RADIATION EFFECT ON MHD ROTATING HEAT TRANSFER FLUID PAST A MOVING VERTICAL PLATE

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ABSTRACT

This work provides a comprehensive theoretical analysis of radiation effects on MHD over a moving isothermal vertical plate in a rotating fluid in the presence of chemical reaction presented. An exact solution is obtained for the axial and transverse components of the velocity by defining a complex velocity using finite difference method. The effects of velocity, temperature and concentration for different parameters graphically discussed.

Key words: *Radiation, MHD, Vertical plate, Chemical reaction*

INTRODUCTION

The effect of radiation on MHD flow and heat transfer problems has become more important in industrial applications. At high operating temperature, radiation effects can be quite significant. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for design of reliable equipment, gas turbines and nuclear plants and various propulsion devices of missiles, satellites, aircraft and space vehicles. Based on these applications, Raptis and Perdikis [5] considered the effects of thermal radiation and free convection flow past a moving vertical plate. Saravanan and Kandaswamy [6] have analyzed the effect of temperature dependent thermal conductivity on buoyancy induced convection in the presence of a uniform magnetic field. It was inferred that it is advantageous to use low Prandtl number liquid metals or alloys as coolants in fast reactors whose thermal conductivity does not depend much on the temperature. Raptis and Perdikis [7] investigated free convection and mass transfer effects on optically thin gray gas past an infinite moving vertical plate.The governing equations were solved analytically. Cai and Zhang [8] studied the heat and mass transfer effects of an infinite vertical plate.

Cavus and Karafistan [9] studied the effects of differential rotation in the lower convective region of the Sun, Ch Kesavaiah et.al. [10] 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.

The problem of flow, heat and mass transfer on mixed convection over a stretching surface in a fluid-saturated porous medium could be very practicable in numerous applications in the polymer technology and metallurgy. For instance, it occurs in many metallurgical processes which involve the cooling of con- tenuous strips or filaments by drawing them through a quiescent fluid and that in the process of drawing, these strips are some- times stretched. The properties of the final products depend greatly on the rate of cooling so that final products of desired characteristics might be achieved. The rate of cooling can be controlled by drawing such strips through an electrically con- ducting fluid in the presence of transverse magnetic field. Heat transfer is the study of the flow of heat. It is an energy transfer due to temperature difference in a medium or between two or more media. In chemical engineering, to predict rates of heat transfer in a variety of process situations. In accident scenarios involving fire and the transport of explosive material, the time available for escape is dependent on the heat transfer rate from the fire to the energetic material. In view of the above Chenna Kesavaiah et.al. [11] Radiation effect on transient MHD free convective flow over a vertical porous plate with heat source, Mallikarjuna Reddy et.al. [12] Radiation and Diffusion thermo effects of visco-elastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, Chenna Kesavaiah and Chandraprakash [13] Radiation and chemical reaction effect on MHD accelerated inclined plate with variable temperature, Chenna Kesavaiah et.al. [14] Forced convective heat flow of a liquid for different depths of the channel with a constant heat source, Chenna Kesavaiah et.al. [15] MHD rotating fluid past a moving vertical plate in the presence of chemical reaction. Srinathuni Lavanya et.al. [16] Radiation, heat and mass transfer effects on magnetohydrodynamic unsteady free convective Walter’s memory flow past a vertical plate with chemical reaction through a porous medium, D Raju [17] Finite difference techniques to hall current effect and rotation effects on MHD free convection heat and mass transfer flow past an accelerated vertical plate, D Raju [18] Radiation effect on unsteady flow past an accelerated infinite vertical plate with variable temperature and chemical reaction, D Raju [19] Finite difference analysis of transient free convective MHD heat transfer flow through porous medium with heat generation.

Hence, the present analysis of radiation effects on MHD over a moving isothermal vertical plate in a rotating fluid in the presence of chemical reaction presented. An exact solution is obtained for the axial and transverse components of the velocity by defining a complex velocity using finite difference method. The effects of velocity, temperature and concentration for different parameters graphically discussed.

MATHEMATICAL MODEL

Three dimensional flow of a viscous, incompressible, electrically conducting fluid past an impulsively started infinite vertical isothermal plate with uniform mass diffusion in a rotating fluid [2,3] is considered. On this plate, the x'-axis is taken along the plate in the vertically upward direction and the y'-axis is taken normal to x'-axis in the plane of the plate and z'-axis is normal to it. Both the fluid and the plate are in a state of rigid rotation with uniform angular velocity Ω' about the z'-axis. The fluid considered here is a gray, absorbing-emitting radiation but a non-scattering medium. A transverse magnetic field B_0 of uniform strength is applied normal to the plate in the z' direction. The induced magnetic field and viscous dissipation is assumed to be negligible. Initially, the plate and fluid are at rest with the temperature T'_∞ and concentration C'_∞ everywhere. At time $t' > 0$, the plate is given an impulsive motion in the vertical direction against gravitational field with constant velocity u_0 in a fluid, in the presence of thermal radiation. At the same time the plate temperature is raised to T'_w and the concentration to T'_w, which are there after maintained constant. Since the plate occupying the plane $z' = 0$ is of infinite extent, all the physical quantities depend only on z' and t'. Then by Boussinesq's approximation, the unsteady flow is governed by the following equations:

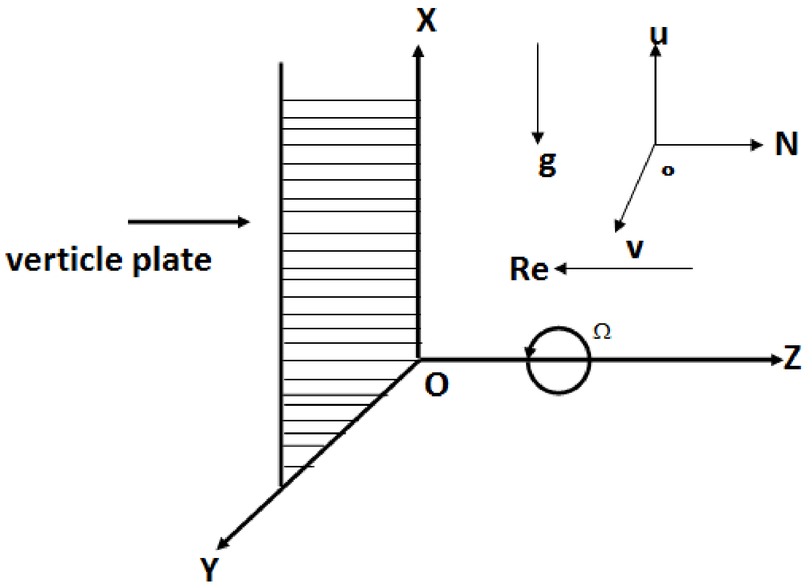

Figure (1): Physical model of the problem

$$\frac{\partial u'}{\partial t'} - 2\Omega' v' = g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) + \nu \frac{\partial^2 u'}{\partial z'^2} - \sigma \frac{B_0^2}{\rho} u' \tag{1}$$

$$\frac{\partial v'}{\partial t'} + 2\Omega' u' = \nu \frac{\partial^2 v'}{\partial z'^2} - \frac{\sigma B_0^2}{\rho} v' \tag{2}$$

$$\rho C_p \frac{\partial T'}{\partial t'} = k \frac{\partial^2 T'}{\partial z'^2} - \frac{\partial q_r}{\partial z'} \tag{3}$$

$$\frac{\partial C'}{\partial t'} = D \frac{\partial^2 C'}{\partial z'^2} - Kr'(C' - C'_\infty) \tag{4}$$

The term $\frac{\partial q_r}{\partial z'}$ represents the change in the radiative flux with distance normal to the plate with the following initial and boundary conditions

$$\begin{aligned} &t' \le 0: \quad u' = 0, \quad T' = T'_\infty, \quad C' = C'_\infty \quad \text{for all } z' \\ &t' > 0: \quad u' = u_0, \quad T' = T'_w, \quad C' = C'_w \quad \text{at} \quad z' = 0 \\ &\qquad\quad u = 0, \quad T \to T_\infty, \quad C' \to C'_\infty \quad \text{as} \quad z' \to \infty \end{aligned} \tag{5}$$

By Rosseland approximation [1, 4], radiative heat flux of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial z'} = -4a^*\sigma(T'^4_\infty - T'^4) \tag{6}$$

It is assume that the temperature differences within the flow are sufficiently small such that T'^4 may be expressed as a linear function of the temperature. This is accomplished by expanding T'^4 in a Taylor series about T'_∞ and neglecting higher-order terms, thus

$$T'^4 \cong 4T'^3_\infty T' - 3T'^4_\infty \tag{7}$$

By using equations (6) and (7), equation (3) reduces to

$$\rho C_p \frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial y'^2} + 16a^*\sigma\, T'^3_\infty (T'_\infty - T') \tag{8}$$

On introducing the following dimensionless quantities:

$$(u,v) = \frac{(u',v')}{u_0}, t = \frac{t'u_0^2}{\nu}, z = \frac{z'u_0}{\nu}, \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}, C = \frac{C' - C'_\infty}{C'_w - C'_\infty}$$
$$Gr = \frac{g\beta\,\nu(T'_w - T'_\infty)}{u_0^3}, Sc = \frac{\nu}{D}, Kr = \frac{\nu Kr'}{u_0^2}, Gc = \frac{\nu g\beta^*(C'_w - c'_\infty)}{u_0^3} \tag{9}$$
$$M = \frac{\sigma B_0^2 u_0}{\rho}, \quad Pr = \frac{\mu C_p}{k}, \quad \Omega = \frac{\Omega'\nu}{u_0^2}, \quad R = \frac{16a^*\nu^2\sigma T'^3_\infty}{ku_0^2}$$

and the complex velocity q = u + iv, $i = \sqrt{-1}$ in equations (1) to (5), the equations relevant to the problem reduces to

$$\frac{\partial q}{\partial t} + 2i\Omega i = Gr\,\theta + Gc\,C + \frac{\partial^2 q}{\partial z^2} - Mq, \tag{10}$$

$$\frac{\partial\theta}{\partial t} = \frac{1}{Pr}\frac{\partial^2\theta}{\partial z^2} - \frac{R}{Pr}\theta \tag{11}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} - Kr\,C \tag{12}$$

The initial and boundary conditions in non-dimensional form are

$$\begin{array}{lllll} & q = 0, & \theta = 0, & C = 0, & \text{forall} \quad z \le 0 \;\&\; t \le 0 \\ t > 0: & q = 1, & \theta = 1, & C = 1, & \text{at} \quad z = 0 \\ & q = 0, & \theta \to 0, & C \to 0, & \text{as} \quad z \to \infty \end{array} \tag{13}$$

All the physical variables are defined in the nomenclature.

METHOD OF SOLUTION

Equation (10) - (12) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (7).

However, these equations can be reduced to a set of ordinary differential equations, which can be solved numerically finite difference technique.

Let us consider a rectangular region with y varying from 0 to $z_{\max}\left(=40\right)$, where $z_{\max}$ represents to $z=\infty$. The region to be examined in $\left(z,t\right)$ space is covered by a rectangular grid with sides parallel to axes with Δz and Δt, the mesh sizes along $z-$direction and time $t-$direction, respectively. The equivalent finite difference schemes of equations for (10) – (12) are as follows:

$$\left(\frac{q_{i,j+1}-q_{i,j}}{\Delta t}\right)=Gr\left(\theta_{i,j}\right)+Gc\left(\phi_{i,j}\right)+\left(\frac{q_{i-1,j}-2q_{i,j}+q_{i+1,j}}{\left(\Delta z\right)^{2}}\right)-M\left(q_{i,j}\right) \tag{14}$$

$$\left(\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}\right)=\frac{1}{\Pr}\left(\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{\left(\Delta z\right)^{2}}\right)-\frac{\mathrm{R}}{\Pr}\left(\theta_{i,j}\right) \tag{15}$$

$$\left(\frac{C_{i,j+1}-C_{i,j}}{\Delta t}\right)=\frac{1}{Sc}\left(\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{\left(\Delta z\right)^{2}}\right)-Kr\left(C_{i,j}\right) \tag{16}$$

Index i refer to y and j refers to time; the mesh system is divided by taking $\Delta z=0.1$

From the initial conditions in (12) we have the following equivalent

$$\begin{aligned} &u\left(0,j\right)=1,\theta\left(0,j\right)=1,\phi\left(0,j\right)=1 \qquad for\ \ all\ \ j \\ &u\left(i_{\max},j\right)=0,\theta\left(i_{\max},j\right)=0,\phi\left(0,j\right)=0 \qquad for\ \ all\ \ j \end{aligned} \tag{17}$$

(here $i_{\max}$ was taken as 200), the velocity at the end of time step viz, $u\left(i,j+1\right)\left(i=1,200\right)$ is coupled form (14) in terms of velocity and temperature at points on the earlier time – step. After that $\theta\left(i,j+1\right)$ is computed for (15) and $C\left(i,j+1\right)$ is computed for equation (16). The procedure is repeated until $t=0.5\left(i.e.\ j=500\right)$, during the computation Δt was chosen as 0.001

RESULTS AND DISCUSSION

The graphical presentation for velocity, temperatue and concetration profiles for various parameters like magnetic field, rotation parameter , radiation parameter, Schmidt number, chemical reaction, thermal Grashof number and mass Grashof number in this section. The velocity profiles for rotation parameter on primary velocity shown in figure (2). It is clear that the primary velocity decreases with increasing the rotation parameter (Ω) in cooling of the plate. This shows that primary velocity decreases in the presence of high thermal rotation. The primary velocity profiles of air for different values of the magnetic parameter (M) are shown in figure (3). It is found that the primary velocity decreases with increasing magnetic parameter This shows that primary velocity decreases in the presence of high magnetic field and rotation. In fact rotation has more influence than magnetic field on primary velocity. Effects of the primary velocity profiles for different thermal Grashof number (Gr), mass Grashof number (Gc) are shown in figure 4(a) and 4 (b). It is readily appearing that the primary velocity increases with increasing thermal Grashof number or mass Grashof number. The primary velocity for different values of chemical reaction parameter (Kr) and Schmidt number (Sc) showed in figure (5) and (6). Form these figures we determined that the primary velocity decreases with increases in chemical reaction parameter or Schmidt number. The effect of thermal radiation parameter is important in temperature profiles. The temperature profiles calculated for different values of thermal radiation parameter (R) are shown in figure (7). It is observed that the temperature decreases with increasing values of radiation parameter. The concentration profiles for different values of the chemical reaction parameter (Kr) and Schmidt number (Sc) are depicted in figure 8(a) and 8(b). from these figures we dipected that the concentration profiles decfease due to increasing the values of the chemical reaction parameter and Schmidt number.

Skin friction

Using equation (16) we get the following expression for skin - friction components τ_x and τ_y

$$\tau_x + i\tau_y = \left(\frac{\partial q}{\partial z}\right)_{z=0}$$

Table (1): Skin-friction τ for different values of Ω versus Gr	
Ω	τ_x
0.2	4.5845
0.4	4.3000
0.6	3.7985
0.8	3.5472

The effect of rotation on skin - friction decreases the component τ_x as Ω increases with fixed values of $Gc = 5.0$ $R = 1.0$ $M = 1.0$ $Sc = 0.6$ $Kr = 1.0$ $n = 0.1$ shown in table (1). As time advances the component τ_x increases. Greater cooling of the plate, due to free - convection currents, lower rises τ_x .

Sherwood Number:

Using equation (14) we get the following expression for Sherwood number

$$S_h = \left(\frac{\partial C}{\partial z}\right)_{z=0} = m_2$$

Table (2): Sherwood number for different values of Sc versus Kr	
Sc	Sh
0.16	0.0035300
0.22	0.0003355
0.31	$5.612\,e^{-005}$
0.60	$1.245\,e^{-005}$

Sherwood numbers for different Schmidt number and time are calculated using equation (18), table (2) shows that as Schmidt number increases Sherwood number increases, but the trend is reversed with time.

Nusselt number

Using equation (15) we get the following expression for Nusselt number

$$N_u = \left(\frac{\partial \theta}{\partial z}\right)_{z=0} = m_6$$

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FIGURES:

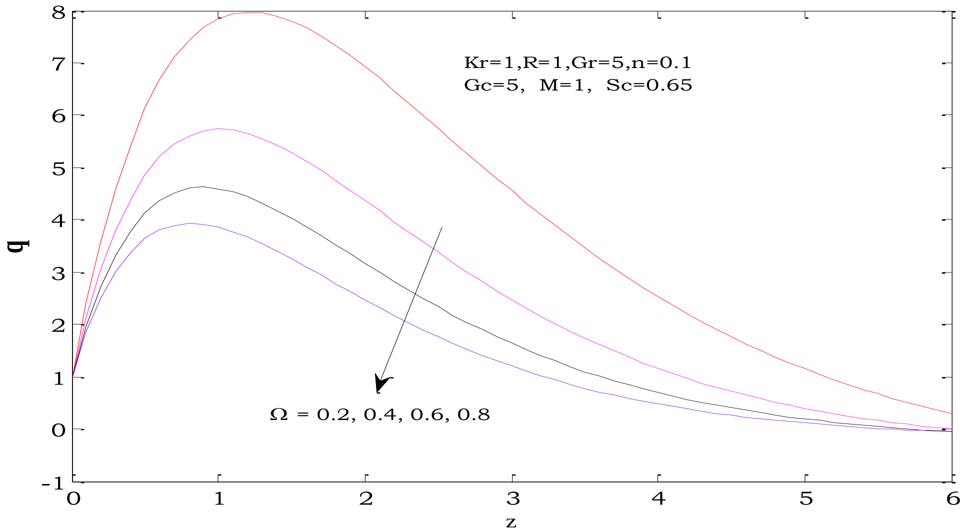

Figure (2): Primary velocity profiles for different values of Ω

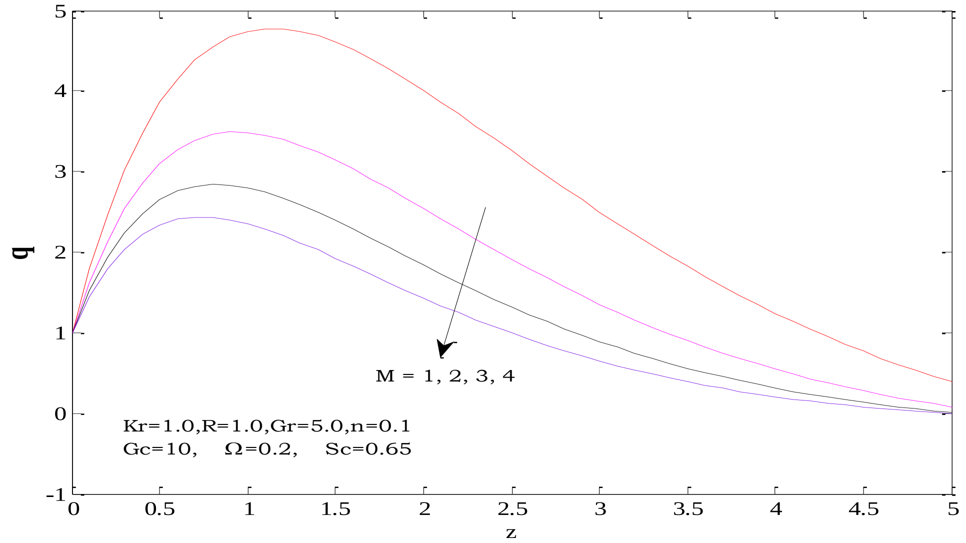

Figure (3): Primary Velocity profiels for different values of M

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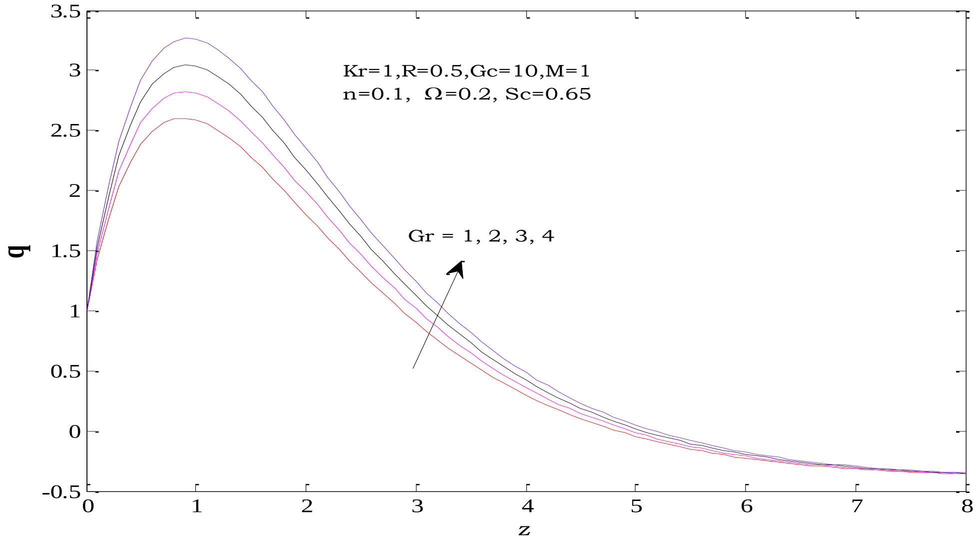

Figure 4 (a): Primary Velocity Profiles for different values of Gr

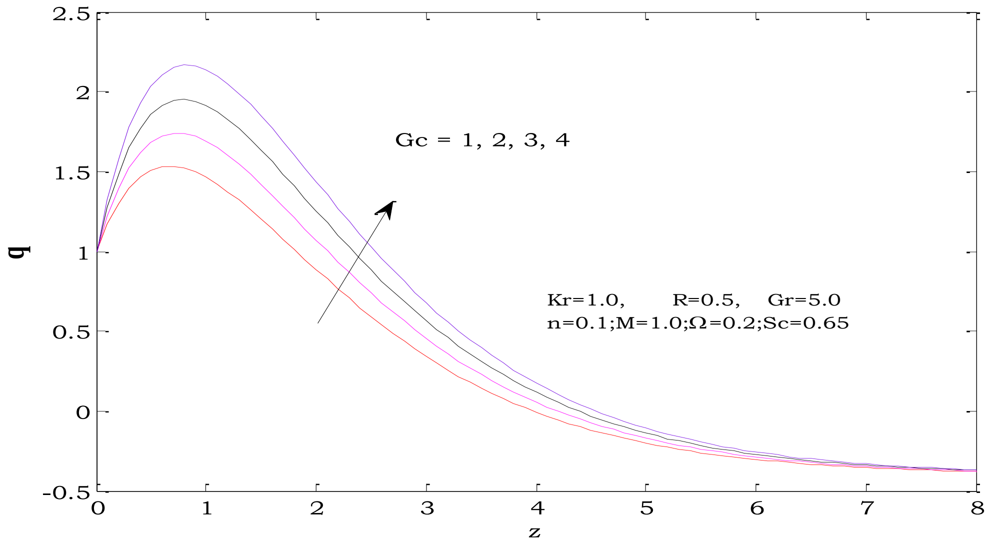

Figure 4 (b): Primary Velocity Profiles for different values of Gc

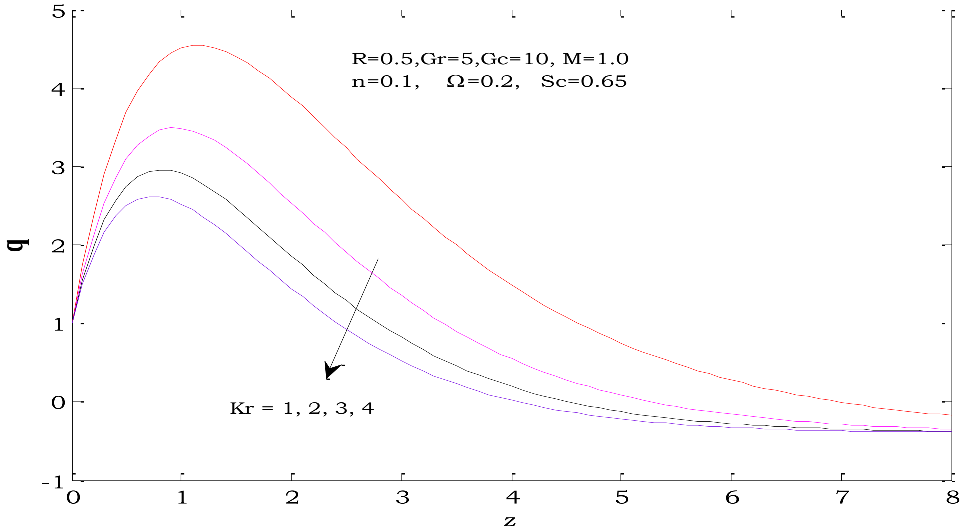

Figure (5): Primary Velocity profiles for different values of Kr

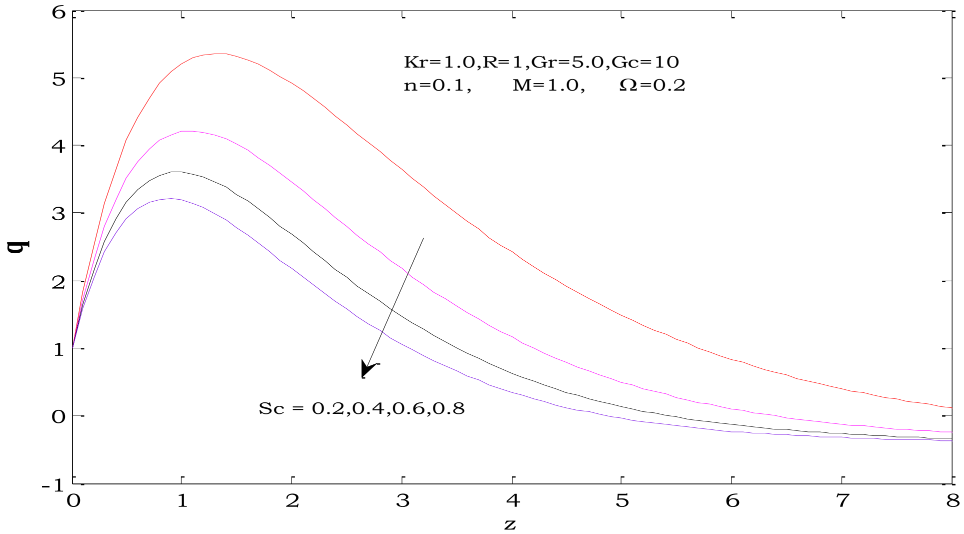

Figure (6): Primary velocity profiles for different values of Sc

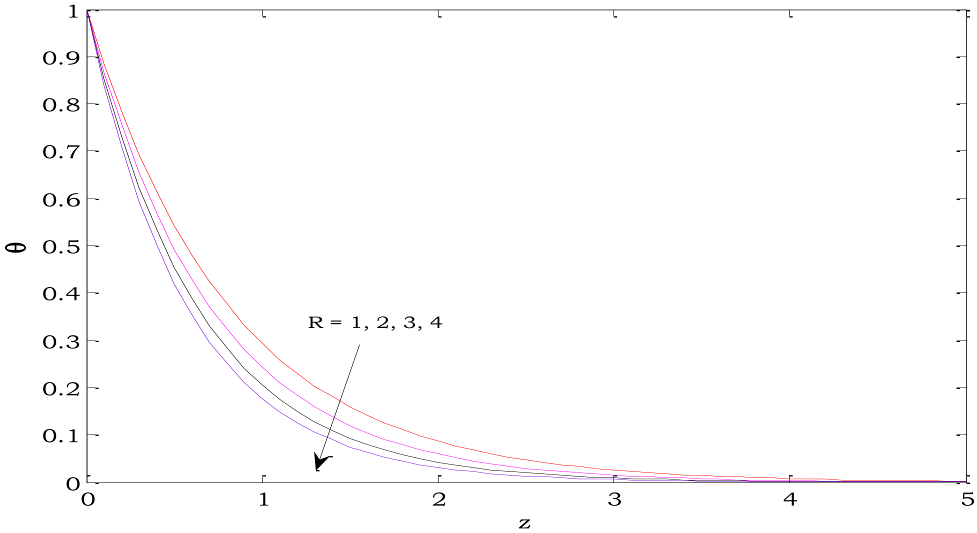

Figure (7): Temperature profiles for different values of R

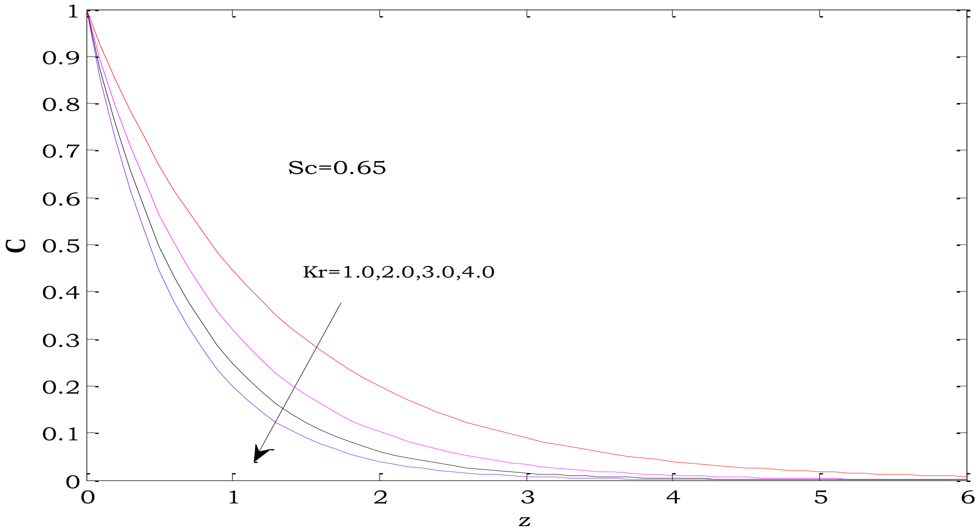

Figure 8(a): Concentration profiles for different values of Kr

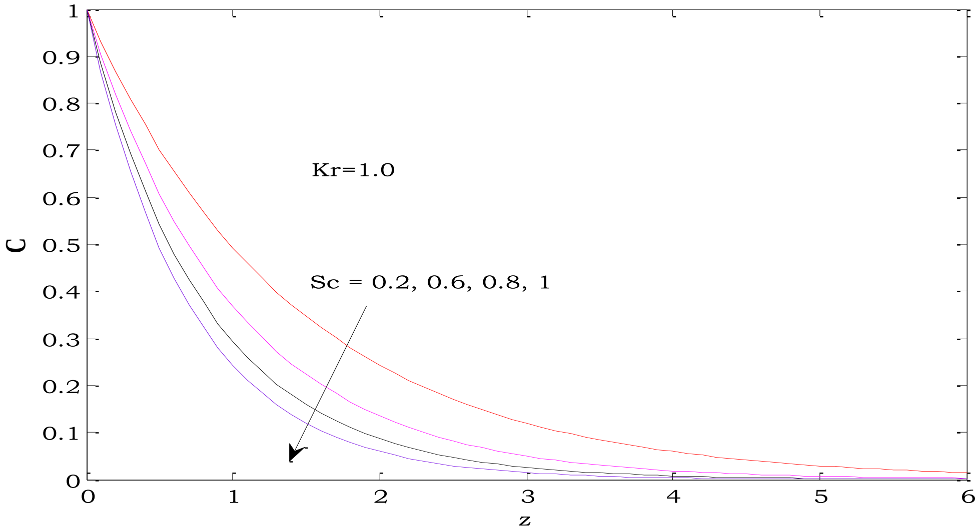

Figure 8(b): Concentration profiles for different values of Sc