Thermal Radiation and Viscous Dissipation Effects on an Oscillatory Heat and Mass Transfer Flow of a Viscoelastic Fluid with Ohmic Heating

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Abstract: An anticipated outcome that is intended chapter is to investigate effects of magnetic field on an oscillatory flow of a viscoelastic fluid with thermal radiation, viscous dissipation with Ohmic heating which bounded by a vertical plane surface, have been studied. Analytical solutions for the quasi – linear hyperbolic partial differential equations are obtained by perturbation technique. Solutions for velocity and temperature distributions are discussed for various values of physical parameters involving in the problem. The effects of cooling and heating of a viscoelastic fluid compared to the Newtonian fluid have been discussed.

Keywords: *MHD, Viscous dissipation, Ohmic heating, Cooling and heating, Oscillatory flow*

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INTRODUCTION

In industrial and real life problems, there exist flows which are simulated not only by the difference of temperature but also by differences of concentration. These mass transfer differences affect the rate of heat transfer. The phenomenon of heat and mass transfer frequently exists in any chemical processes industries like food processing and polymer process. Free convection flows are of great interest in many industrial applications such as fiber and granular insulation, geothermal systems etc. Flow and heat transfer of an in compressible viscous fluid over stretching sheet find applications in manufacturing pro cesses such as the cooling of the metallic plate, nuclear reactor, extrusion of polymers, *etc*. Flow in the neighbourhood of a stagnation point in a plane was initiated by Hiemenz [13]. Crane [15] presented the flow over a stretching sheet and obtained similarity solution in closed analytical form. Fluid flow and heat transfer character is tics on stretching sheet with variable temperature condition have been investigated by Gurbka *et al*. [16]. Watanabe [30, 31] discussed stability of boundary layer and effect of suction/injection in MHD flow under pressure gradient. Noor [3] studied the character is tics of heat transfer on stretching sheet. Chiam [27] discussed the heat transfer in fluid flow on stretching sheet at stagnation point in presence of internal dissipation, heat source/sink and Ohmic heating. Chamka *et al*. [2] considered Hiemenz flow in the presence of magnetic field through porous media. Sharma and Mishra [23] investigated steady MHD flow through horizontal channel: lower being a stretching sheet and upper being a permeable plate bounded by porous medium. Mahapatra and Gupta [28] investigated the magnetohydrodynamic stagnation-point flow towards isothermal stretching sheet and re - ported that velocity de creases/increases with the increase in magnetic field intensity when free stream velocity is smaller/greater than the stretching velocity. Mahapatra and Gupta [29] studied heat transfer in stagnation-point flow on stretching sheet with viscous dissipation effect. Attia [10] analysed the hydromagnetic stagnation point flow on porous stretching sheet with suction and injection. Pop *et al*. [25] discussed the flow over a stretching sheet near a stag nation point taking radiation effect. Chenna Kesavaiah and Sudhakaraiah [7] studied A note on heat transfer to magnetic field oscillatory flow of a viscoelastic fluid, Ch Kesavaiah et.al [6] studied effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction.

Radiative flows are encountered in countless industrial and environment processes e.g. heating and cooling chambers, fossil fuel combustion energy process, evaporation from large open water reservoirs, astrophysical flows, solar power technology and space vehicle re – entry. The study of viscoelastic fluid has become an increasing importance during recent times. This is mainly due to its many applications in petroleum drilling, manufacturing of foods and paper and many other similar activities. The boundary layer concept of such fluids is of special importance due to its applications to many engineering problems among which we cite the possibility of reducing frictional drag on the hulls of ships and submarines. Oscillatory convection in a viscoelastic fluid through a porous layer heated from below was investigated by Rudraiah et.al. [21], later this problem was extended to magnetohydrodynamic boundary layer by Sherief and Ezzat [12]. Elastic fluid flow of magnetohydrodynamic free convection through a porous medium has been studied by Ezzat et.al [17]. Later, magnetohydrodynamic flow and heat transfer in a rectangular duct with temperature dependent viscosity and Hall effects was investigated by Sayed Ahmad et.al. [20]. Atul Kumar Singh et.al [4] studied heat and mass transfer in MHD flow of a viscous fluid past a vertical plate under oscillatory suction velocity. The problem of oscillatory convection with thermal relaxation has been investigated in more generally by Zakaria [19]. Mutucumaraswamy and Senthil Kumar [24] have studied heat and mass transfer effects on moving vertical plate in the presence of thermal radiation. For perfectly conducting viscoelastic fluid free convection effects was studied by El-Bary [1], Chenna Kesavaiah, P V Satyanarayana [8] MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, Bhavtosh Awasthi [5] Joule heating effect in presence of thermal radiation on MHD convective flow past over a vertical surface in a porous medium, Zanchini ([9] Effect of viscous dissipation on the asymptotic behavior of laminar forced convection in circular tubes

Mostly fluids which are very useful in our daily life and industry do not obey the Newtonian expression of viscosity, for examples paints, oil, lubricating greases, human blood, honey, biological fluids etc. These fluids are called non-Newtonian due to their importance in our daily life, in last few years many studies have been reported in which characteristics of non-Newtonian fluids are explored. Also, since the class of non-Newtonian fluids is diverse, so researchers were suggested different models to discus physical properties of these fluids. Takhar et.al. [11] Radiation effects on MHD free convection flow of a radiating gas past a semi-infinite vertical plate, Vajravelu and Sastry [14] Free convective heat transfer in a viscous incompressible fluid confined between a long vertical wavy wall and a parallel flat wall, Sudheer Babu and Satya Narayana [18] Effects of the chemical reaction and radiation absorption on free convection flow through porous medium with variable suction in the presence of uniform magnetic field, Verma and Mathur [22] Unsteady flow of a dusty viscous liquid through a circular tube, Sudheer Kumar et. al. [26] Radiation effect of natural convection over a vertical cylinder in porous media, Ambethkar and Singh [32] Effect of magnetic field on an Oscillatory flow of a viscoelastic fluid with thermal radiation, Bhavana and Chenna Kesavaiah [34] Perturbation solution for thermal diffusion and chemical reaction effects on MHD flow in vertical surface with heat generation.

An anticipated outcome that is intended chapter is to investigate effects of magnetic field on an oscillatory flow of a viscoelastic fluid with thermal radiation, viscous dissipation with Ohmic heating which bounded by a vertical plane surface, have been studied. Analytical solutions for the quasi – linear hyperbolic partial

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differential equations are obtained by perturbation technique. Solutions for velocity and temperature distributions are discussed for various values of physical parameters involving in the problem. The effects of cooling and heating of a viscoelastic fluid compared to the Newtonian fluid have been discussed.

FORMULATION OF THE PROBLEM

Consider a two - dimensional, unsteady free convective flow of a viscoelastic incompressible fluid which is bounded by a vertical infinite plane surface, embedded in a uniform porous medium with heat source under the action of uniform magnetic field applied normal to the direction of the flow. The effect of induced magnetic field is neglected. The magnetic Reynolds number is assumed to be small. The terms due to electrical dissipation is neglected in energy equation. We assume that the surface absorbs the fluid with a constant velocity and the velocity far away from the surface oscillates about a mean constant value with direction parallel to x' - axis. x' - axis is taken along the plane surface with direction opposite to the direction of the gravity and the y' -axis is taken to be normal to the plane surface. The heat due to viscous and joule dissipation are neglected for small velocities. All the fluid properties are assumed constant except that the influence of the density variation with temperature is considered only in the body force term. It is considered that the free stream velocity oscillates in magnitude but not in direction. Under the above stated assumptions and taking the usual Boussinesque approximation into account, the governing equations for the flow and temperature field in dimensionless form are given as under Walters [33]

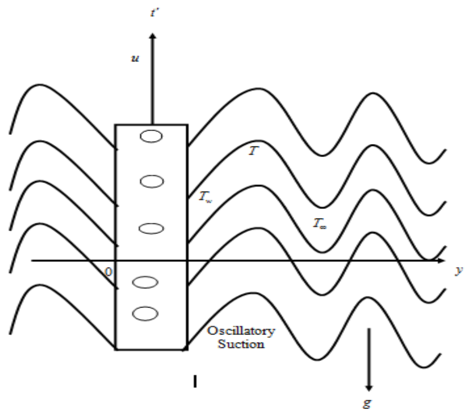

Figure (1): Physical model and geometry of the problem

$$\frac{\partial u}{\partial t}-\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-k_0\left(\frac{\partial^3 u}{\partial y^2\partial t}\right)+Gr\,T+\left(M+\frac{1}{K}\right)u \qquad (1)$$

$$\frac{\partial T}{\partial t}-\frac{\partial T}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2}-\left(\frac{\partial^2 T}{\partial t^2}-\frac{\partial^2 T}{\partial t\,\partial y}\right)+Ec\left(\frac{\partial u}{\partial y}\right)^2-\left(\frac{R}{\Pr}\right)T+EcMu^2 \qquad (2)$$

Initial condition has been neglected as the problem is in semi-infinite region. The relevant boundary conditions in dimensionless form are

$$u=-\left(1+\varepsilon e^{\mathrm{int}}\right),T=\left(1+\varepsilon e^{\mathrm{int}}\right) \quad at \quad y=0$$
$$u\to 0, T\to 0 \qquad as \quad y\to\infty \qquad (3)$$

The dimensionless quantities introduced in the above equations are defined as

$$u=\frac{u'}{v_0},y=\frac{y'v_0}{\nu},t=\frac{t'v_0^{\,2}}{\nu},\ T=\frac{T'-T_\infty'}{T_w'-T_\infty'},K=\frac{k_0v_0^{\,2}}{\nu^2},M=\frac{\sigma B_0^{\,2}\nu}{\rho v_0^{\,2}},Q=\frac{\nu Q_0}{\rho C_p v_0^{\,2}}$$
$$k_0=\frac{1}{\rho}k_0'\left(\frac{v_0^{\,2}}{\nu}\right),\quad Gr=\frac{\nu\beta g\left(T_w'-T_\infty'\right)}{v_0^{\,3}},\quad \Pr=\frac{\nu\rho C_p}{k},\quad R=\frac{16\nu^2\lambda\sigma T_\infty^3}{k\,v_0^2} \qquad (4)$$

where u is the velocity along the x' -axis, is constant obtained after integration conservation of mass in pre-non dimensional form not mentioned, v is the velocity along y' -axis, is the kinematic viscosity, g is the acceleration due to gravity, T is the temperature of the fluid, is the coefficient of volume expansion, C_p is the specific heat at constant pressure, is a constant, σ is the Stefan-Boltzmann constant, λ is the mean absorption coefficient, T_w is the temperature of the surface, is the temperature far away from the surface, $\Pr$ is the Prandtl number, Gr is the Grashof number, q_r is radiative heat flux in y direction, is the density, t is the time, k is the thermal conductivity of the fluid, n is the frequency of oscillation of the fluid and k_0 is the elastic parameter, B_0 is uniform magnetic field strength, M is the magnetic field parameter which is the ratio of magnetic force to the inertial force. It is a measure of the effect of flow on the magnetic field. Finally R is the radiation parameter. The effect of radiation parameter is to increase the rate of energy transport to the gas, thereby making the boundary layer becomes thicker and the fluid becomes warmer. Emissivity has been omitted in the expression of R, because for a black body the value of emissivity is unity. For Non non-Newtonian fluids like thick black paint the value of emissivity is 0.978.

SOLUTION OF THE PROBLEM

Equation (6) – (8) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (9). However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. This can be done by representing the velocity and temperature of the fluid in the neighbourhood of the fluid in the neighbourhood of the plate as

$$u = u_0(y) + \varepsilon e^{it} u_1(y)$$
$$T = T_0(y) + \varepsilon e^{it} T_1(y)$$

(5)

Substituting (5) in Equation (1) – (2) and equating the harmonic and non – harmonic terms, and neglecting the higher order terms of $0(\varepsilon^2)$, we obtain

$$u_0'' + u_0' - \beta^2 u_0 = -Gr\,T_0$$

(6)

$$(1 + ik_0)u_1'' + u_1' - \alpha^2 u_1 = -Gr\,T_1$$

(7)

$$T_0'' - \Pr T_0' - RT_0 = -Ec\Pr u_0'^2 - Ec\Pr M u_0^2$$

(8)

$$T_1'' - \Pr(i-1)T_1' - (i\Pr + R + \Pr)T_1 = -2\Pr Ecu_0'u_1' - 2\Pr EcMu_0u_1$$

(9)

The corresponding boundary conditions can be written as

$$u_0 = -1,\ T_0 = 1,\ T_1 = 1 \qquad at\ y = 0$$
$$u_0 \to 0, T_0 \to 0, T_1 = 0 \qquad as\ y \to \infty$$

(10)

The Equation (6) – (9) still coupled and non-linear equations whose exact solution not possible, so we expand u_0, u_1, T_0, T_1 in terms of (f_0, f_1) of Eckert number (Ec) in the following form as Eckert number is very small for incompressible flows

$$f_0 = f_{01}(y) + Ec\, f_{02}(y)$$
$$f_1 = f_{11}(y) + Ecf_{12}(y)$$

(11)

Substituting (10) in Equations (6) - (9), equating the coefficients of and neglecting the higher order terms of $O(Ec^2)$, we obtain

$$u_{01}'' + u_{01}' - \beta^2 u_{01} = -Gr\,T_{01}$$

$$u_{02}'' + u_{02}' - \beta^2 u_{02} = -Gr\,T_{02}$$

(13)

$$(1 + ik_0)u_{11}'' + u_{11}' - \alpha^2 u_{11} = -Gr\,T_{11}$$

$$(1 + ik_0)u_{12}'' + u_{12}' - \alpha^2 u_{12} = -Gr\,T_{12}$$

(15)

$$T_{01}'' - \Pr T_{01}' - RT_{01} = 0$$

(16)

$$T_{02}'' - \Pr T_{02}' - RT_{02} = -\Pr u_{01}'^2 - \Pr M u_{01}^2 \quad (17)$$

$$T_{11}'' - \Pr(i-1)T_{11}' - (i\Pr + R + \Pr)T_{11} = 0 \quad (18)$$

$$T_{12}'' - \Pr(i-1)T_{12}' - (i\Pr + R + \Pr)T_{12} = -2\Pr u_{01}' u_{11}' - 2\Pr M u_{01} u_{11} \quad (19)$$

The corresponding boundary conditions can be written as

$$\left.\begin{aligned} u_{01} &= -1, u_{02} = 0, T_{01} = 1, T_{02} = 0 \\ u_{11} &= -1, u_{12} = 0, T_{11} = 1, T_{12} = 0 \end{aligned}\right\} \quad at \; y = 0$$

$$\left.\begin{aligned} u_{01} &\to u_{02} \to 0, T_{01} \to T_{02} \to 0 \\ u_{11} &\to u_{12}, \to 0, T_{11} \to T_{12} \to 0 \end{aligned}\right\} \quad as \; y \to \infty \quad (20)$$

Solving these differential equations from (6) – (9) using boundary conditions (10) we obtain mean velocity and mean temperature as follows.

$$u_{01}(y,t) = A_1 e^{m_2 y} + A_2 e^{m_4 y}$$

$$T_{01}(y,t) = e^{m_2 y}$$

$$u_{02}(y,t) = A_{10} e^{m_2 y} + A_{11} e^{2m_4 y} + A_{12} e^{2m_2 y} + A_{13} e^{2m_2 y} + A_{14} e^{2m_4 y} + A_{15} e^{2m_2 y} + A_{16} e^{(m_2+m_4)y}$$

$$T_{02}(y,t) = A_3 e^{2m_4 y} + A_4 e^{2m_2 y} + A_5 e^{2m_2 y} + A_6 e^{2m_4 y} + A_7 e^{2m_2 y} + A_8 e^{(m_2+m_4)y}$$

In view of the above equation (11) becomes;

$$u_0(y,t) = A_1 e^{m_2 y} + A_2 e^{m_4 y} + Ec\{A_{10} e^{m_2 y} + A_{11} e^{2m_4 y} + A_{12} e^{2m_2 y} + A_{13} e^{2m_2 y} + A_{14} e^{2m_4 y} + A_{15} e^{2m_2 y} + A_{16} e^{(m_2+m_4)y}\}$$

$$T_0(y,t) = e^{m_2 y} + Ec\{A_3 e^{2m_4 y} + A_4 e^{2m_2 y} + A_5 e^{2m_2 y} + A_6 e^{2m_4 y} + A_7 e^{2m_2 y} + A_8 e^{(m_2+m_4)y}\}$$

Skin friction

$$\left(\frac{\partial u}{\partial y}\right)_{y=0} = A_1 m_2 + A_2 m_4 + Ec\{A_{10} m_2 + 2A_{11} m_4 + 2A_{12} m_2 + 2A_{13} m_2 + 2A_{14} m_4 + 2A_{15} m_2 + 2A_{16}(m_2 + m_4)\}$$

Rate of heat transfer

$$\left(\frac{\partial T}{\partial y}\right)_{y=0} = m_2 + Ec\{2A_3 m_4 + 2A_4 m_2 + 2A_5 m_2 + 2A_6 m_4 + 2A_7 m_2 + (m_2 + m_4) A_8\}$$

APPENDIX

$$m_2 = -\left(\frac{\Pr + \sqrt{\Pr^2 + 4R}}{2}\right),$$

$$m_8 = -\left(\frac{1 + \sqrt{1 + 4\beta^2}}{2}\right), \beta^2 = \left(M + \frac{1}{K}\right)$$

$$\alpha^2 = \left(i + M + \frac{1}{K}\right), A_1 = -\frac{Gr}{m_2^2 + m_2 - \beta^2},$$

$$A_2 = -(1 + A_1)$$

$$A_3 = -\frac{\Pr m_4^2 A_2^2}{4m_4^2 + 2\Pr m_4 - R},$$

$$A_4 = -\frac{\Pr m_2^2 A_1^2}{4m_2^2 + 2\Pr m_2 - R},$$

$$A_5 = -\frac{2\Pr A_1 A_2}{(m_2 + m_4)^2 + \Pr(m_2 + m_4) - R}$$

$$A_6 = -\frac{\Pr A_2^2}{4m_4^2 + 2\Pr m_4 - R},$$

$$A_7 = -\frac{\Pr A_1^2}{4m_2^2 + 2\Pr m_2 - R},$$

$$A_8 = -\frac{2\Pr A_1 A_2}{(m_2 + m_4)^2 + \Pr(m_2 + m_4) - R}$$

$$A_9 = -(A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8)$$

$$A_{10} = -\frac{GrA_9}{m_6^2 + m_6 - \beta^2}, \; A_{11} = -\frac{GrA_3}{4m_4^2 + 2m_4 - \beta^2},$$

$$A_{12} = -\frac{GrA_4}{4m_2^2 + 2m_2 - \beta^2}, \; A_{13} = -\frac{GrA_5}{4m_2^2 + 2m_2 - \beta^2}$$

$$A_{14} = -\frac{GrA_6}{4m_4^2 + 2m_4 - \beta^2}, \; A_{15} = -\frac{GrA_7}{4m_2^2 + 2m_2 - \beta^2},$$

$$A_{16} = -\frac{GrA_8}{(m_2 + m_4)^2 + (m_2 + m_4) - \beta^2}$$

$$A_{17} = -(A_{10} + A_{11} + A_{12} + A_{13} + A_{14} + A_{15} + A_{16})$$

RESULTS AND DISCUSSION

In order to get clear insight into the problem, numerical computations are carried out for various parameters like Grashof number (Gr), Permeability of the porous medium (K), Radiation parameter (R), Heat source parameter (Q), Prandtl number $(\Pr)$ and Magnetic field parameter (M) are displayed .The numerical values of mean temperature has been obtained for different parameters like R, Q and $\Pr$ as taken in the governing equation (2) . Similarly the numerical values of mean velocity have been obtained for different parameters like $Gr, K, R, Q, \Pr$ and M as taken in the governing equation (1). Plotting the mean velocity profiles, mean temperature profiles, skin friction and Nusselt number are pictorially has been showed from figures (2) - (15). It can be seen that the Prandtl number $(\Pr = 0.71)$ has been taken because this value corresponds to water which is known to be the Newtonian fluid. Free convection currents exist because of the temperature difference $(T_p - T_\infty)$ which may be positive, zero or negative. We know that the Grashof number (Gr) is a common dimensionless group that is used when analyzing the potential effect of convection introduced by large temperature differences. So Grashof number *will* assume positive. From the physical point of view, $Gr < 0$ corresponds to an externally heated plate as free convection currents are carried towards the plate. $Gr > 0$ Corresponds to an externally cooled plate and $Gr = 0$ corresponds to the absence of free convection currents. In this investigation we were taken $Gr > 0$ which corresponds to externally cooled plate. The effect of cooling on the velocity for the Grashof number (Gr) can be observed from figure (2) respectively, we observe from this figure that an increase Grashof number the mean velocity profiles increase in cases of cooling for a viscoelastic fluid. The influence of magnetic parameter (M) is presented graphically in figure (3). As expected, the mean velocity decreases with increasing magnetic parameter. The effect of the transverse magnetic field leads to a resistive type of force similar to drag force, which tends to resist the retarding flow of viscoelastic fluid flow. The effect of thermal radiation parameter is important for temperature profiles. Figure (4) represents the velocity profiles for different permeability parameter. Permeability is the measure of the materials ability to permit liquid or gas through its pores or voids. Filters made of soil and earth dams are very much based upon the permeability of a saturated soil under load. Permeability is part of the proportionality constant in Darcy's law. Darcy's law relates the flow rate and fluid properties to the pressure gradient applied to the porous medium. Hence for an increase in the permeability of the porous medium the velocity boundary layer increases. Thus the velocity profile is highly influenced by the enhancement of permeability. Eckert number expresses the relation between kinetic energy and the enthalpy. The viscous dissipation is characterized by Eckert number. Viscous dissipation plays an important role in the thermal transport of the fluid. Figure (5) illustrates the effect of viscous dissipation. It is revealed from the figure that viscous dissipation gradually reduces the velocity boundary layer with increasing values of Eckert number. Figure (6) displays the effect of Prandtl number $(\Pr)$ on velocity distribution. It is noticed that the velocity increases with increasing values of Prandtl number. Figure (7) illustrates the effects of the radiation parameter (R). It is observed from this figure that velocity goes on increasing with the increase of radiation parameter. Figure (8) is obtained by plotting the temperature distribution against variable y for different values of Eckert number (Ec). From this graph; it is clear that the temperature distribution increases with increase in the value of the Eckert number. Physically, this behaviour is observed because in the presence of viscous dissipation, heat energy is stored in the fluid and there is significant more generation of heat along the surface. Also, it is evident from this figure that the effect of viscous dissipation parameter is to enhance the thermal boundary layer thickness. Figure (9) elucidates that the fluid temperature enhance with an increase in the porous parameter (K). Figure (10) represents the temperature profiles for Prandtl number (Pr) respectively. In this figure the size of the thermal boundary layer decrease with increasing values of Prandtl number. Prandtl number being the ratio of momentum diffusivity to the thermal diffusivity, together with Ohmic heating induces the temperature. Hence, there is a decrease in the thermal boundary layer. The temperature distribution for different values of Grashof number (Gr) observed in figure (11); it is clear that an increases in Grashof number the results were decreases. Figure (12) depicts the temperature profiles that increase in radiation parameter (R) decreases the thermal boundary layer. The increasing value of radiation corresponds to an increased dominance of conduction. This radiation parameter along with Eckert number and magnetic field enhance the thermal boundary layer thickness. Also, it is observed that the magnetic parameter (M) effect due to the effects on electromagnetic work is found to produce an increase in the fluid temperature and thus a decrease in the surface temperature gradient as shown in figure (13). Further, it is found that the effect of viscous heating leads to an increase in the temperature; this effect is more pronounced in the presence of magnetic field. Figure (14) demonstrates the effect of radiation parameter (R) on skin friction. It shows that the skin friction reduces with raising values of radiation parameter. Figure (15) shows that the effect of radiation parameter (R) on Nusselt number. It is examined that the Nusselt number decreases with the increases in radiation parameter.

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FIGURES:

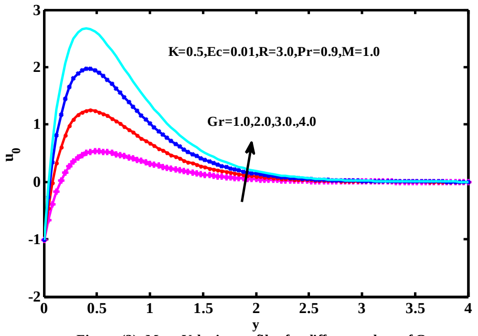

Figure (2): Mean Velocity profiles for different values of Gr

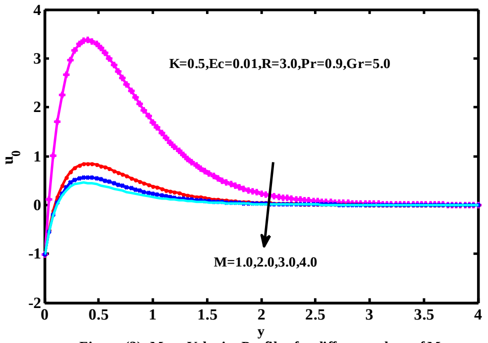

Figure (3): Mean Velocity Profiles for different values of M

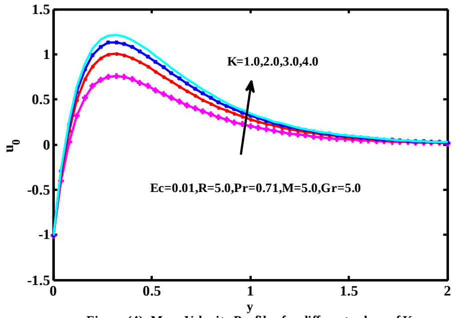

Figure (4): Mean Velocity Profiles for different values of K

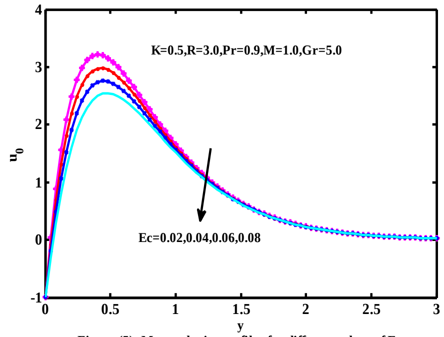

Figure (5): Mean velocity profiles for different values of Ec

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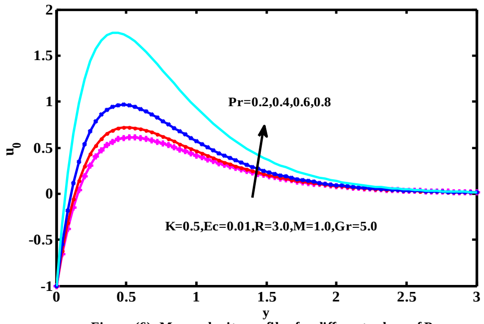

Figure (6): Mean velocity profiles for different values of Pr

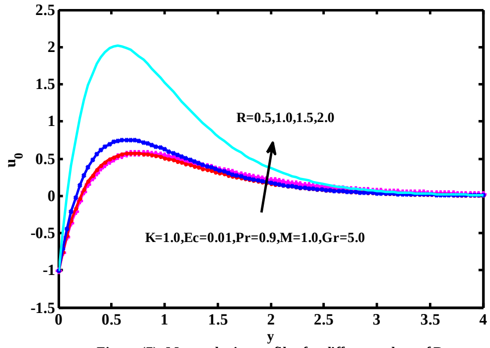

Figure (7): Mean velocity profiles for different values of R

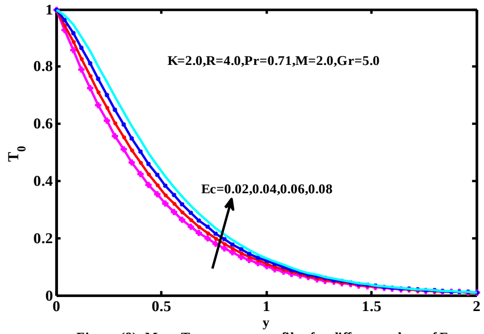

Figure (8): Mean Temperature profiles for different values of Ec

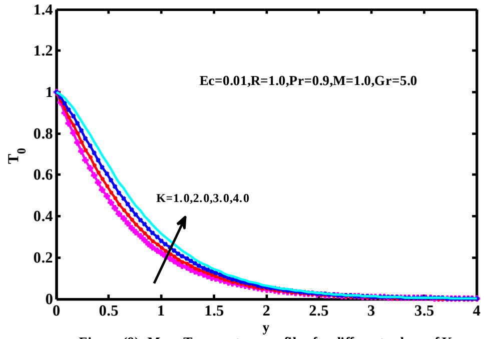

Figure (9): Mean Temperature profiles for different values of K

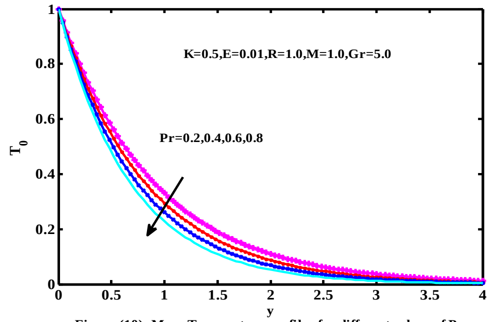

Figure (10): Mean Temperature profiles for different values of Pr

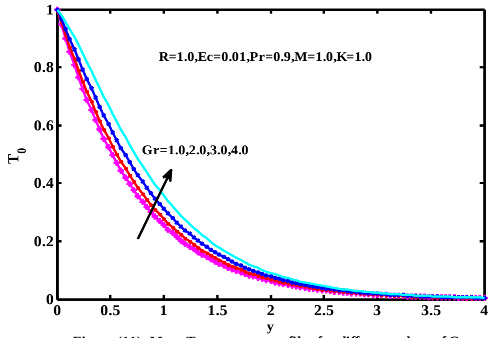

Figure (11): Mean Temperature profiles for different values of Gr

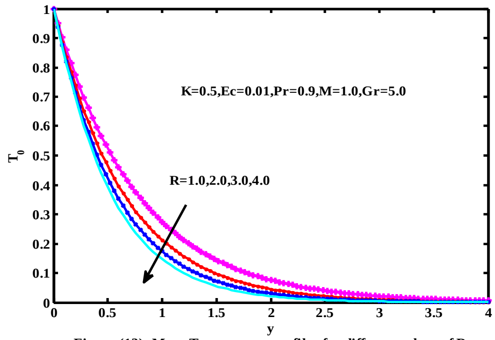

Figure (12): Mean Temperature profiles for different values of R

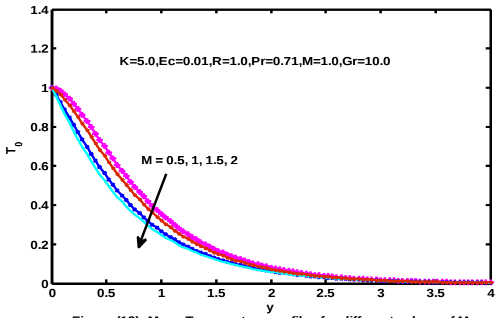

Figure (13): Mean Temperature profiles for different values of M

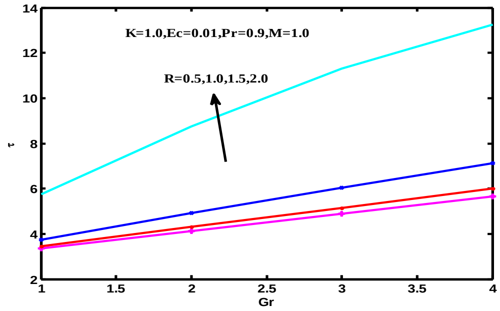

Figure (14): Skin friction for different values of R

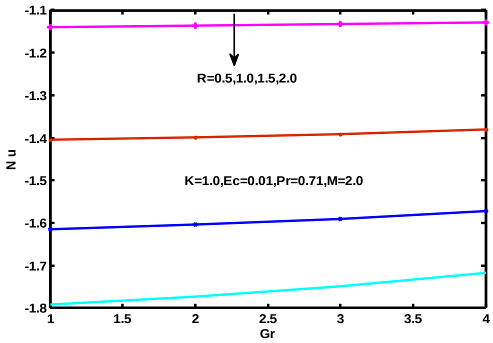

Figure (15): Nusselt number for different values of R

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