HEAT AND MASS TRANSFER OF UNSTEADY HYDROMAGNETIC FREE CONVECTION FLOW IN POROUS MEDIUM PAST A VERTICAL PLATE WITH CHEMICAL REACTION

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Abstract

An analysis is present the study of radiation and magnetohydrodynamic convection flow through a porous medium with heat and mass transfer in the presence of a homogeneous first order chemical reaction and surface temperature oscillation. The governing equations are solved analytically using perturbation technique. The velocity, temperature and concentration profiles are computed and discussed in details for various values of the different parameters and detailed computations of the influence of were discussed through graphs by using MATLAB.

Keywords: Radiation, Convection, Porous medium, Chemical reaction, Heat generation

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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. 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, in atmospheric flows, there exists differences in water concentration and hence the flow is influenced by such concentration difference.[1-12]

Changes in fluid density gradients may be caused by non-reversible chemical reaction in the system as well as by the differences in molecular weight between values of the reactants and the products. 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.[13-26]

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.[27-39]

The aim of this paper is to investigate MHD radiation - convection flow through a porous medium with heat generation, chemical reaction and surface temperature oscillation, and to discuss the effect of the parameters of the flow, and compute the skin frictions at the wall, rate of heat and mass transfer.

FORMULATION OF THE PROBLEM

Consider a two-dimensional unsteady MHD flow of a viscous, incompressible, electrically-conducting fluid in a channel filled with porous medium, with thermal radiation, heat generation/absorption and chemical reaction occupying a semi-infinite region of Space bounded by an infinite vertical plate moving with constant velocity, U, in the presence of a transverse magnetic field and uniform mass diffusion. 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 surface temperature and concentration of the plate oscillates with small amplitude about a non-uniform mean temperature and concentration. The co-ordinate system is such that the x-axis is taken along the plate and y-axis is normal to the plate. A uniform transverse magnetic field B_0, is imposed parallel to y-direction. All the fluid properties are considered constant except the influence of the density variation in the buoyancy term, according to the classical Boussinesq approximation. The radiation heat flux in the x-direction is considered negligible in comparison to the y-direction. Then by usual Boussinesq approximation, the unsteady flow is governed by the following equations.

$$\frac{\partial u'}{\partial t'} = \frac{\partial^2 u'}{\partial y'^2} - \frac{\mu}{K'} u' - \frac{\sigma B_0^2}{\rho} u' + g\beta^* \left(C' - C'_\infty\right) + g\beta\left(T' - T'_\infty\right) \tag{1}$$

$$\frac{\partial T'}{\partial t'} = \frac{1}{\rho C_p}\left[k\frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} - Q_0\left(T' - T'_\infty\right)\right] + Q_l'\left(C' - C'_\infty\right) \tag{2}$$

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

with boundary conditions

$$\left.\begin{aligned} &u' = 0, T' - T'_\infty = \theta_w\left(x\right)\left[1 + \varepsilon e^{i\omega' t'}\right], C' - C'_\infty = C_w\left(x\right)\left[1 + \varepsilon e^{i\omega' t'}\right]\right\} at \quad y' = 0 \\ &u' \to 0, \quad T' \to 0, \; C' \to 0 \quad\; as \;\; y' \to \infty \end{aligned} \tag{4}$$

where $U', v, g, \beta, \beta^*, T', k, \rho, C_p, D_M, \sigma, B_0,\; K', C',\; K^*, u', \varepsilon, \omega'$ and t' are stream velocity, kinematic viscosity coefficient, gravitational force, coefficient of volume expansion due to temperature, coefficient of volume expansion due to concentration, dimensional temperature, thermal conductivity, fluid density, specific heat at constant pressure, coefficient of diffusion, electrical conductivity, externally imposed magnetic field in the y-direction, dimensional concentration, dimensional chemical reaction parameter, axial velocity, a small parameter, dimensional frequency of the oscillation, and dimensional time.

For the case of an optically-thin gray gas, the thermal radiation flux gradient may be expressed as follows,

$$-\frac{\partial q_r}{\partial y'} = 4a\sigma^*\left(T_\infty'^4 - T'^4\right) \tag{5}$$

Where q_r is the radiative heat flux, a is the absorption coefficient of the fluid, and σ^* is the Stefan - Boltzmann constant.

We 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. Expanding T'^4 using Taylor series about T_∞' and neglecting higher order terms, we have

$$T'^4 = 4T_\infty'^3 T' - 3T_\infty'^4 \tag{6}$$

From (5) and (6) then (2) becomes

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} + \frac{16a\sigma^* T_\infty'^3\left(T_\infty' - T'\right)}{\rho C_p} - \frac{Q_0}{\rho' C_p'}\left(T' - T_\infty'\right) + Q_l'\left(C' - C_\infty'\right) \tag{7}$$

The following dimensionless variables and parameters of the problem are

$$\begin{gathered}
u_0 = \frac{u_0'}{U}, u_1 = \frac{u_1' e}{U},\ y = \frac{Uy'}{\nu}, t = \frac{t'U^2}{\nu}, \theta_0 = \frac{T' - T_\infty'}{T_w' - T_\infty'}, \quad C_0 = C_1 = \frac{C' - C_\infty'}{C_w' - C_\infty'} \\
Kr = \frac{Kr^*\nu}{D_M U^2}, \quad \Pr = \frac{\nu\rho C_p}{k}, \quad Sc = \frac{\nu}{D}, \quad Q = \frac{Q_0\nu}{\rho C_p U^2}, K_1 = \frac{16a\sigma^*\nu^2 L T_\infty'^3}{kU^2} \\
\theta_0' = \frac{\theta_0\nu}{UL}, \quad C_0' = \frac{C_0\nu}{UL}, \quad \theta_1' = \frac{\theta_1\nu}{ULe}, \ M^2 = \frac{\sigma B_0^2\nu}{\rho U^2}, \quad Gr = \frac{\nu^2\beta g\theta_w(x)}{U^4 L} \\
Gc = \frac{\nu^2\beta^* g\left(C_w' - C_\infty'\right)}{U^4 L}, \ Da = \frac{K'}{U^2}, \quad \omega = \frac{\nu\omega'}{U^2}, \quad Q_l = \frac{Q_l'\nu\left(C_w' - C_\infty'\right)}{U^2\left(T_w' - T_\infty'\right)}
\end{gathered} \tag{8}$$

Using (8) into (1) to (4) yield the following

$$\frac{\partial u}{\partial t}=\frac{\partial^2 u}{\partial y^2}-\left(S^2+M^2\right)u-Gr\,\theta+Gc\,C \tag{9}$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2}-\frac{K_1}{\Pr}\theta-Q\theta+Q_l C \tag{10}$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-Kr\,C \tag{11}$$

with the following boundary conditions

$$\begin{aligned} &u=U,\theta=1+\varepsilon e^{i\omega t},C=1+\varepsilon e^{i\omega t} && at \quad y=0 \\ &u\to 0,\theta\to 0,C\to 0 && as\ y\to\infty \end{aligned} \tag{12}$$

METHOD OF SOLUTION

In order to reduce the above system of partial differential equation to a system of ordinary differential equations, the velocity, temperature and concentration in the neighbourhood of the porous plate are taken as

Assuming the solutions to equations (9) to (12) as follows

$$\begin{aligned} u(y,t)&=u_0(y)+\varepsilon e^{i\omega t}u_1(y) \\ \theta(y,t)&=\theta_0(y)+\varepsilon e^{i\omega t}\theta_1(y) \\ C(y,t)&=C_0(y)+\varepsilon e^{i\omega t}C_1(y) \end{aligned} \tag{13}$$

Where ω is the frequency of the oscillation, t is the time and $u_0,u_1,\theta_0,\theta_1,C_0$ and C_1 are to be determined. Substituting (13) into (9) to (12), lead to the following

$$\frac{d^2u_0}{dy^2}-\left(S^2+M^2\right)u_0=-Gr\,\theta_0-Gc\,C_0 \tag{14}$$

$$\frac{d^2\theta_0}{dy^2}-\left(K_1+Q\Pr\right)\theta_0=-Q_l\Pr C_0 \tag{15}$$

$$\frac{d^2C_0}{dy^2}-Kr\,C_0=0 \tag{16}$$

The imposed boundary conditions become

$$\begin{aligned} &u_0=1,\theta_0=1,C_0=1 && at \quad y=0 \\ &u_0=0,\theta_0=0,C_0=0 && as\ y\to\infty \end{aligned} \tag{17}$$

$$\frac{d^2u_1}{dy^2} - \left(S^2 + M^2 + i\omega\right)u_1 = -Gr\,\theta_1 - Gc\,C_1 \tag{18}$$

$$\frac{d^2\theta_1}{dy^2} - \left(K_1 + Q\,\mathrm{Pr} + i\omega\,\mathrm{Pr}\right)\theta_1 = -Q_l\,\mathrm{Pr}\,C_1 \tag{19}$$

$$\frac{d^2C_1}{dy^2} - \left(Kr + i\omega\right)Sc\,C_1 = 0 \tag{20}$$

The imposed boundary conditions become

$$\begin{aligned} &u_1 = 1, \theta_1 = 1, C_1 = 1 \quad at \quad y = 0 \\ &u_1 = 0, \theta_1 = 0, C_1 = 0 \quad as \;\; y \to \infty \end{aligned} \tag{21}$$

Equations (14) to (21) are solved and the solutions for temperature, concentration and velocity are given as follows

$$u_0 = L_1\,e^{m_2 y} + L_2\,e^{m_4 y} + L_3\,e^{m_2 y} + L_4\,e^{m_{10} y}$$

$$u_1 = L_5\,e^{m_6 y} + L_6\,e^{m_8 y} + L_7\,e^{m_6 y} + L_8\,e^{m_{12} y}$$

$$\theta_0 = D_1 e^{m_2 y} + D_2 e^{m_4 y}$$

$$\theta_1 = D_3 e^{m_6 y} + D_4 e^{m_8 y}$$

$$C_0 = e^{m_2 y}$$

$$C_1 = e^{m_6 y}$$

In view of the above set of equation we get the solution

$$u\left(y,t\right) = L_1\,e^{m_2 y} + L_2\,e^{m_4 y} + L_3\,e^{m_2 y} + L_4\,e^{m_{10} y} + \varepsilon e^{i\omega t}\left\{L_5\,e^{m_6 y} + L_6\,e^{m_8 y} + L_7\,e^{m_6 y} + L_8\,e^{m_{12} y}\right\}$$

$$\theta\left(y,t\right) = D_1 e^{m_2 y} + D_2 e^{m_4 y} + \varepsilon e^{i\omega t}\left\{D_3 e^{m_6 y} + D_4 e^{m_8 y}\right\}$$

$$C\left(y,t\right) = e^{m_2 y} + \varepsilon e^{i\omega t}\left\{e^{m_6 y}\right\}$$

Skin-friction

$$\left(\frac{\partial u}{\partial y}\right)_{y=0} = L_1\,m_2 + L_2\,m_4 + L_3\,m_2 + L_4\,m_{10} + \varepsilon e^{i\omega t}\left\{L_5\,m_6 + L_6\,m_8 + L_7\,m_6 + L_8\,m_{12}\right\}$$

Heat transfer

$$\left(\frac{\partial T}{\partial y}\right)_{y=0} = m_2 D_1 + m_4 D_2 + \varepsilon e^{i\omega t}\left\{m_6 D_3 + m_8 D_4\right\}$$

Sherwood number

$$\left(\frac{\partial C}{\partial y}\right)_{y=0} = m_2 + \varepsilon e^{i\omega t}\left\{m_6\right\}$$

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), mass Grashof number (Gc) the magnetic field parameter (M), the Darcy number (Da), absorption radiation parameter (Q_l), thermal radiation parameter (K_1), heat absorption (Q), Schmidt number (Sc) and chemical reaction (Kr) on the velocity, temperature and concentration profiles can be analyzed from figures (1) - (18). Figure (1) and (2) shows the influence of thermal buoyancy force parameter Gr and Gc 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 Gc has the same effect on the velocity as Gr. From figure (3) we observe that the effect of magnetic field (Da) is to decrease the value of velocity profile throughout the boundary layer which results in the thinning of the boundary layer thickness. Figure (4) shows that dimensional frequency parameter (ω) on the velocity profiles; it is observed that frequency parameter increases the velocity increases. The velocity profiles for different values of the Schmidt number (Sc) is shown in figure (5). It is observed that the velocity decreases with Schmidt number. Figure (6) illustrates the influence of heat absorption coefficient (Q) 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 (6) in which the velocity decreases as Q increases. The hydrodynamic boundary layer decreases as the heat absorption effects increase. The effect of increasing the value of the absorption parameter (Q_l) on the velocity is shown in figure (7). 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. The velocity profiles for different values of the chemical reaction parameter (Kr) shown in figure (8). It is observed that the velocity decreases with increasing chemical reaction parameter. The influence of thermal radiation (K_1), chemical reaction parameter (Kr), heat absorption (Q), radiation absorption (Q_l), and Schmidt number (Sc) on the temperature distribution is respectively, shown on figures (9) - (13). From figure (9) we observe that the effect of thermal radiation (K_1) is to enhance heat transfer as thermal boundary layer thickness increases with increase in the thermal radiation. We observe that the effect of K_1 is to decrease the temperature distribution in the thermal boundary layer. This is because the increase of K_1 implies increasing of radiation in the thermal boundary layer, and hence decreases the values of the temperature profiles in thermal boundary layer. Figure (10) shows that the effect of chemical reaction parameter (Kr), it is observed that an increasing Kr the temperature decreases. Figure (11) depicts the effects of heat absorption (Q) on the temperature distribution. It is observed that the boundary layer absorbs energy resulting in the temperature to fall considerably with increasing values of Q. This is because when heat is absorbed, the buoyancy force decreases the temperature profile. 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. In figure (13) we see that the temperature profiles decrease with increasing values of the Schmidt number. Figure (14) and (15) depict the influence of the non-dimensional chemical reaction parameter (Kr) and Schmidt number (Sc) on concentration profiles, respectively. The effect of chemical reaction parameter is very important in the concentration field. Chemical reaction increases the rate of interfacial mass transfer. Reaction reduces the local concentration, thus increases its concentration gradient and its flux. In figure (15) we see that the concentration profiles decrease with increasing values of the Schmidt number. The effect of mass Grashof number (Gc) on the skin friction (C_f) is depicted in figure (16). We clearly observe in this figure that the absolute values of the skin friction are increases as the mass Grashof number increases. Figure (17) has been included to show the effects of varying the chemical reaction parameter (Kr) on the local Nusselt number (Nu). The Nusselt number is observed to be reduced by increasing values of (Kr). Figure (18) depicts the effects of varying (ω) on the local Sherwood number. We observe from this figure that with the parameter cause the local Sherwood number to decrease.

APPENDIX

$$m_2 = -\sqrt{KrSc},\ m_4 = -\sqrt{K_1 + Q\,\mathrm{Pr}}\ \ m_6 = -\sqrt{KrSc + iSc\omega}\ \ m_8 = -\sqrt{K_1 + Q\,\mathrm{Pr} + i\,\mathrm{Pr}\,\omega},$$

$$D_1 = -\frac{Q_l\,\mathrm{Pr}}{m_2^{\,2} - (K_1 + Q\,\mathrm{Pr})},\ D_2 = (1 - D_1)\ \ D_3 = -\frac{Q_l\,\mathrm{Pr}}{m_6^{\,2} - (K_1 + Q\,\mathrm{Pr} + i\,\mathrm{Pr}\,\omega)},\ D_4 = (1 - D_3)$$

$$L_1 = -\frac{GrD_1}{m_2^{\,2} - (S^2 + M^2)}, L_2 = -\frac{GrD_2}{m_4^{\,2} - (S^2 + M^2)}$$

$$L_3 = -\frac{Gc}{m_2^{\,2} - (S^2 + M^2)}, L_4 = (1 - L_1 - L_2 - L_3), L_5 = -\frac{GrD_3}{m_6^{\,2} - (S^2 + M^2 + i\omega)}$$

$$L_6 = -\frac{GrD_4}{m_8^{\,2} - (S^2 + M^2 + i\omega)}, L_7 = -\frac{Gc}{m_6^{\,2} - (S^2 + M^2 + i\omega)}, L_8 = (1 - L_5 - L_6 - L_7)$$

Nomenclature	
M	Hartmann number
Gr	Grashof number
Gc	mass Grashof number
K	chemical reaction parameter
Kr	radiation-conduction parameter
Sc	Schmidt number
Pr	Prandtl number
S	porous medium shape factor

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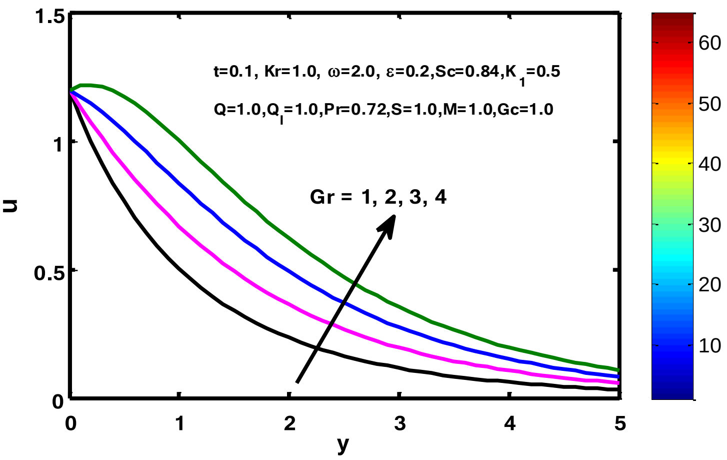

Fig. (1): Velocity profiles for different values of Gr

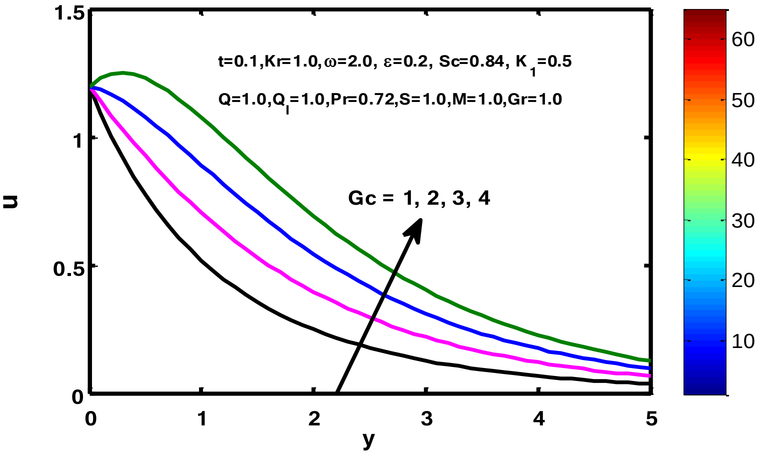

Fig. (2): Velocity profiles for different values of Gc

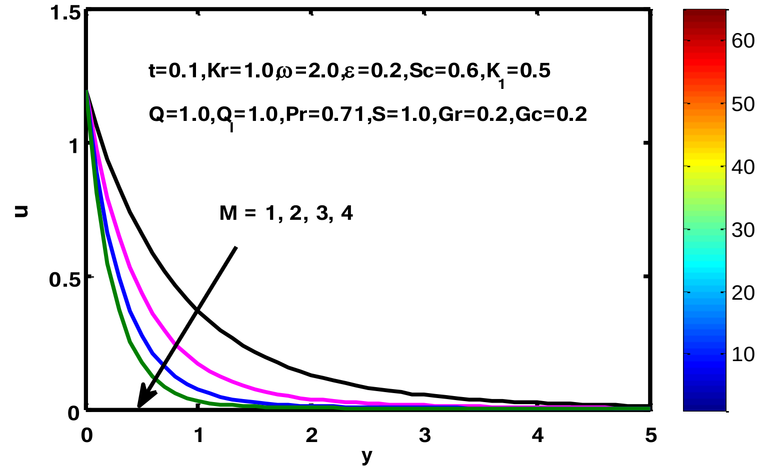

Fig. (3): Velocity profiles for different values of M

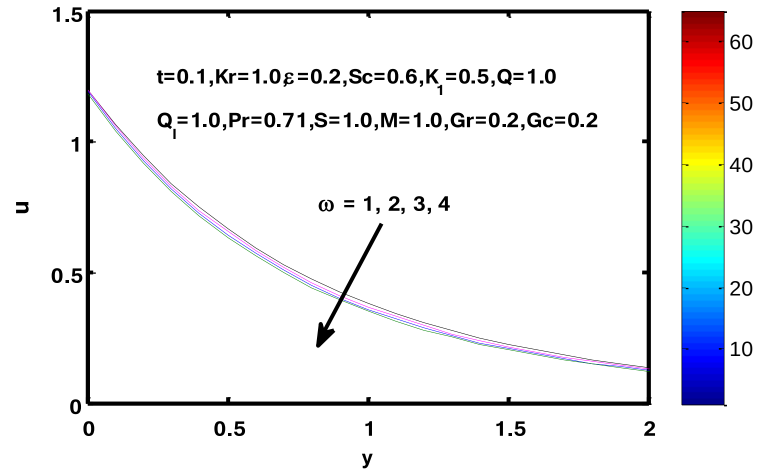

Fig. (4): Velocity profiels for different values of ω

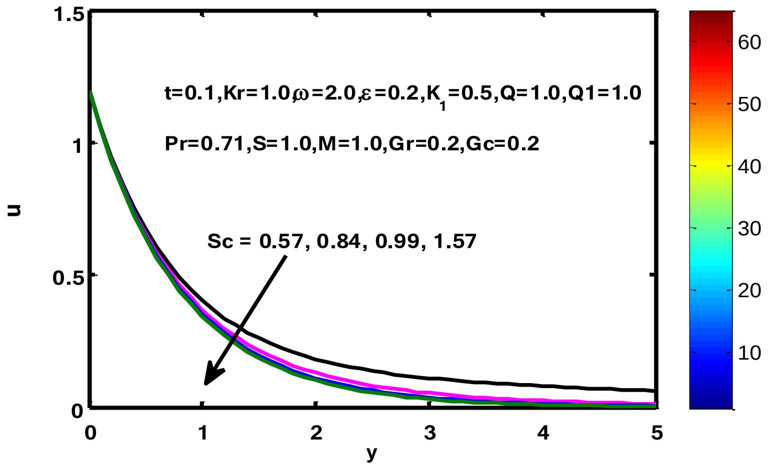

Fig. (5): Velocity profiles for different values of Sc

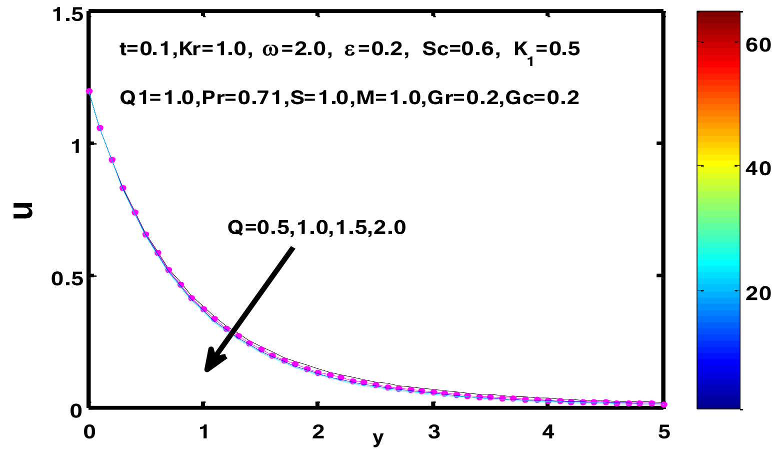

Fig (6):Velocity profiles for different values of Q

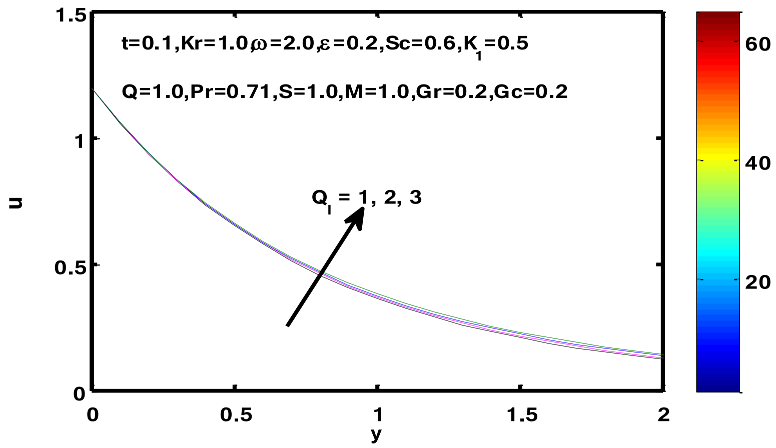

Fig.(7): Velocity profiles for different values of Q_l

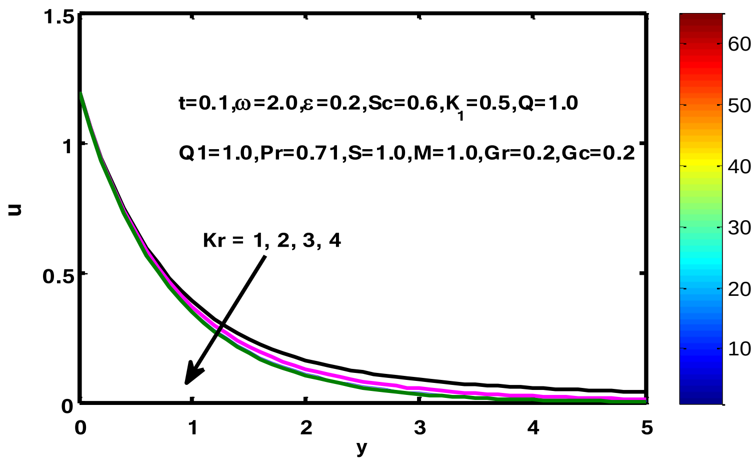

Fig. (8): Velocity profiles for differentn values of Kr

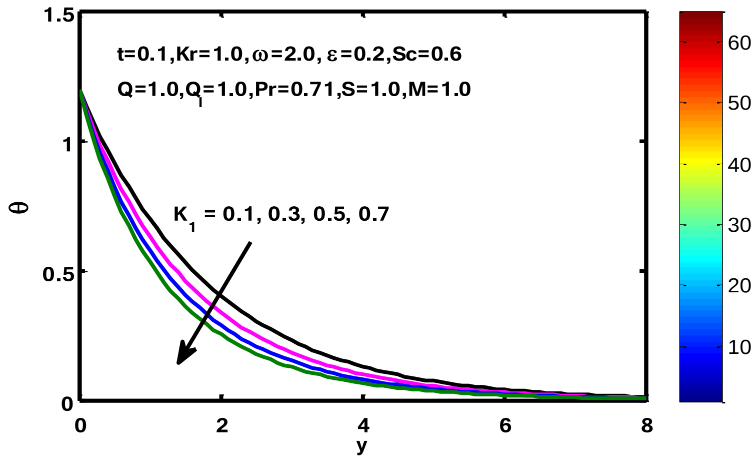

Fig.(9): Temparature profiles for different values K_1

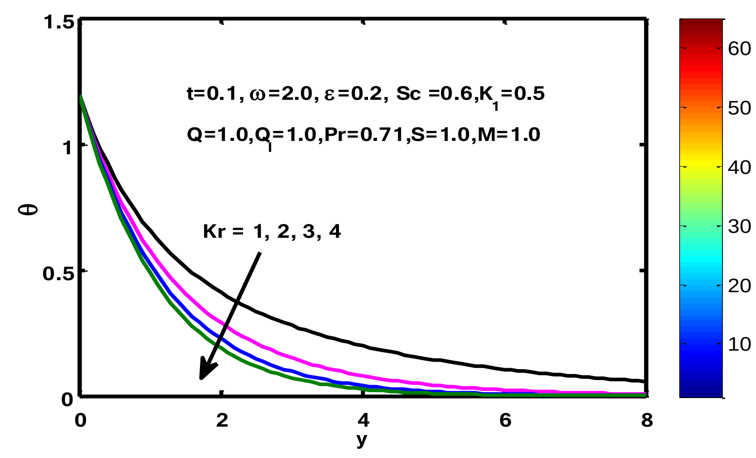

Fig. (10): Temperpature profiles for different values Kr

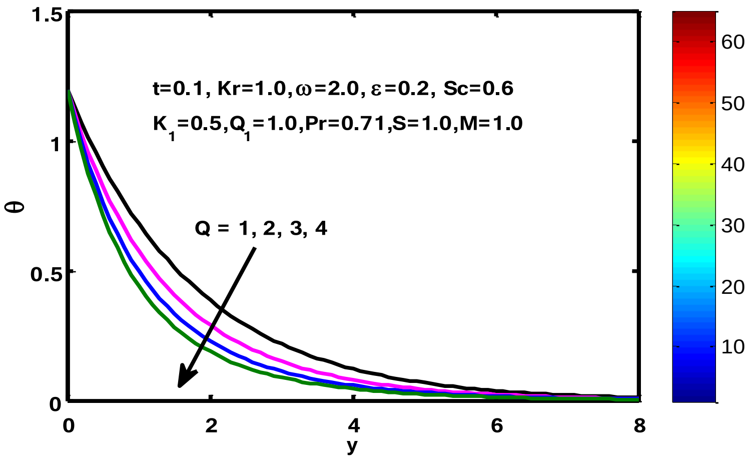

Fig. (11): Temprature profiles for different values of Q

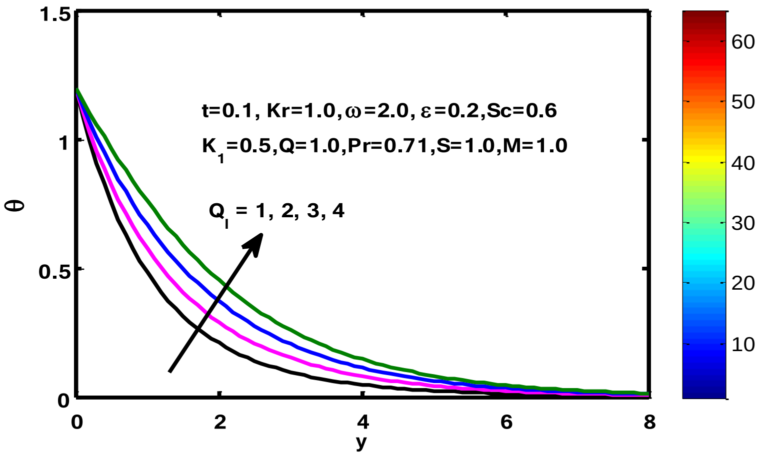

Fig. (12): Temperature profiles for different values of Q_l

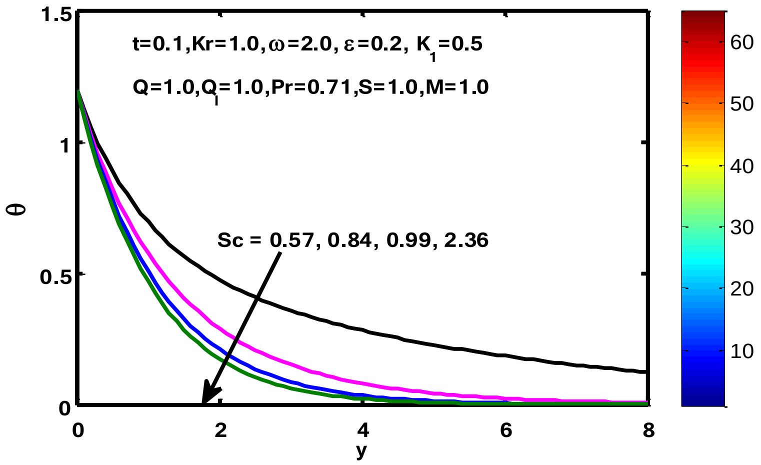

Fig. (13): Temeprature profiles for different values of Sc

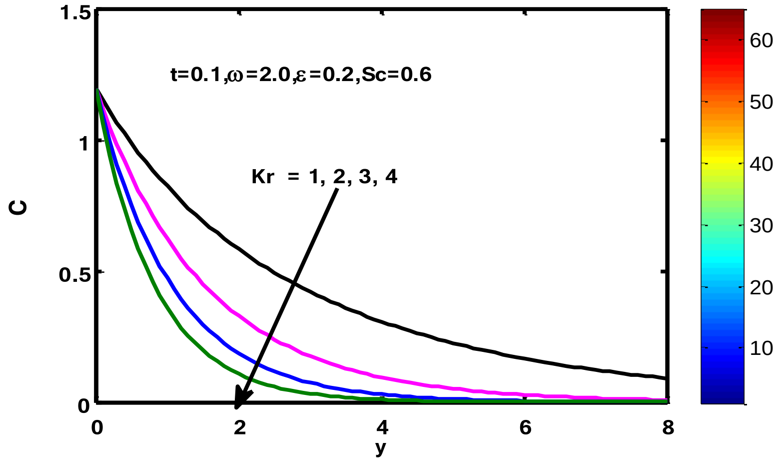

Fig. (14) : Concentration profiles for different values of Kr

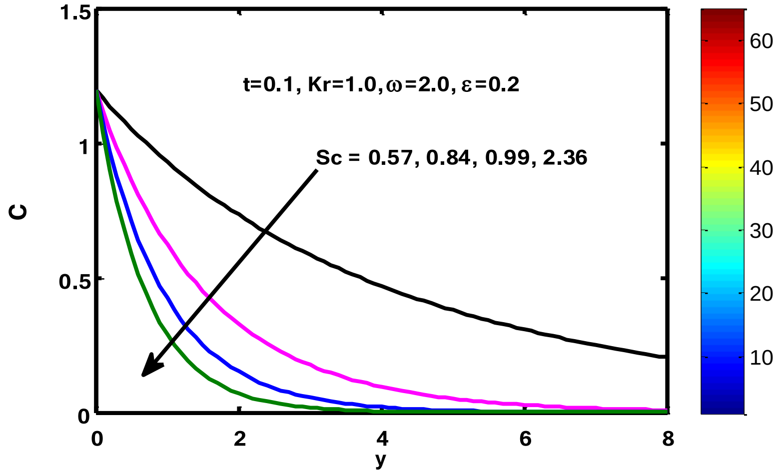

Fig.(15) :Concentration profiels for different values of Sc

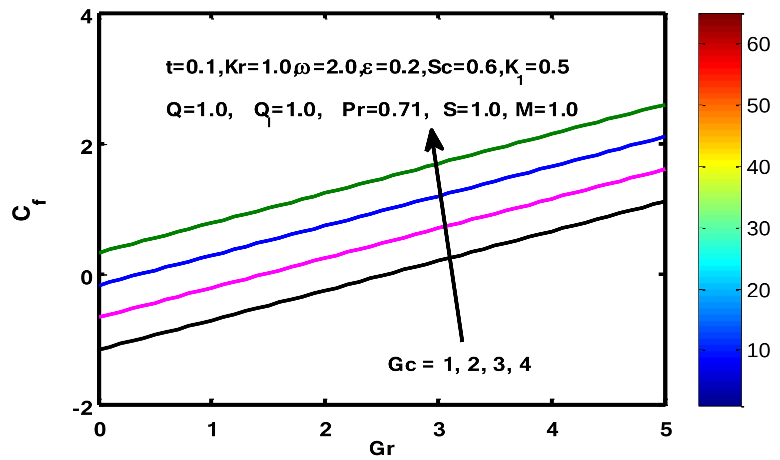

Fig. (16): Skin firction for different values of Gc versus Gr

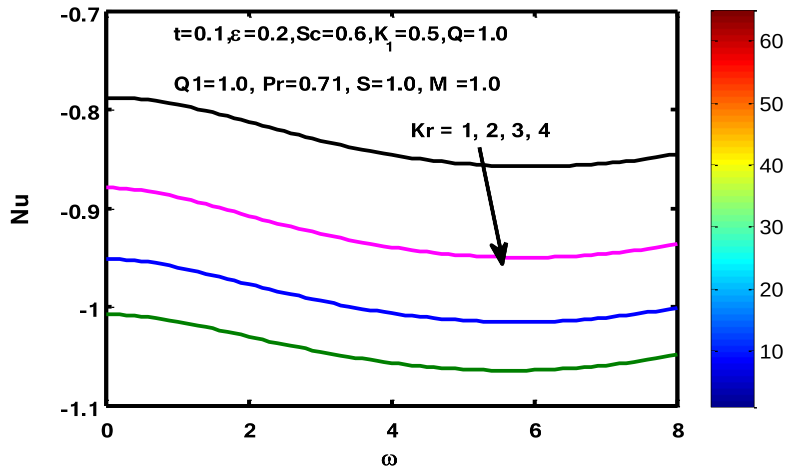

Fig. (17): Nusselt number for different values of Kr versus ω

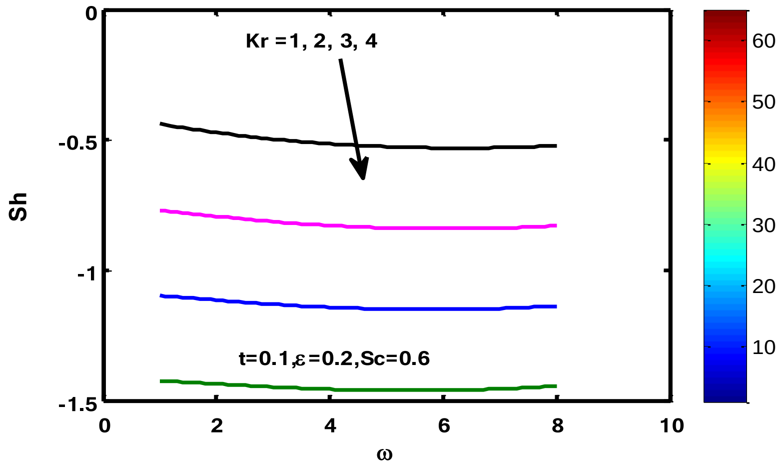

Fig. (18): Sherwood number for different values of Kr versus ω