International Journal of Mathematical Archive-3(6), 2012, 2360-2368
Available online through www.ijma.info ISSN 2229 – 5046

RADIATION EFFECTS ON MHD CONVECTIVE HEAT AND MASS TRANSFER FLOW PAST A SEMI-INFINITE VERTICAL MOVING PLATE EMBEDDED IN A POROUS MEDIUM

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(Received on: 13-06-12; Revised & Accepted on: 30-06-12)

ABSTRACT

Analytical solutions for heat and mass transfer by laminar flow of a Newtonian, viscous, electrically conducting and heat generation/absorbing fluid on a continuously vertical permeable surface in the presence of a radiation, a first-order homogeneous chemical reaction and the mass flux are reported. The plate is assumed to move with a constant velocity in the direction of fluid flow. A uniform magnetic field acts perpendicular to the porous surface, which absorbs the fluid with a suction velocity varying with time. The dimensionless governing Equations for this investigation are solved analytically using two-term harmonic and non-harmonic functions. Graphical results for velocity, temperature and concentration profiles of both phases based on the analytical solutions are presented and discussed.

Keywords: *MHD, Chemical reaction, Porous medium, vertical plate, Radiation, Skin-friction.*

1 INTRODUCTION

Natural convection flow over vertical surfaces immersed in porous media has paramount importance because of its potential applications in soil physics, geo-hydrology, and filtration of solids from liquids, chemical engineering and biological systems. Study of fluid flow in porous medium is based upon the empirically determined Darcy's law. Such flows are considered to be useful in diminishing the free convection, which would otherwise occur intensely on a vertical heated surface. In addition, recent developments in modern technology have intensified more interest of many researchers in studies of heat and mass transfer in fluids due to its wide applications in geothermal and oil reservoir engineering as well as other geophysical and astrophysical studies.

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. Moreover, Al-Odat and Al-Azab [7] 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 [8]. Singh et al. [9] studied the heat transfer over stretching surface in porous media with transverse magnetic field. Singh et al. [10] and [11] also investigated MHD oblique stagnation-point flow towards a stretching sheet with heat transfer for steady and unsteady cases. Elbashbeshy et al. [12] 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 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. [13]. The opposing buoyancy effects on simultaneous heat and mass transfer by natural convection in a fluid saturated porous medium investigated by Angirasa et al.[14]. Ahmed [15] investigates the effects of unsteady free convective MHD flow through a porous

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medium bounded by an infinite vertical porous plate. Ahmed Sahin [16] 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.

In spite of all the previous studies, the unsteady MHD free convection heat and mass transfer for a heat generation/absorption with radiation absorption in the presence of a reacting species over an infinite permeable plate has received little attention. Hence, the main objective of this chapter is to investigate the effects of thermal radiation, chemical reaction, and heat source/sink parameter of an electrically conducting fluid past an infinite vertical porous plate subjected to variable suction. The plate is assumed to be embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of a transverse magnetic field. It is also assumed that temperature over which are superimposed an exponentially varying with time. The Equations of continuity, linear momentum, energy and diffusion, which govern the flow field, are solved by using a regular perturbation method. The behavior of the velocity, temperature, concentration, skin- friction, Nusselt number and Sherwood number has been discussed for variations in the governing parameters.

2. MATHEMATICAL FORMULATION

We consider unsteady two-dimensional flow of a laminar, viscous, electrically conducting and heat-absorbing fluid past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of thermal and concentration buoyancy effects. It is assumed that there is no applied voltage which implies the absence of an electrical field. The fluid properties are assumed to be constant except that the influence of density variation with temperature has been considered only in the body-force term. The concentration of diffusing species is very small in comparison to other chemical species, the concentration of species far from the wall, C_∞, is infinitesimally small (Dekha [2]) and hence the Soret and Dufour effects are neglected. The chemical reactions are taking place in the flow and all thermo-physical properties are assumed to be constant of the linear momentum Equation which is approximated according to the Boussinesq approximation. Due to the semi-infinite plane surface assumption, the flow variables are functions of y*and the time t* only. Under these assumptions, the governing Equations for the problem considered in this chapter are based on the balances of mass, linear momentum, energy and concentration species. These Equations are as given below:

Continuity Equation:

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

Momentum Equation:

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

Energy Equation:

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

Mass diffusion Equation:

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

where 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 the fluid 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_r is the heat flux, 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.

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

$$\begin{aligned} &u' = u_p', \quad T' = T_\infty' + \varepsilon\left(T_w' - T_\infty'\right)e^{n't'}, \; C' = C_\infty' + \varepsilon\left(C_w' - C_\infty'\right)e^{n't'} \quad \text{at} \quad y' = 0 \\ &u' = U_\infty' = U_0 + \varepsilon\left(1 + e^{n't'}\right), \quad T' \to T_\infty', \quad C' \to C_\infty', \quad \text{as} \quad y' \to \infty \end{aligned} \tag{5}$$

where u_p' is the velocity, T_w' and C_w' the temperature and concentration of the wall respectively, U_∞' - the free stream velocity, and U_0, n' - the constants. From 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

$$v' = -v_0(1 + \varepsilon A e^{n't'}) \tag{6}$$

where A is a real positive constant, ε and εA is small values less than unity, and v_0 is scale of suction velocity which is non zero positive constant. The negative sign indicates that the suction is towards the plate.
Outside the boundary layer, Equation (2) gives

$$-\frac{1}{\rho}\frac{\partial p'}{\partial x'} = \frac{dU_\infty'}{dt'} + \frac{\nu}{K'}U_\infty' - \frac{\sigma B_0^2}{\rho}U_\infty' \tag{7}$$

By using the Rosseland diffusion approximation and following among other researchers, the radiative heatflux, q_r is given by

$$q_r = -\frac{4\sigma^*}{3K_s}\frac{\partial T'^4}{\partial y'} \tag{8}$$

Where σ^* and K_s are the Stefan- Boltzmann constant and the Roseland mean absorption coefficient, respectively. We assume that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature.

$$T^4 \approx 4T_\infty^3 T - 3T_\infty^4 \;(8) \tag{9}$$

Using (8) and (9) in the last term of Equation (3) we obtain

$$\frac{\partial q_r}{\partial y'} = -\frac{16\sigma^* T_\infty^3}{3K_s}\frac{\partial^2 T'}{\partial y'^2} \tag{10}$$

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

$$y = \frac{v_0 y'}{\nu},\; u = \frac{u'}{U_0},\; v = \frac{v'}{v_0},\; t = \frac{t' v_0^2}{\nu},\; U_\infty = \frac{U_\infty'}{U_0},\; U_p = \frac{u_p'}{U_0}\;\; \theta = \frac{T' - T_\infty'}{T_w' - T_\infty'},\; C = \frac{C' - C_\infty'}{C_w' - C_\infty'},$$

$$Gr = \frac{g\beta\nu(T_w' - T_\infty')}{v_0^3},\; Gm = \frac{g\beta^*\nu(C_w' - C_\infty')}{v_0^3},\; Sc = \frac{\nu}{D},\; Q = \frac{\nu Q_0}{\rho C_p v_0^2},\; Q_l = \frac{\nu Q_l'\left(C_w' - C_\infty'\right)}{\left(T_w' - T_\infty'\right)v_0^2}$$

$$n=\frac{\nu n'}{v_0^2}\ M=\frac{\sigma B_0^2\nu}{\rho v_0^2}\ K=\frac{K'v_0^2}{\nu^2},K_r=\frac{K_r'\nu}{v_0^2}\ R=\frac{4\sigma^* T_\infty^3}{K_s},\Pr=\frac{\nu\rho C_p}{k} \tag{11}$$

In view of Equations (6) – (11), Equations (2)-(4) reduce to the following dimensional form.

$$\frac{\partial u}{\partial t}-\left(1+\varepsilon Ae^{nt}\right)\frac{\partial u}{\partial y}=\frac{dU_\infty}{dt}+Gr\theta+GmC+\frac{\partial^2 u}{\partial y^2}+N\left(U_\infty-u\right) \tag{12}$$

$$\frac{\partial \theta}{\partial t}-\left(1+\varepsilon Ae^{nt}\right)\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\left(1+\frac{4R}{3}\right)\frac{\partial^2\theta}{\partial y^2}-Q\theta+Q_lC \tag{13}$$

$$\frac{\partial C}{\partial t}-\left(1+\varepsilon Ae^{nt}\right)\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-K_rC \tag{14}$$

where $N=M+\frac{1}{K},Gr,Gm,\Pr,K_r,Sc,Q,Q_l$ and R are the magnetic field parameter, permeability parameter, thermal Grashof number, Solutal Grashof number, Prandtl number, Chemical reaction number, Schmidt number, heat absorption parameter, absorption of radiation parameter and thermal radiation parameter.

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

$$\begin{aligned}&u=U_p,\ \theta=1+\varepsilon e^{nt},\ C=1+\varepsilon e^{nt} \quad \text{at} \quad y=0\\&u\to U_\infty=1+\varepsilon e^{nt},\ \theta\to 0,\ \ C\to 0\ \ \text{as}\ \ y\to\infty\end{aligned} \tag{15}$$

3. SOLUTION OF THE PROBLEM:

Equations (12) – (14) 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

$$\begin{aligned}u(y,t)&=u_0(y)+\varepsilon e^{nt}u_1(y)+o\left(\varepsilon^2\right)+\ldots\ldots\ldots\ldots\\\theta(y,t)&=\theta_0(y)+\varepsilon e^{nt}\theta_1(y)+o\left(\varepsilon^2\right)+\ldots\ldots\ldots\ldots\\C(y,t)&=C_0(y)+\varepsilon e^{nt}C_1(y)+o\left(\varepsilon^2\right)+\ldots\ldots\ldots\ldots\end{aligned} \tag{16}$$

Substituting (16) in Equations (12) – (14) and equating the harmonic and non – harmonic terms, and neglecting the higher order terms of $o\left(\varepsilon^2\right)$, we obtain

$$u_0''+u_0'-Nu_0=-N-Gr\theta_0-GmC_0 \tag{17}$$

$$u_1''+u_1'-\left(N+n\right)u_1=-\left(N+n\right)-Gr\theta_1-GmC_1-Au_0' \tag{18}$$

$$\left(1+\frac{4R}{3}\right)\theta_0''+\Pr\theta_0'-\Pr Q\theta_0=-\Pr Q_lC_0 \tag{19}$$

$$\left(1+\frac{4R}{3}\right)\theta_1''+\Pr\theta_1'-\Pr\left(Q+n\right)\theta_1=-A\Pr\theta_0'-\Pr Q_lC_1 \tag{20}$$

$$C_0''+ScC_0'-ScK_rC_0=0 \tag{21}$$

$$C_1''+ScC_1'-Sc\left(K_r+n\right)C_1=-AScC_0' \tag{22}$$

where prime denotes ordinary differentiation with respect to y.

The corresponding boundary conditions can be written as

$$
\begin{aligned}
&u_0 = U_p, u_1 = 0, \theta_0 = 1, \theta_1 = 1, C_0 = 1, C_1 = 1 \quad \text{at} \quad y = 0 \\
&u_0 \to 1, u_1 \to 1, \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0 \quad \text{as} \quad y \to \infty
\end{aligned} \tag{23}
$$

Solving Equations (17) – (22) under the boundary condition (23) we obtain the velocity, temperature and concentration distribution in the boundary layer as

$$
u(y,t) = 1 + A_{14}\exp(\text{-}m_5 y) \text{-} A_{12}\exp(\text{-}m_1 y) \text{-} A_{13}\exp(\text{-}m_3 y) + \varepsilon\exp(nt)\begin{bmatrix} 1 + A_{25}\exp(\text{-}m_6 y) + A_{20}\exp(\text{-}m_1 y) \text{-} A_{21}\exp(\text{-}m_2 y) \\ \text{-}A_{22}\exp(\text{-}m_3 y) \text{-} A_{23}\exp(\text{-}m_4 y) + A_{24}\exp(\text{-}m_5 y) \end{bmatrix}
$$

$$
\theta(y,t) = A_3\exp(\text{-}m_1 y) + A_4\exp(\text{-}m_3 y) + \varepsilon\exp(nt)\begin{bmatrix} A_8\exp(\text{-}m_1 y) \text{-} A_9\exp(\text{-}m_2 y) \\ +A_{10}\exp(\text{-}m_3 y) + A_{11}\exp(\text{-}m_4 y) \end{bmatrix}
$$

$$
C(y,t) = \exp(\text{-}m_1 y) + \varepsilon\exp(nt)\left[A_1\exp(\text{-}m_1 y) + A_2\exp(\text{-}m_2 y)\right]
$$

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

$$
C_f = \frac{\tau'_w}{\rho U_0 v_0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y} + \varepsilon e^{nt}\frac{\partial u_1}{\partial y}\right)_{y=0}
$$

$$
C_f = -\left[-m5A_{14} + m_1A_{12} + A_{12}m_3 + \varepsilon e^{nt}\begin{pmatrix} -m_6A_{25} - m_1A_{20} + A_{21}m_2 \\ +A_{22}m_3 + m_4A_{23} - A_{24}m_5 \end{pmatrix}\right]
$$

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

$$
N_u = -x\frac{\left(\dfrac{\partial T'}{\partial y'}\right)_{y'=0}}{(T'_w - T'_\infty)} \Rightarrow N_u \operatorname{Re}_x^{-1} = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left(\frac{\partial \theta_0}{\partial y} + \varepsilon e^{nt}\frac{\partial \theta_1}{\partial y}\right)_{y=0}
$$

$$
N_u \operatorname{Re}_x^{-1} = -m_1A_3 - A_4m_3 + \varepsilon e^{nt}\left[-m_1A_8 + m_2A_9 - m_3A_{10} - m_4A_{11}\right]
$$

where $\operatorname{Re}_x = \dfrac{v_0 x}{v}$ is the local Reynolds number.

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

$$
S_h = -x\frac{\left(\dfrac{\partial C'}{\partial y'}\right)_{y'=0}}{(C'_w - C'_\infty)} \Rightarrow S_h \operatorname{Re}_x^{-1} = \left(\frac{\partial C}{\partial y}\right)_{y=0} = \left(\frac{\partial C_0}{\partial y} + \varepsilon e^{nt}\frac{\partial C_1}{\partial y}\right)_{y=0}
$$

$$
S_h \operatorname{Re}_x^{-1} = -\left[-m_1 + \varepsilon\, e^{nt}\left(-m_1A_1 - m_2A_2\right)\right]
$$

4. RESULT 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 1-16 and discussed in detail.

The effect of magnetic field on velocity profiles in the boundary layer is depicted in Fig.1. From this figure it is seen that the velocity starts from minimum value at the surface and increase till it attains the peak value and then starts decreasing until it reaches to the minimum value at the end of the boundary layer for all the values of magnetic field parameter. It is interesting to note that the effect of magnetic field is to decrease the value of the velocity profiles throughout the boundary layer. The effect of magnetic field is more prominent at the point of peak value i.e. the peak value drastically decreases with increases in the value of magnetic field, because the presence of magnetic field in an electrically conducting fluid introduce a force called the Lorentz force, which acts against the flow if the magnetic field is applied in the normal direction, as in the present problem. This type of resisting force slows down the fluid velocity as shown in this figure. Fig.2. shows the velocity distribution u against y for different values of chemical reaction Kr. We noticed that the velocity decreases with an increase Kr. The effect of increasing the value of the heat source parameter is to decrease the boundary layer as shown in Fig.3, which is as expected due to the fact that when heat is absorbed the buoyancy force decreases which retards the flow rate and thereby giving rise to decrease in the velocity profiles. Fig.4 illustrates the velocity profiles for different values of Prandtl number $\Pr$. The numerical results show that the effect of increasing values of Prandtl number result in decreasing velocity. For the case of different values of thermal Grashof number, the velocity profiles in the boundary layer are shown in Fig.5. As expected, it is observed that an increase in Gr leads to increase in the values of velocity due to enhancement in buoyancy force. Here the positive values of Gr correspond to cooling of the surface. Fig.6 presents typical velocity profiles in the boundary layer for various values of the Solutal Grashof number Gm, while all other parameters are kept at some fixed values. The velocity distribution attains a distinctive maximum value in the vicinity of the plate surface and then decrease properly to approach the free stream value. As expected, the fluid velocity increases and the peak value more distinctive due to increase in the concentration buoyancy effects represented by **Gm**. This is evident in the increase in the value of **u** as **Gm** increases. Fig.7 displays the effects of Schmidt number Sc on velocity profiles. As the Schmidt number increases the velocity filed decreases. This causes the velocity buoyancy effects to decreases yielding a reduction in the fluid velocity. The reductions and the velocity profiles are accompanied by simultaneous reductions in the velocity boundary layers. Fig.8 shows the velocity profiles for different values of the permeability parameter **K**, clearly as **K** increases the peak values of the velocity tends to increase. Fig.9 shows the velocity profiles for different values of the radiation parameter **R**, clearly as **R** increases the peak values of the velocity tends to increase. The effect of increasing the value of the absorption parameter **Ql** on the velocity is shown Fig.10. 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.

Fig.11 illustrate the temperature profiles for different values of Prandtl number Pr. It is observed that the temperature decrease as an increasing the Prandtl number. The reason is that smaller values of **Pr** are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of **Pr**. Hence in the case of smaller Prandtl number the thermal boundary layer is thicker and the rate of heat transfer is reduced. Fig.12 has been plotted to depict the variation of temperature profiles against **y** for different values of heat source parameter **Q** by fixing other physical parameters. From this Graph we observe that temperature decrease with increase in the heat source parameter **Q** because when heat is absorbed, the buoyancy force decreases the temperature profiles. Fig.13 illustrates the temperature profiles for different values of radiation parameter **R**. It is observed that the temperature decrease as an increasing the radiation parameter.

The effect of absorption of radiation parameter on the temperature pro file is shown on Fig14. 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. Fig.15 displays the effects of Schmidt number **Sc** on the concentration profiles respectively. As the Schmidt number increases the concentration decreases. Fig 16 displays the effects of the chemical reaction **Kr** on concentration profiles. We observe that concentration profiles decreases with increasing **Kr**.

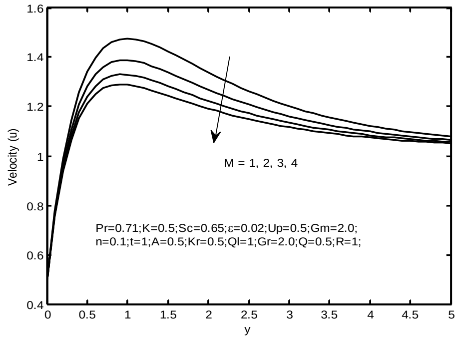

Fig.1. Effects of M on velocity profiles.

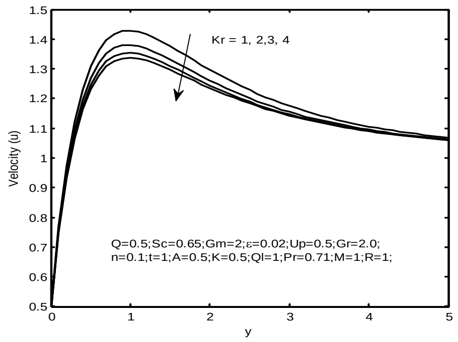

Fig.2. Effects of Kr on velocity profiles.

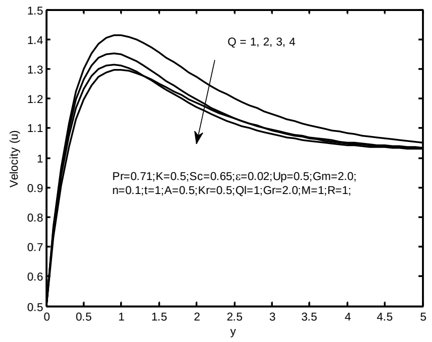

Fig.3. Effects of Q on velocity profiles.

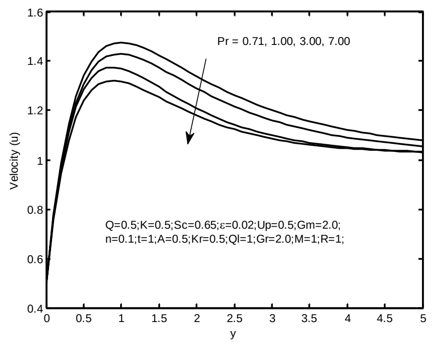

Fig.4. Effects of Pr on velocity profiles.

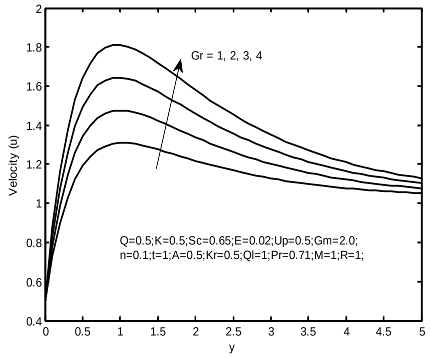

Fig.5. Effects of Gr on velocity profiles.

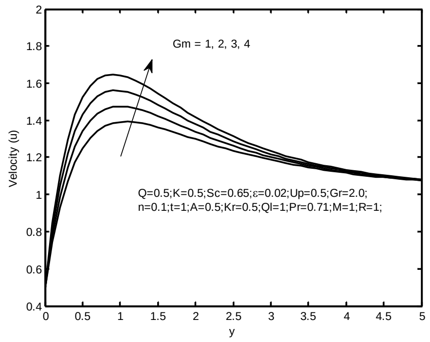

Fig.6. Effects of Gm on velocity profiles.

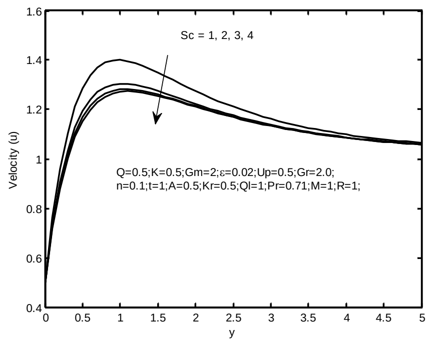

Fig.7. Effects of Sc on velocity profiles.

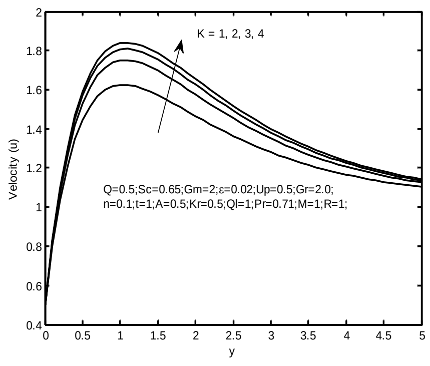

Fig.8. Effects of K on velocity profiles.

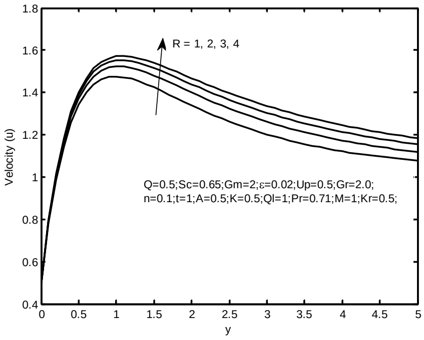

Fig.9. Effects of R on velocity profiles.

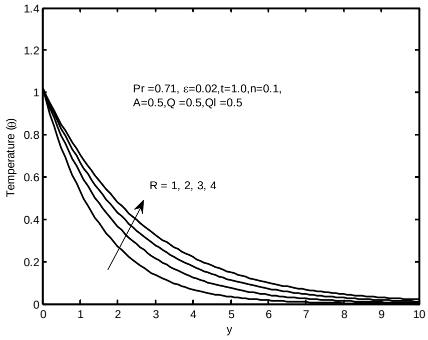

Fig.13. Effects of R on temperature profiles.

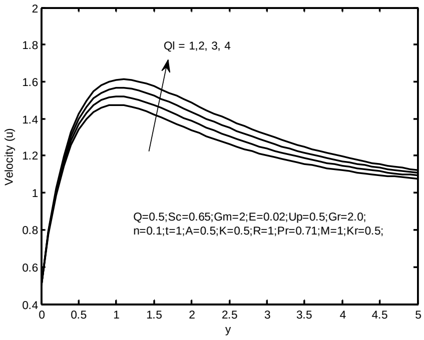

Fig.10. Effects of Ql on velocity profiles.

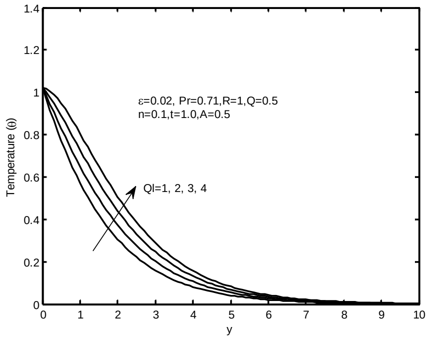

Fig.14. Effects of Ql on temperature profiles.

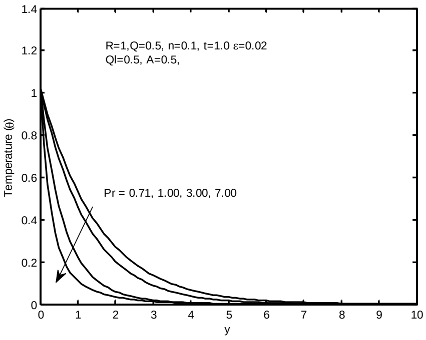

Fig.11. Effects of Pr on temperature profiles.

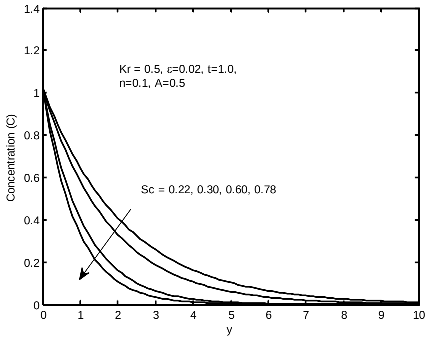

Fig.15. Effects of Sc on concentration profiles.

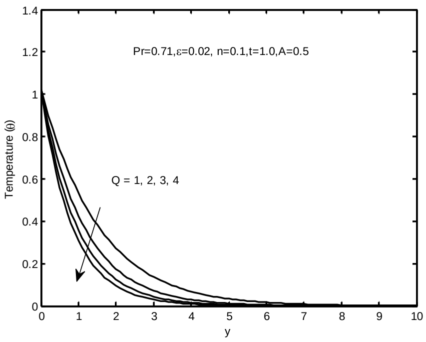

Fig.12. Effects of Q on temperature profiles.

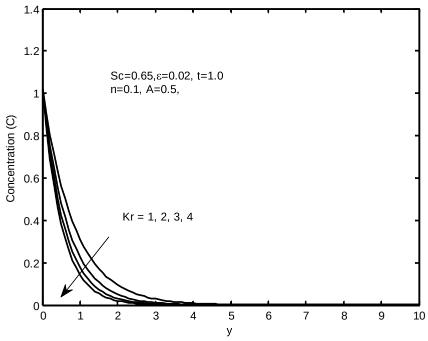

Fig.16. Effects of Kr on concentration profiles.

REFERENCES

[1] Cramer, K. R. and Pai, S. I. Magneto fluid Dynamics for Engineering and Applied Physicists (Mc Graw Hill, New York), (1973).

[2] Muthucumaraswamy.R and Meenakshisundaram.S. Theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature. Theoret. Appl. Mech., vol.33, No.3 (2006), pp.245-257.

[3] Sharma, P. K. Fluctuating thermal and mass diffusion on unsteady free convective flow past a vertical plate in slip-flow regime, Latin American Applied Research, 35, 313-319,(2005).

[4] Anjalidevi, S.P. and R. Kandasamy. Effects of a chemical reaction heat and mass transfer on MHD flow past a semi infinite plate. Z.Angew. Math. Mech., (2000) 80:697-701.

[5] Chaudhary, R. C. and Jha, A. K.,Effects of chemical reactions on MHD micropolar fluid flow past a vertical plate in slip-flow regime, Applied Mathematics and Mechanics, 29 (9), 1179-1194, (2008).

[6] Muthucumaraswamy, R. and Chandrakala, P. Radiation heat and mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction. J. of Applied Mechanics and Engineering, vol. 11 No.3, (2006), pp 639-646.

[7] Al-Odat, M. Q. and Al-Azab. Influence of chemical reaction on transient MHD free convection over a moving vertical plate, Emirates J. Engg. Res., 12 (3), 15-21. (2007).

[8] M.A. El-Aziz, "Radiation effect on the flow and heat transfer over an unsteady stretching sheet", International Communications in Heat and Mass Transfer, Vol. 36, pp 521-524, (2009).

[9] P. Singh, N.S. Tomer and D. Sinha, "Numerical study of heat transfer over stretching surface in porous media with transverse magnetic field", Proceeding of International Conference on Challenges and application of Mathematics in Sciences and Technology (2010), ISBN 023- 032-875-X, pp 422-430.

[10] P. Singh, N.S. Tomer, S. Kumar and D. Sinha, "MHD oblique stagnation-point flow towards a stretching sheet with heat transfer", International Journal of Applied Mathematics and Mechanics, Vol. 6, no.13, pp 94-111, (2010).

[11] P. Singh, A. Jangid, N.S. Tomer, S. Kumar and D. Sinha, "Effects of Thermal Radiation and Magnetic Field on Unsteady Stretching Permeable Sheet in Presence of Free Stream Velocity", International Journal of Information and Mathematical Sciences, Vol.6, no.3, pp-63-69, (2010).

[12] E. M. A. Elbashbeshy, D. M. Yassmin and A. A. Dalia, "Heat Transfer over an Unsteady Porous Stretching Surface Embedded in a Porous Medium with Variable Heat Flux in the Presence of Heat Source or Sink", African Journal of Mathematics and Computer Science Research Vol. 3, no.5, pp 68-73, (2010).

[13] Kandasamy, R., Periasamy, K. and Sivagnana Prabhu, K.K. Chemical reaction, heat and mass transfer on MHD flow over a vertical stretching surface with heat source and thermal stratification effects, Int. J. Heat and Mass Transfer, 48 (21-22), 4557-4561,(2005).

[14] Angirasa, D., Peterson, G. P. and Pop, I. Combined heat and mass transfer by natural convection with opposing buoyancy effects in a fluid saturated porous medium, Int. J. Heat Mass Trans., 40(12), 2755-2773,(1997).

[15] Ahmed, S. Effects of unsteady free convective MHD flow through a porous medium bounded by an infinite vertical porous plate, Bull. Cal. Math. Soc., 99 (5), 511-522, (2007).

[16] Ahmed Sahin. Influence of chemical reaction on transient MHD free Convective flow over a vertical plate in slip - flow Regime. Emirates Journal for Engineering Research, 15 (1), 25-34 (2010).

Source of support: Nil, Conflict of interest: None Declared