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RADIATION AND CHEMICAL REACTION EFFECTS ON MHD ROTATING FLUID PAST A MOVING VERTICAL PLATE

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Abstract. The present paper analyses radiation effect on MHD unsteady free convection heat and mass transfer over a moving isothermal vertical plate in a rotating fluid in the presence of chemical reaction presented. The governing partial differential equations are solved by using perturbation technique. The effects of velocity, temperature and concentration profiles for different parameters discussed graphically.

KEYWORDS: *Radiation, Chemical reaction, MHD, Rotating Fluid*

1. Introduction

Many research works have been done based on the action of a uniform transverse magnetic field either fixed to the fluid or to the plate. Heat and mass transfer on MHD flows have applications in Meteorology, solar physics, cosmic fluid dynamics, astrophysics and geophysics. Magneto convection plays an important role in various industrial applications such as magnetic control of molten iron flow in the steel industry, liquid metal cooling in nuclear reactors, electromagnetic pumps, controlled fusion research, crystal growing, MHD couples and bearings, plasma jets, chemical synthesis and underground nuclear waste storage sites. Radiative heat and mass transfer play an important role in manufacturing industries for the design of reliable equipment, Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles. The effect of coriolis force has wide applications in science and technology. The study of hydromagnetic flow is called hydromagnetic or magnetohydr-odynamics (MHD), which studies the dynamics of electrically conducting fluids. The set of equations which describe MHD are a combination of the Navier - Stokes equation of fluid dynamics and Maxwell's equations of electromagnetism. Viskanta and Grosh [1] studied the transfer of energy in boundary layer flow of an incompressible and radiating medium over wedge. The Rosseland approximation for the radiant heat flux vector was used to simplify the energy equation. Arpaci [2] studied the interaction between thermal radiation and laminar convection of heated vertical plate in a stagnant radiating gas. Greenspan, H.P [3] discussed the theory of rotating fluids owing to its numerous applications in cosmical and geophysical fluid dynamics, meteorology and engineering. England and Emery [4] have presented a correlation between the analytical solution and the experimental results of the convection-radiation interaction upon a vertical flat plate for absorbing and non absorbing gases. The flow past a horizontal plate has been studied by Debnath [5, 6], Puri and Kulshrestha [7]. Soundalgekar et al [8] presented an exact solution of flow past an impulsively started isothermal vertical plate under the action of transversely applied magnetic field.

Flows with chemical reaction in porous media are fundamental phenomena encountered in many natural, industrial and scientific areas. For such flows, most existing studied use continuum assumptions and focus on volume averaged properties on macroscopic scales. Considering the complex porous structures and fluid solid interactions in realistic situations. Flows of miscible fluids in porous media are frequently encountered in natural and industrial processes, like underground water movement, geologic carbon sequestration, enhanced oil recovery and blood transport. Dynamics of such flows are complex due to the unsteady flow, heat and mass transfer, and porous structure involved. This situation becomes more complicated when chemical reactions are introduced. In a porous medium, two fluids containing chemical reaction solutes re put into contact along an interface. Chemical solutes are transported through the interface to react and thereby modify fluids properties, like density and viscosity. Again Soundalgekar et al [9] studied Stokes' problem for an infinite vertical plate whose temperature varies with time in the presence of transverse magnetic field for an incompressible fluid. Singh [10] studied the effects of coriolis as well as magnetic force on the flow field of an electrically conducting fluid past an impulsively started infinite vertical plate. Bestman and Adjepong [11] studied the magnetohydrodynamic free convection flow, with radiative heat transfer, past an infinite moving plate in rotating incompressible, viscous and optically transparent medium. Das et al. [12] have analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate. An analysis of the unsteady magneto hydrodynamic flow of a viscous and electrically conducting fluid past a vertical flat plate by the presence of radiation was done by Raptis and Massalas [13]. Basant Kumar Jha [14] presented the effects of uniform transverse magnetic field on the transient free convective flow of an electrically conducting fluid in a vertical channel, Chenna Kesavaiah et. al. [17] considered natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, Narahari [18] explained effects of thermal radiation and free convection currents on the unsteady Couette flow between two vertical parallel plates with constant heat flux at one boundary, Srinathuni Lavanya et. al. [19] has been considered radiation effect on unsteady free convective MHD flow of a viscoelastic fluid past a tilted porous plate with heat source, Chenna Kesavaiah and Devika [20] studied free convection and heat transfer of a Couette flow an infinite porous plate in the presence radiation effect.

Due to plethora of applications in astronomical technology and processes entangling high temperatures, the payoffs of thermal radiation on the free convection flows have been drawing the consideration of enormous research interest. Furthermore, free convection flow in the presence of magnetic field is crucial because of its significant impact on the boundary layer control and the execution of many engineering devices consuming electrically conducting fluids such as in MHD power generation, plasma studies, nuclear reactor using metal coolant and geothermal energy extraction. That's why it's a burning topic for many current researchers in the world. With the consideration of radiation impacts, the energy equation has to lead to an exceptionally non-linear partial differential equations. In view of the above some of the researchers has been studied, Soundalgekar et.al. [21] Scrutinized the radiation effects on free convection flow of gas past a semi-infinite flat plate, Kumar et. al. [22] Influence of heat source/sink on MHD flow between vertical alternate conducting walls with Hall effect, Mallikarjuna Reddy et. al. [23] contemplates Radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, Chenna Kesavaiah et. al. [24] examined radiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, Rami Reddy et. al. [25] appraise hall effect on MHD flow of a visco-elastic fluid through porous medium over an infinite vertical porous plate with heat source, Chenna Kesavaiah and Venkateswarlu [26] reviewed chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, Nagaraju et. al. [27] surveyed MHD Viscoelastic Fluid flow Past an Infinite Vertical Plate in the Presence of Radiation and Chemical Reaction, Panigrahi et. al. [28] Impact of chemical reaction, hall current and radiation on MHD flow between vertical walls, Ch Kesavaiah et. al. [29] Studied 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, Raju et. al. [30] viewed on heat generation and chemical reaction impact on MHD rotating flow past a vertical porous plate, Chenna Kesavaiah and Venkateswarlu [31] inspects chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, Nagaraju et. al. [32] Influence of Radiation effects on MHD convective heat and mass transfer flow past a semi-infinite vertical moving porous plate in the presence of chemical reaction.

The main objective of this paper is radiation effect on MHD effects on unsteady free convection heat and mass transfer over a moving isothermal vertical plate in a rotating fluid in the presence of chemical reaction presented. The governing partial differential equations are solved by using perturbation technique. The effects of velocity, temperature and concentration for different parameters discussed graphically.

2. Mathematical Formulation

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 [15, 16] 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:

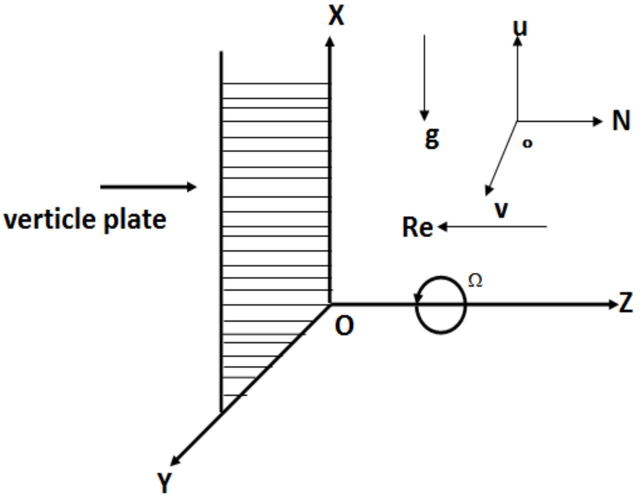

Figure (1): Physical model of the problem

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

(2.1)

$$\frac{\partial v'}{\partial t'} + 2\Omega' u' = \nu\frac{\partial^2 v'}{\partial z'^2} - \frac{\sigma B_0^2}{\rho}v' \qquad (2.2)$$

$$\rho C_p\frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial z'^2} - \frac{\partial q_r}{\partial z'} \qquad (2.3)$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial z'^2} - Kr'(C' - C'_\infty) \qquad (2.4)$$

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

$$\begin{array}{llllll} t' \le 0: & u'=0, & T'=T'_\infty, & C'=C'_\infty & \text{forallz}' & \\ t'>0: & u'=u_0, & T'=T'_w, & C'=C'_w & \text{at} \quad z'=0 & \quad (2.5) \\ & u=0, & T\to T_\infty, & C'\to C'_\infty & \text{as} \quad z'\to\infty. & \end{array}$$

On introducing the following dimensionless quantities:

$$(u,v)=\frac{(u',v')}{u_0}, \quad t=\frac{t'u_0^2}{\nu}, \quad z=\frac{z'u_0}{\nu}, \quad \theta=\frac{T'-T'_\infty}{T'_w-T'_\infty}, C=\frac{C'-C'_\infty}{C'_w-C'_\infty}$$

$$Gr=\frac{g\beta\,\nu(T'_w-T'_\infty)}{u_0^3}, \quad Sc=\frac{\nu}{D}, Kr=\frac{\nu Kr'}{u_0^2}, \quad Gc=\frac{\nu g\beta^*(C'_w-c'_\infty)}{u_0^3}$$

$$M=\frac{\sigma B_0^2u_0}{\rho}, \quad Pr=\frac{\mu C_p}{k}, \quad \Omega=\frac{\Omega'\nu}{u_0^2}, \quad R=\frac{16a^*\nu^2\sigma T'^3_\infty}{ku_0^2}$$

(2.6)

and the complex velocity q = u + iv, $i=\sqrt{-1}$ in equations (2.1) to (2.4), the equations relevant to the problem reduces to

$$\frac{\partial q}{\partial t}+2i\Omega i = Gr\,\theta+Gc\,C+\frac{\partial^2 q}{\partial z^2}-Mq, \tag{2.7}$$

$$\frac{\partial\theta}{\partial t}=\frac{1}{Pr}\frac{\partial^2\theta}{\partial z^2}-\frac{R}{Pr}\theta \tag{2.8}$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial z^2}-Kr\,C \tag{2.9}$$

The initial and boundary conditions in non-dimensional form are

$$\begin{array}{llllll} & q=0, & \theta=0, & C=0, & \text{forall} & z\le 0\ \&\ t\le 0 \\ t>0: & q=1, & \theta=1, & C=1, & \text{at} & z=0 \qquad (2.10) \\ & q=0, & \theta\to 0, & C\to 0, & \text{as} & z\to\infty. \end{array}$$

All the physical variables are defined in the nomenclature.

3. Solution Of The Problem

Equation (2.7) – (2.9) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (2.10). 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

$$\begin{aligned} q(z,t)&=q_0(z)+\varepsilon e^{nt}q_1(z)+O(\varepsilon^2) \\ \theta(z,t)&=\theta_0(z)+\varepsilon e^{nt}\theta_1(z)+O(\varepsilon^2) \qquad (3.1) \\ C(z,t)&=C_0(z)+\varepsilon e^{nt}C_1(z)+O(\varepsilon^2) \end{aligned}$$

Substituting (2.11) in Equation (2.7) – (2.9) and equating the harmonic and non – harmonic terms, and neglecting the higher order terms of $O(\varepsilon^2)$, we obtain

$$q_0''-Mq_0=-Gr\,\theta_0-Gc\,C_0-2\Omega \tag{3.2}$$

$$q_1''-(M+n)q_1=-Gr\,\theta_1-Gc\,C_1 \tag{3.3}$$

$$\theta_0''-R\theta_0=0 \tag{3.4}$$

$$\theta_1''-(R+n)\theta_1=0 \tag{3.5}$$

$$C_0'' - Kr\,Sc\,C_0 = 0 \quad (3.6)$$

$$C_1'' - (Kr + n)Sc\,C_1 = 0 \quad (3.7)$$

The corresponding boundary conditions can be written as

$$\begin{array}{ll} & q = 0,\ \ \theta = 0,\ \ C = 0,\ \ \text{forall}\ \ z \le 0 \,\&\, t \le 0 \\ t > 0: & q_0 = 1,\ \theta_0 = 1,\ C_0 = 1,\ q_1 = 0,\ \theta_1 = 0,\ C_1 = 0 \quad \text{at} \quad z = 0 \\ & q_0 \to 0, \theta_0 \to 0, C_0 \to 0, q_1 \to 0, \theta_1 \to 0, C_1 \to 0 \quad \text{as} \quad z \to \infty. \end{array}$$

(3.8)

Solving Equations (3.2) - (3.7) under the boundary conditions (3.8) we obtain the velocity, temperature and concentration distributions in the boundary layer as

$$q_0 = A_1 e^{m_6 z} + A_2 e^{m_2 z} + A_3 + A_4 e^{m_8 z}; q_1 = 0$$

$$\theta_0 = e^{m_6 z}; \theta_1 = 0$$

$$C_0 = e^{m_2 z}; C_1 = 0$$

In view of the above

$$q(z,t) = A_1 e^{m_6 z} + A_2 e^{m_2 z} + A_3 + A_4 e^{m_8 z}$$
$$\theta(z,t) = e^{m_6 z}$$
$$C(z,t) = e^{m_2 z}$$

4. Results and discussion

The analysis of radiation effect on MHD effects on unsteady free convection heat and mass transfer over a moving isothermal vertical plate in a rotating fluid in the presence of chemical reaction presented. The governing partial differential equations are solved by using perturbation technique. The velocity profiles, temperature profiles, concentration profiles, skin friction, Nusselt number and Sherwood number for different values of the various parameter viz., magnetic field (M), rotation parameter (Ω), radiation parameter (R), Schmidt number (Sc), chemical reaction (Kr), thermal Grashof number (Gr) and mass Grashof number (Gc). The primary velocity profiles of air for different values of the rotation parameter $(\Omega = 0.2, 0.4, 0.6, 0.8)$ are shown in **figure** (2). It is observed 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 parameter. Effects of magnetic field and rotation parameter on primary velocity the primary velocity profiles of air for different values of the magnetic parameter $(M = 1,2,3,4)$ are depicted in **figure** (3). It is observed that the primary velocity decreases with increasing magnetic parameter. This shows that primary velocity decreases in the presence of high magnetic field and rotation parameter. In fact rotation parameter has more influence than magnetic field on primary velocity. Effects of Grashof number$(Gr = 1,2,3,4)$, mass Grashof number $(Gc = 1,2,3,4)$ on primary velocity the primary for different thermal are shown in **figure** 4(a) **and** 4 (b). It is clear that the primary velocity increases with increasing thermal Grashof number or mass Grashof number. The effects of chemical reaction parameter $(Kr = 1,2,3,4)$ on primary velocity appears in **figure** (5), form this figure it is clear that an increasing chemical reaction parameter the results are decreases, and the same effect observed for Schmidt number $(Sc = 1,2,3,4)$ observed on primary velocity in **figure** (6). The effect of thermal radiation parameter is important in temperature profiles, the temperature profiles are calculated for different values of thermal radiation parameter $\left(R=1,2,3,4\right)$ are displayed in **figure** (7). It is observed that the temperature increases with decreasing radiation parameter. Variations in the concentration profiles for different values of the chemical reaction parameter $\left(Kr=1,2,3,4\right)$ and Schmidt number $\left(Sc=0.2,0.4,0.6,0.8\right)$ are depicted in figure 8(a) **and** 8(b). It is observed that there is a fall in concentration due to increasing the values of the chemical reaction parameter and Schmidt number.

Skin friction

Using equation (3.6) we get the following expression for skin-friction components τ_x and τ_y then $\tau_x + i\tau_y = \left(\frac{\partial q}{\partial z}\right)_{z=0}$

In equation (3.6), (3.7) the argument of the complementary error function and error function is complex. Hence in order to obtain the u and v components of the velocity and skin-friction, we have used the following formula due to Abramowitz and stegun [20]: The skin-friction components for different parameter are calculated using Equation (3.6). The skin-friction components at the wall for different values of Ω are shown in table (1).

Table (1): Skin-friction τ for different values of Ω versus Gr with $Gc=5.0\ R=1.0\ M=1.0\ Sc=0.6\ Kr=1.0\ n=0.1$

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. As time advances the component τ_x increases. Greater cooling of the plate, due to free-convection currents, lower rises τ_x .

Nusselt number

Using equation (3.5) we get the following expression for Nusselt number

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

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 (3.8), table (2) shows that as Schmidt number increases Sherwood number increases, but the trend is reversed with time.

APPENDIX

$$m_2 = -\sqrt{Kr\,Sc},\, m_6 = -\sqrt{R},\, m_8 = -\sqrt{M},\, A_1 = -\frac{Gr}{m_6^2 + M}$$

$$A_2 = -\frac{Gc}{m_2^2 + M},\, A_3 = -\frac{2\Omega}{M},\, A_4 = \left(1 - A_1 - A_2 - A_3\right)$$

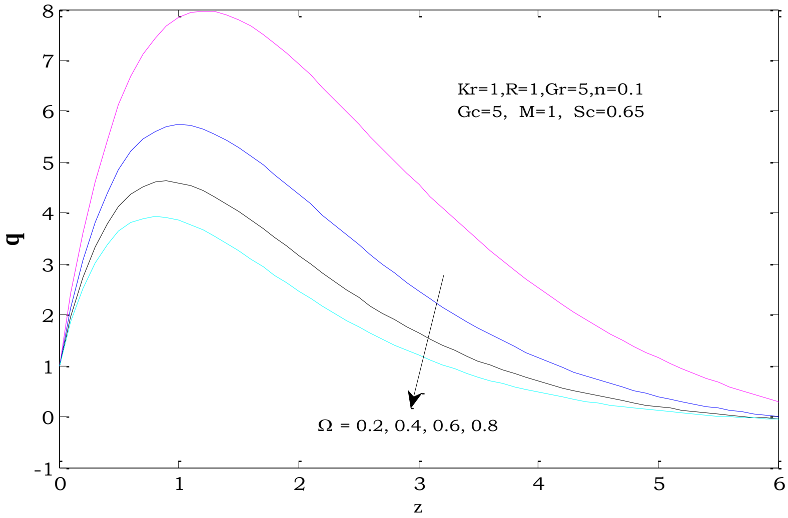

Figure (2): Primary velocity profiles for different values of Ω

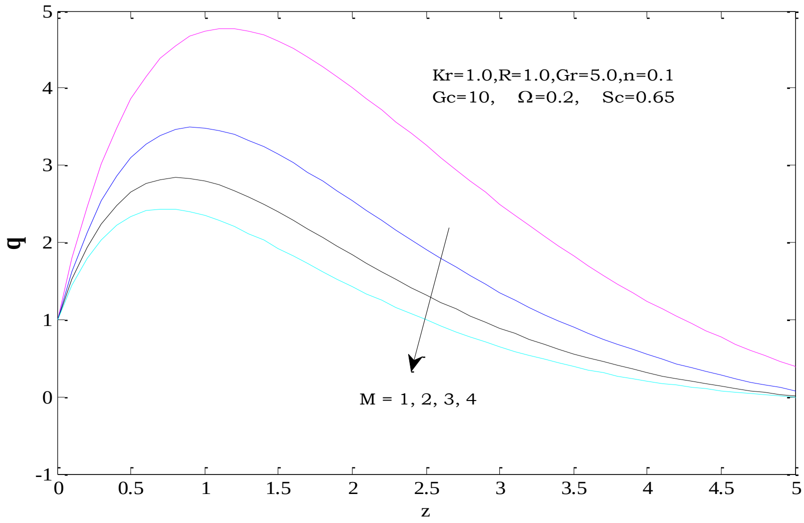

Figure (3): Primary Velocity profiels for different values of M

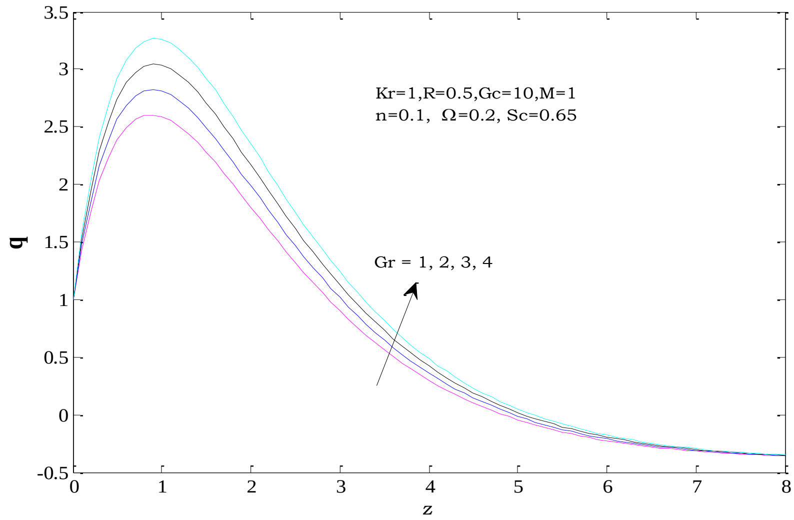

Figure 4 (a): Primary Velocity Profiles for different values of Gr

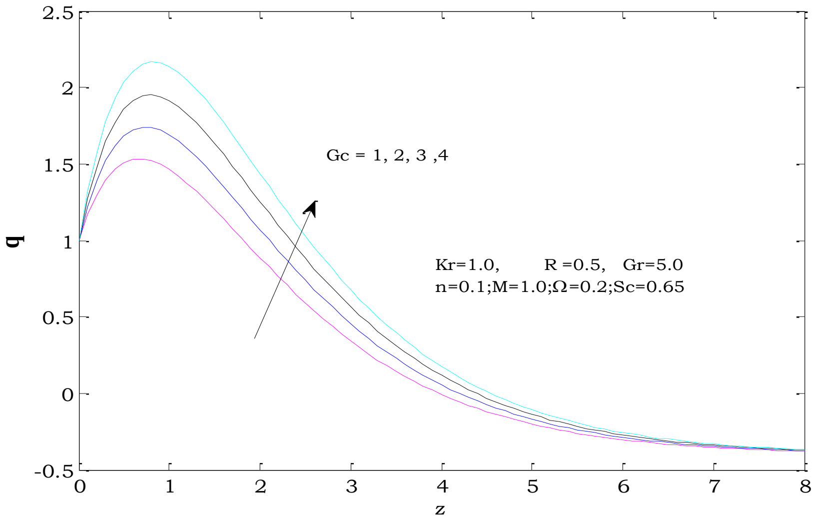

Figure 4 (b): Primary Velocity Profiles for different values of Gc

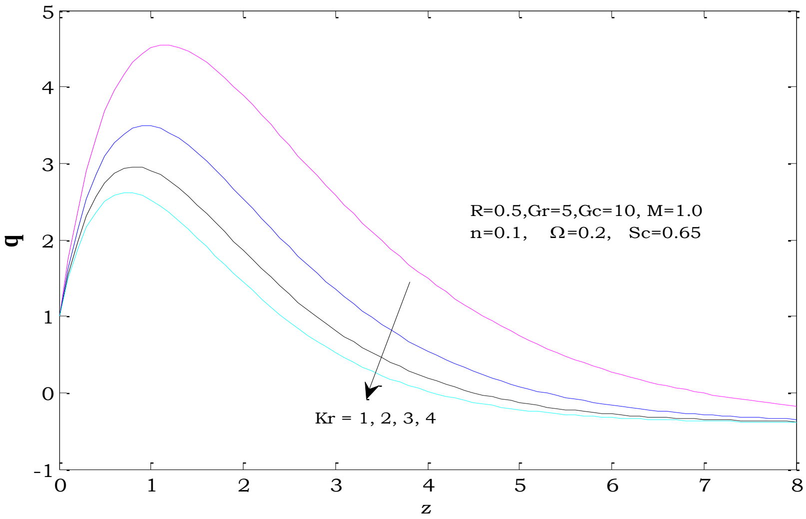

Figure (5): Primary Velocity profiles for different values of Kr

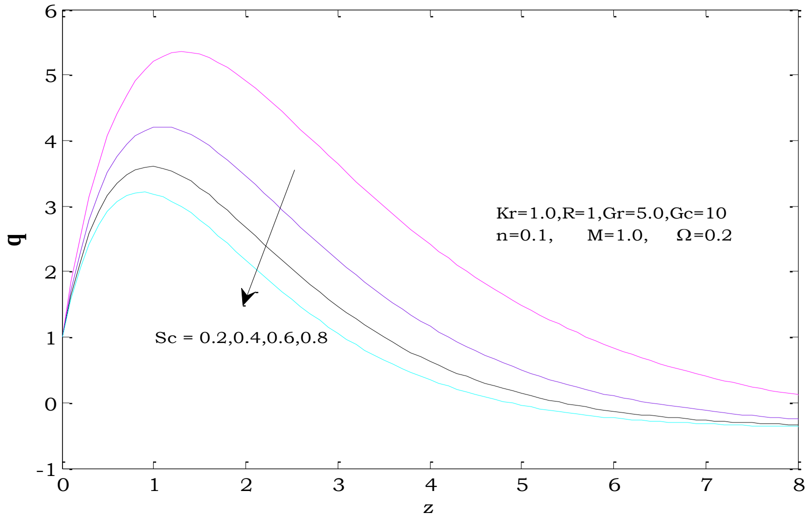

Figure (6): Primary velocity profiles for different values of Sc

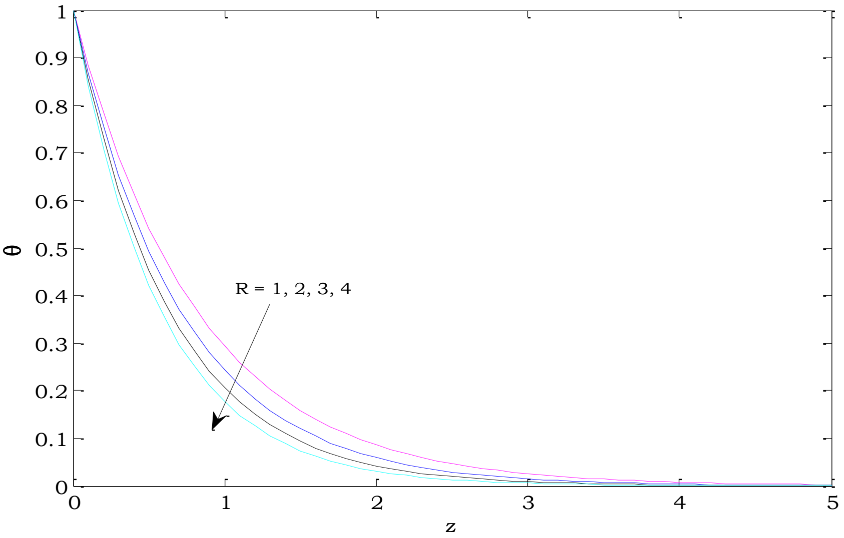

Figure (7): Temperature profiles for different values of R

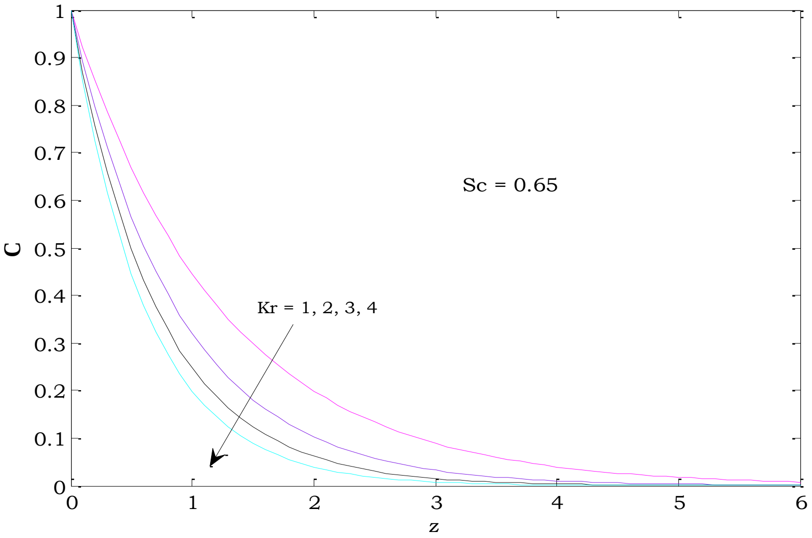

Figure 8(a): Concentration profiles for different values of Kr

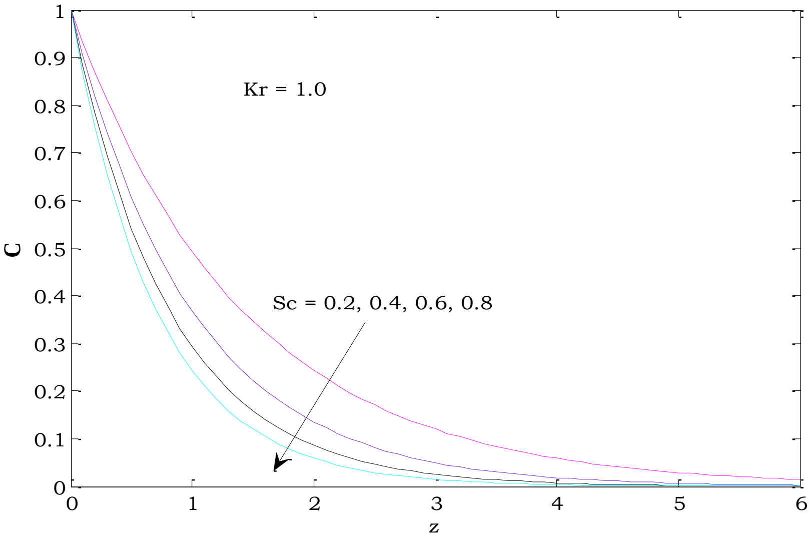

Figure 8(b): Concentration profiles for different values of Sc

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RADIATION AND CHEMICAL REACTION EFFECTS ON MHD ROTATING FLUID PAST A MOVING VERTICAL PLATE

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