# MHD Unsteady Radiating Memory Convective Flow with Variable Suction

**S.A.Hussaini, M.V. Ramana Murthy, Rafiuddin and S. Harisingh Naik**

***Abstract*— A free convective unsteady visco-elastic radiating flow through porous medium of variable permeability bounded by an infinite vertical porous plate with variable suction, constant heat flux under the influence of transverse uniform magnetic field has been investigated in the present study by using perturbation technique. The permeability of porous medium fluctuates with time about the constant mean. Approximate solutions for mean velocity, transient velocity, mean temperature and transient temperature of non-Newtonian flow and skin friction are obtained. The effects of various parameters such as N (Radiation parameter), $P_r$ (Prandtl number), $G_r$ (Grashoff number), M (Hartmann number), ω (Frequency parameter) and $k_0$ (Mean permeability parameter) on the above are depicted, skin friction in terms of amplitude and phase are shown graphically and discussed. Expressions for fluctuating parts of velocity '$M_r$' and '$M_i$' are obtained and plotted graphically, effects of different parameters on them are discussed.**

***Index Terms*— Free convection, Walter's liquid 'B', Variable permeability, Rosseland's approximation and Variable suction.**

## I. INTRODUCTION

The magneto hydrodynamic (MHD) thermal boundary layer flow over a moving plate has attracted considerable attention during the last few decades due to its numerous applications in industrial manufacturing processes such as hot rolling, wire drawing, glass-fiber and paper production, drawing of plastic films, metal and polymer extrusion, and metal spinning. Also magneto hydrodynamics (MHD) boundary layer flow of an electrically conducting fluid through porous/nonporous medium has gained considerable importance in the field of astrophysics, geophysics and engineering. Raptis and Perdikis [11] studied the unsteady natural convection flow of a viscous and incompressible fluid through a porous medium with high porosity bounded by a vertical infinite stationary plate in the presence of radiation. Sharma et al. [14] studied MHD fluctuating free convective flow with radiation embedded in porous medium having variable permeability and heat source / sink. Singh and Kumar [15] have studied the fluctuating heat and mass transfer on unsteady MHD free convection flow of radiating and reacting fluid past a vertical porous plate in slip-flow regime. Hayat and Alsaedi [5] investigated heat and mass transfer effects in the MHD flow of an Oldroyd-B fluid in a porous space. Zhu et al. [20] work focuses on the steady boundary layer flow and heat transfer near the forward stagnation point of plane and axis symmetric sheet towards a stretching sheet with velocity slip and temperature jump. Pal and Talukdar [10] presented the analytical study of unsteady hydro magnetic heat and mass transfer for a micro polar fluid bounded by semi-infinite vertical permeable plate in the presence of first-order chemical reaction, thermal radiation and heat absorption. Nandkeolyar et al. [9] have analyzed the effect of radiation on heat transfer in unsteady MHD natural convection flow of a dusty fluid past an impulsively moving vertical plate. Seini and Makinde [13] studied the radiation effects on the combined heat and mass transfer in MHD flow over an exponentially stretching surface. An analysis is presented by Cortell [3] for the steady non-linear viscous flow of an incompressible viscous fluid over a horizontal surface of variable temperature with a power-law velocity under the influences of suction/blowing, viscous dissipation and thermal radiation. The influence of partial slip, thermal radiation and temperature dependent fluid properties on the hydro magnetic fluid flow and heat transfer over a flat plate with convective surface heat flux at the boundary and non-uniform heat source/sink is studied by Das [4]. Mukhopadhyay et al. [7] given a mathematical model for analyzing the boundary layer forced convective flow and heat transfer of an incompressible fluid past a plate embedded in a Darcy-Forchheimer porous medium. Thermal radiation term is considered in the energy equation. An analysis is carried out to study the steady two-dimensional stagnation-point flow and heat transfer of an incompressible viscous fluid over a porous shrinking sheet in the presence of thermal radiation Mahapatra and Nandy [8].

The aim of the authors is to extend the problem of Hussaini et al. [6] to radiating memory fluid with variable suction. The mixture of polymethylmeha crylate and pyridine at $25^0$ C containing 30.5g of polymer per liter behaves very nearly Walter's liquid model B′ [18, 19].

## II. FORMULATION OF PROBLEM

We consider the flow of convective memory fluid through a porous medium bounded by an infinite vertical porous plate with constant heat flux under the influence of uniform transverse magnetic field. The x - axis is taken along the plate in the upward direction and y - axis normal to it. All the fluid properties are assumed to be constant, except that influence of the density variations with temperature is considered only in the body force term. The magnetic field of small intensity $H_0$ is induced in the y - direction. Since the fluid is slightly conducting, the magnetic Reynolds number is far lesser than unity hence the induced magnetic field is neglected in comparison with the applied magnetic field following Sparrow and Cess [17]. The viscous dissipation and Darcy's

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dissipation terms are neglected for small velocities following Rudraiah et al. [12]. The flow in the medium is entirely due to buoyancy force. So under these conditions the flow with variable suction is governed by the following equations:

$$v = -v_0\left(1+\varepsilon e^{i\omega t}\right) \quad (1)$$

$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} = g\beta_1(T-T_\infty) + \vartheta\frac{\partial^2 u}{\partial y^2} - \frac{vu}{k(t)} - \beta\left(\frac{\partial^3 u}{\partial t\partial y^2} + v\frac{\partial^3 u}{\partial y^3}\right) - \left(\frac{\sigma\mu e^2 H_0^2}{\rho}\right)u \quad (2)$$

$$\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho C_p}\left(\frac{\partial q_r}{\partial y}\right) \quad (3)$$

Where $q_r = \frac{-4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y}$ (4)

The radiative heat flux term by using the Rosseland approximation (Brewster [2]).

The boundary conditions are:

$$y = 0: \quad u = 0, \quad \frac{\partial T}{\partial y} = \frac{-q}{\kappa}$$

$$y \to \infty: \quad u = 0, \quad T = T_\infty \quad (5)$$

we assume that the temperature differences within the flow are sufficiently small such that $T^4$ may be expressed as a linear function of the temperature. This was accomplished by expanding $T^4$ in a Taylor series about $T_\infty$ and neglecting higher-order terms. Thus,

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \quad (6)$$

Using (4) and (6) in (3) gives

$$\frac{\partial T}{\partial t} - v_0\frac{\partial T}{\partial y} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{\vartheta}{C_p}\left(\frac{\partial u}{\partial y}\right)^2 + \frac{1}{\rho C_p}\left(\frac{16\sigma^* T_\infty^3}{3\kappa k^*}\right)\frac{\partial^2 T}{\partial y^2} \quad (7)$$

The permeability of porous medium which is assumed to be of the form following Singh et al. [16] and

$$k(t) = k_0\left(1+\varepsilon e^{i\omega t}\right) \quad (8)$$

is a variable permeability.

## III. METHOD OF SOLUTION

Introducing the following non-dimensional quantities:

$$\bar{y} = \frac{y v_0}{\vartheta}, \bar{t} = \frac{t\, v_0^2}{4\vartheta}, \bar{\omega} = \frac{4\vartheta\omega}{v_0^2}, \bar{u} = \frac{u}{v_0}$$

$$G_r = \frac{g\beta_1 q\vartheta^2}{k v_0^4}, P_r = \frac{\mu C_p}{\kappa}, R_m = \frac{\beta v_0^2}{\vartheta^2},$$

$$\overline{k_0} = \frac{k_0 v_0^2}{\vartheta^2}, \qquad N = \frac{16\sigma^* T_\infty^3}{3\kappa k^*},$$

$$M = \frac{\sigma\mu e^2 H_0^2\vartheta}{v_0^2\rho}, \qquad \theta = \frac{(T-T_\infty)\kappa v_0}{q\vartheta} \quad (9)$$

The Eq. (2) and Eq. (3) in view of Eq.(8) and Eq. (9) become after suppressing bars,

$$\left(\frac{1}{4}\right)\frac{\partial u}{\partial t} - \left(1+\varepsilon e^{i\omega t}\right)\frac{\partial u}{\partial y} = G_r\theta + \frac{\partial^2 u}{\partial y^2} - R_m\left[\left(\frac{1}{4}\right)\frac{\partial^3 u}{\partial t\partial y^2} - \left(1+\varepsilon e^{i\omega t}\right)\frac{\partial^3 u}{\partial y^3}\right] - \frac{u}{k_0}\left(1+\varepsilon e^{i\omega t}\right) - Mu \quad (10)$$

$$\left(\frac{1}{4}\right)\frac{\partial \theta}{\partial t} - \left(1+\varepsilon e^{i\omega t}\right)\frac{\partial \theta}{\partial y} = \left(\frac{1}{f}\right)\frac{\partial^2 \theta}{\partial y^2} \quad (11)$$

The corresponding boundary conditions are:

$$y = 0: \ u = 0, \ \frac{\partial \theta}{\partial y} = -1$$

$$y \to \infty: \ u = 0, \theta = 0 \quad (12)$$

If $\varepsilon$ is small, we obtain solutions using pertubation technique considering $\varepsilon$ very small, we look for sloutions of (10) and (11) in the form.

$$(u,\theta) = (u_0,\theta_0) + \varepsilon\,(u_1,\theta_1) + \cdots \quad (13)$$

Where $u_0$ and $\theta_0$ are solutions for the case $\varepsilon$ equals zero, $u_1$ *and* $\theta_1$ are perturbed quantities relating to $u_0$ and $\theta_0$ substituting Eq. (13) in Eq. (10) and Eq. (11) and equating the coefficients of like powers of ε to zero, we get



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Zero order

$$R_m u_0''' + u_0'' + u_0' - \left(\frac{1}{k_0} + M\right) u_0 = -G_r \theta_0 \quad (14)$$

$$\frac{(1+N)\theta_0''}{P_r} + \theta_0' = 0 \quad (15)$$

First order

$$R_m u_1''' + \left[\left(1 - \frac{iR_m\omega}{4}\right) u_1'' + u_1' - \left(\frac{i\omega}{4} + \frac{1}{k_0} + M\right)\right] u_1' = -G_r\theta_1 - \frac{u_0}{k_0} - u_0' - R_m u_0''' \quad (16)$$

$$\frac{(1+N)\theta_1''}{P_r} + \theta_1' - \frac{i\omega\theta_1}{4} = -\theta_0' \quad (17)$$

Where primes denotes derivatives with respect to y

The corresponding boundary conditions are:

$$y = 0{:}\ u_0 = 0,\ \ u_1 = 0,\ \theta_0' = -1,\ \theta_1' = 0$$

$$y \to \infty{:}\ u_0 = 0, u_1 = 0,\ \theta_0 = 0,\ \theta_1 = 0 \quad (18)$$

Equation (14) and Eq. (16) are third order differential equations when $R_m \neq 0$ and we have two boundary conditions, so we follow Beard and Walter's rule [1],

$$u_0 = u_{01} + R_m u_{02} + O(R_m^2) \quad (19)$$

$$u_1 = u_{11} + R_m u_{12} + O(R_m^2) \quad (20)$$

Substituting these Eq.(19) and Eq.(20) into Eq. (14), equating different powers of $R_m$ and neglecting $O(R_m^2)$, we get

$$u_{01}'' + u_{01}' - \left(\frac{1}{k_0} + M\right) u_{01} = -G_r\theta_0 \quad (21)$$

$$u_{11}'' + u_{11}' - \left(\frac{i\omega}{4} + \frac{1}{k_0} + M\right) u_{11} = \frac{-u_{01}}{k_0} - u_{01}' - G_r\theta_1 \quad (22)$$

$$u_{01}''' + u_{02}'' + u_{02} - \left(\frac{1}{k_0} + M\right) u_{02} = 0 \quad (23)$$

$$u_{11}''' - \frac{i\omega}{4} u_{11}'' + u_{12}'' + u_{12}' - \left(\frac{i\omega}{4} + \frac{1}{k_0} + M\right) u_{12} = \frac{-u_{02}}{k_0} - u_{02}' - u_{01}''' \quad (24)$$

The boundary conditions are:

$$y = 0{:}\ u_{01} = u_{02} = u_{11} = u_{12} = 0$$

$$y \to \infty{:}\ u_{01} = u_{02} = u_{11} = u_{12} = 0 \quad (25)$$

The velocity and temperature fields are given by

$$u = u_0 + \varepsilon u_1 = u_{01} + R_m u_{02} + \varepsilon(u_{11} + R_m u_{12}) \quad (26)$$

$$\theta = \theta_0 + \varepsilon\theta_1 \quad (27)$$

Taking real part of solution for the velocity field and temperature field they can be expressed in terms of fluctuating part as

$$u(y,t) = u_0(y) + \varepsilon(M_r cos\omega t - M_i sin\omega t) \quad (28)$$

$$\theta = \theta_0(y) + \varepsilon(N_r cos\omega t - N_i sin\omega t) \quad (29)$$

Where

$$M_r + iM_i = u_1(y) \quad (30)$$

$$N_r + iN_i = \theta_1(y) \quad (31)$$

The expressions of transient velocity and transient temperature for $\omega t = \pi/2$ are given by

$$u\left(y, \frac{\pi}{2\omega}\right) = u_0(y) - \varepsilon M_i \quad (32)$$

$$\theta\left(y, \frac{\pi}{2\omega}\right) = \theta_0(y) - \varepsilon N_i \quad (33)$$

$$u_0(y) = -l_1(e^{-fy} - e^{-my}) + R_m[l^2 f^4(e^{-fy} - e^{-my}) + l_1 m_1 y e^{-my}] \quad (34)$$

$$M_i = e^{-cy}[H_2 + R_m(D_2 + H_8)]cosdy - e^{-cy}[H_1 + R_m(D_1 + H_3)]sindy + e^{-ay}[4fG_1A_1 + R_m H_6]cosby - e^{-ay}[4fG_1B_1 + R_m H_5]sinby + [R_m D_4 - 4l_2 m_0]e^{-my} + [4G_r N_4 - 64fG_1N_1 + R_m D_6]e^{-fy} - yD_3e^{-my} \quad (35)$$

$$\theta_0(y) = \frac{1}{f}e^{-fy} \quad (36)$$



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$$N_i = \frac{4}{\omega}[\bar{a}fe^{-ay}(bsinby - acosby) + e^{-fy}] \quad (37)$$

$$\begin{aligned} M_r &= e^{-cy}[H_1 + R_m(D_1 + H_7)]cosdy + e^{-cy}[H_2 + R_m(D_2 + H_8)]sindy \\ &+ e^{-ay}[4fG_1A_1 + R_mH_6]sinby + e^{-ay}[4fG_1B_1 + R_mH_5]cosby \\ &+ 16e^{-fy}[G_rN_3 + G_rN_2f^2] + D_5e^{-fy} + D_0e^{-my} \end{aligned} \quad (38)$$

$$N_r = -[\bar{a}f(bcosby + asinby)]\frac{4}{\omega} \quad (39)$$

The skin friction at the plate in terms of amplitude and phase is:

$$C_f = \frac{T_\omega}{\rho v_0^2} = \left(\frac{\partial u}{\partial y}\right)_{y=o} = (m - f)[G_rl_1 + G_r^2l_1^2f^4R_m] + R_mG_rl_1m_1 + \varepsilon|\lambda|cos(\omega t + \alpha) \quad (40)$$

Where

$$f = \frac{P_r}{1 + N} \quad (41)$$

$$|\lambda| = \sqrt{\lambda_r^2 + \lambda_i^2} \quad (42)$$

$$\begin{aligned} \lambda_r &= dH_2 - cH_1 + 4fG_r(bA_1 - aB_1) - 16fG_r(N_3 + f^2N_2) \\ &+ R_m[d(D_2 + H_8) - c(D_1 + H_7) - (fD_5 + mD_0) + (bH_6 - aH_5)] \end{aligned} \quad (43)$$

$$\begin{aligned} \lambda_i &= -(cH_2 + dH_1) - 4fG_r(aA_1 + bB_1) + 4ml_2m_0 - 4f(G_rN_4 - 16fG_1L_1) \\ &+ R_m[-c(D_2 + H_8) - d(H_1 + H_3) - (fD_6 + mD_4 + D_3) - (aH_6 + bH_5)] \end{aligned} \quad (44)$$

$$\alpha = tan^{-1}\frac{\lambda_i}{\lambda_r} \quad (45)$$

The symbols used here are as follows:

$$\theta = tan^{-1}\left(\frac{\omega}{f}\right),\ r = \sqrt{(f^4 + f^2\omega^2)},$$

$$a = \frac{1}{2}\left[f + \sqrt{r}\,cos\frac{\theta}{2}\right],\ b = \frac{1}{2}\sqrt{r}\,sin\frac{\theta}{2}\ ,$$

$$\bar{a} = \frac{1}{a^2+b^2}, M_1 = \left[M + \frac{1}{k_0}\right], l_1 = \frac{G_r}{f(f^2-f-M_1)},$$

$$m = \frac{1}{2}\left[1 + \sqrt{(1 + 4M_1)}\right], m_1 = \frac{m^3}{1-2m}\ ,$$

$$\phi = tan^{-1}\left(\frac{\omega}{1+4M_1}\right),\ R = \sqrt{[(1 + 4M_1)^2 + \omega^2]}\ ,$$

$$c = \frac{1}{2}\left(1 + \sqrt{R}\,cos\frac{\phi}{2}\right),\ d = \sqrt{R}\,sin\frac{\phi}{2},$$

$$N_1 = \frac{1}{k_0} - f\ , m_0 = \frac{1}{k_0} - m\ ,$$

$$a_1 = a^2 - a - m_1 - b^2,\ b_1 = 2ab - b - \frac{\omega}{4}\ ,$$

$$a_0 = \frac{1}{a_1^2+b_1^2},\ A = aa_1 - bb_1\ ,\ B = ba_1 + ab_1\ ,$$

$$A_0 = \frac{1}{A^2+B^2},\ A_1 = A_0A\ ,\ B_1 = A_0B\ ,\ l_2 = \frac{l_1}{\omega},$$

$$G_1 = \frac{G_r}{\omega},\ L_1 = f(f^2 - f - M_1)\ ,$$

$$N_2 = \frac{1}{16L_1^2+\omega^2f^2},\ N_3 = fN_1N_2\ ,\ N_4 = l_1\omega fN_3\ ,$$

$$H_1 = -4[G_1B_1f + 4G_rN_2f^2 + 4N_3G_r]\ ,$$

$$H_2 = 4[16G_1L_1f + l_2m_0 - N_4G_r - G_1A_1]\ ,$$

$$A_2 = a_1a_2 + b_1b_2, B_2 = a_1b_2 - a_2b_1\ ,$$

$$H_3 = A_1A_2 + B_1B_2\ ,\ H_4 = A_1B_2 - A_2B_1\ ,$$

$$l_3 = 1 + f\,l_1\left(f - \frac{1}{k_0}\right),$$

$$l_4 = -m^3 + l_1f^4\left(m + \frac{1}{k_0}\right) + m_1\ ,$$

$$l_0 = \frac{16m^3}{m_1\omega^2}\left[l_1m_1m - \frac{1}{k_0}\right],$$

$$c_1 = c^2 - c - M_1 - d^2\ ,\ d_1 = 2cd - d - \omega/4\ ,$$

$$c_0 = \frac{1}{c_1^2+d_1^2},\ c_2 = c(c^2 - d^2) - 2cd(\omega + d)\ ,$$



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$$d_2 = (c^2 - d^2)(d + \omega/4) + 2c^2 d \,,$$

$$a_2 = a(a^2 - b^2) - 2ab(\omega + b)\,,$$

$$b_2 = (a^2 - b^2)(b + \omega) + 2a^2 b\,,$$

$$c_3 = c_0(c_1 c_2 + d_1 d_2)\,,\ d_3 = c_0(d_1 c_2 + c_1 d_2)\,,$$

$$H_7 = H_1 c_3 - H_2 d_3\,,\ H_8 = H_2 c_3 + H_1 d_3\,,$$

$$H_5 = 4fG_1 a_0 H_4\,,\ H_6 = 4fG_1 a_0 H_3\,,$$

$$L_2 = 16L_1^2 - f^2\omega^2\,,\ w_1 = 8fL_1\omega\,,$$

$$w_2 = l_1 G_r N_1 \omega/4 - 4fG_r N_1\,,$$

$$w_3 = L_2 G_r (L_1 f + 1) - w_1 w_2\,,$$

$$w_4 = w_1(L_1 f + G_r) + L_2 w_2\,,\ w_5 = 16f^4 N_2^2 w_3\,,$$

$$w_6 = 16f^4 N_2^2 w_4\,,\ l_5 = 16f^4 N_2 l_3,$$

$$l_6 = 4l_1 l_3 f^5 N_2\,\omega\,,\ M_0 = \frac{16 l_2 m_0 m^3}{\omega}\,,$$

$$D_1 = l_5 - (H_5 + H_7 + w_5 + M_0 + l_0)\,,$$

$$D_2 = l_6 + \frac{4l_1 l_4}{\omega} - \left(H_6 + H_8 + w_6 + \frac{4\omega M_0}{m}\right),$$

$$D_5 = w_5 - l_5\,,\ D_6 = w_6 - l_6\,,\ D_0 = M_0 + l_0\,,$$

$$D_4 = 4\left[\frac{\omega M_0}{m} - \frac{l_1 l_4}{\omega}\right],\ D_3 = \frac{4l_1 m_1}{\omega}\left(m - \frac{1}{k_0}\right)$$

## IV. DISCUSSION AND CONCLUSIONS

- Mean and Transient velocities are shown graphically in Figures 1 & 2.
- Mean and Transient temperature profiles are plotted in Figures 3 & 4.
- Fluctuating parts Mr & $M_i$ i.e real & imaginary parts are depicted in Figures 5 & 6.
- Amplitude and Phase are referring in Figures 7 & 8.
- In every table underlined bold data is for a standard curve.

The (Radiation parameter) N is directly proportional to heat radiation $\sigma^*$ so, the rise in mean velocity, transient velocity, mean temperature and transient temperature is attributed to higher values of radiation parameter from Eq (9). The (thermal Grashoff number) $G_r$ signifies the relative effect of the thermal buoyancy to the viscous hydrodynamic force, so the rise in mean velocity is due to enhancement of thermal buoyancy force. In the neighborhood of plate sharp rise is noted then gradually diminishing. From Eq. (6), we see that mean permeability parameter is in direct proportion to mean permeability enhancement of mean velocity is attributed to higher values of mean permeability parameter. (Prandtle number) $P_r$ defined by the relative ratio of kinematic viscosity to thermal diffusivity viscous forces tend to slow down the velocity so reduction of mean velocity and transient velocity is due to increase in Prandtle number value. Application of transverse magnetic field gives rise to Lorentz force, which is resistive typed force analogous to drag force, higher values of magnetic field suppresses mean velocity. Transient velocity profiles are influenced by mean velocity and fluctuating part $M_i$ as it contains both in its expressions. Transitive velocities are negative buoyancy force, Lorentz force and viscous force are likely to suppress the transient velocity profiles whereas higher values of mean permeability parameter $k_0$ and frequency parameter ω are influencing the same. The dominant viscous forces diminish the degree of hotness so the effect of Prandtle number is to subside with the temperature distribution in thermal boundary layer. Fluctuating parts namely $M_r$ is positive and $M_i$ is negative, Lorentz force, heat radiation and permeability tend to influence fluctuating parts $M_r$ and Mi whereas buoyancy force enhances $M_r$ and reduces $M_i$ Frequency parameter decreases $M_r$ and increases $M_i$ permeability parameter and frequency parameter have same effect on $M_r$ & $M_i$ .

As expected amplitude is positive buoyancy force, Lorentz force and kinematic viscous force are directly related to increasing amplitude, the more heat radiation the less is amplitude. The phase is positive and the effects of $P_r$ and M are to influence the phase that means there is a phase lead, the more heat radiation the less phase i.e. there is phase lag.

## V. NOMENCLATURE

| | |
|---|---|
| $u$ | Velocity along x-axis |
| $\bar{u}$ | Dimensionless velocity |
| $v$ | Velocity along y-axis |
| $H_0$ | Magnetic field strength |
| $C_p$ | Specific heat at constant pressure |
| $g$ | Acceleration due to gravity |
| $G_r$ | Grashoff number |
| $M$ | Hartmann number |
| $P_r$ | Prandle number |
| $k_0$ | Mean permeablility |
| $\overline{k_0}$ | Dimensionless permeability |
| $k^*$ | Stephen Boltzman constant |
| $N$ | Radiation parameter |
| $q$ | Heat flux |
| $q_r$ | Heat radiation |
| $R_m$ | Magnetic Reylond's number |
| $T$ | Temperature in vicinity of plate |
| $T_w$ | Temperature of the plate |
| $T_\infty$ | Temperature far away from plate |
| $t$ | Time |
| $\bar{t}$ | Dimensionless time |
| $M_r$ | Real part of fluctuating parts |
| $M_i$ | Imaginary part of fluctuating parts |
| $N_r$ | Real part of fluctuating temperature |
| $N_i$ | Imaginary part of fluctuating temperature |



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$v_0$ Suction velocity
$x$ Coordinate along the plate
$\bar{x}$ Dimensionless coordinate along the plate
$y$ Coordinate normal to the plate
$\bar{y}$ Dimensionless coordinate normal to the plate

**Greek Letters**

$\alpha$ Phase angle
$\beta$ Kinematic visco elasticity
$\beta_1$ Coefficient of volume expansion
$\theta$ Dimensionless temperature
$\mathrm{K}$ Thermal conductivity
$\mu$ Dynamic viscosity
$\mu_e$ Magnetic permeability
$\vartheta$ Kinematic viscosity
$\rho$ Density
$\sigma$ Electrical conductivity
$\sigma^*$ Heat radiation
$\omega$ Frequency
$\bar{\omega}$ Dimensionless frequency parameter
$\lambda$ Amplitude
$\lambda_r$ Real part of amplitude
$\lambda_i$ Imaginary part of amplitude

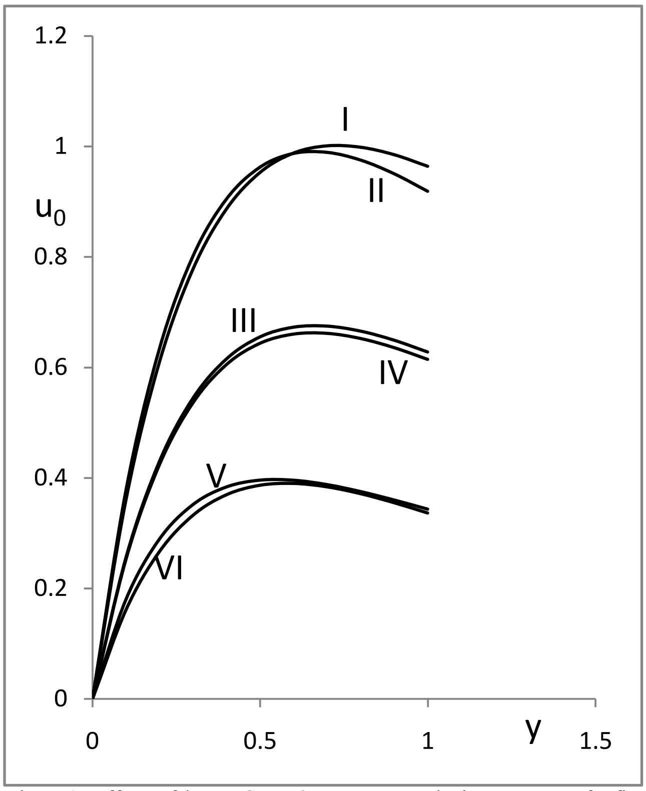


Figure 1: Effects of $k_o$, M, $G_r$, $P_r$ & N on Mean velocity $u_o$ versus y for fixed R = 0.05

| Figure 1 | $P_r$ | M | $G_r$ | $k_0$ | N |
|---|---|---|---|---|---|
| I | 0.71 | 5 | 4 | 3 | 0.6 |
| II | 0.71 | 5 | 6 | 3 | 0.2 |
| III | 0.71 | 5 | 4 | 5 | 0.2 |
| **IV** | **0.71** | **5** | **4** | **3** | **0.2** |
| V | 0.71 | 10 | 4 | 3 | 0.2 |
| VI | 1 | 5 | 4 | 3 | 0.2 |

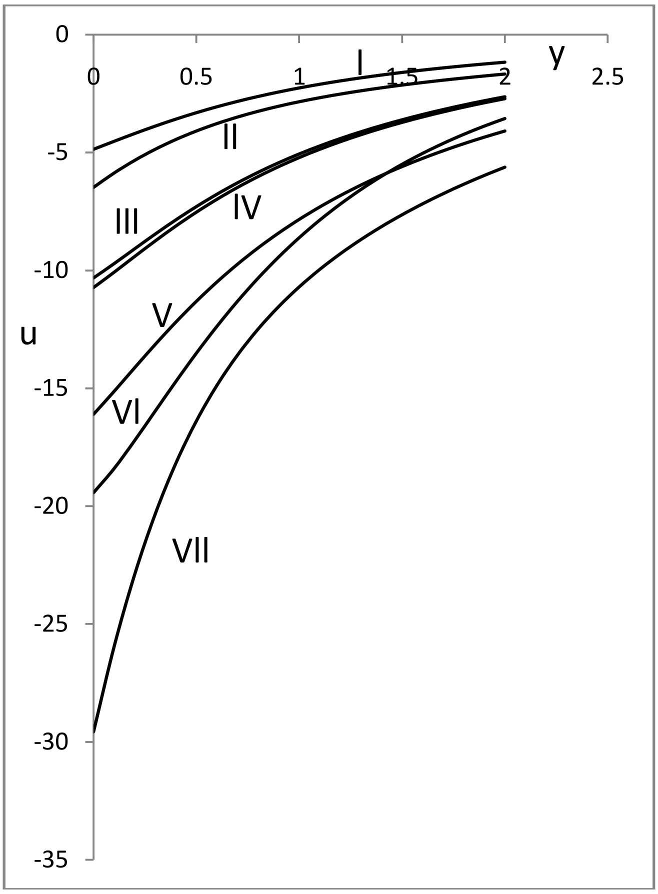


Figure 2: Effect of $k_o$, M, $G_r$, ω, $P_r$ & N on Transient velocity u versus y for fixed $R_m$ = 0.05 and ωt = π/2

| Figure2 | $P_r$ | M | ω | $G_r$ | $k_0$ | N |
|---|---|---|---|---|---|---|
| I | 0.71 | 5 | 10 | 4 | 3 | 0.2 |
| II | 0.71 | 5 | 5 | 4 | 3 | 0.6 |
| III | 0.71 | 5 | 5 | 4 | 5 | 0.2 |
| **IV** | **0.71** | **5** | **5** | **4** | **3** | **0.2** |
| V | 0.71 | 5 | 5 | 6 | 3 | 0.2 |
| VI | 1 | 5 | 5 | 4 | 3 | 0.2 |
| VII | 0.71 | 10 | 5 | 4 | 3 | 0.2 |

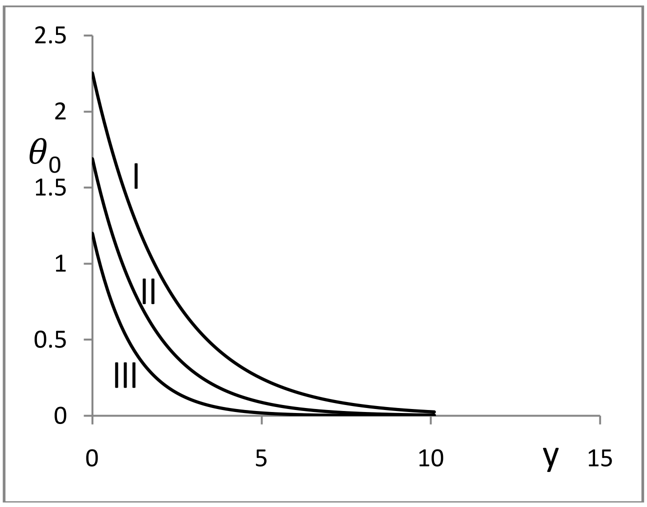


Figure 3:Effects of $P_r$ & N on Mean temperature $\theta_0$ versus y for fixed values of $k_o$=3, M=5, $G_r$=4,ω=5, $R_m$ = 0.05 and ωt = π/2


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| Figure 3 | $P_r$ | N |
|---|---|---|
| I | 0.71 | 0.6 |
| **II** | **0.71** | **0.2** |
| III | 1 | 0.2 |

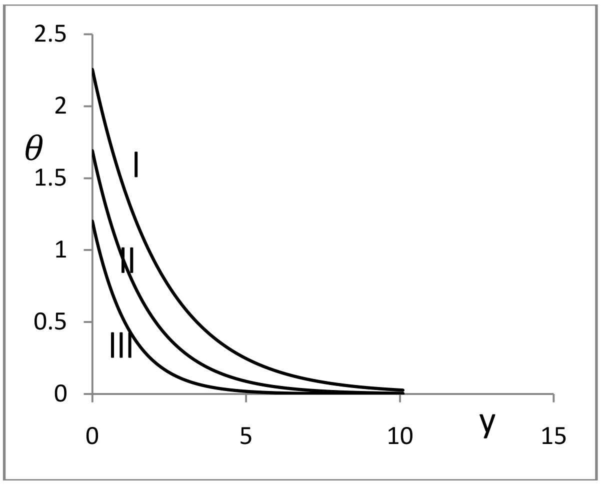


Figure 4: Effects of $P_r$ & N on Transient temperature $\theta$ versus y for fixed values of $k_o = 3$, $M = 5$, $G_r = 4$, $\omega=5$ and $R_m = 0.05$

| Figure4 | $P_r$ | N |
|---|---|---|
| I | 0.71 | 0.6 |
| **II** | **0.71** | **0.2** |
| III | 1 | 0.2 |

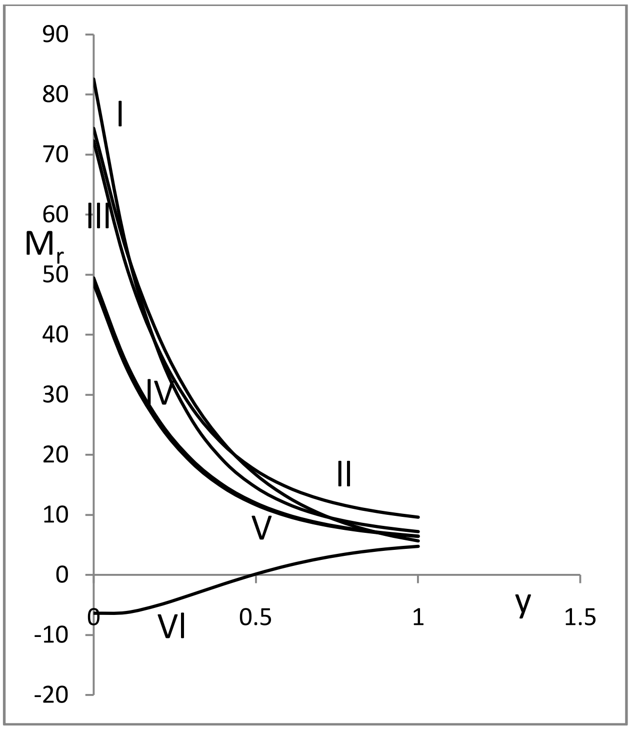


Figure 5: Fluctuating parts of velocity profile $M_r$ for fixed value of $P_r = 0.71$

| Figure5 | M | ω | $G_r$ | $k_0$ | N |
|---|---|---|---|---|---|
| I | 10 | 5 | 4 | 3 | 0.2 |
| II | 5 | 5 | 4 | 3 | 0.6 |
| III | 5 | 5 | 6 | 3 | 0.2 |
| IV | 5 | 5 | 4 | 5 | 0.2 |
| **V** | **5** | **5** | **4** | **3** | **0.2** |
| VI | 5 | 10 | 4 | 3 | 0.2 |

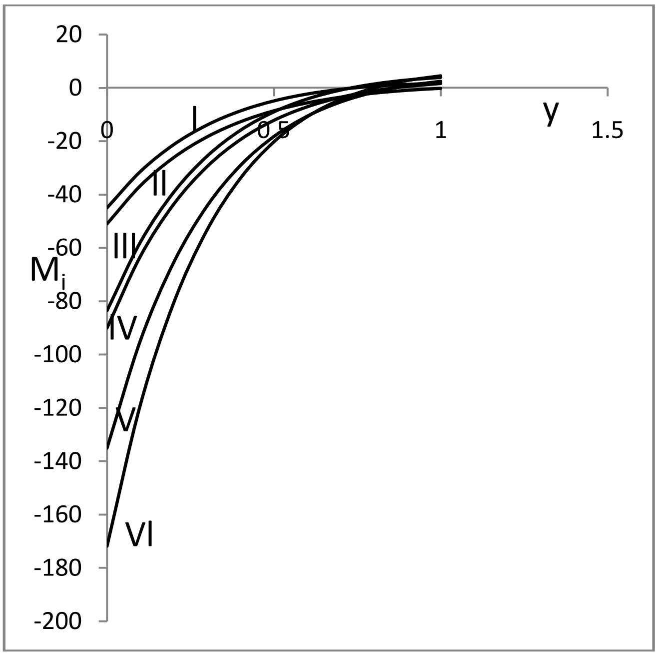


Figure 6: Fluctuating parts of velocity profile $M_i$ for fixed value of M=5

| Figure 6 | $P_r$ | ω | $G_r$ | $k_0$ | N |
|---|---|---|---|---|---|
| I | 0.71 | 10 | 4 | 3 | 0.2 |
| II | 0.71 | 5 | 4 | 3 | 0.6 |
| III | 0.71 | 5 | 4 | 5 | 0.2 |
| **IV** | **0.71** | **5** | **4** | **3** | **0.2** |
| V | 0.71 | 5 | 6 | 3 | 0.2 |
| VI | 1 | 5 | 4 | 3 | 0.2 |



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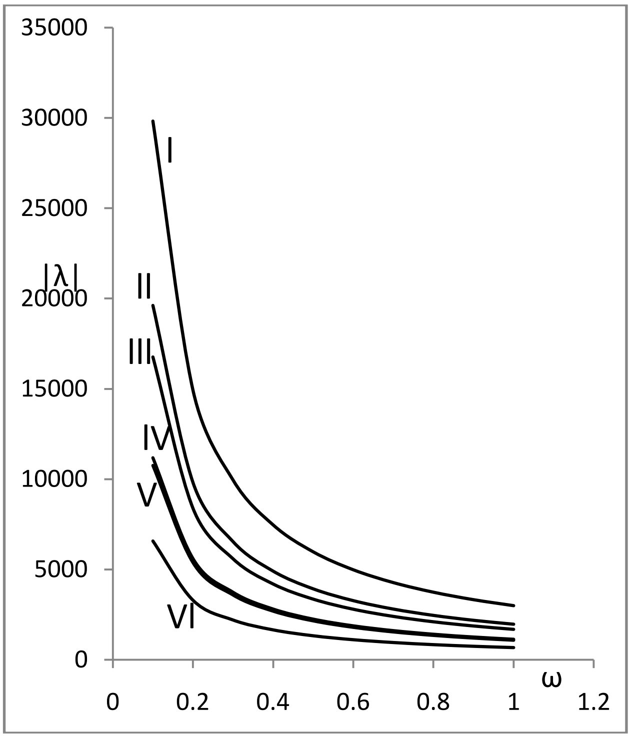


Figure 7: Amplitude versus Frequency parameter ω for fixed value of $R_m$=0.05

| Figure 7 | $P_r$ | N | M | $G_r$ | $k_0$ |
|---|---|---|---|---|---|
| I | 0.71 | 0.2 | 10 | 4 | 3 |
| II | 1 | 0.2 | 5 | 4 | 3 |
| III | 0.71 | 0.2 | 5 | 6 | 3 |
| **IV** | **0.71** | **0.2** | **5** | **4** | **3** |
| V | 0.71 | 0.2 | 5 | 4 | 5 |
| VI | 0.71 | 0.6 | 5 | 4 | 3 |

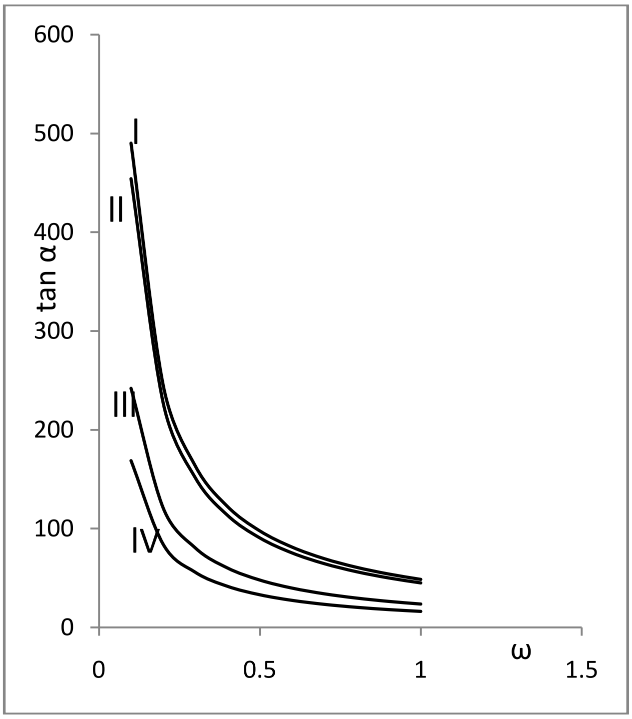


Figure 8: Phase versus Frequency parameter ω for fixed value of $R_m$=0.05

| Figure 8 | M | $P_r$ | N |
|---|---|---|---|
| I | 10 | 0.71 | 0.2 |
| II | 5 | 1 | 0.2 |
| **III** | **5** | **0.71** | **0.2** |
| IV | 5 | 0.71 | 0.6 |

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