RADIATION EFFECT ON MHD FLOW PAST AN OSCILLATING INCLINED PLATE WITH HEAT AND MASS TRANSFER

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ABSTRACT

The present study is carried out to examine the effect of radiation on flow model. The model consists of unsteady MHD flow of a viscous, incompressible and electrically conducting fluid. The flow is along an oscillating inclined plate with variable wall temperature and mass diffusion in the presence of Hall current. The dimensionless governing equations are solved by using Laplace transform technique. The velocity profile is discussed with the help of graphs drawn for different flow parameters. The numerical values of the skin-friction and Nusselt number at the plate are shown in tables.

Keywords- MHD, radiation, oscillating inclined plate, mass diffusion, Hall current.

1 INTRODUCTION

The MHD flow problems play important role in different area of science and technology. These have various applications in industry, for instance, magnetic material processing, glass manufacturing control processes and purification of crude oil. The problems related to radiation effect on MHD flow have been studied by a number of researchers, some of which are mentioned here. Raptis and Perdikis [1] have presented radiation and free convection flow past a moving plate. Radiation effect on the MHD mixed convection flow past a semi-infinite moving vertical plate for high temperature differences was studied by Azzam [2]. Heat and mass transfer effect on moving vertical plate in the presence of thermal radiation was analyzed by Muthucumaraswamy et al. [3]. Chamkha et al. [4] have considered radiative free convective non-Newtonian fluid flow past a wedge embedded in a porous medium. MHD and radiation effect on moving isothermal vertical plate with variable mass diffusion was investigated by Muthucumaraswamy and Janakiraman [5]. Prasad et al. [6] have worked on radiation and mass transfer effects on two-dimensional flow past an impulsively started infinite vertical plate. Mazumder and Deka [7] have presented MHD flow past an impulsively started infinite vertical plate in the presence of thermal radiation. Ahmed and Sarmah [8] have analyzed thermal radiation effect on a transient MHD flow with mass transfer past an impulsively fixed infinite vertical plate. Radiation and mass transfer effects on the magnetohydrodynamic unsteady flow induced by a stretching sheet was considered by Hayat et al. [9]. Rajput and Sahu [10] have investigated combined effects of MHD and radiation on unsteady transient free convection flow between two long vertical parallel plates with constant temperature and mass diffusion. Further Rajput and Kumar [11] have considered radiation effect on MHD flow through porous media past an impulsively started vertical plate with variable heat and mass transfer. Similar researches were done by Thamizhsudar and Pandurangan [12], Murthy and Srinivasa[13], and Babu and Rao [14]. Earlier we [15] have studied chemical reaction effect on unsteady MHD flow past an impulsively started oscillating inclined plate with variable temperature and mass diffusion in the presence of Hall current. In the present study we have modified the energy equation of previous model and accommodated the radiation parameter. Diffusion equation is also changed. Thus we are studying the effect of radiation on the flow without any chemical reaction. The models have been solved using the Laplace transforms technique.

2 MATHEMATICAL ANALYSIS

The geometrical model of the flow problem is shown in Figure-1

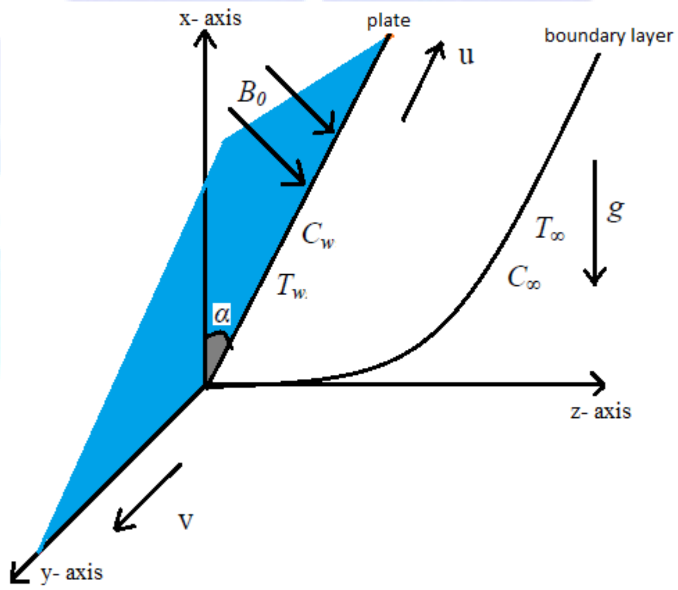

Figure 1: Physical model

MHD flow past an electrically non conducting plate inclined at an angle α from vertical is considered. The x axis is taken along the vertical plane and z normal to it. A transverse magnetic field B_0 of uniform strength is applied on the flow. Initially it has been considered that the plate and fluid temperature is T_∞. The species concentration in the fluid is taken as C_∞. At time t>0, the plate starts oscillating in its own plane with frequency ω, and temperature of the plate is raised to T_w. The concentration C near the plate is raised linearly with respect to time.

The flow model is as under:

$$\frac{\partial u}{\partial t} = \upsilon \frac{\partial^2 u}{\partial z^2} + g\beta Cos\alpha\,(T - T_\infty) + g\beta^* Cos\alpha\,(C - C_\infty) - \frac{\sigma B_0^2 (u + mv)}{\rho(1+m^2)} \quad (1)$$

$$\frac{\partial v}{\partial t} = \upsilon \frac{\partial^2 v}{\partial z^2} + \frac{\sigma B_0^2 (mu - v)}{\rho(1+m^2)} \quad (2)$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2} \quad (3)$$

$$\rho C_p \frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial z^2} - \frac{\partial q_r}{\partial z} \quad (4)$$

The boundary conditions for the flow are as under:

$$\left.\begin{array}{l} t\le 0: u=0,\ v=0,\ T=T_\infty,\ C=C_\infty, \text{for every z.} \\ t>0: u=u_0 Cos\omega t,\ v=0, T=T_\infty+(T_w-T_\infty)A_0,\ C=C_\infty+(C_w-C_\infty)A_0, \text{at z=0.} \\ u\to 0,\ v\to 0,\ T\to T_\infty,\ C\to C_\infty \text{ as } z\to\infty. \end{array}\right\} \quad (5)$$

Here *u* and *v* are the primary and the secondary velocities, respectively. Other symbols used are: C_p- the specific heat at constant pressure, *k*- thermal conductivity of the fluid, *D*-the mass diffusion coefficient, g-the acceleration due to gravity, *β*-volumetric coefficient of thermal expansion, *T*- temp of the fluid, β^*-volumetric coefficient of concentration expansion, *C*- species concentration in the fluid, ν- the kinematic viscosity, *ρ*- the density, T_w - temperature of the plate at $z=0$, C_w -species concentration at the plate $z=0$, B_0- the uniform magnetic field, *σ* - electrical conductivity, t-time, *m*-the Hall current parameter.

The radiant of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial z} = -4a^*\sigma(T_\infty^4 - T^4) \quad (6)$$

where a^* is absorption constant. Considered the temperature difference within the flow sufficiently small, T^4 can be written as the linear function of temperature, and expanding T^4in a Taylor series about T_∞ (neglecting higher-order terms)

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \quad (7)$$

Using equations (6) and (7), equations (4) becomes

$$\rho C_p \frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial z^2} - 16a^*\sigma T_\infty^3 (T - T_\infty) \quad (8)$$

The following non-dimensional quantities are introduced to transform equations (1), (2), (3) and (8) into dimensionless form:

$$\left.\begin{array}{l} P_r = \frac{\mu c_p}{k}, R = \frac{16a^*\sigma\upsilon^2 T_\infty^3}{k u_0^2}, G_r = \frac{g\beta\upsilon(T_w - T_\infty)}{u_0^3}, M = \frac{\sigma B_0^2\upsilon}{\rho u_0^2}, \bar{z} = \frac{z u_0}{\upsilon}, \bar{u} = \frac{u}{u_0}, \bar{v} = \frac{v}{u_0}, \\ S_c = \frac{\upsilon}{D}, \theta = \frac{(T - T_\infty)}{(T_w - T_\infty)}, \mu = \rho\upsilon, G_m = \frac{g\beta^*\upsilon(C_w - C_\infty)}{u_0^3}, \bar{C} = \frac{(C - C_\infty)}{(C_w - C_\infty)}, \bar{\omega} = \frac{\omega\upsilon}{u_0^2}, \bar{t} = \frac{t u_0^2}{\upsilon}. \end{array}\right\} \quad (9)$$

Here $\bar{u}$ and $\bar{v}$ are the dimensionless primary and the secondary velocities, respectively.
Other symbols used are: *μ*-the coefficient of viscosity, P_r-the Prandtl number, S_c-the Schmidt number, *M*-the magnetic parameter, $\bar{t}$ -dimensionless time, ϑ -the dimensionless temperature, $\bar{C}$ -the concentration, G_r-thermal Grashof number, G_m- mass Grashof number, *R* –Radiation parameter.

Thus the model becomes

$$\frac{\partial \bar{u}}{\partial \bar{t}} = \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} + G_r Cos\alpha\, \theta + G_m Cos\alpha\, \bar{C} - \frac{M(\bar{u} + m\bar{v})}{(1+m^2)} \tag{10}$$

$$\frac{\partial \bar{v}}{\partial \bar{t}} = \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} + \frac{M(m\bar{u} - \bar{v})}{(1+m^2)} \tag{11}$$

$$\frac{\partial \bar{C}}{\partial \bar{t}} = \frac{1}{S_c}\frac{\partial^2 \bar{C}}{\partial \bar{z}^2} \tag{12}$$

$$\frac{\partial \theta}{\partial \bar{t}} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial \bar{z}^2} - \frac{R\theta}{P_r} \tag{13}$$

The boundary conditions (5) are transformed:

$$\left.\begin{array}{l} \bar{t} \le 0 : \bar{u} = 0,\ \bar{v} = 0,\ \theta = 0,\ \bar{C} = 0, \text{for every } \bar{z}\,. \\ \bar{t} > 0 : \bar{u} = Cos\,\bar{\omega}\,\bar{t},\ \bar{v} = 0,\ \theta = \bar{t},\ \bar{C} = \bar{t}, \text{at } \bar{z} = 0. \\ \bar{u} \to 0,\ \bar{v} \to 0,\ \theta \to 0,\ \bar{C} \to 0, \text{as } \bar{z} \to \infty \end{array}\right\} \tag{14}$$

Removing the bars and combining the equations (10) and (11), we get

$$\frac{\partial q}{\partial t} = \frac{\partial^2 q}{\partial z^2} + G_r Cos\alpha\, \theta + G_m Cos\alpha\, C - qa \tag{15}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} \tag{16}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2} - \frac{R\theta}{P_r} \tag{17}$$

Here $q = u + iv, a = \frac{M(1-im)}{1+m^2}$ and the corresponding boundary conditions are:

$$\left.\begin{array}{l} t \le 0 : q = 0, \theta = 0, C = 0, \text{for every } z. \\ t > 0 : q = Cos\ \omega t, \theta = t, C = t, \text{at } z=0. \\ q \to 0,\ \theta \to 0,\ C \to 0, \text{as } z \to \infty \end{array}\right\} \tag{18}$$

The dimensionless governing equations (15) to (17), subject to the boundary conditions (18), are solved by the usual Laplace - transform technique. The solutions obtained are as under:

$$C = t\left\{(1 + \frac{z^2 S_c}{2t})erfc[\frac{\sqrt{S_c}}{2\sqrt{t}}] - \frac{z\sqrt{S_c}}{\sqrt{\pi}\sqrt{t}} e^{-\frac{z^2}{4t}S_c}\right\}.$$

$$\theta = \frac{e^{-\sqrt{R}z}}{4\sqrt{R}}\{ erfc[\frac{-2\sqrt{R}t + zP_r}{\sqrt{P_r t}}](2\sqrt{R}t - zR) + e^{2\sqrt{R}z} erfc[\frac{2\sqrt{R}t + zP_r}{\sqrt{P_r t}}](2\sqrt{R}t + zR)\}.$$

$$q=\frac{1}{2}e^{-\sqrt{a}z}A_{33}+\frac{G_rCos\,\alpha}{4(a-R)^2}[\,2e^{-\sqrt{a}z}(A_1+P_rA_2)+2tA_2e^{-\sqrt{a}z}(a-R)\,+zA_3e^{-\sqrt{a}z}(\sqrt{a}-\frac{R}{\sqrt{a}})$$
$$+2A_{12}A_4(1-P_r)]+\frac{G_mCos\,\alpha}{4a^2}[\,e^{-\sqrt{a}z}(2A_1+2\sqrt{a}A_3)+2e^{-\sqrt{a}z}A_2(S_c+at)+2A_{13}A_5(1-S_c)]$$
$$-\frac{P_rG_rCos\,\alpha}{2\sqrt{\pi}(a-R)^2A_{11}}[\,A_{16}A_6\sqrt{\pi}z(at-1-Rt+P_r)+A_{14}A_7\sqrt{\pi}z(1-P_r)+\frac{1}{2}\sqrt{\frac{P_r}{R}}A_{16}A_8A_{11}\sqrt{\pi}z(a-R)]$$
$$-\frac{G_mCos\,\alpha}{2a^2\sqrt{\pi}}[\,2az\sqrt{S_c}e^{-\frac{z^2S_c}{4t}}\sqrt{t}+A_{15}\sqrt{\pi}(az^2S_c+2at+2S_c-2)+A_{13}\sqrt{\pi}(A_9+A_{10}S_c)]$$

The expressions for the symbols involved in the above solution are given in the appendix.

2.1 SKIN FRICTION

The dimensionless skin friction at the plate is

$$\left(\frac{dq}{dz}\right)_{z=0}=\tau_x+i\tau_y\,.$$

The numerical values of τ_x and τ_y, for different parameters are given in table-1.

2.2 NUSSELT NUMBER

The dimensionless Nusselt number is given by

$$Nu=\left(\frac{\partial\theta}{\partial z}\right)_{z=0}=erfc[\frac{\sqrt{Rt}}{\sqrt{tP_r}}](\sqrt{Rt}-\frac{\sqrt{R}}{2}t+\frac{P_r}{4\sqrt{R}})-erfc[-\frac{\sqrt{Rt}}{\sqrt{tP_r}}](\frac{\sqrt{R}}{2}t+\frac{P_r}{4\sqrt{R}})-\frac{e^{-\frac{Rt}{P_r}}\sqrt{tP_r}}{\sqrt{\pi}}$$

The values of *Nu* for various parameters are given in table-2.

3 RESULTS AND DISCUSSION

The velocity profiles for different parameters are shown in figures 1.1 to 2.10. It is observed from figures 1.1 and 2.1 that the u and v velocities of fluid decrease when the angle of inclination (α) of the plate is increased. Figures 1.2, 2.2, 1.3 and 2.3 show the buoyancy effect. It is observed that both the primary and secondary velocities increase on increasing thermal Grashof number $G_r$and mass Grashof number G_m. It implies that the buoyancy force tends to accelerate primary and secondary velocities. Figures (1.4 and 2.4) show the influence of Hall current on primary and secondary velocities. On increasing Hall parameter, *u* increases rapidly near the surface of the plate, whereas *v* increases throughout the boundary layer region. This shows that Hall current tends to accelerate primary velocity in the region near the surface of the plate, however it tends to accelerate secondary velocity throughout the boundary layer region. The influence of magnetic field in a viscous, incompressible and electrically conducting fluid establishes a force that acts against the main flow. So these resisting forces slow down the primary velocity of fluid as detected in figures 1.5 and 2.5. This means that the effect of increasing values of the parameter *M* results in decreasing *u* and increasing *v*. It is observed that when radiation parameter *R* is increased then the velocities are increased (figures 1.6 and 2.6). This is due to the fact that the large values of radiation parameter tend to accelerate velocity of the fluid in the region near the surface of the plate. From figures 1.7 and 2.7 it is deduced that velocities decrease with phase angle. Further, it is observed that velocities decrease when Prandtl number and Schmidt number are increased (figures 1.8, 2.8, 1.9 and 2.9). From figures 1.10 and 2.10, it is observed that velocities increase with time.

Skin friction is given in table1. The value of τ_x increases with the increase in *Gr, Gm, m, R* and *t*. It decreases with *α, M, Pr* and *Sc.* The value of τ_y increases with the increase in *Gr, Gm, M, R* and *t.* Further, it decreases with *α, m, Pr* and *Sc.* Nusselt number is given in table2. The value of Nu decreases with increase in *Pr, R* and t.

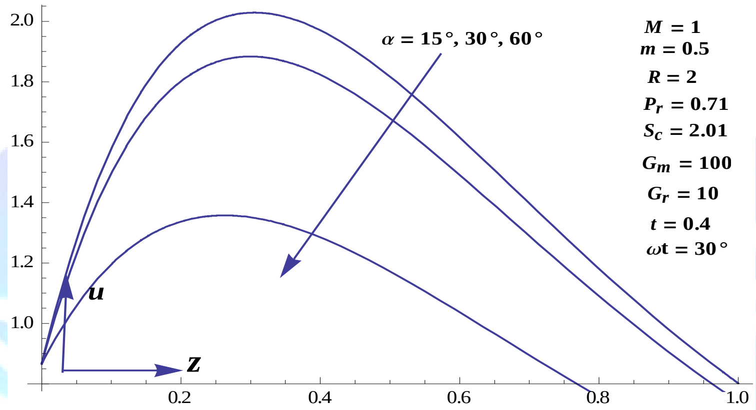

Figure 1.1: velocity *u* for different values of *α*

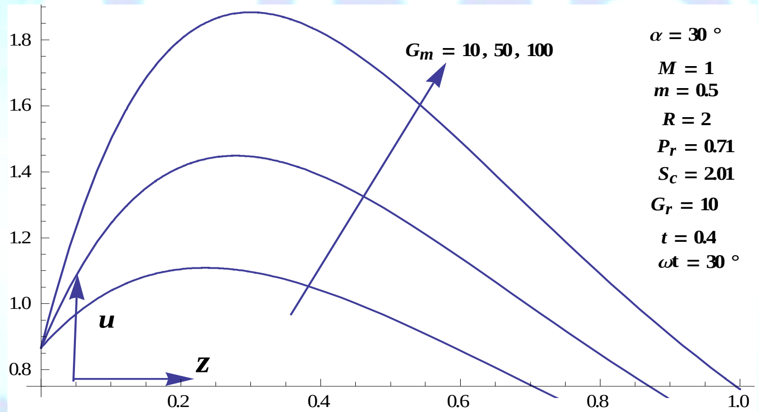

Figure 1.2: velocity *u* for different values of G_m

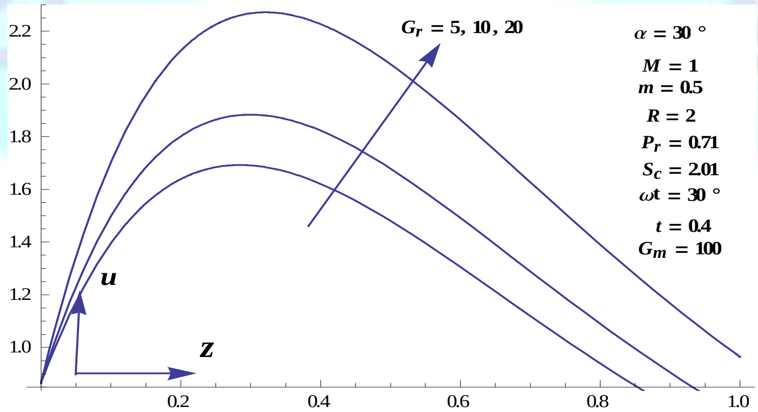

Figure 1.3: velocity *u* for different values of G_r

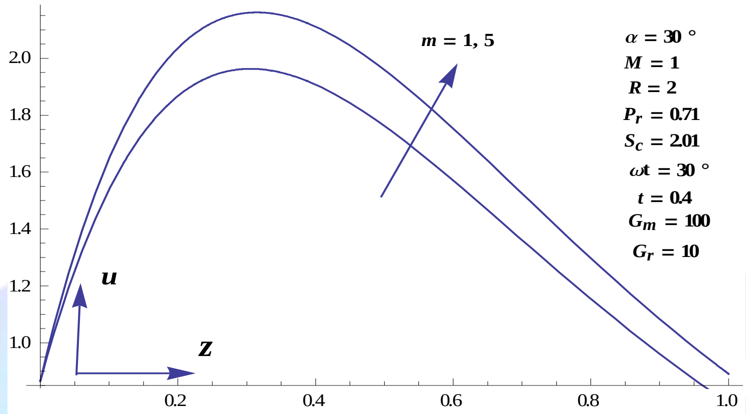

Figure 1.4: velocity *u* for different values of *m*

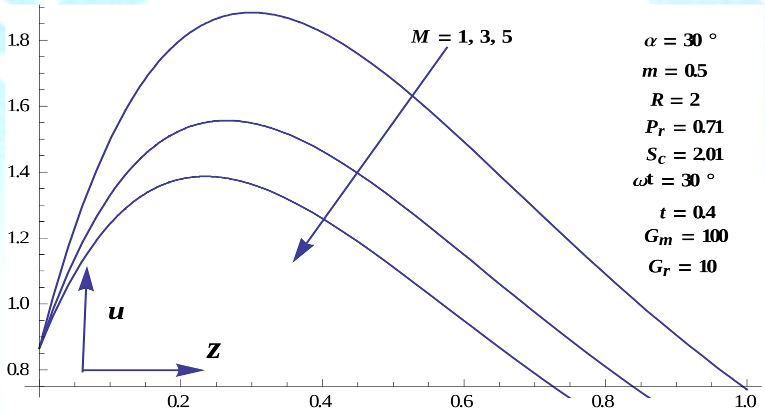

Figure 1.5: velocity *u* for different values of *M*

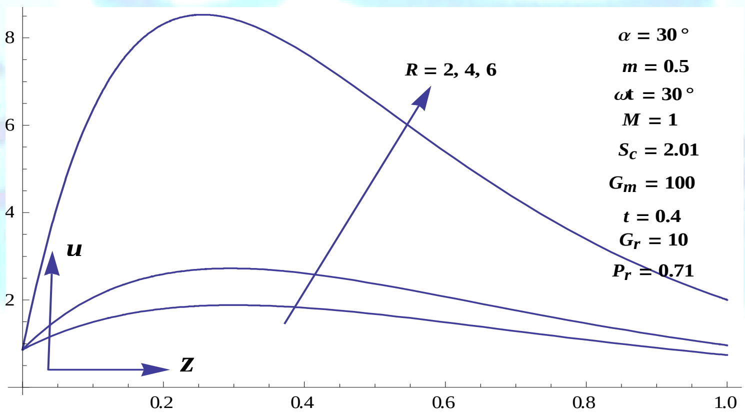

Figure 1.6: velocity *u* for different values of *R*

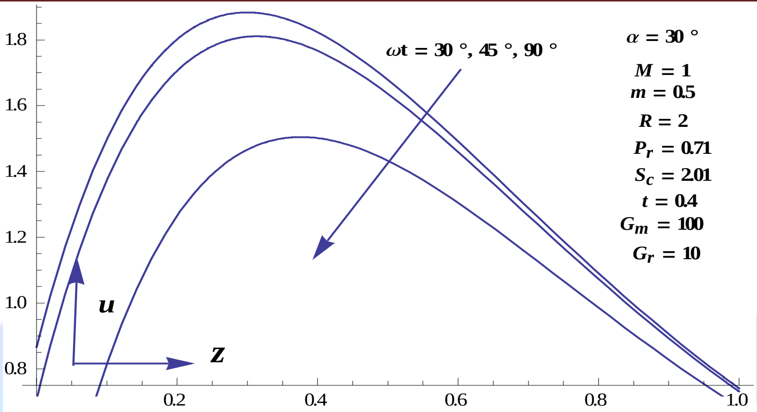

Figure 1.7: velocity *u* for different values of *ωt*

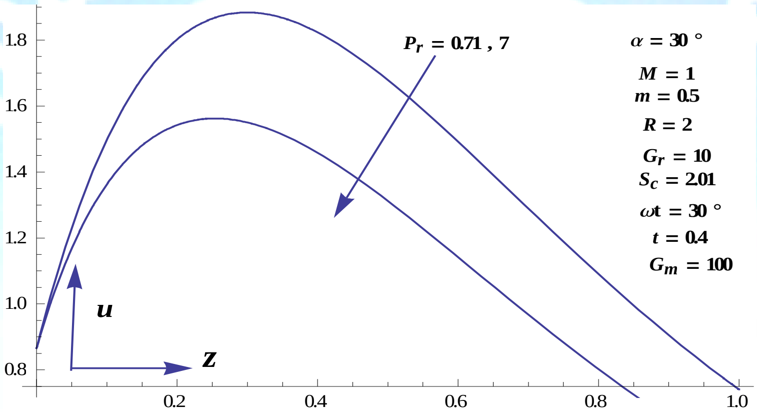

Figure 1.8: velocity *u* for different values of P_r

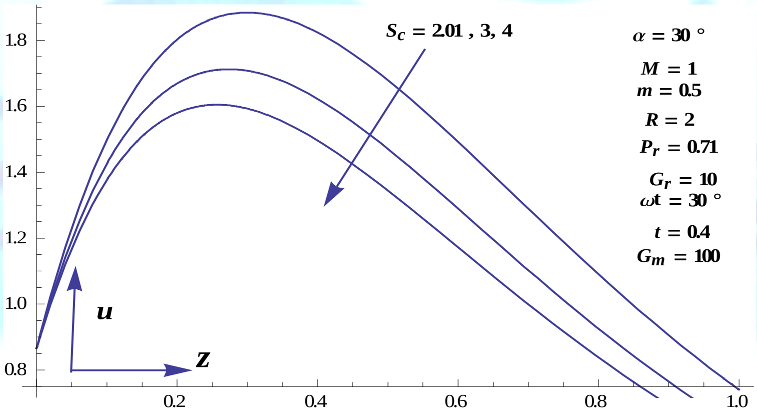

Figure 1.9: velocity *u* for different values of S_c

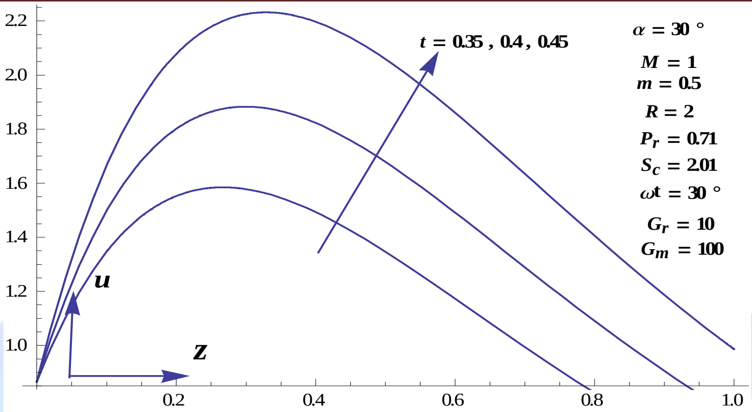

Figure 1.10: velocity u for different values of t

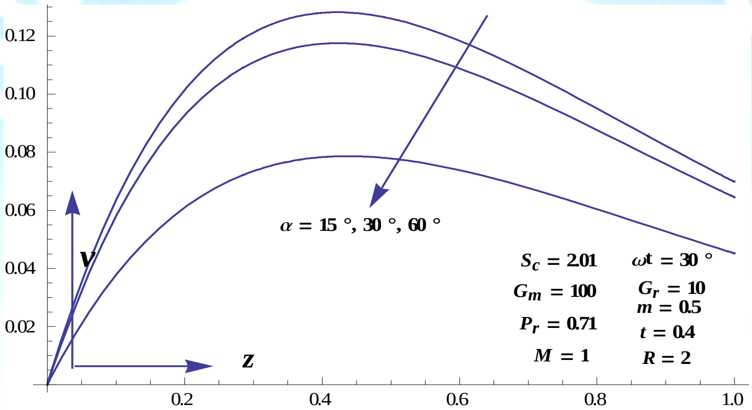

Figure 2.1: velocity v for different values of α

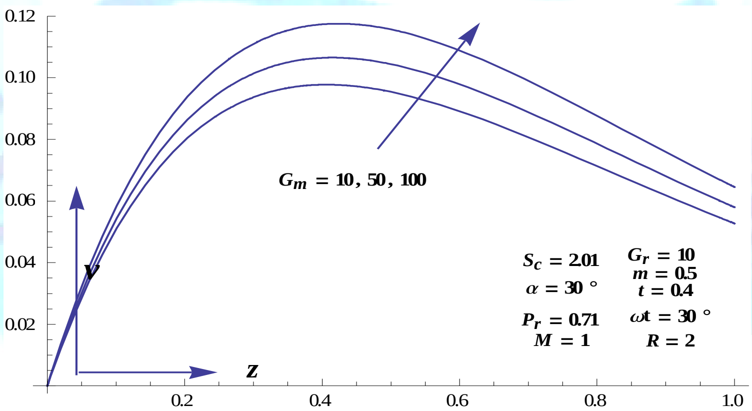

Figure 2.2: velocity v for different values of G_m

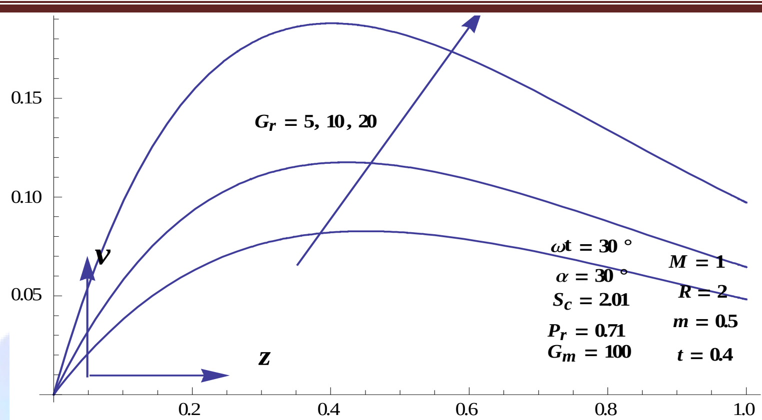

Figure 2.3: velocity *v* for different values of G_r

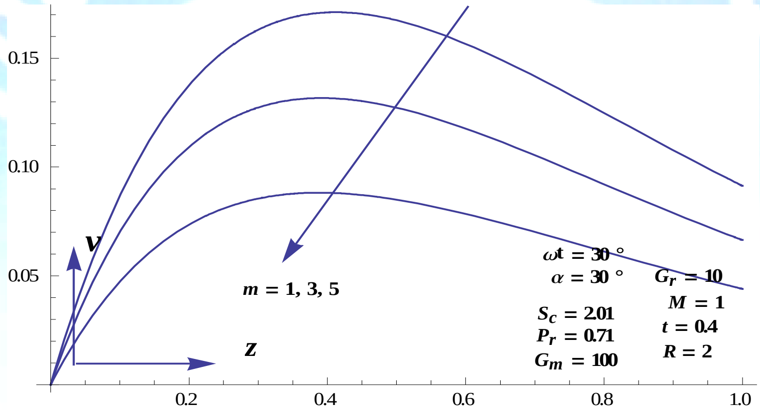

Figure 2.4: velocity *v* for different values of *m*

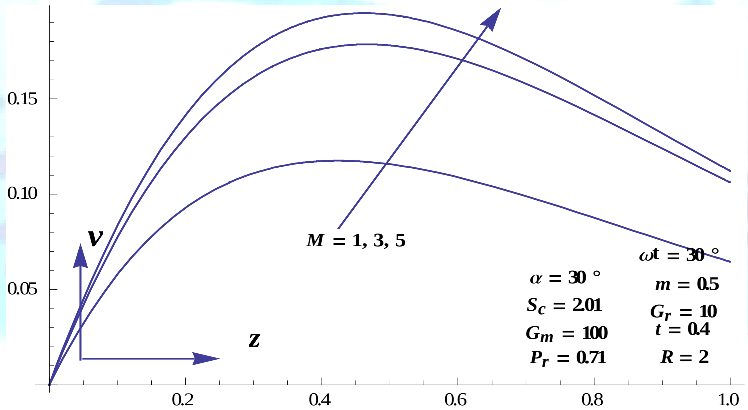

Figure 2.5: velocity *v* for different values of *M*

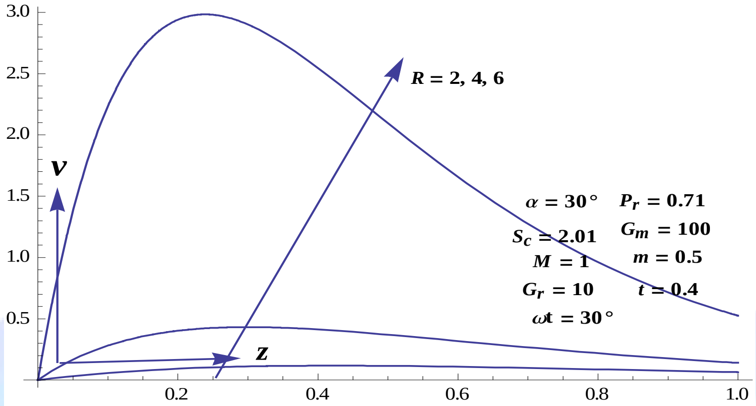

Figure 2.6: velocity *v* for different values of *R*

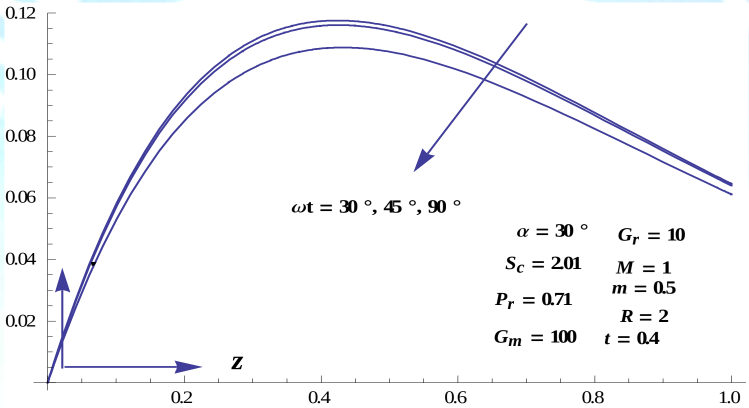

Figure 2.7: velocity *v* for different values of ωt

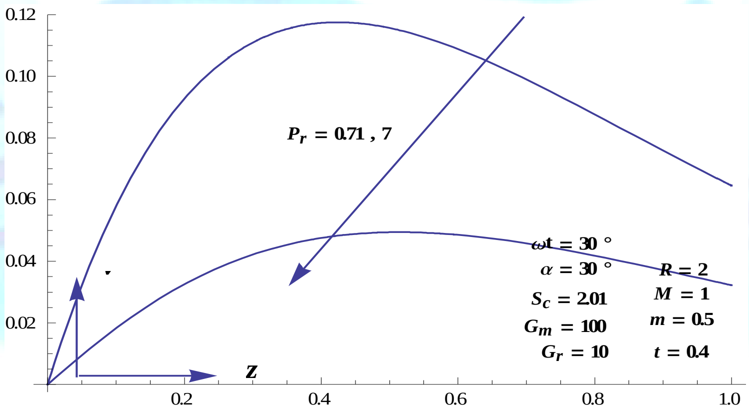

Figure 2.8: velocity *v* for different values of P_r

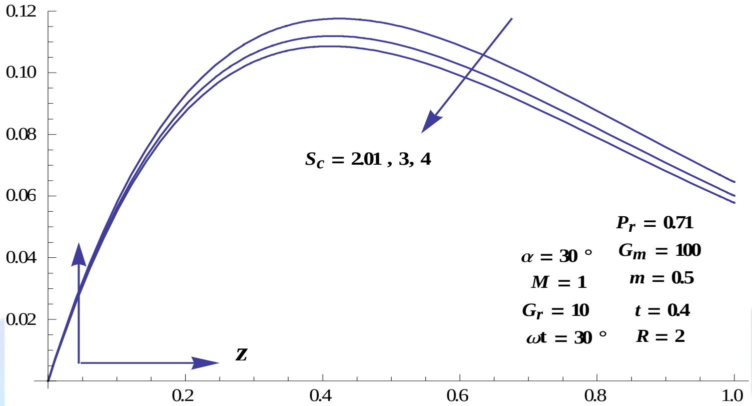

Figure 2.9: velocity *v* for different values of S_c

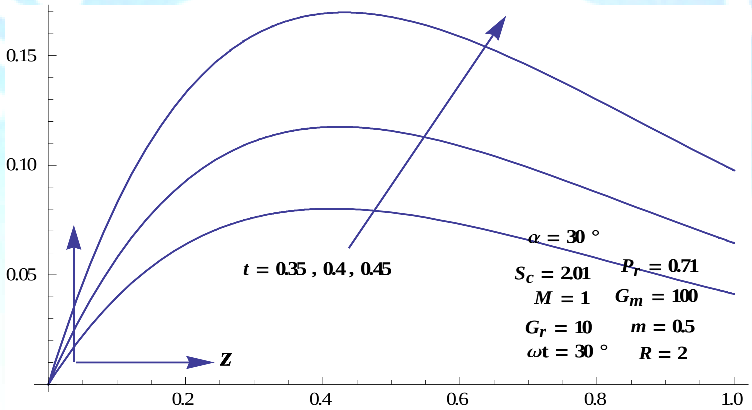

Figure 2.10: velocity *v* for different values of *t*

Table 1: Skin friction for different parameters (*α and ωt are in degrees*)

α	*M*	*m*	*Pr*	*Sc*	*Gm*	*Gr*	*R*	*ωt*	*t*	τ_x	τ_y
30	2	1	0.71	2.01	100	10	2	30	0.2	7265.81	1910.39
60	2	1	0.71	2.01	100	10	2	30	0.2	4194.47	1103.05
30	3	1	0.71	2.01	100	10	2	30	0.2	6091.64	2319.49
30	5	1	0.71	2.01	100	10	2	30	0.2	4245.91	2518.88
30	2	3	0.71	2.01	100	10	2	30	0.2	9267.64	1576.13
30	2	5	0.71	2.01	100	10	2	30	0.2	9705.92	1066.28
30	2	1	7.00	2.01	100	10	2	30	0.2	-0283.57	3.40679
30	2	1	0.71	3.00	100	10	2	30	0.2	7265.54	1910.38
30	2	1	0.71	4.00	100	10	2	30	0.2	7265.35	1910.37
30	2	1	0.71	2.01	050	10	2	30	0.2	7264.62	1910.37
30	2	1	0.71	2.01	100	50	2	30	0.2	36323.8	9550.90
30	2	1	0.71	2.01	100	100	2	30	0.2	72646.2	19101.6

30	2	1	0.71	2.01	100	10	4	30	0.2	12658.3	4156.81
30	2	1	0.71	2.01	100	10	6	30	0.2	24845.3	9866.12
30	2	1	0.71	2.01	100	10	2	45	0.2	7266.35	1910.37
30	2	1	0.71	2.01	100	10	2	60	0.2	7267.04	1910.34
30	2	1	0.71	2.01	100	10	2	30	0.3	17385.6	7494.87
30	2	1	0.71	2.01	100	10	2	30	0.4	31655.4	20386.3

Table 2: Nusselt number for different parameters

Pr	*R*	*t*	*Nu*
0.71	2	0.4	-0.805273
7.00	2	0.4	-1.959260
0.71	3	0.4	-0.894014
0.71	4	0.4	-0.976083
0.71	2	0.5	-0.950956
0.71	2	0.6	-1.094940

6 CONCLUSION

In this paper a theoretical analysis has been done to study effects radiation effect on unsteady MHD flow past an oscillating inclined plate with variable temperature and mass diffusion in the presence of Hall current. The flow model considered in the research has been solved by Laplace transform technique. The model consists of equations of motion, diffusion equation and equation of energy. To study the solutions obtained, standard sets of the values of the parameters have been considered. The numerical data obtained is discussed with the help of graphs and table. We found that the theoretical solution satisfies the actual flow pattern.

Appendix

$$A_0 = \frac{u_0^2 t}{\upsilon},\ A_1 = 1 + e^{2\sqrt{a}z}(1 - A_{18}) - A_{17},\ A_2 = -A_1,\ A_3 = 1 - e^{2\sqrt{a}z}(1 - A_{18}) - A_{17},$$

$$A_4 = -1 + A_{19} + A_{30}(A_{20} - 1),\ A_5 = -1 + A_{21} + A_{28}(A_{22} - 1),\ A_6 = -1 + A_{23} + A_{26}(A_{31} - 1),\ A_7 = -1 + A_{29} + A_{27}(A_{30} - 1),$$

$$A_8 = -1 + A_{23} + A_{26}(A_{31} - 1),\ A_9 = -1 - A_{24} - A_{28}(1 - A_{25}),\ A_{10} = -A_9,\ A_{11} = Abs[z].Abs[P_r],$$

$$A_{12} = \exp\left(\frac{at}{P_r - 1} - \frac{Rt}{P_r - 1} - z\sqrt{\frac{aP_r - R}{P_r - 1}}\right),\ A_{13} = \exp\left(\frac{at}{S_c - 1} - z\sqrt{\frac{aS_c}{S_c - 1}}\right),\ A_{12} = \exp\left(\frac{at}{P_r - 1} - \frac{Rt}{P_r - 1} - Abs[z]\sqrt{\frac{P_r(aP_r - R)}{P_r - 1}}\right),$$

$$A_{15} = -1 + erf\left[\frac{z\sqrt{S_c}}{2\sqrt{t}}\right]\ A_{16} = e^{Abs[z]\sqrt{P_r R}},\ A_{17} = erf\left[\frac{2\sqrt{a}t - z}{2\sqrt{t}}\right],\ A_{18} = erf\left[\frac{2\sqrt{a}t + z}{2\sqrt{t}}\right],$$

$$A_{19} = erf\left[\frac{z - 2t\sqrt{\frac{aP_r - R}{P_r - 1}}}{2t}\right],\ A_{20} = erf\left[\frac{z + 2t\sqrt{\frac{aP_r - R}{P_r - 1}}}{2t}\right],\ A_{21} = erf\left[\frac{z - 2t\sqrt{\frac{aS_c}{S_c - 1}}}{2t}\right],\ A_{22} = erf\left[\frac{z + 2t\sqrt{\frac{aS_c}{S_c - 1}}}{2t}\right],$$

$$A_{23} = erf\left[\frac{Abs[z].Abs[P_r]}{2\sqrt{t}} - \sqrt{\frac{tR}{P_r}}\right],\ A_{26} = e^{2Abs[z]\sqrt{P_r R}},\ A_{24} = erf\left[\frac{2t\sqrt{\frac{a}{S_c - 1}} - 2\sqrt{S_c}}{2t}\right],$$

$$A_{25} = erf\left[\frac{2t\sqrt{\frac{a}{S_c - 1}} + 2\sqrt{S_c}}{2t}\right],\ A_{27} = e^{2Abs[z]\sqrt{\frac{P_r(aP_r - R)}{P_r - 1}}},\ A_{28} = e^{-2z\sqrt{\frac{aS_c}{S_c - 1}}},\ A_{30} = e^{-2z\sqrt{\frac{aP_r - R}{P_r - 1}}},$$

$$A_{29} = erf\left[\frac{Abs[z].Abs[P_r]}{2\sqrt{t}} - \sqrt{\frac{t(R - aP_r)}{P_r(1 - P_r)}}\right],\ A_{31} = erf\left[\frac{Abs[z].Abs[P_r]}{2\sqrt{t}} + \sqrt{\frac{tR}{P_r}}\right],\ A_{32} = erf\left[\frac{Abs[z].Abs[P_r]}{2\sqrt{t}} + \sqrt{\frac{t(R - aP_r)}{P_r(1 - P_r)}}\right],$$

$$A_{33} = A_{34} + A_{35} - e^{-z\sqrt{a+i\omega}}A_{36} - e^{-z\sqrt{a+i\omega}+2it\omega}A_{37},\ A_{34} = e^{-z\sqrt{a+i\omega}} + e^{-z\sqrt{a-i\omega}},$$

$$A_{35} = e^{-z\sqrt{a+i\omega}+2it\omega} + e^{z\sqrt{a-i\omega}+2it\omega},\ A_{36} = erf\left[\frac{z - 2t\sqrt{a - i\omega}}{2\sqrt{t}}\right] + erf\left[\frac{z + 2t\sqrt{a - i\omega}}{2\sqrt{t}}\right],$$

$$A_{37} = erf\left[\frac{z - 2t\sqrt{a + i\omega}}{2\sqrt{t}}\right] + erf\left[\frac{z + 2t\sqrt{a + i\omega}}{2\sqrt{t}}\right],$$

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