Global Journal of Science Frontier Research
Mathematics and Decision Sciences
Volume 12 Issue 14 Version 1.0 Year 2012
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

The Effects of Thermal Radiation, Chemical Reaction and Rotation on Unsteady MHD Viscoelastic Slip Flow

By Aarti Manglesh & M. G. Gorla
Himachal Pradesh University, Shimla

Abstract - This paper investigates the unsteady flow of an electrically conducting incompressible non-Newtonian viscoelastic fluid through a porous medium filled in a vertical porous channel in the presence of transverse magnetic field. The fluid and the channel rotate as a solid body with constant angular velocity, $\mathbf{\Omega}*$, about an axis perpendicular to the planes of the plates. The effects of thermal radiation and chemical reaction are taken into account embedded with slip boundary condition. The closed-form analytical solutions are obtained for momentum, energy and concentration equations. The influences of the various parameters entering into the problem in the velocity, temperature and concentration field are discussed with the help of graphs. Also, numerical values of physical quantities, such as skin friction coefficient, Nusselt number and Sherwood number are presented in tabular form.

Keywords : *thermal radiation, chemical reaction, rotating, viscoelastic, slip flow regime.*

GJSFR-F Classification : *MSC 2010: 76A10, 74F05*

THE EFFECTS OF THERMAL RADIATION, CHEMICAL REACTION AND ROTATION ON UNSTEADY MHD VISCOELASTIC SLIP FLOW

Strictly as per the compliance and regulations of :

Open Association of Research Society, USA
Research | Diversity | Ethics

The Effects of Thermal Radiation, Chemical Reaction and Rotation on Unsteady MHD Viscoelastic Slip Flow

Aarti Manglesh [α] & M. G. Gorla [σ]

Abstract - This paper investigates the unsteady flow of an electrically conducting incompressible non-Newtonian viscoelastic fluid through a porous medium filled in a vertical porous channel in the presence of transverse magnetic field. The fluid and the channel rotate as a solid body with constant angular velocity, $\mathbf{\Omega}^*$, about an axis perpendicular to the planes of the plates. The effects of thermal radiation and chemical reaction are taken into account embedded with slip boundary condition. The closed-form analytical solutions are obtained for momentum, energy and concentration equations. The influences of the various parameters entering into the problem in the velocity, temperature and concentration field are discussed with the help of graphs. Also, numerical values of physical quantities, such as skin friction coefficient, Nusselt number and Sherwood number are presented in tabular form.

Keywords : thermal radiation, chemical reaction, rotating, viscoelastic, slip flow regime.

I. Introduction

Many transport processes exist in nature and industrial application in which the transfer of heat and mass occurs simultaneously as a result of combined buoyancy effects of thermal diffusion and diffusion of chemical species. In the last few decades several efforts have been made to solve the problems on heat and mass transfer in view of their application to astrophysics, geophysics and engineering. Chemical reaction can be codified either heterogeneous or homogeneous processes. Its effect depends on the nature of the reaction whether the reaction is heterogeneous or homogeneous. A reaction is of order n, if the reaction rate is proportional to the nth power of concentration. In particular, a reaction is of first order, if the rate of reaction is directly proportional to concentration itself. In nature, the presence of pure air or water is not possible. Some foreign mass may be present naturally mixed with air or water. The presence of foreign mass in air or water causes some kind of chemical reaction. The study of such type of chemical reaction processes is useful for improving a number of chemical technologies, such as food processing, polymer production and manufacturing of ceramics or glassware. Chambre and Young [5] analyzed the effect of homogeneous first order chemical reactions in the neighborhood of a flat plate for destructive and generative reactions. Das *et al* [9] studied the effect of first order reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. Anjalidevi and Kandasamy [2] investigated the effect of chemical reaction on the flow in the presence of heat transfer and magnetic field. Muthucumaraswamy and Ganesan [14] studied the effect of chemical

Author α σ : Himachal Pradesh University, Shimla 171005. E-mails : raarti3025@gmail.com, m.g.gorla@gmail.com

Ref.

2. Anjalidevi S P, Kandasamy R (2000). Effects of chemical reaction heat and mass transfer on MHD flow past a semi-infinite plate. Z. Angew. Mathematics and Mechanics 80, 697-701.

reaction on unsteady flow past an impulsively started infinite vertical plate. Raptis and Perdikis [15] studied numerically the steady two-dimensional flow in the presence of chemical reaction over a non-linearly semi-infinite stretching sheet. Moreover chemical reaction effects on heat and mass transfer in laminar boundary layer flow have been studied by several scholars e.g. Chamkha [6], Kandasamy *et al.* [12], Afify [1], Takhar *et al.* [20] and Mansour *et al.* [13]etc.

The study of the interaction of the Coriolis force with the electromagnetic force is of great importance. In particular, rotating MHD flows in porous media with heat transfer is one of the important current topics due to its applications in thermofluid transport modeling in magnetic geosystems [3], meteorology, MHD power generators, turbo machinery, solidification process in metallurgy, and in some astrophysical problems. It is generally thought that the existence of the geomagnetic field is due to finite amplitude instability of the Earth's core. Since most cosmic bodies are rotators, the study of convective motions in a rotating electrically conducting fluid is essential in understanding better the magnetohydrodynamics of the interiors of the Earth and other planets. It has motivated a number of studies on convective motions in hydromagnetic rotating systems, which can provide explanations for the observed variations in the geomagnetic field. The rotating flow subjected to different physical effects has been studied by many authors, such as, Vidyanidhu and Nigam [21], Jana and Datta [11], Singh [16, 17, and 18] etc.

Viscoelastic fluid flow through porous media has attracted the attention of scientists and engineers because of its importance notably in the flow of oil through porous rock, the extraction of energy from geothermal regions, the filtration of solids from liquids and drug permeation through human skin. The knowledge of flow through porous media is useful in the recovery of crude oil efficiently from the pores of reservoir rocks by displacement with immiscible fluid. The flow through porous media occurs in the ground-water hydrology, irrigation, drainage problems and also in absorption and filtration processes in chemical engineering. This subject has wide spread applications to specific problems encountered in the civil engineering and agriculture engineering, and many industries. Thus the diffusion and flow of fluids through ceramic materials as bricks and porous earthenware has long been a problem of the ceramic industry. The Scientific treatment of the problem of irrigation, Soil erosion and tile drainage are present developments of porous media. In hydrology, the movement of trace pollutants in water systems can be studied with the knowledge of flow through porous media. The principles of this subject are useful in recovering the water for drinking and irrigation purposes. Thurson was the earliest to recognize the viscoelastic nature of blood and that the viscoelastic behavior is less prominent with increasing shear rate. A series of investigations have been made by different scholars viz: Choudhary and Deb [7] and Gbadeyan *et al* [10], Attia [4] etc.

The objective of above paper is to analyze radiation and chemical reaction effects on an unsteady MHD flow of a viscoelastic, incompressible, electrically conducting fluid through an infinite vertical porous channel with simultaneous injection and suction, embedded in a uniform porous medium, in the presence of transverse magnetic field. The entire system rotates about an axis perpendicular to the plane of the plates.

II. Mathematical Formulation

The geometry of the problem is shown in Fig. 1. The fluid is assumed to be incompressible, viscoelastic, electrically conducting and flows between two infinite vertical parallel non-conducting plates located at the $y = \pm\frac{d}{2}$ planes and extend from $X^* \to -\infty$ to ∞ and from $Z^* \to -\infty$ to ∞. A Cartesian co-ordinate system is introduced such that

Ref.

1. Affy A A (2004). Effects of radiation and chemical reaction on MHD free convective flow past a vertical isothermal cone. Canadian Journal of Physics 82, 447-458.

Global Journal of Science Frontier Research (F) Volume XII Issue XIV Version I Year 2012

X^*-axis lies vertically upward along the centreline of the channel, in the direction of flow and Y^*-axis is perpendicular to the wall of the channel. The channel and the fluid rotate in unision with the uniform angular velocity Ω^* about Y^* axis. A constant magnetic field of strength B_0 is applied perpendicular to the axis of the channel and the effect of induced magnetic field is neglected, which is a valid assumption on laboratory scale under the assumption of small magnetic Reynolds number [19]. The flow field is exposed to the influence of constant injection and suction velocity, thermal and mass buoyancy effect, thermal radiation and chemically reactive species. The temperature and concentration at one of the wall is oscillating. Viscous and Darcy's resistance terms are taken into account with constant permeability of the medium. Further due to the infinite plane surface assumption, the flow variables are functions of y^* and t^* only. Thus the velocity of the fluid, in general, is given by

$$\vec{V}(y,t) = u(y,t)\hat{\imath} + v(y,t)\hat{\jmath} + w(y,t)\hat{k}$$

It is because of conservation of mass i.e. $\nabla.\vec{V} = 0$ and due to uniform suction the velocity component $\vec{v}(y,t)$ is assumed to have a constant value v_0.

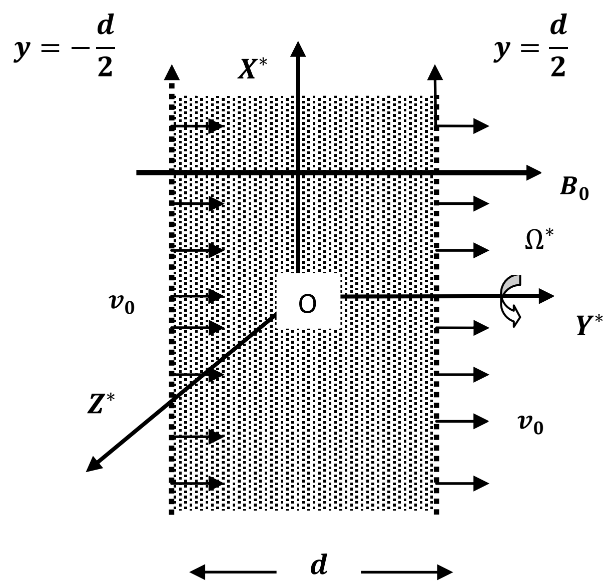

Fig.1 : Schematic presentation of the physical problem

Under the usual Boussinesq's approximation and in the absence of pressure gradient, the unsteady equations governing the MHD flow of viscoelastic fluid are:

$$\frac{\partial u^*}{\partial t^*} + v_0\frac{\partial u^*}{\partial y^*} = \vartheta\frac{\partial^2 u^*}{\partial y^{*2}} - K_0\frac{\partial^3 u^*}{\partial t^*\partial y^{*2}} - \frac{\sigma B_0^2 u^*}{\rho} + 2\Omega^* w^* + g_T\beta T^* + g_C\beta^* C^* - \frac{\vartheta u^*}{K_p^*} \tag{1}$$

$$\frac{\partial w^*}{\partial t^*} + v_0\frac{\partial w^*}{\partial y^*} = \vartheta\frac{\partial^2 w^*}{\partial y^{*2}} - K_0\frac{\partial^3 w^*}{\partial t^*\partial y^{*2}} - \frac{\sigma B_0^2 w^*}{\rho} - 2\Omega^* u^* - \frac{\vartheta w^*}{K_p^*} \tag{2}$$

$$\frac{\partial T^*}{\partial t^*} + v_0\frac{\partial T^*}{\partial y^*} = \frac{\kappa}{\rho P_r}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_p}\frac{\partial q}{\partial y^*} \tag{3}$$

Ref.

19. Sutton G W, Sherman A (1965). Engineering Magnetohydrodynamics, McGraw Hill, New York.

$$\frac{\partial C^*}{\partial t^*} + v_0 \frac{\partial C^*}{\partial y^*} = D_m \frac{\partial^2 C^*}{\partial y^{*2}} - K_1 C^* \tag{4}$$

Boundary conditions of the problem are:

$$\left.\begin{aligned} u^* = L^* \frac{\partial u^*}{\partial y^*}, w^* = L^* \frac{\partial w^*}{\partial y^*}, T^* = 0, C^* = 0 \ \text{at} \ y^* = -\frac{d}{2} \\ u^* = 0, w^* = 0, T^* = \mathrm{T}_0 \cos \omega^* t^*, C^* = \mathrm{C}_0 \cos \omega^* t^* \ \text{at} \ y^* = \frac{d}{2} \end{aligned}\right\} \tag{5}$$

where $L^* = \left(\frac{2-m_1}{m_1}\right) L$, with m_1 is Maxwell's reflexion coefficient, L mean free path and is a constant for an incompressible fluid, 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, Ω^* is rotation , g the acceleration due to gravity, β_T is coefficient of thermal expansion, β_C is coefficient of concentration expansion, 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, ω^* is the frequency of oscillations. Here '*' stands for the dimensional quantities.

At this point, we limit ourselves to the condition of optically thin with relatively low-density fluid such as the one would find in the intergalactic layers where the plasma gas is assumed to be of low density. Thus, in the spirit of Cogley *et al* [8] the radiative heat flux for the present problem become

$$\frac{\partial q}{\partial y^*} = 4\alpha' T^* \tag{6}$$

Where α' is the mean radiation absorption coefficient.

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

$$u = \frac{u^*}{v_0} \quad w = \frac{w^*}{v_0} \quad x = \frac{x^*}{d} \quad y = \frac{y^*}{d} \quad \theta = \frac{T^*}{T_0} \quad C = \frac{C^*}{C_0} \quad t = \frac{t^* \vartheta}{d^2} \quad \omega = \frac{\omega^* d^2}{\vartheta}$$

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,

$\Omega = \frac{\Omega^*}{d^2}$, the rotation parameter,

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

$G_m = \frac{g \beta^* C_0 d^2}{v_0 \vartheta}$, the modified Grashoff number,

Ref.

8. Cogley A C L, Vinvent W G, Giles E S (1968). Differential approximation for radiative transfer in a non-gray near equilibrium, American Institute of Aeronautics and Astronautics, 6: 551-553.

Notes

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

$\chi = \frac{K_1 d^2}{v}$, the chemical reaction parameter,

In terms of these dimensionless quantities equations (1) to (4), written as

$$\frac{\partial u}{\partial t} + \lambda \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - \alpha \frac{\partial^3 u}{\partial t \partial y^2} - M^2 u + 2\Omega w + G_r \theta + G_m C - \frac{u}{K_p} \tag{7}$$

$$\frac{\partial w}{\partial t} + \lambda \frac{\partial w}{\partial y} = \frac{\partial^2 w}{\partial y^2} - \alpha \frac{\partial^3 u}{\partial t \partial y^2} - M^2 w - 2\Omega u - \frac{w}{K_p} \tag{8}$$

$$\frac{\partial \theta}{\partial t} + \lambda \frac{\partial \theta}{\partial y} = \frac{1}{P_r} \frac{\partial^2 \theta}{\partial y^2} - \frac{N^2}{P_r} \theta \tag{9}$$

$$\frac{\partial C}{\partial t} + \lambda \frac{\partial C}{\partial y} = \frac{1}{S_c} \frac{\partial^2 C}{\partial y^2} - \chi C \tag{10}$$

The relevant boundary conditions in non-dimensional form are given by:

$$\left.\begin{aligned} u = h\frac{\partial u}{\partial y}, w = h\frac{\partial w}{\partial y}, \theta = 0, C = 0 \ \text{ at } \ y = -\frac{1}{2} \\ u = 0, w = 0, \theta = \cos \omega t, C = \cos \omega t \ \text{ at } y = \frac{1}{2} \end{aligned}\right\} \tag{11}$$

Where h is velocity slip parameter.

Introducing the complex velocity $F = u + iw$, we find that equation (7) and (8) can be combined into a single equation of the form:

$$\frac{\partial F}{\partial t} + \lambda \frac{\partial F}{\partial y} = \frac{\partial^2 F}{\partial y^2} - \alpha \frac{\partial^3 F}{\partial t \partial y^2} - M^2 F - 2i\Omega F + G_r \theta + G_m C - \frac{F}{K_p} \tag{12}$$

The corresponding boundary conditions reduce to:

$$\left.\begin{aligned} F = h\frac{\partial F}{\partial y}, \theta = 0, C = 0, at \ y = -\frac{1}{2} \\ F = 0, \theta = \cos \omega t, C = \cos \omega t, \ \text{ at } \ y = \frac{1}{2} \end{aligned}\right\} \tag{13}$$

In order to solve the system of equation (9), (10), (12) subject to the boundary condition (13) we assume

$$\left.\begin{aligned} F(y,t) &= F_0(y)e^{i\omega t} \\ \theta(y,t) &= \theta_0(y)e^{i\omega t} \\ C(y,t) &= C_0(y)e^{i\omega t} \end{aligned}\right\} \tag{14}$$

Substituting (14) in equations (9), (10), (12) we get,

$$(1-iA)F_0'' - \lambda F_0' - l^2 F_0 = -G_r\theta_0 - G_m C_0 = 0 \tag{15}$$

$$\theta_0'' - \lambda P_r\theta_0' - a_0\theta_0 = 0 \tag{16}$$

$$C_0'' - S_c\lambda C_0' - a_1 C_0 \tag{17}$$

Where $l^2 = M^2 + 2i\Omega + i\omega + \frac{1}{K_p}$, $A = \alpha\omega$, $a_0 = N^2 + i\omega P_r$ and $a_1 = \chi + i\omega$

Corresponding boundary condition becomes:

$$\left.\begin{aligned} F_0 = h\frac{\partial F_0}{\partial y}, \theta = 0, C = 0, at\ y = -\frac{1}{2} \\ F_0 = 0, \theta_0 = 1, C_0 = 1 \text{ at } y = \frac{1}{2} \end{aligned}\right\} \tag{18}$$

The solution of equation (15), (16) and (17) under boundary condition (18) is

$$F(y,t) = (A_7e^{r_2y} + A_8e^{s_2y} + A_5e^{r_1y} + A_6e^{s_1y} + A_3e^{ry} + A_4e^{sy})e^{i\omega t} \tag{19}$$

$$\theta(y,t) = (A_0e^{ry} + B_0e^{sy})e^{i\omega t} \tag{20}$$

$$C(y,t) = (A_1e^{r_1y} + A_2e^{s_1y})e^{i\omega t} \tag{21}$$

Where

$$r = \frac{\lambda P_r + \sqrt{\lambda^2 P_r^2 + 4a_0}}{2} \qquad s = \frac{\lambda P_r - \sqrt{\lambda^2 P_r^2 + 4a_0}}{2}$$

$$r_1 = \frac{S_c\lambda + \sqrt{S_c^2\lambda^2 + 4S_c a_1}}{2} \qquad s_1 = \frac{S_c\lambda - \sqrt{S_c^2\lambda^2 + 4S_c a_1}}{2}$$

$$r_2 = \frac{\lambda + \sqrt{\lambda^2 + 4l^2(1-iA)}}{2} \qquad s_2 = \frac{\lambda - \sqrt{\lambda^2 + 4l^2(1-iA)}}{2}$$

$$A_0 = -\frac{e^{\frac{-s}{2}}}{2\sin h\left(\frac{s-r}{2}\right)} \qquad B_0 = \frac{e^{\frac{-r}{2}}}{2\sin h\left(\frac{s-r}{2}\right)}$$

$$A_1 = -\frac{e^{\frac{-s1}{2}}}{2\sin h\left(\frac{s1-r1}{2}\right)} \qquad A_2 = \frac{e^{\frac{-r1}{2}}}{2\sin h\left(\frac{s1-r1}{2}\right)}$$

Notes

$$A_3 = -\frac{G_r A_0}{(1-iA)r^2-\lambda r-l^2} \qquad A_4 = -\frac{G_r B_0}{(1-iA)s^2-\lambda s-l^2}$$

$$A_5 = -\frac{G_m A_1}{(1-iA){r_1}^2-\lambda r_1-l^2} \qquad A_6 = -\frac{G_m A_2}{(1-iA)s_1-\lambda s_1-l^2}$$

Notes

$$A_7 = \frac{-1}{\left\{(1-hr_2)e^{\frac{(s_2-r_2)}{2}}-(1-hs_2)e^{\frac{-(s_2-r_2)}{2}}\right\}}\begin{bmatrix} A_3(1-hr)e^{\frac{(s_2-r)}{2}}-(1-hs_2)e^{\frac{-(s_2-r)}{2}} \\ A_4(1-hs)e^{\frac{(s_2-s)}{2}}-(1-hs_2)e^{\frac{-(s_2-s)}{2}} \\ A_5(1-hr_1)e^{\frac{(s_2-r_1)}{2}}-(1-hs_2)e^{\frac{-(s_2-r_1)}{2}} \\ A_6(1-hs_1)e^{\frac{(s_2-s_1)}{2}}-(1-hs_2)e^{\frac{-(s_2-s_1)}{2}} \end{bmatrix}$$

$$A_8 = \frac{1}{\left\{(1-hr_2)e^{\frac{(s_2-r_2)}{2}}-(1-hs_2)e^{\frac{-(s_2-r_2)}{2}}\right\}}\begin{bmatrix} A_3(1-hr)e^{\frac{(r_2-r)}{2}}-(1-hr_2)e^{\frac{-(r_2-r)}{2}} \\ A_4(1-hs)e^{\frac{(r_2-s)}{2}}-(1-hr_2)e^{\frac{-(r_2-s)}{2}} \\ A_5(1-hr_1)e^{\frac{(r_2-r_1)}{2}}-(1-hr_2)e^{\frac{-(r_2-r_1)}{2}} \\ A_6(1-hs_1)e^{\frac{(r_2-s_1)}{2}}-(1-hr_2)e^{\frac{-(s_2-s_1)}{2}} \end{bmatrix}$$

The shear stress, Nusselt number and Sherwood number can now be obtained easily from equations (19), (20) and (21).

Skin friction coefficient τ_L at the left plate in terms of its amplitude and phase is:

$$\tau_L = \left(\frac{\partial F}{\partial y}\right)_{y=-\frac{1}{2}} = \left(\frac{\partial F_0}{\partial y}\right)_{y=-\frac{1}{2}} e^{i\omega t} = |D|\cos(\omega t+\alpha) \tag{22}$$

With $\quad |D| = \sqrt{D_r^2 + D_i^2}$ and $\alpha = \tan^{-1}\left(\frac{D_i}{D_r}\right)$

where $\quad D_r + iD_i = r_2 A_7 e^{\frac{-r_2}{2}} + s_2 A_8 e^{\frac{-s_2}{2}} + r_1 A_5 e^{\frac{-r_1}{2}} + s_1 A_6 e^{\frac{-s_1}{2}} + rA_3 e^{\frac{-r}{2}} + sA_4 e^{\frac{-s}{2}}$

Heat transfer coefficient Nu (Nusselt number) at the left plate in terms of its amplitude and phase is:

$$Nu = \left(\frac{\partial\theta}{\partial y}\right)_{y=-\frac{1}{2}} = \left(\frac{\partial\theta_0}{\partial y}\right)_{y=-\frac{1}{2}} e^{i\omega t} = |H|\cos(\omega t+\beta) \tag{23}$$

with $|H| = \sqrt{H_r^2 + H_i^2}$ and $\beta = \tan^{-1}\left(\frac{H_i}{H_r}\right)$

where $$H_r + iH_i = rA_0 e^{\frac{-r}{2}} + sB_0 e^{\frac{-s}{2}}$$

Mass transfer coefficient Sh (Sherwood number) at the left plate in term of amplitude and phase is:

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=-\frac{1}{2}} = \left(\frac{\partial C_0}{\partial y}\right)_{y=-\frac{1}{2}} e^{i\omega t} \quad = |G|\cos(\omega t + \gamma) \tag{24}$$

with $$|G| = \sqrt{G_r^2 + G_i^2} \text{ and } \gamma = \tan^{-1}\left(\frac{G_i}{G_r}\right)$$

where $$G_r + iG_i = r_1 A_1 e^{\frac{-r_1}{2}} + s_1 A_2 e^{\frac{-s_1}{2}}$$

III. Result and Discussion

Numerical evaluation for the analytical solution of this problem is performed and the results are illustrated graphically in Figs. 2-16 to show the interesting features of significant parameters on velocity, temperature and concentration distribution in rotating channel. Throughout the computation we employ $t = 0,\ \lambda = 0.5,\ \omega = 5, M = 1, K_p = 0.5, N = 1,\ G_r = 2,\ G_m = 2,\ \alpha = 0.05,\ \chi = 0.2,\ P_r = 3$ and $h = 0.2$ unless otherwise stated. The effect of rotation on the velocity profile is shown in Fig.2. The rotation parameter defines the relative magnitude of the Coriolis force and the viscous force in the regime; therefore it is clear that high magnitude Coriolis forces are counter- productive for the flow. The velocity profiles initially remain parabolic with maximum at the centre of the channel for small values of rotation parameter Ω and then as rotation increases the velocity profiles flatten. For further increase in Ω (= 25) the maximum of velocity profiles no longer occurs at the centre but shift towards the right wall of the channel. It means that for large rotation there arise boundary layers on the walls of the channel.

The effect of different parameters on velocity profile for small rotation ($\Omega = 1$) and large rotation ($\Omega = 25$) are illustrated in Figs. 3-14 with the help of solid and dotted lines respectively. Figure -3 represents that the increase in slip parameter has the tendency to reduce the frictional forces which increase the fluid velocity in case of small rotation but for large rotation there is very small change in the velocity profile. Increase in thermal and solutal Grashoff numbers significantly increase the boundary layer thickness which resulted into rapid enhancement of fluid velocity for both cases, which is displayed in Figs 4 and 6. The rate of radiative heat transferred to fluid is decreased and consequently the velocity decreases as radiation parameter increases, for both cases of rotation, is represented in Fig. 5. It is obvious that the increase in the frequency of oscillation decrease the velocity for small and large rotation and that is presented in Fig. 7. Fig. 8 illustrate that the presence of transverse magnetic field produces a resistive force on the fluid flow. This force is called Lorentz force, which slows down the motion of the fluid for small as well large rotation.

Fig. 9 shows the effect of viscoelastic parameter on fluid velocity. Increasing viscoelastic parameter the hydrodynamic boundary layer adheres strongly to the surface which in term retards the flow in the left half of channel, but accelerates the flow in right half with no slip boundary condition. The pattern is same for small and large rotation. Increase in Schmidt number and chemical reaction parameter decrease the concentration. This causes the concentration buoyancy effect to decrease yielding a reduction in the fluid

Notes

Notes

velocity, which is displayed in Figs. 10 and 11. It can be interpreted from Fig. 12 that velocity decreases with increase of suction parameter indicating the usual fact that suction stabilize the boundary layer growth. Sucking decelerated fluid particle through the porous wall reduces the growth of fluid boundary layer and hence velocity. Fig. 13 displays that the increase in the permeability coefficient of porous medium act against the porosity of the porous medium which increase the fluid velocity for small as well as large rotation. Fig. 14 represents that increase in Prandtl number is due to increase in viscosity of the fluid which makes the fluid thick and causes a decrease in velocity for small and large rotation.

a) Temperature profile

Fig. 15 illustrate 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. It is also clear from the figure that as Prandtl number increases, the temperature profile decreases. This is because the fluid is highly conductive for small value of Prandtl number. Physically, if Prandtl number increases, the thermal diffusivity decreases and this phenomenon lead to the deceasing manner of the energy transfer ability that reduces the thermal boundary layer.

b) Concentration Profile

Fig. 16 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. Also with the increase in Schmidt number concentration profile also decreases.

Table-1 shows the effect of different parameters in skin friction at the left wall. From the table it is clear that skin friction(τ), decreases with an increase in $\omega, \lambda, \alpha, M, N, \chi$ and P_r and increases with an increase in G_r and G_m, for large as well as small rotation. But in case of permeability parameter and Schmidt number skin friction coefficient decreases for small rotation and increases for large rotation, while a reverse effect is found with increase of slip parameter. From Table-2 it is clear that Nusselt number increases with an increase in Prandtl number and frequency of oscillation, but decreases with radiation and suction parameter. Numerical values of Sherwood number at the left wall is given in Table-3. Table shows that Sherwood number decreases for an increase in chemical reaction parameter, Schmidt number suction parameter and frequency of oscillations.

IV. Conclusions

This paper investigates the effect of heat and mass transfer on MHD slip flow in a vertical porous channel with rotation, chemical reaction and thermal radiation under the effect of transversely applied magnetic field. The resulting partial differential equations are transformed into a set of ordinary differential equation using normalisation and solved in closed-form. Numerical evaluations of the closed- form results are performed and graphical results are obtained to illustrate the details of the flow and heat and mass transfer characteristics and their dependence on some physical parameter. It is observed that the velocity profile is increasing with increasing slip parameter, Grashof number and mass Grashof number, viscoelastic parameter and permeability of porous medium. Also, velocity reducing with increasing rotation, frequency of oscillation, radiation parameter, magnetic parameter, Schmidt number, suction parameter, chemical reaction parameter and Prandtl number. The fluid temperature is reduced by increases in the values of the Prandtl number and radiation parameters. Concentration is reducing with increase in

Schmidt number and chemical reaction parameter. In addition, it is found that skin friction coefficient decreases with frequency of oscillation, suction parameter, viscoelastic parameter, magnetic parameter, radiation parameter, chemical reaction parameter and Prandtl number but increases with thermal and mass Grashof number. However, the Nusselt number increases with an increase in Prandtl number and frequency of oscillation, but decreases with radiation and suction parameter.

Notes

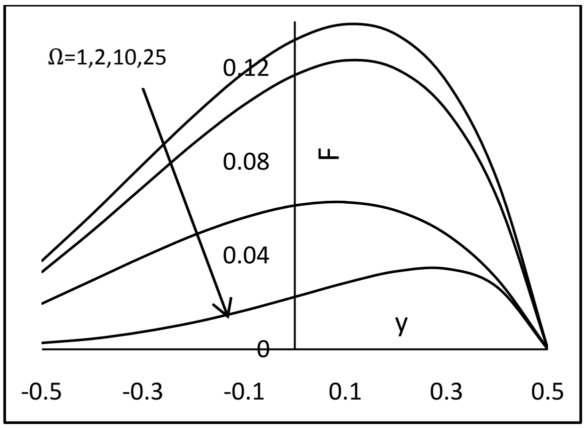

Fig. 2 : Velocity profile for different values of Ω.

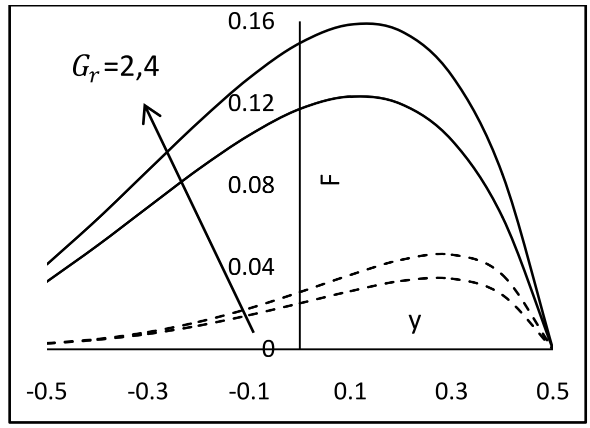

Fig. 4 : Velocity profile for different values of G_r.

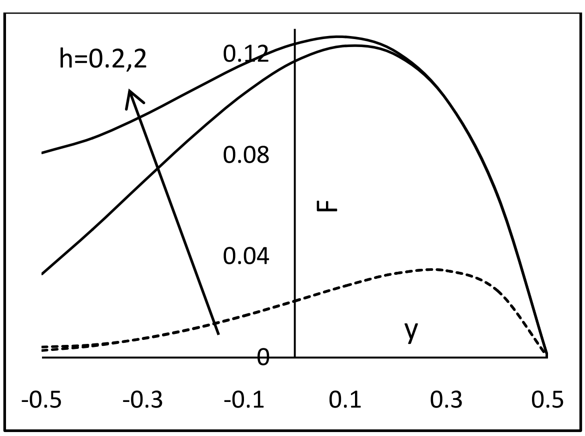

Fig. 3 : Velocity profile for different values of h.

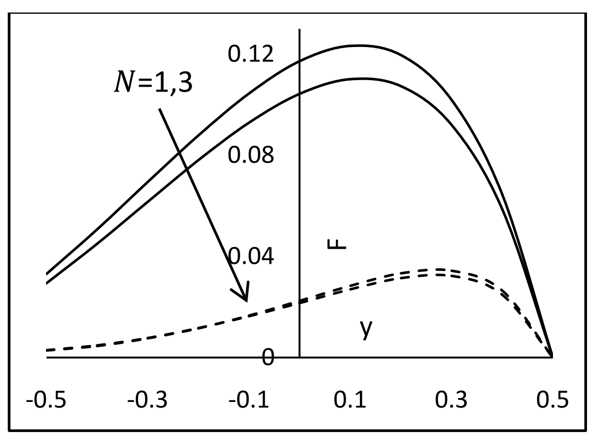

Fig. 5 : Velocity profile for different values of N.

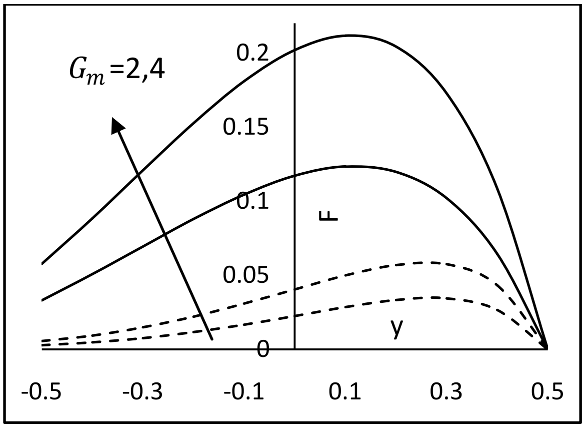

Fig. 6 : Velocity profile for different values of G_m.

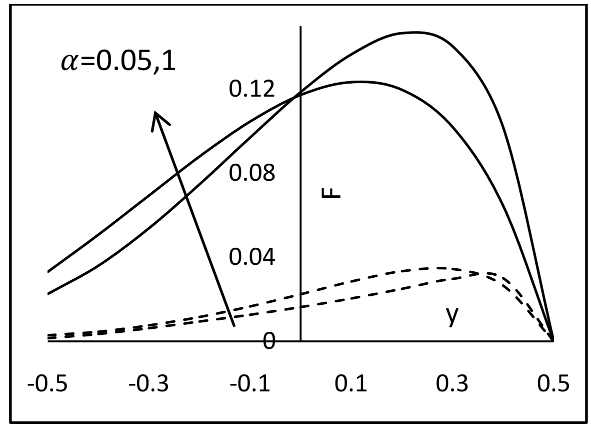

Fig. 9 : Velocity profile for different values of α.

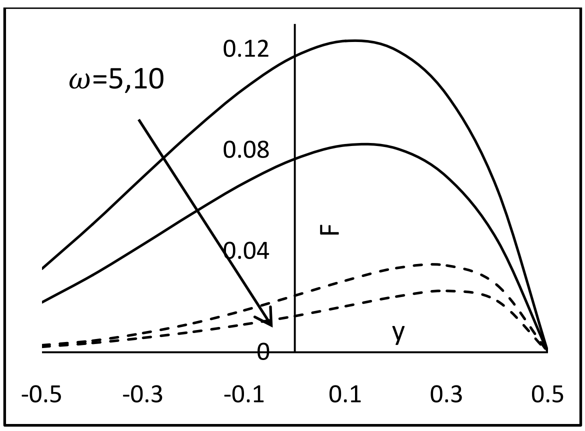

Fig. 7 : Velocity profile for different values of ω.

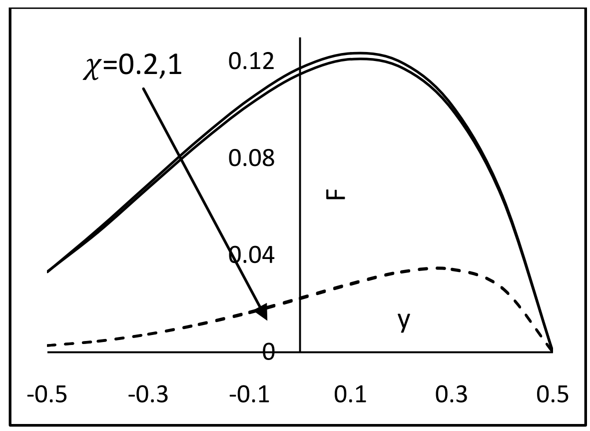

Fig. 10 : Velocity profile for different values of χ.

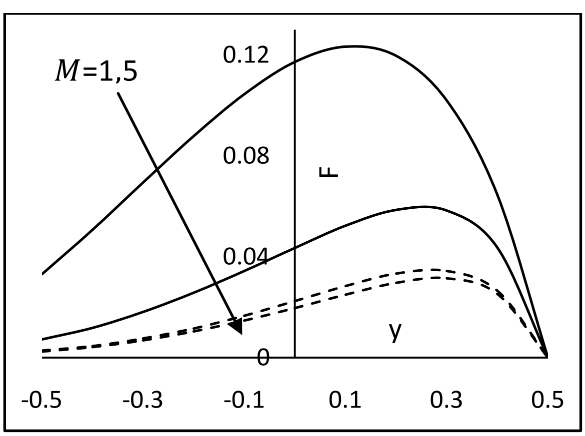

Fig. 8 : Velocity profile for different values of M.

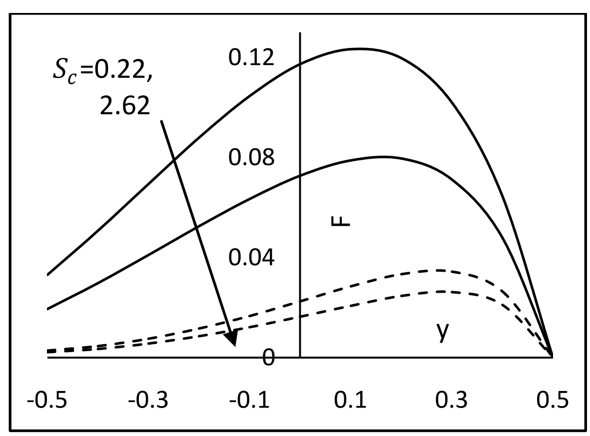

Fig. 11 : Velocity profile for different values of S_c.

Notes

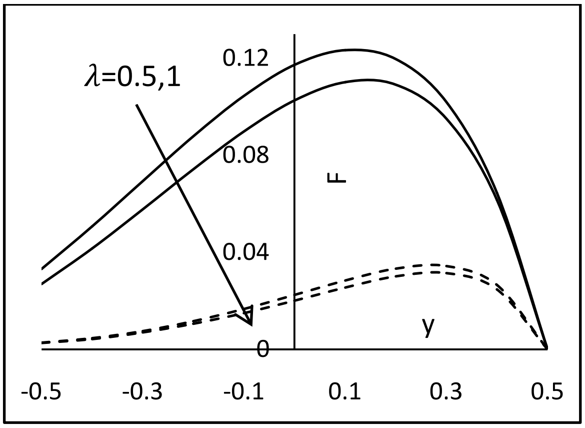

Fig. 12 : Velocity profile for different values of λ.

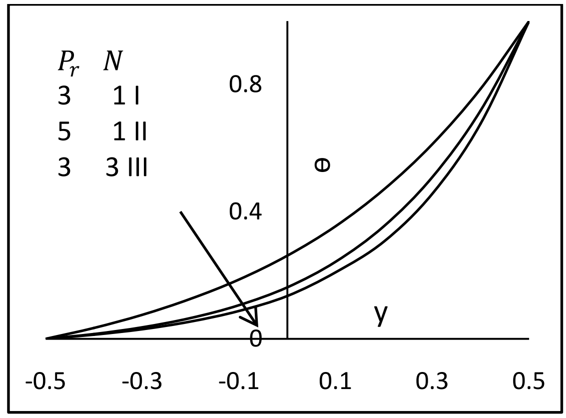

Fig. 15 : Temperature distribution for $\omega = 5, \lambda = 0.5$ and $t = 0$.

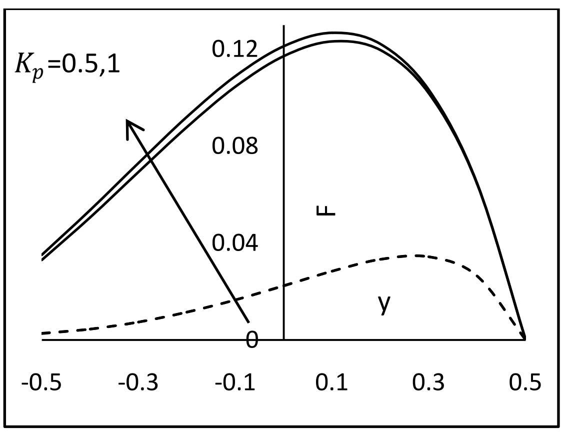

Fig. 13 : Velocity profile for different values of K_p.

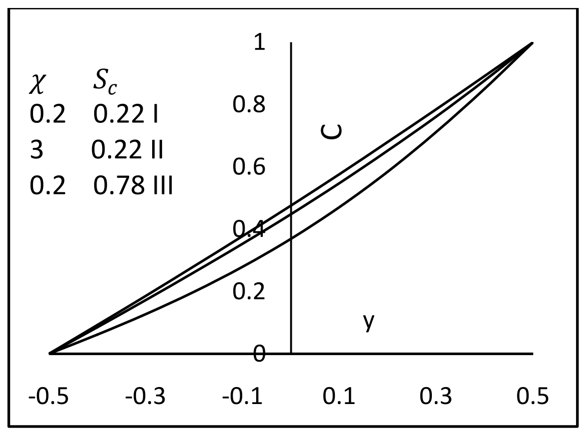

Fig. 16 : Concentration profile for $\omega = 1, \lambda = 0.5$ and $t = 0$.

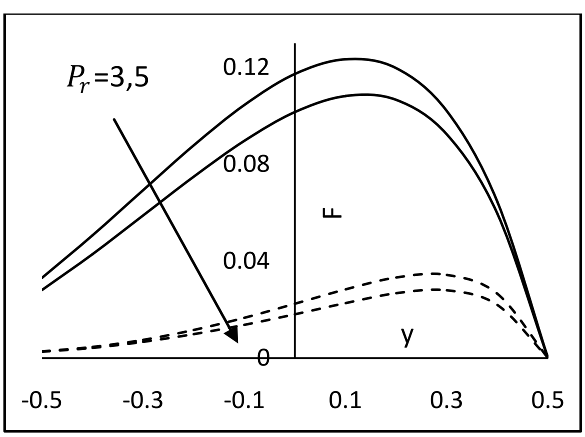

Fig. 14 : Velocity profile for different values of P_r.

Notes

G_r	G_m	ω	λ	K_p	h	α	M	N	χ	S_c	P_r	$\tau_{-\frac{1}{2}}$ Ω=1	$\tau_{-\frac{1}{2}}$ Ω=25
2	2	5	0.5	0.5	0.2	0.05	1	1	0.2	0.22	3	0.079424	0.010192
4	2	5	0.5	0.5	0.2	0.05	1	1	0.2	0.22	3	0.096165	0.013390
2	4	5	0.5	0.5	0.2	0.05	1	1	0.2	0.22	3	0.14211	0.017186
2	2	10	0.5	0.5	0.2	0.05	1	1	0.2	0.22	3	0.0054732	0.0059049
2	2	5	1	0.5	0.2	0.05	1	1	0.2	0.22	3	0.072659	0.0072924
2	2	5	0.5	1	0.2	0.05	1	1	0.2	0.22	3	0.072397	0.010455
2	2	5	0.5	0.5	2	0.05	1	1	0.2	0.22	3	0.101011	0.001816
2	2	5	0.5	0.5	0.2	1	1	1	0.2	0.22	3	0.013681	0.0021440
2	2	5	0.5	0.5	0.2	0.05	3	1	0.2	0.22	3	0.064965	0.0078971
2	2	5	0.5	0.5	0.2	0.05	1	3	0.2	0.22	3	0.074226	0.0088919
2	2	5	0.5	0.5	0.2	0.05	1	1	2	0.22	3	0.073474	0.0098028
2	2	5	0.5	0.5	0.2	0.05	1	1	0.2	0.78	3	0.004753	0.013572
2	2	5	0.5	0.5	0.2	0.05	1	1	0.2	0.22	5	0.060887	0.0065786

Table 1 : Values of skin-friction coefficient for small and large rotation.

P_r	N	λ	ω	$(N_u)_{-\frac{1}{2}}$
3	1	0.5	5	0.05925
5	1	0.5	5	0.060498
3	3	0.5	5	0.0044209
3	1	1	5	0.017097
3	1	0.5	10	0.096453

Table 2 : Values of Nusselt number.

χ	S_c	λ	ω	$(Sh)_{-\frac{1}{2}}$
0.2	0.22	0.5	5	0.91742
2	0.22	0.5	5	0.86087
0.2	0.78	0.5	5	0.59933
0.2	0.22	1	5	0.86707
0.2	0.22	0.5	10	0.85568

Table 3 : Values of Sherwood number.

References Références Referencias

1. Afify A A (2004). Effects of radiation and chemical reaction on MHD free convective flow past a vertical isothermal cone. Canadian Journal of Physics 82, 447-458.
2. Anjalidevi S P, Kandasamy R (2000). Effects of chemical reaction heat and mass transfer on MHD flow past a semi-infinite plate. Z. Angew. Mathematics and Mechanics 80, 697-701.
3. Armstead H C (1982). Geothermal Energy, EN Spon. London.
4. Attia H A (2008). Effect of hall current on transient hydromagnetic Couette-Poiseuille flow of viscoelastic fluid with heat transfer. Applied Mathematical Modeling 32, 375-388.
5. Chambre P L, Young J D (1958). On the diffusion of a chemically reactive species in a laminar boundary layer flow. Physics of Fluids 1, 48-54.
6. Chamkha A (2003). MHD flow of a uniformly stretched permeable surface in the presence of heat generation/absorption and chemical reaction. International Communication in Heat Mass Transfer 30, 413-422.
7. Choudhary R, Deb H R (2012). Heat and mass transfer for viscoelastic MHD boundary layer flow past a vertical flat plate. International Journal of Engineering, Science and Technology, 4(7), 3124-3133.
8. Cogley A C L, Vinvent W G, Giles E S (1968). Differential approximation for radiative transfer in a non-gray near equilibrium, American Institute of Aeronautics and Astronautics, 6: 551-553.
9. Das U N, Deka R K, Soundalgekar V M (1994). Effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction. Forsch. Ingenieurwes 60, 284-287.
10. Gbadeyan, J A, Idowu A S, Ogunsola A W, Agboola O O, Olanrewaju P O (2011). Heat and mass transfer for soret and dufour's effect on mixed convection boundary flow over a stretching vertical surface in a porous medium filled with a viscoelastic fluid in the presence of magnetic field, Global J of Science Frontier Research, 11 (8) 97-114.
11. Jana R N, Datta N (1977). Couette flow and heat transfer in a rotating system, Acta Mech., 26, 301-306.
12. Kandasamy R, Periasamy K, Sivagnana Prabhu K K (2005). Effects of chemical reactions heat and mass transfer along a wedge with heat source in the presence of suction/injection. International Journal of Heat Mass Transfer 48, 1388-1393
13. Mansour M A, El-Anssary N F, Aly A M (2008). Effects of chemical reaction and viscous dissipation on MHD natural convection flows saturated in porous media. International Journal of Applied Mathematics and Mechanics 4(2), 60-76.
14. Muthucumaraswamy R, Ganesan P. (2001). First order chemical reaction on flow past an impulsively started vertical plate with uniform heat and mass flux. Acta Mechanica 147, 45-57.
15. Raptis A, Perdikis C. (2006). Viscous flow over a non-linearly stretching sheet in the presence of a chemical reaction and magnetic field. International Journal of Non-Linear Mechanics 41, 527-529.
16. Singh K D (2000). An oscillatory hydromagnetic Couette flow in a rotating system. J. Appl. Math and Mech., 80, 429-432.
17. Singh K D, Gorla M G, Hans Raj. (2005), A periodic solution of oscillatory Couette flow through porous medium in rotating system, Indian J. pure appl. Math., 36(3), 151-159.

Notes

Notes

18. Singh K D, Mathew A (2012). An oscillatory free convective flow through porous medium in a rotating vertical porous channel, Global J of Science Frontier Research, 12 (3), 51-64.
19. Sutton G W, Sherman A (1965). Engineering Magnetohydrodynamics, McGraw Hill, New York.
20. Takhar H S, Chamkha A J , Nath G (2000).. Flow and mass transfer on a stretching sheet with a magnetic field and chemically reactive species. International Journal of Engineering and Science 38, 1303-1306.
21. Vidyanidhu V, Nigam S D (1967). Secondary flow in a rotating channel, J. Math And Phys. Sci., 1,85-100.