MHD Free Convection Effects of Radiating Memory Flow

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Abstract **– Two dimensional unsteady radiating oscillatory memory flow past an infinite plane porous wall is investigated. Expressions for the mean velocity and the mean temperature are obtained. The effects of various parameters such as Permeability parameter (K), Grashoff number (G_r), Hartmann number (M), Radiation parameter (N), Prandle number (P_r) are depicted graphically. Nusselt number (Nu) and Skin friction (C_f) are discussed by tables.**

Index Terms **– Suction, Porous medium, Walter's liquid- B and Rosseland's approximation.**

I. INTRODUCTION

The study of flow of electrically conducting fluid, the so-called magneto-hydrodynamics (MHD) has a lot of attention due to its diverse applications in astrophysics and geophysics. It is important to study the effect of the interaction of magnetic field on the temperature distribution and heat transfer when the fluid is not only electrically conducting but also when it is capable of emitting and absorbing thermal radiation. Heat transfer by thermal radiation is important when we are concerned with space technology applications and in power engineering. Seddeek [3] studied the effects of radiation and variable viscosity on a MHD free convection flow past an semi-infinite flat plate with an aligned magnetic field in the case of unsteady flow. Mazumdar and Deka [4] investigated MHD flow past an impulsively started infinite vertical plate in presence of thermal radiation. Analytical closed-form solution of the unsteady hydro-magnetic natural convection heat and mass transfer flow of a rotating, incompressible, viscous Boussinesq fluid was presented by Mbeledogu and Ogulu [5]. Mbeledogu et al. [6] also studied the free convection flow of a compressible Boussinesq fluid under the simultaneous action of buoyancy and transverse magnetic field. Mohamed and Abo- Dahab [7] analysis, the effects of chemical reaction and thermal radiation on hydromagnetic free convection heat and mass transfer for a micropolar fluid via a porous medium bounded by a semi-infinite vertical porous plate in the presence of heat generation. Natural convection of an electrically conducting and radiating fluid in the presence of an external magnetic field is investigated numerically by Young [8]. Zueco and Anwar [9] studied the steady-state, magneto hydrodynamic, optically thick, dissipative gas boundary layer flow and heat transfer past a non-isothermal porous wedge embedded in a scattering, homogenous, isotropic Darcy_Forchheimer porous medium, with significant thermal radiation effects in the presence of heat sink/sources and surface transpiration, in a (x, y) coordinate system. Ahmed and Sarmah [10] analyzed the joint effect of thermal radiation and transverse magnetic field on an unsteady convection and mass transfer flow of an incompressible viscous electrically conducting fluid past a suddenly fixed vertical plate. Ishak [11] worked mixed convection boundary layer flow over a horizontal plate with thermal radiation. Soret and Dufour effects on free convection flow of non-Newtonian fluids along a vertical plate embedded in a porous medium with thermal radiation were studied by Tai and Char [12]. Israel – Cookey and Nwaigwe [13] considered unsteady MHD flow of a radiating fluid over a vertical moving heated porous plate with time – dependent suction. Narahari [14] studied the effects of thermal radiation and free convection currents on the unsteady Couette flow between two vertical parallel plates with constant heat flux at one boundary. Israel – Cookey et al. [15] investigated the combined effects of radiative heat transfer and a transverse magnetic field on steady flow of an electrically conducting optically thin fluid through a horizontal channel filled with porous medium and non- uniform temperatures at the walls. Singh et al. [16] studied the effect of surface mass transfer on MHD mixed convection flow past a heated vertical flat permeable surface in the presence of thermophoresis, radiative heat flux and heat source/sink. Ahmed [17] given the exact solution to the problem of MHD transient free convection and mass

transfer flow of a viscous, incompressible, and electrically conducting fluid past a suddenly started infinite vertical plate taking into account the thermal diffusion as well as the thermal radiation was presented. The heat and mass transfer characteristics of the unsteady electrically conducting fluid flow past a suddenly started vertical infinite flat plate studied by Turkyilmazoglu and Pop [18]. Free convective heat and mass transfer flow over a moving permeable flat vertical stretching sheet in the presence of non-uniform magnetic field is numerically investigated by Ferdows et al. [19].

Now we study the free convection effects on the fluctuating flow of radiating memory flow past an infinite porous wall with constant suction through porous medium.

II. FORMULATION OF PROBLEM

We consider the free convective flow due to fluctuating mean stream of memory fluid (Walter's Liquid Model-B) flow past an infinite plane, porous wall with constant suction at the surface. Let y=0 be the wall in the presence of magnetic field normal to the direction of flow. Let u and v be the velocity components along and normal to the wall.

We make the following assumptions:

1) That all the fluid properties are constant except the density in the buoyancy force term;
2) That the term due to the electrically dissipation is neglected in energy equation (2.2) as the magnetic field is not strong enough to cause Joule heating (electrical dissipation)
3) That the Eckert number E_c and the magnetic Renold's numbers are small so that the induced magnetic field can be neglected. The x-axis is taken along the surface in the upwards direction and y-axis is taken normal to it.

As the bounding surface is infinite in length, all the variables are functions of y alone. By the usual boundary layer approximation the basic equation for unsteady flow are

$$v = -v_0 \qquad (2.1)$$

$$\frac{\partial u}{\partial t} - v_0\frac{\partial u}{\partial y} = \frac{dU}{dt} + g\beta_1(T - T_\infty) + \vartheta\frac{\partial^2 u}{\partial y^2}$$
$$- \frac{\beta}{\rho}\left[\frac{\partial^3 u}{\partial t\,\partial y^2} - v_0\frac{\partial^3 u}{\partial y^3}\right] - \frac{\vartheta u}{K}$$
$$- \left(\frac{\sigma\mu_e^2 H_0^2}{\rho}\right)u \qquad (2.2)$$

$$\frac{\partial T}{\partial t} - v_0\frac{\partial T}{\partial y} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{\vartheta}{C_p}\left(\frac{\partial u}{\partial y}\right)^2$$
$$- \frac{1}{\rho C_p}\left(\frac{\partial q_r}{\partial y}\right) \qquad (2.3)$$

where the Rosseland's approximation (Brewster[2]) is used, which leads to

$$q_r = \frac{-4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \qquad (2.4)$$

The boundary conditions are:

$$u(0,t) = 0,\, T(0,t) = T_w,\, T(\infty,t) = T_\infty$$

$$u(y,t) = U = U_0(1 + \varepsilon e^{i\omega t}) \text{ as } y \to \infty \qquad (2.5)$$

We assumed 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_∞ and neglecting higher-order terms. Thus,

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \qquad (2.6)$$

Using (2.4) and (2.6) in (2.3) gives

$$\frac{\partial T}{\partial t} - v_0\frac{\partial T}{\partial y} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{\vartheta}{C_p}\left(\frac{\partial u}{\partial y}\right)^2$$
$$+ \frac{1}{\rho C_p}\left(\frac{16\sigma^* T_\infty^3}{3\kappa k^*}\right) \qquad (2.7)$$

Introducing the following non-dimensional quantities:

$$\bar{y} = \frac{y v_0}{\vartheta},\ \ \bar{t} = \frac{t v_0^2}{\vartheta},\ \overline{K} = \frac{K v_0^2}{\vartheta^2},\ \bar{\omega} = \frac{\vartheta\omega}{v_0^2},$$

$$M = \frac{\sigma\vartheta H_0^2\mu_e^2}{\rho v_0^2},\ \ N = \frac{16\sigma^* T_\infty^3}{3\kappa k^*},\ \ \bar{u} = \frac{u}{U_0},$$

$$W = \frac{u(t)}{U_0},\ \ G_r = \frac{g\beta_1(T_w - T_\infty)}{U_0 v_0^4},$$

$$R_m = \frac{\beta v_0^2}{\vartheta^2},\ \ \ E = \frac{u_0^2}{C_p(T_w - T_\infty)}$$

$$P_r = \frac{\vartheta\rho C_p}{\kappa},\ \ \ \theta = \frac{T - T_\infty}{T_w - T_\infty} \qquad (2.8)$$

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Using equation (2.2) into (2.3), then with the help of (2.8), the following equations are obtained

$$\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = \frac{dW}{dt} + G_r\theta + \frac{\partial^2 u}{\partial y^2} - R_m\left(\frac{\partial^3 u}{\partial t \partial y^2} - \frac{\partial^3 u}{\partial y^3}\right)$$

$$-u\left(\frac{1}{K} + M\right) \qquad (2.9)$$

$$\frac{\partial\theta}{\partial t} - E\left(\frac{\partial u}{\partial y}\right)^2 = \left(\frac{1+N}{P_r}\right)\frac{\partial^2\theta}{\partial y^2} + \frac{\partial\theta}{\partial y} \qquad (2.10)$$

The corresponding boundary conditions becomes

$$\theta = 1, \qquad u = 0 \quad \text{at} \quad y = 0$$

$$\theta \to 0, \qquad w \to W(t) \quad \text{as} \quad y \to \infty$$

Free-stream boundary condition

$$W(t) = (1 + \varepsilon e^{i\omega t}) \quad \text{as } y \to \infty \qquad (2.11)$$

Where

ρ   Density of fluid,
β   Kinematic visco-elasticity,
β_1 Coefficient of volume expansion,
H_o Magnetic intensity,
μ_e Magnetic permeability,
R_m Magnetic Renolds number,
ϑ Kinematic viscosity,
K   Permeability parameter,
C_p Specific heat at constant pressure,
N   Thermal radiation parameter,
K   Thermal conductivity,
G_r Grashoff number,
P_r Prandtl number,
M   Hartmann number,
E   Eckert number,
q   Heat flux,
σ   Electric conductivity,
σ^* Stephan-Boltzman constant,
k^* Mean absorption coefficient,
$f_1 = \left(\frac{P_r}{1+N}\right)$

III. SOLUTION OF THE PROBLEM

Following Lighthill, [1] we put velocity and temperature field as

$$u = u_0 + \varepsilon e^{i\omega t}u_1 \qquad (3.1)$$

$$\theta = \theta_0 + \varepsilon e^{i\omega t}\theta_1 \qquad (3.2)$$

since free stream velocity fluctuates, we may take

$$W(t) = (1 + \varepsilon e^{i\omega t}) \qquad (3.3)$$

Where 'ω' is the frequency and 'ε' is very small quantity <<1.

Now making use of (3.1) and (3.2) into the equations (2.9) and (2.10), equating harmonic and non-harmonic terms, we get

Zeroth order

$$R_m u_0''' + u_0'' + u_0' = -M_1 u_0 = -G_r\theta_0 \qquad (3.4)$$

$$\left(\frac{1+N}{P_r}\right)\theta_0'' + \theta_0' = -E(u_0')^2 \qquad (3.5)$$

First order

$$R_m u_1''' + (1 - si\omega)u_1'' + u_1' - (M_1 + i\omega)u_1 = -i\omega - u_0' - G_r\theta_1 \qquad (3.6)$$

$$\theta_1'' + f_1\theta_1' - f_1 i\omega\theta_1 = -f_1[\theta_0 + 2Eu_0'u_1'] \qquad (3.7)$$

Boundary conditions are

$$\theta_0 = 1, \theta_1 = u_0 = u_1 = 0 \ \text{as y} = 0$$

$$\theta_0 = \theta_1 = 0, u_0 = u_1 = 1 \ \text{as y} \to \infty \qquad (3.8)$$

In equations (3.4) and (3.6), because of the presence of elasticity term, we get third order differential equation. To solve this, we need three boundary conditions but we have two. So following Beard and Walters (1964), we assume the solution as

$$F = F_1(y) + R_m F_2(y) + o(\ R_m^2) \qquad (3.9)$$

$$u_0(y) = u_{01}(y) + R_m u_{02}(y) + o(\ R_m^2)$$

$$\theta_0(y) = \theta_{01}(y) + R_m\theta_{02}(y) + o(\ R_m^2)$$

$$u_1(y) = u_{11}(y) + R_m u_{12}(y) + o(\ R_m^2)$$

$$\theta_1(y) = \theta_{11}(y) + R_m\theta_{12}(y) + o(\ R_m^2) \qquad (3.10)$$

Where u_0 and θ_0 are the mean velocity and mean temperature and u_1 and θ_1 are the fluctuating parts of the velocity and temperature respectively.

Using equations (3.10) into equations (3.4) – (3.7) equating the coefficients of different powers of R_m and neglecting those of R_m^2

Thereafter considering differential equations related to mean parts

$$u''_{01} + u'_{01} - M_1 u_{01} = -G_r \theta_{01} \qquad (3.11)$$

$$u'''_{01} + u''_{02} + u'_{02} - M_1 u_{02} = -G_r \theta_{02} \qquad (3.12)$$

$$\theta''_{01} + f_1 \theta'_{01} = E f_1 (u'_{01})^2 \qquad (3.13)$$

$$\theta''_{02} + f_1 \theta'_{02} = E f_1 2 u'_{01} u'_{02} \qquad (3.14)$$

Boundary conditions are

$$\theta_{01} = 1, \theta_{02} == u_{01} = u_{02} \to 0 \text{ as } y \to 0$$

$$\theta_{01} = \theta_{02} = 0, u_{01} = 1, u_{02} = 0 \text{ as } y \to \infty \qquad (3.15)$$

We solve the equations (3.11) – (3.14), we expand u and θ in powers of E because of Eckert number E is very small (<< 1) for incompressible fluid

$$F = F_1 + E F_2 \qquad (3.16)$$

Replacing F by $u_{01}, u_{02}, \theta_{01}, \theta_{02}$, we get

$$u''_{011} + u'_{011} - M_1 u_{011} = -G_r \theta_{011} \qquad (3.17)$$

$$u'''_{011} + u''_{021} + u'_{021} - M_1 u_{021} \\ = -G_r \theta_{021} \qquad (3.18)$$

$$u''_{012} + u'_{012} - M_1 u_{012} = -G_r \theta_{012} \qquad (3.19)$$

$$u'''_{012} + u''_{022} + u'_{022} - M_1 u_{022} \\ = -G_r \theta_{022} \qquad (3.20)$$

$$\theta''_{011} + f_1 \theta'_{011} = 0 \qquad (3.21)$$

$$\theta''_{021} + f_1 \theta'_{021} = 0 \qquad (3.22)$$

$$\theta''_{012} + f_1 \theta'_{012} = f_1 (u'_{011})^2 \qquad (3.23)$$

$$\theta''_{022} + f_1 \theta'_{022} = 2 f_1 u'_{011} u'_{021} \qquad (3.24)$$

Boundary conditions are

$$\theta_{011} = \theta_{012} = \theta_{021} = \theta_{022} = 0$$

$$u_{011} = u_{012} = u_{021} = u_{022} = 0 \text{ as } y \to 0$$

$$u_{011} = 1, u_{012} = u_{021} = u_{022} = 0$$

$$\theta_{011} = \theta_{012} = \theta_{021} = \theta_{022} = 0 \text{ as } y \to \infty$$

$$(3.25)$$

We get the following solutions for the mean temperature profiles as

$$\theta_{011} = e^{-f_1 y} \qquad (3.26)$$

$$\theta_{012} = G_r^2 \left[b_2 e^{-f_1 y} + a_1^2 f_1 m_1 e^{-2my} + \frac{a_1^2 f_1 e^{-2f_1 y}}{2} \\ - a_1^2 f_1 f_2 e^{-(m+f_1)y} \right] \qquad (3.27)$$

$$\theta_{021} = 0 \qquad (3.28)$$

$$\theta_{022} = 2 G_r^2 a_1 f_1 \left[-\{m_4 + m_5 - m_6 + f_4\} e^{-f_1 y} \\ + (m_5 - m_6) e^{-2my} \\ + (m_4 - f_2 f_3) e^{-(m+f_1)y} + \frac{a_1^2 f_1^3 e^{-2f_1 y}}{2} \\ - m_0 y e^{-2my} \\ + m_3 y e^{-(m+f_1)y} \right] \qquad (3.29)$$

$$\theta = \theta_0 + \varepsilon \theta_1 \qquad (3.30)$$

$$\theta_0 = \theta_{01} + R_m \theta_{02} \qquad (3.31)$$

$$\theta_0 = (\theta_{011} + E \theta_{012}) + R_m (\theta_{021} + E \theta_{022}) \qquad (3.32)$$

Mean dimensionless coefficient of heat transfer i.e., Nusselt's number is given by

$$Nu = \theta'_0 |_{y=0} \\ = -f_1 \\ + E[G_r^2 \{-b_2 f_1 - 2 m a_1^2 f_1 m_1 - a_1^2 f_1^2 + a_1^2 f_1 f_2 (m + f_6)\}] \\ + R_m E \begin{bmatrix} 2 G_r^2 a_1 f_1 \{m_4 + m_5 - m_6 + f_4\} f_1 \\ -2m(m_5 - m_6) - \\ (m + f_1)(m_4 - f_2 f_3) - \\ a_1^2 f_1^4 - m_0 + m_3 \end{bmatrix} \\ \qquad (3.33)$$

Now we get the following solutions for the mean velocity profiles.

$$u_{011} = G_r a_1 \left[e^{-my} - e^{-f_1 y} \right] \qquad (3.34)$$

$$u_{021} \\ = G_r \left[f_1^3 a_1^2 e^{-my} \\ - a_1 b_1 y e^{-my} - a_1^2 f_1^3 e^{-f_1 y} \right] \qquad (3.35)$$

$$u_{012} = \frac{G_r^2}{b_1}[(a_8 + a_9 + a_{10} - a_{11})e^{-my}]$$
$$- \frac{G_r^3}{b_1}[(a_8 e^{-f_1 y} + a_9 e^{-2f_1 y}$$
$$+ a_{10} e^{-2my} - a_{11} e^{-(m+f_1)y})] \tag{3.36}$$

$$u_{022}$$
$$= G_r^3[(2f_1 a_7 + a_{16})e^{-my} + (2f_1 a_3 - a_{12})e^{-f_1 y}$$
$$- (2f_1 a_4 + 2f_1 a_1 m_{10} + a_{14})e^{-2my} - (2f_1 a_1 a_6$$
$$+ a_{13})e^{-2f_1 y} - (2f_1 a_1 a_5 + 2f_1 a_1 m_3 f_6 - a_{15})e^{-(m+f_1)y}$$
$$- (2f_1 a_1 m_9 + a_8 + a_9 + a_{10} - a_{11})ye^{-my}$$
$$- (2f_1 a_1 m_3 f_5)ye^{-(m+f_1)y}] \tag{3.37}$$

$$u_0 = (u_{011} + Eu_{012}) + R_m(u_{021} + Eu_{022}) \tag{3.38}$$

Mean non-dimensional skin friction is given by

$$C_f = u_0'|_{y=0} = [G_r a_1 (f_1 - m)]$$
$$+ E\left[\frac{G_r^2}{b_1}\{m(a_{11} - a_{10} - a_9 - a_8)\}\right.$$
$$- \frac{G_r^3}{b_1}\{a_{11}(m + f_1) - 2ma_{10} - 2a_9 f_1$$
$$\left. - a_8 f_1\}\right]$$
$$+ R_m[\{G_r(a_1^2 f_1^4 - a_1^2 f_1^3 m - a_1 b_1)\}$$
$$+ EG_r^3\{-m(2f_1 a_7 + a_{16})$$
$$- f_1(2f_1 a_3 - a_{12})$$
$$+ 2m(2f_1 a_4 + 2f_1 a_1 m_{10} + a_{14})$$
$$+ 2f_1(2f_1 a_1 a_6 + a_{13})$$
$$+ (m + f_1)(2f_1 a_1 a_5 + 2f_1 a_1 m_3 f_6$$
$$- a_{15})$$
$$- (2f_1 a_1 m_9 + a_8 + a_9 + a_{10} - a_{11})$$
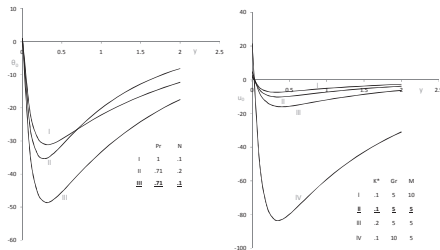$$- 2f_1 a_1 m_3 f_5\}] \tag{3.39}$$

figure-1
Mean temperature distribution θ₀ versus y for fixed values of
M=5,K=0.1 , G_r=5, E=0.01and R_m=0.4

figure-2
Mean velocity distribution u₀ versus y for fixed values of
N=0.1,E=0.01 and R_m=0.4

NUSSELT'S NUMBER TABLE 1

K	Nusselt's Number	Pr	Nusselt's Number	Gr	Nusselt's Number	M	Nusselt's Number	N	Nusselt's Number
0.2	12136.7	0.2	23105.0	2	19196.8	2	14873.3	0.2	19889.8
0.4	8915.03	0.4	22848.7	4	19210.2	4	17740.4	0.4	20997.3
0.6	7894.28	0.6	20488.8	6	19232.5	6	20729.7	0.6	21844.3
0.8	7394.51	0.8	18269.2	8	19263.8	8	23834.5	0.8	22480.3
1.0	7098.13	1.0	16459.3	10	19304.1	10	27048.8	1.0	22945.5

For fixed values of K=0.1,Pr=0.71,Gr=5,M=5, N=0.1and
Rm = 0.4

SKIN FRICTION TABLE 2

K	Skin Friction	Pr	Skin Friction	Gr	Skin Friction	M	Skin Friction	N	Skin Friction
0.2	11.182	0.2	26.9039	2	3.6201	2	12.9959	0.2	16.1654
0.4	6.0182	0.4	20.3494	4	9.5948	4	13.9239	0.4	18.5692
0.6	2.7696	0.6	17.5894	6	20.2742	6	14.3923	0.6	19.7510
0.8	0.6292	0.8	10.6247	8	38.0083	8	14.6059	0.8	20.2481
1.0	-0.8731	1.0	0.41004	10	65.1472	10	14.6717	1.0	20.3468

For fixed values of K=0.1,Pr=0.71,Gr=5,M=5, N=0.1and
Rm = 0.4

CONCLUSIONS

We observe that as permeability parameter K and Groshoff number G_r suppress velocity distribution it is due to the fact that in Rosseland's approximation the temperature differences are very small, that is why adverse trend is noted. In general permeability parameter K and Groshoff number G_r influence velocity distribution, whereas Lorentz force influences the velocity distribution because of the Roseland's approximation refer fig-2

We see that temperature is in direct proportion to radiation parameter N from (2.8), so the effect of radiation parameter N is to influence the temperature distribution and also we note that as Prandle number P_r increases temperature distribution increases refer fig-1

The effect of K (Permeability parameter) and P_r (Prandle number) is to decrease the heat transfer whereas G_r (Grashoff number), M (Hartmann number) and N (Radiation parameter) is to influence the heat transfer. The above parameters have the same effect on skin friction refer table 1 & 2.

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