MHD Convective rotating flow past an oscillating porous plate with chemical reaction and Hall effects

M Veera Krishna¹ and M Gangadhar Reddy²*

¹Assistant Professor, Department of Mathematics, Rayalaseema University, Kurnool, Andhra Pradesh, India.
²*Research Scholar in Mathematics, Rayalaseema University, Kurnool, Andhra Pradesh, India.

E-mail: veerakrishna_maths@yahoo.com

Abstract. In this paper, we have considered Hall effects on the unsteady MHD free convective rotating flow of visco-elastic fluid with heat and mass transfer near oscillating porous plate. The equations of the flow are solved by perturbation method for small elastic parameter. The analytical expressions for the velocity, temperature, concentration have been derived and also its behaviour is computationally discussed with the help of graphs. The skin friction, Nusselt number, and Sherwood number are also obtained analytically and their behaviour discussed.

Keywords: Hall effects, Heat transfer, porous plate and visco-elastic fluids.

1. Introduction:

The magnetohydrodynamic (MHD) rotating channel flows of visco-elastic fluids are very imperative since their abundant uses in Cosmic and geophysical fluid dynamics. A lot of applications on the flow through porous media to industrial disciplines like the food, chemical industry, centrifugation and filtration processes and rotating machinery. Many researchers [1-17] discussed the flow through planar channels with different configurations. Hayat et al. [18-19] investigated the MHD Couette flow of non-Newtonian fluids in a rotating system. Rahman et al. [20] studied the MHD flow of a visco-elastic fluid through a rectangular channel. Singh et al. [21] discussed MHD flow of a dusty visco-elastic fluid through between parallel plates. Oscillatory motion of visco-elastic fluid over a stretching sheet was studied by Rajagopal et al. [22]. Prasuna et al. [23] discussed unsteady flow of a visco-elastic fluid through two impermeable plates. Sahoo [24] studied MHD flow of a visco-elastic fluid through an oscillating porous plate in slip flow regime.

When the strength of the magnetic field is strong enough then one cannot neglect the effects of Hall currents. Even though it is of considerable importance to study how the results of the hydro dynamical problems get modified by the effects of Hall currents. A comprehensive discussion of Hall currents was given by many researchers [25-30]. The slip flow is an additional important phenomenon that is extensively encountered in this era of industrialization. In lubrication of mechanical devices
where a thin film of lubricant is attached to the surface slipping over one another or when the surfaces are coated with special coatings to minimize the friction between them. Marques et al. [31] discussed the effect of the fluid slippage at the plate. Rhodes et al. [32] studied the hydrodynamic lubrication of partial porous metal bearings. The problem of the slip-flow regime is very important in this era of modern science, technology and huge ranging industrialization. Hayat et al. [33] analyzed slip flow and heat transfer of a second grade fluid past a stretching sheet. Mehmood and Ali [34] extended the problem of oscillatory MHD flow in a channel filled with porous medium and studied by Makinde and Mhone [35] to slip-flow regime. Kumar et al. [36] studied the same for the unsteady MHD periodic flow through planer channel by applying the perturbation technique.

Keeping from above mentioned facts, in this paper, the MHD rotating free convection flow of visco-elastic fluid past an oscillating porous plate has been discussed.

2. Mathematical Formulation and Solution of the problem:

We consider Hall effects on the MHD free convection rotating flow of visco-elastic fluid past an oscillating porous plate. Initially both the plate and fluid rotate with the same angular velocity \( \Omega \). The plate temperature is stable to be maintained. The visco-elastic and Darcy’s resistance are deemed with constant permeability of the porous medium.

We consider the Cartesian co-ordinate system such that \( z = 0 \) on the plate. The suction velocity normal to the plate is a constant and may be written as \( w = -W_0 \). All the fluid properties considered constant except that the influence of the density variation with temperature. The influence of the density variation in other terms of the momentum and the energy equation and the variation of the expansion coefficient with temperature is negligible. This is the well-known Boussinesq approximation. Under these conditions, the unsteady hydromagnetic flow through porous medium is governed by the equations:

\[
\frac{\partial w}{\partial z} = 0
\]  
\[
\left(1 + \frac{\partial}{\partial t}\right) \frac{\partial u}{\partial t} + w \frac{\partial u}{\partial z} - 2\Omega v = \nu \frac{\partial^2 u}{\partial z^2} + \left(1 + \frac{\partial}{\partial t}\right) \left(B_0 J_x - \frac{\nu}{k}\right) u + g \beta (T - T_e) + g \beta^* (C - C_e) 
\]  
\[
\left(1 + \frac{\partial}{\partial t}\right) \frac{\partial v}{\partial t} + w \frac{\partial v}{\partial z} + 2\Omega u = \nu \frac{\partial^2 v}{\partial z^2} - \left(1 + \frac{\partial}{\partial t}\right) \left(B_0 J_x + \frac{\nu}{k}\right) v
\]  
\[
\frac{\partial T}{\partial t} + w \frac{\partial T}{\partial z} = \alpha \frac{\partial^2 T}{\partial z^2} - \frac{\partial q_r}{\partial z}
\]  
\[
\frac{\partial C}{\partial t} + w \frac{\partial C}{\partial z} = D \frac{\partial^2 C}{\partial z^2}
\]

Where, \( u, v \) are the velocity components along \( x \) and \( y \) directions; \( T \) and \( C \) are the temperature and concentrations, \( \nu \) the kinematic viscosity. \( \rho \) the density, \( \sigma \) the electric conductivity, \( B_0 \) the magnetic induction, \( k \) the permeability of the porous medium, \( g \) the acceleration due to gravity, \( \beta \) the thermal expansion co-efficient, \( \beta^* \) the concentration expansion co-efficient, \( \alpha \) the thermal conductivity and \( D \) is the concentration diffusivity \( q_r \) is the radiation heat flux. Using Rosseland approximation for radiation,

\[
\frac{\partial q_r}{\partial z} = 4\alpha^2 (T - T_e)
\]
The boundary conditions are
\[ \begin{align*}
  u = v = 0, T = T_w, C = C_w & \quad \text{at } z = 0 \quad (7) \\
  u = v = 0, T = T_w, C = C_w & \quad \text{at } z \to \infty \quad (8)
\end{align*} \]

When the strength of the magnetic field is very hefty, the generalized ohm’s law is modified to include the hall current so that
\[ J + \frac{\omega_e \tau_e}{B_0} (J \times B) = \sigma \left[ E + \frac{1}{\epsilon \eta_e} \nabla P_e \right] \quad (9) \]

Where, \( \omega_e \) the cyclotron frequency of the electrons, \( \tau_e \) the electron collision time, \( \sigma \) the electrical conductivity, \( \epsilon \) the electron charge and \( P_e \) the electron pressure. The ion-slip and thermo electric effects are not included in equation (9). Further it is assumed that \( \omega_e \tau_e \sim O(1) \) and \( \omega_i \tau_i \ll 1 \), where \( \omega_i \) and \( \tau_i \) are the cyclotron frequency and collision time for ions respectively. In the equation (9) the electron pressure gradient, the ion-slip and thermo-electric effects are neglected. We also assume that the electric field \( E=0 \) under assumptions reduces to
\[ \begin{align*}
  J_x + m J_y &= \sigma B_0 v \\
  J_y - m J_x &= -\sigma B_0 u
\end{align*} \quad (10) \]
\[ \begin{align*}
  J_x &= \frac{\sigma B_0}{1 + m^2} (v + mu) \\
  J_y &= \frac{\sigma B_0}{1 + m^2} (mv - u)
\end{align*} \quad (12) \]

Substituting the equations (12) and (13) in (3) and (2) respectively, we obtain
\[
\left(1 + \lambda \frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t} + w\frac{\partial u}{\partial z} - 2\Omega v = \nu \frac{\partial^2 u}{\partial z^2} + \left(1 + \lambda \frac{\partial}{\partial t}\right) \left(\frac{\sigma B^2_0}{1 + m^2} (mv - u) - \frac{v}{k}\right) u + 
\]
\[
g\beta(T - T_o) + g\beta^* (C - C_o) + \frac{\sigma B^2_0}{1 + m^2} (v + mu) + \frac{v}{k} v
\]
(14)

\[
\left(1 + \lambda \frac{\partial}{\partial t}\right)\frac{\partial v}{\partial t} + w\frac{\partial v}{\partial z} + 2\Omega u = \nu \frac{\partial^2 v}{\partial z^2} - \left(1 + \lambda \frac{\partial}{\partial t}\right) \left(\frac{\sigma B^2_0}{1 + m^2} (v + mu) + \frac{v}{k}\right) v
\]
(15)

We choose, \( q = u + iv \), combining equations (14) and (15), we obtain

\[
\left(1 + \lambda \frac{\partial}{\partial t}\right)\frac{\partial q}{\partial t} + w\frac{\partial q}{\partial z} + 2i\Omega q = \nu \frac{\partial^2 q}{\partial z^2} - \left(1 + \lambda \frac{\partial}{\partial t}\right) \left(\frac{\sigma B^2_0}{1 + m^2} + \frac{v}{k}\right) q
\]
\[
g\beta(T - T_o) + g\beta^* (C - C_o)
\]
(16)

We introduce the non-dimensional variables,

\[
u^* = \frac{u}{W_0}, v^* = \frac{v}{W_0}, q^* = \frac{q}{W_0}, t^* = \frac{tW^2_0}{\nu}, z^* = \frac{zW_0}{\nu}, \theta = \frac{T - T_o}{T_w - T_o}, C = \frac{C - C_o}{C_v - C_o}
\]

Making use of non-dimensional variables, the governing equations reduces to (Dropping asterisks)

\[
\left(1 + \lambda \frac{\partial}{\partial t}\right)\frac{\partial \tilde{q}}{\partial t} + w\frac{\partial \tilde{q}}{\partial z} + 2i\Omega \tilde{q} = \nu \frac{\partial^2 \tilde{q}}{\partial z^2} - \left(1 + \lambda \frac{\partial}{\partial t}\right) \left(\frac{M^2}{1 + m^2} + \frac{1}{K}\right) \tilde{q} + Gr(\theta + \phi C)
\]
(17)

\[
\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial z} = \frac{1}{Pr} \frac{\partial^2 \theta}{\partial z^2} - R\theta
\]
(18)

\[
\frac{\partial C}{\partial t} - \frac{\partial C}{\partial z} = \frac{1}{Sc} \frac{\partial^2 C}{\partial z^2}
\]
(19)

The relevant boundary conditions are

\[
q = 0, \theta = 1, C = 1 \quad \text{at} \quad z = 0
\]
(20)

\[
q = 0, \theta = 0, C = 0 \quad \text{at} \quad z \to \infty
\]
(21)

Where

\[
M^2 = \frac{\sigma B_0^2 \nu}{\rho W_0^2} \quad \text{the Hartmann number}, \quad K = \frac{kw_0^2}{\nu}
\]

\[
E = \frac{\Omega \nu}{W_0^2} \quad \text{the Rotation parameter}, \quad R = \frac{4\alpha^2 W_0^2}{\nu} \quad \text{the Radiation parameter}, \quad Pr = \frac{\nu}{\alpha}
\]

\[
Sc = \frac{\nu}{D} \quad \text{the Schmidt number}, \quad \lambda = \frac{\lambda W_0}{\nu} \quad \text{the Visco-elastic parameter}, \quad Gr = \frac{\beta \nu(T_w - T_o)}{W_0^2}
\]

\[
\text{the thermal Grashof number and} \quad \phi = \frac{\beta^* (C_v - C_o)}{\beta(T_w - T_o)} \quad \text{the Buoyancy ratio}.
\]

We assume the solutions of the equations (17) to (19) as,

\[
q(z,t) = q_0(t)e^{\text{i}\omega t}, \quad \theta(z,t) = \theta_0(t)e^{\text{i}\omega t}, \quad C(z,t) = C_0(t)e^{\text{i}\omega t}
\]
(22)

Using the equations (22), the equations (17) to (19) reduces to

\[
\frac{d^2 q_0}{dz^2} + \frac{d\theta_0}{dz} - \left(2iE + \left(\frac{M^2}{1 + m^2} + \frac{1}{K} - i\omega \lambda\right)\right) q_0 = -Gr(\theta_0 + \phi C_0)
\]
(23)

\[
\frac{d^2 \theta_0}{dz^2} + Pr\frac{d\theta_0}{dz} + Pr(i\omega - R)\theta_0 = 0
\]
(24)
The corresponding boundary conditions are

\[q_0 = 0, \theta_0 = 1, C_0 = 1 \quad \text{at} \quad z = 0\]  \hspace{1cm} (26)

\[q_0 = 0, \theta_0 = 0, C_0 = 0 \quad \text{at} \quad z \to \infty\]  \hspace{1cm} (27)

Solving the equations (23) to (25) making use of the boundary conditions (26) and (27),

\[q_0 = (a_1 + a_3) e^{-m_1 z} - a_1 e^{-m_2 z} - a_2 e^{-m_2 z}\]  \hspace{1cm} (28)

\[\theta_0 = e^{-m_2 z}\]  \hspace{1cm} (29)

\[C_0 = e^{-m_3 z}\]  \hspace{1cm} (30)

Substituting the equations (28) to (30) in the equation (22), we obtained the velocity, temperature and concentration distributions.

Skin friction:

\[\tau = \left(\frac{\partial q}{\partial z}\right)_{z=0} = -\left(m_1(a_1 + a_3) + a_2m_2 + a_3m_3\right) e^{i\omega z}\]  \hspace{1cm} (31)

Nusselt number:

\[Nu = -\left(\frac{\partial \theta}{\partial z}\right)_{z=0} = m_2 e^{i\omega z}\]  \hspace{1cm} (32)

Sherwood number:

\[Sh = -\left(\frac{\partial C}{\partial z}\right)_{z=0} = m_3 e^{i\omega z}\]  \hspace{1cm} (33)

3. Results and Discussion

We have considered Hall effects on MHD free convection flow of visco-elastic fluid near an oscillating porous plate. The plate temperature is constant to be maintained. The velocity, temperature, concentration derived analytically and computationally discussed with reference to flow parameters as shown in the line graphs (Figures 2-18) using MATHEMATICA (WOLFRAM).

We noticed that, the magnitude of the velocity components \(u\) increases and \(v\) reduces with increasing Rotation parameter \(E\) or hall parameter \(m\) being the other parameters fixed (Figures 2-3). But the resultant velocity enhances with increasing hall parameter \(m\). From the Figures (4, 10-11), we noticed that the magnitude of the velocity components \(u\) and \(v\) reduces with increasing the intensity of the magnetic field \(M\) or Prandtl number \(Pr\) or Schmidt number \(Sc\). The similar behaviour is observed for the resultant velocity with increasing \(M\), \(Pr\) and \(Sc\). The velocity components \(u\), \(v\) and the resultant velocity enhance with increasing Grashof number \(Gr\) or Buoyancy ratio \(I\) (Figures 7 & 8). The Figures (5-6 & 12) depicts the velocity components \(u\) enhances and \(v\) reduces with increasing the permeability parameter \(K\) throughout the fluid region. Lower the permeability of the porous medium lesser the fluid speed in the entire region. The reversal behaviour is observed with increasing visco-elastic parameter \(\lambda\) or the frequency of oscillation \(\omega\) (Figures 6 & 12). The magnitude of the velocity component \(u\) enhances and the experiences retardation in the flow field with increasing radiation parameter \(R\) and reverse trend is observed with increasing time, whereas velocity component \(v\) increases with increasing \(R\) and \(t\) (Figures 9 and 13). Figures (14) showed the effect of Radiation parameter \(R\), the Prandtl number \(Pr\), and the frequency of oscillation \(\omega\) and time \(t\) on the temperature of the flow field. We noted that the temperature of the flow field \(\theta\) diminishes as the Prandtl number increases. This is consistent with the fact that the thermal boundary layer thickness decreases with increasing Prandtl number. With increasing radiation parameter reduces the temperature of the flow field. This may happen due the elastic property of the fluid. It is observed that temperature of the flow field diminishes as the time parameter or the frequency of oscillation increases.
Fig. 2: The velocity Profiles for $u$ and $v$ against $E$
$M=1.5, K=1, m=1, \Pr =0.71, Sc=0.78, R=1, \lambda =1, \phi =0.2, \omega = \pi / 4, t =0.1$

Fig. 3: The velocity Profiles for $u$ and $v$ against $m$
$M=1.5, K=1, E=1, \Pr =0.71, Sc=0.78, R=1, \lambda =1, \phi =0.2, \omega = \pi / 4, t =0.1$

Fig. 4: The velocity Profiles for $u$ and $v$ against $M$
$K=1, m=1, E=1, \Pr =0.71, Sc=0.78, R=1, \lambda =1, \phi =0.2, \omega = \pi / 4, t =0.1$
Fig. 5: The velocity Profiles for $u$ and $v$ against $K$

$M=2$, $m=1$, $E=1$, $Pr=0.71$, $Sc=0.78$, $R=1$, $K=10$, $\lambda=1$, $\phi=0.2$, $\omega=\pi/4$, $t=0.1$

Fig. 6: The velocity Profiles for $u$ and $v$ against $\lambda$

$M=2$, $m=1$, $E=1$, $Pr=0.71$, $Sc=0.78$, $R=1$, $Gr=10$, $K=1$, $\lambda=1$, $\phi=0.2$, $\omega=\pi/4$, $t=0.1$

Fig. 7: The velocity Profiles for $u$ and $v$ against $Gr$

$M=2$, $m=1$, $E=1$, $Pr=0.71$, $Sc=0.78$, $R=1$, $K=1$, $\lambda=1$, $\phi=0.2$, $\omega=\pi/4$, $t=0.1$
Fig. 8: The velocity Profiles for $u$ and $v$ against $\phi$
$M=2$, $m=1$, $E=1$, $Pr=0.71$, $Sc=0.78$, $R=1$, $\lambda=1$, $K=1$, $\omega=\pi/4$, $t=0.1$

Fig. 9: The velocity Profiles for $u$ and $v$ against $R$
$M=2$, $m=1$, $E=1$, $Pr=0.71$, $Sc=0.78$, $K=1$, $Gr=10$, $\lambda=1$, $\phi=0.2$, $\omega=\pi/4$, $t=0.1$

Fig. 10: The velocity Profiles for $u$ and $v$ against $Pr$
$M=2$, $m=1$, $E=1$, $K=1$, $Sc=0.78$, $R=1$, $Gr=10$, $\lambda=1$, $\phi=0.2$, $\omega=\pi/4$, $t=0.1$
Fig. 11: The velocity Profiles for $u$ and $v$ against $Sc$
$M=2$, $m=1$, $E=1$, $Pr=0.71$, $K=1$, $R=10$, $\lambda=1$, $\phi=0.2$, $\omega=\pi/4$, $t=0.1$

Fig. 12: The velocity Profiles for $u$ and $v$ against $\omega$
$M=2$, $m=1$, $E=1$, $Pr=0.71$, $Sc=0.78$, $R=1$, $\lambda=1$, $\phi=0.2$, $K=1$, $t=0.1$

Fig. 13: The velocity Profiles for $u$ and $v$ against time $t$
$M=2$, $m=1$, $E=1$, $Pr=0.71$, $Sc=0.78$, $R=10$, $\lambda=1$, $\phi=0.2$, $\omega=\pi/4$, $K=1$
Fig. 14. The Temperature Profiles for $\theta$ with $R$, $Pr$, $\omega$ and $t$

Fig. 15. The Concentration Profiles for $C$ with $Sc$ and $\omega$
Figures (15) depict the effect of the Schmidt number $Sc$ and the frequency of oscillation $\omega$ on concentration distribution. The concentration decreases with the increase in the Schmidt number $Sc$. The weighty diffusing species have superior retarding consequence on concentration. Also, it is observed that presence of the frequency of oscillation $\omega$ reduces the concentration distribution.

| $M$ | $K$ | $\dot{\lambda}$ | $R$ | $Pr$ | $Gr$ | $\phi$ | $Sc$ | $\omega$ | $t$ | $m$ | $E$ | $\tau$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 6.406991 |
| 2.5 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 5.515753 |
| 3 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 4.757022 |
| 2 | 2 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 6.895465 |
| 2 | 3 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 7.064886 |
| 2 | 1 | 1.5 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 6.202688 |
| 2 | 1 | 2 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 6.069719 |
| 2 | 1 | 1 | 2 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 6.101300 |
| 2 | 1 | 1 | 3 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 5.627370 |
| 2 | 1 | 1 | 3 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 3.920567 |
| 2 | 1 | 1 | 1 | 7 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 2.644119 |
| 2 | 1 | 1 | 1 | 0.71 | 15 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 9.610487 |
| 2 | 1 | 1 | 1 | 0.71 | 20 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 12.81398 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.5 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 8.299571 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.7 | 0.22 | $\pi/4$ | 0.1 | 1 | 1 | 9.561291 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.6 | $\pi/4$ | 0.1 | 1 | 1 | 6.147386 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.78 | $\pi/4$ | 0.1 | 1 | 1 | 6.062867 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/3$ | 0.1 | 1 | 1 | 6.122192 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/2$ | 0.1 | 1 | 1 | 5.379949 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.5 | 1 | 1 | 6.338017 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.8 | 1 | 1 | 5.876448 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 2 | 1 | 7.546339 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 2 | 1 | 7.599155 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1.5 | 7 | 6.061074 |
| 2 | 1 | 1 | 1 | 0.71 | 10 | 0.2 | 0.22 | $\pi/4$ | 0.1 | 1 | 2 | 5.368135 |

The skin friction is significant phenomenon which characterizes the frictional drag force at the solid surface. From Table 1, it is observed that the skin friction increases with the increase in hall parameter $m$, permeability parameter $K$, thermal Grashof number $Gr$, and Buoyancy ratio $\phi$, but it is interesting to note that the skin friction decreases with the increase in Hartmann number $M$, Radiation parameter $R$, visco-elastic parameter $\dot{\lambda}$, the frequency of oscillation $\omega$, Prandtl number $Pr$, Schmidt number $Sc$, Rotation parameter $E$ and time $t$. From Table 2, it is to note that all the entries are positive. It is seen that Radiation parameter $R$, the Prandtl number $Pr$ and the frequency of oscillations $\omega$ increase the rate of heat transfer (Nusselt number $Nu$) at the surface of the plate, the Nusselt number $Nu$ reduces with increasing time $t$. From Table 3 it is to note that all the entries are positive. It is observed that Schmidt number $Sc$, the frequency of oscillations $\omega$ and time $t$ increase the rate of mass transfer at the surface of the plate.
Table 2. Nusselt number

| $R$ | $Pr$ | $\omega$ | $t$ | $Nu$ |
|-----|------|----------|-----|------|
| 1   | 0.71 | $\pi/4$  | 0.1 | 1.333165 |
| 2   | 0.71 | $\pi/4$  | 0.1 | 1.630177 |
| 3   | 0.71 | $\pi/4$  | 0.1 | 1.876962 |
| 1   | 3    | $\pi/4$  | 0.1 | 3.873236 |
| 1   | 7    | $\pi/4$  | 0.1 | 7.955346 |
| 1   | 0.71 | $\pi/3$  | 0.1 | 1.375590 |
| 1   | 0.71 | $\pi/2$  | 0.1 | 1.476144 |
| 1   | 0.71 | $\pi/4$  | 0.8 | 1.234201 |
| 1   | 0.71 | $\pi/4$  | 1.2 | 1.007703 |

Table 3. Sherwood number

| $Sc$ | $\omega$ | $t$ | $Sh$ |
|------|----------|-----|------|
| 0.22 | $\pi/4$  | 0.1 | 0.435384 |
| 0.3  | $\pi/4$  | 0.1 | 0.534097 |
| 0.6  | $\pi/4$  | 0.1 | 0.865805 |
| 0.78 | $\pi/4$  | 0.1 | 1.051093 |
| 0.22 | $\pi/3$  | 0.1 | 0.490472 |
| 0.22 | $\pi/2$  | 0.1 | 0.590352 |
| 0.22 | $\pi/4$  | 0.5 | 0.491463 |
| 0.22 | $\pi/4$  | 0.8 | 0.502078 |
| 0.22 | $\pi/4$  | 1.2 | 0.473191 |

4. Conclusions:

Hall currents on MHD free convective rotating flow of Visco-elastic fluid past an oscillating porous plate have been discussed. From the results obtained, the findings are:

1. The magnitude of the resultant velocity reduces with increasing $M$, $Pr$, $Sc$, $\lambda$ or $\omega$; enhances with increasing $K$, $m$, $E$, $Gr$ or $\phi$.
2. The magnitude of the resultant velocity enhances and the experiences retardation in the flow field with increasing $R$ and reverse trend is observed with increasing time.
3. The temperature diminishes as $Pr$ or time or the frequency of oscillation. The concentration reduces with the increase in $Sc$, and presence of the frequency of oscillation $\omega$ reduces it.
4. Also, the skin friction enhances with increase in $m$, $K$, $Gr$ and $\phi$, reduces with increase in $M$, $\lambda$, $\omega$, $Pr$, $R$, $Sc$ and $t$. The Nusselt number ($Nu$) at the surface of the plate enhances with increase $R$, $Pr$ or $\omega$, and reduces with increasing time $t$. The Schmidt number $Sc$, $\omega$ and time $t$ increase Sherwood number.

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