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Effect of thermal diffusion on transient MHD Free Convective flow past an Infinite Vertical Porous Plate in a Rotating System with Hall Current

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***Abstract* - Aim of this problem to investigate the effect of thermal diffusion on a transit free convective flow past an electrically conducting viscous incompressible fluid past an infinite vertical porous plate in a rotating system taking into account the effect of Hall current is presented when the temperature as well as the concentration at the plate varies periodically with time. The fluid with the plate rotates with a constant angular velocity about the normal to the plate. A uniform magnetic field is assumed to be applied along the normal to the plate directed into the fluid region. The magnetic Reynolds number is assumed to be so small that the induced magnetic field can be neglected. The expressions for the temperature, concentration, primary and secondary velocity fields are obtained in non-dimensional form. The velocity fields, temperature distribution, species concentration are demonstrated graphically.**

***Keyword* - Hall current, free convection, MHD, thermal diffusion, rotation, mass diffusion.**

Nomenclature

A	: Thermal diffusion parameter
Q	: Velocity vector
Ω	: Angular velocity
r	: position vector
ρ	: Fluid density
p	: Fluid pressure
$\vec{J}, J$	: Current density
$\vec{B}$	: Magnetic induction vector
B_0	: Strength of the applied magnetic field
β	:Coefficient of volume expansion for heat transfer
$\bar{\beta}$	:Coefficient of volume expansion for mass transfer
$\vec{g}$	: Acceleration due to gravity
μ	: Coefficient of viscosity
Cp	: Specific heat at constant pressure
k	: Thermal conductivity
Φ	: Frictional heat
v_0	: Constant suction velocity
$\frac{J^2}{\sigma}$	: Ohmic dissipation
σ	: Electrical conductivity
$\bar{C}$	: Species concentration
C_0	: Reference concentration
C_∞	: Concentration of the fluid far as from the plate
D	: Coefficient of mass diffusivity
T_∞	: Fluid temperature for away from the plate
$\bar{T}_0$	: Reference temperature
$\bar{T}$	: Temperature
$\bar{t}$, t	: Time
Gr	: Grashof number for heat transfer
Gm	: Grashof number for mass transfer
M	: Hartmann number
m	: Hall parameter
η_e	: Number density of electron
ω_e	: Electron frequency
τ_e	: Electron collision time
Pr	: Prandtl number
Sc	: Schmidt number
e	: Electron charge
θ	: Non-dimensional temperature
ϕ	: Non-dimensional species concentration
Pe	: Electron pressure
$\bar{E}$	: Electric field
$2\Omega\times q$	: Coriolis acceleration
$\Omega\times(\Omega\times r)$	: Centripetal acceleration

$(\bar{x},\bar{y},\bar{z}),\ (x,y,z)$: The coordinates in three dimensions

$(\bar{u},\bar{v},\bar{w}),\ (u,v,w)$: The velocity components along $(\bar{x},\bar{y},\bar{z})/(x,y,z)$ axes

$(\bar{J}_x, \bar{J}_y, \bar{J}_z)$, (J_x, J_y, J_z) :The current density components along $(\bar{x}, \bar{y}, \bar{z})/(x, y, z)$ axes, where the bars represent dimensional quantities

INTRODUCTION

MHD is the science of motion of electrically conducting fluid in presence of magnetic field. There are numerous examples of application of MHD principle. Engineer apply MHD principle in fusion reactors, dispersion of metals, metallurgy, design of MHD pumps, MHD generators and MHD flow meters etc. The dynamo and motor is classical example of MHD principle. Geophysics encounters MHD characteristics in the interaction of conducting fluid and magnetic field. MHD convection problems are also very significant in fields of Stellar and Planetary magnetospheres, aeronautics and chemical and electrical engineering. The MHD principle also finds its application in Medicine and Biology. Application in biomedical engineering includes cardiac MRI, ECG etc. The principle of MHD is also used in stabilizing a flow against the transition from laminar to turbulent flow.

MHD in its present form is due to the pioneer contribution of several notable authors like Alfven [3], Cowling [14], Shercliff [6], Ferraro and Plumption [15] and Crammer and Pai [7]. It was emphasized by Cowling [14] that when the strength of the magnetic field is sufficiently large, Ohm's law needs to be modified to include Hall current. The Hall Effect is due merely to the sideways magnetic force on the drifting free charges. The electric field has to have a component transverse to the direction of the current density to balance this force. In many works on plasma physics, the Hall Effect is ignored. But if the strength of magnetic field is high and the number density of electrons is small, the Hall Effect cannot be disregarded as it has a significant effect on the flow pattern of an ionized gas. Hall Effect results in a development of an additional potential difference between opposite surface of a conductor for which a current is induced perpendicular to both the electric and magnetic field. This current is termed as Hall current. Model studies on the effect of Hall current on MHD convection flows have been carried out by many authors due to application of such studies in the problems of MHD generators and Hall accelerators. Some of them are Pop [5], Kinyanjui et al. [11], Aboeldahab [2], Datta et al. [13], Acharya et al. [10], Sharma et al. [1] and Maleque and Sattar [12], Swarup et. Al. [16], Kumar et. Al. [17].

The rotating flow of an electrically conducting fluid in presence of a magnetic field is encountered in Geophysical fluid dynamics. It is also important in the solar physics dealing with the sunspot development, the solar cycle and the structure of rotating magnetic stars. It is well known that a number of astronomical bodies possess fluid interiors and magnetic fields. Changes that take place in the rate of rotation, suggest the possible importance of hydro magnetic spin-up. Many authors have studied this problem of spin-up in MHD under different conditions of whom the names of Debnath [9], Singh [8] and Takhar et al. [4] are worth mentioning. Recently, Ahmed and Kalita [18] have studied on transient MHD Free Convection from an Infinite Vertical Porous Plate in a Rotating System with Mass Transfer and Hall Current.

Due to importance of studying MHD free convection through porous medium problems in rotating system, we have proposed in the present paper to investigate the effect of thermal diffusion on the unsteady MHD free convective flow past an electrically conducting viscous fluid past an infinite vertical porous plate taking into account the effect of the Hall current when the plate and the fluid in unison rotate about the normal to the plate. Here our main objective is to study the effects of thermal diffusion parameter, the magnetic field, rotation of the fluid and Hall current on the flow and transport characteristics.

BASIC EQUATIONS

The equations governing the motion of an incompressible viscous electrically conducting fluid in a rotation system in presence of a magnetic field are

Equation of continuity:

$$\vec{\nabla}.\vec{q} = 0 \qquad \ldots(1)$$

Momentum equation:

$$\rho\left[\frac{\partial \vec{q}}{\partial \bar{t}} + 2\vec{\Omega}\times\vec{q} + \vec{\Omega}\times\left(\vec{\Omega}\times\vec{r}\right) + \left(\vec{q}.\vec{\nabla}\right)\vec{q}\right] = -\vec{\nabla}p + \vec{J}\times\vec{B} + \rho\vec{g} + \mu\nabla^2\vec{q} \qquad \ldots(2)$$

Energy equation:

$$\rho C_p\left[\frac{\partial \bar{T}}{\partial \bar{t}} + \left(\vec{q}.\vec{\nabla}\right)\bar{T}\right] = k\nabla^2\bar{T} + \Phi + \frac{\vec{J}^2}{\alpha} \qquad \ldots(3)$$

Species continuity equation:

$$\frac{\partial \bar{C}}{\partial t} + \left(\vec{q}.\vec{\nabla}\right)\bar{C} = D\nabla^2\bar{C} + D_1\nabla^2\bar{T} \qquad \ldots(4)$$

Kirchhoff's first law:

$$\vec{\nabla}.\vec{J} = 0 \qquad \ldots(5)$$

General Ohm's law:

$$\vec{J} + \frac{\omega_e\tau_e}{B_o}\left(\vec{J}\times\vec{B}\right) = \sigma\left[\vec{E} + \vec{q}\times\vec{B} + \frac{1}{e\eta_e}\vec{\nabla}p_e\right] \qquad \ldots(6)$$

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Gauss's law of magnetism

$\vec{\nabla}.\ \vec{B}=0$ …(7)

The physical quantities involves in the above equations are defined in the Nomenclature

We now consider an unsteady flow of an incompressible viscous electrically conducting fluid past an infinite vertical porous plate in a rotating system with constant suction (the plate suction velocity being quite small) taking into account the species concentration and Hall current in presence of a uniform transverse magnetic field. Our investigation is restricted to the following assumptions.

(i) All the fluid properties except the density in the buoyancy force term are constants.
(ii) The plate is electrically non-conducting.
(iii) The entire system is rotating with angular velocity $\overline{\Omega}$ about the normal to the plate.
(iv) The magnetic Reynolds number is so small that the induced magnetic field can be neglected. Also, the electrical conductivity σ of the fluid is reasonably low and hence the Ohmic dissipation may be neglected.
(v) The electron pressure P_e is constant.
(vi) $\overline{E}=0$ *i. e.* the electric field is negligible.
(vii) $|\overrightarrow{\Omega}|$ is so small that $|\vec{\Omega}\times(\vec{\Omega}\times\vec{r})|$ i.e. the centrifugal force may be neglected.

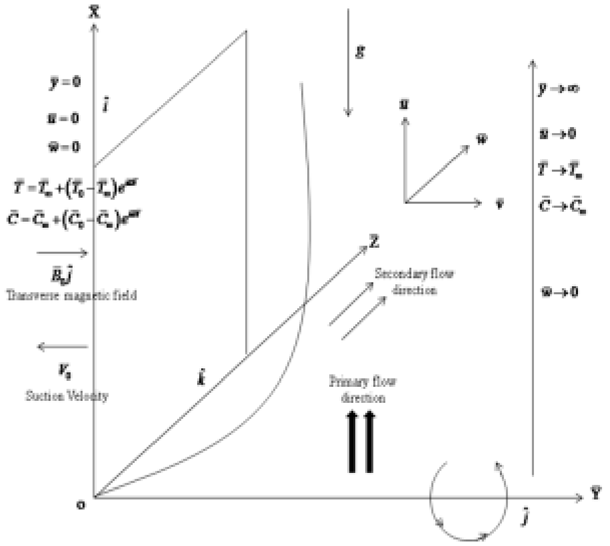

Figure 1. Flow configuration.

We introduce a coordinate system $\left(\bar{X},\ \bar{Y},\ \bar{Z}\right)$ with *X*-axis along the direction of the buoyancy force, *Y*-axis normal to the plate directed into the fluid region which is the axis of rotation and Z-axis along the width of the plate. Let $\vec{q}=\hat{i}\vec{u}+\hat{j}\vec{v}+\hat{k}\vec{w}$ be the fluid velocity, $\vec{J}=\vec{J}_x\hat{i}+\vec{J}_y\hat{j}+\vec{J}_z\hat{k}$ be the current density at the point $P\left(\bar{x},\bar{y},\bar{z},\bar{t}\right)$ and $\vec{B}=B_0\hat{j}$ be the applied magnetic field, $\hat{i},\hat{j},\hat{k}$ being the unit vectors along *X*-axis, *Y*-axis and *Z*-axis respectively. As the plate is infinite in *X*-direction and *Z*-direction, therefore all the quantities except possibly the pressure are independent of $\bar{x}$ and $\bar{z}$.

The equation (1) gives $\dfrac{\partial\bar{v}}{\partial y}=0$ …(8)

Which is trivially satisfied by $\bar{v}=-v_0$ …(9)

v_o being the suction velocity and it is fairly small. Therefore the velocity vector $\vec{q}$ is given by

$$\vec{q}=\vec{u}\hat{i}-v_o\hat{j}+\vec{w}\hat{k} \quad \text{…(10)}$$

The equation (7) is satisfied by $\vec{B}=B_oJ$ …(11)

The equation (5) reduces to $\dfrac{\partial\bar{J}_y}{\partial\bar{y}}=0$ which shows that $\bar{J}_y=0$ …(12)

(As the plate is electrically non-conducting) Hence the current density is given by

$$\vec{J}=\vec{J}_x\hat{i}+\vec{J}_z\hat{k} \quad \text{…(13)}$$

Under the assumption (v) and (vi), the equation (6) takes the form

$$\vec{J}+\frac{m}{B_0}\left(\vec{J}\times\vec{B}\right)=\sigma\left(\vec{q}\times\vec{B}\right) \quad \text{…(14)}$$

Where $m=\omega_e\tau_e$ is the Hall parameter.

The equations (10), (11), (13), and (14) yield,

$$\overrightarrow{J_x}=\frac{\sigma B_0}{1+m^2}\left(m\bar{u}-\bar{w}\right) \quad \text{…(15)}$$

$$\overrightarrow{J_z}=\frac{\sigma B_0}{1+m^2}\left(\bar{u}+m\bar{w}\right) \quad \text{…(16)}$$

With the foregoing assumptions and under the usual boundary layer and Boussinesq approximation the equations (2), (3) and (4) reduce to

$$\frac{\partial\bar{u}}{\partial\bar{t}}-v_0\frac{\partial\bar{u}}{\partial\bar{y}}+2\bar{\Omega}\bar{w} =\upsilon\frac{\partial^2\bar{u}}{\partial\bar{y}^2}+g\beta\left(\bar{T}-\bar{T}_\infty\right)+g\bar{\beta}\left(\bar{C}-\bar{C}_\infty\right)-\frac{\sigma B_0^2\left(\bar{u}+m\bar{w}\right)}{\rho\left(1+m^2\right)} \quad \text{…(17)}$$

$$\frac{\partial\bar{w}}{\partial\bar{t}}-v_o\frac{\partial\bar{w}}{\partial\bar{y}}-2\bar{u}\bar{\Omega}=\upsilon\frac{\partial^2\bar{w}}{\partial\bar{y}^2}+\frac{\sigma B_0{}^2\left(m\bar{u}-\bar{w}\right)}{\rho\left(1+m^2\right)}-\frac{\upsilon}{K}\bar{w} \quad (18)$$

$$\frac{\partial\bar{T}}{\partial\bar{t}}-v_0\frac{\partial\bar{T}}{\partial\bar{y}}=\frac{k}{\rho C_p}\frac{\partial^2\bar{T}}{\partial\bar{y}^2} \quad \text{…(19)}$$

$$\frac{\partial\bar{C}}{\partial\bar{t}}-v_0\frac{\partial\bar{C}}{\partial\bar{y}}=D\frac{\partial^2\bar{C}}{\partial\bar{y}^2}+D_1\frac{\partial^2\bar{T}}{\partial\bar{y}^2} \quad \text{…(20)}$$

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The relevant boundary conditions are

$$\bar{y}=0:\ \bar{u}=0,\ \bar{w}=0,$$

$$\bar{T}=\bar{T}_{\infty}+\left(\bar{T}_0-\bar{T}_{\infty}\right)e^{i\bar{\omega}\bar{t}},\ \ \bar{C}=\bar{C}_{\infty}+\left(\bar{C}_0-\bar{C}_{\infty}\right)e^{i\bar{\omega}\bar{t}} \quad ...(21)$$

$$\bar{y}\to\infty:\ \bar{u}\to 0,\ \bar{w}\to 0,\ \bar{T}\to\bar{T}_{\infty},\ \bar{C}\to\bar{C}_{\infty} \quad ...(22)$$

We introduce the following non-dimensional variables and parameters.

$$y=\frac{v_o\bar{y}}{\upsilon},t=\frac{v_0^2\bar{t}}{\upsilon},u=\frac{\bar{u}}{v_0},w=\frac{\bar{w}}{v_0},\theta=\frac{\bar{T}-\bar{T}_{\infty}}{\bar{T}_0-\bar{T}_{\infty}},\phi=\frac{\bar{C}-\bar{C}_{\infty}}{\bar{C}_0-\bar{C}_{\infty}}$$

$$Gr=\frac{\upsilon g\beta\left(\bar{T}_0-\bar{T}_{\infty}\right)}{v_0^3},Gm=\frac{\upsilon g\bar{\beta}\left(\bar{C}_0-\bar{C}_{\infty}\right)}{v_0^3},M=\frac{\sigma B_0^2\upsilon}{\rho v_0^2}$$

$$\Pr=\frac{\mu C_p}{k}\ \ Sc=\frac{\upsilon}{D},\Omega=\frac{2\bar{\Omega}\upsilon}{V_0^2},\eta=\frac{\upsilon\bar{\omega}}{V_0^2}\ \ D_1=\frac{A\upsilon\left(\bar{C}_0-\bar{C}_{\infty}\right)}{\left(\bar{T}_0-\bar{T}_{\infty}\right)}$$

The non-dimensional form of the equations (17), (18), (19) and (20) are

$$\frac{\partial u}{\partial t}-\frac{\partial u}{\partial y}+\Omega w=\frac{\partial^2 u}{\partial y^2}-\frac{M}{1+m^2}\left(mw+u\right)+Gr\theta+Gm\phi \quad ...(23)$$

$$\frac{\partial w}{\partial t}-\frac{\partial w}{\partial y}-\Omega u=\frac{\partial^2 w}{\partial y^2}+\frac{M}{1+m^2}\left(mu-w\right) \quad ...(24)$$

$$\frac{\partial\theta}{\partial t}-\frac{\partial\theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2} \quad ...(25)$$

$$\frac{\partial\phi}{\partial t}-\frac{\partial\phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}+A\frac{\partial^2\theta}{\partial y^2} \quad ...(26)$$

Subject to the boundary conditions.

$$y=0:\ \ u=0,\ \ w=0,\ \ \theta=e^{i\eta t},\ \ \phi=e^{i\eta t} \quad ...(27)$$

$$y\to\infty:\ \ u=0,\ \ w=0,\ \ \theta=0,\ \ \phi=0 \quad ...(28)$$

METHOD OF SOLUTION

We now introduce a new complex variable q defined by

$$q=u+iw \quad ...(29)$$

Where $i=\sqrt{-1}$

Then non-dimensional form of the equations governing the flow and transport characteristics can be rewritten as follows:

$$\frac{\partial q}{\partial t}-\frac{\partial q}{\partial y}=\frac{\partial^2 q}{\partial y^2}+Gr\theta+Gm\phi-\left[\frac{M\left(1-im\right)}{1+m^2}-i\Omega\right]q \quad ...(30)$$

$$\frac{\partial\theta}{\partial t}-\frac{\partial\theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2} \quad ...(31)$$

$$\frac{\partial\phi}{\partial t}-\frac{\partial\phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}+A\frac{\partial^2\theta}{\partial y^2} \quad ...(32)$$

Subject to the boundary conditions:

$$y=0:\ \ q=0,\ \ \theta=e^{i\eta t},\ \ \phi=e^{i\eta t} \quad ...(33)$$

$$y\to\infty:\ \ q=0,\ \ \theta=0,\ \ \phi=0 \quad ...(34)$$

The conditions (33) and (34) suggest that the solutions of the equations (30), (31) and (32) are of the form.

$$q=f(y).e^{i\eta t} \quad ...(35)$$

$$\theta=h(y).e^{i\eta t} \quad ...(36)$$

$$\phi=\psi(y).e^{i\eta t} \quad ...(37)$$

On substitutions of (35), (36) and (37) in (30), (31) and (32) respectively the following differential equation are obtained.

$$f''(y)+f'(y)-\left[A_1+i\eta\right]f(y)=-Grh(y)-Gm\psi(y) \quad (38)$$

$$h''(y)+\Pr h'(y)-i\eta\Pr h(y)=0 \quad ...(39)$$

$$\psi''(y)+Sc\psi'(y)-i\eta Sc\psi(y)=-ScAh''(y) \quad ...(40)$$

Subject to the conditions

$$f(0)=0,\ \ f(\infty)=0 \quad ...(41)$$

$$h(0)=1,\ \ h(\infty)=0 \quad ...(42)$$

$$\psi(0)=1,\ \ \psi(\infty)=0 \quad ...(43)$$

The solutions of the equations (38), (39) and (40) subject to the boundary conditions (41), (42) and (43) are follows:

$$f(y)=A_6e^{-m_1y}-A_4e^{-m_2y}-A_5e^{-m_3y} \quad ...(44)$$

$$h(y)=e^{-m_2y} \quad ...(45)$$

$$\psi(y)=A_3e^{-m_3y}-A_2e^{-m_2y} \quad ...(46)$$

Where, $A_1=\left[\dfrac{M\left(1-im\right)}{1+m^2}-i\Omega\right]$

$$A_2=\frac{ScAm_2^2}{m_2^2-Scm_2-i\eta Sc}$$

$$A_3=1+A_2$$

$$A_4=\frac{\left(Gr-GmA_2\right)}{m_2^2-m_2-\left(A_1+i\eta\right)}$$

$$A_5=\frac{GmA_3}{m_3^2-m_3-\left(A_1+i\eta\right)}$$

$$A_6=A_4+A_5$$

$$m_1=\frac{1+\sqrt{1+4\left(A_1+i\eta\right)}}{2}$$

$$m_2 = \frac{\Pr + \sqrt{\Pr^2 + 4i\eta \Pr}}{2}$$

$$m_3 = \frac{Sc + \sqrt{Sc^2 + 4i\eta Sc}}{2}$$

Hence the non-dimensional velocity, temperature and concentration distributions are given by

$$q = u + iv = \left(A_6 e^{-m_1 y} - A_4 e^{-m_2 y} - A_5 e^{-m_3 y}\right).e^{i\eta t} \qquad \ldots(47)$$

$$\theta = \left(e^{-m_2 y}\right).e^{i\eta t} \qquad \ldots(48)$$

$$\phi = \left(A_3 e^{-m_3 y} - A_2 e^{-m_2 y}\right).e^{i\eta t} \qquad \ldots(49)$$

Temperature Andconcentration Fields

On splitting (48) and (49) into real and imaginary parts and considering the real parts only, the temperature and concentration fields are obtained as

$$\theta(y,t) = e^{-\left(\frac{\Pr+\alpha_2}{2}\right)y}.Cos\left(\eta t - \frac{\beta_2 y}{2}\right) \qquad \ldots(50)$$

$$\phi(y,t) = e^{-\alpha_7 y}.\alpha_9 - e^{-\alpha_8 y}.\alpha_{10} \qquad \ldots(51)$$

Velocity Fields

Spiting (47) into real and imaginary parts we get the primary and secondary velocity fields as follows:

$$u = \alpha_{25}.Cos(\eta t) - \beta_{25}.Sin(\eta t) \qquad \ldots(52)$$

$$w = \beta_{25}.Cos(\eta t) + \alpha_{25}.Sin(\eta t) \qquad \ldots(53)$$

Results and Discussion

we have carried out numerical calculations for the dimensionless concentration ϕ, temperature θ, primary velocity u, secondary velocity w and skin frictions τ_1 *and* τ_2 at the plate due to both the primary and secondary velocity fields respectively for different values of the rotation parameter Ω, the frequency parameter η, Schmidt number Sc, Hartmann Number M. Hall parameter m, Grashof number Gr, Modified Grashof number Gm, thermal diffusion parameter A, Prandtl number Pr and normal coordinate y keeping the values of time t = 0.01and these numerical values have been displayed in different graphs.

Figures – (1) and (2) shows the variation of primary and secondary velocity profile of fluid for different value of Magnetic field parameter (M). We observe that the primary velocity (u) of fluid is accelerated due to increase in the values of M, but the secondary velocity (w) reduced due to increase in the values of M.

Figures – (3) and (4) demonstrate show the primary and secondary velocity profile of fluid for different value of Hall current parameter (m). It is observed that the primary and secondary velocity decreases with increases the value of Hall current parameter (m) continuously.

Figures – (5), (6), (7), (8), (9) and (10) present the variation of the primary velocity u under the influence of Gr, Gm, Ω, A, Pr and Sc. It is inferred from those figures that the primary velocity u remains negative for small and moderate values of y. That is the fluid flows in the downward vertical direction in the portion of the fluid region adjacent to the plate and at a large distance from the plate the fluid has a tendency to move in the upward vertical direction before it vanishes at $y \to \infty$. It is also marked in these figures that for the fluid region adjacent to the plate, the magnitude of the primary velocity (u) is accelerated due to increase in each of values of Gr, Gm and A. But it is seen that the primary velocity is reduced due to increase in the values of Ω, Pr and Sc. These results are clearly supported from the physical point of view.

The profiles for the secondary velocity (w) are shown in figures – (11), (12), (13), (14), (15) and (16) for different value of Gr, Gm, Ω, A, Pr and Sc. It is observed from these figures that the secondary velocity profiles (w) show wavy character about Y-axis (the axis rotation) near the plate. This secondary velocity (w) remains negative in a thin layer adjacent to the plate and after this layer it becomes positive and increases up to an another consecutive thin layer as y increases and finally it asymptomatically decreases and it vanishes as y $\to \infty$. It is clear from these figures the secondary velocity profile (w) is accelerated due to increase in each of values of Gr, Gm and A. But it is seen that the primary velocity is reduced due to increase in the values of Ω, Pr and Sc, same as primary velocity profile. This phenomenon establishes the fact that due to application of the effect of the rotation and Hall current on the secondary flow becomes immaterial for which the secondary flow is stabilized.

Figures – (17) and (18) shows the variation of primary and secondary velocity profile of fluid for different value of the frequency of oscillation (η). We observe that the primary velocity (u) of fluid is accelerated due to increase in the values of η, but the secondary velocity (w) reduced due to increase in the values of η.

Figures – (19) and (20) demonstrate the species concentrations profile (ϕ) is affected by mass diffusion. These two figures indicate that the concentration profile (ϕ) first increases in a very thin layer adjacent to the plate and there after it asymptotically decreases to zero as $y \to \infty$. The figures – (19) & (20) further show that the concentration rises near the plate and falls away from the plate when y is increased. It may be noted that an increase in Sc means a decrease in mass diffusion. But the concentration profile (ϕ) is increased when thermal diffusion parameter (A) increases.

Figures – (21) show the species temperature profile (θ) is affected by the thermal diffusion. These two figures indicate that the temperature profile (θ) first increases in a very thin layer adjacent to the plate and there after it asymptotically decreases to zero as $y \to \infty$. The figures

– (21) further show that the temperature profile (θ) decreases due to increasing Prandtl number Pr.

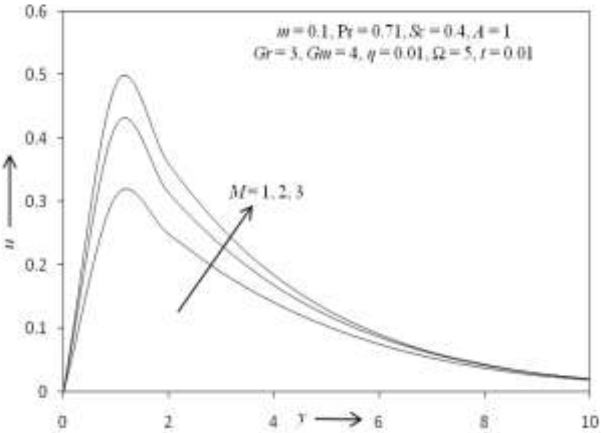

Fig. - 1: The primary velocity profile for different value of M.

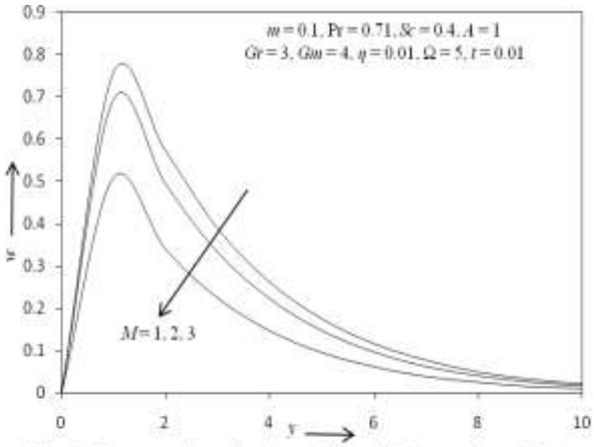

Fig. 2: The secondary velocity profile for different values of M.

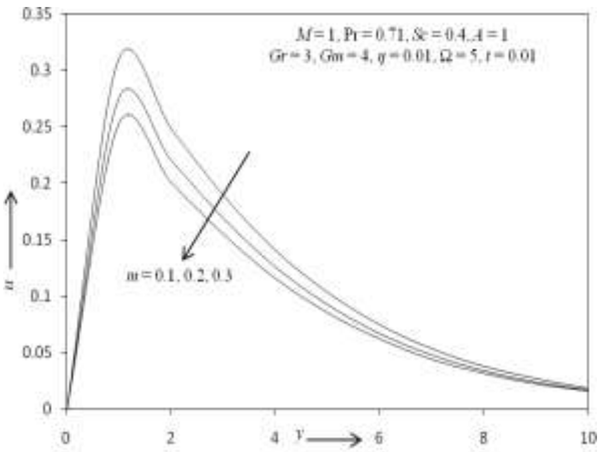

Fig. - 3: The primary velocity profile for different value of m.

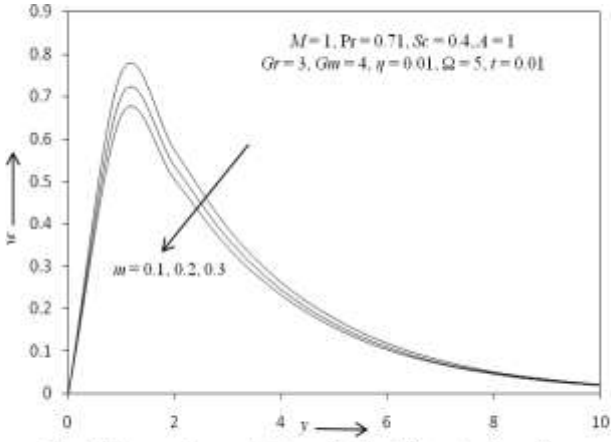

Fig. 4: The secondary velocity profile for different values of m.

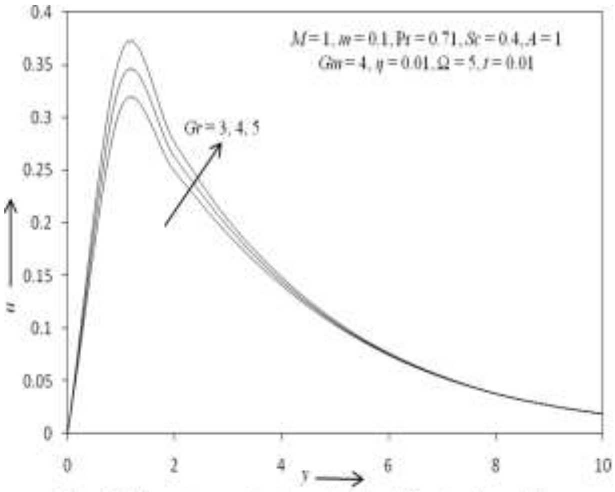

Fig. - 5: The primary velocity profile for different value of Gr.

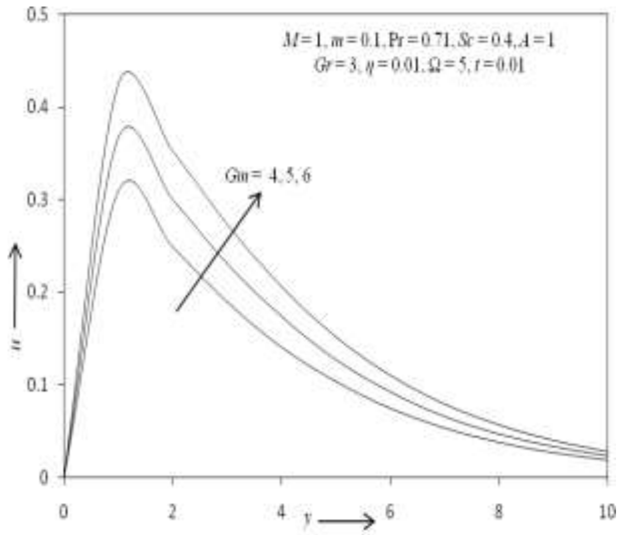

Fig. - 6: The primary velocity profile for different value of Gm.

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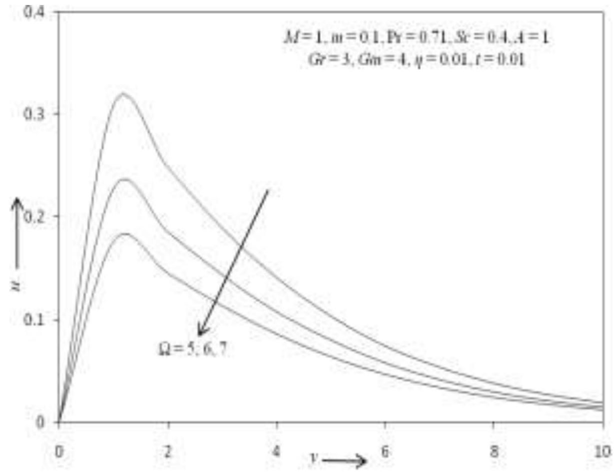

Fig. - 7: The primary velocity profile for different value of Ω.

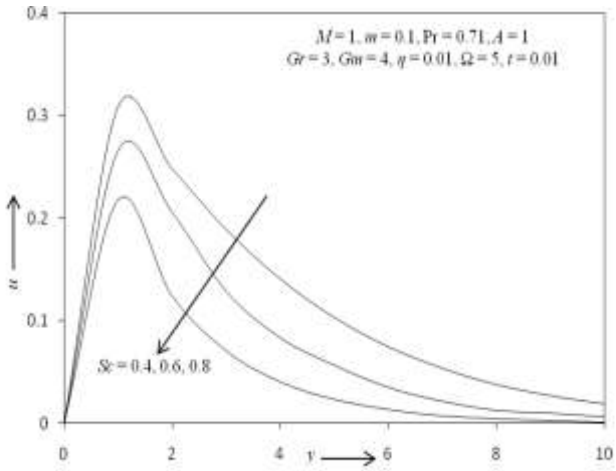

Fig. - 10: The primary velocity profile for different value of *Sc*.

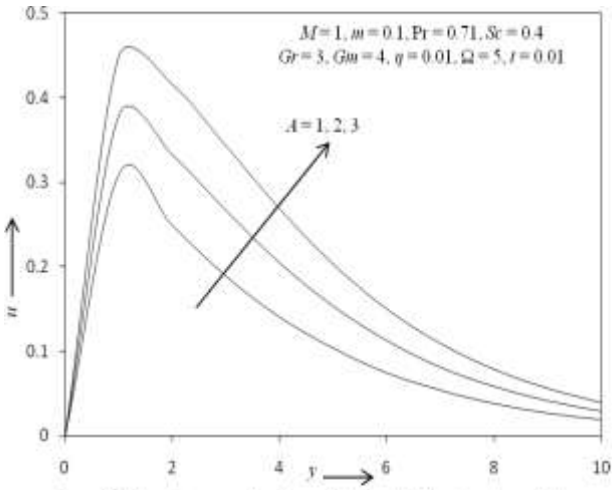

Fig. - 8: The primary velocity profile for different value of *A*.

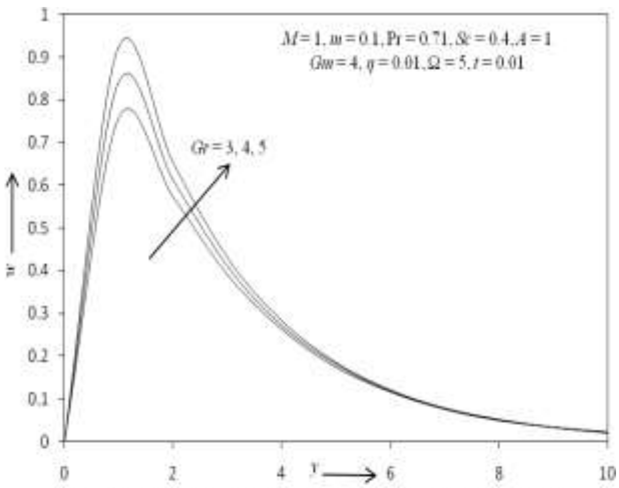

Fig. 11: The secondary velocity profile for different values of *Gr*.

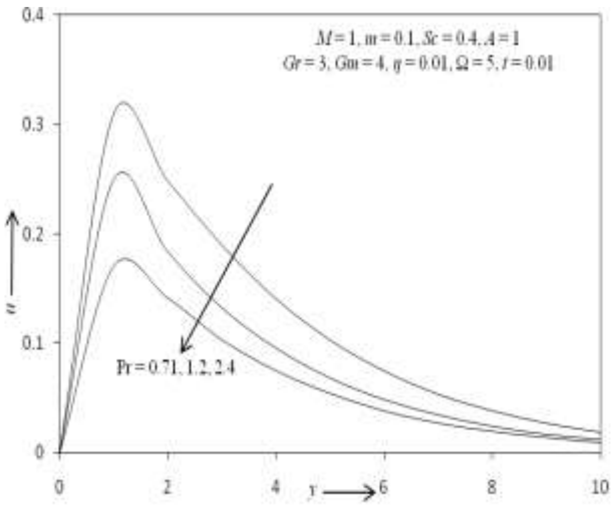

Fig. - 9: The primary velocity profile for different value of Pr.

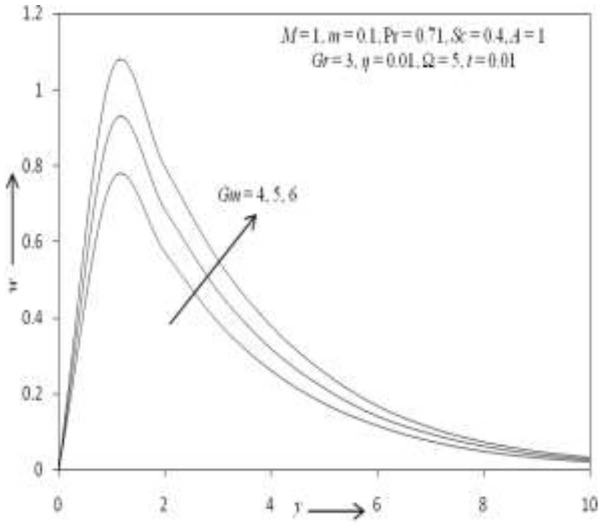

Fig. 12: The secondary velocity profile for different values of *Gm*.

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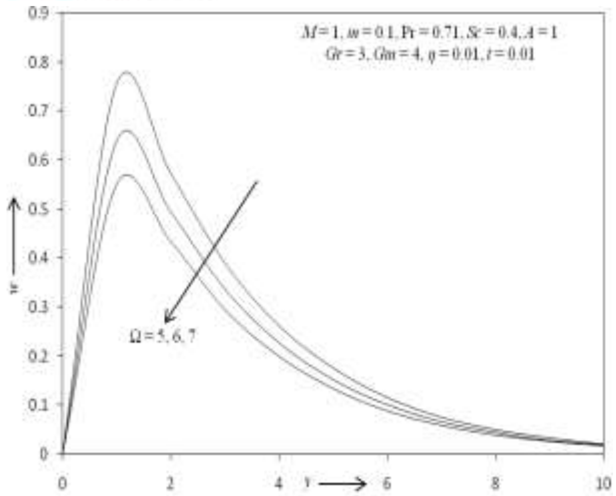

Fig. 13: The secondary velocity profile for different values of Ω.

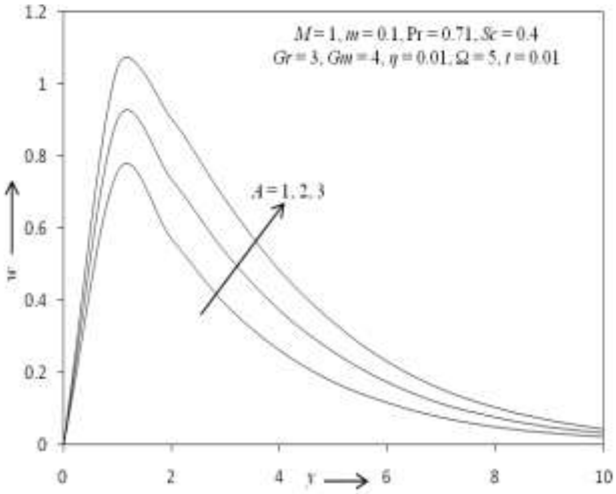

Fig. 14: The secondary velocity profile for different values of A.

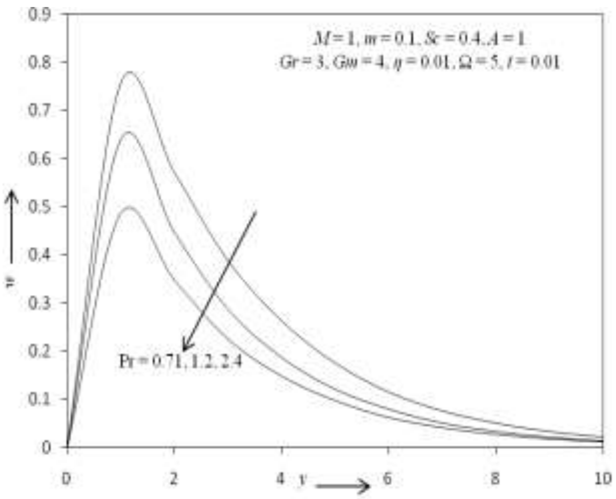

Fig. 15: The secondary velocity profile for different values of Pr.

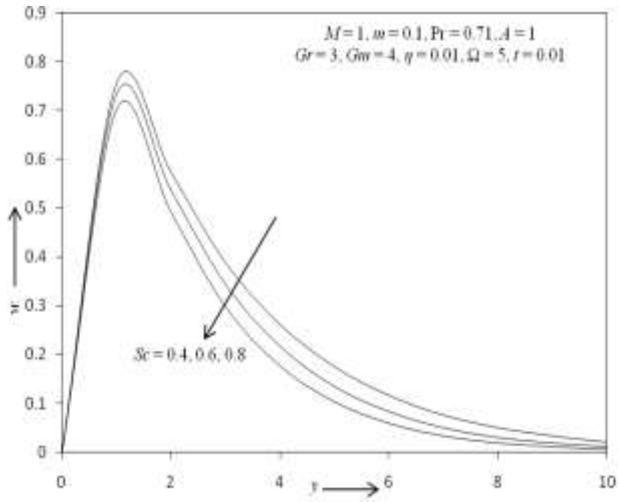

Fig. 16: The secondary velocity profile for different values of Sc.

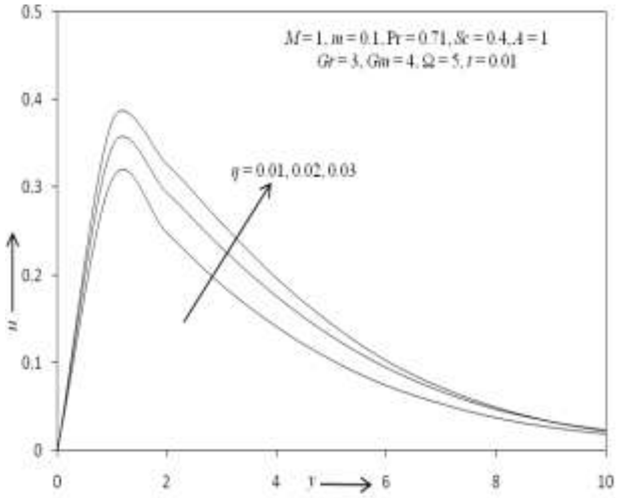

Fig. - 17: The primary velocity profile for different value of η.

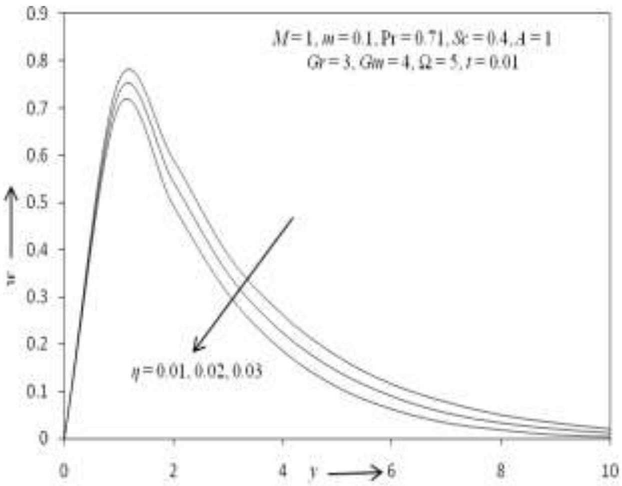

Fig. 18: The secondary velocity profile for different values of η.

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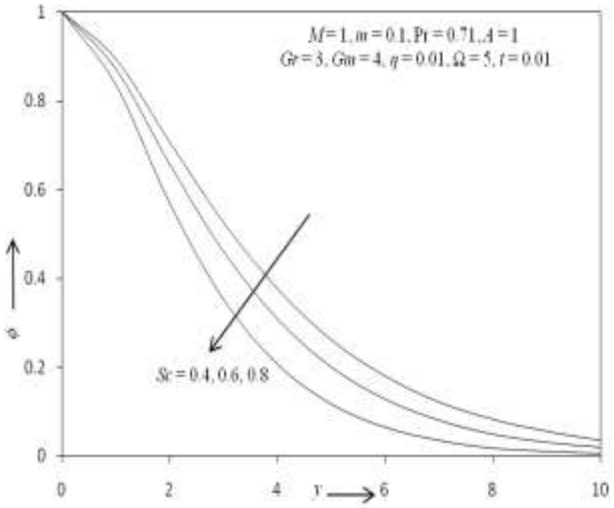

Fig. - 19: The Concentration Profile for different Value of *Sc*.

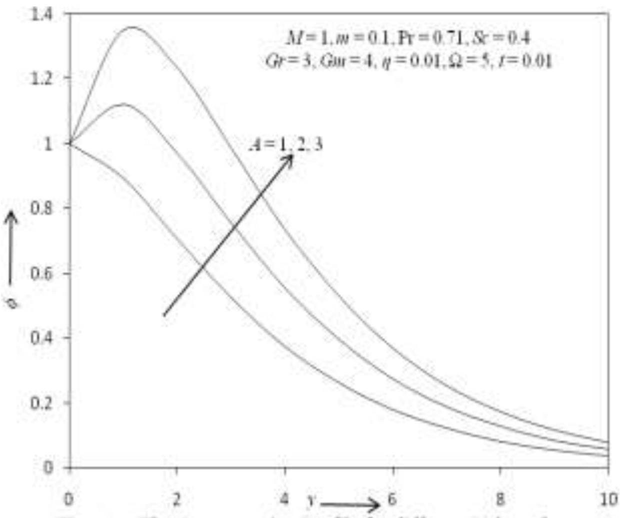

Fig. - 20: The Concentration Profile for different Value of *A*.

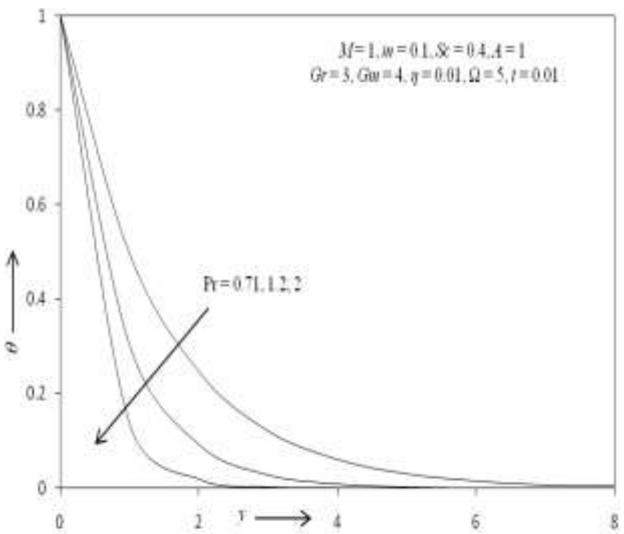

Fig. - 21: The temperature Profile for different Value of Pr.

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