ISSN 0976 – 1411

Available online at www.internationaleJournals.com

International eJournals

INTERNATIONAL eJOURNAL OF MATHEMATICS AND ENGINEERING

International eJournal of Mathematics and Engineering 39 (2010) 382 - 397

www.InternationaleJournals.com

Author's personal copy

EFFECTS OF CHEMICAL REACTION ON AN UNSTEADY MHD FREE CONVECTION FLUID FLOW THROUGH A POROUS MEDIUM WITH OSCILLATING TEMPERATURE

J Anand Rao[1] and S Shivaiah[2]

[1]Department of Mathematics, Osmania University, Hyderabad-500007, India.

[2] Department of Mathematics, BVRIT, Narsapur, Medak-502313, India.

Email: anandrao_jakkula@yahoo.com, sreddy7@yahoo.co.in

Abstract:

Aim of the paper is to investigate an unsteady magnetohydrodynamic free convection fluid flow through a porous medium with oscillating temperature here, taking into account of the homogeneous chemical reaction of first order. The dimensionless governing equations are solved numerically by using finite element technique. The effects of the various physical parameters on the velocity, temperature and concentration are discussed numerically and presented through graphs and Tables. The skin-friction coefficient, the Nusselt number and the Sherwood number at the plate are discussed and their numerical values for various values of physical parameters are presented through tables.

Key words: chemical reaction, MHD, oscillating temperature, finite element method.

1 Introduction:

The present trend in the field of chemical reaction analysis is to give a mathematical model for the system to predict the reactor performance. The effect of a chemical reaction depend whether the reaction is heterogeneous or homogeneous. This depends on whether they occur at an interface or as a single phase volume reaction. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be of the order n, if the reaction rate if proportional to the n^{th} power of the concentration. In particular, a reaction is said to be first order, if the rate of reaction is directly proportional to concentration itself.

The flow of a viscous incompressible fluid past an infinite isothermal vertical impermeable plate was solved by Soundalgekar [1]. The effect of mass transfer on the flow past an infinite vertical plate in the presence of constant heat flux has been studied by Soundalgekar et al [2]. Kafousias et al [3]. have studied the effects of free convection currents and the Stoke's problem for the flow of viscous incompressible fluid past an infinite porous plate with constant suction. Free convection effects on flow past a moving vertical infinite porous plate were studied by Perdiks et al [4]. The transient effect in natural convection cooling of vertical parallel plates was studied by Joshi [5]. MHD transient free-convection flow past a semi-infinite vertical plate with constant heat flux was studied by Gokhale el al [6]. Bejan and Khair [7] presented an analysis of heat and mass transfer about a vertical plate in porous medium they considered concentration gradient which assists or opposes thermal gradient. Chamkha [8] investigated unsteady convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption where it was found that increase in solutal Grashof number enhanced the concentration buoyancy effects leading to an increase in the velocity.

In all these investigations, the viscous dissipation is neglected. The viscous dissipation heat in the natural convective flow is important, when the flow field is of extreme size or at low temperature or in high gravitational field. Gebhart [9] that the viscous dissipative heat in natural convective flow is important when the flow field is of extreme size or extremely low temperature or in high gravity field. Soundalgekar et al [10]. studied the effect of an incompressible, viscous dissipative fluid past an infinite vertical porous plate with constant suction. The unsteady transient free convection flow of an incompressible dissipative viscous fluid past an infinite vertical plate is consider Sreekanth et al [11]. on taking into account viscous dissipative heat under the influence of a uniform transfers magnetic field. The effect of applied magnetic field on transient free-convective flow in a vertical channel was studied by Jha [12].

The effect of chemical reaction on MHD flows also plays an important role. This effect depends on whether the reaction is heterogeneous or homogeneous, in turn depends on whether they occur at an interface or single phase volume reaction. In well- mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if takes place in solution. In the most cases of chemical reactions, the reaction rate depends on the concentration of the species.
Muthucumaraswamy and Ganesan [13] investigated the diffusion and first order chemical reaction on impulsively started infinite vertical plate with variable temperature. The effects of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge with heat radiation in the presence of suction or injection was studied by Kandasamy et al [14]. Muthucumaraswamy and Janakiraman [15] investigated the mass transfer effects on isothermal vertical oscillating plate in the presence of chemical reaction. Radiative heat and mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction was studied by muthucumaraswamy et al [16].

The objective of the present paper is to analyze the effects of chemical reaction on an unsteady MHD free convection fluid flow through a porous medium with oscillating temperature into account. The governing equations are transformed by using unsteady similarity transformation and the resultant dimensionless equations are solved by using the finite element method. The effects of various governing parameters on the velocity, temperature, concentration, skin-friction coefficient, Nusselt number and Sherwood number are shown in figures and tables and discussed in detail.

Author's personal copy

2 Mathematical Analysis:

An unsteady two dimensional flow of an incompressible, electrically conducting and chemically reacting viscous fluid along an infinite vertical plate, that is a porous medium with oscillating temperature is considered. Let the x'-axis is taken along the plate in the vertically upward direction and the y'-axis is taken normal to the plate. At time $t'>0$, the plate is given an impulsive motion in the vertical direction against gravitational field with constant velocity u_0. At the same time concentration level is also raised to C_w and temperature of the plate is raised to T_w. It is also assumed that there exists first order chemical reaction between the fluid and the species concentration. Then under usual Boussinesq's approximation the unsteady flow is governed by the following equations:

Momentum equation

$$\frac{\partial u'}{\partial t'} = \nu \frac{\partial^2 u'}{\partial y'^2} + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) - \frac{\sigma B_0^2}{\rho} u' - \frac{\nu}{k'} u' \tag{1}$$

Energy equation

$$\frac{\partial T}{\partial t'} = \alpha \frac{\partial^2 T}{\partial y'^2} + \frac{\mu}{\rho\, c_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{2}$$

Diffusion equation

$$\frac{\partial C}{\partial t'} = D \frac{\partial^2 C}{\partial y'^2} - k_r' \,(C - C_\infty) \tag{3}$$

The initial and boundary conditions are as follows:

$$\begin{aligned} t' \le 0:&\quad u' = 0,\quad T = T_\infty,\quad C = C_\infty, && \textit{for all}\quad y' \\ t' > 0:&\quad u' = 0,\quad T = T_w + \varepsilon(T_w - T_\infty)\cos\omega t,\ C = C_w, && \textit{at}\quad y' = 0 \\ &\quad u' = 0,\quad T = T_\infty,\quad C = C_\infty && \textit{as}\quad y' \to \infty \end{aligned} \tag{4}$$

To reduce the above equations into non- dimensional form, let us introduce the following non-dimensional quantities are:

$$u = \frac{u'}{u_0},\quad y = \frac{u_0 y'}{\nu},\quad t = \frac{u_0^2 t'}{\nu},\quad K = \frac{u_0^2 k'}{\nu^2},\quad \theta = \frac{T - T_\infty}{T_w - T_\infty},\quad \phi = \frac{C - C_\infty}{C_w - C_\infty}$$

$$\Pr = \frac{\nu\, \rho\, c_p}{k} = \frac{\nu}{\alpha},\quad Sc = \frac{\nu}{D},\quad Gr = \frac{g\beta\nu(T_w - T_\infty)}{u_0^3},\quad Gm = \frac{g\beta^*\nu(C_w - C_\infty)}{u_0^3},$$

$$Ec = \frac{U_0^2}{c_p(T_w - T_\infty)},\quad k_r = \frac{k_r'\,\nu}{u_0^2},\quad M = \frac{\sigma B_0^2 \nu}{\rho u_0^3} \tag{5}$$

In view of the equations (5) and Equations (1) - (3) reduce to the following dimensionless form.

Author's personal copy

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gm\phi - \left(M + \frac{1}{K}\right)u \tag{6}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} + Ec\left(\frac{\partial u}{\partial y}\right)^2 \tag{7}$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} - k_r\phi \tag{8}$$

The initial and boundary conditions in non-dimensional form are:

$$\begin{aligned}
t \le 0:&\quad u = 0,\quad \theta = 0,\quad \phi = 0,\quad && for\ all\quad y\\
t > 0:&\quad u = 0,\quad \theta = 1 + \varepsilon\cos\omega t,\quad \phi = 1,\quad && at\quad y = 0\\
&\quad u \to 0,\quad \theta \to 0,\quad \phi \to 0,\quad && as\quad y \to \infty
\end{aligned} \tag{9}$$

3 Method of solution:

The linear functional for equation (6) over a typical line segment element (e), $(y_j \le y \le y_k)$ is

$$J^{(e)}(u) = \frac{1}{2}\int_{y_j}^{y_k}\left\{\left(\frac{\partial u^{(e)}}{\partial y}\right)^2 + M_1 u^{(e)^2} + 2u^{(e)}\frac{\partial u^{(e)}}{\partial t} - 2u^{(e)}(Gr\theta + Gm\phi)\right\}dy = \text{minimum.}$$

Where $M_1 = M + \frac{1}{K}$.

Let $u^{(e)} = N_j u_j + N_k u_k$ be the linear piecewise approximation solution over the element (e), $(y_j \le y \le y_k)$, where u_j, u_k are the values of the function u at the ends of the element (e) and $N_j = \frac{y_k - y}{y_k - y_j}, N_k = \frac{y - y_j}{y_k - y_j}$ are the basis functions. One obtains

$$\frac{1}{l^{(e)}}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} + \frac{M_1 l^{(e)}}{6}\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} u_j \\ u_k \end{bmatrix} + \frac{l^{(e)}}{6}\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} u_j^{\bullet} \\ u_k^{\bullet} \end{bmatrix} - (Gr\theta + Gm\phi)\frac{l^{(e)}}{2}\begin{bmatrix} 1 \\ 1 \end{bmatrix} = 0$$

where dot denotes the differentiation with respect to t and $l^{(e)} = y_k - y_j$. Assembling the element equations for two consecutive elements $y_{i-1} \le y \le y_i$ and $y_i \le y \le y_{i+1}$, the following is obtained:

$$\frac{1}{l^{(e)}}\begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} + \frac{M_1 l^{(e)}}{6}\begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} + \frac{l^{(e)}}{6}\begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix}\begin{bmatrix} u_{i-1}^{\bullet} \\ u_i^{\bullet} \\ u_{i+1}^{\bullet} \end{bmatrix} = (Gr\theta + Gm\phi)\frac{l^{(e)}}{2}\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$$

Now put row corresponding to the node i to zero, the difference schemes with $l^{(e)} = h$ is

Author's personal copy

$$\left(u_{i-1}^{\bullet}+4u_{i}^{\bullet}+u_{i+1}^{\bullet}\right)=\frac{1}{h^{2}}\left(6-M_{1}h^{2}\right)\left(u_{i-1}+u_{i+1}\right)+\frac{1}{h^{2}}\left(12+4M_{1}h^{2}\right)u_{i}+6\left(Gr\theta+Gm\phi\right)$$

Applying the trapezoidal rule, the following system of equations in Crank-Nicholson method are obtained:

$$\left(1-3r+\frac{1}{2}rM_{1}h^{2}\right)u_{i-1}^{j+1}+\left(4+6r+2rM_{1}h^{2}\right)u_{i}^{j+1}+\left(1-3r+\frac{1}{2}rM_{1}h^{2}\right)u_{i+1}^{j+1}=\left(1+3r-\frac{1}{2}rM_{1}h^{2}\right)u_{i-1}^{j}$$
$$+\left(4-6r-2rM_{1}h^{2}\right)u_{i}^{j}+\left(1+3r-\frac{1}{2}rM_{1}h^{2}\right)u_{i+1}^{j}+6k\left(Gr\theta_{i}^{j}+Gm\phi_{i}^{j}\right) \qquad (10)$$

Now from equations (7) and (8), following equations are obtained:

$$\left(\Pr-3r\right)\theta_{i-1}^{j+1}+\left(4\Pr+6r\right)\theta_{i}^{j+1}+\left(\Pr-3r\right)\theta_{i+1}^{j+1}=\left(\Pr+3r\right)\theta_{i-1}^{j}+\left(4\Pr-6r\right)\theta_{i}^{j}+\left(\Pr+3r\right)\theta_{i+1}^{j}$$
$$+6r\Pr Ec\left(u_{i+1}^{j}-u_{i}^{j}\right)^{2} \qquad (11)$$

$$\left(2Sc+k_{r}Sc-6r\right)\phi_{i-1}^{j+1}+\left(8Sc+4k_{r}Sc+12r\right)\phi_{i}^{j+1}+\left(2Sc+k_{r}Sc-6r\right)\phi_{i+1}^{j+1}=$$
$$\left(2Sc-k_{r}Sc+6r\right)\phi_{i-1}^{j}+\left(8Sc-4k_{r}Sc-12r\right)\phi_{i}^{j}+\left(2Sc-k_{r}Sc+6r\right)\phi_{i+1}^{j} \qquad (12)$$

Here $r=\frac{k}{h^{2}}$ and h,k are mesh sizes along $y-$direction and time $t-$direction respectively. Index i refers to the space and j refers to the time. In the above equations $(10)-(12)$ taking $i=1(1)n$ and using initial and boundary conditions (9), the following tri-diagonal system of equations are obtained:

$$AU=B \qquad (13)$$
$$D\theta=E \qquad (14)$$
$$F\phi=G \qquad (15)$$

where A,D and F are tri-diagonal matrices of order - n and whose elements are given by

$a_{i,i}=4+6r+2rM_{1}h^{2}$, $d_{i,i}=4\Pr+6r$, $f_{i,i}=8Sc+4k_{r}Sc+12r$ $\qquad i=1(1)n$

$a_{i-1,j}=a_{i,j-1}=1-3r+\frac{1}{2}rM_{1}h^{2}$, $d_{i-1,j}=d_{i.j-1}=\Pr-3r$,

$f_{i-1,j}=f_{i,j-1}=2Sc+k_{r}Sc-6r$ $\qquad i=2(1)n$

Author's personal copy

Here U,θ,ϕ and B,E,G are column matrices having the n-components $u_i^{j+1}, \theta_i^{j+1}, \phi_i^{j+1}$ and $u_i^j, \theta_i^j, \phi_i^j$ respectively. The solutions of the above system of equations are obtained by using Thomas algorithm for velocity, temperature and concentration. Also, the numerical solutions for these equations are obtained by C – program. In order to prove the convergence and stability of Ritz finite element method, the computations are carried out for slightly changed values of h and k by running the same C – program. No significant change was observed in the values of u,θ and ϕ. Hence, finite element method is convergent and stable.

Skin-friction, Rate of heat and Mass Transfer

Skin-friction coefficient (C_f) is given by $C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0}$ (16)

Heat transfer coefficient (Nu) at the plate is $Nu = -\left(\frac{d\theta}{dy}\right)_{y=0}$ (17)

Mass transfer coefficient (Sh) at the plate is $Sh = -\left(\frac{d\phi}{dy}\right)_{y=0}$ (18)

4 Results and discussion:

In order to analyze the results, the numerical computations has been carried out for various values of the material parameters such as thermal Grashof number , solutal Grashof number, Magnetic parameter, Permeability parameter, Prandtl number, Eckert number, Schmidt number and chemical reaction parameter respectively. The effects of these parameters on the velocity, temperature, concentration, skin-friction coefficient and heat and mass transfer coefficients in terms of Nusselt number and Sherwood number have been discussed. The numerical calculations of these results are presented graphically in figures. Here we fixed $\varepsilon = 0.1$ and $wt = 0$.

The velocity profiles for different values of the thermal Grashof number Gr are shown in Fig.1. It is observed that an increase in Gr leads to arise in the values of velocity. For the case of various values of the solutal Grashof number Gm , the velocity profiles are displays in Fig.2. It is noticed that an increase Gm leads to arise in the values of velocity.

The effect of magnetic field parameter M on the velocity is shown in Fig.3. The velocity decreases with an increase in the magnetic parameter. Fig.4. shows the effect of the permeability of the porous medium parameter K on the velocity distribution. It is found that an increase in K leads to arise in the values of velocity

Authors personal copy

For different values of the Prandtl number Pr , the velocity and temperature profiles are plotted in Figs 5(a) and 5(b). It is observer that the increasing values of Pr results in a decreasing the velocity and temperature distribution.

The velocity and temperature profiles are shown in Figs 6(a) and 6(b) for different values of Eckert number Ec. An increase in Eckert number Ec leads to increase in both velocity and temperature.

The effects of Schmidt number Sc on the velocity and concentration profiles are plotted in Figs 7(a) and 7(b) respectively. It is found that an increase in Sc leads to a decrease in both the values of velocity and concentration.

Figs 8(a) and 8(b) illustrates the behavior velocity and concentration for different values of chemical reaction parameter k_r . It is observed that an increase in k_r leads to a decrease in both the values of velocity and concentration.

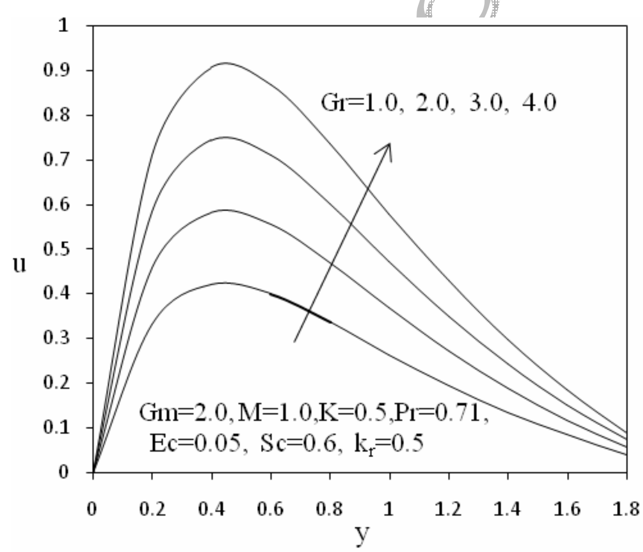

Fig.1. Velocity profiles for different values of Gr

Author-personal copy

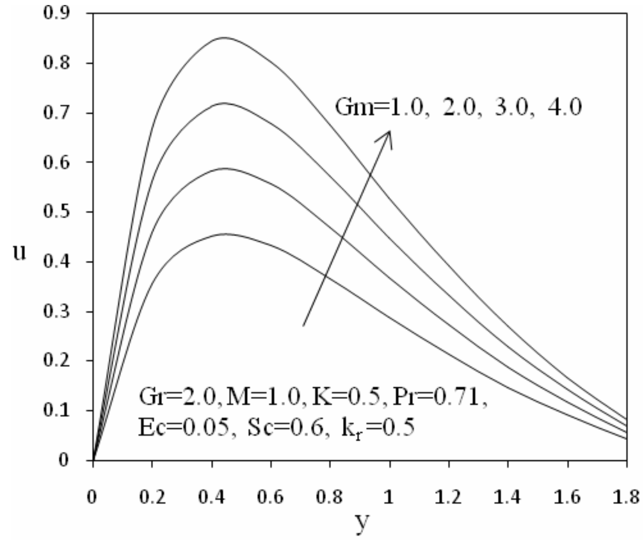

Fig.2. Velocity profiles for different values of Gm

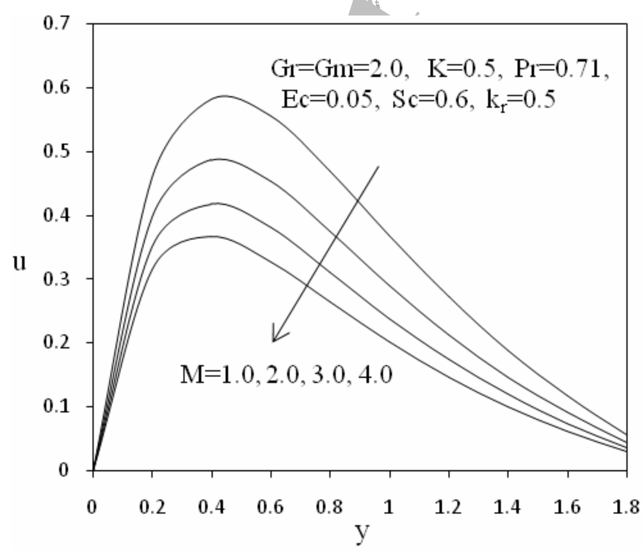

Fig.3. Velocity profiles for different values of M

Author's personal copy

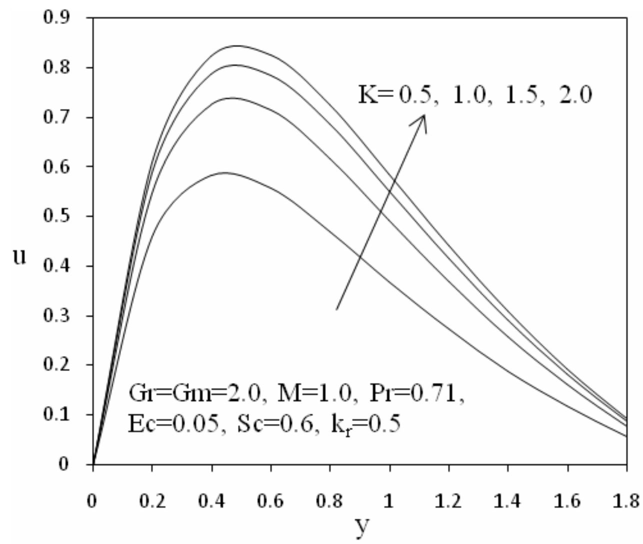

Fig.4. Velocity profiles for different values of K

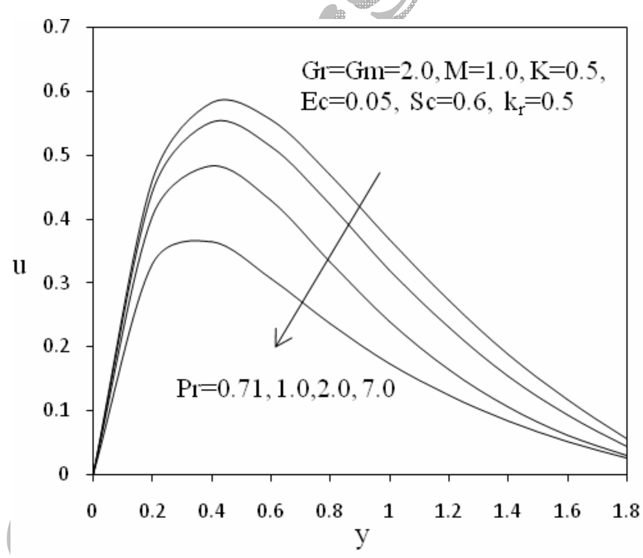

Fig.5(a). Velocity profiles for different values of Pr

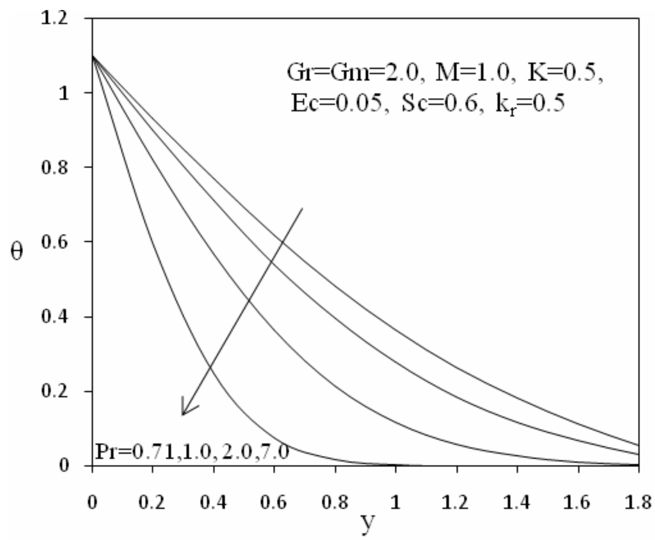

Fig.5(b). Temperature profiles for different values of Pr

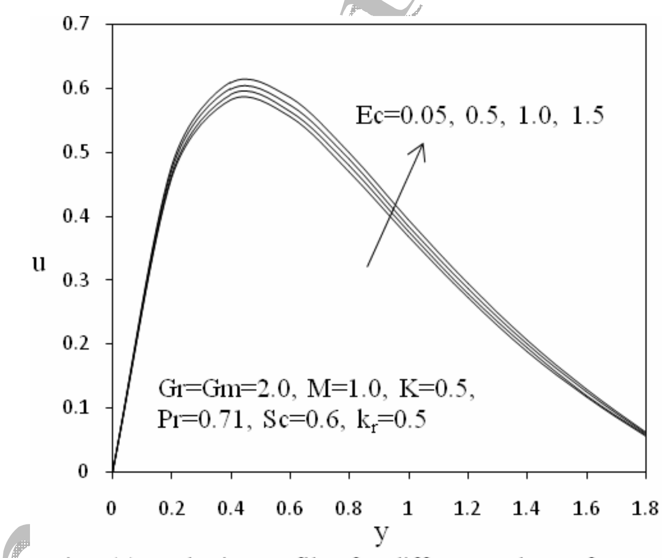

Fig.6(a). Velocity profiles for different values of Ec

Author personal copy

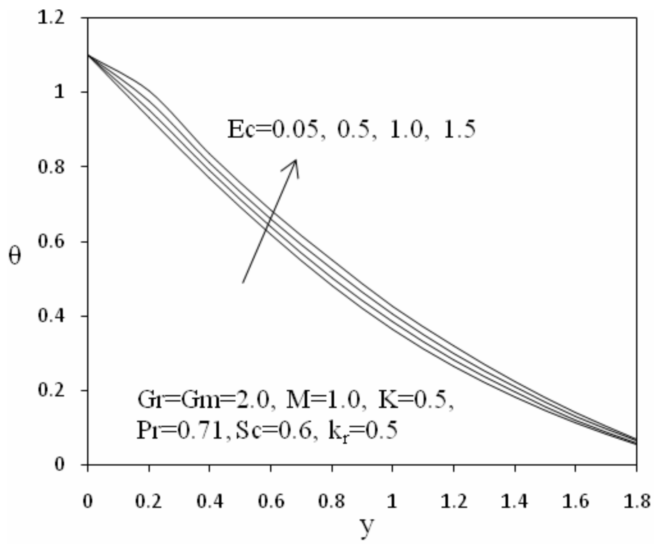

Fig.6(b). Temperature profiles for different values of Ec

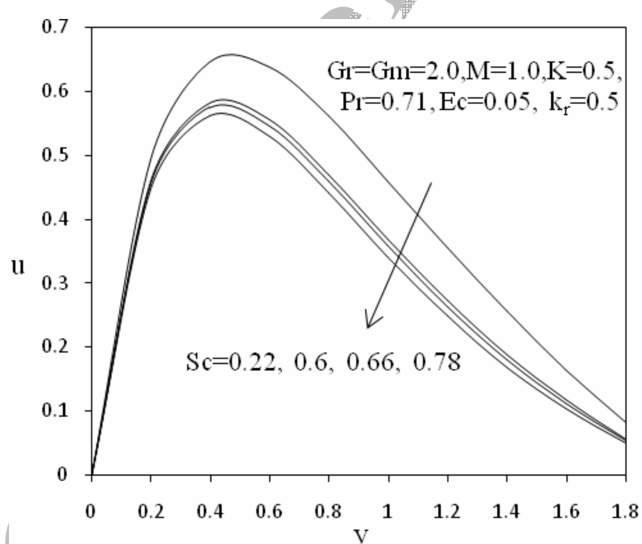

Fig.7(a). Velocity profiles for different values of Sc

Author personal copy

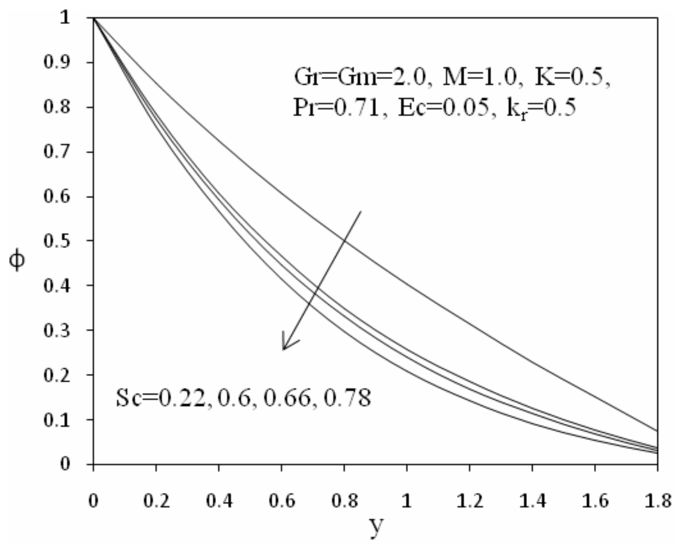

Fig.7(b).Concentration profiles for different values of Sc

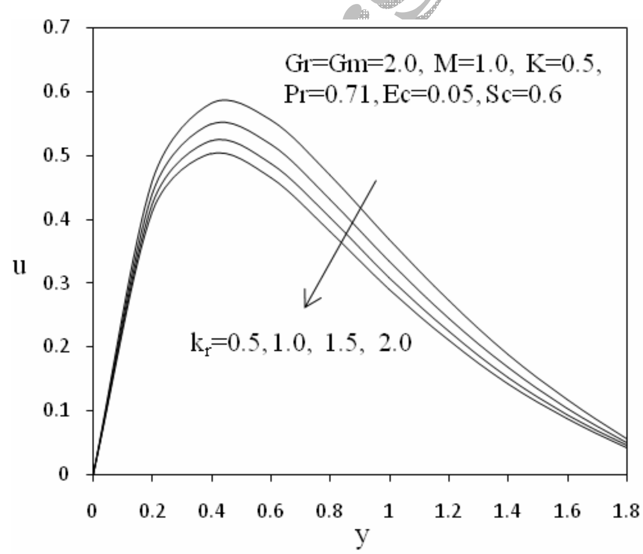

Fig.8(a). Velocity profiles for different values of k_r

Author's copy

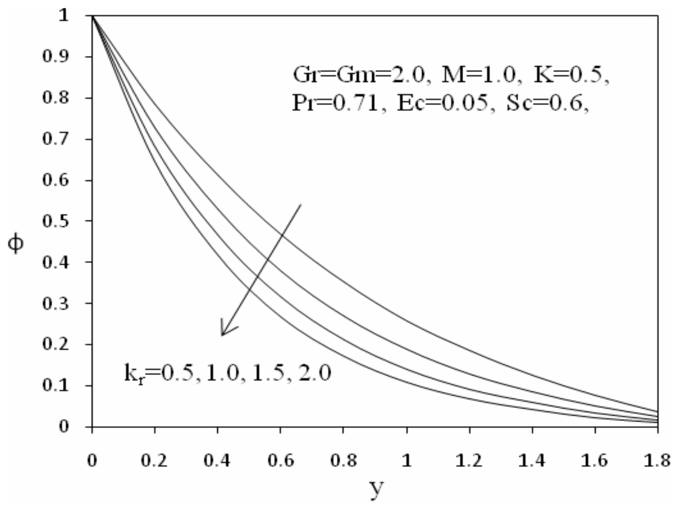

Fig.8(b).Concentration profiles for different values of k_r

The effects of Gr, Gm, M, K, Pr, Ec, Sc and k_r on the skin-friction C_f, Nusselt number Nu, Sherwood number Sh are shown in Tables 1 to 3. From Table 1, it is observed that as Gr or Gm or K increases, the skin-friction coefficient increases, where as the skin-friction coefficient decreases as M increases. From Table 2, it is noticed that as Ec increases, the skin-friction coefficient increases while the Nusselt number increases and Pr increases, the skin-friction coefficient decreases while the Nusselt number decreases. From Table 3, it is found that as Sc or k_r increases, the skin-friction coefficient decreases while the Sherwood number decreases.

Table 1 : Effect of Gr, Gm, M and K on C_f
(Pr =0.71, Ec=0.05, Sc =0.6, k_r =0.5)

Gr	Gm	M	K	C_f
2.0	2.0	1.0	0.5	1.6160
4.0	2.0	1.0	0.5	2.4959
2.0	4.0	1.0	0.5	2.3592
2.0	2.0	2.0	0.5	1.4434
2.0	2.0	1.0	1.0	1.8599

Table 2 : Effect of Pr and Ec on C_f and Nu
(Gr=2.0, Gm =2.0, M =1.0, K =0.5, Sc =0.6, k_r =0.5)

Pr	Ec	C_f	Nu
0.71	0.05	1.6160	0.4152
7.0	0.05	1.2710	1.2989
0.71	0.5	1.6324	0.3056

Author's personal copy

Table 3 : Effect of Sc and k_r on C_f and Sh
(Gr=2.0, Gm =2.0, M =1.0, K =0.5, Pr =0.71, Ec=0.05)

Sc	k_r	C_f	Sh
0.22	0.5	1.7081	0.3794
0.60	0.5	1.6160	0.5813
0.22	1.0	1.6691	0.4820

5 Conclusions:

In this paper, the governing equations for Effects of chemical reaction on an unsteady MHD free convection fluid flow through a porous medium with oscillating temperature, on taking into account viscous dissipative heat has been presented. Employing the highly efficient Ritz finite element method, the leading equations are solved numerically. The results illustrate the flow characteristics for the velocity, temperature, concentration, skin-friction, rate of heat and mass transfer and show how the flow fields are influenced by the material parameters on the problem. The conclusions from these results are:

1. The velocity increases with the increase in thermal Grashof number and solutal Grashof number.
2. The velocity decreases with an increase in the magnetic parameter.
3. The velocity increases with an increase in the permeability of the porous medium parameter.
4. An increase in the Eckert number increases the velocity and temperature.
5. An increase in the Prandtl number decreases the velocity and temperature.
6. An increase in the radiation parameter leads to increase in the velocity and temperature.
7. The velocity as well as concentration decreases with an increase in the Schmidt number.
8. The velocity as well as concentration decreases with an increase in the chemical reaction parameter.

Nomenclature

u'	velocity of the fluid	u	dimensionless velocity
σ	fluid electrical conductivity	g	acceleration due to gravity
T	temperature of the fluid in near the plate	C	species concentration in the fluid
t'	time	t	dimensionless time
β	coefficient of volume expansion due to temperature	β^*	coefficient of volume expansion due to concentration
ρ	density	μ	viscosity of the fluid

Author's personal copy

ν	kinematic viscosity	M	magnetic parameter
k	thermal conductively	c_p	specific heat at constant pressure
Sc	Schmidt number	Pr	Prandtl number
K	Permeability parameter	D	mass diffusion coefficient
k_r	chemical reaction parameter	Ec	Eckert number
Gr	free-convection parameter due to temperature	Gm	free-convection parameter due to concentration
θ	dimensionless temperature	ϕ	dimensionless concentration

Subscripts

w	condition at the wall
∞	free stream conditions

References:

1. Soundalgekar, V.M., (1979): Free-convection effects on the flow past a vertical oscillating plate, *Astrophysics and Space Science*, 64, 165.

2. Soundalgekar, V.M, Lahurikar, R .M, Pohanerkar, S G & Birajdar, N. S., (1994): Effect of mass transfer on the flow past an oscillating infinite vertical plate with constant heat flux, *Thermophysics and Aero Mechanics*, 1, 119.

3. Kafoussias, N. G., Nanousis, N. D. and Georgantopoulos, G. A., (1979): Free convection effects on the stokes problem for an infinite vertical-limiting surface with constant suction, *Astrophysics and Space Science*, Vol. 64a, 391.
4. Perdiks, C.P., and Takhar, H.S., (1986): Free convection effects on the flow past a moving vertical infinite porous plate, *Astrophysics and Space Sciences*, 125, 205.

5. Joshi, H.M., (1988): Transient effects in natural convection cooling of vertical parallel plates, *Int. Comm. Heat Transfer,* 15, 227.

6. Gokhale, M.Y., and Soundalgekar, V.M., (1991): MHD transient free convection flow past a semi infinite vertical plate with constant heat flux, *Can. J. Physics*, 69,1451.

7. Bejan, A and khair, K.R., (1985): Heat and mass transfer by natural convection in the porous medium , *International Journal of Heat and Mass Transfer,*28, 909.

8. Chamkha, A.J., (2004): Unsteady MHD convective heat and mass transfer past a semi-inifinite vertical permeable moving plate with heat absorption, *International Journal of Engineering Science*, 42, 217.

Author's personal copy

9. Gebhart, B., (1962): Effects of viscous dissipative in natural convection, *J. Fluid Mech.*, 14, 225.

10. Srikanth,S.Nagarajan, A.S.,and Venkatramana S., (2001): Transient MHD free-convection flow of an incompressible viscous dissipative fluid, *Indian J. of Pure and Applied Maths,* 32(7), 1051 .

11. Soundalgekar, V.M., (1972): Viscous dissipation effects on unsteady free convective flow past an infinite vertical porous plate with constant suction, *Int. J. Heat Mass Transfer,* 15, 1253.

12. Basant Kumar Jha ,(1998): Effects of applied magnetic field on transient free-convection flow in a vertical channel, *Indian J. of Pure and Applied Maths,* 29(4), 441.

13. Muthucumaraswamy R & Ganesan, P., (2002): Diffusion and first order chemical reaction on impulsively started infinite vertical plate with variable temperature, *Int.J. Therm.Sci,* 41 , 474.

14. Kandasamy R, Abd Wahib B, Md. Raj & Azme B. Khamis., (2006): Effects of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge with heat radiation in presence of suction or injection, *Theorical Applied Mechanics Belgrade,* 33, 123.

15. Muthucumaraswamy R & Janakiraman, B., (2008): Mass transfer effects on isothermal vertical oscillating plate in the presence of chemical reaction, *Int.J. Appl. Math. And Mech,* 4 , 66.

16. Muthucumaraswamy R Chandrakala P & Antony Raj S., (2006): Radiative heat and mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction. *Int. J. Applied Mechanics and Engineering,* 11, 639.

Author's personal copy