CHAPTER-I

RADIATION AND CHEMICAL REACTION EFFECTS ON MHD FLOW OVER AN INFINITE VERTICAL POROUS PLATE

1. INTRODUCTION

The study of heat and mass transfer with chemical reaction is of great practical important to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. In particular, the study of chemical reaction, heat and mass transfer with heat radiation is of considerable importance in chemical and hydrometallurgical industries. A reaction is said to be first-order if the rate of reaction is directly proportional to the concentration itself. In many chemical processes, a chemical reaction occurs between a foreign mass and a fluid in which a plate is moving. These processes take place in numerous industrial applications, e.g., polymer production, manufacturing of ceramics or glassware and food processing Cussler [1]. Chambre and Young [2] analyzed the diffusion of chemically reactive species in a laminar boundary layer flow. Vajravelu [3] studied the exact solution for hydrodynamic boundary layer flow and heat transfer over a continuous, moving horizontal flat surface with uniform suction and internal heat generation/absorption. Chamkha [4] presented an analytical solution for heat and mass transfer by laminar flow of a Newtonian, viscous, electrically conducting fluid and heat generation/absorption.

If the temperature of surrounding fluid is rather high, radiation effects play an important role and this situation does not exist in space technology. In such cases one has to take into account the effect of thermal radiation and mass diffusion. Boundary layer flow on moving horizontal surfaces was studied by Sakiadas [5]. The effects of transversely applied magnetic field on the flow of an electrically conducting fluid past an impulsively started isothermal vertical plate was studied by Soundalgekar *et al.* [6]. MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field were studied by Soundalgekar *et al.* [7]. The dimensionless governing equations were solved using Laplace transform technique. Kumari and Nath [8] studied the development of the asymmetric flow of a viscous electrically conducting fluid in the forward stagnation point of a two-dimensional body and over a stretching surface with an applied magnetic field. The governing equations were solved using Laplace transform technique. England and Emery [9] have studied the thermal radiation effects of an optically thin gray gas bounded by a stationary vertical plate. Soundalgekar and Takhar [10] have considered the radiation free convection flow of an optically thin gray- gas past a semi- infinite vertical plate.

Radiation effects on mixed convection along isothermal vertical plate were studied by Hossain and Takhar [11]. In all above studies, the stationary vertical plate is considered. Raptis and Perdikis [12] studied the effects of thermal radiation and free convection flow past a moving vertical plate. The governing equations were solved analytically. Also, Sahin Ahmed and Liu [13] analyzed the effects of mixed convection and mass transfer of three-dimensional oscillatory flow of a viscous incompressible fluid past an infinite vertical porous plate in presence of transverse sinusoidal suction velocity oscillating with time and a constant free stream velocity. Sahin Ahmed [14] studied effects of radiation and magnetic Prandtl number on the steady mixed convective heat and mass transfer flow of an optically thin gray gas over an infinite vertical porous plate with constant suction in presence of transverse magnetic field.

Recently, Sahin Ahmed [15] investigated the effects of radiation and chemical reaction on a steady mixed convective heat and mass transfer past an infinite vertical permeable plate with constant suction taking into account the induced magnetic field. Sahin Ahmed and Zueco [16] studied the effect of the transverse magnetic field on a steady mixed convective heat and mass transfer flow past an infinite vertical isothermal porous plate taking into account the induced magnetic field, viscous and magnetic dissipations of energy in presence of chemical reaction and heat generation/absorption and the non-linear coupled equations are solved by network simulation technique. Sahin Ahmed and Chamkha [17] investigated the effects of radiation and chemical reaction on steady mixed convective heat and mass transfer flow of an optically thin gray gas over an infinite vertical porous plate with constant suction taking into account the induced magnetic field and viscous dissipation of energy.

Jaiswal and Soundalgekar [18] obtained an approximate solution to the problem of an unsteady flow past an infinite vertical plate with constant suction and embedded in a porous medium with oscillating plate temperature. Kumar and Verma [19] studied the problem of an unsteady flow past an infinite vertical permeable plate with constant suction and transverse magnetic field with oscillating plate temperature. Turkyilmazoglu [20] presented an exact analytical solution for heat and mass transfer of MHD slip flow in nanofluids. Turkyilmazoglu and Pop [21] reported the Soret and heat source effects on the unsteady radiative MHD free convection flow from an impulsively started infinite vertical plate. Heat and mass transfer of unsteady natural convection flow of some nanofluids past a vertical infinite flat plate with radiation effect was discussed by Turkyilmazoglu and Pop [22]. Pal and Mondal [23] proposed the Soret and Dufour effects on MHD non-Darcian mixed convection heat and mass transfer over a stretching sheet with non-uniform heat source/sink.

In this chapter, we consider the effects of chemical reaction as well as magnetic field on the heat and mass transfer of Newtonian fluids over an infinite vertical oscillating permeable plate with variable mass diffusion. The magnetic field is imposed transversely to the plate. The temperature and concentration of the plate is oscillating with time about a constant nonzero mean value. The dimensionless governing equations involved in the present analysis are solved using a closed analytical method and discussed qualitatively and graphically.

2. FORMATION OF THE PROBLEM

Thermal radiation and mass transfer effects on unsteady MHD flow of a viscous incompressible fluid past along a vertical oscillating plate with variable temperature and also with variable mass diffusion in the presence of transverse applied magnetic field has been studied. The $x'-$axis is taken along the plate in the vertical upward direction and the $y'-$axis is taken normal to the plate. Initially it is assumed that the plate and fluid are at the same temperature T'_∞ in the stationary condition with concentration level C'_∞ at all the points. At time $t > 0$, the plate is given an oscillatory motion in its own plane with velocity $U_0 \cos(\omega' t')$. At the same time the plate temperature is raised linearly with time and also masSs is diffused from the plate linearly with time. A transverse magnetic field of uniform strength B_0 is assumed to be applied normal to the plate. The induced magnetic field and viscous dissipation is assumed to be negligible as the magnetic Reynolds number of the flow is taken to be very small. The fluid considered here is gray, absorbing/emitting radiation but a non-scattering medium. Then by usual Boussinesq's approximation, the unsteady flow is governed by the following equations.

$$\frac{\partial u'}{\partial t'} = \frac{\partial^2 u'}{\partial y^2} + g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) - \frac{u'}{K'} - \frac{\sigma}{\rho} B_0^2 u' \tag{2.1}$$

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p} \frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p} \frac{\partial q'_r}{\partial y'} \tag{2.2}$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} - K'_r\left(C' - C'_\infty\right) \tag{2.3}$$

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

$$t' \le 0 : u' = 0,\ \ T' = T'_\infty,\ C' = C'_\infty \ \ \forall\ y$$

$$t' > 0 \begin{cases} u' = u_0 \cos(\omega' t'),\ T' = T'_\infty + \varepsilon\left(T'_w - T'_\infty\right) e^{n't'},\ C' = C'_\infty + \varepsilon\left(C'_w - C'_\infty\right) e^{n't'} & \text{at} \quad y' = 0 \\ u' \to 0, \quad T' \to T'_\infty, \quad C' \to C'_\infty & \text{as} \quad y' \to \infty \end{cases}$$

(2.4)

where u' is the velocity in the x' -direction, v' is the velocity in the y' – direction, K' is the permeability parameter, β is the volumetric coefficient of thermal expansion , β^* is the volumetric coefficient of expansion for concentration, ρ is the density, σ is the electrical conductivity , k – the thermal conductivity, g – the acceleration due to gravity, T' is the temperature, T'_w – the fluid temperature at the plate, T'_∞ – the fluid temperature in the free stream, C' is the species concentration, C_p is the specific heat at constant pressure, C'_∞ – Species concentration in the free stream, C'_w – Species concentration at the surface, D is the chemical molecular diffusivity, K'_r is the chemical reaction parameter, q_r is the radioactive flux and $\varepsilon << 1$ is a positive constant. .

The local radiant absorption for the case of an optically thin gray gas is expressed as

$$q'_r = -4a^* \sigma^* \left(T'^4_\infty - T'^4\right) \tag{2.5}$$

where σ^* and a^* are the Stefan-Boltzmann constant and the Mean absorption coefficient respectively. Following Chamkha [4] and others, we assume that the temperature differences within the flow are sufficiently small so that T'^4 can be expressed as a linear function of T' after using Taylor's series to expand T'^4 about the free stream temperature T'_∞ and neglecting higher-order terms. This results in the following approximation:

$$T'^4 \cong 4T'^3_\infty T' - 3T'^4_\infty \tag{2.6}$$

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{16a^*\sigma^*}{\rho C_p}T_\infty'^3\left(T' - T_\infty'\right) \tag{2.7}$$

In order to write the governing equations and the boundary conditions in non dimensional form, the following non dimensional quantities are introduced.

$$\left.\begin{aligned} &u = \frac{u'}{u_0},\ y = \frac{u_0 y'}{v},\ t = \frac{t' u_0^2}{v},\ \theta = \frac{T' - T_\infty'}{T_w' - T_\infty'},\ \phi = \frac{C' - C_\infty'}{C_w' - C_\infty'},\ \omega = \frac{\omega' \nu}{u_0^2},\ n = \frac{n'\nu}{u_0^2} \\ &K = \frac{K' u_0^2}{v^2},\ \Pr = \frac{v\rho C_p}{k},\ Sc = \frac{v}{D},\ M = \frac{\sigma B_0^2 v}{\rho u_0^2},\ Gr = \frac{v\beta g\left(T_w' - T_\infty'\right)}{u_0^3}, \\ &Gm = \frac{v\beta^* g\left(C_w' - C_\infty'\right)}{u_0^3},\ K_r = \frac{K_r' v}{u_0^2},\ R = \frac{16a^*\nu\sigma^* T_\infty'^3}{k u_0^2},\ A = \frac{u_0^2}{\nu} \end{aligned}\right\} \tag{2.8}$$

Using the transformations (2.8) the non dimensional forms of (2.1), (2.3) and (2.7) are

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gm\phi - \left(M + \frac{1}{K}\right)u \tag{2.9}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - \frac{R}{\Pr}\theta \tag{2.10}$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} - Kr\phi \tag{2.11}$$

The corresponding boundary conditions are;

$$\begin{aligned} &u = \cos(\omega t), \quad \theta = 1 + \varepsilon e^{nt}, \quad \phi = 1 + \varepsilon e^{nt} \quad \text{at} \quad y = 0 \\ &u \to 0, \quad \theta \to 0, \quad \phi \to 0 \quad \text{as} \quad y \to \infty \end{aligned} \tag{2.12}$$

where $M, K, Gr, Gm, \Pr, Kr, Sc, R$ are the magnetic parameter, permeability parameter, Grashof number for heat transfer, Grashof number for mass transfer, Prandtl number, Chemical reaction parameter, Schmidt number and radiation parameter respectively.

3. SOLUTION OF THE SOLUTION

In order to reduce the above system of partial differential equations to a system of ordinary differential equations in dimensionless form, we assume the trial solution for the velocity, temperature and concentration as:

$$u(y,t) = u_0(y) + \varepsilon e^{nt} u_1(y) \tag{3.1}$$

$$\theta(y,t) = \theta_0(y) + \varepsilon e^{\omega t} \theta_1(y) \tag{3.2}$$

$$\phi(y,t) = \phi_0(y) + \varepsilon e^{nt} \phi_1(y) \tag{3.3}$$

Substituting Equations (3.1), (3.2) and (3.3) in Equations (2.9), (2.10) and (2.11), we obtain:

$$u_0'' - \left(M + \frac{1}{K}\right) u_0 = -\left[Gr\theta_0 + Gm\phi_0\right] \tag{3.4}$$

$$\theta_0'' - R\Pr\theta_0 = 0 \tag{3.5}$$

$$\phi_0'' - ScKr\phi_0 = 0 \tag{3.6}$$

$$u_1'' - \left(M + \frac{1}{K} + n\right) u_1 = -\left[Gr\theta_1 + Gm\phi_1\right] \tag{3.7}$$

$$\theta_1'' - \Pr(R+n)\theta_1 = 0 \tag{3.8}$$

$$\phi_1'' - Sc(Kr+n)\phi_1 = 0 \tag{3.9}$$

Here the primes denote the differentiation with respect to y.

The corresponding boundary conditions can be written as

$$\begin{aligned} &u_0 = \cos(\omega t),\ u_1 = 0,\ \theta_0 = 1,\ \theta_1 = 1,\ \phi_0 = 1,\ \phi_1 = 1 \quad \text{at} \quad y = 0 \\ &u_0 \to 0,\ u_1 \to 0,\ \theta_0 \to 0,\ \theta_1 \to 0,\ \phi_0 \to 0,\ \phi_1 \to 0 \quad \text{as} \quad y \to \infty \end{aligned} \tag{3.10}$$

The closed analytical solutions of equations (3.4) – (3.9) with satisfying the boundary conditions (3.10) are given by the velocity, temperature and concentration distributions in the boundary layer become

$$u(y,t) = k_3 \exp(-m_5 y) + k_1 \exp(-m_3 y) + k_2 \exp(-m_1 y)$$
$$+\varepsilon \exp(nt)\left[k_6 \exp(-m_6 y) + k_4 \exp(-m_4 y) + k_5 \exp(-m_2 y)\right] \quad (3.11)$$

$$\theta\left(y,t\right) = \exp(-m_3 y) + \varepsilon \exp(nt) \exp(-m_4 y) \quad (3.12)$$

$$\phi(y,t) = \exp(-m_1 y) + \varepsilon \exp(nt) \exp(-m_2 y) \quad (3.13)$$

It is now important to calculate the physical quantities of primary interest, which are the local wall shear stress, the local surface heat and mass flux. Given the velocity field in the boundary layer, we can now calculate the local wall shear stress (i.e., skin- friction) is given by $\tau_w^* = \mu \left(\frac{\partial u'}{\partial y'} \right)_{y'=0}$

And in non-dimensionl form, we obtain:

$$C_f = -\left(\frac{\partial u}{\partial y} \right)_{y=0} = k_3 m_5 + k_1 m_2 + k_2 m_1 + \varepsilon \exp(nt)\left[k_6 m_6 + k_4 m_4 + k_5 m_2\right]$$

From temperature field, now we study the rate of heat transfer which is given in non - dimensional form as:

$$Nu = -\left(\frac{\partial \theta}{\partial y} \right)_{y=0} = m_3 + \varepsilon \exp(nt)\left(m_4\right)$$

From concentration field, now we study the rate of mass transfer which is given in non - dimensional form as:

$$Sh = -\left(\frac{\partial \phi}{\partial y} \right)_{y=0} = m_1 + \varepsilon \exp\left(nt\right)\left(m_2\right)$$

where

$$m_1 = \sqrt{ScKr},\ m_2 = \sqrt{Sc(Kr+n)},\ \ m_3 = \sqrt{R\Pr},\ m_4 = \sqrt{\Pr(R+n)},$$
$$m_5 = \sqrt{M+1/K}, m_6 = \sqrt{M+n+1/K},\ k_1 = -\frac{Gr}{m_3^2-(M+1/K)},$$
$$k_2 = -\frac{Gm}{m_1^2-(M+1/K)},\ k_3 = \cos(\omega t)-(k_1+k_2), k_4 = -\frac{Gr}{m_4^2-(M+n+1/K)},$$
$$k_5 = -\frac{Gm}{m_2^2-(M+n+1/K)},\ k_6 = -(k_4+k_5)$$

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 1-14 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. For the case of different values of thermal Grashof number the velocity profiles on the boundary layer are shown in Fig.2. As expected, it is observed that an increase in Grashof number leads to increase in the values of velocity due to enhancement in buoyancy force. Here the positive values of Grashof number correspond to cooling of the surface.

Fig.3 shows the velocity profiles for different values of the radiation parameter, clearly as radiation parameter increases the peak values of the velocity tends to increases. Fig.4 represents typical velocity profiles in the boundary layer for various values of the modified Grashof number, 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 modified Grashof number. This is evident in the increase in the value of velocity as modified Grashof number increases. For different values of the Schmidt number the velocity profiles are plotted in Fig.5. It is obvious that an increase in the Schmidt number results in decrease in the velocity within the boundary layer. Fig.6 illustrates the behavior velocity for different values of chemical reaction parameter Kr . It is observed that an increase in leads to a decrease in the values of velocity. Fig.7 shows the velocity profiles for different values of the permeability parameter, clearly as permeability parameter increases the peak values of the velocity tends to increase.

Fig.8 illustrates the temperature profiles for different values of Prandtl number. It is observed that the temperature decrease as an increasing the Prandtl number. The reason is that smaller values of Prandtl number 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 Prandtl number. Hence in the case of smaller Prandtl number the thermal boundary layer is thicker and the rate of heat transfer is reduced. Fig.9 has been plotted to depict the variation of temperature profiles for different values of radiation parameter R by fixing other physical parameters. From this Graph we observe that temperature decrease with increase in the radiation parameter. Fig.10 displays the effect of Schmidt number ***Sc*** on the concentration profiles respectively. As the Schmidt number increases the concentration decreases. Fig.11 displays the effect of the chemical reaction on concentration profiles. We observe that concentration profiles decreases with increasing chemical reaction parameter.

The effect of magnetic parameter on the skin-friction is shown in Fig.12. As the magnetic parameter increases, the skin-friction is found to be increases. Fig.13 illustrates the effect of the radiation parameter on the Nusselt number of the fluid under consideration. As the radiation parameter increases, the Nusselt number is found to be increases. Fig.14 illustrates the effect of Schmidt number on Sherwood number of the fluid under consideration. As the Schmidt number increases the Nusselt number is found to be increases.

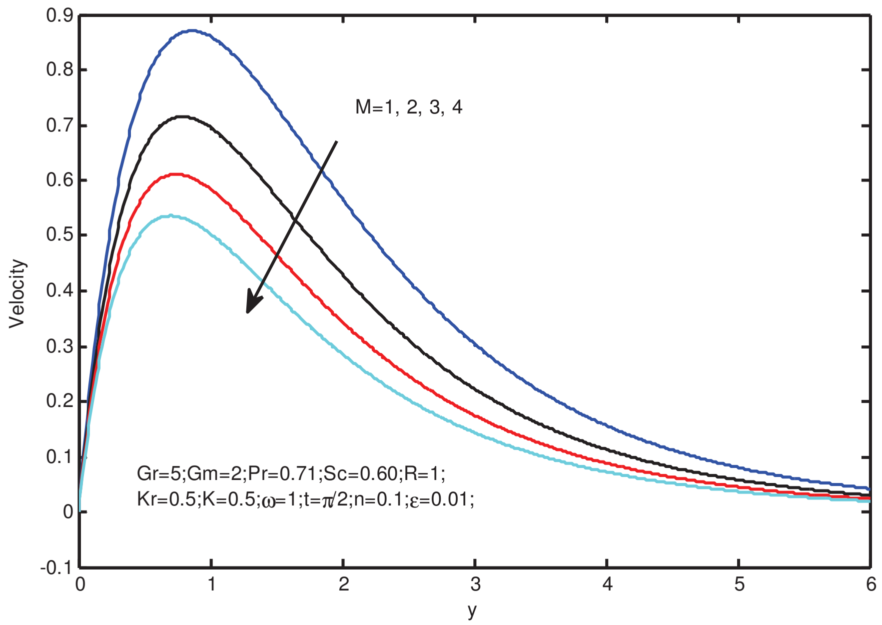

Fig.1. Velocity profiles for different values of magnetic parameter.

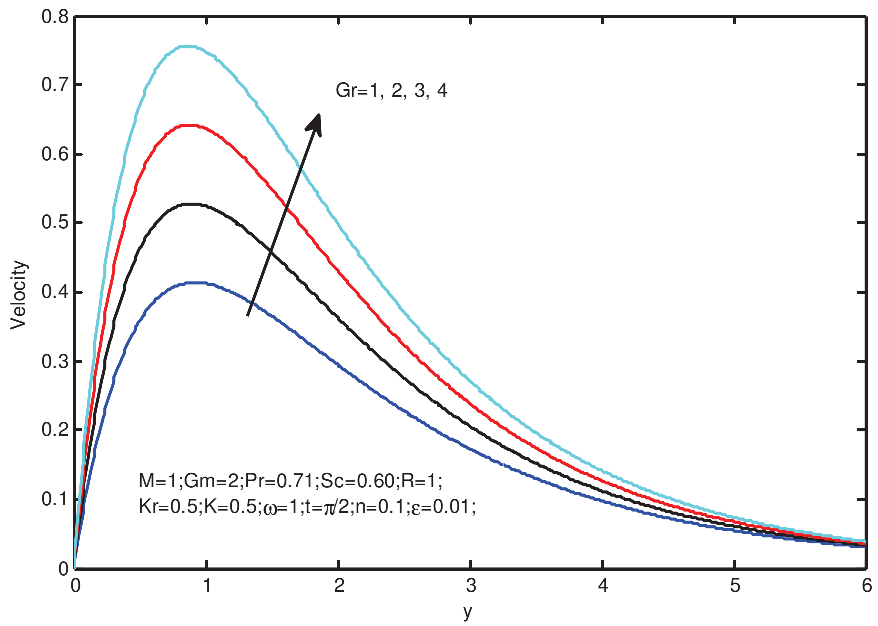

Fig.2. Velocity profiles for different values of Grashof number.

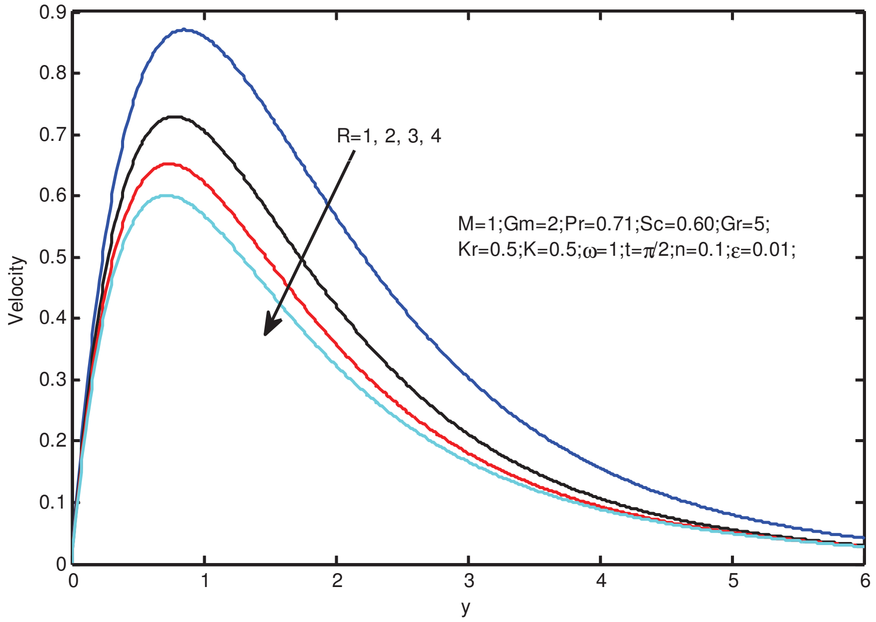

Fig.3. Velocity profiles for different values of radiation parameter.

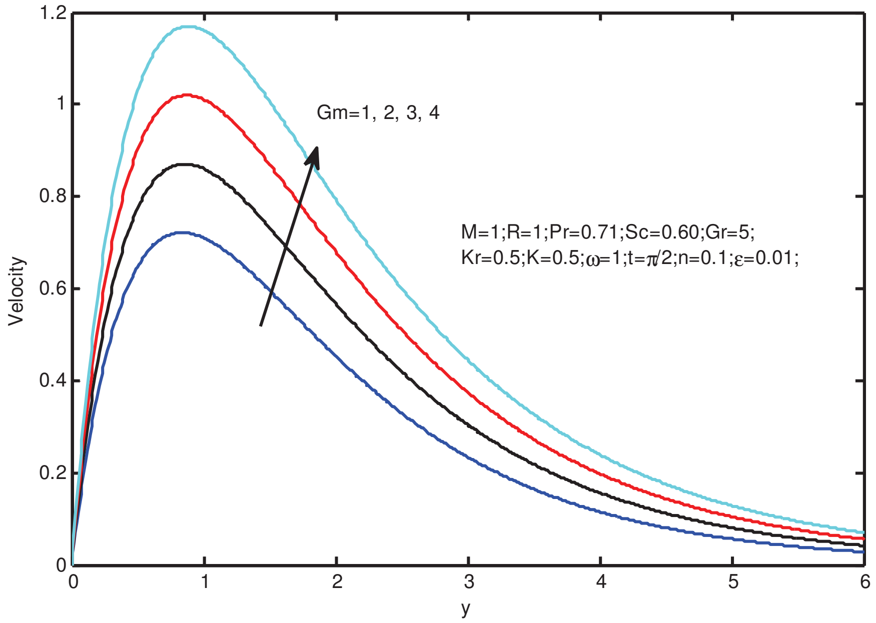

Fig.4. Velocity profiles for different values of modified Grashof number.

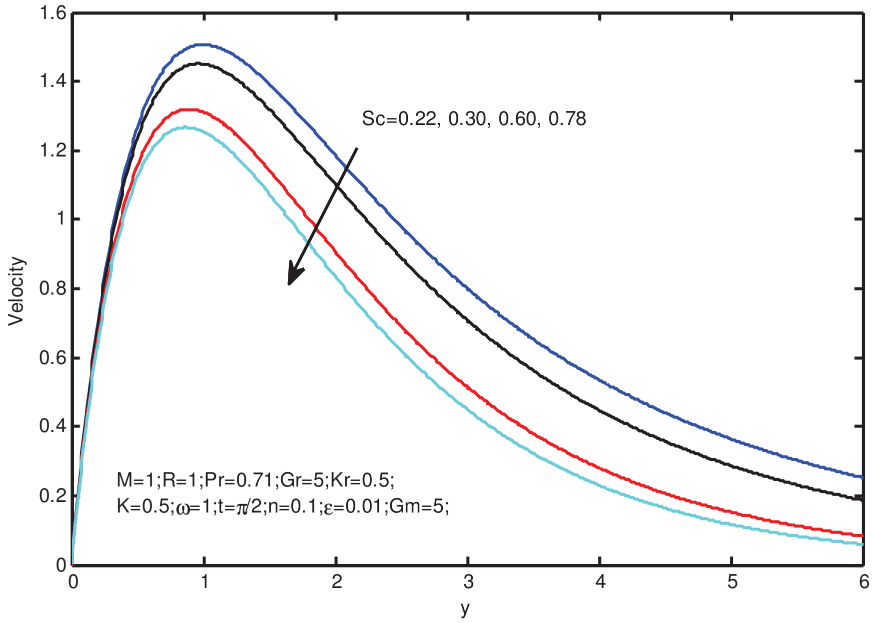

Fig.5. Velocity profiles for different values of Schmidt number.

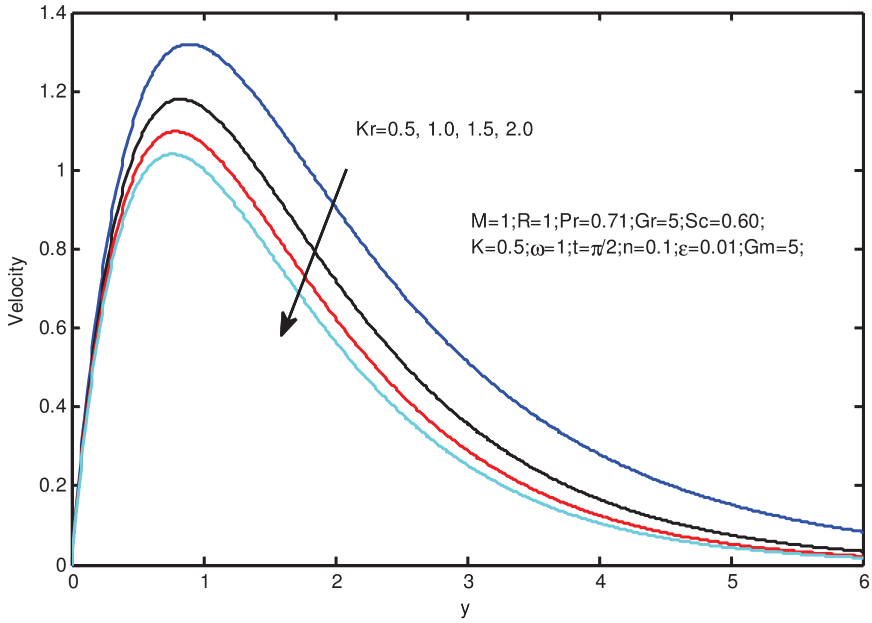

Fig.6. Velocity profiles for different values of chemical reaction parameter.

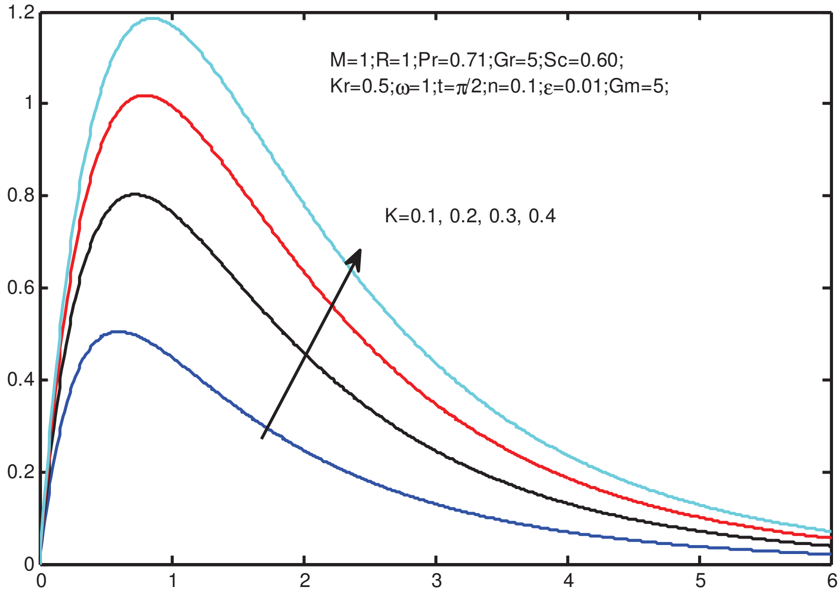

Fig.7. Velocity profiles for different values of permeability parameter.

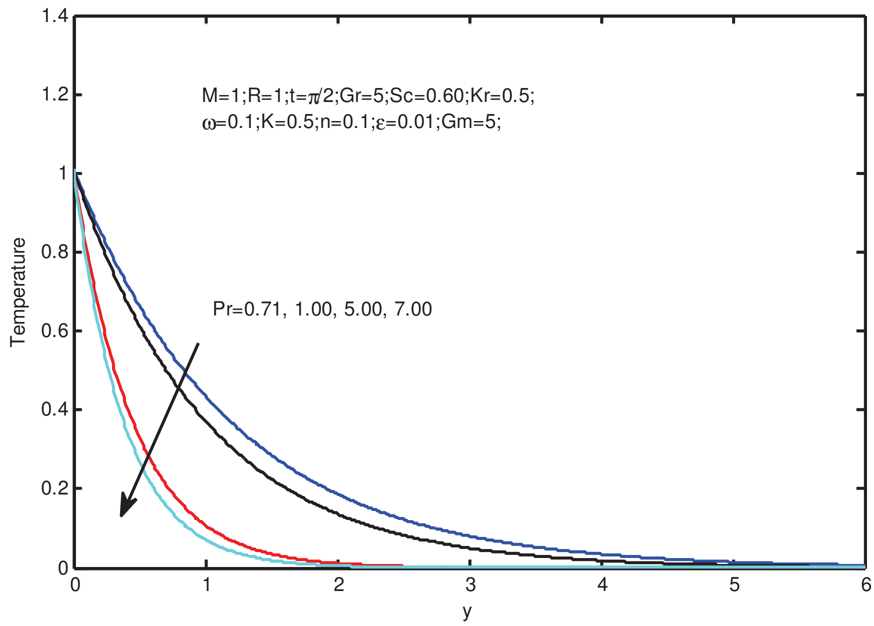

Fig.8. Temperature profiles for different values of Prandtl number.

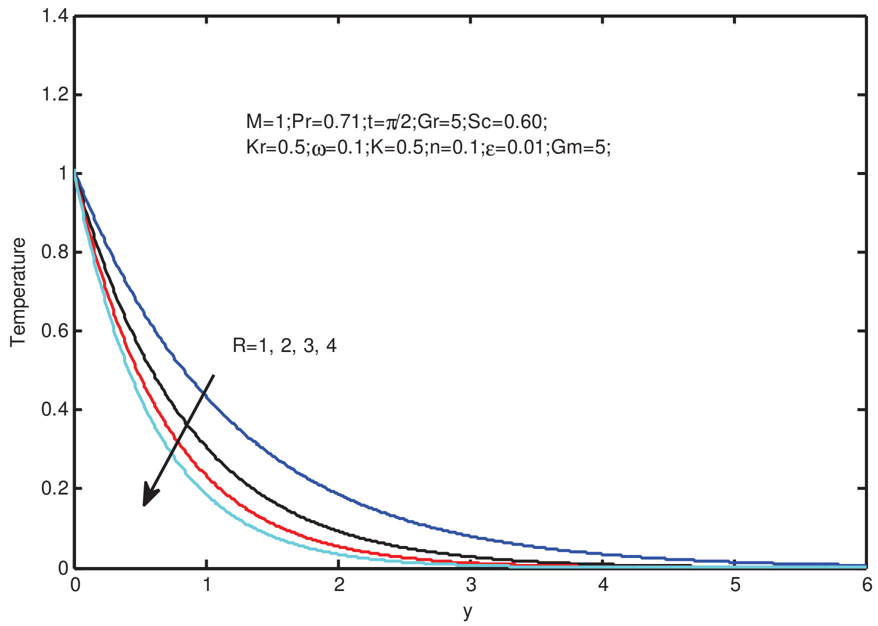

Fig.9. Temperature profiles for different values of radiation parameter.

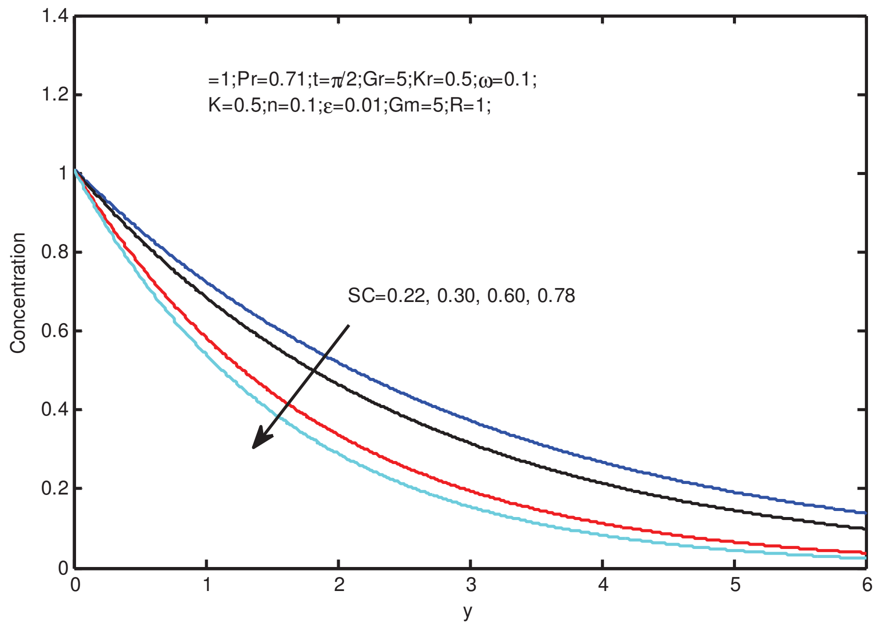

Fig.10. Concentration profiles for different values of Schmidt number.

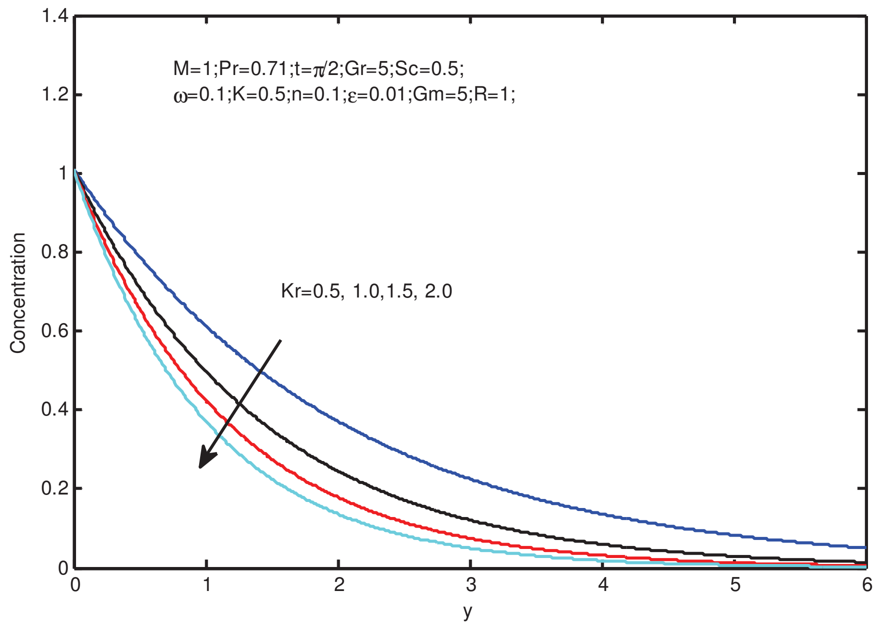

Fig.11. Concentration profiles for different values of chemical reaction parameter.

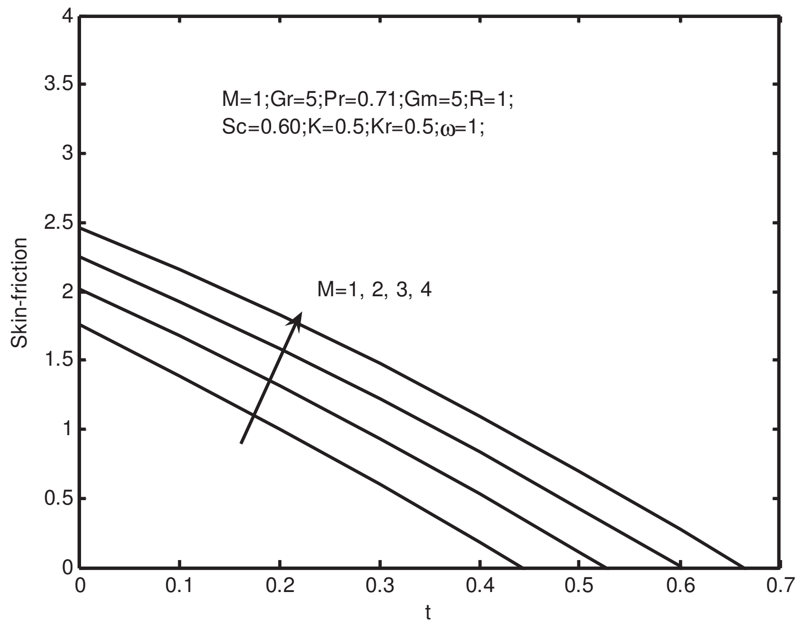

Fig.12. Effect of magnetic parameter on skin-friction.

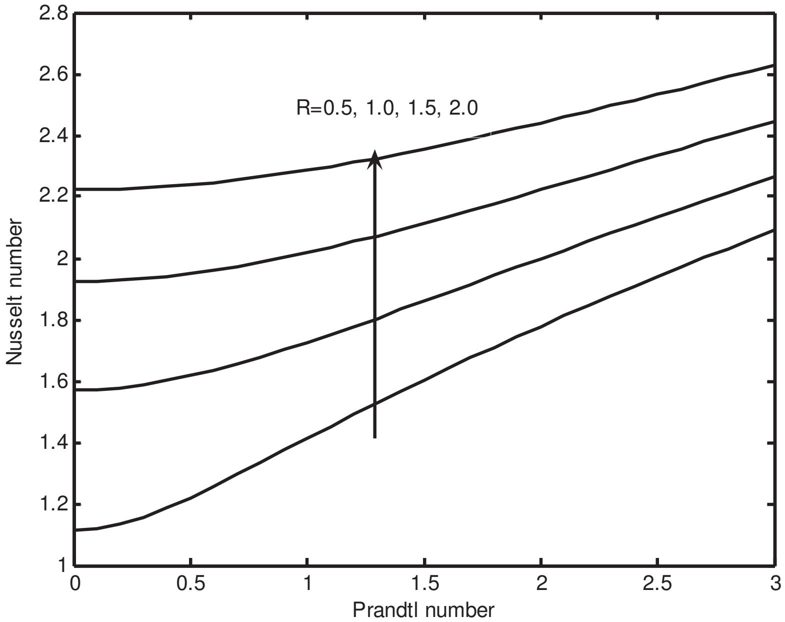

Fig.13. Effect of radiation parameter on Nusselt number.

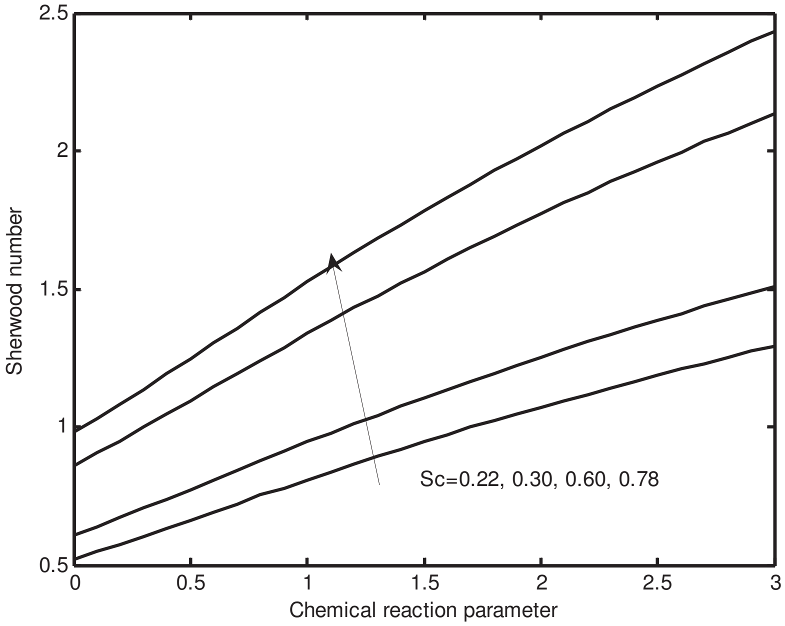

Fig.14. Effect of Schmidt number on Sherwood number.

5. REFERENCES

[1] E. L. Cussler: Diffusion Mass Transfer in Fluid Systems, 2nd edition, *Cambridge University Press,* Cambridge, 1998.

[2] P. L Chambre and J. D. Young: On the Diffusion of Chemically Reactive Species in a Laminar Boundary Layer Flow, *Phys. Fluids*,Vol. 1, pp. 48-54, 1958.

[3] K. Vajravelu: Hydrodynamic Flow and Heat Transfer over Continuous, Moving Porous, Flat Surface, *Acta Mechanica*, Vol. 64, pp.179-185, 1986

[4] A. Chamkha: MHD Flow of Uniformly Stretched Vertical Permeable Surface in the Presence of Heat Generation/ Absorption and a Chemical Reaction, *Int. Comm. Heat and Mass Transfer*, Vol. 30, pp.413-422, 2003.

[5] B. C. Sakiadis: Boundary layer behavior on continuous solid surfaces: II boundary layer on a continuous solid flat surfaces, *AiChE journal*, Vol. 7, pp.221-225, 1961.

[6] V. M. Soundalgekar, S. K. Gupta, and N.S. Birajdar: Effects of mass transfer and free convection currents on MHD Stokes problem for a vertical plate, *Nuclear Engg Des,* Vol. 53, pp. 339-346, 1979.

[7] V. M. Soundalgekar, M. R. Patil, and M. D. Jahagirdar: MHD stokes problem for a vertical plate with variable temperature, *Nuclear Engg Des*, Vol.64, pp. 39-42, 1981.

[8] M. Kumari and G. Nath: Devolvement of two dimensional boundary layer with an applied magnetic field due to an impulsive motion, *Indian journal of Pure and Applied Mathematics,* Vol. 30, pp. 695-708, 1999.

[9] W. G. England and A. F.Emery: Thermal radiation effects on the laminar free convection boundary layer of an absorbing gas, *Journal of Heat transfer,* Vol. 91, pp. 37-44, 1969.

[10] V. M. Soundalgekar and H.S.Takhar: Radiation effects on free convection flow past a semi-infinite vertical plate, *Modeling, Measurement and Control*, B.51, pp. 31-40, 1993.

[11] M.A.Hossain and H.S.Takhar: Radiation effect on mixed convection along a vertical plate with uniform surface temperature, *Heat and mass transfer,* Vol. 31, pp. 243-248, 1996.

[12] A. Raptis and C. Perdikis: Radiation and free convection flow past a moving plate, *International journal of Applied Mechanics and Engineering,* Vol. 4, pp.817-821, 1999.

[13] S. Ahmed and I-Chung. Liu: Mixed convective three-dimensional heat and mass transfer flow with transversely periodic suction velocity, *International journal of Applied Mathematics and Mechanics,* Vol. 6, pp. 58-73, 2010.

[14] S. Ahmed: Induced magnetic field with radiating fluid over a porous vertical plate: Analytical study, *Journal of Naval Architecture and Marine Engineering,* Vol. 7, pp. 83-94, 2010

[15] S. Ahmed: A study of induced magnetic field with chemically reacting and radiating fluid past a vertical permeable plate, *Journal of Engineering Physics and Thermo physics*, Vol. 84, No. 6, pp. 1360-1368, 2011.

[16] S. Ahmed and J. Zueco: Combined heat and mass transfer by mixed convection MHD flow along a porous plate with chemical reaction in presence of heat source, *Applied Mathematics and Mechanics,* Vol. 31, No. 10, pp.1217-1230, 2010.

[17] S. Ahmed and A. J. Chamkha: Effects of chemical reaction, heat and mass transfer and radiation on MHD flow along a vertical porous wall in the presence of induced magnetic field, *International Journal of Industrial Mathematics,* (In Press), 2010.

[18] B. S. Jaiswal and V. M. Soundalgekar: Oscillating plate temperature effects on a flow past an infinite vertical porous late with constant suction and embedded in a porous medium, *Heat and Mass Transfer*, Vol. 37, pp.125-131, 2001.

[19] A. G. V. Kumar and S. V. K. Verma: Thermal radiation and mass transfer effects on MHD flow past a vertical oscillating plate with variable temperature effects variable mass diffusion, *International Journal of Engineering*, Vol. 3, pp.493-499, 2011.

[20] M. Turkyilmazoglu: Exact analytical solutions for heat and mass transfer of MHD slip flow in nanofluids, *Chem. Eng. Sci*. Vol. 84, 182–187, 2012.

[21] M. Turkyilmazoglu and I. Pop: Soret and heat source effects on the unsteady radiative MHD free convection flow from an impulsively started infinite vertical plate, *International Journal of Heat and Mass Transfer*, Vol. 55,pp. 7635-7644, 2012.

[22] M. Turkyilmazoglu and I. Pop: Heat and mass transfer of unsteady natural convection flow of some nanofluids past a vertical infinite flat plate with radiation effect, *International Journal of Heat and Mass Transfer*, Vol. 59, pp. 167-171, 2013.

[23] D. Pal and H. Mondal: Soret and Dufour effects on MHD non-Darcian mixed convection heat and mass transfer over a stretching sheet with non-uniform heat source/sink, *Physica B: Condensed Matter,* Vol. 407, pp.642-651, 2012