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Convective Heat and Mass Transfer Flow from a Vertical Surface with Radiation, Chemical reaction and Heat Source/Absorption

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Abstract-*The effects of heat and mass transfer on MHD mixed convection flow of a vertical surface with radiation, heat source/absorption and chemical reaction has been is discussed. The resulting set of coupled non-linear ordinary differential equations is solved by perturbation technique and for graphs we used MATLAB software. Approximate solutions have been derived for the velocity, temperature, concentration profiles, skin friction and Nusselt number. The obtained results are discussed with the help of the graphs to observe the effect of various parameters like Grashof number, modified Grashof number, Schmidt number, Prandtl number, Magnetic parameter, Radiation parameter, Chemical reaction, Heat source parameter, Radiation absorption parameter.*

***Index Terms**: Mass transfer, Vertical Surface, Radiation, MHD, Chemical reaction, Heat source and Radiation absorption*

I. INTRODUCTION

Convective flows with simultaneous heat and mass transfer under the influence of a magnetic field and chemical reaction arise in many transport processes both naturally and artificially in many branches of science and engineering applications. This phenomenon plays an important role in the chemical industry, power and cooling industry for drying, chemical vapour deposition on surfaces, cooling of nuclear reactors and petroleum industries. The study of heat and mass transfer with chemical reaction is of great practical importance in many branches of science and engineering. Chemical reactions can be modelled as either homogeneous or heterogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. A homogeneous reaction is one that occurs uniformly throughout a given phase. On the other hand, a heterogeneous reaction takes place in a restricted area or within the boundary of a phase. Chemical reactions can be modelled as either homogeneous or heterogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. A homogeneous reaction is one that occurs uniformly throughout a given phase.

On the other hand, a heterogeneous reaction takes place in a restricted area or within the boundary of a phase. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be of first order, if the rate of reaction is directly proportional to the concentration itself. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be of first order, if the rate of reaction is directly proportional to the concentration itself. For example, the formation of smog is a first order homogeneous reaction. Consider the emission of nitrogen dioxide from automobiles and other smoke-stacks. This nitrogen dioxide reacts chemically in the atmosphere with unburned hydrocarbons (aided by sunlight) and produces peroxyacetylnitrate, which forms an envelope which is termed photo-chemical smog. An approximate numerical solution of chemical reaction, heat and mass transfer on MHD flow along a vertical stretching surface over a wedge with heat source and concentration in the presence of suction or injection was studied by Kandasamy et al. [6]. The variable viscosity and chemical reaction effects on flow, heat and mass transfer characteristics in a viscous fluid over a porous wedge in the presence of heat radiation were introduced by Kandasamy et al. [7]. Kumar *et al.* [10], in their work, presented a systematic analysis on heat transfer in MHD viscoelastic boundary layer flow with constant suction over a porous flat surface. Kesavaiah et. al [9] 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. Tak et.al [24] MHD mixed convection boundary layer flow with double diffusion and thermal radiation adjacent to a vertical permeable surface embedded in a porous medium. Naga Leela Kumari and Sarojamma [26] Effect of hall currents on unsteady mixed convective heat and mass transfer flow of a chemically reacting viscous fluid in a horizontal channel with traveling thermal waves. Pal and Talukdar [17] Perturbation analysis of unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with a thermal radiation and chemical reaction. Makinde and Aziz [13] MHD mixed convection from a vertical plate embedded in a porous medium with a convective boundary condition. Makinde and Sibanda [14] Magnetohydrodynamic mixed convective flow and heat and mass transfer past a vertical plate in a porous medium with constant wall suction.

Natural convection flow occurs frequently in nature. It occurs due to temperature differences, as well as due to concentration differences or the combination of these two, for example in atmospheric flows, there exists differences in water concentration and hence the flow is influenced by such concentration difference. In recent years, progress has been considerably made in the study of heat and mass transfer in magnetohydrodynamic (MHD) flows due to its application in many devices, like the MHD power generators and Hall accelerators. Combined heat and mass transfer by mixed convection in a porous medium has attracted considerable attention in the last several decades, due to its many important engineering and geophysical applications. In a mixed convection problem, when the free stream velocity of the fluid is small and the temperature and concentration differences between the surface and ambient fluid are large then the Buoyancy effects on forced convective heat and mass transfer become important. A large amount of research work has been reported in this field. Particularly, the study of heat and mass transfer with chemical reactions is of considerable importance in the chemical and hydrometallurgical industries. Kesavaiah et.al. [8] Radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation. Shateyi et.al [22]. The Effects of Thermal Radiation, Hall Currents, Soret, and Dufour on MHD Flow by Mixed Convection over a Vertical Surface in Porous Media. Muthucumaraswamy [16] have investigated the effects of heat and mass transfer on a continuously moving isothermal vertical surface with uniform suction. Mahdy [11] described the numerical solutions for the effects of radiation on a MHD convective heat transfer past a semi-infinite porous plate with a magnetic field. Seethamahalakshmi et.al. [21] Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical moving in a porous medium with heat source and suction. Singh et.al. [23] A study of the effect of chemical reaction and radiation absorption on MHD convective heat and mass transfer flow past a semi-infinite vertical moving plate with time dependent suction. Damala Ch Kesavaiah et.al [5] Radiation absorption, chemical reaction and magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux.

The study of heat generation or absorption in moving fluids is important in problems dealing with chemical reactions and those concerned with dissociating fluids. Heat generation effects may alter the temperature distribution and this in turn can affect the particle deposition rate in nuclear reactors, electronic chips and semi conductor wafers. Although exact modelling of internal heat generation or absorption is quite difficult, some simple mathematical models can be used to express its general behaviour for most physical situations. Heat generation or absorption can be assumed to be constant, space-dependent or temperature-dependent. Crepeau and Clarksean [4] have used a space-dependent exponentially decaying heat generation or absorption in their study on flow and heat transfer from a vertical plate. Several interesting computational studies of reactive MHD boundary layer flows with heat and mass transfer in the presence of heat generation or absorption have appeared in recent years. Patil and Kulkarni [18], Salem and El-Aziz, [19], Samad and Mohebujjaman [20], Mohamed [15], Mahd [12]. Damala Ch Kesavaiah and Venkataramana [25] A study of some convective flows with heat transfer effects. Beg et.al [1] Magnetohydrodynamic convection flow from a sphere to a non-Darcian porous medium with heat generation or absorption effects: network simulation. Chamkha and Khaled [2] Similarity solutions for hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through a porous medium.

In spite of all the previous studies, the effects of magnetohydrodynamic and mass transfer on MHD mixed convection flow of a vertical surface with radiation, heat generation/absorption and chemical reaction has received little attention. The governing equations are transformed into a system of nonlinear ordinary differential equations by using suitable perturbation technique. Graphical results for the velocity, temperature and concentration profiles based on the numerical solutions are presented and discussed. We also discuss the effects of various parameters on the skin-friction coefficient and the rate of heat and mass transfer at the surface.

II. FORMULATION OF THE PROBLEM

We consider the mixed convection flow of an incompressible, electrically conducting, radiating, heat source/absorbing and chemically reacting fluid. The x^*-axis is taken along the plate in upwards direction and y^*-axis is normal to it. A transverse constant magnetic field is applied i.e. in the direction of y^*- axis. Since the motion is two dimensional and length of the plate is large therefore all the physical variables are independent of x^*. Let u^* and v^* be the components of velocity in x^* and y^* directions, respectively, taken along and perpendicular to the plate. The governing equations of continuity, momentum and energy for a flow of an electrically conducting fluid along a hot, non-conducting porous vertical plate in the presence of concentration and radiation is given by

$$\frac{\partial v^*}{\partial y^*} = 0 \tag{1}$$

$$v^* = -v_0 \text{ (Constant)} \tag{2}$$

$$\frac{\partial p^*}{\partial y^*} = 0 \Rightarrow p^* \text{ is independent of } y^* \tag{3}$$

$$\rho\left(v^*\frac{\partial u^*}{\partial y^*}\right) = \mu\frac{\partial^2 u^*}{\partial y^{*2}} + \rho g\,\beta(T^* - T_\infty) + \rho g\beta^*(C^* - C_\infty) - \sigma B_0^2 u^* \tag{4}$$

$$\rho C_p\left(v^*\frac{\partial T^*}{\partial y^*}\right) = k\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\partial q_r^*}{\partial y^*} - Q_0\left(T^* - T_\infty\right) + Q_l^*\left(C^* - C_\infty\right) \tag{5}$$

$$v^*\frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - Kr^*\left(C^* - C_\infty\right) \tag{6}$$

Here, g is the acceleration due to gravity, T^* the temperature of the fluid near the plate, T_∞ the free stream temperature, C^* concentration, β the coefficient of thermal expansion, k the thermal conductivity, P^* the pressure, C_p the specific heat of constant pressure, B_0 the magnetic field coefficient, μ viscosity of the fluid, q^* the radiative heat flux, ρ the density, σ the magnetic permeability of fluid V_0 constant suction velocity, ν the kinematic viscosity and D molecular diffusivity.

The radiative heat flux q_r^* is given by equation (5) in the sprit of Cogly et.al [3]

$$\frac{\partial q_r^*}{\partial y^*} = 4(T^* - T_\infty)I \tag{7}$$

where $I = \int_0^\infty K_{\lambda w}\frac{\partial e_{b\lambda}}{\partial T^*}d\lambda,\ K_{\lambda w} -$ is the absorption coefficient at the wall and $e_{b\lambda}$ is Planck's function, I is absorption coefficient

The boundary conditions are

$$\begin{aligned} &u^* = 0,\ \ T^* = T_w,\ C_\infty = C \qquad y^* = 0 \\ &u^* \to 0,\ T^* \to T_\infty, C^* \to C_\infty \quad y^* \to \infty \end{aligned} \tag{8}$$

Introducing the following non-dimensional quantities

$$\begin{aligned} &u = \frac{u^*}{v_0}, y = \frac{v_0 y^*}{\nu},\ \theta = \frac{T^* - T_\infty}{T_w - T_\infty}, C = \frac{C^* - C_\infty}{C_w - C_\infty} \\ &\phi = \frac{Q_0}{\rho C_p v_0^2},\ Gm = \frac{\rho\beta^* g(C - C_\infty)}{v_0^3},\ \Pr = \frac{\mu C_p}{k} \\ &M^2 = \frac{B_0{}^2\nu^2\sigma}{v_0{}^2\mu}, R = \frac{4\nu I}{\rho C_p v_0^2}, Kr = \frac{Kr^*\nu}{v_0^2}, Sc = \frac{\nu}{D} \\ &Gr = \frac{\rho\beta g\nu^2(T_w - T_\infty)}{v_0^3\mu},\ Q_l = \frac{Ql^*\left(C_w - C_\infty\right)\nu}{\rho C_p v_0^2\left(T_w - T_\infty\right)} \end{aligned} \tag{9}$$

III. SOLUTION OF THE PROBLEM

In the equations (4), (5), (6) and (8), we get

$$\frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y} - M^2 u = -Gr\theta - GmC \tag{10}$$

$$\frac{\partial^2\theta}{\partial y^2} + \Pr\frac{\partial\theta}{\partial y} - \left(R + \phi\right)\Pr\theta + Q_l C = 0 \tag{11}$$

$$\frac{\partial^2 C}{\partial y^2} + Sc\frac{\partial C}{\partial y} - ScKrC = 0 \tag{12}$$

where Gr is Grashof number, Gm is the mass Groshof number, $\Pr$ is Prandtl number, M is magnetic parameter, R is Radiation parameter, Sc is Schmidt number, ϕ is heat source parameter, Kr is Chemical reaction parameter, Q_l is the heat absorption parameter.

The corresponding boundary condition in dimensionless form are reduced to

$$\begin{aligned} &u=0, \quad \theta=1, \quad C=1 \qquad y=0 \\ &u\to 0, \; \theta\to 0, \; C\to 0 \qquad y\to\infty \end{aligned} \tag{13}$$

The physical variables u, θ and C can be expanded in the power of $(\varepsilon << 1)$. This can be possible physically as ε for the flow of an incompressible fluid is always less than unity. This can be done by representing the velocity, temperature and concentration of the fluid in the neighborhood of the fluid in the neighborhood of the plate as

$$\begin{aligned} u &= u_0(y)+\varepsilon e^{nt}u_1(y) + 0(\varepsilon^2)+\ldots\ldots \\ \theta &= \theta_0(y)+\varepsilon e^{nt}\theta_1(y) + 0(\varepsilon^2)+\ldots\ldots \\ C &= C_0(y)+\varepsilon e^{nt}C_1(y)+0(\varepsilon^2)+\ldots\ldots \end{aligned} \tag{14}$$

Using equation (14) in equations (10)–(12) and equating the coefficient of like powers of E, we have

$$u_0''+u_0'-M^2u_0=-Gr\,\theta_0-Gm\,C_0 \tag{15}$$

$$\theta_0''+\Pr\,\theta_0'-(R+\phi)\Pr\theta_0=-Q_lC_0 \tag{16}$$

$$C_0''+Sc\,C_0'-KrC_0=0 \tag{17}$$

$$u_1''+u_1'-M^2u_1=-Gr\,\theta_1-Gm\,C_1 \tag{18}$$

$$\theta_1''+\Pr\theta_1'-(R+\phi)\Pr\theta_1=-Q_lC_1 \tag{19}$$

$$C_1''+Sc\,C_1'-KrC_1=0 \tag{20}$$

The corresponding boundary conditions are

$$\begin{aligned} &\left.\begin{aligned} u_0=0, \quad \theta_0=1, \quad C_0=1 \\ u_1=0, \quad \theta_1=0, \quad C_1=0 \end{aligned}\right\} \quad y=0 \\ &\left.\begin{aligned} u_0\to 0, C_0\to 0, \theta_0\to 0 \\ u_1\to 0, \theta_1\to 0, C_1\to 0 \end{aligned}\right\} \quad y\to\infty \end{aligned} \tag{21}$$

Solving equations (15) to (20) with the help of (21), we get

$$u_0=L_1e^{m_1y}+L_2e^{m_2y}+L_3e^{m_1y}+L_4e^{m_3y}$$

$$\theta_0=Z_1e^{m_1y}+Z_2e^{m_2y}$$

$$C_0=e^{m_1y}$$

$$u_1=0; \theta_1=0; C_1=0$$

In view of the above equation the solution

$$u=L_1e^{m_1y}+L_2e^{m_2y}+L_3e^{m_1y}+L_4e^{m_3y}$$

$$\theta=Z_1e^{m_1y}+Z_2e^{m_2y}$$

$$C=e^{m_1y}$$

Skin – friction:

The skin-friction coefficient at the plate is given by

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}=m_1L_1+m_2L_2+m_1L_3+m_3L_4$$

Heat Transfer:

The rate of heat transfer in terms of Nusselt number at the plate is given by

$$Nu=\left(\frac{\partial \theta}{\partial y}\right)_{y=0}=m_1Z_1+m_2Z_2$$

Sherwood number

$$Sh=\left(\frac{\partial C}{\partial y}\right)_{y=0}=m_1$$

IV. RESULTS AND DISCUSSION

Final results are computed for the main physical parameters which are presented by means of graphs. The influence of the thermal Grashof number (Gr), solutal Grashof number (Gm), the magnetic field parameter (M), absorption radiation parameter (Q_l), thermal radiation parameter (R), Prandtl number $(\Pr)$, heat source parameter (ϕ), chemical reaction parameter (Kr) and Schmidt number (Sc) on the velocity, temperature and concentration profiles can be analyzed from Figures (1) - (17).

Velocity profiles:

Figure (1) shows the influence of thermal buoyancy force parameter Gr on the velocity. As can be seen from this figure, the velocity profile increases with increases in the values of the thermal buoyancy. We actually observe that the velocity overshoot in the boundary layer region. Buoyancy force acts like a favourable pressure gradient which accelerates the fluid within the boundary layer therefore the solutal buoyancy force parameter Gr has the same effect on the velocity as Gr. From figure (2) we observe that the effect of magnetic field (M) is results in decreasing velocity distribution across the boundary layer because of the application of transfer magnetic field will result a restrictive type force (Lorentz force) similar to drag force which tends to resist the fluid flow and thus reducing its velocity.

The effect of increasing the value of the absorption parameter (Q_l) on the velocity is shown in figure (3). We observe in this figure that increasing the value of the absorption of the radiation parameter due to increase in the buoyancy force accelerates the flow rate. Figure (4) depicts the effect of varying thermal radiation parameter (R) on the flow velocity. We observe that the thermal radiation increases enhances convective flow. Figure (5) illustrates the influence of heat absorption coefficient ϕ on the velocity. Physically, the presence of heat absorption (thermal sink) effect has the tendency in resulting in a net reduction in the flow velocity. This behaviour is seen from figure (5) in which the velocity increases as ϕ increases. The hydrodynamic boundary layer decreases as the heat absorption effects increase. The velocity profiles for different values of solutal Grashof number (Gm) are described in figure (6). It is observed that an increasing in Gm leads to a rise in the values of velocity. In addition, the curves show that the peak value of velocity increases rapidly near the wall of the porous plate as soultal Grashof number increases, and then decays to the relevant free stream velocity. The influences of chemical reaction parameter (Kr) on the velocity profiles across the boundary layer are presented in Figure (7). We see that the velocity distribution across the boundary layer decreases with increasing of chemical reaction parameter (Kr). Figure (8) shows the velocity profiles across the boundary layer for different values of Prandtl number $(\Pr)$. The results show that the effect of increasing values of Pr results in a decreasing the velocity. For different values of the Schmidt number (Sc), the velocity profiles are plotted in figure (9). It is obvious that the effect of increasing values of Sc results in a decreasing velocity distribution across the boundary layer.

Temperature profiles:

The influence of heat absorption, Prandtl number, radiation absorption, thermal radiation chemical reaction parameter and Schmidt number on the temperature distribution is respectively, shown on figures (10) - (15). Figure (10) depicts the effects of heat source (ϕ) on the temperature distribution. It is observed that the boundary layer absorbs energy resulting in the temperature to fall considerably with increasing values of (ϕ). This is because when heat is absorbed, the buoyancy force decreases the temperature profile. Figure (11) temperature decreases with the increasing value of the Prandtl number $(\Pr)$. Prandtl number is very important for temperature profiles. It is clear that increasing $\Pr$ increases θ and the thickness of the thermal boundary layer. An increase Pr leads to a fall in the temperature. This emphasizes the influence of the injected flow in the cooling process. The effect of absorption of radiation parameter (Q_l) on the temperature profile is shown on figure (12). It is seen from this figure that the effect of absorption of radiation is to increase temperature in the boundary layer as the radiated heat is absorbed by the fluid which in turn increases the temperature of the fluid very close to the porous boundary layer and its effect diminishes far away from the boundary layer. From figure (13) we observe that the effect of thermal radiation (R) is to enhance heat transfer as thermal boundary layer thickness decreases with increase in the thermal radiation. We observe that the effect of radiation parameter (R) is to increase the temperature distribution decreases in the thermal boundary layer. This is because the increase of R implies increasing of radiation in the thermal boundary layer, and hence increases the values of the temperature profiles in thermal boundary layer. Figure (14) is the graph of temperature profiles for different values of chemical reaction parameter (Kr). It can easily be seen that the thermal boundary layer release the energy which causes the temperature of the fluid to increases with increase in the chemical reaction parameter (Kr). Lastly the effect of Schmidt number (Sc) on the temperature field is displayed in figure (15). We see that the temperature profiles decrease with increasing values of (Sc). This is because sucking decelerates fluid particles through the porous wall reducing the growth of the fluid boundary layer as well as thermal and concentration boundary layers.

Spices Concentration profiles:

The effect of reaction parameter Kr on the species concentration profiles for generative chemical reaction is shown in figure (16). It is noticed for the graph that there is marked effect of increasing the value of the chemical reaction rate parameter Kr on concentration distribution in the boundary layer. It is clearly observed from this figure that the concentration of spices which is greater than 1 at the start of the boundary layer decreases slowly till it attains the minimum value of zero at the end of the boundary layer and this trend is seen for al the values of reaction parameter. Further, it is due to the fact that an increasing the value of the chemical reaction parameter $\left(Kr\right)$ decreases the concentration of spices of the boundary layer. Schmidt number very important in concentration. Figure (17) gives the species concentration for different values of gasses like Sc it is observed that the concentration at all points in the flow field decreases exponentially with y and tends to zero as $y \to \infty$. Physically the increase of Sc means decrease of molecular diffusivity$\left(D\right)$. That results in decrease of decrease of concentration boundary layer. Hence, the concentration of the species is higher for small values of Sc and lower for larger values of Sc. Figure (18) illustrates the effect of Prandtl number on the skin-friction versus M of the fluid under consideration. As the Prandtl number increases the ski-friction is found to be decreases. Figure (19) illustrates the effect of the Prandtl number versus Q_l on the Nusselt number of the fluid under consideration. As the Prandtl number increases, the Nusselt number decreases.

APPENDIX

$$m_1 = -\left(\frac{Sc + \sqrt{Sc^2 + 4KrSc}}{2}\right)$$

$$m_2 = -\left(\frac{\Pr + \sqrt{\Pr^2 + 4\left(R+\phi\right)\Pr}}{2}\right)$$

$$m_3 = -\left(\frac{1+\sqrt{1+4M^2}}{2}\right)$$

$$Z_1 = -\frac{Q_l}{m_1^{\,2} + \Pr m_1 - \left(R+\phi\right)\Pr}$$

$$Z_2 = 1 - Z_1, L_1 = -\frac{Gm}{m_1^{\,2} + m_1 - M^2}$$

$$L_2 = -\frac{GrZ_2}{m_2^{\,2} + m_2 - M^2}$$

$$L_3 = -\frac{GrZ_1}{m_1^{\,2} + m_1 - M^2} \quad L_4 = -\left(L_1 + L_2 + +L_3\right)$$

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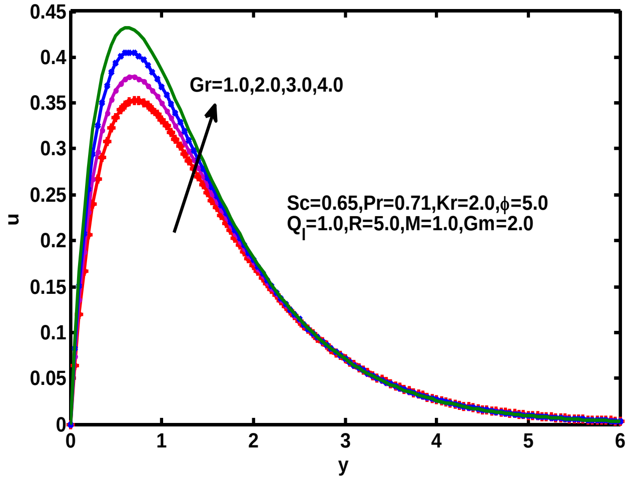

Figure 1: Velocity profiles for different values of Gr

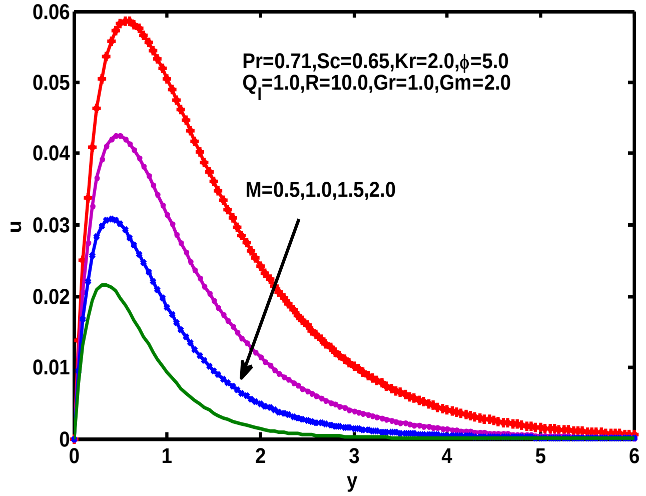

Figure 2: Velocity profiles for different values of M

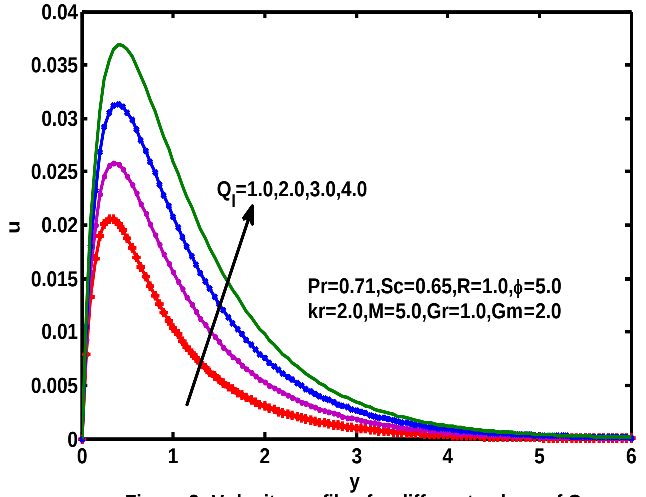

Figure 3: Velocity profiles for different values of Q_l

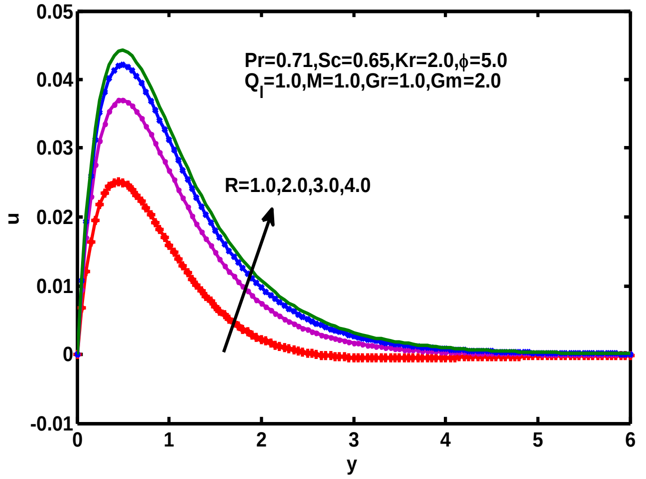

Figure 4: Velocity profiles for different values of R

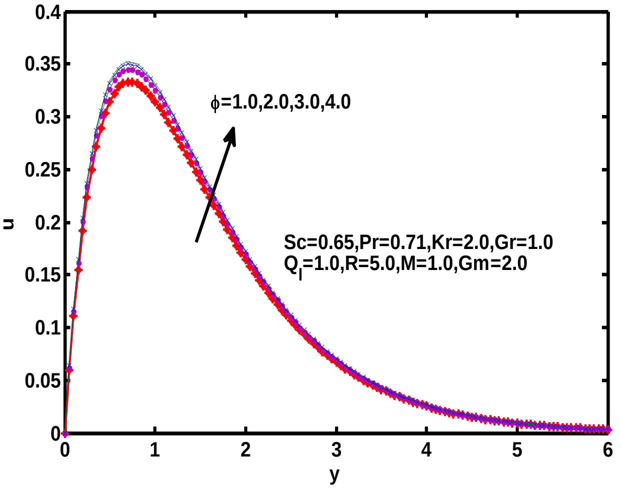

Figure 5: Velocity profiles for different values of ϕ

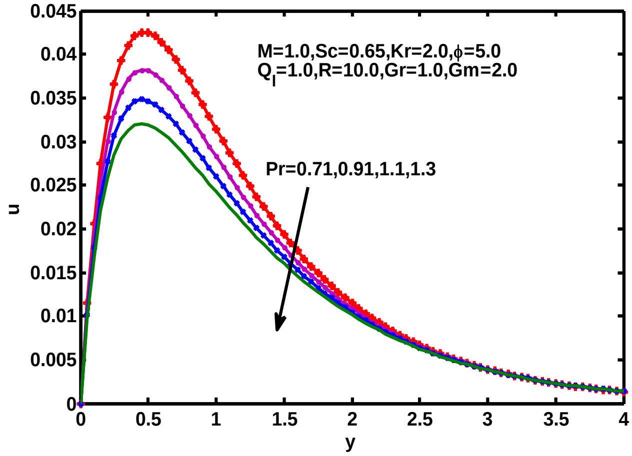

Figure 8: Velocity profiles for different values of Pr

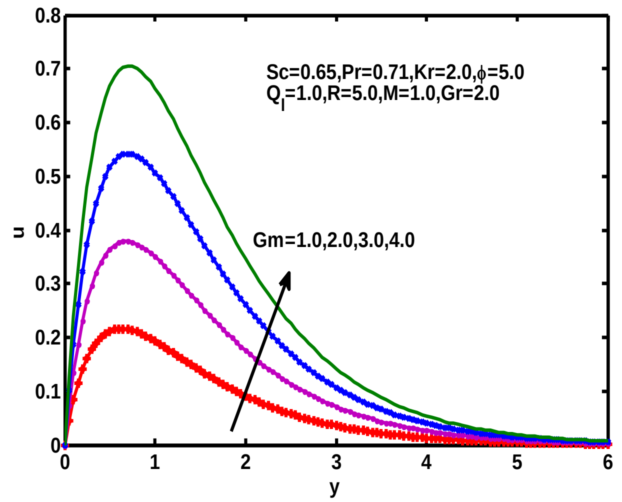

Figure 6:Velocity profiles for different values of Gm

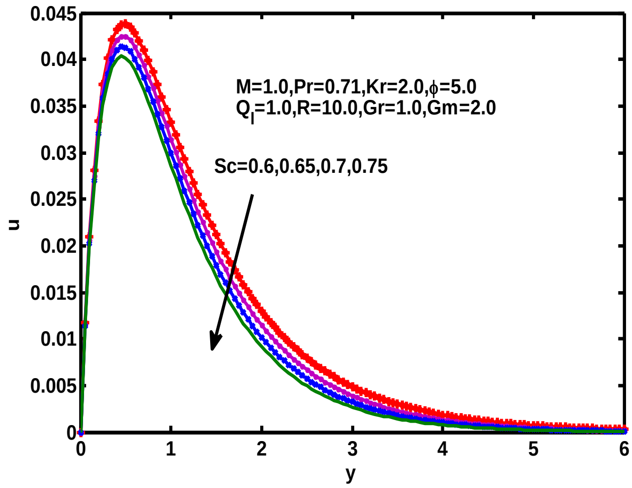

Figure 9: Velocity profiles for different values of Sc

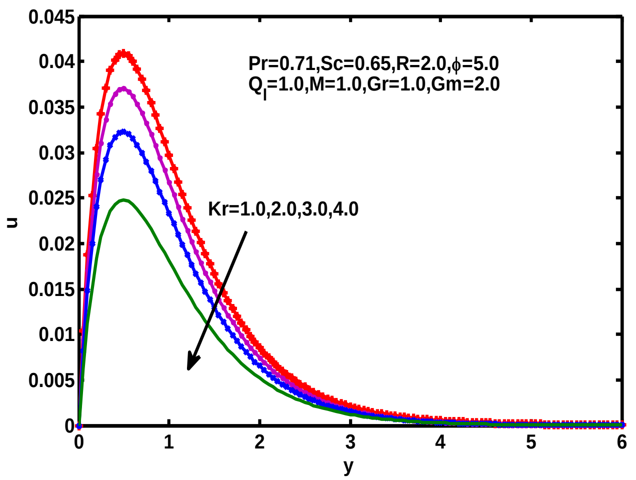

Figure 7: Velocity profiles for different values of Kr

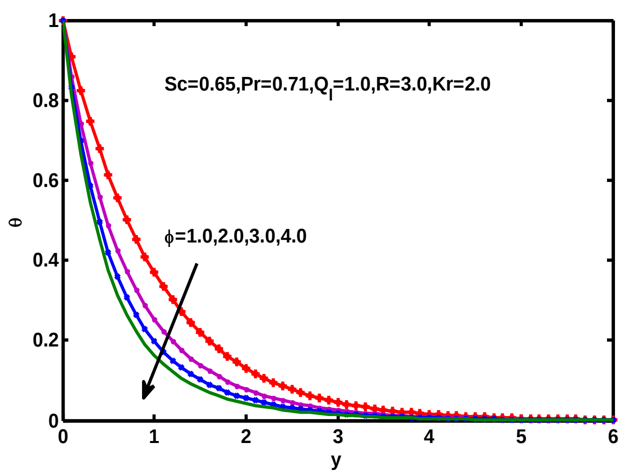

Figure 10: Temperature profiles for different values of ϕ

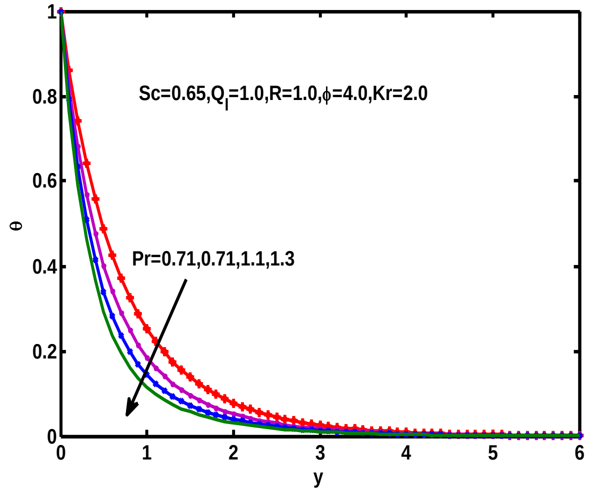

Figure 11: Temperature profiles for different values of Pr

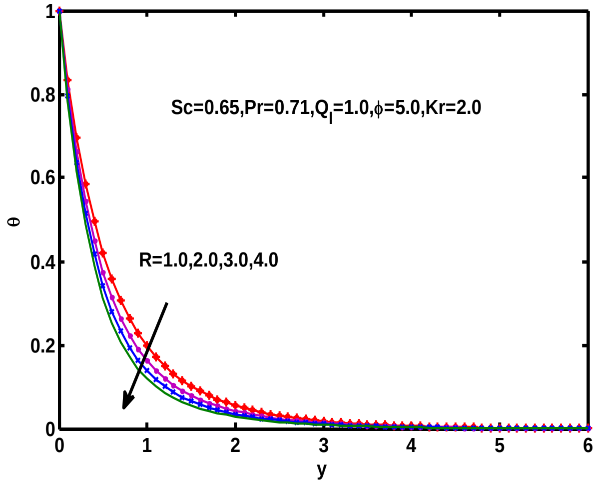

Figure 13: Temperature profiles for different values of R

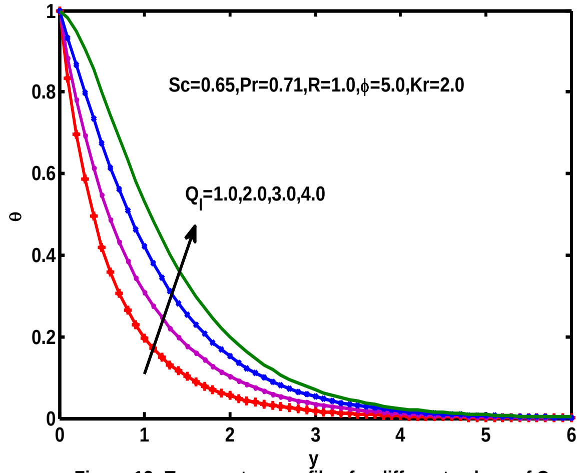

Figure 12: Temperature profiles for different values of Q_l

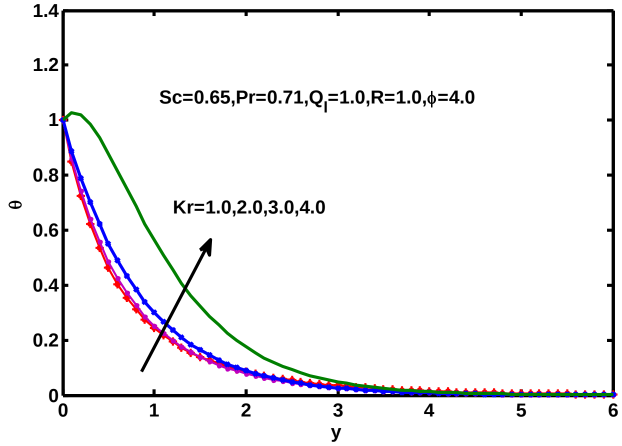

Figure 14: Temperature profiles for different values of Kr

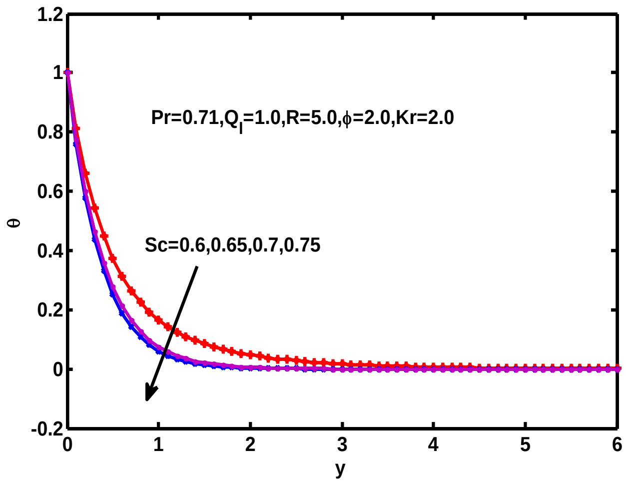

Figure 15: Temperature profiles for different values of Sc

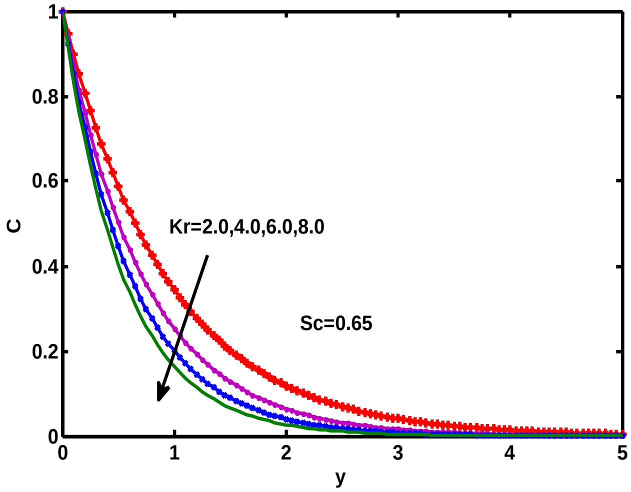

Figure 16: Concentration profiles for different values of Kr

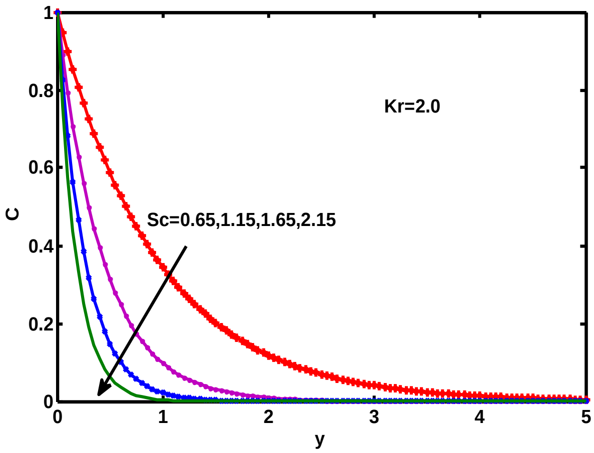

Figure 17: Concentration profiles for different values of Sc

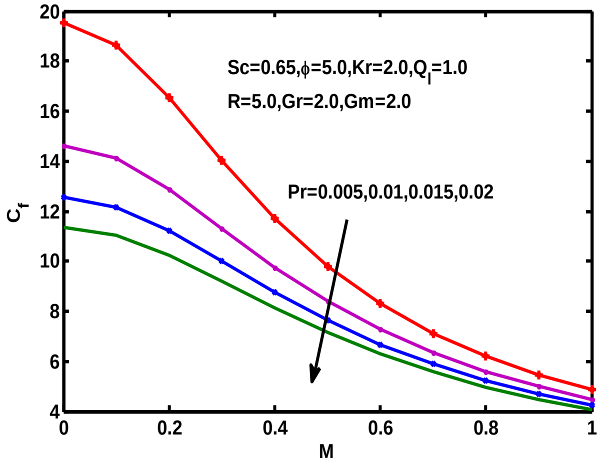

Figure 18: Skin friction for different values of Pr versus M

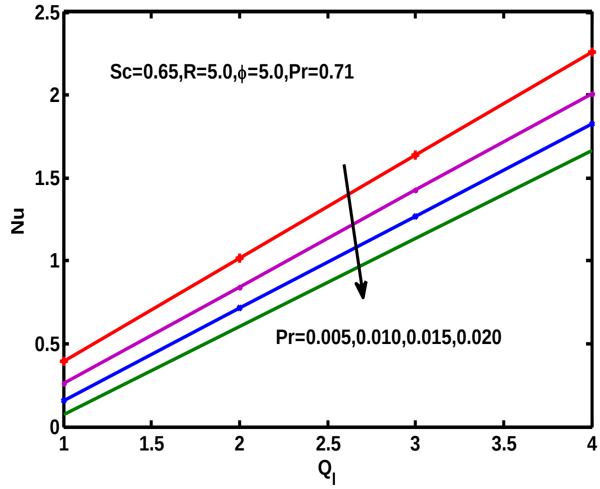

Figure 19: Nusselt number for Pr versus Q_l