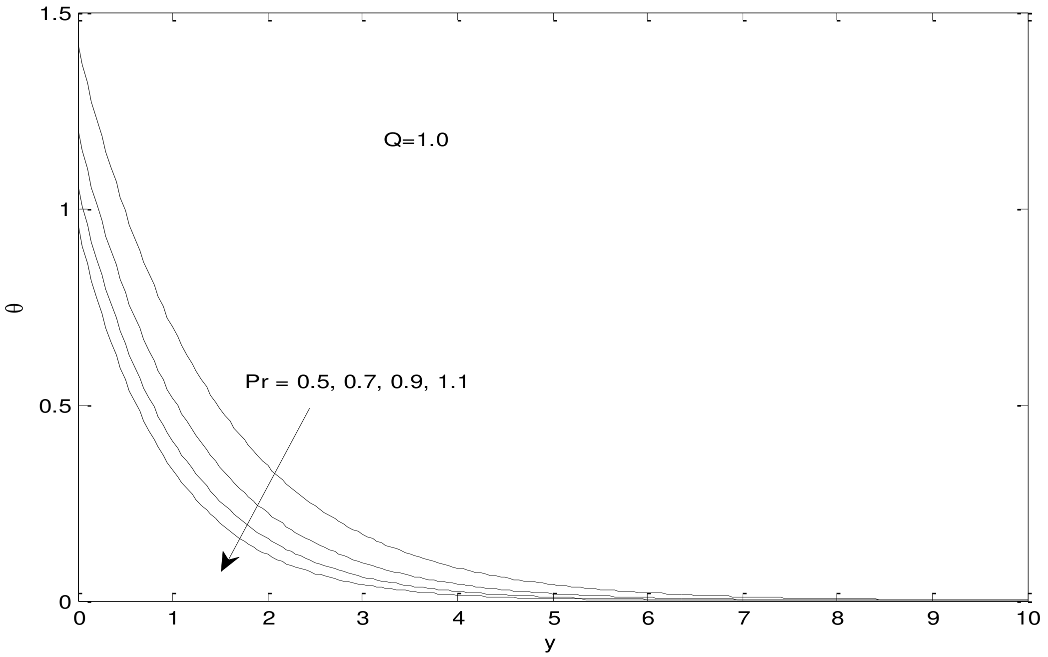

Figure (10): Temperature profiles for Pr

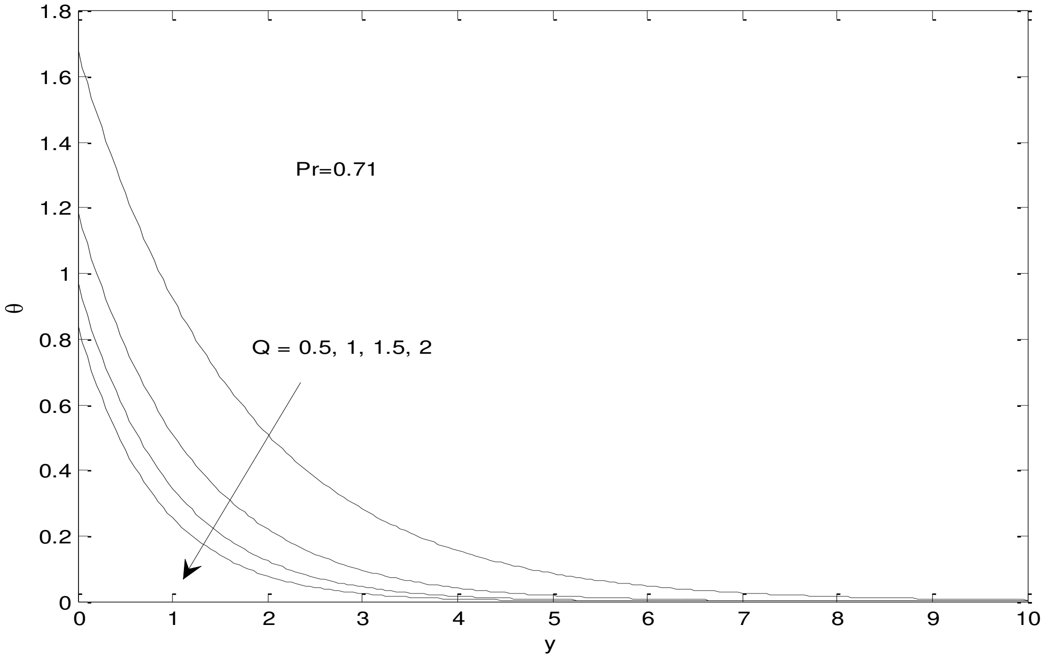

Figure (11): Temperature profiles for Q

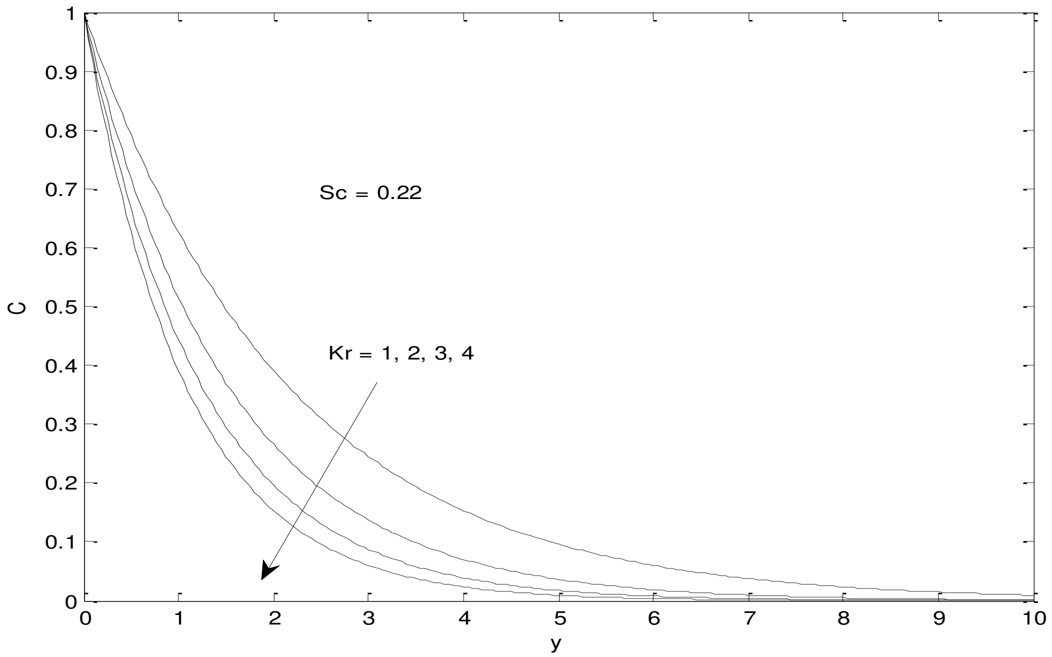

Figure (12): Concentration profiles for Kr

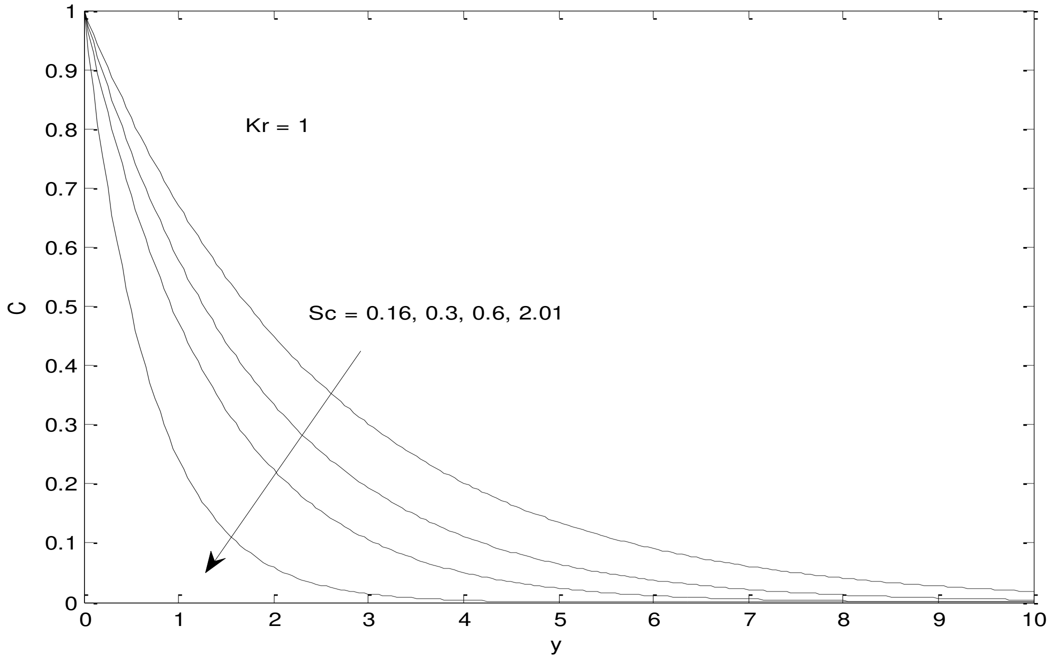

Figure (13): Concentration profiles for Sc

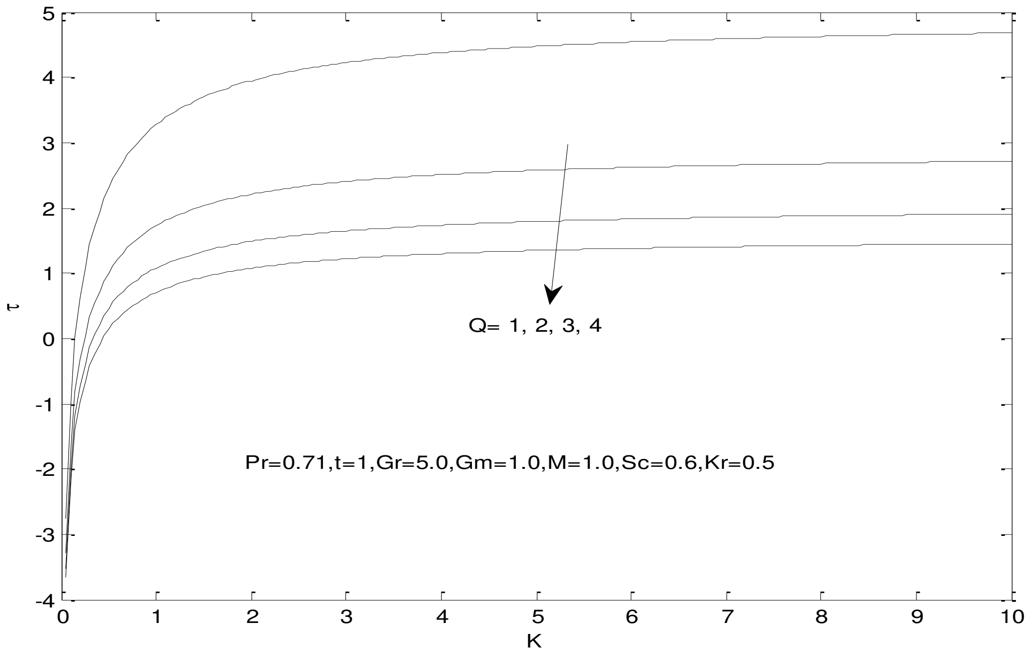

Figure (14): Skin friction for Q

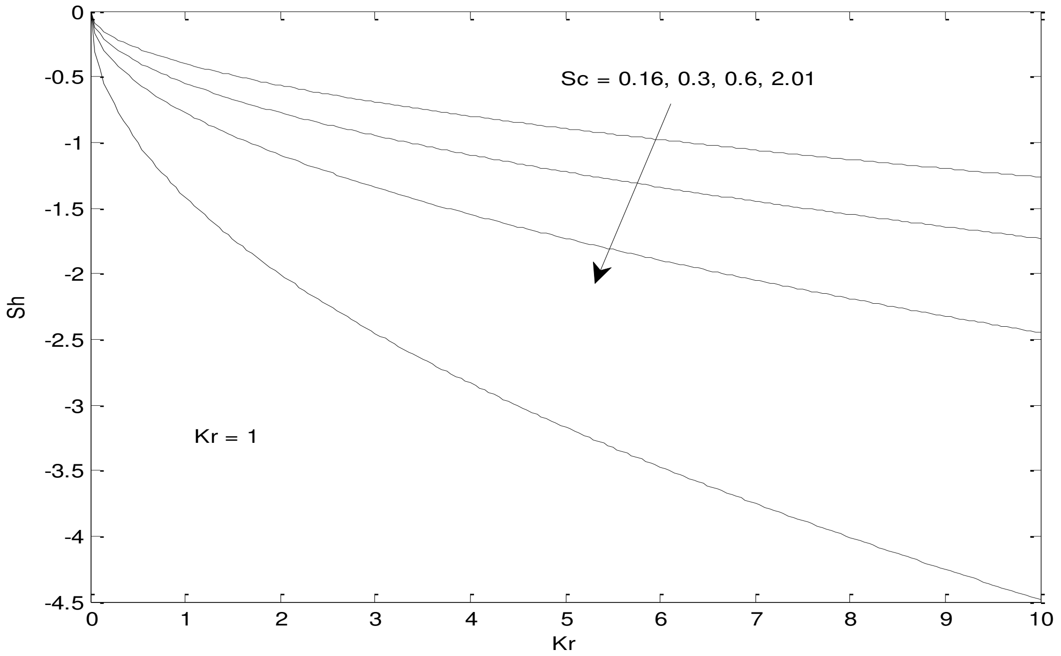

Figure (15): Sherwood number for different values of Sc