Radiation Absorption and Chemical Reaction Effects on Unsteady Magneto hydrodynamic Convective Heat and Mass Transfer Flow in a Rotating System With Hall Effects

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Abstract
The objective of the present paper is to analyze the effects of permeability variation, mass transfer and chemical reaction on flow of a viscous incompressible fluid past an infinite vertical porous surface in a rotating system, when the temperature of the surface varies with time about a non-zero constant mean and the temperature at the free stream is constant .
Keywords: Chemical Reaction, Radiation Absorption, Heat and mass transfer, Hall effect.

1. INTRODUCTION

The study of effects of magnetic field on free convection flow is important in liquid-metals, electrolytes and ionized gases. The thermal physics of hydromagnetic flow problems with mass transfer is of interest in power engineering and metallurgy. Free convection flows are of great interest in a number of industrial applications such as fiber and granular insulation, geothermal systems, *etc.* Buoyancy is also of importance in an environment where differences between land and air temperatures can give rise to complicated flow patterns. Magnetohydrodynamic (MHD) flows have attracted the attention of a large number of scholars due to their diverse applications. In astrophysics and geophysics, they are applied to study the stellar and solar structures, interstellar matter, radio propagation through the ionosphere, *etc.* In engineering, MHD flows find their application in MHD pumps, MHD bearings, *etc.* Convection in porous media has applications in geothermal energy recovery, oil extraction, thermal energy storage and flow through filtering devices. The phenomenon of mass transfer is also very common in the theory of stellar structure and observable effects are detectable, at least on the solar surface.

Malathy and Srinivas [10] investigated the pulsating flow of a hydromagnetic fluid between two permeable beds. Singh [21] analyzed the influence of a moving magnetic field on 3-D Couette flow. Das *et al*. [3] discussed mass transfer effects on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source.

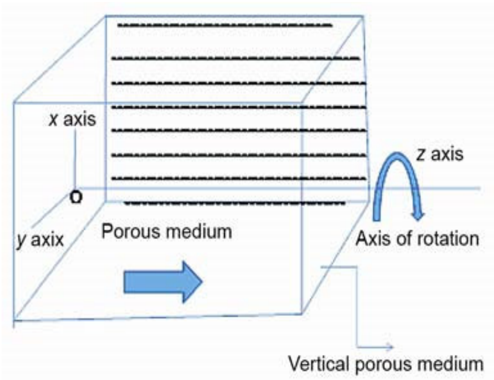
Muthucumaraswamy and Ganesh [11] studied unsteady flow of an incompressible fluid past an impulsively started vertical plate with heat and mass transfer. Acharya *et al*. [1] discussed magnetic field effects on free convection and mass transfer flow through porous medium with constant suction and constant heat flux. Chaudhary and Jain [2] analyzed combined heat and mass transfer effects on MHD free convection flow past an oscillating plate embedded in porous medium. Muthuraj and Srinivas [13] discussed heat transfer effects on MHD oscillatory flow in an asymmetric wavy channel. Muthucumaraswamy *et al*. [12] analyzed chemical reaction effects on infinite vertical plate with uniform heat flux and variable mass diffusion. Singh and Varma [18] discussed heat transfer effects in a 3-D flow through a porous medium with a periodic permeability. Gersten and Gross [5] analyzed flow and heat transfer effects along a plane wall with periodic suction. Singh [21] discussed the effect of injection/suction parameter on 3-D Couette flow with transpiration cooling. Gupta and Johari [7] studied the effect of MHD incompressible flow past a highly porous medium which was bounded by a vertical infinite porous plate. Singh *et al*. [20] analyzed the heat transfer effects on 3-D fluctuating flow through a porous medium with a variable permeability. Rashidi and Sadri [16] analyzed the solution of the laminar viscous flow in a semi-porous channel in the presence of a uniform magnetic field by using the differential transform method. Rashidi and Erfani [17] discussed a new analytical study of MHD stagnation-point flow in porous media with heat transfer.

Jain and Gupta [8] discussed free convection effects on 3-D Couette flow with transpiration cooling. Singh and Rakesh [21] analyzed the MHD effects on 3-D Couette flow with transpiration cooling. Singh *et al*. [20] studied the effects of permeability and rotation parameters on oscillatory Couette flow through a porous medium in a rotating system. Raptis and Perdikis [15] discussed the effect of permeability on oscillatory and free convection flow through a porous medium. Chemical reactions can be classified as either heterogeneous or homogenous processes. This depends on whether they occur at an interface or as a single phase volume reaction. In well-mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be of first order, if the rate of reaction is directly proportional to the concentration itself. A few representative fields of interest in which combined heat and mass transfer along with chemical reaction play an important role in chemical process industries such as food processing and polymer production. Recently

Govindarajan et al [6] have discussed the chemical reaction effects on unsteady magnetohydrodynamic free convective flow in a rotating porous medium with mass transfer.

An investigation of unsteady magnetohydrodynamic free convective flow and mass transfer during the motion of a viscous incompressible fluid through a porous medium, bounded by an infinite vertical porous surface, in a rotating system is presented. The porous plane surface and the porous medium are assumed to rotate in a solid body rotation. The vertical surface is subjected to uniform constant suction perpendicular to it and the temperature at this surface fluctuates in time about a non-zero constant mean. Analytical expressions for the velocity, temperature and concentration fields are obtained using the perturbation technique. The effects of rotation parameter, permeability parameter, Hartmann number, and frequency parameter on the flow characteristics are discussed. It is observed that the primary velocity component decreases with the increase in either of the rotation parameter, the permeability parameter, or the Hartmann number. It is also noted that the primary skin friction increases whenever there is an increase in the Grashof number or the modified Grashof number. It is clear that the heat transfer coefficient in terms of the Nusselt number decreases in the case of both air and water when there is an increase in the Hartmann number. It is observed that the magnitude of the secondary velocity profiles increases whenever there is an increase in either of the Grashof number or the modified Grashof number for mass transfer or the permeability of the porous media. Concentration profiles decreases with an increase in the Schmidt number.

In the studies mentioned above, unsteady free convective flow with heat and mass transfer effects in a rotating porous medium have not been discussed while such flows are very important in geophysical and astrophysical problems. Therefore, the objective of the present chapter is to analyze the effects of permeability variation, mass transfer and chemical reaction on flow of a viscous incompressible fluid past an infinite vertical porous surface in a rotating system, when the temperature of the surface varies with time about a non-zero constant mean and the temperature at the free stream is constant.



2. FORMULATION OF THE PROBLEM:

We consider an unsteady flow of a viscous, electrically conducting incompressible fluid through a porous medium occupying a semi-infinite region of the space bounded by a vertical infinite porous plate in a rotating system under the action of a uniform magnetic field of strength Ho applied normal to the direction of the flow. The temperature of the surface varies with time about a non-zero constant mean and the temperature of the free surface is constant. The porous medium is,in fact ,a non-homogeneous medium which may be replaced by a homogeneous fluid having dynamical properties equal to those of a non-homogeneous continuum. Also ,we assume that the fluid properties are not affected by the temperature and concentration differences except by the density ρ in the body force term; the influence of the density variations in the momentum and energy equations is negligible. It is assumed that the effect of viscous dissipation is negligible in the energy equation and there is a first order chemical reaction between the diffusing species and the fluid. Initially the plate and the fluid are of same temperature T_∞ and the species concentration C_∞.The plate temperature is raised to Tw and the species concentration level near the plate is made raise to Cw.

We consider that the vertical infinite porous plate rotates in unison with a viscous fluid occupying the porous region with the constant angular velocity Ω about an axis which is perpendicular to the vertical plate surface. The Cartesian co-ordinate system is chosen such that x,y axes respectively, are in the vertical upward and perpendicular directions on the plane of the vertical porous surface z=0 while z-axis is normal to it as shown in fig.1.with the above frame of reference and assumptions, the physical variables, except the pressure p, are functions of t only. Consequently, the equations expressing the conservation of mass, momentum, and energy and the equation of mass transfer, neglecting the heat due to viscous dissipation which is valid for small velocities, are given by

$$\frac{\partial w}{\partial z} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t}+w\frac{\partial u}{\partial z}-2\Omega v=\beta g(T-T_\infty)+\beta^{\bullet}g(C-C_\infty)+\nu\frac{\partial^2 u}{\partial z^2}-(\frac{\nu}{k})u+\frac{\sigma\mu_e^2H_o^2}{\rho}(mv-u) \quad (2)$$

$$\frac{\partial v}{\partial t}+w\frac{\partial v}{\partial z}+2\Omega u=\nu\frac{\partial^2 v}{\partial z^2}-(\frac{\nu}{k})v-\frac{\sigma\mu_e^2H_o^2}{\rho}(mu-v) \quad (3)$$

$$0=-\frac{1}{\rho}\frac{\partial p}{\partial z}-(\frac{\nu}{k})w \quad (4)$$

$$\frac{\partial T}{\partial t}+w\frac{\partial T}{\partial z}=\frac{k_f}{\rho C_p}\frac{\partial^2 T}{\partial z^2}-\frac{Q_h}{\rho C_p}(T-T_\infty)+\frac{Q_1'}{\rho C_p}(C-C_\infty) \quad (5)$$

$$\frac{\partial C}{\partial t}+w\frac{\partial C}{\partial z}=D_B\frac{\partial^2 C}{\partial z^2}-k_r'(C-C_\infty) \quad (6)$$

The relevant boundary conditions are

$$u=0,v=0,T=T_w+\varepsilon(T_w-T_\infty)e^{i\omega t},C=C_w=0 \qquad at\ \ z=0$$
$$u,v\to 0,T\to T_\infty,C\to C_\infty \qquad as\ \ z\to\infty \quad (7)$$

In a physical, realistic situation, we cannot ensure perfect insulation in any experiment set-up. There will always be some fluctuations in the temperature. The plate temperature is assumed to vary harmonically with time. It varies from $T_w\pm\varepsilon(T_w-T_\infty)$ as t varies from 0 to $2\pi/\omega$.since ε is small, the plate temperature varies only slightly from the mean value Tw.

For constant suction, we have from equation(1) in view of (7):

$$w=-w_0 \quad (8)$$

Considering V=u+iv and taking into account equation (8),the equations(2)&(3) can be written as

$$\frac{\partial V}{\partial t}-w_0\frac{\partial V}{\partial z}+2i\Omega V=\beta g(T-T_\infty)+\beta^{\bullet}g(C-C_\infty)+\nu\frac{\partial^2 V}{\partial z^2}-(\frac{\nu}{k})V-\frac{\sigma\mu_e^2H_o^2(1-im)}{\rho(1+m^2)}V \quad (9)$$

We introduce the following non-dimensional quantities :

$$z'=\frac{zw_0}{\nu},V'=\frac{V}{w_0},t'=\frac{tw_0^2}{\nu},\omega'=\frac{\omega\nu}{w_0^2},\theta=\frac{T-T_\infty}{T_w-T_\infty},\phi=\frac{C-C_\infty}{C_w-C_\infty},Sc=\frac{\nu}{D_B},\Pr=\frac{\rho\nu C_p}{k_f},$$

$$D^{-1}=\frac{\nu^2}{w_0^2k},G=\frac{\beta g\nu(T_w-T_\infty)}{w_0^3},N=\frac{\beta^{\bullet}(C_w-C_\infty)}{\beta(T_w-T_\infty)},R=\frac{\Omega\nu}{w_0^2},\gamma=\frac{k_r'\nu}{w_0},\alpha=\frac{Q_H\nu^2}{w_0^2\rho C_p},Q_1=\frac{Q_1'(C_w-C_\infty)\nu^2}{C_p(T_w-T_\infty)w_o^2}$$

By introducing the non-dimensional quantities ,equations (5),(6) and (9) reduce to

$$\frac{\partial V}{\partial t}-\frac{\partial V}{\partial z}+2iRV=Gr(\theta+N\phi)+\frac{\partial^2 V}{\partial z^2}-(D^{-1}+\frac{M^2(1-im)}{(1+m^2)})V \quad (10)$$

$$\frac{\partial\theta}{\partial t}-\frac{\partial\theta}{\partial z}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial z^2}-\alpha\theta+Q_1\phi \quad (11)$$

$$\frac{\partial\phi}{\partial t}-\frac{\partial\phi}{\partial z}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial z^2}-\gamma\phi \quad (12)$$

The corresponding boundary conditions are

$$V=0,\quad \theta=1+\varepsilon e^{i\omega t},\quad \phi=1\ at\ \ z=0,$$
$$V\to 0,\theta\to 0,\phi\to 0 \qquad as\ \ z\to\infty \quad (13)$$

3. METHOD OF SOLUTION

In order to reduce the system of partial differential equations (10)-(12) under their boundary conditions(13), to a system of ordinary differential equations in the non-dimensional form, we assume the following for velocity, temperature and concentration of the flow field as the amplitude ε (<<1) of the permeability variations is very small.

$$V(z,t)=V_0(z)+\varepsilon e^{i\omega t}V_1(z)$$
$$\theta(z,t)=\theta_0(z)+\varepsilon e^{i\omega t}\theta_1(z)$$
$$\phi(z,t)=\phi_0(z)+\varepsilon e^{i\omega t}\phi_1(z) \quad (14)$$

Substituting system (14) into the system(10)-(12) and equating harmonic and non-harmonic terms we get

$$\frac{d^2V_0}{dz^2}+\frac{dV_0}{dz}-2iRV_0-M_1^2V_0=-Gr(\theta_0+N\phi_0) \quad (15)$$
$$\frac{d^2V_1}{dz^2}+\frac{dV_1}{dz}-2iRV_1-M_1^2V_1=-Gr(\theta_1+N\phi_1) \quad (16)$$
$$\frac{d^2\theta_0}{dz^2}+\Pr\frac{d\theta_0}{dz}-\alpha\theta_0=-Q_1\phi_0 \quad (17)$$
$$\frac{d^2\theta_1}{dz^2}+\Pr\frac{d\theta_1}{dz}-\varepsilon(i\omega+\alpha)\theta_1=-Q_1\phi_1 \quad (18)$$
$$\frac{d^2\phi_0}{dz^2}+Sc\frac{d\phi_0}{dz}-\gamma Sc\phi_0=0 \quad (19)$$
$$\frac{d^2\phi_1}{dz^2}+Sc\frac{d\phi_1}{dz}-(i\omega+kr)Sc\phi_1=0 \quad (20)$$

The corresponding boundary conditions are

$$V_0(0)=0,\theta_0(0)=1,\phi_0(0)=1;V_1(0)=0,\theta_1(0)=1,\phi_1(0)=0$$
$$V_0(\infty)\to 0,\theta_0(\infty)\to 0,\phi_0(\infty)\to 0:V_1(\infty)\to 0,\theta_1(\infty)\to 0,\phi_1(\infty)\to 0: \quad (21)$$

Solving the equations(15)-(20) subject to the boundary conditions (21) we obtain

$$V(z,t)=V_0(z)+\varepsilon e^{i\omega t}V_1(z) \quad (22)$$
$$\theta(z,t)=\theta_0(z)+\varepsilon e^{i\omega t}\theta_1(z) \quad (23)$$
$$\phi(z,t)=\phi_0(z) \quad (24)$$
$$\phi_0(z)=\exp(-m_1z),\theta_0(z)=(1+a_1)Exp(-m_2z)-a_1Ecxp(-m_1y)$$
$$V_0(z)=a_2\exp(-m_1z)+a_3\exp(-m_2z)+a_4\exp(-m_4z)$$
$$\theta_1(z)=(1-a_5)\exp(-m_5z)+a_5\exp(-m_3z),$$
$$\phi_1(z)=\exp(-m_3z)$$
$$V_1(z)=a_6(\exp(-m_{34}z)-\exp(-m_6z))+a_7(\exp(-m_5z)-\exp(-m_3z))$$

It is convenient to write the primary and secondary velocity fields, in terms of the fluctuating parts, separating the real and imaginary part from equations (22)-(24) and taking only the real parts as they have physical significance, the velocity and temperature distribution of the flow field can be expressed in fluctuating parts as:

$$\frac{u}{w_0}=u_0+\varepsilon\{N_rCos(\omega t)-N_iSin(\omega t)\} \quad (25)$$
$$\frac{v}{w_0}=v_0+\varepsilon\{N_rSin(\omega t)+N_iCos(\omega t)\} \quad (26)$$

Where $u_0+iv_0=V_0$ and $Nr + iNi=V_1$

Hence the expressions for the transient velocity profiles for $\omega t=\pi/2$ are given by

$$\frac{u}{w_0}(z,\frac{\pi}{2\omega})=u_0(z)-\varepsilon N_i(z) \quad and \quad \frac{v}{w_0}(z,\frac{\pi}{2\omega})=v_0(z)-\varepsilon N_r(z)$$

SKIN FRICTION, RATE OF HEAT TRANSFER, RATE OF MASS TRANSFER

The skin friction, Rate of heat transfer, Rate of mass transfer at the plate z=0 in terms of amplitude and phase is given by

$$(\frac{dV}{dz})_{z=0} = (\frac{dV_0}{dz})_{z=0} + \varepsilon e^{i\omega t}(\frac{dV_1}{dz})_{z=0}$$
$$= (-a_4 m_4 - a_2 m_1 - a_3 m_2) + \varepsilon e^{i\omega t}(a_4(m_6 - m_3) + a_7(m_3 - m_5)) \quad (27)$$

$$(\frac{d\theta}{dz})_{z=0} = (\frac{d\theta_0}{dz})_{z=0} + \varepsilon e^{i\omega t}(\frac{d\theta_1}{dz})_{z=0}$$
$$= a_1 m_1 - m_2(1 + a_1) + \varepsilon e^{i\omega t}((a_5 - 1)m_5 - a_5 m_3)$$

$$(\frac{d\phi}{dz})_{z=0} = (\frac{d\phi_0}{dz})_{z=0} + \varepsilon e^{i\omega t}(\frac{d\phi_1}{dz})_{z=0}$$
$$= -m_1 + \varepsilon e^{i\omega t}(m_5)$$

COMPARISION : In the absence of Hall effects(m=0), radiation absorption(Q_1=0) and heat sources (α=0) the results are in good agreement with Govindarajan et al (6).

4. RESULTS AND DISCUSSION

We analyse the effect of radiation absorption and chemical reaction on the unsteady convective heat and mass transfer flow of a rotating fluid past a vertical plate.

Figs.1-3 represent the variation of the primary velocity (u) with m,γ, and Q1.The variation of u with m,M,D^{-1} shows that lesser the permeability of the porous medium/higher the Lorentz force smaller the velocity u in the flow region. An increase in the Hall parameter (m) enhances the velocity u (fig.1). The velocity u enhances with radiation absorption parameter Q_1 (fig.2). With reference to the chemical reaction parameter γ, we find that u reduces in the degenerating chemical reaction case (fig.3).

The secondary velocity(v) is exhibited in figs.4-6 for different parametric variations.The secondary velocity enhances with increase in m or Q_1 (figs.4 & 5). $|v|$ depreciates in the degenerating chemical reaction parameter(fig.6).

The non-dimensional temperature(θ) is shown in Figs.7-8 for different values of Q1 and γ. An increase in Q1 enhances the temperature in the flow region(fig.7). With reference to the chemical reaction parameter γ, it can be seen from the profiles that the temperature reduces in the degenerating chemical reaction case (fig.8).

The concentration distribution(C) is exhibited in figs.9 for different γ. It is found that the concentration reduces with increase in Sc and γ.Thus lesser the molecular diffusivity smaller the concentration in the entire flow region.

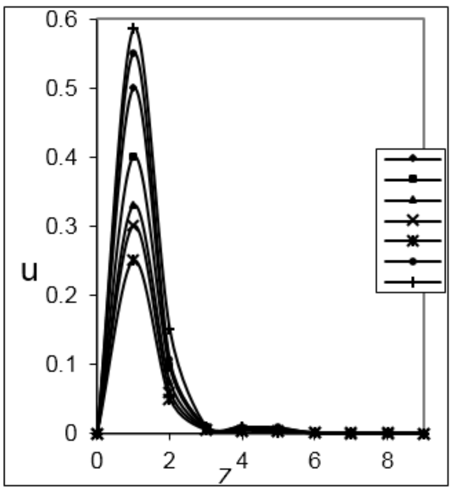


Fig.1 Variation of u with M, D^{-1}& m

	I	II	III	IV	V	VI	VII
M	2	4	6	2	2	2	2
D^{-1}	2	2	2	4	6	2	2
m	0.5	0.5	0.5	0.5	0.5	1.0	1.5

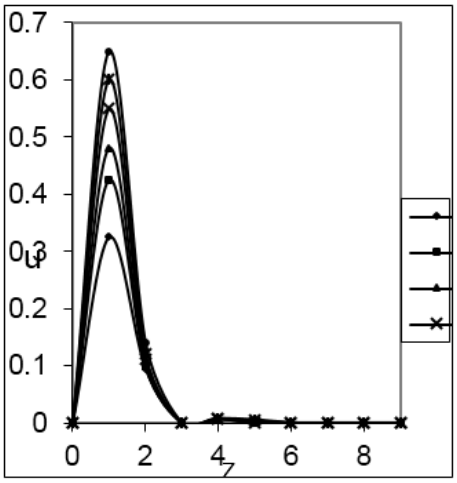


Fig.2 Variation of u with Sc&Q1

	I	II	III	IV	V	VI
Sc	0.24	0.66	1.3	2.01	1.3	1.3
Q1	0.5	0.5	0.5	0.5	1.5	2.5

ISSN 2224-719X (Paper) ISSN 2225-0638 (Online)
Vol.52, 2016

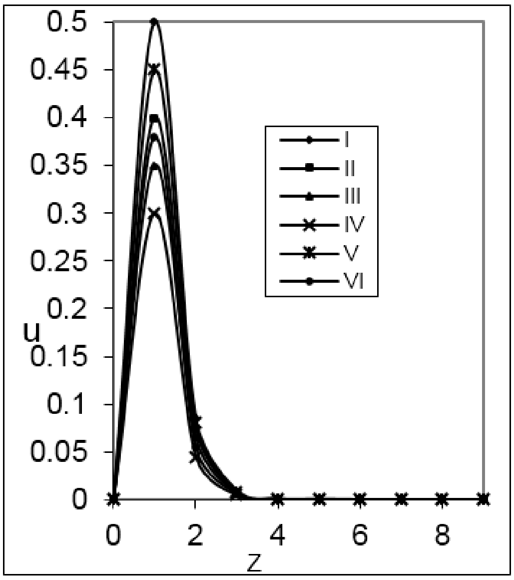


Fig.3 Variation of u with γ &ω

	I	II	III	IV	V	VI
γ	0.5	1.5	2.5	3.5	0.5	0.5
ω	5	5	5	5	10	15

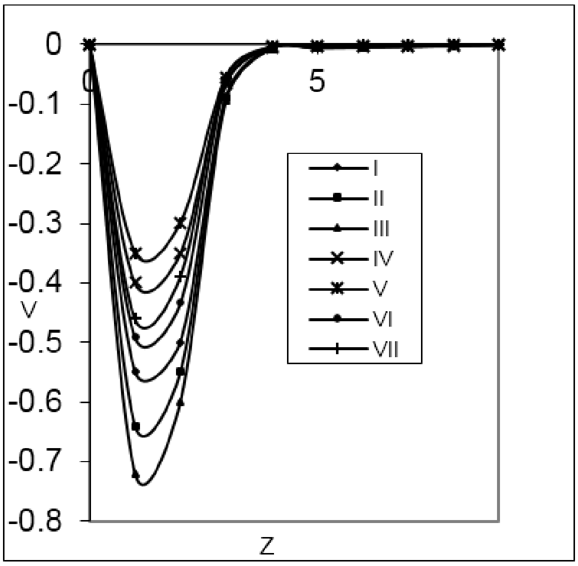


Fig.4 Variation of v with M, D^{-1}&m

	I	II	III	IV	V	VI	VII
M	2	4	6	2	2	2	2
D^{-1}	2	2	2	4	6	2	2
m	0.5	0.5	0.5	0.5	0.5	1.5	2.5

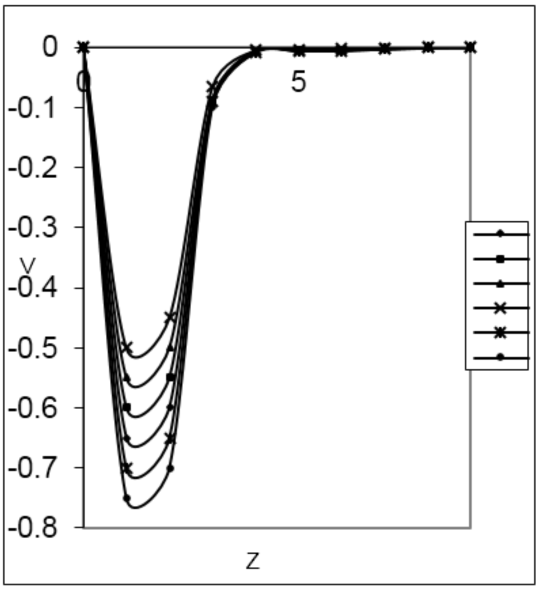


Fig.5 Variation of v with Sc&Q1

	I	II	III	IV	V	VI
Sc	0.24	0.66	1.3	2.01	1.3	1.3
Q1	0.5	0.5	0.5	0.5	1.5	2.5

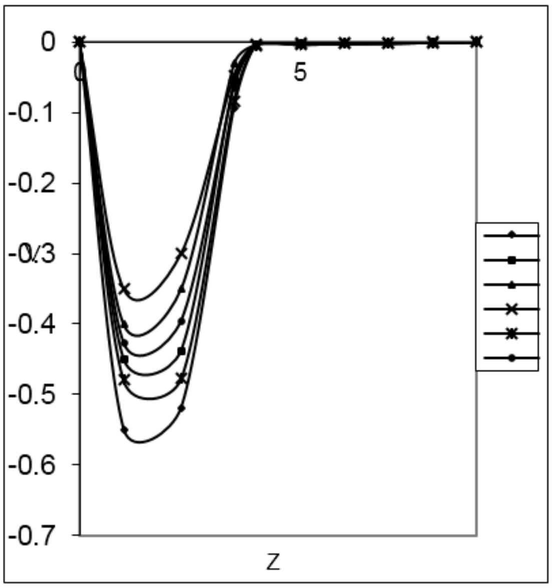


Fig.6 Variation of v with γ&ω

	I	II	III	IV	V	VI
γ	0.5	1.5	2.5	3.5	0.5	0.5
ω	5	5	5	5	10	15

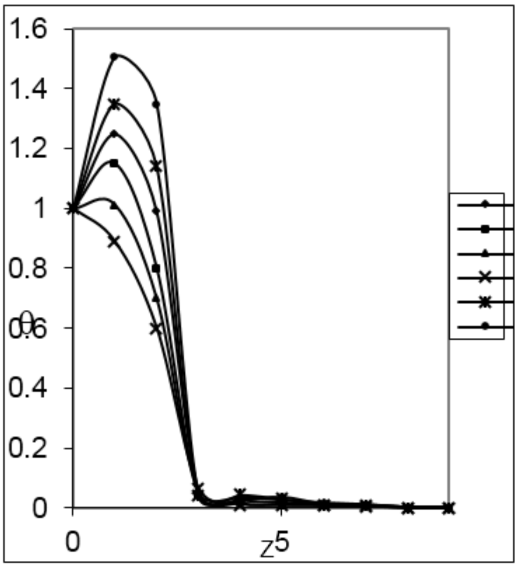


Fig.7 Variation of θ with α & Q1

	I	II	III	IV	V	VI
α	2	4	6	8	2	2
Q1	0.5	0.5	0.5	0.5	1.5	2.5

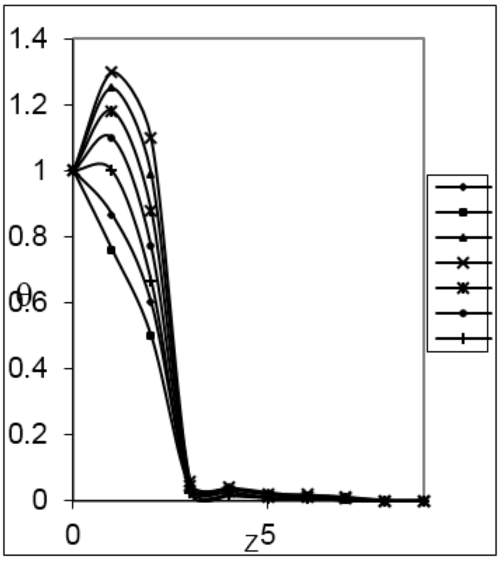


Fig.8 Variation of θ with Sc & γ

	I	II	III	IV	V	VI	VII
Sc	0.24	0.66	1.3	2.01	1.3	1.3	1.3
γ	0.5	0.5	0.5	0.5	1.5	2.5	3.5

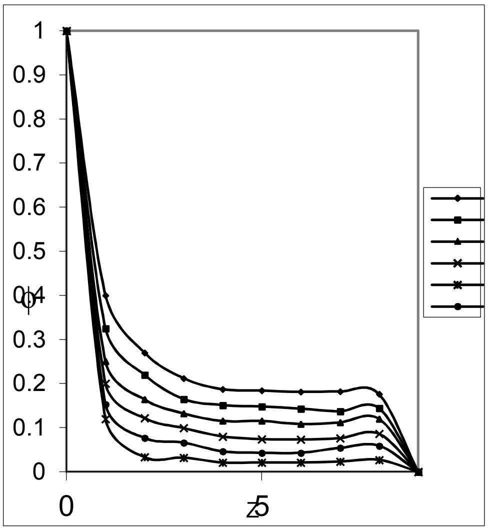


Fig.9 Variation of Concentration (ϕ)with Sc&γ

	I	II	III	IV	V	VI
Sc	0.24	0.6	1.3	2.01	1.3	1.3
γ	0.5	0.5	0.5	0.5	1.5	2.5

The skin friction(τ) at the plate y=0 is exhibited in table.1-2 for different values of Q1,γ and m .It is found from the numerical values that the skin friction components τ_x and τ_z enhance with increase in Q_1.They reduce with γ . With reference to the Hall parameter m we find that they increase with m≤1.5 and for larger values of m≥2.5, $|\tau_x|$ enhances while $|\tau_z|$ reduses at the plate y=0. An increase in the chemical reaction parameter γ enhances ,$|\tau_x|$ and reduces ,$|\tau_z|$ at the plate fixing the other parameters.

The rate of heat transfer(Nusselt number) at the wall y=0 is depicted in table-3 for different parametric values. $|Nu|$ enhances in the degenerating chemical reaction case. Also $|Nu|$ enhances with increase in the radiation absorption parameter Q_1.

The rate of mass transfer(Sherwood number) at y=0 is shown in table.4.It is observed from the numerical values the rate of mass transfer enhances with increase in Sc or γ .

Table-1: τ_x at z=0

G	I	II	III	IV	V	VI	VII	VIII
2	0.9827	1.2173	1.3345	1.3439	0.6825	0.4993	1.5692	2.2586
5	*2.4566*	*3.0432*	*3.3363*	*3.3599*	*1.7063*	*1.2483*	*3.5199*	*5.6464*
10	4.9113	5.0863	6.6726	6.7197	3.4126	2.5698	7.0398	11.2928
m	0.5	1.5	2.5	3.5	0.5	0.5	0.5	0.5
γ	0.5	0.5	0.5	0.5	1.5	2.5	0.5	0.5
Q1	0.5	0.5	0.5	0.5	0.5	0.5	1.5	2.5

Table-2: τ_y at z=0

G	I	II	III	IV	V	VI	VII	VIII
2	0.0772	0.1570	0.0742	0.0135	0.0256	-0.0181	0.0925	0.1995
5	*0.1931*	*0.3926*	*0.1855*	*0.0336*	*0.0642*	*-0.0452*	*0.2950*	*0.4988*
10	0.3961	0.7852	0.3711	0.0673	0.1282	-0.01056	0.5899	0.9977
m	0.5	1.5	2.5	3.5	0.5	0.5	0.5	0.5
γ	0.5	0.5	0.5	0.5	1.5	2.5	0.5	0.5
Q1	0.5	0.5	0.5	0.5	0.5	0.5	1.5	2.5

Table-3: Nusselt number (Nu) at z=0

γ	I	II	III
0.5	-0.1918	0.2113	-0.5755
1.5	-0.2986	0.4493	-0.8957
2.5	-1.2116	0.6703	-0.3308
Q1	0.5	1.5	2.5

Table-4: Nusselt number (Nu) at z=0

γ	I	II	III	IV
0.5	-0.9073	-1.2351	-1.5455	-1.8022
1.5	-1.0522	-1.4101	-1.7382	-2.0033
2.5	-1.1515	-1.5321	-1.8755	-2.1495
Sc	0.24	0.66	1.3	2.01

APPENDIX

$$m_1=\frac{Sc+\sqrt{Sc^2+4krSc}}{2},\quad m_2=\frac{\Pr+\sqrt{\Pr^2+12R\alpha)}}{2(3R+4)},$$

$$m_3=\frac{Sc+\sqrt{Sc^2+4Sc(i\omega+\gamma)}}{2},m_4=\frac{1+\sqrt{1+4(2iR+M_1^2)}}{2}$$

$$m_5=\frac{3R\Pr+\sqrt{9R^2\Pr^2+12R(\alpha+i\omega)(3R+4))}}{2(3R+4)},m_6=\frac{1+\sqrt{1+4(M_1^2+i(\omega+2R))}}{2},$$

$$m_5=\frac{1+\sqrt{1+4((i(2R+\omega)+M_1^2)}}{2},a_1=\frac{-Q_1}{)m_1^2-\Pr m_1-\alpha},$$

$$a_2=-\frac{G(N+a_1)}{m_1^2-m_1-(2iR+M_1^2)},a_3=-\frac{G(1+a_1)}{m_2^2-m_2-(2iR+M_1^2)},a_4=-(a_2+a_3)$$

$$a_5=-\frac{-3RQ_1}{m_3^2-\Pr m_3-(\alpha+i\omega)}$$

$$a_6=-\frac{-G(N+a_5)}{m_3^2-m_3-(M_1^2+i(\omega+2R))},a_7=-\frac{-G(1-a_5)}{m_3^2-m_3-(M_1^2+i(\omega+2R))}$$

CONCLUSIONS

1. An increase in Q1 enhances the primary velocity u,secondary velocity v,the temperature , the skin friction components τ_x and τ_z and $|$Nu$|$ in the flow region.
2. An increase in the chemical reaction parameter γ reduses the primary velocity u,secondary velocity v,the

temperature , the skin friction components τ_z enhances τ_x and the rate of mass transfer $|Nu|$.

3. An increase in the Hall parameter (m) enhances the velocity u,the secondary velocity and with refers to the Hall parameter m we find that they increase with m≤1.5 and for larger values of m≥2.5, $|\tau_x|$ enhances while $|\tau_z|$ reduces at the Y=0.
4. The primary velocity u,the temperature enhances and the secondary velocity reduces with increase in the rotation parameter (R). An increase in the rotation parameter (R) reduces transfer $|Nu|$ at the wall Y=0.

REFERENCES

1. Acharya, M., *et al*., Magnetic Field Effects on the Free Convection and Mass Transfer Flow through Porous Medium with Constant Suction and Constant Heat Flux, *Indian J. Pure Appl. Math., 31* (2000), 1, pp. 1-18.
2. Chaudhary, C., Jain, A., Combined Heat and Mass Transfer Effects on MHD Free Convection Flow past an Oscillating Plate Embedded in Porous Medium, *Rom. Journ. Phys., 52* (2007), 5-7, pp. 505-524.
3. Das, S. S., *et al.*, Mass Transfer Effects on MHD Flow and Heat Transfer past a Vertical Porous Plate through a Porous Medium under Oscillatory Suction and Heat Source, *International Journal of Heat and Mass Transfer, 52* (2009), 25-26, pp. 5962-5969.
4. Dinarvand, S., Rashidi, M. M., A Reliable Treatment of Homotopy Analysis Method for Two-Dimensional Viscous Flow in a Rectangular Domain Bounded by Two Moving Porous Walls, Nonlinear Analysis, *Real World Applications 11* (2010), 1, pp. 1502-1512.
5. Gersten, K., Gross, J. F., Flow and Heat Transfer along a Plane Wall with Periodic Solution, *Journal of Applied Mathematics and Physics, 25* (1974), 4, pp. 200-205.
6. Govindarajan,A.Ali.J.Chamkha,Kesavan,S,Vidhya,M : Chemical reaction effects on unsteady magnetohydrodynamic free convective flow in a rotating porous medium with mass transfer. Thermal Science, 18 (2014), 2, pp:S515-S526.
7. Gupta, G. D., Johari, R., MHD Three Dimensional Flow past a Porous Plate, *Indian J. Pure Appl. Math., 32* (2001), 3, pp. 377-386.
8. Jain, N. C., Gupta, P., Three Dimensional Free Convection Couette Flow with Transpiration Cooling, *Journal of Zhejiang Univ. Science A, 7* (2006), 3, pp. 340-346.
9. Mahato, P. K., Maiti, D. K., Unsteady Free Convective Flow and Mass Transfer in a Rotating Porous Medium, *Indian Journal of Technology, 26* (1988), pp. 255-259.
10. Malathy, T., Srinivas, S., Pulsating Flow of a Hydro Magnetic Fluid between Permeable Beds, *International Communications in Heat and Mass Transfer*, *35(2008),5,pp:681-688.*
11. Muthucumaraswamy, R., Ganesh, P., Unsteady Flow past an Impulsively Started Vertical Plate with Heat and Mass Transfer, *Journal Heat and Mass Transfer, 344* (1998), 2-3, pp. 1051-1059
12. Muthucumaraswamy, R., *et al*., Chemical Reaction Effects on Infinite Vertical Plate with Uniform Heat Flux and Variable Mass Diffusion, *International Review of Pure and Applied Mathematics, 3* (2007), pp. 263-272
13. Muthuraj, R., Srinivas, S., A Note on Heat Transfer to MHD Oscillatory Flow in an Asymmetric Wavy Channel, *International Communications in Heat and Mass Transfer, 37* (2010), 9, pp. 1255-1260
14. Perry, E. D., *Chemical Engineers Handbook,* 4^{th} ed., McGraw-Hill Book Company, New York, USA, 1963.
15. Raptis, A., Perdikis, C., Oscillatory Flow through a Porous Medium by the Presence of Free Convective Flow, *International Journal Engineering Sciences, 23* (1985), 1, pp. 51-55.
16. Rashidi, M. M., Sadri, S. M., Solution of the Laminar Viscous Flow in a Semi-Porous Channel in the Presence of a Uniform Magnetic Field by Using the Differential Transform Method, *Int. J. Contemp. Math. Sciences, 5* (2010), 15, pp. 711-720.
17. Rashidi, M. M., Erfani, E., A New Analytical Study of MHD Stagnation-Point Flow in Porous Media with Heat Transfer, *Computers and Fluids, 40* (2011), 1, pp. 172-178
18. Singh, K. D., Verma, G. N., Three Dimensional Oscillatory Flow through a Porous Medium with Periodic Permeability, *Z. Angew. Math. Mech., 75* (1995), 8, pp. 599-604
19. Singh, K. D., Three Dimensional Couette Flow with Transpiration Cooling, *Z. Angew. Maths. Phys., 50* (1999), 4, pp. 661-668
20. Singh, K. D., *et al.*, Three Dimensional Fluctuating Flow and Heat Transfer through a Porous Medium with Variable Permeability, *ZAMM, 80* (2000), 7, pp. 473-480.
21. Singh, K. D., Rakesh, S., MHD Three Dimensional Couette Flow with Transpiration Cooling, Z. *Angew. Math. Mech., 81* (2001), 10, pp. 715-720.
22. Singh, K. D., Influence of Moving Magnetic Field on Three Dimensional Couette Flow, *ZAMP, 55* (2004), 5, pp. 894-902.
23. Singh, K. D., *et al*., Periodic Solution of Oscillatory Couette Flow through Porous Medium in Rotating System, *Indian J. Pure Appl. Math., 36* (2005), 3, pp. 1