MHD FLOW OF VISCOELASTIC FLUID WITH VARIABLE SUCTION AND PERMEABILITY BETWEEN TWO INFINITE POROUS PLATES MOVING IN OPPOSITE DIRECTION

Aarti Manglesh, M. G. Gorla & Rajeev Kumar

Department of Mathematics & Statistics,

H. P. University, Shimla-5

E-mails: raarti3025@gmail.com, m.g.gorla@gmail.com,

rajeevkumar2012math@gmail.com

Abstract: Heat and mass transfer of unsteady incompressible electrically conducting viscoelastic fluid flow between two infinite vertical parallel porous plates moving in opposite direction with thermal radiation and chemical reaction is investigated. A uniform magnetic field acts perpendicular to the porous plates. The permeability of porous medium is dependent on time. A closed form solutions of the equations governing the flow are obtained for the velocity, temperature and concentration profile considering the Hall Effect. The velocity, temperature and concentration profiles are evaluated numerically and shown graphically for different values of flow parameters.

Keywords: Viscoelastic fluid, Thermal Radiation, Chemical Reaction, Hall Current.

INTRODUCTION

In recent years free convective flows in a porous medium have received much attention due to its wide applications in geothermal and oil reservoir engineering as well as other geophysical, astrophysical and biological studies. Convective flow in porous media is particularly important in environmental studies involving air and water pollution. Moreover, considerable interest has been shown in radiation interaction with convection for heat transfer in fluids. This is due to the significant role of thermal radiation in the surface heat transfer when convection heat transfer is small, particularly in free convection problems involving absorbing-emitting fluids. The effects of transversely applied magnetic field on the flow of electrically conducting viscous fluids have been discussed widely owing to their astrophysics, geophysical and engineering applications. The radiative convective flow of an electrically conducting fluid in the presence of a magnetic field is encountered in geophysical and cosmical fluid dynamics. It is also

important in the solar physics involved in the sunspot development. It is applied to study the stellar and solar structure, interstellar matter and radio propagation through the ionosphere. In engineering, it finds its application in MHD pump and MHD bearing. More applications and a good insight into the subject are given by Acharya et al. [1], Alogoa et al. [3], Singh & Singh [14], Jha & Singh [8] and many others.

In an ionized gas where the density is low and/or the magnetic field is very strong, the conductivity normal to the magnetic field is reduced due to the free spiralling of electrons and ions about the magnetic lines of force before suffering collisions and a current is induced in a direction normal to both the electric and the magnetic fields. This current, well known in the literature, is called the Hall currents. Due to Hall currents the electrical conductivity of the fluid becomes anisotropic and this causes the secondary flow making flow three dimensional. Hall currents are of great importance in many astrophysical problems. In processes, such as drying, evaporation at the surface of water body, energy transfer in wet cooling tower and the flow in a desert cooler, the heat and mass transfer occur simultaneously. Therefore, the combine heat and mass transfer problem with chemical reaction have received a considerable amount of attention and is studied by many scholars e.g. Chamkha [4], Kandasamy et al. [9], Afify [2], Takhar et al. [17] and Mansour et al. [12].

This paper is extension of the study of Manglesh & Gorla [11] following Srekanth et al. [16], Chand and Sharma [5], Das et al. [7], Uwanta et al. [18]. The aim of present investigation is to study the effect of permeability variation and oscillatory suction/injection velocity on free convective heat and mass transfer MHD flow of a viscoelastic incompressible electrically conducting fluid between two vertical plates moving in opposite direction. The permeability of porous medium is considered to be $K_p^* = K_0^* \left(1 + \varepsilon e^{i\omega^* t^*}\right)$ and suction/injection velocity is assumed to be $v_0 \left(1 + \varepsilon e^{i\omega^* t^*}\right)$.

MATHEMATICAL FORMULATION

Consider an unsteady MHD flow of a viscoelastic incompressible electrically conducting fluid past infinitely long vertical flat plates located at the $y^* = 0$ and $y^* = d$ planes and extend from $x^* \to -\infty$ to ∞ and from $z^* \to -\infty$ to ∞ embedded in a porous medium on taking Hall current into account. A Cartesian co-ordinate system is introduced such that x^*-axis lies vertically upward and y^*-axis is perpendicular to it (see Fig.1). The plates are moving in opposite directions with velocity $U\left(1 + \varepsilon \cos \omega^* t^*\right)$, U being the mean velocity, ω^* being the frequency of the

oscillations and ε is a real number. The fluid is considered to be gray, absorbing-emitting radiation but non-scattering medium. The flow field is exposed to the influence of injection and suction velocity, thermal and mass buoyancy effect, thermal radiation and chemically reactive species. Darcy's resistance term is taken into account with variable permeability of the medium. Further due to the infinite plane surface assumption, the flow variables are functions of y^* and t^* only.
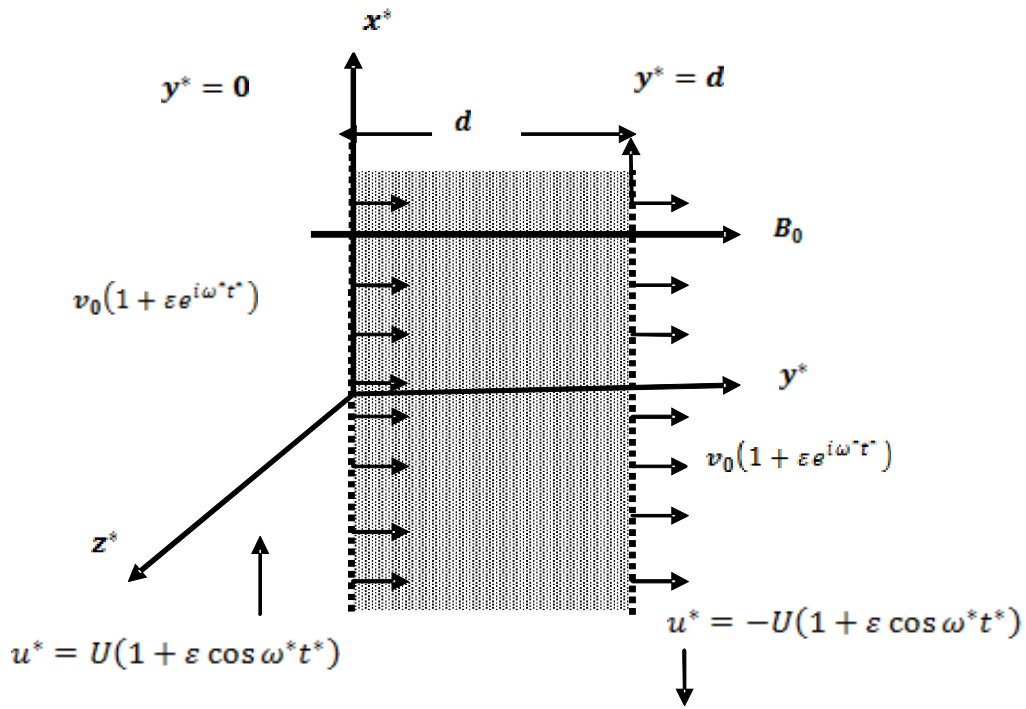
Fig.1: Schematic presentation of the physical problem

Since the Hall current term is retained and if (j_x^*, j_y^*, j_z^*) are the components of electric current density, $\vec{j}$. The equation of conservation of electric charge, $\nabla.\vec{j} = 0$, gives j_y^* =constant. Since the plates are electrically non-conducting, $j_y^* = 0$ and is zero everywhere in the flow. When the magnetic field is large, the generalized Ohm's law, in the absence of electric field, neglecting the ion slips and thermo electric effect Meyer [13] yields:

(1) $\qquad j_x^* - \omega_e \tau_e j_z^* = -\sigma \mu_e H_0 w^*$

(2) $\qquad j_z^* + \omega_e \tau_e j_x^* = \sigma \mu_e H_0 u^*$

The solutions of equations (1) and (2) are:

(3) $\qquad j_x^* = \frac{\sigma \mu_e H_0}{1+m^2} (mu^* - w^*)$

(4) $\qquad j_z^* = \frac{\sigma \mu_e H_0}{1+m^2} (u^* + mw^*)$

where $m = \omega_e \tau_e$ is Hall parameter, ω_e: the cyclotron frequency, τ_e: the electron collision time, μ_e: the magnetic permeability, σ: the electrical conductivity of the fluid. The chemical reactions are taking place in the flow and all thermo physical properties are assumed to be constant. Under the usual Boussinesq's approximation and in the absence of pressure gradient, the unsteady equations governing the MHD flow of viscoelastic fluid are:

(5)
$$\frac{\partial u^*}{\partial t^*} + v_0 \left(1 + \varepsilon e^{i\omega^* t^*}\right) \frac{\partial u^*}{\partial y^*} = \vartheta \frac{\partial^2 u^*}{\partial y^{*2}} - K_0 \frac{\partial^3 u^*}{\partial t^* \partial y^{*2}} - \frac{\sigma b_0^2}{\rho(1+m^2)} (u^* + mw^*) + g_T \beta (T^* -$$
$$T_d) + g_c \beta^* (C^* - C_d) - \frac{\partial u^*}{K_0^*(1+\varepsilon e^{i\omega^* t^*})}$$

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(6)

$$\frac{\partial w^*}{\partial t^*} + v_0\left(1 + \varepsilon e^{i\omega^* t^*}\right)\frac{\partial w^*}{\partial y^*} = \vartheta \frac{\partial^2 w^*}{\partial y^{*2}} - K_0 \frac{\partial^3 w^*}{\partial t^* \partial y^{*2}} + \frac{\sigma B_0^2}{\rho(1+m^2)}(mu^* - w^*) -$$
$$\frac{\vartheta w^*}{K_p^*(1+\varepsilon e^{i\omega^* t^*})}$$

(7) $\quad \frac{\partial T^*}{\partial t^*} + v_0\left(1 + \varepsilon e^{i\omega^* t^*}\right)\frac{\partial T^*}{\partial y^*} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_p}\frac{\partial q^*}{\partial y^*}$

(8) $\quad \frac{\partial C^*}{\partial t^*} + v_0\left(1 + \varepsilon e^{i\omega^* t^*}\right)\frac{\partial C^*}{\partial y^*} = D_m \frac{\partial^2 C^*}{\partial y^{*2}} - K_1(C^* - C_d)$

Boundary conditions of the problem are:

(9)
$$\begin{cases} u^* = U(1 + \varepsilon \cos\omega^* t^*), w^* = 0, T^* = T_0 + \varepsilon(T_0 - T_d)\cos\omega^* t^* \\[2mm] \qquad C^* = C_0 + \varepsilon(C_0 - C_d)\cos\omega^* t^* \ at \ y^* = 0 \\[2mm] \qquad\qquad and \\[2mm] u^* = -U(1 + \varepsilon\cos\omega^* t^*), w^* = 0, T^* = T_d, C^* = C_d \ at \ y^* = d \end{cases}$$

T* is the temperature, C^* is concentration, $t^*$is the time, ρ is the density, ϑ is the kinematic viscosity, $K_0^*$is the viscoelasticity, σ is the electric conductivity, g the acceleration due to gravity, K_p^*, is the permeability of the porous medium, κ is thermal conductivity, P_r is Prandtl number, C_p is the specific heat at constant pressure, D_m is chemical molecular diffusivity, K_1 is chemical reaction. Here '*' stands for the dimensional quantities.

In the spirit of Cogley *et a*l [6] the radiative heat flux for the present problem become

(10) $\qquad \frac{\partial q^*}{\partial y^*} = 4\alpha T^*$

Where α is the mean radiation absorption coefficient.

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Equations can be made dimensionless by introducing the following dimensionless variables:

$$u = \frac{u^*}{U} \quad w = \frac{w^*}{U} \quad x = \frac{x^*}{d} \quad y = \frac{y^*}{d} \quad \theta = \frac{T^*-T_d}{T_0-T_d} \quad C = \frac{c^*-c_d}{c_0-c_d} \quad t = \frac{t^*\vartheta}{d^2} \quad \omega = \frac{\omega^* d^2}{\vartheta}$$

We also define the following dimensionless parameters:

$\lambda = \frac{v_0 d}{\vartheta}$, the suction parameter,

$\alpha = \frac{K_0}{d^2}$, the Viscoelastic parameter,

$M = B_0 d \sqrt{\frac{\sigma}{\mu}}$, the Hartmann number,

$G_m = \frac{g\beta^*(c_0-c_d)d^2}{v_0\vartheta}$, modified Grashoff number,

$G_r = \frac{g\beta\,(T_0-T_d)d^2}{v_0\,\vartheta}$, the Grashoff number,

$K_p = \frac{K_p^*}{d^2}$, the permeability parameter,

$P_r = \frac{\mu c_p}{k}$, the Prandtl number,

$S_c = \frac{\vartheta}{D_m}$, the Schmidt number,

$N = \frac{2\alpha d}{\sqrt{\kappa}}$, the radiation parameter,

$\chi = \frac{K_i d^2}{v}$, the chemical reaction parameter,

In terms of these dimensionless quantities equations (5) to (8), and boundary condition (9) are written as

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(11) $\quad \dfrac{\partial u}{\partial t} + \lambda\left(1 + \varepsilon e^{i\omega t}\right)\dfrac{\partial u}{\partial y} = \dfrac{\partial^2 u}{\partial y^2} - \alpha' \dfrac{\partial^3 u}{\partial t \partial y^2} - \dfrac{M}{1+m^2}(u + mw) + G_r\theta + G_m C$

$\qquad - \dfrac{u}{K_0(1+\varepsilon e^{i\omega t})}$

(12) $\quad \dfrac{\partial w}{\partial t} + \lambda\left(1 + \varepsilon e^{i\omega t}\right)\dfrac{\partial w}{\partial y} = \dfrac{\partial^2 w}{\partial y^2} - \alpha' \dfrac{\partial^3 u}{\partial t \partial y^2} + \dfrac{M}{1+m^2}(mu - w) - \dfrac{w}{K_0(1+\varepsilon e^{i\omega t})}$

(13) $\quad \dfrac{\partial\theta}{\partial t} + \lambda\left(1 + \varepsilon e^{i\omega t}\right)\dfrac{\partial\theta}{\partial y} = \dfrac{1}{P_r}\dfrac{\partial^2\theta}{\partial y^2} - \dfrac{N^2}{P_r}\theta$

(14) $\quad \dfrac{\partial C}{\partial t} + \lambda\left(1 + \varepsilon e^{i\omega t}\right)\dfrac{\partial C}{\partial y} = \dfrac{1}{S_c}\dfrac{\partial^2 C}{\partial y^2} - \chi C$

(15)
$$\begin{cases} u = 1 + \varepsilon\cos\omega t, w = 0, \theta = 1 + \epsilon\cos\omega t, C = 1 + \epsilon\cos\omega t \text{ at } y = 0 \\[6pt] u^* = -(1+\varepsilon\cos\omega t), w = 0, \theta = 0, C = 0 \text{ at } y = 1 \end{cases}$$

Using complex velocity $q = u + iw$ equation (11) and (12) can be combine to give:

(16) $\quad \dfrac{\partial q}{\partial t} + \lambda\left(1 + \varepsilon e^{i\omega t}\right)\dfrac{\partial q}{\partial y} = \dfrac{\partial^2 q}{\partial y^2} - \alpha'\dfrac{\partial^3 q}{\partial t \partial y^2} - \dfrac{M}{1+m^2}(1-im)q + G_r\theta + G_m C -$

$\qquad \dfrac{q}{K_0(1+\varepsilon e^{i\omega t})}$

(17)
$$\begin{cases} q = \left\{1 + \dfrac{\varepsilon}{2}\left(e^{i\omega t} + e^{-i\omega t}\right)\right\}, \theta = \left\{1 + \dfrac{\varepsilon}{2}\left(e^{i\omega t} + e^{-i\omega t}\right)\right\}, \\[8pt] C = \left\{1 + \dfrac{\varepsilon}{2}\left(e^{i\omega t} + e^{-i\omega t}\right)\right\}, at\ y = 0 \\[8pt] q = -\left\{1 + \dfrac{\varepsilon}{2}\left(e^{i\omega t} + e^{-i\omega t}\right)\right\}, \theta = 0, C = 0\ at\ y = 1 \end{cases}$$

are the boundary conditions in complex notation.

In order to solve the system of equations (13), (14), (16) subject to the boundary conditions (17), following Singh & Mathew [15] and Kumar & Singh [10], we assume the solution is of the form

$$(18) \quad \begin{cases} q(y,t) = q_0(y) + \frac{\varepsilon}{2}\{q_1(y)e^{i\omega t} + q_2(y)e^{-i\omega t}\} \\[2mm] \theta(y,t) = \theta_0(y) + \frac{\varepsilon}{2}\{\theta_1(y)e^{i\omega t} + \theta_2(y)e^{-i\omega t}\} \\[2mm] C(y,t) = C_0(y) + \frac{\varepsilon}{2}\{q_1(y)e^{i\omega t} + q_2(y)e^{-i\omega t}\} \end{cases}$$

Substituting (18) in equations (13), (14) and (16) we get,

(19) $\quad \theta_0'' - \lambda P_r(1 + \varepsilon e^{i\omega t})\theta_0' - N^2\theta_0 = 0$

(20) $\quad \theta_1'' - \lambda P_r(1 + \varepsilon e^{i\omega t})\theta_1' - (N^2 + i\omega P_r)\theta_1 = 0$

(21) $\quad \theta_2'' - \lambda P_r(1 + \varepsilon e^{i\omega t})\theta_2' - (N^2 - i\omega P_r)\theta_2 = 0$

(22) $\quad C_0'' - S_c\lambda(1 + \varepsilon e^{i\omega t})C_0' - \chi S_c C_0 = 0$

(23) $\quad C_1'' - S_c\lambda(1 + \varepsilon e^{i\omega t})C_1' - (\chi S_c + i\omega)C_1 = 0$

(24) $\quad C_2'' - S_c\lambda(1 + \varepsilon e^{i\omega t})C_2' - (\chi S_c - i\omega)C_2 = 0$

(25) $\quad q_0'' - \lambda(1 + \varepsilon e^{i\omega t})q_0' - \left\{\frac{M}{1+m^2}(1 + im) + \frac{1}{K_0(1+\varepsilon e^{i\omega t})}\right\}q_0 = -G_r\theta_0 - G_m C_0$

(26) $\quad (1 - \alpha' i\omega)q_1'' - \lambda(1 + \varepsilon e^{i\omega t})q_1' - \left\{\frac{M}{1+m^2}(1 + im) + \frac{1}{K_0(1+\varepsilon e^{i\omega t})} + i\omega\right\}q_1 =$
$\qquad -G_r\theta_1 - G_m C_1$

(27) $\quad (1 + \alpha' i\omega)q_2'' - \lambda(1 + \varepsilon e^{i\omega t})q_1' - \left\{\frac{M}{1+m^2}(1 + im) + \frac{1}{K_0(1+\varepsilon e^{i\omega t})} - i\omega\right\}q_0 =$
$\qquad -G_r\theta_2 - G_m C_2$

Corresponding boundary conditions become:

$$(28) \quad \begin{cases} q_0 = q_1 = q_2 = 1, \theta_0 = \theta_1 = \theta_2 = 1, C_0 = C_1 = C_2 = 1, at\ y = 0 \\[2mm] q_0 = q_1 = q_2 = -1, \theta_0 = \theta_1 = \theta_2 = 0, C_0 = C_1 = C_2 = 0, at\ y = 1 \end{cases}$$

The solution of above equations under boundary conditions are:

$$(29) \qquad \theta_0 = \frac{1}{(e^{m_1} - e^{m_2})}\{e^{m_1 + m_2 y} - e^{m_2 + m_1 y}\}$$

$$(30) \qquad \theta_1 = \frac{1}{(e^{m_3} - e^{m_4})}\{e^{m_3 + m_4 y} - e^{m_4 + m_3 y}\}$$

$$(31) \qquad \theta_2 = \frac{1}{(e^{m_5} - e^{m_6})}\{e^{m_5 + m_6 y} - e^{m_6 + m_5 y}\}$$

$$(32) \qquad C_0 = \frac{1}{(e^{m_7} - e^{m_8})}\{e^{m_7 + m_8 y} - e^{m_8 + m_7 y}\}$$

$$(33) \qquad C_1 = \frac{1}{(e^{m_9} - e^{m_{10}})}\{e^{m_9 + m_{10} y} - e^{m_{10} + m_9 y}\}$$

$$(34) \qquad C_2 = \frac{1}{(e^{m_{11}} - e^{m_{12}})}\{e^{m_{11} + m_{12} y} - e^{m_{12} + m_{11} y}\}$$

$$(35) \qquad q_0 = A_5 e^{m_{13} y} + A_6 e^{m_{14} y} + A_1 e^{m_2 y} + A_2 e^{m_1 y} + A_3 e^{m_3 y} + A_4 e^{m_7 y}$$

$$(36) \qquad q_1 = A_{11} e^{m_{15} y} + A_{12} e^{m_{16} y} + A_7 e^{m_4 y} + A_8 e^{m_5 y} + A_9 e^{m_{10} y} + A_{10} e^{m_9 y}$$

$$(37) \qquad q_2 = A_{17} e^{m_{17} y} + A_{18} e^{m_{18} y} | + A_{13} e^{m_6 y} + A_{14} e^{m_5 y} + A_{15} e^{m_{12} y} + A_{16} e^{m_{11} y}$$

Where constants appear in the above equations are:

$$m_1 = \frac{a + \sqrt{a^2 + 4N^2}}{2}, \quad m_2 = \frac{a - \sqrt{a^2 + 4N^2}}{2}, \quad m_3 = \frac{a + \sqrt{a^2 + 4b}}{2}, \quad m_4 = \frac{a - \sqrt{a^2 + 4b}}{2}$$

$$m_5 = \frac{a + \sqrt{a^2 + 4c}}{2}, \quad m_6 = \frac{a - \sqrt{a^2 + 4c}}{2}, \quad m_7 = \frac{d + \sqrt{d^2 + 4e}}{2}, \quad m_8 = \frac{d - \sqrt{d^2 + 4e}}{2},$$

$$m_9 = \frac{d + \sqrt{d^2 + 4f}}{2}, \quad m_{10} = \frac{d - \sqrt{d^2 + 4e}}{2}, \quad m_{11} = \frac{d + \sqrt{d^2 + 4g}}{2}, \quad m_{12} = \frac{d - \sqrt{d^2 + 4g}}{2},$$

$$m_{13} = \frac{h + \sqrt{h^2 + 4i}}{2}, \quad m_{14} = \frac{h - \sqrt{h^2 + 4i}}{2}, \quad m_{15} = \frac{h + \sqrt{h^2 + 4jk}}{2}, \quad m_{16} = \frac{h - \sqrt{h^2 + 4jk}}{2},$$

$$m_{17} = \frac{h + \sqrt{h^2 + 4lm}}{2}, \quad m_{18} = \frac{h - \sqrt{h^2 + 4lm}}{2}$$

$$a = \lambda P_r\left(1 + \varepsilon e^{i\omega t}\right), \quad b = N^2 + i\omega P_r, \quad c = N^2 - pi\omega P_r, \quad d = \lambda S_c\left(1 + \varepsilon e^{i\omega t}\right),$$

$$e = \chi S_c, \quad f = \chi S_c + i\omega, \quad g = \chi S_c - i\omega, \quad h = \lambda\left(1 + \varepsilon e^{i\omega t}\right),$$

$$i = \frac{M}{1+m^2}(1+im) + \frac{1}{K_0(1+\varepsilon e^{i\omega t}} \qquad j = 1 - \alpha' i\omega$$

$$k = \frac{M}{1+m^2}(1+im)\frac{1}{K_0(1+\varepsilon e^{i\omega t}} + i\omega, \quad l = 1 + \alpha' i\omega,$$

$$m = \frac{M}{1+m^2}(1+im)\frac{1}{K_0(1+\varepsilon e^{i\omega t}} - i\omega$$

The Shear stress, Nusselt number and Sherwood number at the left plate are given by:

$$\tau_L = \left(\frac{\partial q}{\partial y}\right)_{y=0} = \left[q_0'(y) + \frac{\varepsilon}{2}\left\{q_1'(y)e^{i\omega t} + q_2'(y)e^{-i\omega t}\right\}\right]_{y=0}$$

$$Nu_L = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left[\theta_0'(y) + \frac{\varepsilon}{2}\left\{\theta_1'(y)e^{i\omega t} + \theta_2'(y)e^{-i\omega t}\right\}\right]_{y=0}$$

$$Sh_L = \left(\frac{\partial C}{\partial y}\right)_{y=0} = \left[C_0'(y) + \frac{\varepsilon}{2}\left\{C_1'(y)e^{i\omega t} + C_2'(y)e^{-i\omega t}\right\}\right]_{y=0}$$

Results and Discussions

Graphical representation of results is very useful to demonstrate the effects of different parameters in the solution. Here we have examined the nature of variation of various physical quantities associated with the problem under consideration. The effects of different parameters on velocity, temperature and concentration distributions are shown Figs. 2-10.

Figs.2-8 shows the magnitude of velocity for different parameters and from these figures we find that the transition point, as plates are moving in opposite directions, for the fluid velocity situated relatively closer to $y = 0.6$. Increasing viscoelastic parameter

the hydrodynamic boundary layer adheres strongly to the surface which in turn retards the flow in the left half of channel in the vicinity of upward moving plate and the reverse effect is seen on the downward moving plate due to its opposite direction.

Permeability is an important parameter for characterizing the transport properties i.e. heat and mass transfer in porous medium. It is observed from Fig.3 that as K_p increases the velocity increases because increase in permeability of medium implies less resistance due to the porous matrix present in the medium. It is clear from Fig. 4, that with the increase of radiation parameter, velocity decreases. This is due to the fact that large values of N correspond to an increased dominance of conduction over radiation. From Fig.5 we find that velocity decreases with the increase of Hartmann number and is due to the effect of transverse magnetic field on electrically conducting fluid which gives rise to a resistive type of force called Lorentz force similar to drag force which slows down the motion of fluid.

From Fig. 6 it can be interpreted that velocity increases in the left half of the channel due to injection at left upward moving plate and decreases in right half with suction on right plate as suction stabilize the boundary layer growth. Sucking decelerated fluid particle through the porous wall reduces the growth of fluid boundary layer and hence velocity. Increase in thermal and solutal Grashoff numbers significantly increase the boundary layer thickness which resulted into rapid enhancement of fluid velocity in left half of channel, and a reverse trend is absorbed in right half as the right plate is moving downward, which is shown in Figs.7 & 8.

Fig. 9 illustrates that fluid temperature decreases with an increase in radiation parameter. This result qualitatively agrees with expectations, since the effect of radiation decrease the rate of energy transport to the fluid, thereby decreasing the fluid temperature. Fig. 10 shows that we obtain a destructive type chemical reaction because

the concentration decreases for increasing chemical reaction parameter which indicates that the diffusion rates can be tremendously changed by chemical reaction.

The amplitude of Shear stress at the left plate versus Grashof number G_r is depicted in Fig.-11. It is clear from the figure that coefficient of skin-friction increases with an increase in radiation parameter, frequency of oscillation and coefficient of viscoelastic parameter and decreases with increasing Prandtl number. Fig.-12 illustrates the variation of rate of heat transfer (N_u) versus the suction velocity parameter (λ) for various parameters. Numerical results show that for given material parameter i.e. radiation parameter, frequency of oscillation and Prandtl number, the surface heat transfer tends to decrease by increasing the magnitude of suction velocity. It is also clear from the figure that rate of heat transfer at the left plate of the channel increases with an increase in radiation parameter and frequency of oscillation but decreases with increasing Prandtl number. The variation of Sherwood number (Sh) versus the suction velocity parameter (λ) is shown in Fig.-13. The figure reveals that Sherwood number at the left plate decreases with radiation parameter but decreases with increasing frequency of oscillation and Prandtl number.

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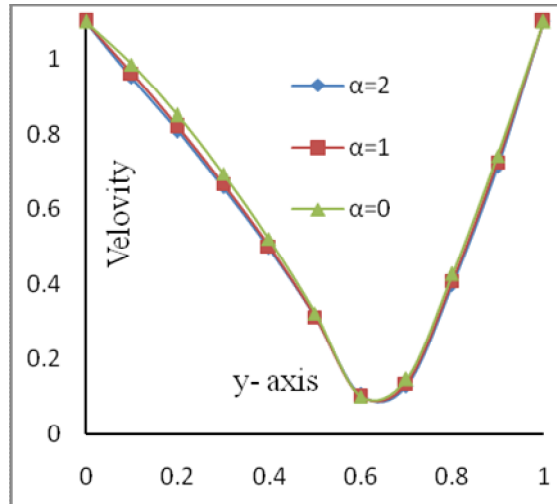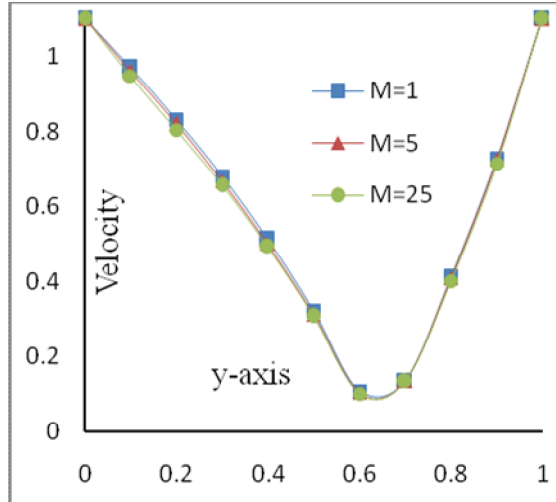
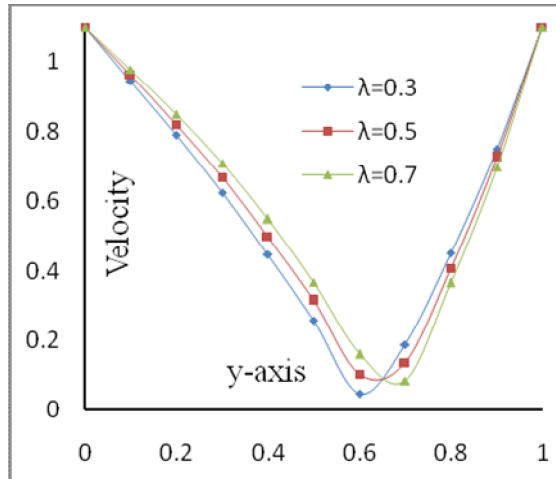**Fig. 2 Variation of velocity with viscoelastic parameter.**
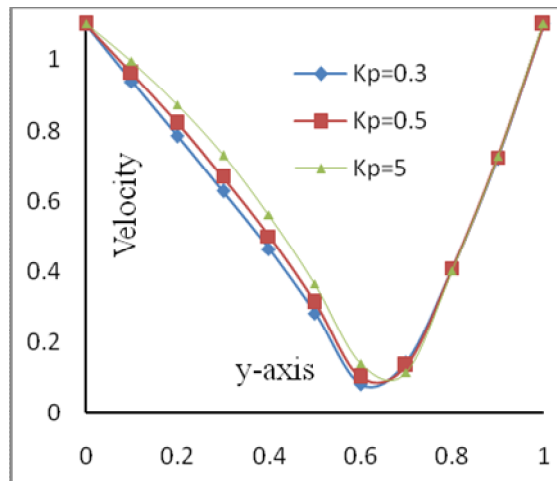
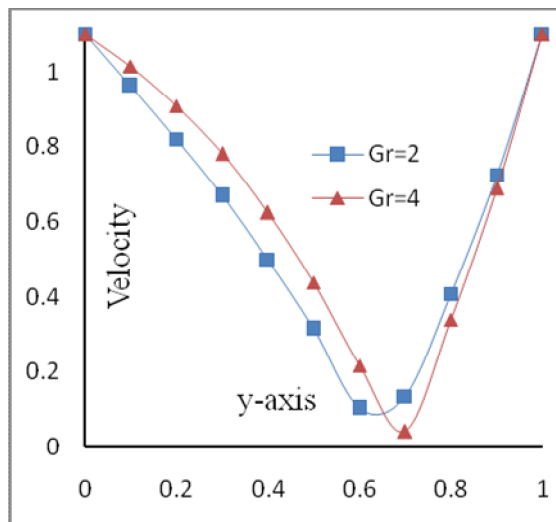**Fig. 3 Variation of velocity with permeability parameter.**
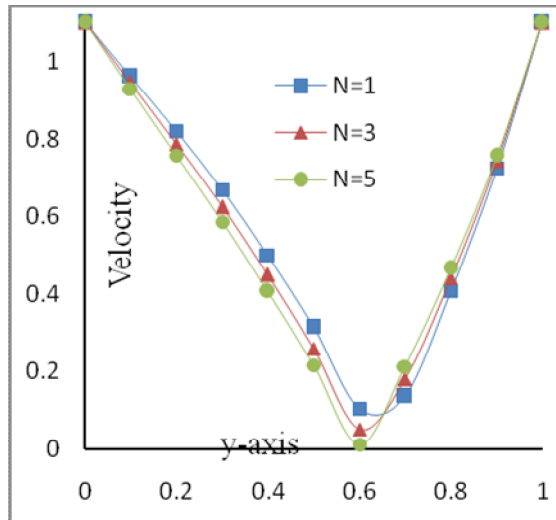
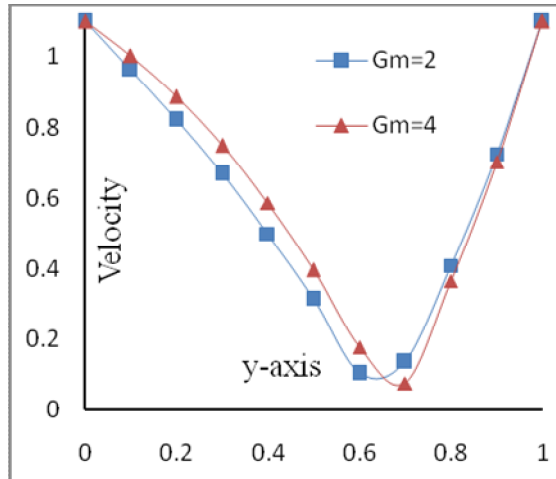**Fig. 4 Variation of velocity with radiation parameter.**

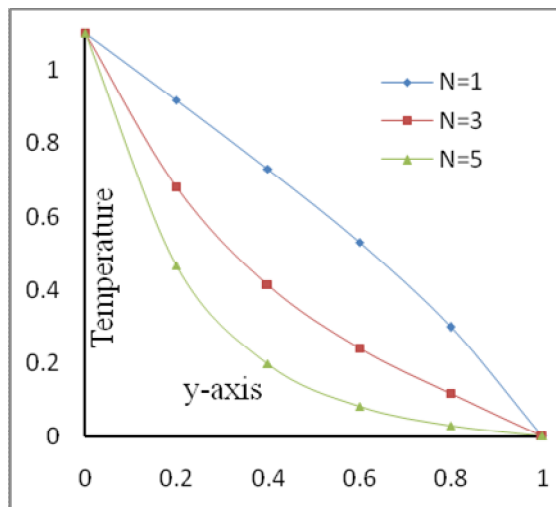**Fig. 5 Variation of velocity with Hartmann number.**

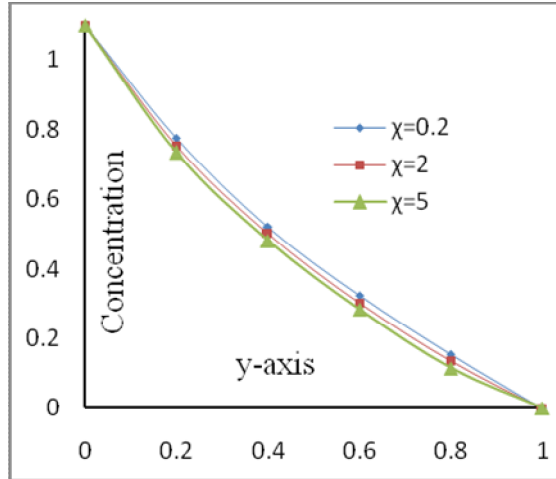**Fig. 6 Variation of velocity with suction parameter.**

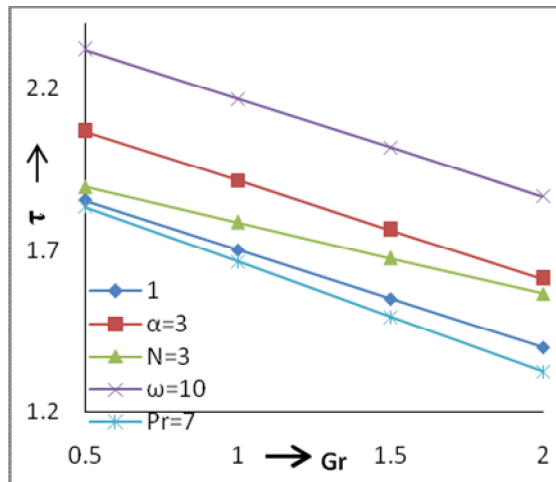**Fig. 7 Variation of velocity with Grashoff number.**

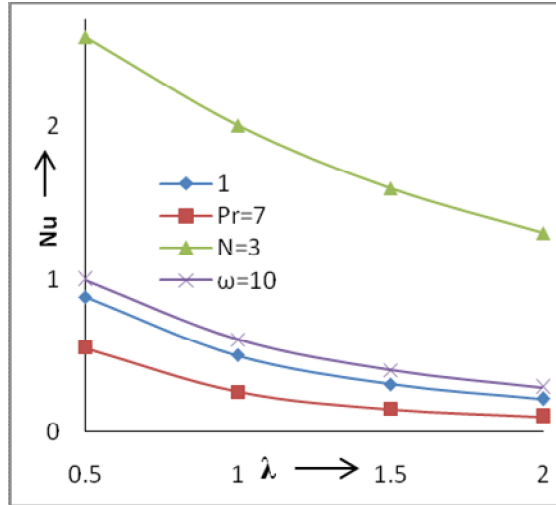**Fig. 8 Variation of velocity with modified Grashoff number.**

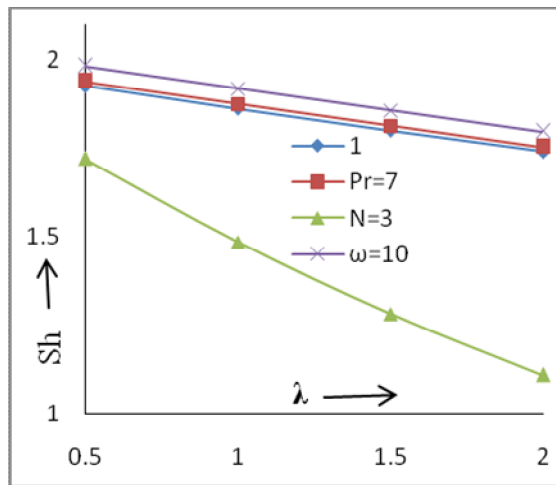**Fig. 9 Variation of Temperature with radiation parameter.**

Fig. 10 Variation of concentration with chemical reaction parameter.

Fig. 11 Variation of amplitude of Shear stress with Grashoff number.

Fig. 12 Variation of Nusselt number with suction parameter.

Fig. 13 Variation of Sherwood number with suction parameter.