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Chemical Reaction and Radiation Effects on Unsteady MHD Convective flow Through a Porous Medium in the Presence of Heat Absorption

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Abstract

Influences of chemical reaction and radiation on unsteady magnetohydodynamic free convection flow of an electrically conducting fluid past an exponentially accelerated infinite vertical plate through a porous medium with constant heat flux under the presence of uniform magnetic field fixed relative to the fluid or to the plate in the consideration of heat absorption have been studied. The governing partial differential equations of the flow have been solved analytically by using Laplace transform technique and the profiles for the velocity, temperature and concentration were discussed. The effects of various physical parameters such as the Prandtl number, heat absorption parameter, radiation parameter, Grashof number, Chemical reaction parameter, magnetic field parameter and permeability parameters on the flow fields are analyzed through graphs.

Key words: MHD, Free convection, Porous medium, Heat and Mass transfer, Thermal Diffusion, heat absorption parameter, Chemical reaction parameter-58D30(Applications in Quantum Mechanics, relativity, fluid dynamics etc.,

Subject classification code:58D30-Applications(in quantum mechanics (Feynman path integrals), relativity, fluid dynamics, etc.,)

Introduction

In recent years researchers were focused very much attention to analyse the unsteady free convection flows through a porous medium due to its wide range of applications in geothermal and oil reservoir engineering. Radiation effects on heat and mass transfer are of greater importance in many processes such as transpiration, cooling gaseous diffusion and blood flow in arteries, in the design of spacecraft, filtrations processes, the drying of porous material in textile industries, solar energy collector and nuclear reactors.The present trend is that the chemical reaction analysis gives a mathematical model for the system to predict the reactor performance.

A considerable amount of research work has been reported in this field. BalaAnki Reddy *et.al.*[1] examined the radiation effects on unsteady flow of a viscous incompressible fluid past an exponentially accelerated isothermal infinite vertical plate with uniform mass diffusion in the presence of magnetic field and heat source. . Basanth Kumar Jhaand Ravindra Prasad[2] have studied the hydromagnetic effects on flow past an exponentially accelerated infinite vertical plate. Girish Kumar *et.al.*[3] gave a finite difference solution of mass transfer effects on MHD flow of incompressible viscous dissipative fluid past an exponentially accelerated isothermal vertical plateby taking viscous dissipative heat into account under the influence of chemical reaction through porous medium. Kinyanju *et.al.*[4] investigated the Buoynce effect of thermal and mass diffusion past a finite vertical plate.Narahari and Debnath[5] studied the unsteady free convection flow of an electrically conducting fluid past an accelerated infinite vertical plate with constant heat flux under the influence of uniform transverse magnetic field fixed relative to the fluid or to the plate in the presence of heat generation or absorption. Rajesh and Chamka[6] studied the unsteady free convection flow of a dissipative fluid past an exponentially accelerated infinite vertical porous plate in the presence of Newtonian heating and mass diffusion. Sathappan and Muthucumaraswamy[7] studied the thermal radiation effects on unsteady free convective flow of a viscous incompressible flow past an exponentially accelerated infinite isothermal vertical plate with uniform mass diffusionSeth *et.al.*[8] investigated the unsteady MHD natural convection flow of an electrically conducting, viscous, incompressible, heat absorbing and radiating fluid past an exponentially accelerated vertical plate with ramped temperature through a porous medium taking Hall effects into account and find an exact solution for fluid velocity and fluid temperature by using Laplace transform techniqueSingh and Naveen Kumar[9] analysed the free conviction flow of an incompressible and viscous fluid past an exponentially accelerated infinite vertical plate. Muthucumaraswamy and Prema[10] examined hall current and rotation effects on unsteady MHD free convection flow past an exponentially accelerated infinite vertical plate with uniform temperature and variable mass diffusion . Mohammed Ibrahim Shaik and Suneetha Karna[11] discussed the Soret and chemical reaction effects on MHD free convection flow through a vertical porous surface in the presence of radiation and viscous dissipation with heat source. Rajput and Gaurav Kumar[12] analysed hall current effects on unsteady magneto hydro dynamic flow past an impulsively started inclined oscillating plate with variable temperature and mass diffusion . Ashish Paul[13] gave analytical solution of one-dimensional unsteady laminar boundary layer MHD flow of a viscous incompressible fluid past an exponentially accelerated infinite vertical porous plate in presence of transverse magnetic field. Prema and Muthucumaraswamy[14] examined the effects of the thermal radiation effects on unsteady free convective flow of a viscous incompressible flow past an exponentially accelerated infinite vertical plate with variable temperature and mass diffusion

By influencing the above studies we analysed the effect of Radiation parameter on unsteady free convection flow of an electrically conducting fluid past an exponentially accelerated infinite vertical plate with constant heat flux through a porous medium under the influence of uniform magnetic field fixed to the fluid or to the plate in the presence of chemical reaction and heat absorption. The governing coupled linear partial differential equations are solved analytically by using the Laplace transform technique. The present problem identifies typical applications in designing of aeronautics spacecraft and the study of the thermal plumesinto atmosphere which are responsible for atmospheric pollution.

Mathematical Formulation :

Consider the unsteady free convection flow of an electrically conducting fluid past an exponentially accelerated infinite vertical plate with constant heat flux through a porous medium under the influence of uniform magnetic field which is fixed to the fluid or to the plate in the presence of chemical reaction and heat absorption. The x' - axis is taken along the plate in the upward direction and the y' – axis perpendicular to the plate into the fluid by choosing an arbitrary point on this plate as the origin. A uniformmagnetic field of strength B_0 is applied along y' - direction. Initially, at time $t' \le 0$ the plate and the fluid are at rest and are at the same temperature T'_∞ and the concentration C'_∞ . At time $t'>0$, suddenly the plate accelerated with velocity $u_0 e^{a'_0 t'}$ in its own plane along the x' - axis against the gravitational field and heat is supplied to the plate at a constant rate in the presence of temperature dependent heat absorption. All the physical properties of the fluid are assumed to be constant except the density variations with temperature in the body force term. The magnetic Reynoldsnumber of the flow is assumed to be small so that the induced magnetic field is neglected in comparison with applied magnetic field B_0. As the plate is infinite extent in x' direction, all the physical quantities are functions of the space coordinate y' and time t' only and therefore the inertia terms are negligible. Inthe energy equationneglecting viscous dissipation and Joule heating under usual Boussinesq's approximation, The flow can be shown to be governed by the following equations

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

$$\rho C_p \frac{\partial T'}{\partial t'} = k \frac{\partial^2 T'}{\partial y'^2} - Q'(T' - T'_\infty) - \frac{\partial q_r}{\partial y'} \tag{2}$$

$$\frac{\partial C'}{\partial t'} = D \frac{\partial^2 t'}{\partial y'^2} - Kr'(C' - C'_\infty) \tag{3}$$

where u', T' and C' are velocity, temperature and concentration of the fluid respectively, g is acceleration due to gravity, β is thermal expansion coefficient, β^* is concentration expansion coefficient, ν is kinematic viscosity, ρ is density, σ is electrical conductivity, C_p is specific heat at constant pressure, κ is thermal conductivity, Q is dimensional heat absorption coefficient, D is mass diffusivity, K'_r is rate of chemical reaction, k' is permeability coefficient of porous medium and q_r is the radiation heat flux.The local radiant for the case of an optically thin grey gas is expressed by $\frac{\partial q_r}{\partial y} = -4a^*\sigma\left(T'^4_\infty - T'^4\right)$ where a^* is absorption coefficient and σ is Stephan Boltzmann constant. We assume that the temperature differences within theflow 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 Taylor series about T_∞ and neglecting higher order terms, thus $T'^4 \cong 4T'^4_\infty T' - 3T'^4_\infty$

Equation (1) is valid when the magnetic lines of force are fixed relative to the fluid. If the magnetic field relative to the plate, the momentum equations (1) is replaced by

$$\frac{\partial u'}{\partial t'} = \upsilon \frac{\partial^2 u'}{dy'^2} + g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) - \sigma \frac{B_0^2}{\rho}\left(u' - u_0 e^{a'_0 t'}\right) - \frac{\upsilon}{k'} u' \tag{4}$$

Note that the velocity $u_0 f\left(t'\right)$ of magnetic field B_0 in equation (4) appears because of the magnetic lines offorce are fixed relative to the plate, which accelerates with velocity $u_0 e^{a_0' t'}$
Equations (1) and (4) can becombined as

$$\frac{\partial u'}{\partial t'} = \upsilon \frac{\partial^2 u'}{dy'^2} + g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) - \sigma \frac{B_0^2}{\rho}\left(u' - Ku_0 e^{a_0' t'}\right) - \frac{\upsilon}{k'} u' \tag{5}$$

Where $K = \begin{cases} 0\, if\ B_0\ is\ fixed\ relative\ to\ the\ fluid \\ 1\, if\ B_0\ is\ fixed\ relative\ to\ the\ plate \end{cases}$

The corresponding initial and boundary conditions are

$$t' \le 0\ : u' = 0, T' = T'_\infty,\ C' = C'_\infty \quad for\ all\ \ y \ge 0 \tag{7}$$

$$t' > 0 : \begin{cases} u' = u_0 e^{a_0' t'},\ \dfrac{\partial T'}{\partial y'} = -\dfrac{q}{k}, C' = C'_w \ \ for\ y = 0 \\ u' \to 0, T' \to T'_\infty,\ C' \to C'_\infty \qquad as\ \ y \to \infty \end{cases}$$

Where u_0 is dimensional constant and q is constant heat flux per unit area at the plate, a_0' is the dimensional constant of accelerated plate.
Non dimensional quantities are

$$u = \frac{u'}{u_0},\ t = \frac{u_0^2 t'}{\upsilon},\ \ y = \frac{u_0 y'}{\upsilon},\quad \theta = \frac{\left(T' - T'_\infty\right)}{\dfrac{q\upsilon}{ku_0}},\ \ Gr = \frac{g\beta\upsilon^2 q}{ku_0^4},\ M = \frac{\sigma B_0^2 \upsilon}{\rho u_0^2}.$$

$$a_0 = \frac{a_0'\upsilon}{u_0^2},\ \Pr = \frac{\mu C_p}{k},\ Q = \frac{Q'\upsilon^2}{ku_0^2},\ \ k = \frac{k' u_0^2}{\upsilon^2},\ C = \left(\frac{C' - C'_\infty}{m\upsilon}\right) u_0 D,$$

$$Kr = \frac{Kr'\upsilon}{u_0^2},\quad Sc = \frac{\upsilon}{D},\quad Gc = \frac{g\beta^*\upsilon^2 m}{u_0^4 D},\quad R = \frac{16a^*\upsilon^2\sigma T_\infty'^4}{ku_0^2} \tag{8}$$

With the help non-dimensional quantities the equations (5), (2) and (3) becomes

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial t^2} + Gr\theta + GcC - \left(M + \frac{1}{k}\right) u + MKe^{a_0 t} \tag{9}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\left(\frac{\partial^2 \theta}{\partial y^2}\right) - \left(\frac{Q + R}{\Pr}\right)\theta \tag{10}$$

$$Sc\frac{\partial C}{\partial t}=\frac{\partial^2 C}{\partial t^2}-ScKrC \tag{11}$$

With following initial and boundary conditions

$$t \le 0 \quad : u=0, \quad \theta=0, \quad C=0 \qquad for \;\; y \ge 0 \tag{12}$$

$$t>0: \begin{cases} u=e^{a_0 t}, \dfrac{\partial\theta}{\partial y}=-1, C=1 \;\; for\; y=0 \\ u\to\infty, \; \theta\to 0, \;\; C\to 0 \quad as \;\; y\to\infty \end{cases}$$

Where Gr and Gc denotes thermal Grashof number and solutalGrashof number, Pr is Prandtl numbers, Sc is Schmidt number M is magnetic field parameter and θ is the dimensionless temperature, C is the dimensionless concentration

Solution of the problem :

The equations (9), (10) and (11) subject to the initial and boundary conditions (12) are solved exactly by the usual Laplace transform technique without any restriction and the solutions obtained for different cases are as follows:

$$C(y.t)=\frac{1}{2}\left[e^{-y\sqrt{Sc(Sc+Kr)}}erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}-\sqrt{Kr\,t}\right)+e^{y\sqrt{Sc(Sc+Kr)}}erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}+\sqrt{Kr\,t}\right)\right]$$

$$\theta(y,t)=b_7\left[e^{-yb_6}erfc\left(\frac{y\sqrt{b_3}}{2\sqrt{t}}-\sqrt{b_4 t}\right)-e^{yb_6}erfc\left(\frac{y\sqrt{b_3}}{2\sqrt{t}}+\sqrt{b_4 t}\right)\right]$$

$$u(y,t)=d_9\frac{e^{a_0 t}}{2}\left[e^{-y\sqrt{a_0+d_1}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(a_0+d_1)t}\right)+e^{y\sqrt{a_0+d_1}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(a_0+d_1)t}\right)\right]$$

$$-d_7\frac{\sqrt{d_1}}{2b_4}\left[e^{-y\sqrt{d_1}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{d_1 t}\right)-e^{y\sqrt{d_1}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{d_1 t}\right)\right]+$$

$$d_7\frac{\sqrt{d_1-d_3}e^{-d_3 t}}{2(b_4-d_3)}\left[e^{-y\sqrt{d_1-d_3}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(d_1-d_3)t}\right)-e^{y\sqrt{d_1-d_3}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(d_1-d_3)t}\right)\right]+$$

$$\frac{i\sqrt{b_4+d_3}e^{-b_4 t}}{2(b_4-d_3)}\left[e^{iy\sqrt{b_4-d_1}}erfc\left(\frac{y}{2\sqrt{t}}+i\sqrt{(d_4-d_1)t}\right)-e^{-iy\sqrt{b_4-d_1}}erfc\left(\frac{y}{2\sqrt{t}}-i\sqrt{(d_4-d_1)t}\right)\right]$$

$$-\frac{d_8}{2}\left[e^{-y\sqrt{d_1}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{d_1 t}\right)+e^{y\sqrt{d_1}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{d_1 t}\right)\right]+$$

$$d_8\frac{e^{a_5 t}}{2}\left[e^{-y\sqrt{d_1-d_5}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(d_1-d_5)t}\right)+e^{y\sqrt{a_0+d_1}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(d_1-d_5)t}\right)\right]+$$

$$d_6 e^{-d_1 t} erfc\left(\frac{y}{2\sqrt{t}}\right) + d_7\left[e^{-yb_6} erfc\left(\frac{y\sqrt{b_3}}{2\sqrt{t}} - \sqrt{b_4 t}\right) - e^{yb_6} erfc\left(\frac{y\sqrt{b_3}}{2\sqrt{t}} + \sqrt{b_4 t}\right)\right] -$$

$$d_7 \frac{\sqrt{b_4 - d_3} e^{-d_3 t}}{2(b_4 - d_3)}\left[e^{-y\sqrt{b_3(b_4-d_1)}} erfc\left(\frac{y\sqrt{b_3}}{2\sqrt{t}} + i\sqrt{(b_4 - d_3)t}\right) - e^{y\sqrt{b_3(b_4-d_1)}} erfc\left(\frac{y\sqrt{b_3}}{2\sqrt{t}} + i\sqrt{(b_4 - d_3)t}\right)\right] +$$

$$\frac{i\sqrt{b_4 + d_3} e^{-b_4 t}}{(b_4 - d_3)}\left[erfc\left(\frac{y\sqrt{b_3}}{2\sqrt{t}}\right)\right] + \frac{d8}{2}\left[e^{-y\sqrt{(Sc+Kr)}} erfc\left(\frac{y}{2\sqrt{t}} - \sqrt{Kr\,t}\right) + e^{y\sqrt{(Sc+Kr)}} erfc\left(\frac{y}{2\sqrt{t}} + \sqrt{Kr\,t}\right)\right] -$$

$$d_8 \frac{e^{-d_5 t}}{2}\left[e^{-y\sqrt{Sc(Kr-d_5)}} erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} - \sqrt{(Kr - d_5)t}\right) + e^{y\sqrt{Sc(Kr-d_5)}} erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} + \sqrt{(Kr - d_5)t} + \right)\right] +$$

$$d\; e^{a_0 t} - d_6 e^{-d_1 t}$$

Results and Discussions

The problem of unsteady magneto hydrodynamic free convective flow of a viscous, incompressible fluid past an infinite electrically conducting vertical plate through porous medium has been formulated analysed and solved analytically using Laplace transform technique. The effects of the flow parameters such as magnetic parameter (M), Radiation parameter (R), Grashof number for heat transfer (Gr), Schmidt number (Sc), Chemical reaction parameter (Kr), Prandtl number (Pr), Heat absorption parameter (Q) and permeability parameter (k) on the velocity, temperature and concentration profiles of the flow field are presented with help of graphs.

Figure. 1. represents that as time increases velocity increases in either case of the uniform magnetic field fixed relative to the fluid or plate. The trend shows that the contribution of mass diffusion is very dominant in the velocity field. Figure. 2 asserts that the Influence of the radiation parameter on the velocity profiles. It is interesting to observe that there is significant enhancement in the velocity distribution in each case of uniform magnetic field fixed relative to fluid or plate. Physically, an increase in the radiation releases the heat to the flow, which helps to enhance the momentum boundary layer thickness. Figure. 3. shows as heat absorption parameter Q increases it is evident that velocityof the fluid increases in either cases. Figure. 4. interprets as Magnetic parameter M increases velocity of the fluid decreases in each case of the uniform magnetic field fixed relative to the fluid or plate. It is because the application of transverse magnetic field will results in a resistive type force (Lorentz force) similar to drag force which tend to resist the fluid flow and reduces its velocity. Figure.5 depicts that as chemical reaction parameter Kr increases velocity decreases. Therefore an increase in Kr leads to a fall in the momentum boundary layer.

Figure. 6 reveals that as radiation parameter R increases temperature decreases the temperature and its corresponding boundary layer thickness increase by increasing thermal radiation parameter. Figure.7 shows that as heat absorption parameter Q increases temperature decreases because in the presence of heat absorption within the boundary layer produces the opposite effect and thus the temperature of the fluid decreases.Figure.8represents that as Prandtl number Pr increases temperature decreases because an increase in the Prandtl number results in decrease of the boundary layer thickness and in generally lowers the average temperature within the boundary layer.

Figure. 9 shows that as chemical reaction parameter Kr increases concentration decreases because as the chemical reaction rate is inversely proportion to the mass diffusivity as a result, the concentration decreased when the more mass diffusivity takes place.Figure.10. shows that as Sc increases concentration decreases. The concentration fluid decreases when the values of Schmidt number are increased. This is because of the fact that by increasing the Schmidt number, the mass diffusivity decreases and solute boundary layer decreases.

Appendix

$$a_1 = \sqrt{ScKr},\ \ a_2 = \sqrt{Sc}\ ,\ b_1 = \frac{1}{\Pr}, b_2 = \frac{(Q+R)}{\Pr}, b_3 = \frac{\Pr}{b_1},\ b_4 = \frac{b_2}{\Pr}, b_5 = \frac{1}{\sqrt{b_3}}$$

$$b_6 = \sqrt{b_3 b_4},\ b_7 = \frac{b_5}{2b_6},\ d_1 = M + \frac{1}{k},\ d_2 = \left(\frac{-Grb_5}{b_3 - 1}\right),\ d_3 = \left(\frac{b_3 b_4 - d_1}{b_3 - 1}\right),\ d_4 = \left(\frac{-Gc}{Sc - 1}\right)$$

$$d_5 = \left(\frac{ScKr - d_1}{Sc - 1}\right),\ d_6 = \left(\frac{MK}{a_0 + d_1}\right), d_7 = \frac{d_2}{d_3},\ d_8 = \frac{d_4}{d_5},\ d_9 = 1 - d_6$$

Graphs

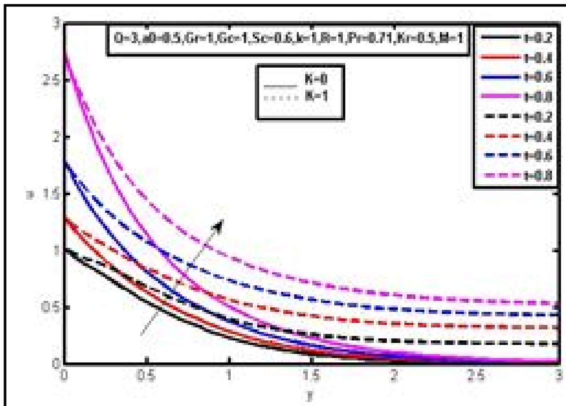


Figure 1.Velocity for different values of t

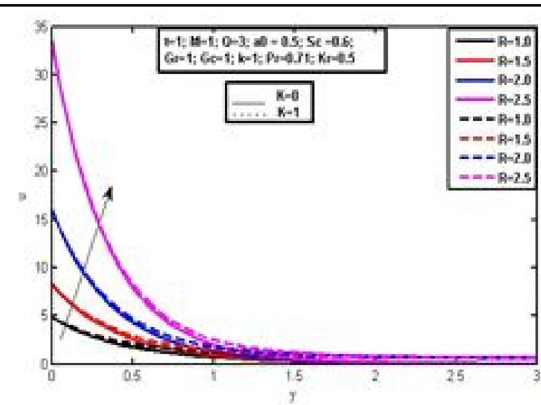


Figure 2. Velocity for different values of R

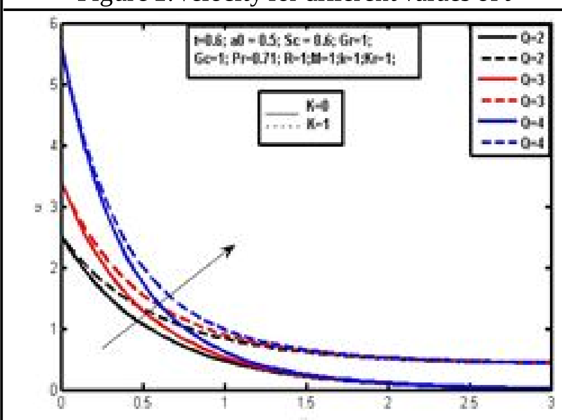


Figure 3. Velocity for different values of Q

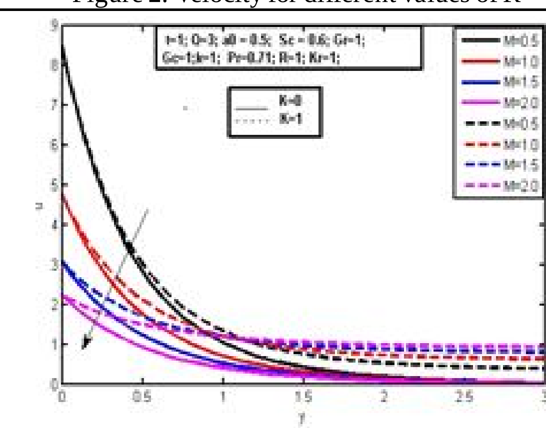


Figure 4. Velocity for different values M

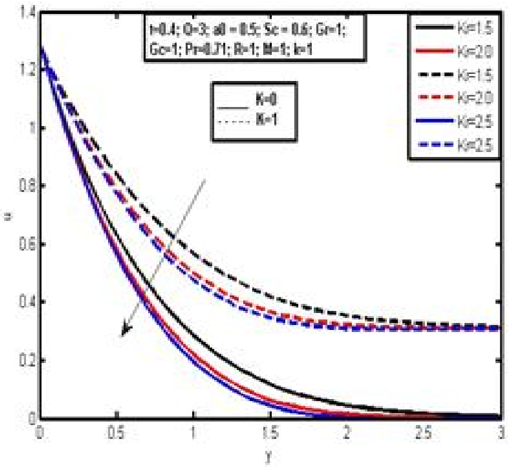


Figure 5.Velocity for different values of Kr

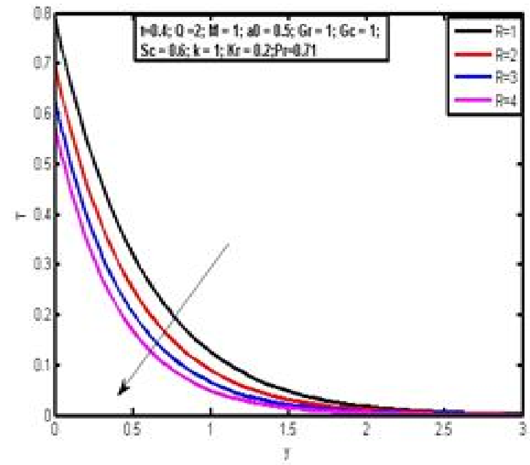


Figure 6.Temparature for different values of R

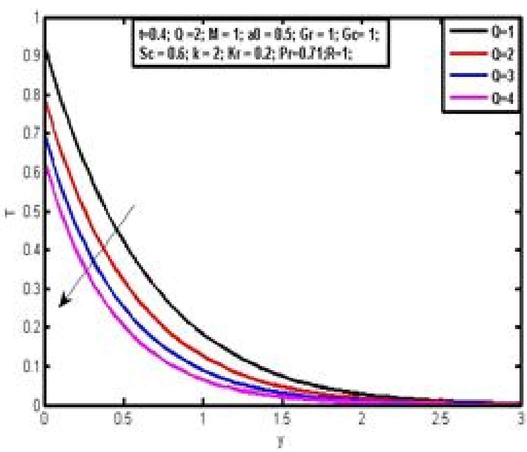


Figure 7.Temparature for different values of Q

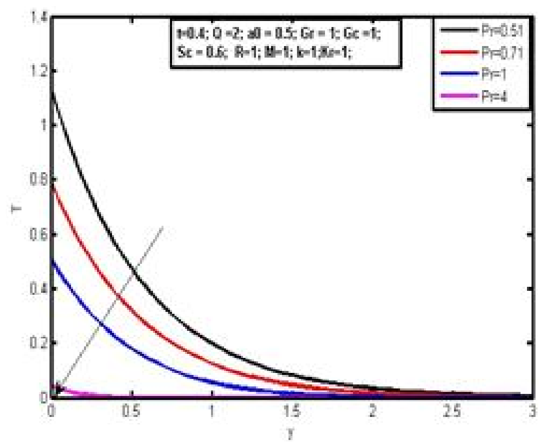
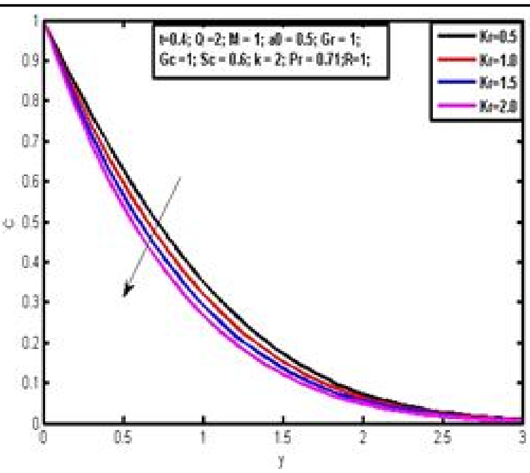
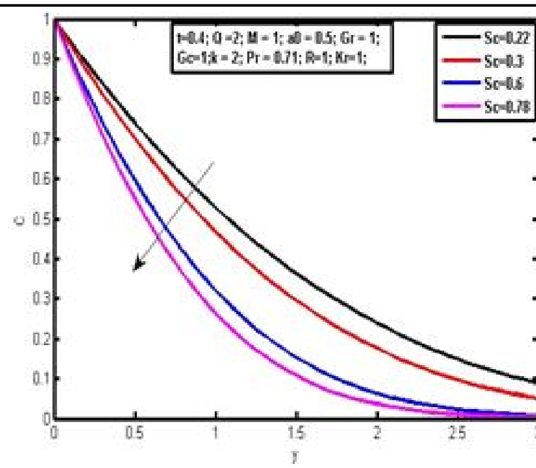


Figure 8.Temparature for different values of Pr



Ffigure 9. concentration for different values of kr



Ffigure 10.concentration for different values of Sc

Conclusions

The uniform magnetic field fixed relative to the fluid (K=0) or to the plate (K=1) is considered and in both the cases

- As time t increases velocity increases
- As radiation parameter R increases velocity increases and temperature decreases
- As heat absorption parameter Q increases velocity increases and temperature decreases
- As magnetic parameter M increases velocity decreases
- As chemical reaction parameter Kr increases velocity and concentration of the fluid decreases
- As Prandtl number Pr increases temperature decreases
- As Schmidt number Sc increases Concentration of the fluid decreases

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