RADIATION EFFECT ON UNSTEADY MHD FLOW THROUGH POROUS MEDIUM PAST AN EXPONENTIALLY ACCELERATED INCLINED PLATE WITH VARIABLE TEMPERATURE AND MASS DIFFUSION IN THE PRESENCE OF HALL CURRENT

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ABSTRACT
Radiation effect on unsteady MHD flow through porous medium past an exponentially accelerated inclined plate with variable temperature and mass diffusion in the presence of Hall current is studied here. The fluid considered is viscous, incompressible and electrically conducting.The flow is along an impulsively started exponentially accelerated inclined plate with variable wall temperature and mass diffusion. The magnetic field is applied perpendicular to the plate.The plate temperature and the concentration level near the plate increase linearly with time. The governing equations involved in the flow model are solved by the Laplace-transform technique. The results obtained have been analyzed with the help of graphs drawn for different parameters. The numerical values obtained for skin-friction and Nusselt number have been tabulated. The results are found to be in good agreement and the data obtained is in concurrence with the actual flow phenomenon.

Keywords: MHD flow, radiation, porous medium,accelerated plate, mass diffusion, Hall current.

1. INTRODUCTION

The influence of magnetic field on flow with heat and mass transfer plays important role in different area of science and technology. It has many applications in magnetic material processing, glass manufacturing control processes and purification of crude oil. Radiation effect on MHD flow is also significant in many cases. Some such problems already studied are mentioned here. Radiation effects on free convection flow past a semi-infinite vertical plate was analyzed by Soundalgekar and Takhar (1993). Raptis (1988) has considered radiation and free convection flow through a porous medium. Radiation and free convection flow past a moving plate was investigated Raptis and Perdikis (1999). The effect of radiation in free convection from a porous vertical plate was studied by Hossain et al. (1999). Raptis and Perdikis (2004) have worked on unsteady flow through a highly porous medium in the presence of radiation. Radiation effect on combined convection over a vertical flat plate embedded in a porous medium of variable porosity was presented by Pal and Mondal (2009). Vyas and Srivastava (2010) have analyzed radiative MHD flow over a non-isothermal stretching sheet in a porous medium. Rajput and Kumar (2013) have considered radiation effect on MHD flow through porous media past an impulsively started vertical plate with variable heat and mass transfer. Radiation effect on MHD flows past an infinite vertical plate with variable temperature and uniform mass diffusion was analyzed by Deka and Deka (2011). Some papers related with combined effects of Hall current with radiation are also mentioned here. Guchhait et al. (2013) have investigated combined effects of Hall current and radiation on MHD free convective flow in a vertical channel with an oscillatory wall temperature. Thamizhsudar and Pandurangan (2014) have worked on combined effects of radiation and Hall current on MHD flow past an exponentially accelerated vertical plate in the presence of rotation. Combined effects of Hall current and magnetic field on unsteady flow past a semi-infinite vertical plate with thermal radiation and heat source was studied bySrihari (2015). 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 was investigated by us (2016). The main purpose of the present investigation is to study the effect of radiation on unsteady MHD flow through porous medium past an exponentially accelerated inclined platewith variable temperature and mass diffusion in the presence of Hall current. The model has been solved using the Laplace transforms technique. The results are shown with the help of graphs and table.

2. MATHEMATICAL ANALYSIS

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

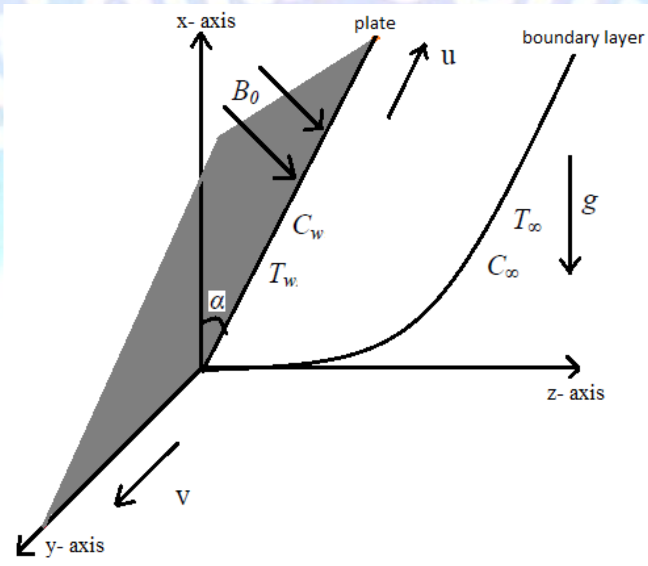

Figure-1

The x axis is taken along the vertical plane and z axis is normal to it. The plate is inclined at angle α from vertical. A transverse magnetic field B_0 of uniform strength is applied on the flow. Initially it has been considered that the plate as well as the fluid is at the same temperature T_∞. The species concentration in the fluid is taken as C_∞. At time $t > 0$, the plate starts exponentially accelerating in its own plane with velocity $u=u_0 e^{bt}$, 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:

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

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

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

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

The initial and boundary conditions are

$$\left.\begin{aligned} &t \le 0 : u = 0,\ v = 0,\ T = T_\infty,\ C = C_\infty, \text{for every } z. \\ &t > 0 : u = u_0 e^{bt},\ v = 0,\ T = T_\infty + (T_w - T_\infty)\frac{u_0^2 t}{\upsilon},\ C = C_\infty + (C_w - C_\infty)\frac{u_0^2 t}{\upsilon}, \text{at } z=0. \\ &u \to 0,\ v \to 0,\ T \to T_\infty,\ C \to C_\infty \text{ as } z \to \infty. \end{aligned}\right\} \quad (5)$$

Here *u* and v are the primary and the secondary velocities along x and z respectively, v- the kinematic viscosity, *ρ*- the density, C_p- the specific heat at constant pressure, k- thermal conductivity of the fluid, *K*- the permeability parameter, *D*- the mass diffusion coefficient, g- gravitational acceleration, *β*- volumetric coefficient of thermal expansion, *t*- time,m- the Hall current parameter, *T*- temperature of the fluid, β^*- volumetric coefficient of concentration expansion, *C*- species concentration in the fluid, T_w- temperature of the plate, C_w- species concentration, B_0- the uniform magnetic field, *σ*- electrical conductivity, K- the permeability parameter.

The local radiant for the case 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 expressed as the linear function of temperature. This is accomplished by expanding T^4 in a Taylor series about T_∞ and 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:

$$\left.\begin{aligned} &\bar{z} = \frac{zu_0}{\upsilon},\ \bar{u} = \frac{u}{u_0},\ \bar{v} = \frac{v}{u_0},\ \theta = \frac{(T - T_\infty)}{(T_w - T_\infty)},\ \mu = \rho\upsilon,\ P_r = \frac{\mu c_p}{k}, R = \frac{16a^*\sigma\upsilon^2 T_\infty^3}{ku_0^2}, \bar{C} = \frac{(C - C_\infty)}{(C_w - C_\infty)}, \\ &G_r = \frac{g\beta\upsilon(T_w - T_\infty)}{u_0^3},\ M = \frac{\sigma B_0^2\upsilon}{\rho u_0^2},\ G_m = \frac{g\beta^*\upsilon(C_w - C_\infty)}{u_0^3},\ S_c = \frac{\upsilon}{D}, \bar{K} = \frac{u_0}{\upsilon^2}K,\ \bar{b} = \frac{b\upsilon}{u_0^2},\ \bar{t} = \frac{tu_0^2}{\upsilon}. \end{aligned}\right\} (9)$$

The symbols in dimensionless form are as under:

θ - the temperature, $\bar{C}$ - the concentration, G_r - thermal Grashof number, $\bar{u}$ - the primary velocity, $\bar{v}$ - the secondary velocity, , *μ*- the coefficient of viscosity, P_r- the Prandtl number, S_c- the Schmidt number, $\bar{K}$ -the permeability parameter, $\bar{t}$ - time, G_r- mass Grashof number, *H*-heat absorption parameter, *M*- the magnetic parameter, $\bar{K}$ - the permeability parameter.

Thus the model becomes

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

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

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

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

The corresponding boundary conditions become

$$\left.\begin{array}{l} \bar{t} \le 0 : \bar{u} = 0,\ \bar{v} = 0,\ \theta = 0,\ \bar{C} = 0, \text{for every } \bar{z} \\ \bar{t} > 0 : \bar{u} = e^{\bar{b}\bar{t}},\ \bar{v} = 0,\ \theta = \bar{t},\ \bar{C} = \bar{t}, \text{at } \bar{z} = 0 \\ \bar{u} \to 0,\ \bar{v} \to 0,\ \theta \to 0,\ \bar{C} \to 0, \text{ as } \bar{z} \to \infty \end{array}\right\} \quad (14)$$

Dropping bars in the above equations, we get

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial z^2} + G_r Cos\alpha\,\theta + G_m Cos\alpha\,C - \frac{M(u+mv)}{(1+m^2)} - \frac{1}{K}u \quad (15)$$

$$\frac{\partial v}{\partial t} = \frac{\partial^2 v}{\partial z^2} + \frac{M(mu-v)}{(1+m^2)} - \frac{1}{K}v \quad (16)$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} \quad (17)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2} - \frac{R\theta}{P_r} \quad (18)$$

The boundary conditions are

$$\left.\begin{array}{l} t \le 0 : u = 0, v = 0, \theta = 0, C = 0, \text{for every } z \\ t > 0 : u = e^{bt}, v = 0,\ \theta = t,\ C = t, \text{at } z=0 \quad (19) \\ u \to 0,\ v \to 0,\ \theta \to 0,\ C \to 0, \text{as } z \to \infty \end{array}\right\}$$

Combining equations (15) and (16), the model becomes

$$\frac{\partial q}{\partial t} = \frac{\partial^2 q}{\partial z^2} + G_r Cos\alpha\,\theta + G_m Cos\alpha\,C - qa \quad (20)$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} \quad (21)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2} - \frac{R\theta}{P_r} \quad (22)$$

Finally, the boundary conditions become:

$$\left.\begin{array}{l} t \le 0: q = 0, \theta = 0, C = 0, \text{for every } z \\ t > 0: q = e^{\bar{b}\bar{t}}, \theta = t, C = t, \text{at } z=0 \\ q \to 0,\ \theta \to 0,\ C \to 0, \text{as } z \to \infty \end{array}\right\} \quad (23)$$

Here $q = u + i\,v$, $a = \dfrac{M(1-im)}{1+m^2} + \dfrac{1}{K}$.

The dimensionless governing equations (20) to (22), subject to the boundary conditions (23), are solved by the usual Laplace - transform technique. The solution obtained is as under:

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

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

$$q = \frac{1}{2}e^{-\sqrt{a}z}A_{33} + \frac{G_r Cos\alpha}{4(a-R)^2}[2e^{-\sqrt{a}z}(A_1 + P_r A_2) + 2tA_2 e^{-\sqrt{a}z}(a-R) + zA_3 e^{-\sqrt{a}z}(\sqrt{a} - \frac{R}{\sqrt{a}})$$
$$+ 2A_{12}A_4(1-P_r)] + \frac{G_m Cos\alpha}{4a^2}[e^{-\sqrt{a}z}(2A_1 + 2\sqrt{a}A_3) + 2e^{-\sqrt{a}z}A_2(S_c + at) + 2A_{13}A_5(1-S_c)]$$
$$- \frac{P_r G_r Cos\alpha}{2\sqrt{\pi}(a-R)^2 A_{11}}[A_{16}A_6\sqrt{\pi}z(at - 1 - Rt + P_r) + A_{14}A_7\sqrt{\pi}z(1-P_r) + \frac{1}{2\sqrt{R/P_r}}A_{16}A_8A_{11} \text{ The}$$
$$\sqrt{\pi}z(a-R)] - \frac{G_m Cos\alpha}{2a^2\sqrt{\pi}}[2az\sqrt{S_c}e^{-\frac{z^2 S_c}{4t}}\sqrt{t} + A_{15}\sqrt{\pi}(az^2 S_c + 2at + 2S_c - 2) + A_{13}\sqrt{\pi}(A_9$$
$$+ A_{10}S_c)]$$

expressions for the constants involved in the above equations are given in the appendix.

2.1 SKIN FRICTION

Now we calculate the non-dimensional form of the skin friction from the velocity field as

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

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

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 numerical values of Nusselt number are given in table-2for different parameters.

3. RESULT AND DISCUSSIONS

In this present paper we have studied the effects of radiation and permeability of porous medium on the flow. The behavior of other parameters like magnetic field, Hall current and thermal buoyancy is almost similar to the earlier model studied by us (2016). The analytical results are shown graphically in figures 2 to 8. Effect of radiation on fluid is shown by figures 2 and 3. It is seen here that when radiation parameter *R* increases, primary and secondary velocities increase throughout the boundary layer region. This implies that effect of radiation tends to accelerate fluid velocity in the boundary layer region. From figures 4 and 5, it is observed that primary and secondary velocities increase with permeability parameter *(K)*. This result is due to the fact that increases in the value of *(K)* results in reducing the drag force, and hence increasing the fluid velocity. It is deduced that velocities are increases when acceleration parameter b is increased (figures 6 and 7). Further, it is observed that the temperature decreases when Prandtl number and radiation parameter are increased (figures 6 and 7). However, from figure 8 it is observed that the temperature increases with time. This is due the reason heat is transported to the system continuously.

The numerical values of skin friction are given in table 1. The value ofτ_x increases with the increase in *R* and *K*. But theτ_x decreases with *b*. The value ofτ_y increases with the increase in *R*, *K* and *b*. The numerical values of Nusselt number are presented in table 2. The value of Nusselt number decreases with increases in *Pr, R* and *t*.

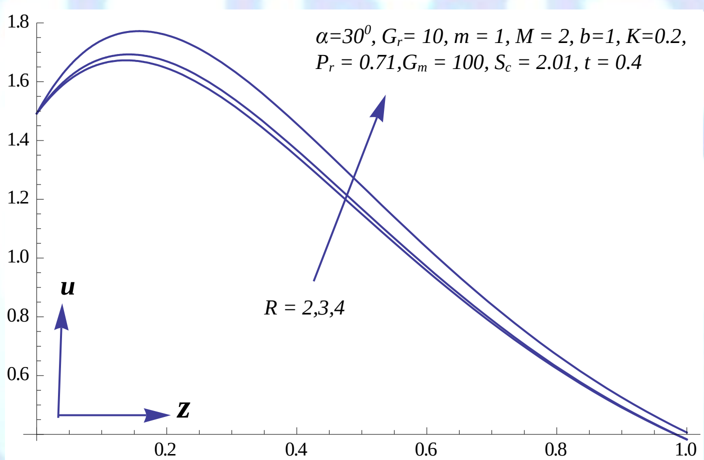

Figure 2: Velocity *u* for different values of *R*

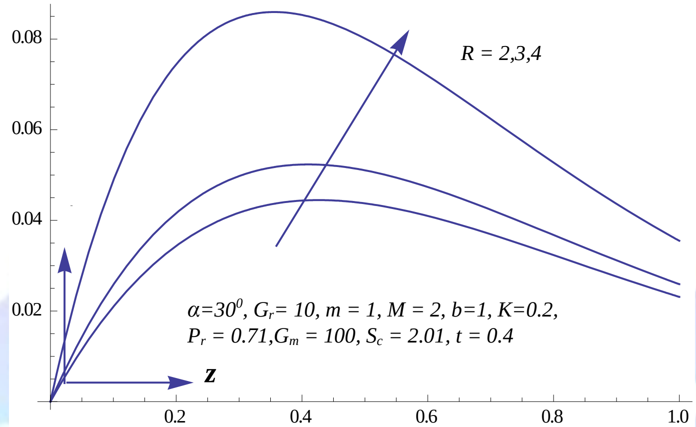

Figure 3: Velocity v for different values of R

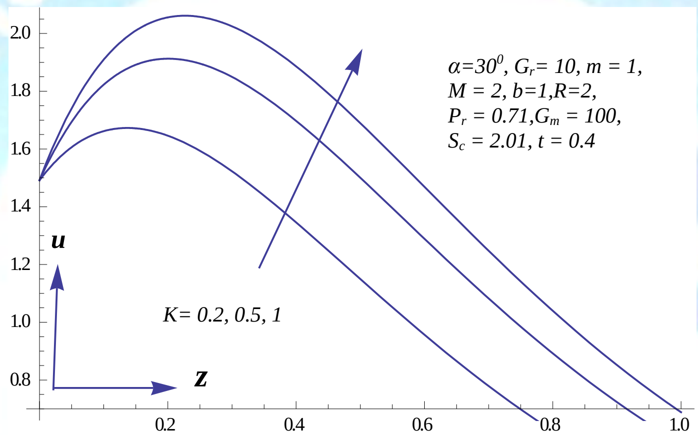

Figure 4: Velocity u for different values of K

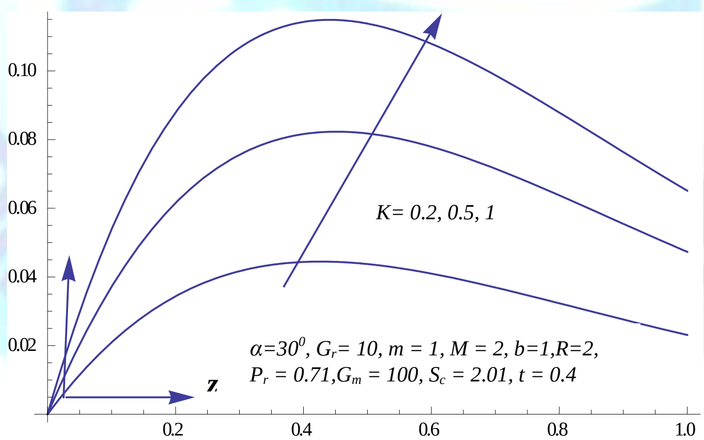

Figure 5: Velocity v for different values of K

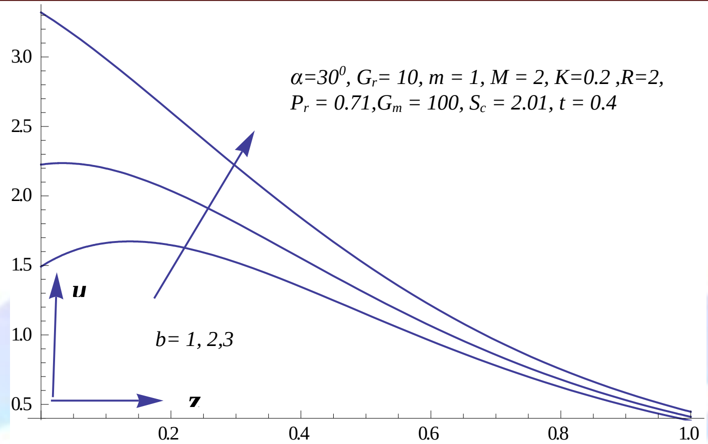

Figure 6: Velocity u for different values of b

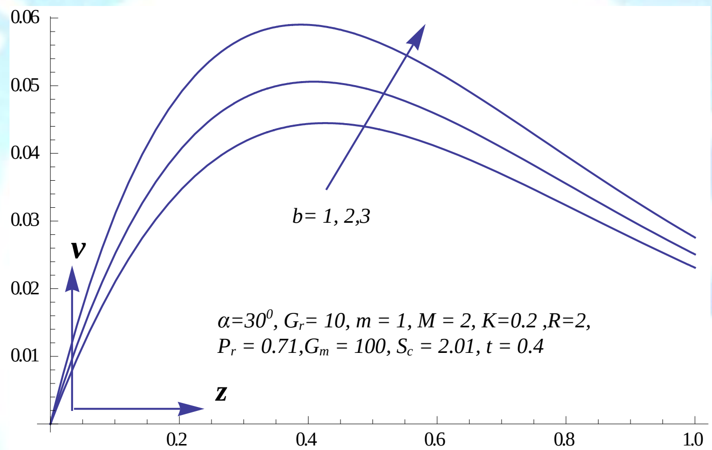

Figure 7: Velocity v for different values of b

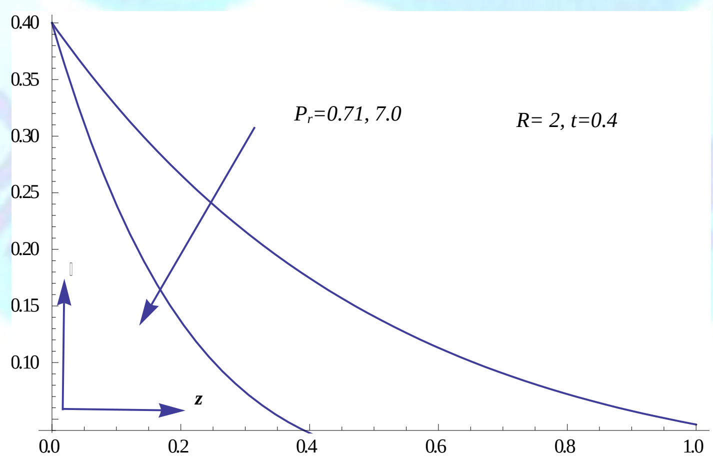

Figure 8: Temperature θ for different values of P_r

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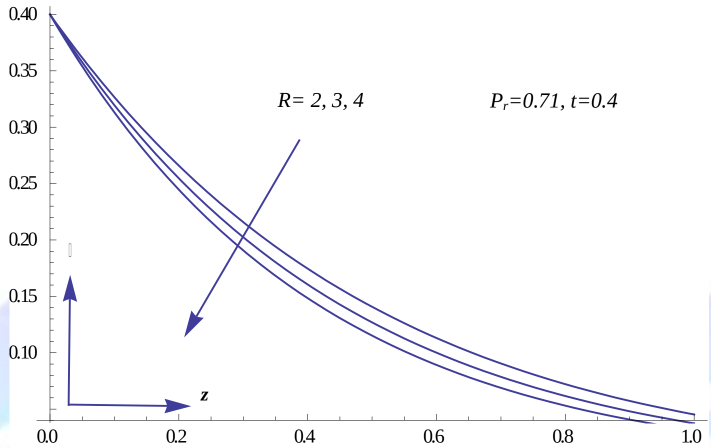

Figure 9: Temperature θ for different values of R

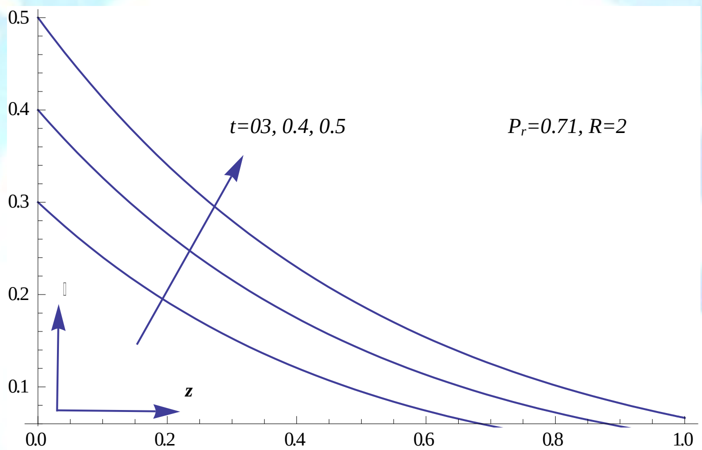

Figure 10: Temperature θ for different values of t

Table 1: Skin friction for different parameters

α (in degree)	M	m	Pr	Sc	Gm	Gr	R	K	b	t	τ_x	τ_y
30	2	1	0.71	2.01	100	10	3	0.2	1	0.4	96.5013134	22.7388253
30	2	1	0.71	2.01	100	10	4	0.2	1	0.4	121.840992	35.6504160
30	2	1	0.71	2.01	100	10	2	0.5	1	0.4	163.427044	60.5973789
30	2	1	0.71	2.01	100	10	2	1.0	1	0.4	232.476375	112.396113
30	2	1	0.71	2.01	100	10	2	0.2	2	0.4	77.2167023	15.6189863
30	2	1	0.71	2.01	100	10	2	0.2	3	0.4	73.6675274	15.7685801

T

able 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

4. CONCLUSION

In this paper a theoretical analysis has been done to study effects of radiation and porosity of the medium on unsteady MHD flow past exponentially accelerated inclined plate with variable temperature and mass diffusion in the presence of Hall current. It is observed that the primary velocity increases with increasing the values of radiation parameter, acceleration parameter and permeability of the porous medium. The effect is similar on the secondary velocity. The skin friction at the plate is increases with increase in radiation parameter and permeability of the porous medium. The Nusselt number decreases with increases in radiation parameter

5. APPLICATIONS OF THE STUDY

This study is expected to be useful in understanding the influence of magnetic field and Hall current on astrophysical problems. Moreover, the findings of the research will be useful in improving the devices like Hall accelerators and Hall sensors. It is also useful to study the flow of plasma in MHD power generators, enhanced oil recovery and filtration systems. The importance of the problem can be seen in cooling of electronic components of a nuclear reactor, bed thermal storage and heat sink in the turbine blades.

6. APPENDEX:

$$A_1 = 1 + e^{2\sqrt{a}z}(1 - A_{18}) - A_{17},\ A_2 = -A_1,\ A_3 = 1 - e^{2\sqrt{a}z}(1 - A_{18}) - A_{17},\ A_4 = -1 + A_{19} + A_{30}(A_{20} - 1),$$

$$A_5 = -1 + A_{21} + A_{28}(A_{22} - 1),\ A_6 = -1 + A_{23} + A_{26}(A_{31} - 1),\ A_7 = -1 + A_{29} + A_{27}(A_{30} - 1),\ A_8 = -1 + A_{23} + A_{26}(A_{31} - 1),$$

$$A_9 = -1 - A_{24} - A_{28}(1 - A_{25}),\ A_{10} = -A_9,\ A_{11} = Abs[z].Abs[P_r],\ A_{12} = e^{\frac{at}{P_r - 1} - \frac{Rt}{P_r - 1} - z\sqrt{\frac{aP_r - R}{P_r - 1}}},$$

$$A_{13} = e^{\frac{at}{S_c - 1} - z\sqrt{\frac{aS_c}{S_c - 1}}},\ A_{12} = e^{\frac{at}{P_r - 1} - \frac{Rt}{P_r - 1} - Abs[z]\sqrt{\frac{P_r(aP_r - R)}{P_r - 1}}},\ A_{15} = -1 + erf[\frac{z\sqrt{S_c}}{2\sqrt{t}}]\ A_{16} = e^{Abs[z]\sqrt{P_r R}},$$

$$A_{17} = erf[\frac{2\sqrt{a}t - z}{2\sqrt{t}}],\ A_{18} = erf[\frac{2\sqrt{a}t + z}{2\sqrt{t}}],\ A_{19} = erf[\frac{z - 2t\sqrt{\frac{aP_r - R}{P_r - 1}}}{2t}],\ A_{20} = erf[\frac{z + 2t\sqrt{\frac{aP_r - R}{P_r - 1}}}{2t}],$$

$$A_{21} = erf[\frac{z - 2t\sqrt{\frac{aS_c}{S_c - 1}}}{2t}],\ A_{22} = erf[\frac{z + 2t\sqrt{\frac{aS_c}{S_c - 1}}}{2t}],\ A_{23} = erf[\frac{Abs[z].Abs[P_r]}{2\sqrt{t}} - \sqrt{\frac{tR}{P_r}}],\ A_{24} = erf[\frac{2t\sqrt{\frac{a}{S_c - 1}} - 2\sqrt{S_c}}{2t}],$$

$$A_{25} = erf[\frac{2t\sqrt{\frac{a}{S_c - 1}} + 2\sqrt{S_c}}{2t}],\ A_{26} = e^{2Abs[z]\sqrt{P_r R}},\ A_{27} = e^{2Abs[z]\sqrt{\frac{P_r(aP_r - R)}{P_r - 1}}},\ A_{28} = e^{-2z\sqrt{\frac{aS_c}{S_c - 1}}},$$

$$A_{29} = erf[\frac{Abs[z].Abs[P_r]}{2\sqrt{t}} - \sqrt{\frac{t(R - aP_r)}{P_r(1 - P_r)}}],\ A_{30} = e^{-2z\sqrt{\frac{aP_r - R}{P_r - 1}}},\ A_{31} = erf[\frac{Abs[z].Abs[P_r]}{2\sqrt{t}} + \sqrt{\frac{tR}{P_r}}],$$

$$A_{32} = erf[\frac{Abs[z].Abs[P_r]}{2\sqrt{t}} + \sqrt{\frac{t(R - aP_r)}{P_r(1 - P_r)}}],\ A_{33} = 1 + A_{34} + e^{2\sqrt{a+bz}} A_{35},\ A_{34} = erf[\frac{2\sqrt{a + bt} - z}{2\sqrt{t}}],$$

$$A_{35} = erfc[\frac{2\sqrt{a + bt} + z}{2\sqrt{t}}],$$

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