HEAT AND MASS TRANSFER EFFECTS OVER ISOTHERMAL INFINITE VERTICAL PLATE OF NEWTONIAN FLUID WITH CHEMICAL REACTION

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ABSTRACT

The present investigation is theoretical solution of unsteady radiative flow past a uniformly accelerated isothermal infinite vertical plate with uniform mass diffusion is presented here, taking in to account the homogeneous chemical reaction of first order. The plate temperature is raised to T_w and the concentration level near the plate is also raised to C_w . The dimensionless governing equations are solved using perturbation technique. The velocity, temperature and concentration fields are studied for different physical parameters through graphically.

KEYWORDS: Accelerated; Isothermal; Vertical plate; Chemical reaction; Radiation.
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INTRODUCTION

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 device for aircraft, combustion and furnace design, materials processing, energy utilization, temperature measurements, remote sensing for astronomy and space exploration, food processing and cryogenic engineering, as well as numerous agricultural, health and military applications. In view of the above (Chenna Kesavaiah et. al, 2022) observed the radiation and mass transfer effects on MHD mixed convective flow from a vertical surface with heat source and chemical reaction, (Chenna Kesavaiah et. al, 2022) motivated study on 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, (Mohamad, 2009) has been considered double diffusive convection – radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effect was studied, (Chenna Kesavaiah et. al, 2022) explained in detailed information on chemical reaction, heat and mass transfer effects on MHD peristaltic transport in a vertical channel through space porosity and wall properties, (Chenna Kesavaiah et. al, 2022) observed on MHD Effect on boundary layer flow of an unsteady incompressible micropolar fluid over a stretching surface, (Chenna Kesavaiah et. al, 2022) shows that the chemical reaction and MHD effects on free convection flow of a viscoelastic dusty gas through a semi infinite plate moving with radiative heat transfer, (Muthucumaraswamy and Ravi Shankar, 2011) studied the first order chemical reaction and thermal radiation effects on unsteady flow past an accelerated isothermal infinite vertical plate, (Chenna Kesavaiah et. al, 2021) extended the research on 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, 2021) reviewed on hall effect on MHD flow of a viscoelastic fluid through porous medium over an infinite vertical porous plate with heat source, (Seddek, 2005) viewed on finite-element Method for the effects of chemical reaction, variable viscosity, thermophoresis and heat generation/ absorption on a boundary-layer hydro magnetic flow with heat and mass transfer over a heat surface, (Mallikarjuna Reddy et. al, , 2018) has been studied the effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates,

Chemical reactions can be codified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. In well-mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. 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 view of the above (Chenna Kesavaiah and Venkateswarlu, 2020) expressed their views on chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, (Mallikarjuna Reddy et. al, 2019) explained on radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, (Srinathuni Lavanya and Chenna Kesavaiah, 2017) motivated study on heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, (Chenna Kesavaiah and Sudhakaraiah, 2014) observed the effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, (Rajaiah et. al, 2015) contemplate the chemical and Soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium, (Chenna Kesavaiah et. al, 2013) examined the natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, (Chenna Kesavaiah and Satyanarayana, 2013) apprise on MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, (Chenna Kesavaiah et. al, 2013) noticed on the radiation and Thermo - Diffusion effects on mixed convective heat and mass transfer flow of a viscous dissipated fluid over a vertical surface in the presence of chemical reaction with heat source, (Ch Kesavaiah et. al, 2013) remarked on effects of radiation and free convection currents on unsteady Couette flow between two vertical parallel plates with constant heat flux and heat source through porous medium, (Rajaiah and Sudhakaraiah, 2015) has been considered an unsteady MHD free convection flow past an accelerated vertical plate with chemical reaction and Ohmic heating, (Ch Kesavaiah, 2012) explained in detailed the radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation, (Haranth and Sudhakaraiah, 2015) expressed their research views on viscosity and Soret effects on unsteady hydromagnetic gas flow along an inclined plane, (Chenna Kesavaiah et. al, 2021) distinguished on MHD effect on convective flow of dusty viscous fluid with fraction in a porous medium and heat generation.

The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions. Possible heat generation effects may alter the temperature distribution and consequently, the particle deposition rate in nuclear reactors, electric chips and semiconductor wafers. (Rajaiah et. al, 2014) discovered an unsteady MHD free convective fluid flow past a vertical porous plate with Ohmic heating In the presence of suction or injection, (Chenna Kesavaiah et. al, 2019) has been considered the radiation effect to MHD oscillatory flow in a channel filled through a porous medium with heat generation, (Rajaiah and Sudhakaraiah, 2015) expressed the effect of Radiation and Soret effect on Unsteady MHD flow past a parabolic started vertical plate in the presence of chemical reaction with magnetic dissipation through a porous medium, (Chenna Kesavaiah et. al, 2017) declared that an Analytical study on induced magnetic field with radiating fluid over a porous vertical plate with heat generation, (Yeddala et. al, 2016) commented on finite difference solution for an MHD free convective rotating flow past an accelerated vertical plate, (Chamkha et. al, 2001) remarked on radiation effects on free convection flow past a semi- infinite vertical plate with mass transfer, (Dulal Pal and Babulal Talukdar, 2010) observed that perturbation analysis of unsteady magneto hydro dynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction, (Ibrahim et. al, 2008) motivated study on effect of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction, (Patil and Kulkarni, 2008) the effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation,(Karunakar Reddy et. al, 2013) viewed on MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction.

Hence, it is proposed to study the first order chemical reaction on unsteady flow past a uniformly accelerated isothermal infinite vertical plate with heat and mass transfer, in the presence of radiation absorption with heat source. The dimensionless governing equations are solved using the perturbation technique. The solutions are in terms of exponential and complementary error function. Such a study found useful in chemical process industries such as wire drawing, fibre drawing, food processing and polymer production.

MATHEMATICAL FORMULATION

We considered an unsteady radiative flow of a viscous incompressible fluid past a uniformly accelerated isothermal infinite vertical plate with uniform mass diffusion in the presence of chemical reaction of first order has been considered. Here the unsteady flow of a viscous incompressible fluid which is initially at rest and surrounds an infinite vertical plate with temperature T_∞ and concentration C'_∞ .

The x-axis is taken along the plate in the vertically upward direction and the y-axis is taken normal to the plate. At time $t' \leq 0$, the plate and fluid are at the same temperature T_∞. At time $t' \geq 0$, the plate is accelerated with a velocity in its own plane and the temperature from the plate is raised to T_w and the concentration levels near the plate are also raised to C'_∞ . It is assumed that the effect of viscous dissipation is negligible in the energy equation and there is a first order chemical reaction between the diffusing species and the fluid. The fluid considered here is a gray, absorbing emitting radiation but a non-scattering medium. Then under usual Boussinesq's approximation the unsteady flow is governed by the following equations:

$$\frac{\partial u'}{\partial t'} = g\beta\left(T' - T_\infty\right) + g\beta'\left(C' - C'_\infty\right) + \nu\frac{\partial^2 u'}{\partial y^2} - \frac{\sigma B_0^{\,2}}{\rho}u' \qquad (1)$$

$$\rho C_p \frac{\partial T'}{\partial t'} = K\frac{\partial^2 T'}{\partial y^2} - Q_0\left(T' - T'_\infty\right) - Q_l'\left(C' - C'_\infty\right) \qquad (2)$$

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

The initial and boundary conditions for the velocity, temperature and concentration fields are

$$u' = 0, T' = T'_\infty, C' = C'_\infty \quad \forall \quad y,\, t' \leq 0$$

$$\left.\begin{array}{l} u' = \dfrac{u_0^{\,3} t'}{\nu}, T' = T_w \\ C' = C'_w \;, \end{array}\right\} t' > 0 \quad at \quad y = 0 \qquad (4)$$

$$u \to 0, T \to T_\infty, C' \to C'_\infty \;\; as \;\; y \to \infty$$

Where u' is the velocity of the fluid along the plate in the x' - direction, t' is the time, g is the acceleration due to gravity, β is the coefficient of volume expansion, β' is the coefficient of thermal expansion with concentration, T_∞ is the temperature of the fluid near the plate, T'_w is the temperature of the fluid far away from the plate, T_w is the temperature of the fluid, C' is the species concentration in the fluid near the plate, C'_∞ is the species concentration in the fluid far away from the plate, ν is the kinematic viscosity, σ is the electrical conductivity of the fluid, B_0 is the strength of applied magnetic field, ρ is the density of the fluid, C_p is the specific heat at constant pressure, K is the thermal conductivity of the fluid, μ is the viscosity of the fluid, D is the molecular diffusivity, u_0 is the velocity of the plate.

On introducing the following non-dimensional quantities

$$U = \frac{u'}{u_0}, Y = \frac{u_0 y}{\nu}, Q = \frac{\nu Q_0}{\rho C_p u_0^{\,2}}, Sc = \frac{\nu}{D}$$

$$C = \frac{C' - C'_\infty}{C'_w - C'_\infty}, \qquad Gr = \frac{\nu\beta g\left(T_w{}' - T'_\infty\right)}{u_0^{\,3}}$$

$$Gr = \frac{\nu\beta' g\left(C'_w - C'_\infty\right)}{u_0^{\,3}}, \qquad M = \frac{\sigma B_0^{\,2}\nu}{\rho u_0^{\,2}} \quad (5)$$

$$\theta = \frac{T' - T'_\infty}{T_w{}' - T'_\infty}, \; \Pr = \frac{\mu C_p}{K}, \qquad Kr = \frac{Kr'\nu}{u_0^{\,2}}$$

$$Q_l = \frac{Q_l'\left(C'_w - C'_\infty\right)}{\rho C_p u_0^{\,2}\left(T'_w - T'_\infty\right)}, \qquad t = \frac{t' u_0^{\,2}}{\nu}$$

where Gr is the thermal Grashof number, Gc is modified Grashof Number, $\Pr$ is Prandtl Number, M is the magnetic field, Sc is Schmdit number, Kr is Chemical Reaction, K is Porous Permeability, Q is Heat source parameter respectively.

In terms of the above dimensionless quantities, Equations (1) - (2) reduces to

$$\frac{\partial U}{\partial t} = Gr\,\theta + Gm\;C + \frac{\partial^2 U}{\partial Y^2} - M\;U \qquad (6)$$

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

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

The negative sign of Kr in the last term of the equation (8) indicates that the chemical reaction takes place from higher level of concentration to lower level of concentration. The corresponding boundary conditions are

$$U=0,\theta=0,C=0;t\le 0 \qquad \forall\ Y$$

$$\left.\begin{array}{l}U=t,\theta=1,\\ C=1,\end{array}\right\} \quad t>0\ \ at\quad Y=0 \qquad (9)$$

$$U\to 0,\theta\to 0,C\to 0\ \ as\ \ Y\to\infty$$

SOLUTION OF THE PROBLEM

Equation (6) – (8) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (9). 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

$$U=U_0\left(Y\right)+\varepsilon e^{nt}U_1\left(Y\right)$$

$$\theta=\theta_0\left(Y\right)+\varepsilon e^{nt}\theta_1\left(Y\right) \qquad (10)$$

$$C=C_0\left(Y\right)+\varepsilon e^{nt}C_1\left(Y\right)$$

Substituting (10) in equation (6) – (8) and equating the harmonic and non – harmonic terms, we obtain

$$U_0''-MU_0=-Gr\theta_0-GmC_0 \qquad (11)$$

$$U_1''-\beta_3U_1=-Gr\theta_1-GmC_1 \qquad (12)$$

$$\theta_0''-Q\Pr\theta_0=Q_l\Pr C_0 \qquad (13)$$

$$\theta_1''-\beta_2\theta_1=Q_l\Pr C_1 \qquad (14)$$

$$C_0''-Sc\,Kr\,C_0=0 \qquad (15)$$

$$C_1''-\beta_1C_1=0 \qquad (16)$$

The corresponding boundary conditions can be written as

$$\left.\begin{array}{l}U_0=t,U_1=0,\ \theta_0=1,\\ \theta_1=0,C_0=1,C_1=0\end{array}\right\} \quad at\ Y=0$$

$$\left.\begin{array}{l}U_0\to 0,U_1\to 0,\ \theta_0\to 0,\\ \theta_1\to 0,C_0\to 0,C_1\to 0\end{array}\right\} as\ Y\to\infty \qquad (17)$$

Solving equations (11) - (16) under the boundary conditions (17) we obtain the velocity, temperature and concentration distributions in the boundary layer as

$$U\left(Y\right)=L_1e^{\alpha_2y}+L_2e^{\alpha_1y}+L_3e^{\alpha_1y}+L_4e^{\alpha_3y}$$

$$\theta\left(Y\right)=J_1e^{\alpha_1y}+J_2e^{\alpha_2y}$$

$$C\left(Y\right)=e^{\alpha_1y}$$

RESULTS AND DISCUSION

For physical interpretation of the problem, the numerical computations are carried out for different physical parameters like; thermal Grashof number$\left(Gr\right)$, mass Grashof number$\left(Gc\right)$, Chemical reaction parameter$\left(Kr\right)$, heat source parameter $\left(Q\right)$ heat absorption parameter$\left(Q_l\right)$, and Schmidt number $\left(Sc\right)$ at $t=0.2$ and upon the nature of the flow and transport. The value of the Schmidt number taken to be which corresponds to water vapour $\left(Sc=0.6\right)$. Also, the value of Prandtl number is chosen such that they represent hydrogen $\left(\Pr=0.16\right)$ for fixed values of $Gr=5,Gc=5,Kr=1,\ Q=1,\ Q_l=1,\ t=0.2$ Figures (1) – (8) show that the velocity profiles for different values of the parameters like; thermal Grashof number, mass Grashof number, Chemical reaction parameter, Prandtl number, heat source parameter, heat absorption parameter, Schmidt number and time parameter. Velocity profiles upsurges in a thin layer adjacent to the plate and its nature take reverse turn outside the layer as thermal Grashof number upsurges as demonstrated in figure (1). So, thermal buoyancy forces hikes velocity in a small layer surrounding the plate but lowers velocity outside the layer. Velocity rises with increment in solutal Grashof number as noticed in figure (2). Thus, solutal buoyancy force upsurges velocity. Hence higher mass diffusivity raises velocity field but increasing thermal diffusivity reduces velocity. Figure (3) shows that the velocity reduces with increasing chemical reaction parameter. This is because increasing chemical reaction parameter accelerates the process of collision between fluid molecules and as a results, kinetic energy is lost. Figure (4) shows that ascending values of Prandtl number lowered velocity profiles. Thus higher thermal diffusivity diminished velocity. Figure (5) shows that the velocity profiles for various values of heat source parameter observed form this figure it is clear that an increasing values of heat source parameter, the results is decreases. Figure (6) depicts that the velocity profiles for different values of radiation absorption parameter, we noticed that an increasing values of heat absorption the velocity profiles also decreases. Figure (7) exhibits that increasing Schmidt number decreases velocity profiles. Thus, high mass diffusivity escalates fluid velocity. Figure (8) reveals that as time progresses, the velocity profiles increases. Consequently, a large concentration gradient relative to the temperature gradient results in a dip in the velocity profiles. Figures (9) – (13) illustrate the variation of temperature field versus normal co-ordinate y. Figure (9) shows that the temperature field upsurges with increment in chemical reaction parameter. Increasing chemical reaction parameter upsurges collision between fluid molecules and as a result temperature of fluid hikes.

Figure (10) suggests that the temperature field elevates with an uplift in Schmidt number. Thus, the temperature field decreases with increasing mass diffusivity.
To observe the effect of heat source parameter (Q) and radiation absorption parameter (Q_l) depicted form figures (11) and (12), form these figures it is clear that the temperature profiles decreases with an increasing values of Q, Q_l. Figures (13) and and (14) display the variation of concentration field versus normal co-ordinate y. Figure (13) reveals that there is a comprehensive fall in the concentration field for increasing chemical reaction parameter. A faster chemical reaction consumes chemical substances present in the fluid rapidly and as a result concentration of the fluid declines. The behaviour of concentration profiles for various fluids such as hydrogen (Sc = 0.5), ammonia (Sc = 0.57), oxygen (Sc = 0.84), water methane (Sc = 0.99) and are demonstrated in Fig. (14). It suggests that a higher Schmidt number lowers the concentration field. Thus higher mass diffusivity hikes the concentration field.

CONCLUSION

The theoretical solution of radiative flow past a uniformly accelerated isothermal infinite vertical plate with uniform mass diffusion, radiating and absorbing in the presence of homogeneous chemical reaction of first order has been studied. The dimensionless governing equations were solved by the usual perturbation technique. The effect of different physical parameters like chemical reaction parameter, heat source parameter, heat absorption parameter, thermal Grashof number, mass Grashof number and *t* are studied graphically. It is observed that the velocity increases with increasing values of Gr, Gc and t. But the trend is just reversed with respect to the chemical reaction and Schmidt number.

Table (1) Shows that the computational values of Nusselt number for various heat source parameter, versus heat absorption parameter when t = 0.2

Table (1): Nusselt number

Q	Q_l	Pr	Nu
0.5	0.5	0.72	1.51256
1.0	1.0	0.72	1.33697
1.5	1.5	0.72	1.01458

Table (2) Shows that the computational values of skin friction for various Solutal Grashof number versus thermal Grashof number when t = 0.2, Pr = 0.71, Sc = 0.22, M = 0.5, Kr = 0.5, Q = 1, Ql = 0.5,

Table (2): Skin friction

Gr	Gc	$\Pr$	C_f
1.0	1.0	0.72	10.15684
5.0	2.0	0.72	25.48791
10.0	3.0	0.72	31.63292

APPENDIX

$$\beta_1 = (Kr + n)Sc,\ \beta_2 = (Q + n)\Pr,$$

$$\beta_3 = (M + n)$$

$$\alpha_1 = -\sqrt{Kr\,Sc},\ \alpha_2 = -\sqrt{Q\Pr},\ \alpha_3 = -\sqrt{M}$$

$$J_1 = -\frac{Q_l \Pr}{m_2{}^2 - Q\Pr},\ J_2 = (1 - J_1)$$

$$L_1 = -\frac{GrJ_2}{\alpha_2^2 - M}, L_2 = -\frac{GrJ_1}{\alpha_1^2 - M}, L_3 = -\frac{Gc}{\alpha_1^2 - M}$$

$$L_4 = (t - L_1 - L_2 - L_3)$$

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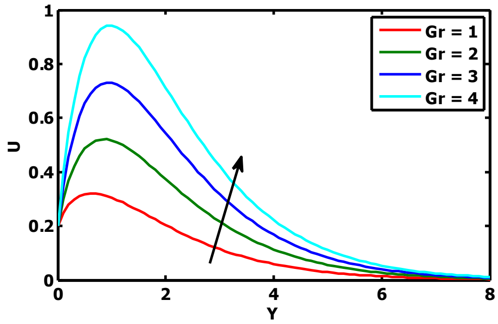

Fig. (1): Velocity profiles for different values of Gr

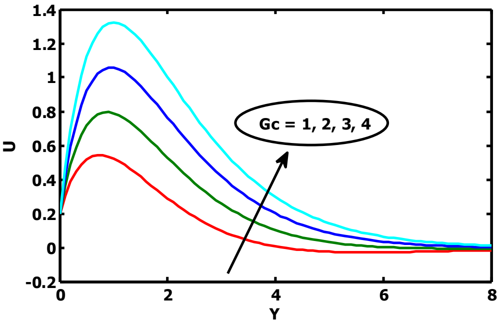

Fig. (2): Velocity profiles for different values of Gc

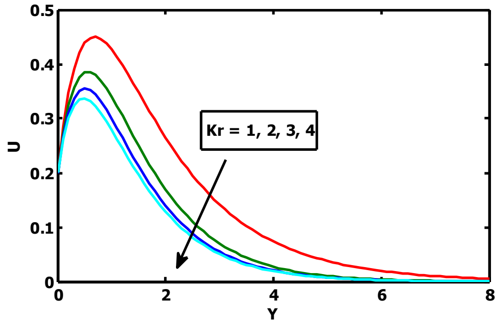

Fig. (3): Velocity profiles for different values of Kr

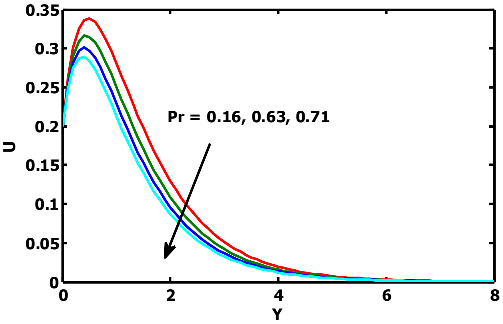

Fig. (4): Velocity profiles for different values of Pr

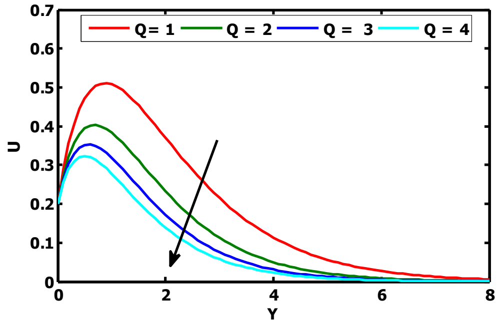

Fig. (5): Velocity profiles for different values of Q

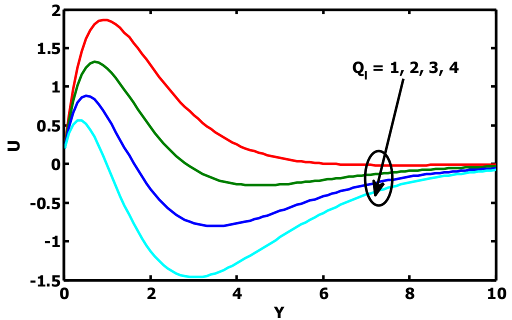

Fig. (6): Velocity profiles for different values of $_{l}Q$

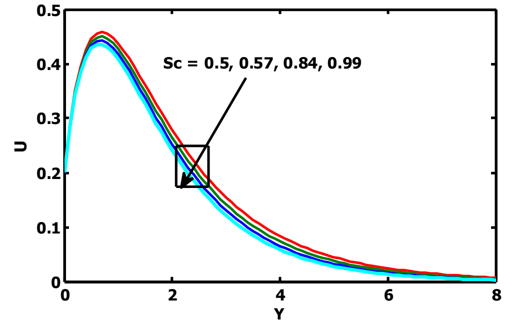

Fig. (7): Velocity profiles for different values of Sc

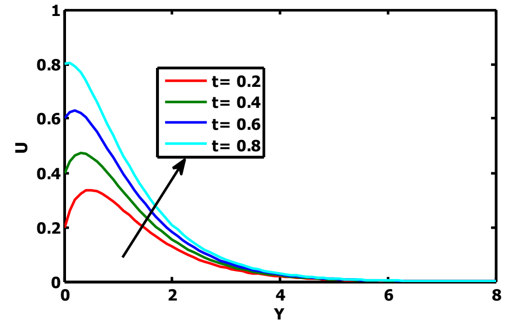

Fig. (8): Velocity profiles for different values of t

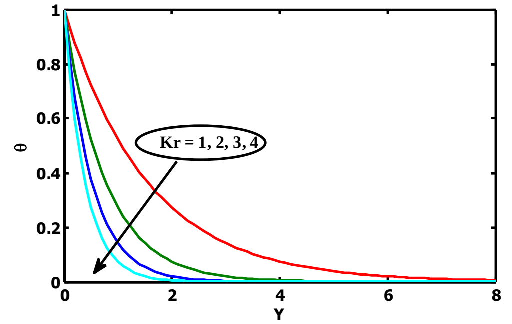

Fig. (9): Temperature profiles for different values of Kr

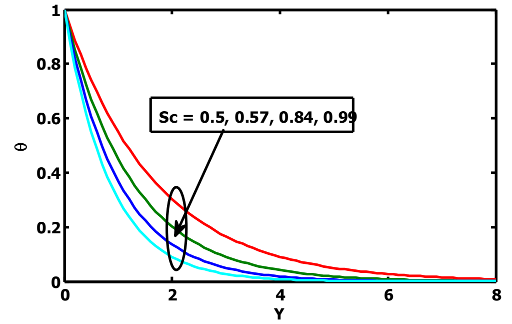

Fig. (10): Temperature profiles for different values of Sc

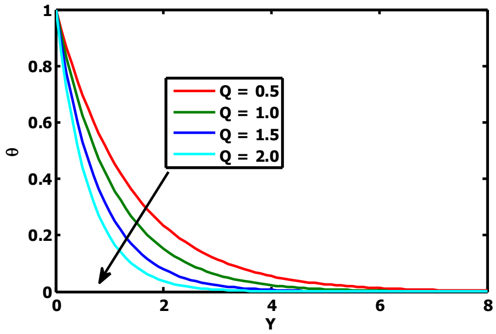

Fig. (11): Temperature profiles for different values of Q

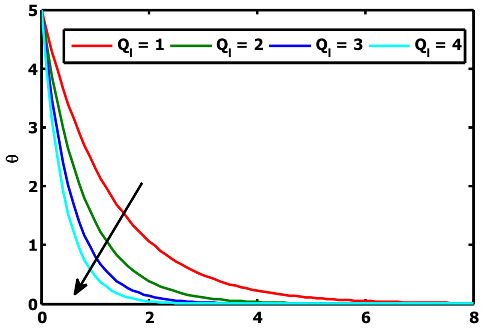

Fig. (12): Temperature profiles for different values of Q_l

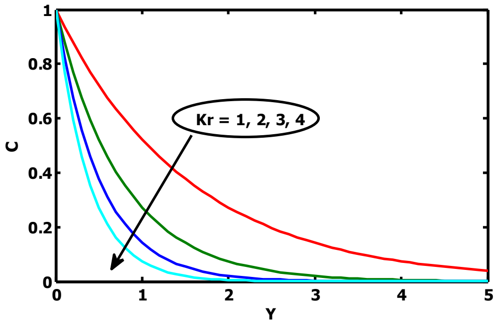

Fig. (13). Concentration profiles for different values of Kr

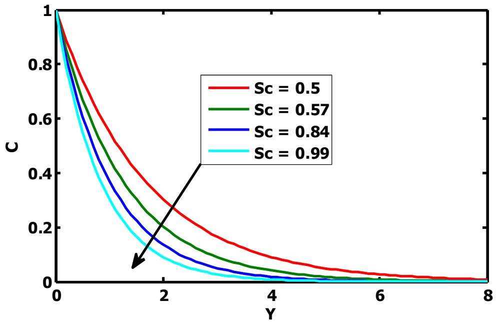

Fig. (14). Concentration profiles for different values of Sc