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CHEMICAL AND RADIATION ABSORPTION EFFECTS ON MHD CONVECTIVE HEAT AND MASS TRANSFER FLOW PAST A SEMI-INFINITE VERTICAL MOVING POROUS PLATE WITH TIME DEPENDENT SUCTION

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ABSTRACT

An attempt has been made to study the effect of chemical reaction and radiation absorption on MHD free convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate with time dependent suction. The governing equations of motion are reduced to non-dimensional form and then exactly solved be regular perturbation method. The effect of various parameters like magnetic field parameter, chemical reaction parameter, Schmidt number, radiation absorption coefficient, heat absorption coefficient, porous permeability parameter, Prandtl number and time on the velocity, temperature and concentration profile as well as the surface skin-friction, surface heat transfer and surface mass transfer coefficient are obtained numerically and discussed graphically.

INTRODUCTION

The hydrodynamic rotating flow of electrically conducting viscous incompressible fluids has gained considerable attention because of its numerous applications in physics and engineering. In geophysics it is applied to measure and study the positions and velocities with respect to a fixed frame of reference on the surface of earth which rotate with respect to an inertial frame in the presence of its magnetic field. The subject of geophysical dynamics nowadays has become an important branch of fluid dynamics due to the increasing interest to study environment. In astrophysics it is applied to study the stellar and solar structure, inter planetary and inter stellar matter, solar storms and flares etc. In engineering it finds its application in MHD generators, ion propulsion, MHD bearings, MHD pumps, MHD boundary layer control of reentry vehicles etc.

Cramer, K. R. and Pai, S. I. [1] taken transverse applied magnetic field and magnetic Reynolds number are assumed to be very small, so that the induced magnetic field is negligible Muthucumaraswamy et al. [2] have studied the effect of homogenous chemical reaction of first order and free convection on the oscillating infinite vertical plate with variable temperature and mass diffusion. Sharma [3] investigate the effect of periodic heat and mass transfer on the unsteady free convection flow past a vertical flat plate in slip flow regime when suction velocity oscillates in time. Chaudhary and Jha [4] studied the effects of chemical reactions on MHD micropolar fluid flow past a vertical plate in slip-flow regime. Anjalidevi et al. [5] have examined the effect of chemical reaction on the flow in the presence of heat transfer and magnetic field. Muthucumaraswamy et al. [6] have investigated the effect of thermal radiation effects on flow past an impulsively started infinite isothermal vertical plate in the presence of first order chemical reaction. Deka et al. [7] studied the effect of the first order homogeneous chemical reaction on the process of an unsteady flow past an infinite vertical plate with a constant heat and mass transfer. Chamkha [8] studied the MHD flow of a numerical of uniformly stretched vertical permeable surface in the presence of heat generation/absorption and a chemical reaction. Soundalgekar and Patti [9] studied the problem of the flow past an impulsively started isothermal infinite vertical plate with mass transfer effects. The effects of foreign mass on the free-convection flow past semi-infinite vertical plates were studied [10]. Chamkha [11] assumed that the plate is embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of a transverse magnetic field. Raptis [12] investigate the steady flow of a viscous fluid through a very porous medium bounded by a porous plate subjected to a constant suction velocity by the presence of thermal radiation. Ibrahim et al [13] studied 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. Mohamed [14] investigate the effect of a first-order homogeneous chemical reaction, thermal radiation, heat source and thermal diffusion on the unsteady MHD double-diffusive free convection fluid flow past a vertical porous plate in the presence of mass blowing or suction. Recently, Baker [15] investigate free convection heat and mass transfer adjacent to moving vertical porous infinite plate for incompressible, micropolar fluid in a rotating frame of reference in the presence of heat generation or absorption effects, a first-order chemical reactions.

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Moreover, Al-Odat and Al-Azab [16] studied the influence of magnetic field on unsteady free convective heat and mass transfer flow along an impulsively started semi-infinite vertical plate taking into account a homogeneous chemical reaction of first order. The effect of radiation on the heat and fluid flow over an unsteady stretching surface has been analyzed by El-Aziz [17]. Singh et al. [18] studied the heat transfer over stretching surface in porous media with transverse magnetic field. Singh et al. [19] and [20] also investigated MHD oblique stagnation-point flow towards a stretching sheet with heat transfer for steady and unsteady cases. Elbashbeshy et al. [21] investigated the effects of thermal radiation and magnetic field on unsteady boundary layer mixed convection flow and heat transfer problem from a vertical porous stretching surface. Ahmed Sahin[22] studied influence of chemical reaction on transient MHD free Convective flow over a vertical plate. Recently, the chemical reaction, heat and mass transfer on MHD flow over a vertical stretching surface with heat source and thermal stratification have been presented by Kandasamy et al. [23]. The opposing buoyancy effects on simultaneous heat and mass transfer by natural convection in a fluid saturated porous medium investigated by Angirasa et al. [24]. Ahmed [25] investigates the effects of unsteady free convective MHD flow through a porous medium bounded by an infinite vertical porous plate. Ahmed Sahin [26] studied the Magneto hydrodynamic and chemical reaction effects on unsteady flow, heat and mass transfer characteristics in a viscous, incompressible and electrically conduction fluid over a semi-infinite vertical porous plate in a slip-flow regime.

The aim of the present study is to investigate the effect of chemical reaction and radiation absorption on MHD free convection flow past a semi-infinite vertical porous medium and moves a constant velocity in the flow direction when the transverse magnetic field is imposed to the plate and subjected to variable suction. It is assumed that the free stream velocity, temperature and concentration over which are superimposed an exponentially varying with time. The effects of various parameters have been shown numerically and discussed graphically.

Formulation of the Problem

Let us consider unsteady, two-dimensional, MHD free convection with heat and mass transfer flow of a laminar, viscous incompressible fluid past a semi-infinite vertical porous moving plate embedded in a porous medium and subjected to a transverse magnetic field in the presence of radiation, thermal and concentration buoyancy effects. In our problem there is no applied voltage which implies the absence of an electrical field. The magnetic Reynolds number of flow is taken to be sufficiently small enough, so that the induced magnetic field can be neglected. Due to the semi-infinite plate assumption, the physical variables are function of y' and the time t' only, therefore, the governing equations here are:

$$\frac{\partial v'}{\partial y'} = 0 \tag{1}$$

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

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{1}{\rho C_p}\left[k\frac{\partial^2 T'}{\partial y'^2} - Q_0\left(T' - T'_\infty\right)\right] + Q'_1\left(C' - C'_\infty\right) \tag{3}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - K'_r\left(C' - C'_\infty\right) \tag{4}$$

where the first and second terms on the RHS of the momentum equation (2) denote the thermal and concentration buoyancy effects, respectively, also the second and third terms on the RHS of the energy equation (3) represent the heat absorption and radiation absorption effects, respectively and the last term of the concentration equation (4) represents the chemical concentration buoyancy effects. It is assumed that permeable plate moves with a constant velocity in the direction of fluid flow, and the free stream velocity follows an exponentially increasing small perturbation method. In addition, it is assumed that the temperature and concentration at the wall as well as the suction velocity are exponentially varying with time.

where x', y' are the dimensional distance along and perpendicular to the plate, respectively. u' and v' are the velocity components in the x', y' directions respectively, g is the gravitational acceleration, ρ is thefluid density, β and β^* are the thermal and concentration expansion coefficients respectively, K' is the Darcy permeability, B_0 is the magnetic induction, T' is the thermal temperature inside the thermal boundary layer and C' is the corresponding concentration, σ is the electric conductivity, C_p is the specific heat at constant pressure, D is the diffusion coefficient, Q_0 is the dimensional heat absorption coefficient, Q_l' is the coefficient of proportionality of the radiation and K_r' is the chemical reaction parameter.

Using these assumptions, the boundary conditions for the velocity, temperature and concentration fields are

$$\begin{aligned} &u' = u_p', \quad T' = T_w', \quad C' = C_w' \quad \text{at} \quad y' = 0 \\ &u' \to U'(t'), \quad T' \to T_\infty', \; C' \to C_\infty', \quad \text{as} \quad y' \to \infty \end{aligned} \tag{5}$$

where u_p' is the velocity, T_w' and C_w' the temperature and concentration of the wall respectively, from the continuity equation (1), it is clear that the suction velocity at the plate is either a constant and or a function of time.

Hence the suction velocity normal to the plate is assumed in the form

$$v' = -V_0\left(1+\varepsilon f(t)\right) \tag{6}$$

order to write the governing Equations and the boundary conditions in dimensional following non-dimensional Quantities are introduced.

$$y = \frac{V_0 y'}{\nu},\; u = \frac{u'}{V_0},\; v = \frac{v'}{V_0},\; t = \frac{t' V_0^2}{\nu},\; u_p = \frac{u_p'}{V_0}\;\; \theta = \frac{T' - T_\infty'}{T_w' - T_\infty'},\; C = \frac{C' - C_\infty'}{C_w' - C_\infty'},\; U(t) = \frac{U'(t')}{V_0}$$

$$Gr = \frac{g\beta\nu(T_w' - T_\infty')}{V_0^3},\; Gm = \frac{g\beta^*\nu(C_w' - C_\infty')}{V_0^3},\; Sc = \frac{\nu}{D},\; \phi = \frac{\nu Q_0}{\rho C_p V_0^2},\; Q_1 = \frac{\nu Q_1'(C_w' - C_\infty')}{(T_w' - T_\infty')V_0^2}$$

$$M = \frac{\sigma B_0^2 \nu}{\rho V_0^2}\;\; K = \frac{K' V_0^2}{\nu^2},\; \gamma = \frac{K_r' \nu}{V_0^2},\; \Pr = \frac{\mu C_p}{k} \tag{7}$$

In view of Equations (6) and (7), Equations (2)-(4) reduce to the following dimensional form.

$$\frac{\partial u}{\partial t} - \left(1+\varepsilon f(t)\right)\frac{\partial u}{\partial y} = Gr\theta + GmC + \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{K}\right)u \tag{8}$$

$$\frac{\partial \theta}{\partial t} - \left(1+\varepsilon f(t)\right)\frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - \phi\theta + Q_l C \tag{9}$$

$$\frac{\partial C}{\partial t} - \left(1+\varepsilon f(t)\right)\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - \gamma C \tag{10}$$

where $M, K, Gr, Gm, \Pr, \gamma, Sc, \phi$ and Q_1 are the magnetic field parameter, permeability parameter, thermal Grashof number, Solutal Grashof number, Prandtl number, Chemical reaction number, Schmidt number, heat absorption parameter and absorption of radiation parameter.

The corresponding boundary conditions for $t > 0$ are transformed to:

$$\begin{aligned} &u = u_p, \quad \theta = 1, \quad C = 1 \quad \text{at} \quad y = 0 \\ &u \to U(t),\; \theta \to 0,\; C \to 0 \quad \text{as} \quad y \to \infty \end{aligned} \tag{11}$$

3. SOLUTION OF THE PROBLEM:

Equations (8) – (10) are coupled, non – linear partial differential Equations and these cannot be solved in closed form. 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 neighborhood of the fluid in the neighborhood of the plate as

$$\begin{aligned} u(y,t) &= u_0(y) + \varepsilon f(t) u_1(y) + o(\varepsilon^2) + \ldots\ldots\ldots\ldots \\ \theta(y,t) &= \theta_0(y) + \varepsilon f(t) \theta_1(y) + o(\varepsilon^2) + \ldots\ldots\ldots\ldots \\ C(y,t) &= C_0(y) + \varepsilon f(t) C_1(y) + o(\varepsilon^2) + \ldots\ldots\ldots\ldots \end{aligned} \tag{12}$$

Let us considering $f(t) = e^{\omega t}$,Substituting (12) in Equations (8) – (10) and equating the harmonic and non – harmonic terms, and neglecting the higher order terms of $o(\varepsilon^2)$, we obtain

$$u_0'' + u_0' - n_3 u_0 = -Gr\theta_0 - GmC_0 \tag{13}$$

$$u_1'' + u_1' - n_4 u_1 = -Gr\theta_1 - GmC_1 - u_0' \tag{14}$$

$$\theta_0'' + \Pr\theta_0' - \Pr\phi\theta_0 = -\Pr Q_1 C_0 \tag{15}$$

$$\theta_1'' + \Pr\theta_1' - \Pr n_2\theta_1 = -\Pr\theta_0' - \Pr Q_1 C_1 \tag{16}$$

$$C_0'' + ScC_0' - Sc\gamma C_0 = 0 \tag{17}$$

$$C_1'' + ScC_1' - Scn_1 C_1 = -ScC_0' \tag{18}$$

where prime denotes ordinary differentiation with respect to y.

The corresponding boundary conditions can be written as

$$\begin{aligned} &u_0 = u_p,\ u_1 = 0, \theta_0 = 1,\ \theta_1 = 0, C_0 = 1, C_1 = 0 \quad \text{at} \quad y = 0 \\ &u_0 \to 1, u_1 \to 1, \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0 \ \text{ as } \ y \to \infty \end{aligned} \tag{19}$$

Let us consider $f(t) = e^{\omega t}$ then solving equations (13) – (18) under the boundary conditions (19), we obtain the velocity, temperature and concentration distribution in the boundary layer as

$$u(y,t) = 1 + A_{11}\exp(-m_5 y) - A_8\exp(-m_3 y) + A_9\exp(-m_1 y) + A_{10}\exp(-m_1 y) + \varepsilon\exp(\omega t)\begin{bmatrix} 1 + A_{23}\exp(-m_6 y) + A_{12}\exp(-m_5 y) + A_{13}\exp(-m_3 y) \\ + A_{14}\exp(-m_1 y) + A_{15}\exp(-m_1 y) + A_{16}\exp(-m_4 y) + \\ A_{17}\exp(-m_3 y) + A_{18}\exp(-m_1 y) + A_{19}\exp(-m_2 y) \\ + A_{20}\exp(-m_1 y) + A_{21}\exp(-m_1 y) + A_{22}\exp(-m_2 y) \end{bmatrix}$$

$$\theta(y,t) = (1 - A_2)\exp(-m_3 y) + A_2\exp(-m_1 y) + \varepsilon\exp(\omega t)\begin{bmatrix} A_7\exp(-m_4 y) + A_3\exp(-m_3 y) + A_4\exp(-m_1 y) \\ + A_5\exp(-m_2 y) + A_6\exp(-m_1 y) \end{bmatrix}$$

$$C(y,t) = \exp(-m_1 y) + \varepsilon\exp(\omega t)\left[A_1\left[\exp(-m_1 y) - \exp(-m_2 y)\right]\right]$$

The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow.

Skin friction

Knowing the velocity field, the skin – friction at the plate can be obtained, which in non –dimensional form is given by

$$C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0} = m_5 A_{11} + m_3 A_8 + m_1 A_9 + m_1 A_{10} + \varepsilon e^{\omega t} \begin{pmatrix} m_6 A_{23} + m_5 A_{12} + m_3 A_{13} + m_1 A_{14} \\ + m_1 A_{15} + m_4 A_{16} + m_3 A_{17} + m_1 A_{18} \\ + m_2 A_{19} + m_1 A_{20} + m_1 A_{21} + m_2 A_{22} \end{pmatrix}$$

Nusselt number

Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non –dimensional form is given, in terms of the Nusselt number, is given by

$$N_u = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = m_3\left(1 - A_2\right) + m_1 A_2 + \varepsilon e^{\omega t}\left(m_4 A_7 + m_3 A_3 + m_1 A_4 + m_2 A_5 + m_1 A_6\right)$$

Sherwood number

Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in non –dimensional form, in terms of the Sherwood number, is given by

$$S_h = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = m_1 + \varepsilon e^{\omega t} A_1\left(m_1 - m_2\right)$$

Here the constants are not given because sake of brevity.

4. RESULTS AND DISCUSSION

In order to get a physical insight in to the problem the effects of various governing parameters on the physical quantities are computed and represented in Figures 1-17 and discussed in detail.

The formulation of the effects of chemical reaction and heat absorption on MHD convective flow and mass transfer of an incompressible, viscous fluid along a semi infinite vertical porous moving plate in a porous medium has been performed in the preceding sections. This enables us to carry out the numerical calculations for the distribution of the velocity, temperature and concentration across the boundary layer for various values of the parameters.

The influence of Magnetic field on the velocity profiles has been studied in Fig .1. It is seen that the increase in the applied magnetic intensity contributes to the decrease in the velocity. Further, it is seen that the magnetic influence does not contribute significantly as we move away from the bounding surface. The influence of Schmidt number *Sc* on velocity profiles has been illustrated in Fig.2. It is observed that, while all other participating parameters are held constant and *Sc* is increased, it is seen that the velocity decreases in general. Further, it is noticed that as we move far away from the plate, the fluid velocity goes down. The effect of Prandtl number on the velocity profiles has been illustrated in Fig.3. It is observed that as the Prandtl number increases, the velocity decreases in general. The dispersion in the velocity profiles is found to be more significant for smaller values of Pr and not that significant at higher values of Prandtl number.

The effect of Grashof number on the velocity profiles is seen in Fig. 4. Increase in *Gr* contributes to an increase in velocity when all other parameters that appear in the velocity field are held constant. Also it is noticed that as we move away from the plate the influence of *Gr* is not that significant. The effect of modified Grashof number *Gm* on the velocity profiles is observed in Fig.5. Increase in *Gm* is found to influence the velocity to increase. Also, it is seen that as we move far away from the plate it is seen that the effect of *Gm* is found to be not that significant. The contribution of absorption heat radiation parameter on the velocity profiles is noticed in Fig.6. The increase an absorption heat radiation parameter contributes to the increase in the velocity field. Further, it is noticed that the velocity decreases as we move away from the plate which is found to be independent of absorption heat radiation parameter. The influence of the porosity of the boundary on the velocity of the fluid medium has been shown in Fig 7. It is seen that as the porosity of the fluid bed increases, the velocity also increases which is in tune with the realistic situation. Further, the porosity of the boundary does not influence of the fluid motion as we move far away from the bounding surface. Fig.8

shows that the effect of increasing the chemical reaction parameter on velocity profiles. It is noticed that velocity of flow field are decreasing, as the values of chemical reaction are increasing.

The Effect of Prandtl number on the temperature field has been illustrated in Fig.9. It is observed that as the Prandtl number increases, the temperature in the fluid medium decreases. Also, as we move away from the boundary, the Prandtl number has not much of significant influence on the temperature. The dispersion is not found to be significant. The influence of Schmidt number on the temperature is illustrated in Fig. 10. It is observed that increase in Sc contributes to decrease of temperature of the fluid medium and trend gets reversed. Further, it is seen that Sc does not contributes much to the temperature field as we move far away from the bounding surface. Fig.11 illustrates the influence of the radiation absorption parameter on the temperature profiles in the boundary layer. As radiation absorption parameter increases, temperature distributions increase when the other physical parameters are fixed. Fig.12 represents the decreasing result of temperature when heat absorption parameter is increasing.

The influence of Schmidt number on the concentration is illustrated in Fig. 13. It is observed that increase in Sc contributes to decrease of concentration of the fluid medium. Further, it is seen that Sc does not contributes much to the concentration field as we move far away from the bounding surface. Fig.14 shows that the effect of increasing the chemical reaction parameter on concentration profiles. It is noticed that species concentration are decreasing, as the values of chemical reaction are increasing. The effect of chemical reaction on velocity and temperature is less dominant in comparison to concentration.

Skin friction for various values of magnetic field strength is portrayed through Fig 15. It is seen that skin friction decreases, as magnetic parameter increases, whereas it is increasing when time parameter is increasing. The rate of heat transfer is displayed in the Fig 16. It is increasing when Prandtl number and time parameter (t) are increasing. The consolidated influence of Schmidt number with respect to time over rate of mass transfer is seen in Fig. 17. It is seen that in general, increase in Sc contributes to increase of rate of mass transfer and is found to be independent of Sc. Further, for a constant Sc, as t increases the rate of mass transfer remains almost constant

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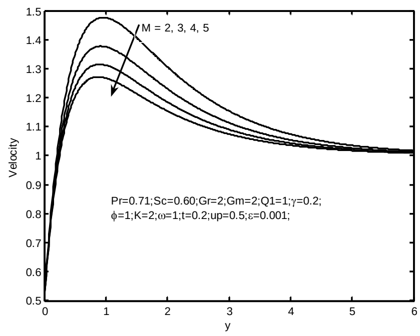

Fig.1. Effect of magnetic field on velocity profiles.

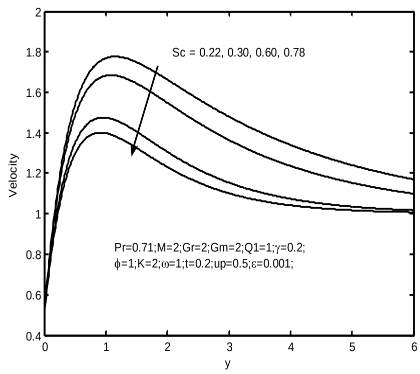

Fig.2. Effect of Schmidt number on velocity profiles.

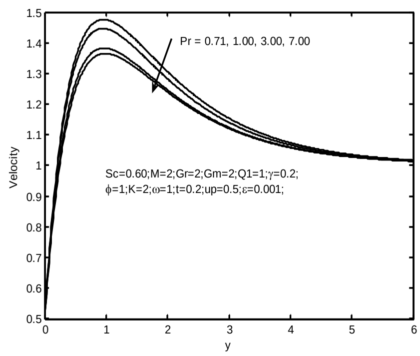

Fig.3. Effect of Prandtl number on velocity profiles.

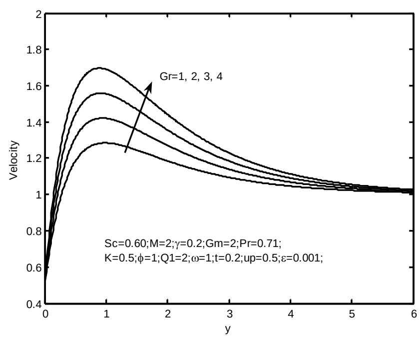

Fig.4. Effect of Grashof number on velocity profiles.

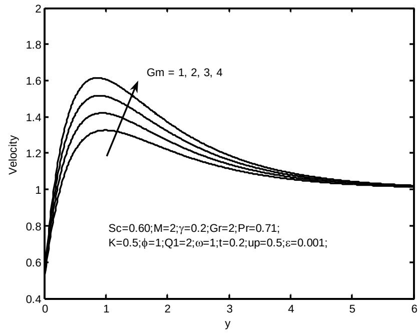

Fig.5. Effect of mass Grashof number on velocity profiles.

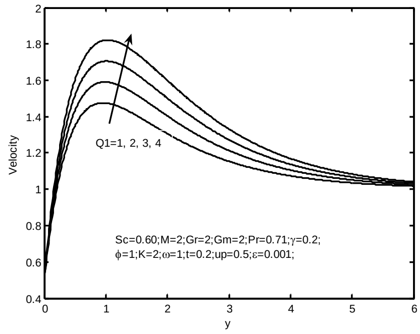

Fig.6. Effect of radiation absorption parameter on velocity profiles.

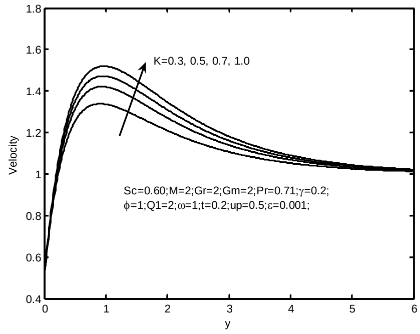

Fig.7. Effect of permeability parameter on velocity profiles.

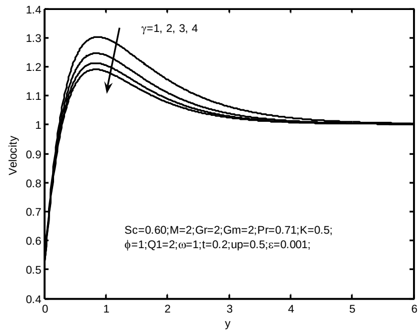

Fig.8. Effect of chemical reaction parameter on velocity profiles.

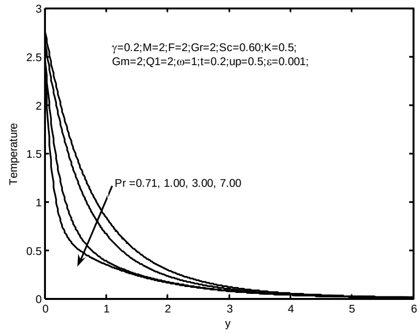

Fig.9. Effect of Prandtl number on temperature profiles.

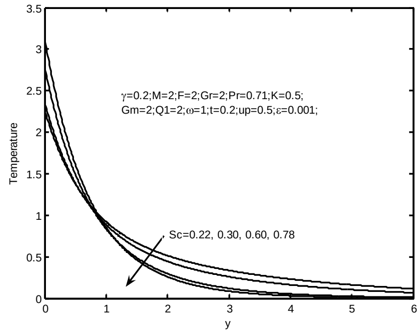

Fig.10. Effect of Schmidt number on temperature profiles.

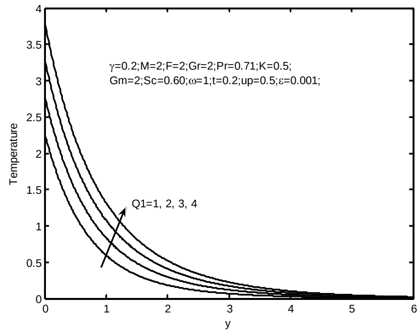

Fig.11. Effect of radiation absorption parameter on temperature profiles.

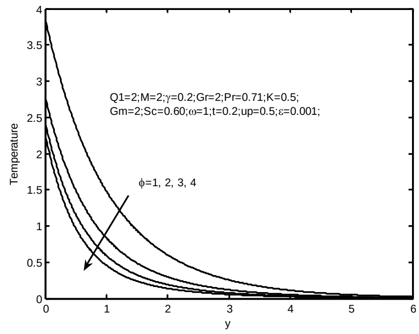

Fig.12. Effect of radiation heat source parameter on temperature profiles.

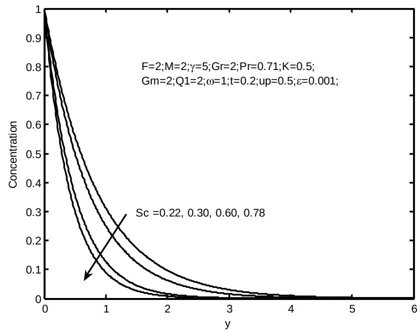

Fig.13. Effect of Schmidt number on concentration profiles.

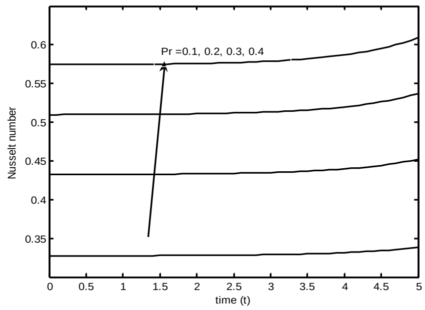

Fig.16. Effect of Prandtl number on Nusselt number.

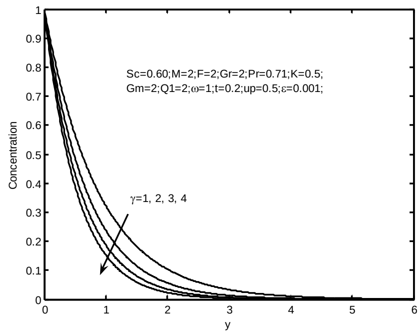

Fig.14. Effect of chemical reaction parameter on concentration profiles.

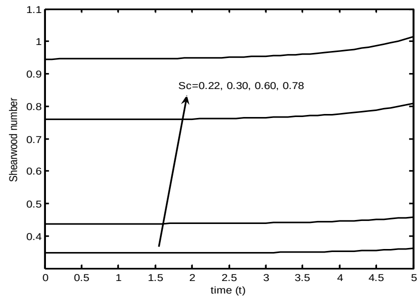

Fig.17. Effect of Schmidt number on Sherwood number.

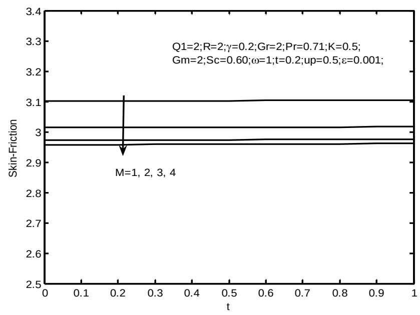

Fig.15. Effect of magnetic field on skin-friction.

