Heat and Mass Transfer to Unsteady MHD Viscoelastic Slip Flow through a Porous Medium with Chemical Reaction

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Abstract - In the present paper, an analysis is carried out to heat and mass transfer to unsteady flow of an electrically conducting incompressible non-Newtonian viscoelastic fluid filled in a vertical channel in the presence of transverse magnetic field through porous medium with heat source. The fluid and the channel rotate as a solid body with constant angular velocity, 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 momentum, energy and concentration equations are solved by using closed-from of analytical solution. The influences of the various parameters entering into the problem are illustrated with the help of graphs. Possible applications of the present study include engineering science and applied mathematics in the context of aerodynamics, geophysics and aeronautics.

Keywords: *Heat and mass transfer, chemical reaction, viscoelastic, slip flow regime, Grashof number.*

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1. 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.

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 groundwater 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 behaviour is less prominent with increasing shear rate. A series of investigations have been made by different scholars viz: Attia [10], Choudhary and Deb [11] and Gbadeyan et.al [12] heat transfer to MHD oscillatory flow in a channel filled with porous medium. Chenna Kesavaiah et.al. [29] Studied natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate.

Magnotohydrodynamics is currently undergoing a period of great enlargement and differentiation of subject matter. It is important in the design of MHD generators and accelerators in geophysics, underground water storage system, soil sciences, astrophysics, nuclear power reactor, solar structures, and so on. Moreover, there exist flows which are caused not only by temperature differences but also by concentration differences. There are several engineering situations wherein combined heat and mass transport arise such as dehumidifiers, humidifiers, desert coolers, and chemical reactors etc. the interest in these new problems generates from their importance in liquid metals, electrolytes and ionized gases. On account of their varied importance, these flows have been studied by several authors – notable amongst them are Hall Effect on MHD mixed convective flow of a viscous incompressible fluid past a vertical porous plate immersed in a porous medium with heat source/sink was studied by Sharma *et al.* [19]. Singh and Singh [20] they investigated MHD flow of viscous dissipation and chemical reaction over a stretching porous plate in a porous medium numerically. Omokhuale and Onwuka [21] Effect of mass transfer and Hall current on unsteady MHD flow of a viscoelastic fluid in a porous medium.

The flow of an electrically conducting fluid has important applications in many branches of engineering science such as magnetohydrodynamic (MHD) generators, plasma studies, nuclear reactor, geothermal energy extraction, electromagnetic propulsion, and the boundary layer control in the field of aerodynamics. In the light of these applications, MHD flow in a channel has been studied by many authors; some of them are Nigam and Singh [1], Soundalgekar and Bhat [2], Vajravelu [3], and Attia and Kotb [4]. A survey of MHD studies in the technological fields can be found in Moreau [5]. The flow of fluids through porous media is an important topic because of the recovery of crude oil from the pores of the reservoir rocks; in this case, Darcy's law represents the gross effect. Raptis et al. [6] have analysed the hydromagnetic free convection flow through a porous medium between two parallel plates. Aldoss et al. [7] have studied mixed convection flow from a vertical plate embedded in a porous medium in the presence of a magnetic field. Makinde and Mhone [8] have considered heat transfer to MHD oscillatory flow in a channel filled with porous medium.

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 thermo fluid transport modelling in magnetic geosystems by Arm stead [9], 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 magnetohydrodynamic 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 [17], Jana and Datta [13], Singh [14, 15, 16]. Aarti Manglesh and Gorla [18] The Effects of thermal radiation, chemical reaction and rotation on unsteady MHD viscoelastic slip flow.

Chemical reactions are classified as either heterogeneous or homogeneous processes depending on whether they occur at an interface or as a single-phase volume reaction. A reaction is said to be first-order if the rate of reaction is directly proportional to the concentration itself. In many chemical processes, a chemical reaction occurs between a foreign mass and a fluid in which a plate is moving. These processes take place in numerous industrial applications, e.g., polymer production, manufacturing of ceramics or glassware, and food processing Cussler [22]. Chambre and Young [23] analyzed the diffusion of chemically reactive species in a laminar boundary layer flow. Vajravelu [24] studied the exact solution for hydrodynamic boundary layer flow and heat transfer over a continuous, moving horizontal flat surface with uniform suction and internal heat generation/absorption. Das et al. [25] studied the effect of a homogeneous first-order chemical reaction on the flow past an impulsively started infinite vertical plate with constant heat flux and mass transfer. Kandasamy et al. [26] studied the nonlinear MHD flow, with heat and mass transfer characteristics, of an incompressible, viscous, electrically conducting, Boussinesq fluid on a vertical stretching surface with chemical reaction and thermal stratification effects.

The objective of above paper is to analyze heat and mass transfer, 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

2. FORMULATION OF THE PROBLEM

The geometry of the problem is shown in below figure. The fluid is assumed to be an unsteady incompressible, viscoelastic, heat absorbing, 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 temperature dependent heat source is assumed to be present in the flow. A Cartesian co-ordinate system is introduced such that 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 unison 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 by Sutton and Sherman [27]. 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 $\vec{V}(y,t)=u(y,t)\hat{i}+v(y,t)\hat{j}+w(y,t)\hat{k}$ It is because of conservation of mass i.e. $\Delta\Box V=0$ and due to uniform suction the velocity component $\vec{v}(y,t)$ is assumed to have a constant value v_0.

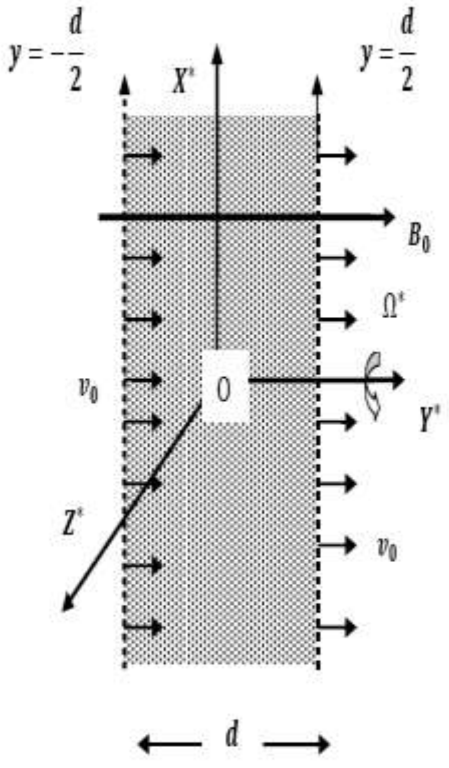

Figure: Schematic presentation of the physical problem

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

$$\frac{\partial u^*}{\partial t^*}+v_0\frac{\partial u^*}{\partial y^*}=\nu\frac{\partial^2 u^*}{\partial y^{*2}}-K_0\left(\frac{\partial^3 u^*}{\partial t^*\partial y^{*2}}\right)-\frac{\sigma B_0^2}{\rho}u^*+g_T\beta T^*+g_T\beta C^*-\frac{\nu}{K_p^*}u^* \quad (1)$$

$$\frac{\partial \omega^*}{\partial t^*}+v_0\frac{\partial \omega^*}{\partial y^*}=\nu\frac{\partial^2 \omega^*}{\partial y^{*2}}-K_0\left(\frac{\partial^3 u^*}{\partial t^*\partial y^{*2}}\right)-\frac{\sigma B_0^2}{\rho}w^*+2\Omega^* u^*-\frac{\nu}{K_p^*}w^* \quad (2)$$

$$\frac{\partial T^*}{\partial t^*}+v_0\frac{\partial T^*}{\partial y^*}=\frac{\kappa}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^*}-\frac{Q_0}{\rho C_p}T^* \quad (3)$$

$$\frac{\partial C^*}{\partial t^*}+v_0\frac{\partial C^*}{\partial y^*}=D_M\frac{\partial^2 C^*}{\partial y^{*2}}-Kr^* C^* \quad (4)$$

Boundary conditions of the problem are

$$u^*=L^*\frac{\partial u^*}{\partial y^*},\ w^*=L^*\frac{\partial w^*}{\partial y^*},\ T^*=0,\ C^*=0 \ \ at\ y^*=-\frac{d}{2}$$

$$u^*=0,\ w^*=0,\ T^*=T_0\cos\omega^* t^*,\ C^*=\cos\omega^* t^* \ \ at\ y^*=\frac{d}{2}$$

(5)

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 [28] the radiative heat flux for the present problem become

$$\frac{\partial q_r}{\partial y^*}=4\alpha' T^* \quad (6)$$

Where α' is the mean radiation absorption coefficient.

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

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

We also define the following dimensionless parameters

$$\lambda=\frac{v_0 d}{\nu},\ Gr=\frac{g\beta T_0 d^2}{v_0\nu},\ \Omega=\frac{\Omega^*}{d^2},\ M=B_0 d\sqrt{\frac{\sigma}{\mu}},$$

$$\alpha=\frac{K_0}{d^2},\ Gm=\frac{g\beta^* C_0 d^2}{v_0\nu},\ K_p=\frac{K_p^*}{d^2},\ Sc=\frac{\nu}{D_M},$$

$$Q=\frac{Q_0 d^2}{k},\ \Pr=\frac{\mu C_p}{k},\ N=\frac{2\alpha' d}{\sqrt{k}},\ Kr=\frac{Kr^* d^2}{\nu}$$

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

$$\frac{\partial u}{\partial t}+\lambda\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}-\alpha\frac{\partial^3 u}{\partial t\partial y^2}+M^2 u+2\Omega w+Gr\,\theta+Gm\,C-\frac{u}{K_p} \quad (7)$$

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

$$\frac{\partial \theta}{\partial t}+\lambda\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2}-\frac{1}{\Pr}\left(N^2+Q\right)\theta \quad (9)$$

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$$\frac{\partial C}{\partial t}+\lambda\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-Kr\,C \qquad (10)$$

Gr is Thermal Grashof number , Gm is modified Grashof Number , $\Pr$ is Prandtl Number, Kr is Chemical reaction parameter , Q is heat source parameter , M is Hartman number, K is Permeability parameter, λ is Suction parameter, Ω is Visco elastic parameter, α is Rotation parameter, Sc is Schmidt number, $L^*=\left(\frac{2-m_1}{m_1}\right)L$, with m_1 is Maxwell's reflexion coefficient, L is mean free path and is a constant for an incompressible fluid, T^* is the temperature, C^* is Concentration, t^* is the time, K_0 is Visco elasticity, g is Acceleration due to gravity, K_p^* is Permeability of the porous medium, C_p is Specific heat at constant pressure, D_M is Chemical molecular diffusivity, here '*' stands for the dimensional quantities. , ρ is Density, ν is Kinematic viscosity, ω^* is Frequency of oscillations, κ is Thermal conductivity, σ is Electric conductivity, Ω^* is Rotation β_T is Coefficient of thermal expansion, β_C is Coefficient of concentration expansion

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

$$u=h\frac{\partial u}{\partial y},\ w=h\frac{\partial w}{\partial y},\ \theta=0, C=0 \quad at \quad y=-\frac{1}{2}$$

$$u=0,\ w=0,\ \theta=\cos\omega t,\ C=\cos\omega t \quad at \quad y=\frac{1}{2}$$

(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:

$$\frac{\partial F}{\partial t}+\lambda\frac{\partial F}{\partial y}=\frac{\partial^2 F}{\partial y^2}-\alpha\frac{\partial^3 F}{\partial t\,\partial y^2}-M^2F-2i\Omega F+Gr\,\theta+Gm\,C-\frac{F}{K_p}$$

(12)

The corresponding boundary conditions reduce to:

$$F=h\frac{\partial u}{\partial y},\ \theta=0, C=0 \quad at \quad y=-\frac{1}{2}$$

$$F=0,\ \theta=\cos\omega t,\ C=\cos\omega t \quad at \quad y=\frac{1}{2} \qquad (13)$$

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

$$F(y,t)=F_0(y)e^{i\omega t}$$

$$\theta(y,t)=\theta_0(y)e^{i\omega t}$$

$$C(y,t)=C_0(y)e^{i\omega t}$$

(14)

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

$$(1-iA)F_0''-\lambda F_0'-l^2F_0=-Gr\theta_0-GmC_0$$

(15)

$$\theta_0''-\lambda\Pr\theta_0'-a_0\theta_0=0 \qquad (16)$$

$$C_0''-Sc\lambda C_0'-a_1C_0=0 \qquad (17)$$

Where $l^2=M^2+2i\Omega+i\omega+\frac{1}{K_p}, A=\alpha\omega, a_0=N^2+Q+i\omega\Pr, a_1=Kr+i\omega$

Corresponding boundary condition becomes

$$F_0=h\frac{\partial F_0}{\partial y},\ \theta_0=0, C_0=0 \quad at \quad y=-\frac{1}{2}$$

$$F_0=0,\ \theta_0=1, C_0=1 \quad at \quad y=\frac{1}{2} \qquad (18)$$

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

$$F=\left[\begin{array}{l}L_1e^{M_2y}+L_2e^{M_1y}+L_3e^{M_4y}+\\ L_4e^{M_3y\frac{-b\pm\sqrt{b^2-4ac}}{2a}}+L_6e^{M_6y}+L_8e^{M_5y}\end{array}\right]e^{i\omega t}$$

(19)

$$\theta=\left[A_1e^{M_2y}+A_2e^{M_1y}\right]e^{i\omega t} \qquad (20)$$

$$C=\left[B_1e^{M_4y}+B_2e^{M_3y}\right]e^{i\omega t} \qquad (21)$$

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

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

(22)

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

Where $D_r + iD_i = \left[\begin{array}{l} M_2 L_1 e^{\frac{M_2}{2}} + M_1 L_2 e^{\frac{M_1}{2}} + \\ M_4 L_3 e^{\frac{M_4}{2}} + M_3 L_4 e^{\frac{M_3}{2}} + \\ M_6 L_6 e^{\frac{M_6}{2}} + M_5 L_8 e^{\frac{M_5}{2}} \end{array} \right] e^{i\omega t}$

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

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

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

where $H_r + iH_i = \left[M_2 A_1 e^{\frac{M_2}{2}} + M_1 A_2 e^{\frac{M_1}{2}} \right] e^{i\omega t}$

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

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

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

where $G_r + iG_i = \left[M_4 B_1 e^{\frac{M_4}{2}} + M_3 B_2 e^{\frac{M_3}{2}} \right] e^{i\omega t}$

APPENDIX:

$$M_1 = \frac{\lambda \Pr + \sqrt{\lambda^2 \Pr^2 + 4a_0}}{2}, \quad M_2 = \frac{\lambda \Pr - \sqrt{\lambda^2 \Pr^2 + 4a_0}}{2},$$

$$M_3 = \frac{\lambda Sc + \sqrt{\lambda^2 Sc^2 + 4Sca_1}}{2}, \quad M_4 = \frac{\lambda Sc - \sqrt{\lambda^2 Sc^2 + 4Sca_1}}{2}$$

` $$M_5 = \frac{\lambda + \sqrt{\lambda^2 + 4l^2(1-iA)}}{2}, M_6 = \frac{\lambda - \sqrt{\lambda^2 + 4l^2(1-iA)}}{2}$$

$$\beta_1 = \frac{M_1 - M_2}{2}, \beta_2 = -\beta_1, \beta_3 = \frac{M_3 - M_4}{2}, \beta_4 = -\beta_3,$$

$$\beta_5 = \frac{M_5 - M_6}{2}, \beta_6 = -\beta_5, \beta_7 = \frac{M_5 - M_2}{2}$$

$$\beta_8 = -\beta_7, \beta_9 = \frac{M_5 - M_1}{2}, \beta_{10} = -\beta_9, \beta_{11} = \frac{M_5 - M_4}{2}, \beta_{12} = -\beta_{11},$$

$$\beta_{13} = \frac{M_5 - M_3}{2}, \beta_{14} = -\beta_{13}\ \beta_{15} = \frac{M_2 - M_6}{2}, \beta_{16} = -\beta_{15},$$

$$\beta_{17} = \frac{M_1 - M_6}{2}, \beta_{18} = -\beta_{17}, \beta_{19} = \frac{M_4 - M_6}{2}, \beta_{20} = -\beta_{19},$$

$$\beta_{21} = \frac{M_3 - M_6}{2}, \beta_{22} = -\beta_{21}, A_1 = -\frac{e^{-\frac{M_1}{2}}}{2\sinh \beta_1}, A_2 = -\frac{e^{-\frac{M_2}{2}}}{2\sinh \beta_2},$$

$$B_1 = -\frac{e^{-\frac{M_3}{2}}}{2\sinh \beta_3}, B_2 = -\frac{e^{-\frac{M_4}{2}}}{2\sinh \beta_4}$$

$$L_1 = -\frac{GrA_1}{(1-iA)M_2^2 - \lambda M_2 - l^2}, L_2 = -\frac{GrA_2}{(1-iA)M_1^2 - \lambda M_1 - l^2}$$

$$L_3 = -\frac{GmB_1}{(1-iA)M_4^2 - \lambda M_4 - l^2}, L_4 = -\frac{GmB_2}{(1-iA)M_3^2 - \lambda M_3 - l^2}$$

$$L_5 = -\Big\{ L_1\big((hM_2-1)e^{\beta_7} - (hM_5-1)e^{\beta_8}\big) + L_2\big((hM_1-1)e^{\beta_9} - (hM_5-1)e^{\beta_{10}}\big)$$
$$+ L_3\big((hM_4-1)e^{\beta_{11}} - (hM_5-1)e^{\beta_{12}}\big) + L_4\big((hM_3-1)e^{\beta_{13}} - (hM_5-1)e^{\beta_{14}}\big) \Big\}$$

$$L_6 = \frac{L_5}{(hM_6-1)e^{\beta_5} - (hM_5-1)e^{\beta_6}}$$

$$L_7 = -\Big\{ L_1\big((hM_6-1)e^{\beta_{15}} - (hM_2-1)e^{\beta_{16}}\big) + L_2\big((hM_6-1)e^{\beta_{17}} - (hM_1-1)e^{\beta_{18}}\big)$$

$$+ L_3\big((hM_6-1)e^{\beta_{19}} - (hM_4-1)e^{\beta_{20}}\big) + L_4\big((hM_6-1)e^{\beta_{21}} - (hM_3-1)e^{\beta_{22}}\big) \Big\}$$

$$L_8 = \frac{L_7}{(hM_6-1)e^{\beta_5} - (hM_5-1)e^{\beta_6}}$$

RESULTS AND DISCUSSION

Numerical evaluation for the analytical solution of this problem is performed and the results are illustrated graphically in Figures (1) – (22) to show the interesting features of significant parameters on velocity, temperature and concentration distribution in rotating channel. 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.

Velocity Profiles

Decrease in thermal Grashoff numbers and increase in solutal Grashoff numbers significantly decreases and increase the boundary layer thickness which resulted into rapid enhancement of fluid velocity for both cases, which is displayed in figures (1) and (2). From figure (3) we observe that the magnitude of the stream wise velocity decreases and the inflection point for the velocity distribution moves further away from the surface. The time required to reach the steady state decreases with increasing chemical reaction parameter. This shows that the contribution of mass diffusion to the buoyancy force increases the maximum

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velocity significantly. It can be interpreted from figure (4) that velocity increases 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. The rate of radiative heat transferred to fluid is increased and consequently the velocity decreases as radiation parameter increases, for both cases of rotation, is represented in figure (5). 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=4.0 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 Ω=1 and large rotation Ω=4.0 are illustrated in Figures (6) with the help of solid and dotted lines respectively. It is observed that the rotation parameter increases the velocity decreases. The effects of heat generation Q on the velocity profiles across the boundary layer are presented in figure (7). It is shown that the velocity across the boundary layer increases with an increasing of Q. From figure (8) we observe that the magnitude of the stream wise velocity decreases and the inflection point for the velocity distribution moves further away from the surface. The time required to reach the steady state decreases with increasing Schmidt number. This shows that the contribution of mass diffusion to the buoyancy force increases the maximum velocity significantly. It is obvious that the increase in the frequency of oscillation decrease the velocity for small and large rotation and that is presented in figure (9). Figure (10) shows the effect of viscoelastic parameter (α) 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. Figure (11) 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.

Temperature profiles

Figure (12) 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 (13) 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. It is noticed from figure (14) and (15) that temperature for different values of Prandtl number (Pr) and heat source parameter (Q) ; it is observed that the fluid temperature decreases due to increase in both.

Concentration profiles

Figure (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. Figure (17) show that effect of Schmidt number on the concentration profiles we observe that decrease the concentration with increasing values of Schmidt number. This causes the concentration buoyancy effect to decrease yielding a reduction in the fluid rotation on the velocity profile. Increase with the frequency parameter ω the concentration profiles decreases are shown in figure (18).

Figure (19) and (20) shows the effect of different parameters in skin friction at the left wall. From the figures it is clear that skin friction (τ) decreases with an increase in Kr and increases with an increase in Gm for large as well as small rotation versus Gr. From figure (21) it is clear that Nusselt number increases with an increase in Prandtl number versus the frequency of oscillation. Numerical values of Sherwood number at the left wall is given in figure (22). This graph shows that Sherwood number decreases for an increase in Schmidt number suction parameter versus the frequency of oscillations.

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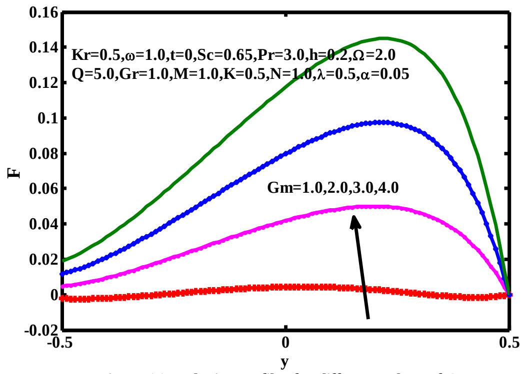

Figure (1): Velocity Profiles for different values of Gm

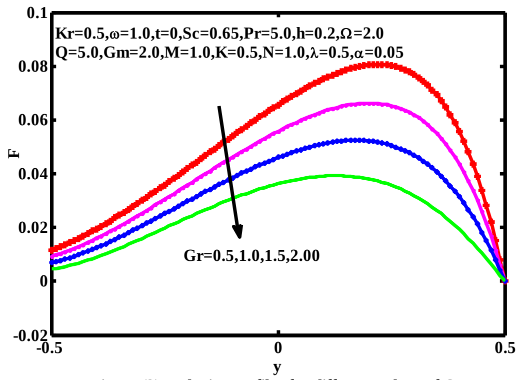

Figure (2): Velocity Profiles for different values of Gr

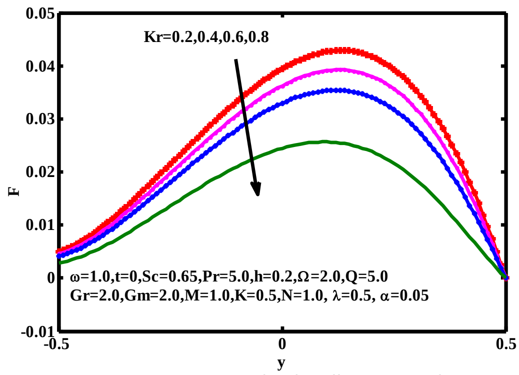

Figure (3): Velocity profiles for different values of Kr

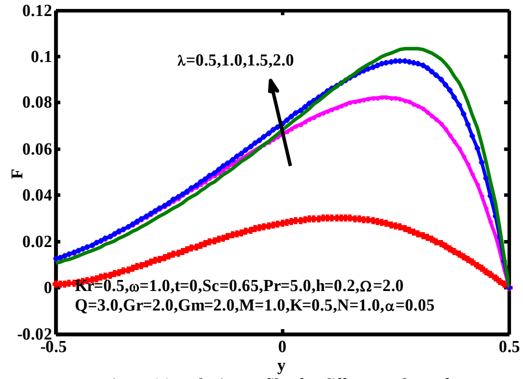

Figure (4): Velocity profiles for different values of λ

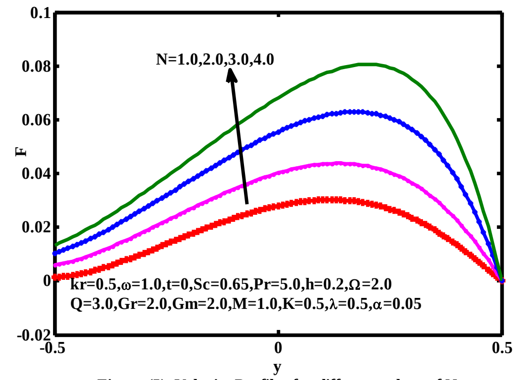

Figure (5): Velocity Profiles for different values of N

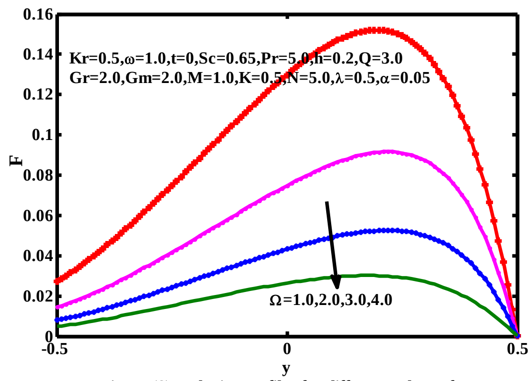

Figure (6): Velocity Profiles for different values of Ω

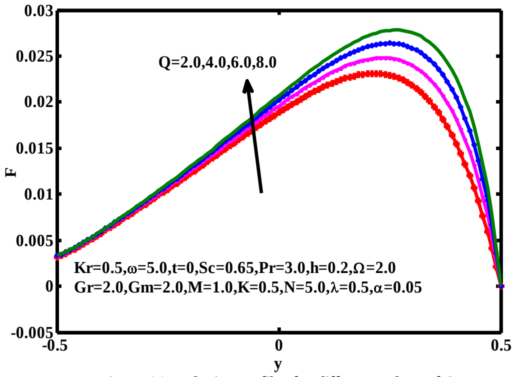

Figure (7): Velocity Profiles for different values of Q

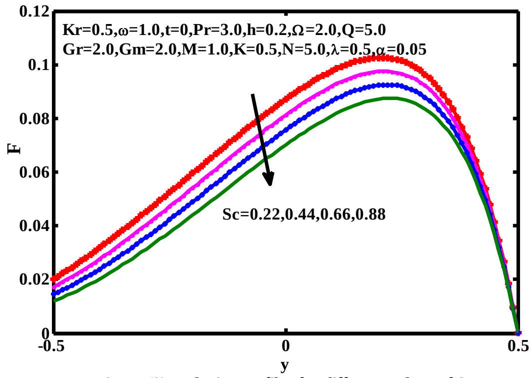

Figure (8): Velocity Profiles for different values of Sc

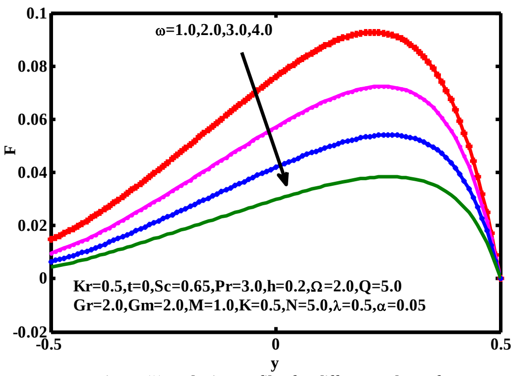

Figure (9): Velocity Profiles for different values of ω

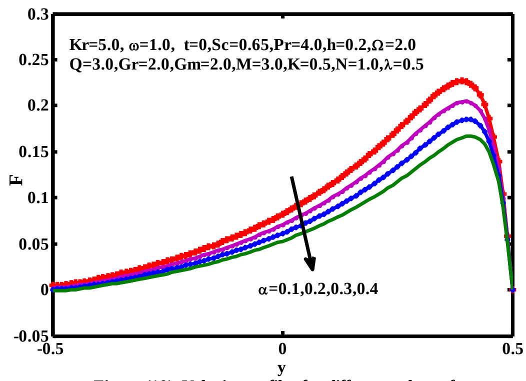

Figure (10): Velocity profiles for different values of α

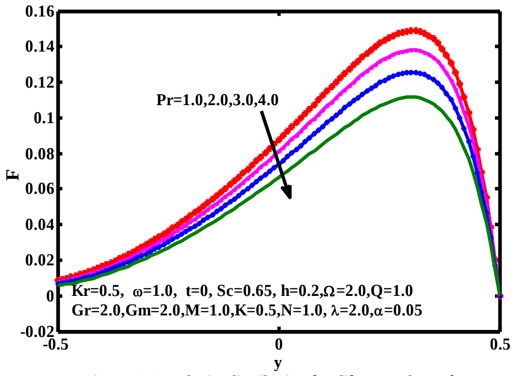

Figure (11): Velocity distribution for diferent values of Pr

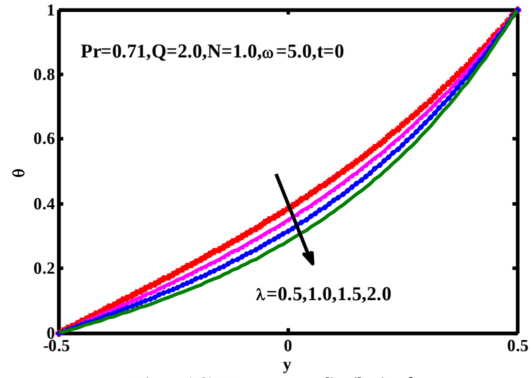

Figure (12): Temperature distribution for λ

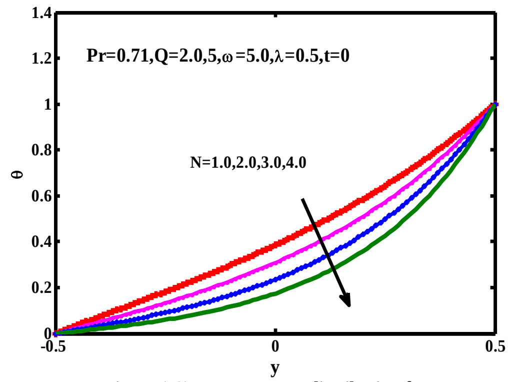

Figure (13): Temperature distribution for N

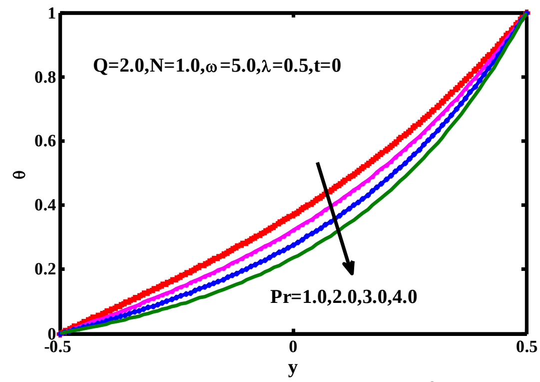

Figure (14): Temperature distribution for Pr

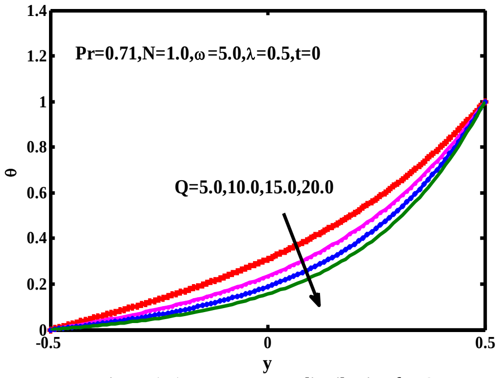

Figure (15): Temperature distribution for Q

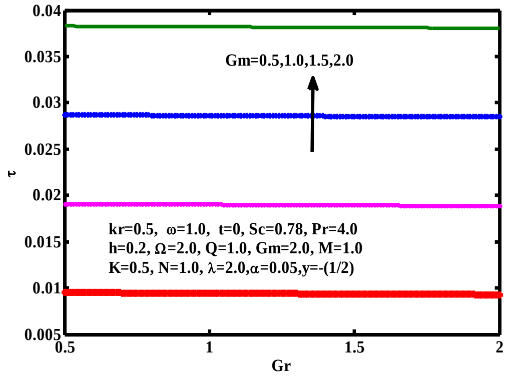

Figure (19): Skin friction for different values of Gm versus Gr

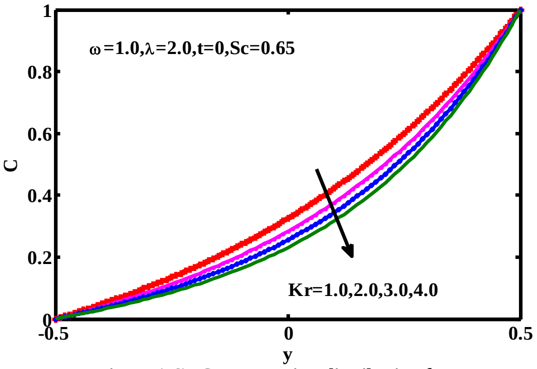

Figure (16): Concentration distribution for Kr

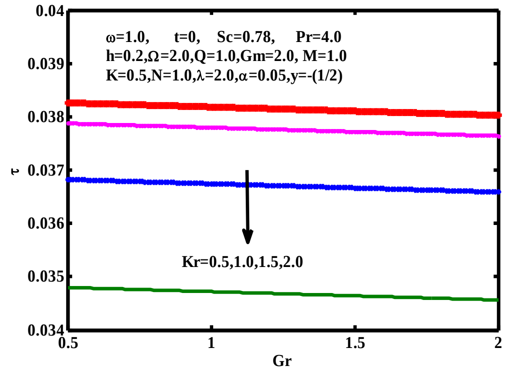

Figure (20): Skin friction for different values of Kr versus Gr

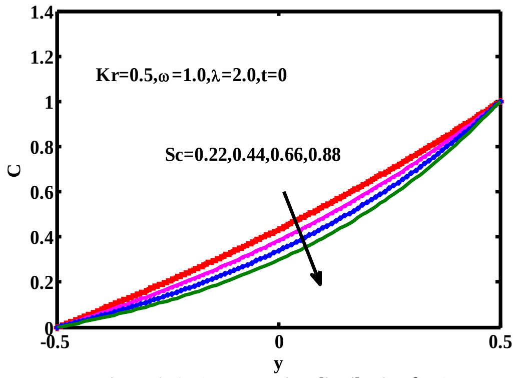

Figure (17): Concentration distribution for Sc

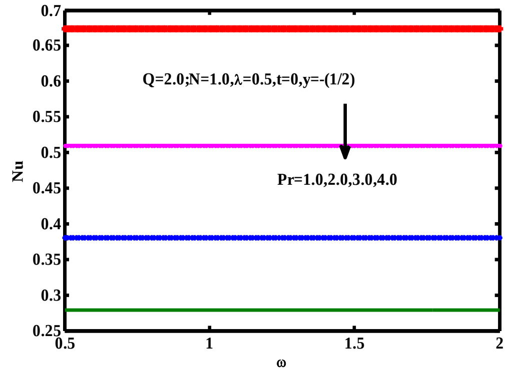

Figure (21): Nusselt number for different values of Pr versus ω

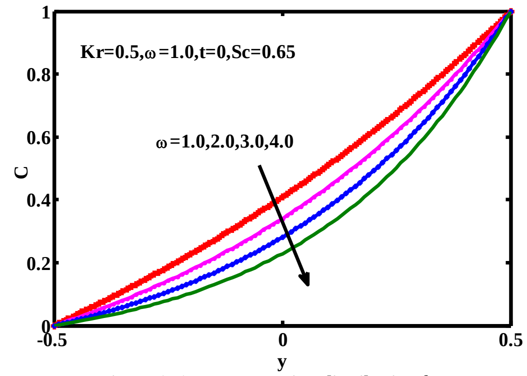

Figure (18): Concentration distribution for ω

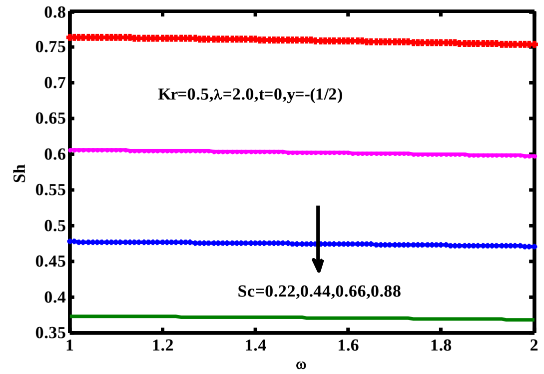

Figure (22): Sherwood number for different values of Sc versus ω