

Effects of Hall Current on MHD Flow Past an Exponentially Accelerated Inclined Plate in the Presence of Rotation

LOGANATHAN S[1], THAMIZHSUDAR M [2], MUTHUCUMARASWAMY R[3]

[1] Assistant professor, Department of Mathematics, School of Arts and Science, AV Campus, Vinayaka Missions Research Foundation(DU), Chennai, Tamil Nadu, India

[2] Assistant Professor, Department of Mathematics, Aarupadai veedu Institute of Technology, Vinayaka Missions Research Foundation(DU), Chennai, Tamil Nadu, India
[3] Professor, Department of Applied Mathematics, Sri Venkateswara college of Engineering, Sriperumbudur,Tamil Nadu, India

Abstract

A theoretical solution of magneto hydro dynamic fluid flow past an exponentially accelerated inclined plate in the presence of Hall current relative to the rotating fluid with uniform temperature and mass diffusion is presented with uniform magnetic field. The dimensionless equations are solved using Laplace method. Effects of various parameters like Schmidt number, Prandtl number, Hall parameter (m), Hartmann number (M), Rotation parameter (Ω), thermal Grashof number (Gr), mass Grashof number (Gc) and the angle of inclination(α) on the axial and transverse velocity are studied and shown graphically.

Key words: *Hall effect, MHD flow, exponentially, Inclined plate, Rotation parameter.*

Introduction

MHD flow problem associated with heat and mass transfer plays an important role in different areas of science and technology. Such flows are driven by the multiple buoyancy effects arising from the density variations caused by the variations in temperature as well as species concentrations. The study of MHD flow an electrically conducting fluid in the presence of a magnetic fluid has sparked a lot of interest and concern due its application in petroleum industry, gas turbines, plasma physics, food processing industries, geothermal energy, nuclear power plants, cooling of nuclear reactors and lubrication industries, etc. It is also widely utilized in laboratory for chemical, medicinal and biological research.

Heat and mass transfer in MHD boundary layer flow past an inclined plate with viscous dissipation in porous medium was studied by Singh [7]. Saidul Islam et al.[12] have analyzed the MHD free convection and mass transfer flow with heat generation through an inclined plate. They found that velocity distribution increases with the increases of magnetic parameter while the temperature and concentration distribution increase with increase of Magnetic parameter. Sudersan Reddy et.al [20] have investigated the radiation and chemical reaction effects on MHD heat and mass transfer flow inclined porous heat plate. Mohana Ramana and Girish Kumar [11] analyzed the chemical reaction effects on MHD free convective flow past an inclined plate. Rajput and Gaurav Kumar [15] studied an unsteady MHD flow past an impulsively started

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inclined plate with variable temperature and mass diffusion in the presence of Hall current using Laplace transform technique. They found that the velocity in the boundary layer increases with the values of Hall current parameter. Gilbert Magiboi Nalisi et.al [3] have investigated Unsteady MHD free convective flow past an inclined parabolic accelerated plate with Hall current, radiation effects and variable temperature in a porous medium. Jothi and Selvaraj[9] have discussed the Performance of Dufour Effect on Unsteady MHD Flow past through Porous Medium an Exponentially Accelerated Inclined Vertical plate with Variable Temperature and Mass Diffusion. Dufour Effect on MHD Free Convection Heat and Mass Transfer Effects Flow over an Inclined Plate Embedded in a Porous Medium solved using the closed analytical method was studied by Islam and Begum[6]. They discussed that velocity profile decreases with the increase of Hartmann number, heat source parameter, radiation parameter whereas the velocity profile increases with the increasing values of Dufour number, Schmidt number, Grashof number, dimensionless time, Prandtl number. Rajput and Neetu Kananujia [17] have discussed effects of Hall current on MHD flow past a rotating inclined plate with heat transfer and mass diffusion. It is observed that the both velocities (viz primary and secondary) effects is similar at the parameters i.e. heat absorption, and angle of inclination of plate. Rajput and Gaurav Kumar [16] has analyzed rotation and radiation effects on MHD flow past an inclined plate with variable wall temperature and mass diffusion in the presence of Hall current. It has been found that the velocity in the boundary layer region decreases with the values of radiation parameter. Balamurugan et al[1] examined how Heat and mass transfer effects on linearly accelerated isothermal inclined plate using Laplace Transform method. They discussed that the fluid velocity is reduced by radiation parameter, Prandtl number and inclined angle parameter. Steady on MHD heat and mass transfer flow of an inclined porous plate in the presence of radiation and chemical reaction was studied by Sandhiya et.al [18]. They observed that velocity decreases with the increase of magnetic field parameter, chemical reaction parameter, Schmidt number, heat source parameter, Prandtl number and angle of inclination.

Husna Izzati Osman et al[5] analyzed the Study of MHD Free Convection Flow Past an Infinite Inclined Plate using Laplace Transform technique. They observed that the increment value of inclination angle accelerates the fluid motion along the plate. Bijoy Krishna Taid and Nazibuddin Ahmid [2] analyzed the MHD free convective flow across an inclined porous plate in the presence of heat source, soret effect and chemical reaction affected by viscous dissipation ohmic heating. MHD casson fluid flow with an inclined plate in the presence of hall and aligned magnetic effects are solved using perturbation method was studied by Kranthi kumar et al[10]. They observed that fluid velocity is decreased in increasing angle of inclination. Vijayaragavan et al[21] have investigated Heat and mass transfer effect of a Magnetohydrodynamic Casson fluid flow in the presence of inclined plate by

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Laplace transformation process. They noticed that with an increase in the Dufour number, the axial velocity decreases and it is also noted that the concentration of the species decreases with an increase in the Dufour number. Singh [8] have studied Hall and induced magnetic field effects an convective flow of viscoelastic fluid within an inclined channel with periodic surface condition. Sudarsana Reddy and Sreedevi[19]have studied MHD boundary layer heat and mass transfer flow of nanofluid through porous media over inclined plate with chemical reaction. Raghunath Kodi and Venkateswaraju Konuru[14] have studied Heat and mass transfer on MHD convective unsteady flow of a Jeffery fluid past an inclined vertical porous plate with thermal diffusion Soret and Aligned magnetic field. Gollapalli Shankar et al[4] have studied Heat and mass transfer effects on unsteady MHD flow a past an inclined plate embedded in porous medium in the presence of hall current and viscous dissipation. Muthucumaraswamy et.al [13] have worked on Hall effects and rotation effects on MHD flow past an exponentially accelerated vertical plate with combined heat and mass transfer effects. They solved the governing flow model by using Laplace transform technique and observed that the both axial and transverse velocities increase with decreasing values of magnetic field parameter. We, in a sense, are extending work to study the effect of Hall current on MHD flow past an exponentially accelerated inclined plate in the presence of rotation. The effect of Hall current on the both axial and transverse velocities are observed with the help of graphs.

Mathematical Formulation

We consider an electrically conducting viscous incompressible fluid past an infinite plate occupying the plane $z'=0$. The x'-axis is taken in the direction of the motion of the plate and y'-axis is normal to both x' and z' axes. Initially, the fluid and the plate rotate in unison with a uniform angular velocity Ω' about the z'-axis normal to the plate, also the temperature of the plate and concentration near the plate are assumed to be T_∞ *and* c'_∞. At time $t' > 0$, the plate is exponentially accelerated with a velocity $u' = \frac{u_0}{A}\exp(a't')$ in its own plane along x'-axis and the temperature from the plate raised to T_w and the concentration level near the plate is kept at c'_w. Here the plate is electrically non conducting. Also, a uniform magnetic field B_0 is applied parallel to z'-axis. Also the pressure is uniform in the flow field. Let u', v', w' represent the components of the velocity vector F. The equation of continuity $\nabla.F = 0$ gives $w' = 0$ everywhere in the flow. Here the flow quantities depend on z' and t' only and it is assumed that the flow far away from the plate is undisturbed. Under these assumptions the unsteady flow is governed by the following equations.

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$$\frac{\partial u'}{\partial t'} = \upsilon \frac{\partial^2 u'}{\partial z'^2} + 2\Omega' v' - \frac{\sigma \mu_e^2 B_0^2}{\rho(1+m^2)}(u' + mv')$$
$$+g\beta(T\text{-}T_\infty)\ cos\alpha + g\beta^*(c'\text{-}c'_\infty)\ cos\alpha \quad (1)$$

$$\frac{\partial v'}{\partial t'} = \upsilon \frac{\partial^2 v'}{\partial z'^2} - 2\Omega' u'$$
$$+\frac{\sigma \mu_e^2 B_0^2}{\rho(1+m^2)}(mu' - v') \quad (2)$$

$$\rho\, c_p \frac{\partial T}{\partial t'} = K \frac{\partial^2 T}{\partial z'^2} \quad (3)$$

$$\frac{\partial c'}{\partial t'} = D \frac{\partial^2 c'}{\partial z'^2} \quad (4)$$

Where u' is the axial velocity and v' is the transverse velocity. The prescribed initial and boundary conditions are

$$u' = 0, v' = 0, T = T_\infty, c' = c'_\infty$$
$$\text{at } t' \le 0 \ \ for\ all\ \ z'$$

$$u' = \frac{u_0}{A} e^{a' t'},\ v' = 0, T = T_w, c' = c'_w$$
$$at\ \ z' = 0\ \ for\ all\ \ t' > 0$$

$$u' \to 0, v' \to 0, T \to T_\infty,$$
$$c' \to c'_\infty\ \ as\ \ z' \to \infty$$

where $A = \left(\frac{u_0^2}{\upsilon}\right)^{\frac{1}{3}}$ is a constant.

On introducing the following non-dimensional quantities,

$$u = \frac{u'}{(u_0 \upsilon)^{\frac{1}{3}}}, \quad v = \frac{v'}{(u_0 \upsilon)^{\frac{1}{3}}},$$
$$z = z' \left(\frac{u_0}{\upsilon^2}\right)^{\frac{1}{3}}, \quad t = \left(\frac{u_0{}^2}{\upsilon}\right)^{\frac{1}{3}} t',$$
$$\Omega = \Omega' \left(\frac{\upsilon}{u_0^2}\right)^{\frac{1}{3}}, \quad M^2 = \frac{\sigma\, \mu_e^2\, B_0^2\, \upsilon^{\frac{1}{3}}}{2\, \rho\, u_0^{\frac{2}{3}}},$$

$$a = \left(\frac{\upsilon}{u_0^2}\right)^{\frac{1}{3}} a', Gc = \frac{g\beta^*(c'_w - c'_\infty)}{u_0},$$
$$Gr = \frac{g\beta(T_w - T_\infty)}{u_0}, \quad C = \frac{c' - c'_\infty}{c'_w - c'_\infty}$$
$$\theta = \frac{T - T_\infty}{T_w - T_\infty}, \quad Pr = \frac{\mu\, c_p}{K}, \quad Sc = \frac{\upsilon}{D}$$

The equations (1), (2), (3) and (4) reduce to the following non-dimensional form of governing equations

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial z^2} + 2\,\Omega\, v - \frac{2M^2}{1+m^2}(u + mv)$$
$$+Gr\theta\ cos\alpha + GcC\ cos\alpha \quad (5)$$

$$\frac{\partial v}{\partial t} = \frac{\partial^2 v}{\partial z^2} - 2\,\Omega\, u + \frac{2M^2}{1+m^2}(mu - v) \quad (6)$$

$$\frac{\partial \theta}{\partial t} = Pr \frac{\partial^2 \theta}{\partial z^2} \quad (7)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc} \frac{\partial^2 C}{\partial z^2} \quad (8)$$

With initial and boundary conditions

$$u = 0,\ \ v = 0,\ \ \theta = 0,\ C = 0\ \ at\ \ t \le 0\ \ for\ all\ \ z \quad (9)$$

$$u = e^{at},\ \ v = 0,\ \ \theta = 1,\ \ C = 1\ \ \ at\ \ t > 0,\ \ z = 0 \quad (10)$$

$$u \to 0,\ \ v \to 0,\ \ \theta \to 0,\ \ C \to 0\ \ \ as\ \ z \to \infty \quad (11)$$

The equations (5) - (6) and boundary conditions (9)-(11) are combined and presented.

$$\frac{\partial q}{\partial t} = \frac{\partial^2 q}{\partial z^2} - 2\, q \left[\frac{M^2}{1+m^2} + i\left(\Omega - \frac{M^2 m}{1+m^2}\right)\right]$$
$$+ Gr\ \theta\ cos\alpha + \ Gc\ C\ \ cos\alpha \quad (12)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{pr} \frac{\partial^2 \theta}{\partial z^2} \quad (13)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc} \frac{\partial^2 C}{\partial Z^2} \quad (14)$$

With boundary conditions

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$q = 0\,,\ \theta = 0,\ C = 0 \quad at \quad t \leq 0\ for\ all\ z$ (15)

$q = e^{at},\ \theta = 1,\ C = 1 \quad at \quad z = 0,\ for\ all\ t > 0$ (16)

$q \to 0,\ \ \theta \to 0,\ \ C \to 0 \ \text{ as } \ z \to \infty$ (17)

Where $q= u+iv$.

solution of the problem.

To solve the dimensionless governing equations (12) to (14), subject to the initial and boundary conditions (15)-(17) Laplace –Transform technique is used. The solutions are in terms of exponential and complementary error function:

$$C = erfc\ (\eta\sqrt{Sc}) \qquad (18)$$

$$\theta = erfc\ (\eta\sqrt{Pr}) \qquad (19)$$

$$q = \frac{e^{at}}{2}\begin{bmatrix} exp(2\eta\sqrt{(a+b)t}erfc(\eta+\sqrt{(a+b)t})+ \\ exp(-2\eta\sqrt{(a+b)t}erfc(\eta-\sqrt{(a+b)t}) \end{bmatrix} - \frac{1}{2}\left[\frac{c_1}{b_1}+\frac{c_2}{b_2}\right]\begin{bmatrix} exp(-2\eta\sqrt{bt})erfc(\eta-\sqrt{bt})+ \\ exp(2\eta\sqrt{bt})erfc(\eta+\sqrt{bt}) \end{bmatrix}$$

$$+\left[\frac{c_1}{b_1}\right]\left[\frac{e^{b_1t}}{2}\right]\begin{bmatrix} exp(-2\eta\sqrt{(b_1+b)t}\ erfc(\eta-\sqrt{(b_1+b)t} \\ +\ exp(2\eta\sqrt{(b_1+b)t}\ erfc(\eta+\sqrt{(b_1+b)t} \end{bmatrix}$$

$$+\left[\frac{c_2}{b_2}\right]\left[\frac{e^{b_2t}}{2}\right]\begin{bmatrix} exp(-2\eta\sqrt{(b_2+b)t}\ erfc(\eta-\sqrt{(b_2+b)t} \\ +\ exp(2\eta\sqrt{(b_2+b)t}\ erfc(\eta+\sqrt{(b_2+b)t} \end{bmatrix}$$

$$-\left[\frac{c_1}{b_1}\right]\left[\frac{e^{b_1t}}{2}\right]\begin{bmatrix} exp(-2\eta\sqrt{b_1prt})erfc(\eta\sqrt{pr}-\sqrt{b_1t}) \\ +\ exp(2\eta\sqrt{b_1prt})erfc(\eta\sqrt{pr}+\sqrt{b_1t}) \end{bmatrix} + \left[\frac{c_2}{b_2}\right]\left[erfc(\eta\sqrt{sc})\right] + \left[\frac{c_1}{b_1}\right]\left[erfc(\eta\sqrt{Pr})\right]$$

$$-\frac{c_2}{b_2}\left[\frac{e^{b_2t}}{2}\right]\begin{bmatrix} exp(-2\eta\sqrt{Scb_2t})erfc(\eta\sqrt{Sc}-\sqrt{b_2t})+ \\ exp(2\eta\sqrt{Scb_2t})erfc(\eta\sqrt{Sc}+\sqrt{b_2t}) \end{bmatrix}$$

(20)

Where $b = 2\left[\frac{M^2}{1+m^2}+i\left(\Omega-\frac{M^2m}{1+m^2}\right)\right]$, $b_1 = \frac{b}{pr-1}$,

$c_1 = \frac{Gr\ cos\alpha}{Pr-1}$, $b_2 = \frac{b}{sc-1}$, $c_2 = \frac{Gccos\alpha}{sc-1}$,

$\eta = z/2\sqrt{t}$

In order to get a clear understanding of the flow field, we have separated q into real and imaginary parts to obtain axial and transverse components u and v.

Results and Discussion

To interpret the results for a better understanding of the problem, numerical calculations are carried out for different physical parameters M, m, Ω, Gr, Gc, Pr and Sc. The value of Prandtl number is chosen to be 7.0 which corresponds to water.

"Figure1" illustrates the effect of Schmidt number (Sc=0.16, 0.6, 2.01, when M=m=0.5, Ω =0.5, a=2.0, t=0.2 Gr=Gc=5.0) on the concentration field. It is observed that, as the Schmidt number increases, the concentration of the fluid medium decreases.

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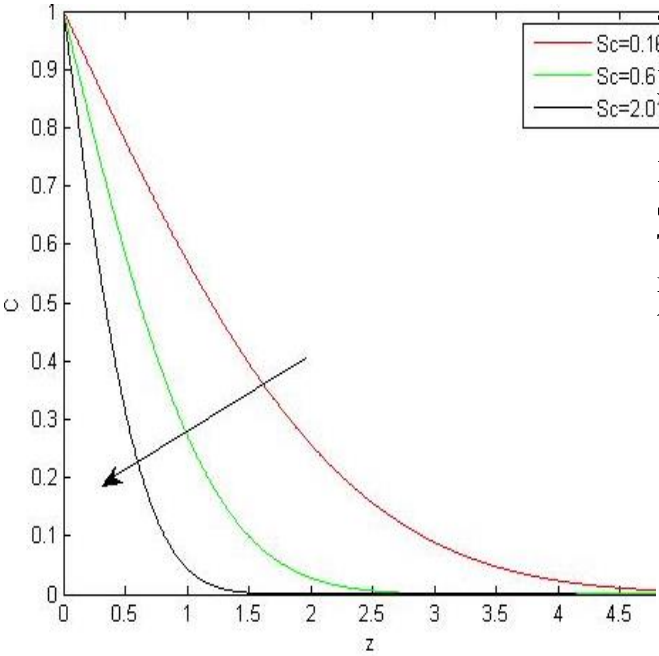

Figure.1. concentration profiles for different values of *Sc*

The effect of Prandtl number (*Pr*) on the temperature field is shown in "Figure2". It is noticed that an increase in the prandtl number leads to a decrease in the temperature.

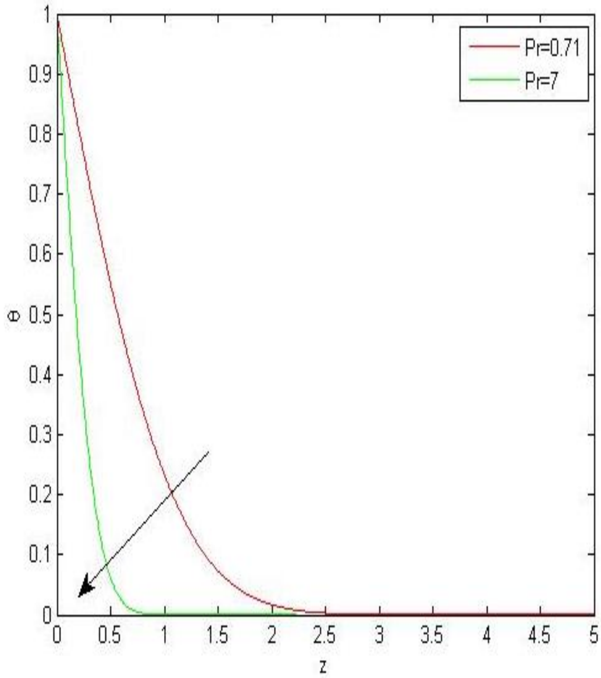

Figure.2.Temperature profiles for different values of *Pr*.

"Figure 3" illustrates that effects of the Magnetic field parameter (*M*=1.0, 3.0, 5.0, when *Gr* = *Gc*=5.0, *m*=0.5, *a*=2.0, Ω =0.5,*t*=0.2 and α=π/3) on axial velocity. It is observed that, the axial velocity decreases with the increasing value of *M*. This agrees with the expectations, since the magnetic field exerts a retarding force on the free convective flow.

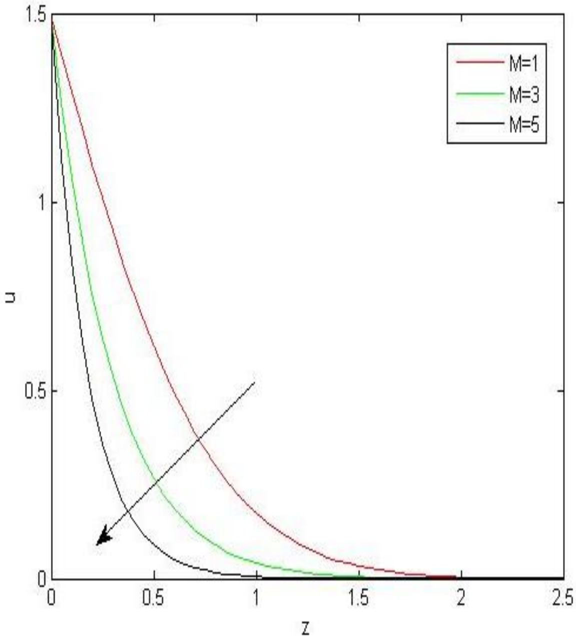

Figure.3. Axial velocity profiles for different values of *M*

The effect of Rotation parameter on axial velocity is shown in "Figure.4." It is observed that the velocity decrease with increasing values of Ω (1.0, 5.0, 8.0).

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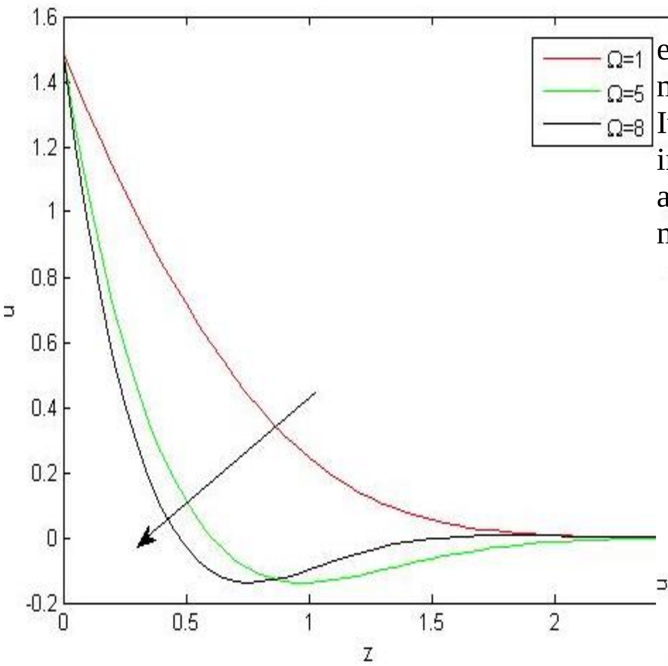

Figure.4.Axial velocity profiles for different values of Ω.

"Figure 5" demonstrates the effect of Hall parameter *m* on axial velocity. It has been noticed that the velocity decreases and gets merged with increasing values of Hall parameter.

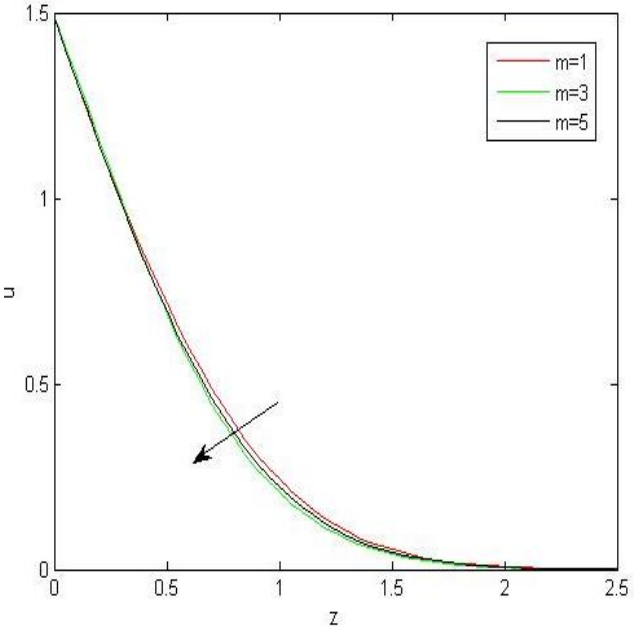

Figure.5. Axial velocity profiles for different values of *m*

"Figures 6 and 7" respectively show the effects of thermal Grashof number *Gr* and mass Grashof number *Gc* on axial velocity. It has been noticed that the velocity increases with increasing values of both *Gr* and *Gc*, but the effects are seems to be meager.

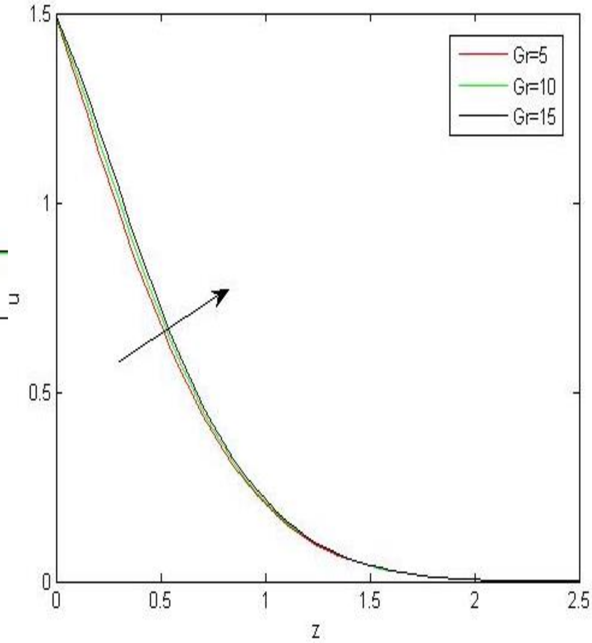

Figure.6.Axial velocity profiles for different values of *Gr*

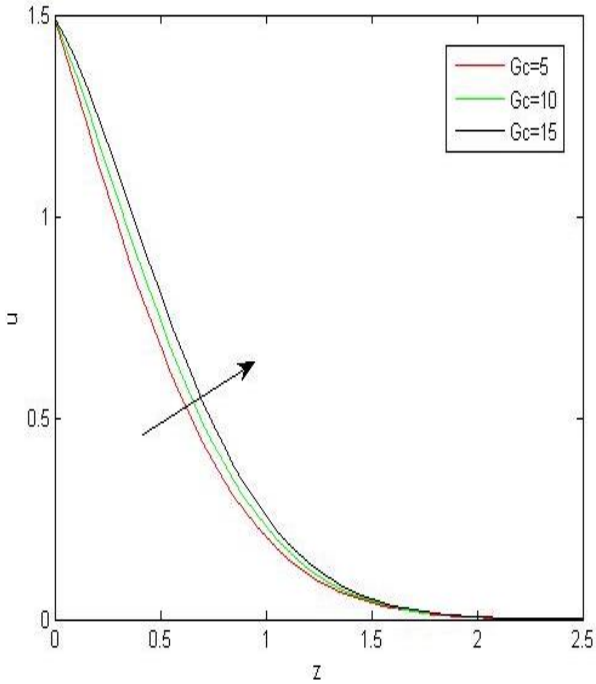

Figure.7.Axial velocity profiles for different values of *Gc*

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The effect of angle of inclination on axial velocity is shown in "Figure.8." It is observed that the velocity decrease with increasing values of α.

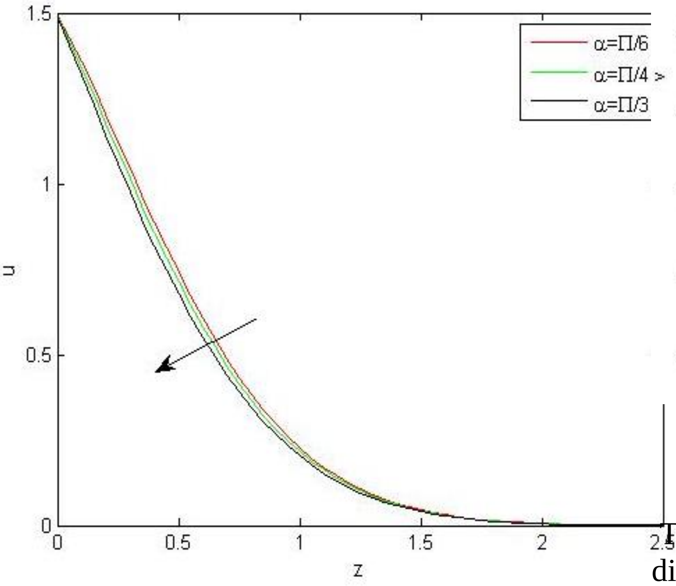

Figure.8. Axial velocity profiles for different values of *α*

"Figure 9" illustrates the effects of Magnetic field parameter *M* on transverse velocity. It is observed that the transverse velocity increases with increasing values of *M* upto M=1.But it is also observed that when M>1, the transverse velocity starts decreasing.

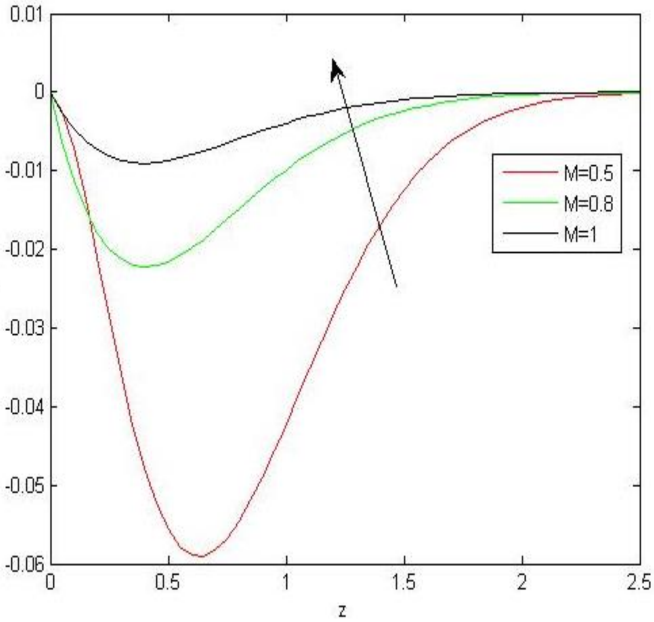

Figure.9. Transverse velocity profiles for different values of *M*.

The Transverse velocity profiles for different values of Rotaion parameter Ω *a*re shown in "Figure 10". It is observed that the velocity decreases with increasing values of Ω .

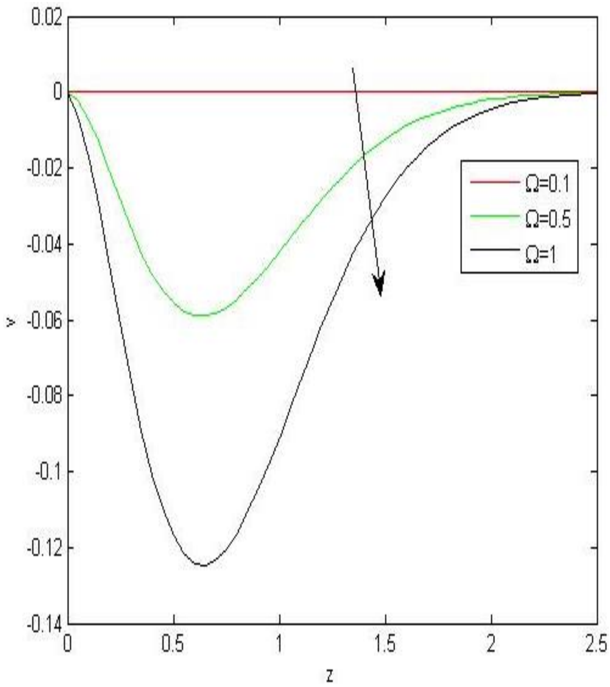

Figure.10. Transverse velocity profiles for different values of **Ω**.

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"Figure 11" shows the effect of Hall parameter *m* on transverse velocity. It is found that the velocity decreases with increasing values of *m*.

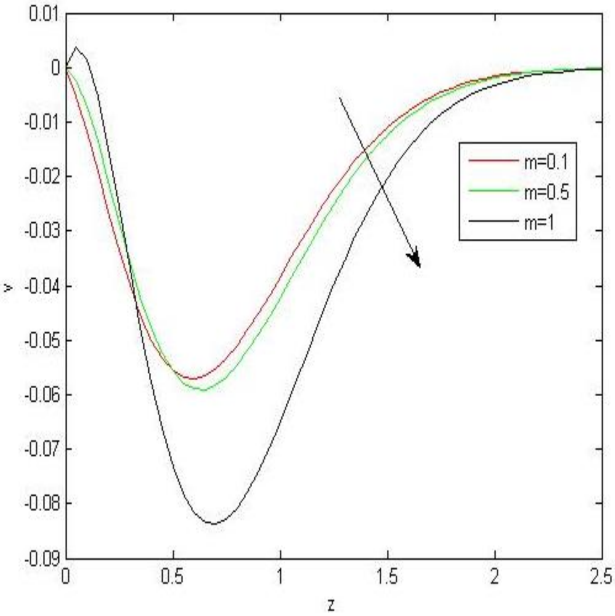

Figure.11. Transverse velocity profiles for different values of *m*.

"Figure 12" demonstrates the effect of Thermal Grashof number *Gr* on transverse velocity. It is observed that there is an decrease in velocity as there is a increase in *Gr*

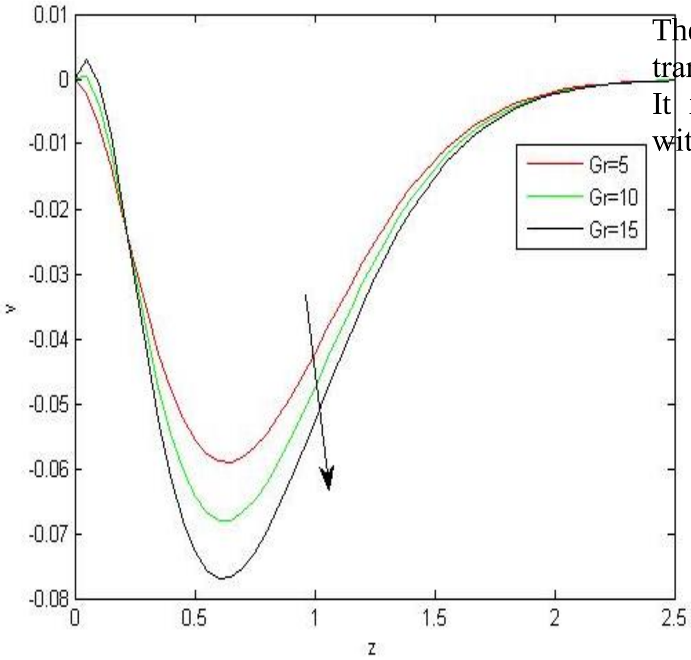

Figure.12. Transverse velocity profiles for different values of *Gr*

The effect of Mass Grashof number on transverse velocity is shown in "Figure 13" Numerical calculations were carried out for different values of *Gc* namely 5.0, 10.0,15.0. From the Figure it has been noticed that with increasing values of *Gc* the transverse velocity is decreases.

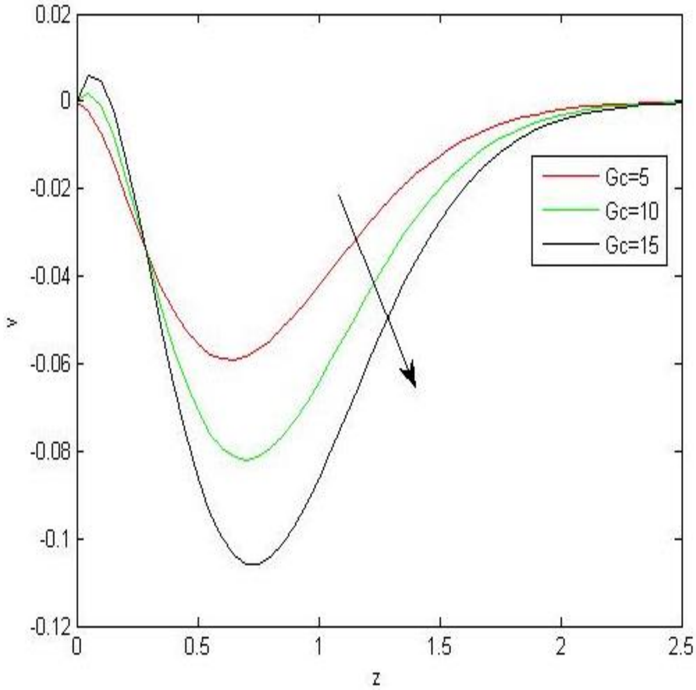

Figure.13. Transverse velocity profiles for different values of *Gc*

The effect of angle of inclination on transverse velocity is shown in "Figure14." It is observed that the velocity increase with increasing values of α.

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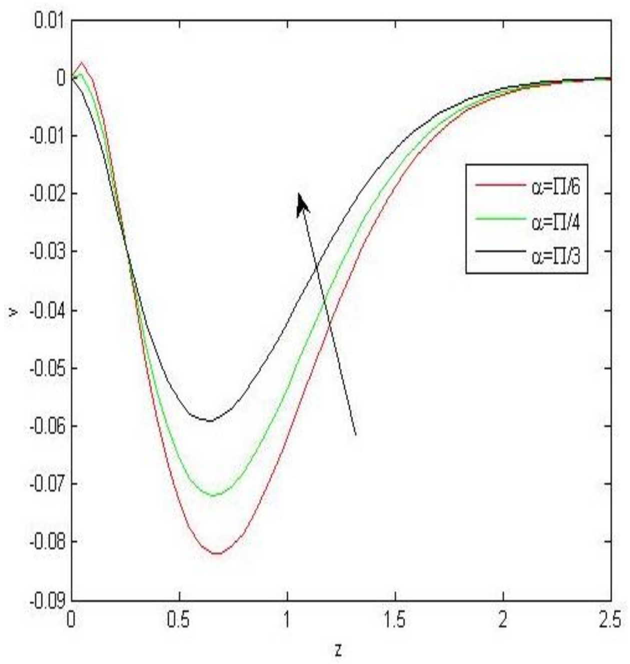

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Figure.14.Transverse velocity profiles for different values of α

Conclusion

In this paper we have studied the effects of Hall current, Rotation effect on MHD flow through an exponentially accelerated inclined plate with uniform temperature and mass diffusion. In the analysis of the flow the following conclusions are made.

- The temperature of the plate decreases with increasing values of prandtl number.
- The concentration near the plate increases with decreasing values of the Schmidt number.
- Axial velocity increases with decreasing values of Magnetic field parameter or Rotation parameter and seems to be merged for the different values of hall parameter, Thermal Grashof number, Mass Grashof number and angle of inclination.
- Transverse velocity increases with decreasing values of Magnetic parameter or Hall parameter or Thermal Grashof number or Mass Grashof number or. Rotation parameter But the trend gets reversed in the case of angle of inclination

Nomenclature

$a\,,A\,,a' \rightarrow$ Constants

$B_0 \rightarrow$ Applied Magnetic Field

$C \rightarrow$ Dimensionless concentration

$c' \rightarrow$ Species concentration in the fluid

$c_p \rightarrow$ Specific heat at constant pressure

$c'_w \rightarrow$ Concentration at the plate

$c'_\infty \rightarrow$ Concentration of the fluid far away from the plate

$D \rightarrow$ Mass diffusion co-efficient

$erfc \rightarrow$ Complementary error function

$Gc \rightarrow$ Mass Grashof number

$Gr \rightarrow$ Thermal Grashof number

$g \rightarrow$ Acceleration due to gravity

$k \rightarrow$ Thermal conductivity

$M \rightarrow$ Hartmann number

$m \rightarrow$ Hall parameter

$Pr \rightarrow$ Prandtl number

$Sc \rightarrow$ Schmidt number

$T \rightarrow$ Temperature of the fluid near the plate

$T_w \rightarrow$ Temperature of the plate

$T_\infty \rightarrow$ Temperature of the fluid far away from the plate

$t \rightarrow$ Dimensionless time

t' - Time

$u_0 \rightarrow$ Velocity of the plate

$(u' \quad v' \quad w') \rightarrow$ Components of Velocity Field F.

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$(u \quad v \quad w) \rightarrow$ Non-Dimensional Velocity Components
$(x' \quad y' \quad z') \rightarrow$ Cartesian Co-ordinates
$z \rightarrow$ Non-Dimensional co-ordinate normal to the plate.
$\mu_e \rightarrow$ Magnetic Permeability
$\upsilon \rightarrow$ Kinematic Viscosity
$\theta \rightarrow$ Dimensionless temperature
$\eta \rightarrow$ Similarity parameter
$\beta \rightarrow$ Volumetric coefficient of thermal expansion
$\alpha \rightarrow$ angle of inclination
$\beta^* \rightarrow$ Volumetric coefficient of expansion with concentration
$\Omega' \rightarrow$ Component of Angular Velocity
$\Omega \rightarrow$ Non -Dimensional Angular Velocity
$\rho \rightarrow$ Fluid Density
$\sigma \rightarrow$ Electric Conductivity

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