Radiation absorption and chemical reaction effects on MHD free convection flow heat and mass transfer past an accelerated vertical plate

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In this paper we consider unsteady MHD natural convection flow heat and mass transfer of an electrically conducting, viscous, incompressible fluid past an infinite vertical plate embedded in a uniform porous medium in a rotating system taking Hall current in the presence of influence of chemical reaction and radiation absorption effects into account. The expression for velocity, temperature and concentration distribution, skin friction, rate of heat and mass transfer coefficients at the plate are obtained using perturbation technique. The effect of various physical parameters occurring into the problem discussed with the help of graphs.

Keywords: Hall current, Free convection, Porous medium, Hear source, Heat absorption

Introduction

In many chemical engineering processes, the chemical reaction do occur between mass and fluid in which plate is moving. These processes take place in numerous industrial applications such as polymer production, manufacturing of ceramics or glassware and food processing. In the light of the fact that, the combination of heat and mass transfer problems with chemical reaction are of importance in many process, and have therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electricity is one in which electrical energy is extracted directly from the moving conducting fluid.[1-8]

The study of heat generation or absorption effects in moving fluids is importance in view of several physical problems, such as fluids in moving fluids is importance in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions.[9-15]

Investigation of hydromagnetic natural convection flow with heat and mass transfer in porous and non-porous media has drawn considerable attentions of several researchers owing to its applications in geophysics, astrophysics, aeronautics, meteorology, electronics, chemical, and metallurgy and petroleum industries. Magnetohydrodynamic (MHD) natural convection flow of an electrically conducting fluid with porous medium has also been successfully exploited in crystal formation.[18-26]

The study of natural convection flow induced by the simultaneous action of thermal and solutal buoyancy forces acting over bodies with different geometries in a fluid with porous medium is prevalent in many natural phenomena and has varied a wide range of industrial applications. For example, the presence of pure air or water is impossible because some foreign mass may be present either naturally or mixed with air or water due to industrial emissions, in atmospheric flows.

Natural processes such as attenuation of toxic waste in water bodies, vaporization of mist and fog, photosynthesis, transpiration, sea-wind formation, drying of porous solids, and formation of ocean currents.[27-36]

Hence, in view of the above consideration, we discussed unsteady MHD natural convection flow heat and mass transfer of an electrically conducting, viscous, incompressible fluid past an infinite vertical plate embedded in a uniform porous medium in a rotating system taking Hall current in the presence of influence of chemical reaction and radiation absorption effects into account.

Formulation of the problem

Consider unsteady MHD natural convection flow heat and mass transfer of an electrically conducting, viscous, incompressible fluid past an infinite vertical plate embedded in a uniform porous medium in a rotating system taking Hall current, chemical reaction and radiation absorption into account. Assuming Hall currents, the generalized Ohm's la[16] may be put in the following form:

$$\vec{j}=\frac{\sigma}{1+m^2}\left(\vec{E}+\vec{V}\times\vec{B}-\frac{1}{\sigma n_e}\vec{j}\times\vec{B}\right)$$

where $\vec{V}$ represent the velocity vector, $\vec{E}$ is the intensity vector of the electric field, $\vec{B}$ is the magnetic induction vector, $\vec{j}$ is the electric current density vector, m is the Hall current parameter, is the electrical conductivity and is the number density of the electron. A very interesting fact that the effect of Hall current gives rise to a force in the z' direction which in turn produces a cross flow velocity in this direction and thus the flow becomes three-dimensional.

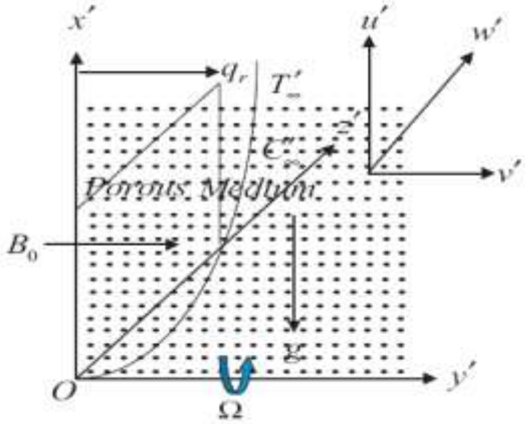

Figure (1): Geometry of the problem

Coordinate system is chosen in such a way that $x'-$is considered along the plate in upward direction and $y'-$axis normal to plane of the plate in the fluid. A uniform transverse magnetic field B_0 is applied in a direction which is parallel to $y'-$axis. The fluid and plate rotate in unison with uniform angular velocity Ω' about $y'-$axis. Initially, i.e. at time $t'\leq 0$, both the fluid and plate are at rest and are maintained at a uniform temperature T'_∞. Also species concentration at the surface of the plate as well as at every point within the fluid is maintained at uniform concentration C'_∞. At the time $t'>0$, plate starts moving in $x'-$ direction with a velocity $u''=U\,t'$ in its plane. The temperature at the surface of the plate is raised to uniform temperature T'_w and the spices concentration at the surface of the plate is raised to uniform species concentration C'_w and is maintained thereafter. Geometry of the problem is presented in figure (1). Since plate is of infinite extent in x' and z' directions and is electrically non-conducting, all physical quantities except pressure depend on y' and t' only. Also no applied or polarized voltage exists so the effect of polarization of fluid is negligible. This correspondence to the case where no energy is added or extracted from the fluid by electrical means[17]. It is assumed that the induced magnetic field generated by fluid motion is negligible in comparison to the applied one. This assumption is justified because magnetic Reynolds number is very small for liquid metals and partially ionized fluids which are commonly used in industrial applications.

Conservation of momentum

$$\frac{\partial u'}{\partial t'} + 2\Omega w' = \nu \frac{\partial^2 u'}{\partial y'^2} + \frac{\sigma B_0^2}{\rho\left(1+m^2\right)}\left(u' + mw'\right) + g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) - \frac{\nu}{K'_1}u' \quad (1)$$

$$\frac{\partial w'}{\partial t'} + 2\Omega u' = \nu \frac{\partial^2 w'}{\partial y'^2} + \frac{\sigma B_0^2}{\rho\left(1+m^2\right)}\left(mu' - w'\right) - \frac{\nu}{K'_1}w' \quad (2)$$

Conservation of energy

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{Q_0}{\rho C_p}\left(T' - T'_\infty\right) + Q_l'\left(C' - C'_\infty\right) \quad (3)$$

$$\frac{\partial C'}{\partial t'} = D_M \frac{\partial^2 C'}{\partial y'^2} - Kr'\left(C' - C'_\infty\right) \quad (4)$$

with boundary conditions

$$\begin{aligned} &u' = 0, \quad T' - T'_\infty = \theta_w(x)\left[1 + \varepsilon e^{i\omega' t'}\right], \\ &C' - C'_\infty = C_w(x)\left[1 + \varepsilon e^{i\omega' t'}\right] \; at \; y' = 0 \\ &u' \to \infty, T' \to \infty, C' \to \infty \;\; as \; y' \to \infty \end{aligned} \quad (5)$$

where $U', \nu, g, \beta, \beta^*, T', k, \rho, C_p, D_1, \sigma, B_0, K', C', K^*, u', \varepsilon, \omega'$ 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.

The following dimensionless variables and parameters of the problem are

$$\begin{aligned} &u = \frac{u'_0}{U}, \quad y = \frac{Uy'}{\nu}, \quad t = \frac{t'U^2}{\nu}, \quad \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty} \\ &\phi = \frac{C' - C'_\infty}{C'_w - C'_\infty}, \omega = \frac{\nu\omega'}{U^2}, Da = \frac{K'}{U^2}, \; Sc = \frac{\nu}{D} \\ &Kr = \frac{Kr^*\nu}{D_1 U^2}, \quad Q = \frac{Q_0 \nu}{\rho C_p U^2}, \quad \Pr = \frac{\nu \rho C_p}{k} \\ &K_1 = \frac{16 a\sigma^* \nu^2 L T'^3_\infty}{kU^2}, \quad Gr = \frac{\nu^2 \beta g \theta_w(x)}{U^4 L} \\ &M^2 = \frac{\sigma B_0^2 \nu}{\rho U^2}, \quad Q_l = \frac{Q_l' \nu\left(C'_w - C'_\infty\right)}{U^2\left(T'_w - T'_\infty\right)} \\ &Gc = \frac{\nu^2 \beta^* g\left(C'_w - C'_\infty\right)}{U^4 L} \end{aligned} \quad (6)$$

Using (6) into (1) to (4) yield the following

$$\frac{\partial u}{\partial t} + 2K^2 w = \frac{\partial^2 u}{\partial y^2} - \frac{M^2}{1+m^2}\left(u + mw\right) + Gr\,\theta + Gm\,\phi - \frac{u}{K_1} \quad (7)$$

$$\frac{\partial w}{\partial t} + 2K^2 u = \frac{\partial^2 w}{\partial y^2} + \frac{M^2}{\left(1+m^2\right)}\left(mu - w\right) - \frac{w}{K_1} \quad (8)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - Q\theta + Q_l C \quad (9)$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} - Kr\,\phi \quad (10)$$

where $Gr, Gc, M, K, K_1, Kr, Sc, \Pr, Q, Q_l$ are the Grashof number, mass Grashof number, Hartmann number, rotation parameter, permeability of the porous medium, chemical reaction parameter, Schmidt number, Prandtl number, heat source parameter, radiation absorption parameter respectively. With the following boundary conditions

$$\begin{aligned} &u = w = 0, \theta = 0, \phi = 0 \quad \forall\ y \quad \&\ t \le 0 \\ &u = t, w = 0, \theta = 1, \phi = 1 \text{ at } y = 0\ \&\ t > 0 \\ &u \to 0,\ w \to 0,\ \theta \to 0,\ \phi \to 0 \\ &\qquad as\ \ y \to \infty \text{ for } t > 0 \end{aligned} \tag{11}$$

Equations (7) and (8) are presented, in complex form, as

$$\frac{\partial F}{\partial t} = \frac{\partial^2 F}{\partial y^2} - \alpha F + Gr\,\theta + Gm\,\phi \tag{12}$$

where

$F = u + iv$ and $\alpha = \dfrac{M^2(1-im)}{1+m^2} + \dfrac{1}{K_1 - 2iK^2}$

The initial and boundary conditions (11) in compact form, become

$$\begin{aligned} &F = 0, \theta = 0, \phi = 0 \text{ for all } y \quad \text{and } t \le 0 \\ &F = t, \theta = 1, \phi = 1 \quad \text{at} \quad y = 0 \quad \text{and } t > 0 \\ &F \to 0,\ \theta \to 0_{\infty},\ \phi \to 0 \qquad as\ \ y \to \infty \\ &\qquad \text{for } t > 0 \end{aligned} \tag{13}$$

The system of differential Equations (9), (10) and (12) together with the initial and boundary conditions (13) describes our model for the MHD free convective heat and mass transfer flow of a viscous, incompressible, electrically conducting fluid past an infinite vertical plate embedded in a porous medium taking Hall current, rotation into consideration.

Method of solution

In order to reduce the above system of partial differential equations (9), (10) and (12) under the boundary conditions given equations (14) we assume in complex form the solution of the problems as

$$\begin{aligned} F(y,t) &= F_0(y)\, e^{i\omega t} \\ \theta(y,t) &= \theta_0(y)\, e^{i\omega t} \\ \phi(y,t) &= \phi_0(y) e^{i\omega t} \end{aligned} \tag{14}$$

Substitute equation (14) in to the equations (9), (10) and (12) the set of ordinary differential equations are the following form

$$F_0'' - (\alpha + i\omega) F_0 = -Gr\theta_0 - Gm\phi_0 \tag{15}$$

$$\theta_0'' - (i\omega + Q)\Pr\theta_0 = -Q_l \Pr\phi_0 \tag{16}$$

$$\phi_0'' - (i\omega + Kr) Sc\,\phi_0 = 0 \tag{17}$$

The initial and boundary conditions (14) in compact form, become

$$\begin{aligned} &F_0 = t, \theta_0 = 1, \phi_0 = 1 \text{ at } y = 0 \ \ \&\ t > 0 \\ &F_1 \to 0,\ \ \theta_0 \to 0,\ \ \phi_0 \to 0 \\ &\qquad as\ \ y \to \infty \text{ for } t > 0 \end{aligned} \tag{18}$$

The exact solution for the fluid temperature $\theta(y,t)$, species concentration $\phi(y,t)$ and fluid velocity $F(y,t)$ are obtained and expressed from equations from (15) - (17) under the boundary condition (18) in the following form:

$$\begin{aligned} F(y,t) &= \left\{ Z_1 e^{m_2 y} + Z_2 e^{m_4 y} + Z_3 e^{m_2 y} + Z_4 e^{m_6 y} \right\} e^{i\omega t} \\ \theta(y,t) &= \left\{ D_1 e^{m_2 y} + D_2 e^{m_4 y} \right\} e^{i\omega t} \\ \phi(y,t) &= \left\{ e^{m_2 y} \right\} e^{i\omega t} \end{aligned}$$

Skin-friction

$$\left(\frac{\partial F}{\partial y}\right)_{y=0} = \left(m_2 Z_1 + m_4 Z_2 + m_2 Z_3 + m_6 Z_4\right)\cos \omega t$$

Sherwood number

$$\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = \left(m_2\right)\cos \omega t$$

Nusselt number

$$\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left(D_1 m_2 + D_2 m_4\right)\cos \omega t$$

Table (1): Skin friction (τ) versus Gr

Gc	Q_l	Pr	Sc	m	Kr	K_1	M	ω	K	Q	t	τ
1.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**-1.197**
2.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**-0.493**
3.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**0.2092**
4.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**0.9123**
5.0	**1.0**	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**12.4**
5.0	**2.0**	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**12.7**
5.0	**3.0**	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**13.01**
5.0	**4.0**	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**13.31**
5.0	1.0	**0.3**	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**12.4**
5.0	1.0	**0.5**	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**12.1**
5.0	1.0	**0.71**	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**11.86**
5.0	1.0	**1.0**	0.22	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**11.47**
5.0	1.0	0.71	**0.16**	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**12.56**
5.0	1.0	0.71	**0.22**	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**12.4**
5.0	1.0	0.71	**0.31**	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**12.1**
5.0	1.0	0.71	**0.60**	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**11.88**
5.0	1.0	0.71	0.22	**0.5**	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**1.615**
5.0	1.0	0.71	0.22	**1.0**	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**1.724**
5.0	1.0	0.71	0.22	**1.5**	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**1.757**
5.0	1.0	0.71	0.22	**2.0**	1.0	1.0	1.0	0.5	1.0	1.0	1.0	**1.766**
5.0	1.0	0.71	0.22	0.5	**1.0**	1.0	1.0	0.5	1.0	1.0	1.0	**1.615**
5.0	1.0	0.71	0.22	0.5	**2.0**	1.0	1.0	0.5	1.0	1.0	1.0	**1.655**
5.0	1.0	0.71	0.22	0.5	**3.0**	1.0	1.0	0.5	1.0	1.0	1.0	**1.731**
5.0	1.0	0.71	0.22	0.5	**4.0**	1.0	1.0	0.5	1.0	1.0	1.0	**2.002**
5.0	1.0	0.71	0.22	0.5	1.0	**1.0**	1.0	0.5	1.0	1.0	1.0	**1.615**
5.0	1.0	0.71	0.22	0.5	1.0	**2.0**	1.0	0.5	1.0	1.0	1.0	**1.746**
5.0	1.0	0.71	0.22	0.5	1.0	**3.0**	1.0	0.5	1.0	1.0	1.0	**1.778**
5.0	1.0	0.71	0.22	0.5	1.0	**4.0**	1.0	0.5	1.0	1.0	1.0	**1.791**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	**1.0**	0.5	1.0	1.0	1.0	**1.615**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	**2.0**	0.5	1.0	1.0	1.0	**1.129**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	**3.0**	0.5	1.0	1.0	1.0	**0.0219**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	**4.0**	0.5	1.0	1.0	1.0	**-1.756**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	**0.5**	1.0	1.0	1.0	**1.615**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	**1.0**	1.0	1.0	1.0	**0.7038**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	**1.5**	1.0	1.0	1.0	**-3.474**

5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	**2.0**	1.0	1.0	1.0	**-11.24**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	**0.5**	1.0	1.0	**12.2**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	**1.0**	1.0	1.0	**12.4**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	**1.5**	1.0	1.0	**12.86**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	**2.0**	1.0	1.0	**14.71**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	**1.0**	1.0	**2.054**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	**2.0**	1.0	**0.2283**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	**3.0**	1.0	**-0.1058**
5.0	1.0	0.71	0.22	0.5	1.0	1.0	1.0	0.5	1.0	**4.0**	1.0	**-4.016**

Table (2): Nusselt number (Nu) versus ω

Q	Pr	t	Nu
1.0	0.3	0.2	**-0.5626**
2.0	0.3	0.2	**-0.6746**
3.0	0.3	0.2	**-0.8175**
4.0	0.3	0.2	**-0.9717**
1.0	**0.3**	0.2	**-0.5626**
1.0	**0.5**	0.2	**-0.7481**
1.0	**0.71**	0.2	**-0.959**
1.0	**1.0**	0.2	**-1.368**
1.0	0.22	**0.2**	**-0.5626**
1.0	0.22	**0.4**	**-1.1330**
1.0	0.22	**0.6**	**-1.3170**
1.0	0.22	**0.8**	**-1.3470**

Table (3): Sherwood number (Sh) versus ω

Kr	Sc	t	Sh
1.0	0.22	0.2	**-0.5603**
2.0	0.22	0.2	**-0.6724**
3.0	0.22	0.2	**-0.8124**
4.0	0.22	0.2	**-0.9381**
1.0	**0.16**	0.2	**-0.4778**
1.0	**0.22**	0.2	**-0.5603**
1.0	**0.31**	0.2	**-0.6651**
1.0	**0.60**	0.2	**-0.9253**
1.0	0.22	**0.2**	**-0.5603**
1.0	0.22	**0.4**	**-1.2750**
1.0	0.22	**0.6**	**-1.1290**
1.0	0.22	**0.8**	**-1.1210**

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), rotation parameter (K), thermal radiation parameter (K_1), chemical reaction (Kr), the magnetic field parameter (M), Hall current (m), the Prandtl number $(\Pr)$, heat absorption (Q), radiation absorption parameter (Q_l) and Schmidt number (Sc) on the velocity, temperature and concentration profiles can be analyzed from figures (2) - (16). Figure (2) and (3) 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 (4) we observe that the effect of K is to decrease the velocity profile throughout the boundary layer which results in the thinning of the boundary layer thickness with increasing values of rotation parameter. Figure (5) shows that K_1 on the velocity profiles; it is observed that increases in K_1 the velocity increases. The velocity profiles for different values of the Kr shown in figure (6). It is observed that the velocity decreases with increasing chemical reaction parameter. The influence of M on the velocity profiles has been studied in figure (7). 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. Figure (8) demonstrate the effect of m on the velocity profiles respectively. It is perceived form this figure that, the velocity increasing on increasing the values of m throughout the boundary layer region. This implies that, Hall current tends to accelerate the fluid velocity throughout the boundary layer region which is consistent with the fact that Hall current induces flow in the flow filled. Figure (9) is sketched to show the effects of $\Pr$ on velocity profiles. Four different realistic values of $\Pr$ that are physically correspond to air, electrolytic solution, water and engine oil respectively are chosen. It is observed that the velocity decreases with increasing values of $\Pr$. This is due to the fact that fluid with large Prandtl number has high viscosity and small thermal conductivity, which make the fluid thick and causes a decrease in fluid velocity. Figure (10) illustrates the influence of 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 (10) in which the velocity decreases as Q increases. The hydrodynamic boundary layer decreases as the Q increase. The effect of increasing the value of the Q_l on the velocity is shown in figure (11). 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 Schmidt number (Sc) is shown in figure (12). It is observed that the velocity decreases with Schmidt number. The influence of Prandtl number $(\Pr)$, heat source parameter (Q) on the temperature distribution is respectively, shown on figures (13) - (14). From figure (13) we observe that the effect of $\Pr$ is to enhance heat transfer as thermal boundary layer thickness decreases with increase in $\Pr$. Figure (14) depicts the effects of 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. Figure (15) and (16) depict the influence of the non-dimensional Sc and Kr on concentration profiles, respectively. In figure (15) we see that the concentration profiles decrease with increasing values of th**e** Schmidt number. The effect of Kr is very important in the concentration field. Kr increases the rate of interfacial mass transfer. Reaction reduces the local concentration, thus increases its concentration gradient and its flux shown in figure (16). Knowing the velocity profiles, temperature profiles and concentration profiles, it is customary to study the skin friction; Nusselt number and Sherwood number in dimensionless form are as follows. The local values of the skin friction, Nusselt number and Sherwood number for fixed parameters and are depicted in table (1) – (3) respectively. Table (1) shows that the axial coordinate for different values of mass Grashof number, radiation absorption, Prandtl number, Schmidt member, hall current, chemical reaction, permeability of the porous medium, magnetic parameter, cyclotron frequency, rotation parameter and heat source parameter. It is observed that an increasing values of mass Grashof number, radiation absorption parameter, hall current, chemical reaction parameter, permeability of the porous medium, rotation parameter the skin friction increases. The reverse effect is observed for the parameters Prandtl number, Schmidt member, magnetic parameter, cyclotron frequency and heat source parameter. Table (2) depicted Nusselt number for different values of Prandtl number heat source parameter and dimensionless time parameter, it is clear that an increasing values of the above parameter results were decreases. Form table (3) we observed that Sherwood number for various values of chemical reaction parameter, Schmidt number and time; it is evident that an increasing values of the parameters the effects is decreases.

Appendix

$$m_2 = -\sqrt{KrSc + i\omega Sc}, m_4 = -\sqrt{Q\,\mathrm{Pr} + i\omega\,\mathrm{Pr}}$$

$$m_6 = -\sqrt{\alpha + i\omega},\ D_1 = -\frac{Q_l\,\mathrm{Pr}}{m_2^2 - (Q\,\mathrm{Pr} + i\omega\,\mathrm{Pr})}$$

$$D_2 = (1 - D_1), \qquad Z_1 = -\frac{GrD_1}{m_2^2 - (\alpha + i\omega)}$$

$$Z_2 = -\frac{GrD_2}{m_4^2 - (\alpha + i\omega)}, Z_3 = -\frac{Gc}{m_2^2 - (\alpha + i\omega)}$$

$$Z_4 = (t - Z_1 - Z_2 - Z_3)$$

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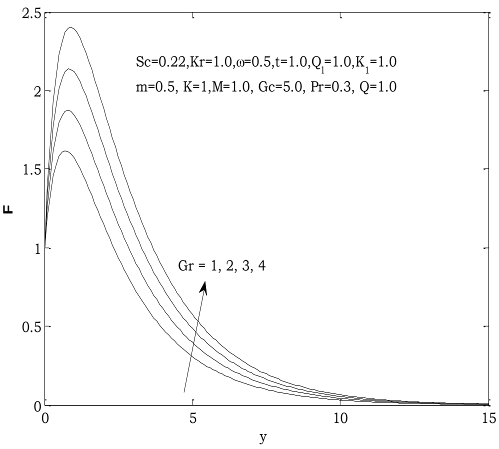


Figure (2): Velocity profiles for different values of Gr

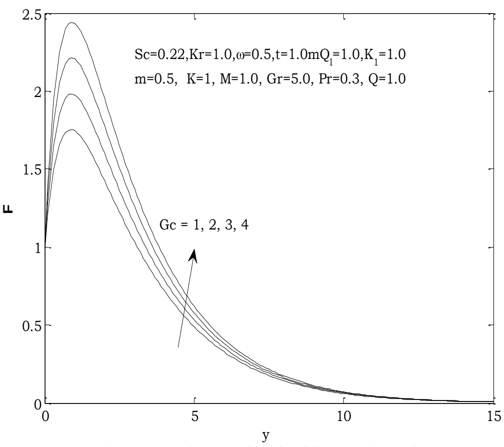


Figure (3): Velocity profiles for different values of Gc

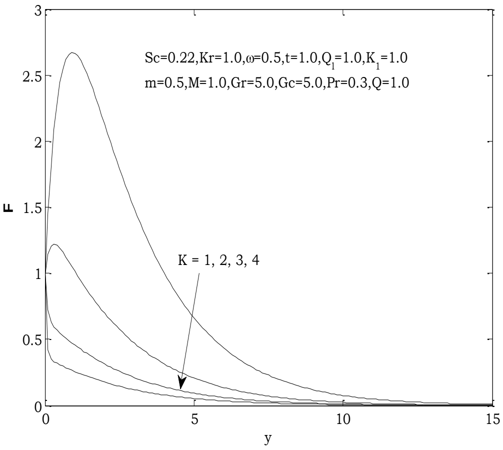


Figure (4): Velocity profiles for different values of K

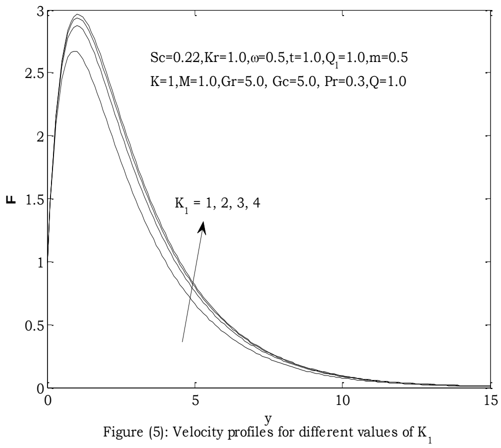


Figure (5): Velocity profiles for different values of K_1

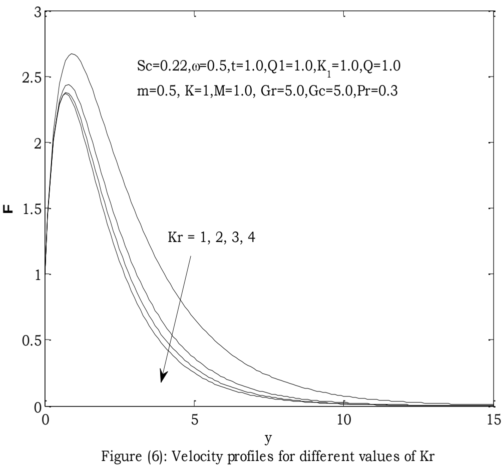
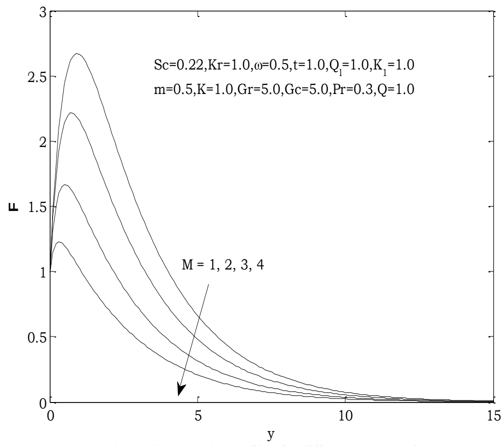


Figure (6): Velocity profiles for different values of Kr



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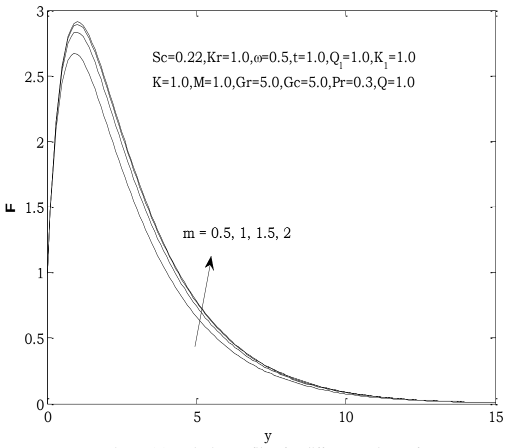

Figure (8): Velocity profiles for different values of m

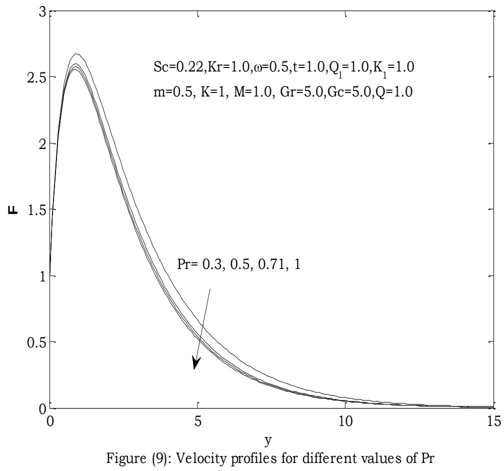

Figure (9): Velocity profiles for different values of Pr

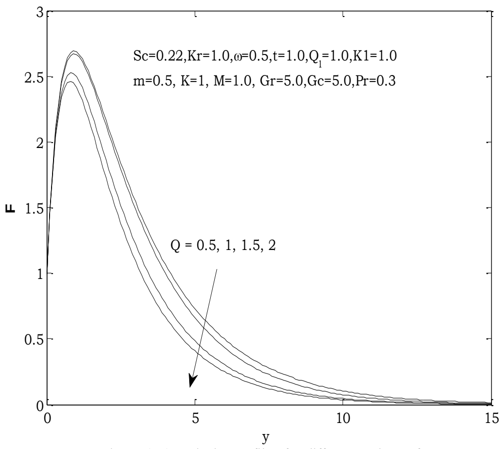

Figure (10): Velocity profiles for different values of Q

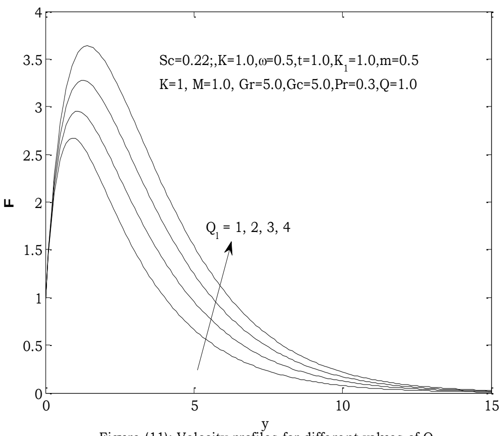

Figure (11): Velocity profiles for different values of Q_1

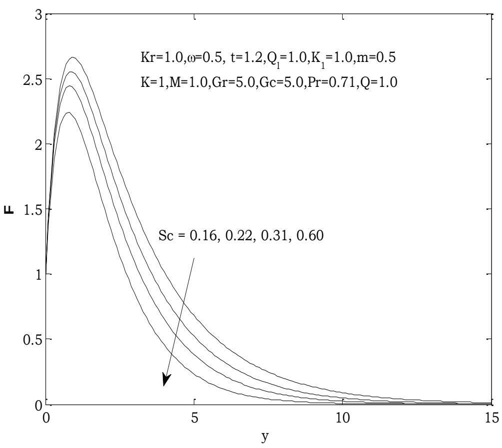

Figure (12): Velocity profiles for different values of Sc

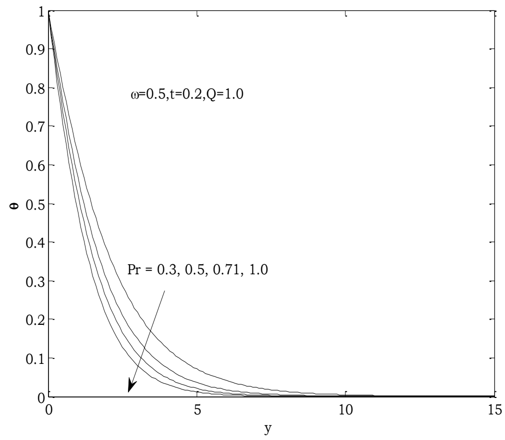

Figure (13): Temperature profiles for different values of Pr

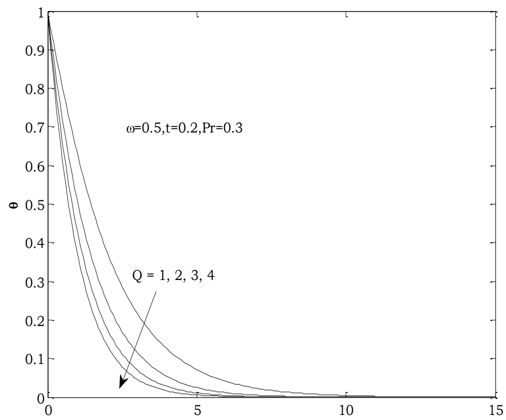

Figure (14): Temperature profiles for different values of Q

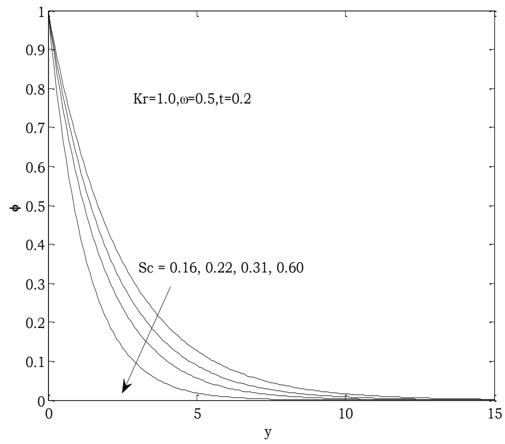

Figure (15): Concentration profiles for different values of Sc

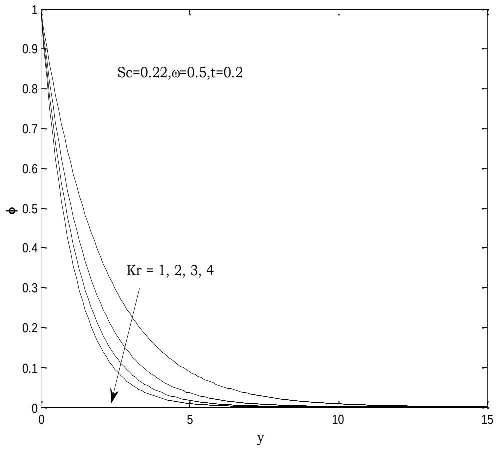

Figure (16): Concentration profiles for different values of Kr