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# Heat transfer on Unsteady MHD flow through a porous medium in two vertical plates with Hall effects

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**Abstract**

The effects of radiation and hall current on MHD convective three dimensional flow in a vertical channel filled with a porous medium has been studied. We consider an incompressible viscous and electrically conducting incompressible viscous fluid in a parallel plate channel bounded by a loosely packed porous medium. The fluid is driven by a uniform pressure gradient parallel to the channel plates and the entire flow field is subjected to a uniform inclined magnetic field of strength $H_o$ inclined at an angle of inclination $\alpha$ with the normal to the boundaries in the transverse *xy*-plane. The temperature of one of the plates varies periodically and the temperature difference of the plates is high enough to induce radiative heat transfer. The effects of various parameters on the velocity profiles, the skin friction, temperature field, rate of heat transfer in terms of their amplitude and phase angles are shown graphically.

*Key words:* Optically thin fluid, parallel plate channel, porous medium, radiative heat transfer, steady hydro magnetic flows, three dimensional flows.

**Subject Classification codes:** 80A20, 76Sxx, 76N20, 76A05, 76A10

## 1. Introduction

The study of magnetohydrodynamics (MHD) of an incompressible fluids through a porous medium has attracted the attentions of many researchers. This is due to its engineering and industrial applications such as food processing and polymer production[1-9]. Hayat *et al.*[10] has investigated the electrical conducting of second grade fluid through a porous space. This problem has been solved analytically by using Homotopy Analysis Method. The stretching sheet of the plate also considered in this problem which exhibit the slip condition for boundary condition of momentum equation. The analytical solutions for MHD flows embedded in

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a porous medium also studied by Khan *et al.*[11]. But, in their research, the solutions of the problem have been obtained by using method of Fourier Sine transform. Samiulhaq *et al.*[12] has contributed a new problem of unsteady free convection flow of second grade fluid with the effect of MHD flows and porous medium. Difference with Hayat *et al.*[10] and Khan *et al.*[11], Laplace transform method was used by these researchers. Two cases of thermal conditions have been discussed in this problem, which are isothermal and ramped wall temperatures. Nowadays, the study of free convection flows in rotating fluid phenomena has been studied by several authors in their research[13-14]. Recently, Krishna *et al.*[15-18] discussed the MHD flows through a porous medium. Our present paper, the effects of radiation and hall current on MHD convective three dimensional flow in a vertical channel filled with a porous medium has been studied. Veera Krishna *et al.*[19] discussed heat and mass transfer on unsteady MHD oscillatory flow of blood through porous arteriole. The effects of radiation and Hall current on an unsteady MHD free convective flow in a vertical channel filled with a porous medium have been studied by Veera Krishna *et al.*[20]. The heat generation/absorption and thermo-diffusion on an unsteady free convective MHD flow of radiating and chemically reactive second grade fluid near an infinite vertical plate through a porous medium and taking the Hall current into account have been studied by Veera Krishna and Chamkha[21]. In this paper, the effects of radiation and hall current on MHD convective three dimensional flow in a vertical channel filled with a porous medium has been studied.

*2. Formulation and Solution of the Problem :*

Consider an unsteady MHD free convective flow of an electrically conducting, viscous, incompressible fluid through a porous medium bounded between two insulated infinite vertical plates in the presence of Hall current and thermal radiation. The plates are at a distance *d* apart. A Cartesian coordinate system with *x*-axis oriented vertically upward along the centre line of the channel is introduced. The *z*-axis is taken perpendicular to the planes of the plates as shown in Fig. 1.

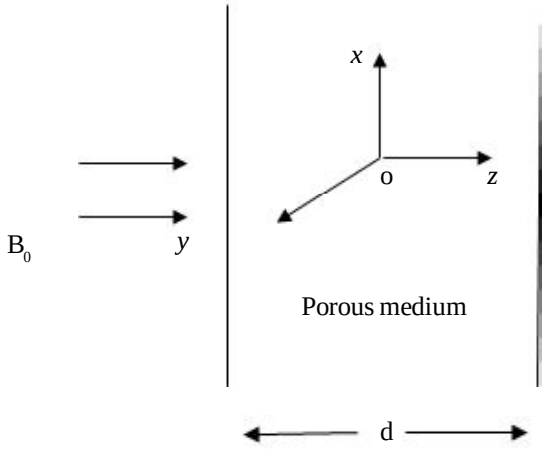



Fig. 1 Physical Configuration of the Problem

We choose a Cartesian system O(*x, y, z*) such that the boundary walls are at *z=0* and *z=l* and are assumed to be parallel to *xy*-plane. The steady flow through porous medium is governed by Brinkman's equations. At the interface the fluid satisfies the continuity condition of velocity and stress. The boundary plates are assumed to be parallel to *xy*-plane and the magnetic field of strength $H_o$ inclined at an angle of inclinationto the

*z*-axis in the transverse *xz*-plane. The component along *z*-direction induces a secondary flow in that direction while its *x*-components changes perturbation to the axial flow. The steady hydro magnetic equations governing the incompressible fluid under the influence of a uniform inclined magnetic field of strength $H_o$ inclined at an angle of inclination with reference to a frame are

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu \frac{\partial^2 u}{\partial z^2} - \frac{\mu_e J_z H_0 Sin\alpha}{\rho} - \frac{\nu}{k}u + g\beta T \tag{2.1}$$

$$\frac{\partial w}{\partial t} = \nu \frac{\partial^2 w}{\partial z^2} + \frac{\mu_e J_x H_0 Sin\alpha}{\rho} - \frac{\nu}{k}w \tag{2.2}$$

Where, All the physical quantities in the above equation have their usual meaning. (*u, w*) are the velocity components along O(*x, z*) directions respectively. $\rho$ is the density of the fluid, $\mu_e$ is the magnetic permeability, $\nu$ is the coefficient of kinematic viscosity, *k* is the permeability of the medium, $H_o$ is the applied magnetic field. When the strength of the magnetic field is very large, the generalized Ohm's law is modified to include the Hall current, so that

$$J + \frac{\omega_e \tau_e}{H_0} J \times H = \sigma\ (E + \mu_e\, q \times H) \tag{2.3}$$

Where, $\boldsymbol{q}$ is the velocity vector, $H$ is the magnetic field intensity vector, $E$ is the electric field , $J$ is the current density vector, $\omega_e$ is the cyclotron frequency, $\tau_e$ is the electron collision time, $\sigma$ is the fluid conductivity and, $\mu_e$ is the magnetic permeability. In equation (2.3) 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

$$J_x - m\ J_z Sin\alpha = -\sigma\mu_e H_0 w\, Sin\alpha \tag{2.4}$$

$$J_z + m\, J_x Sin\alpha = -\sigma\mu_e H_0 u Sin\alpha \tag{2.5}$$

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

On solving equations (2.3) and (2.4) we obtain

$$J_x = \frac{\sigma\mu_e H_0 Sin\alpha}{1 + m^2 Sin^2\alpha}(umSin\alpha - w) \tag{2.6}$$

$$J_z = \frac{\sigma\mu_e H_0 Sin\alpha}{1 + m^2 Sin^2\alpha}(u + w\, mSin\alpha) \tag{2.7}$$

Using the equations (2.6.) and (2.7), the equations of the motion with reference to frame are given by

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu \frac{\partial^2 u}{\partial z^2} - \frac{\sigma\mu_e{}^2 H_0{}^2 Sin\alpha}{\rho(1 + m^2 Sin^2\alpha)}(u + w\, mSin\alpha) - \frac{\nu}{k}u + g\beta T \tag{2.8}$$

$$\frac{\partial w}{\partial t} = \nu \frac{\partial^2 w}{\partial z^2} + \frac{\sigma\mu_e{}^2 H_0{}^2 Sin\alpha}{\rho(1 + m^2 Sin^2\alpha)}(umSin\alpha - w) - \frac{\nu}{k}w \tag{2.9}$$

$$\rho C_p \frac{\partial T}{\partial t} = K \frac{\partial^2 T}{\partial z^2} - \frac{\partial q}{\partial z} \tag{2.10}$$

The boundary conditions for the problem are

$$u = w = T = 0, \quad z = -\frac{d}{2} \tag{2.11}$$

$$u = w = 0, T = T_w Cos\,\omega t, \qquad z = \frac{d}{2} \tag{2.12}$$

Where $T_w$ is the mean temperature of the plate at z=d/2 and $\omega$ is the frequency of oscillations. Following Cogley *et.al.*[22], the last term in the energy equation (2.10),

$$\frac{\partial q}{\partial z} = 4\alpha^2 (T - T_0) \tag{2.13}$$

Stands for radiative heat flux modifies to

$$\frac{\partial q}{\partial z} = 4\alpha^2 T \tag{2.14}$$

In view of the reference temperature $T_0 = 0$, where $\alpha$ is mean radiation absorption co-efficient.
We introduce the following non-dimensional variables and parameters.

$$z^* = \frac{z}{d}, x = \frac{x}{d}, u = \frac{u^*}{U}, v = \frac{v^*}{U}, \; q = \frac{q^*}{U}, \; t^* = \frac{tU}{d},$$

$$\omega^* = \frac{\omega d}{U} \; p^* = \frac{p}{\rho U^2}, \; T^* = \frac{T}{T_w}$$

Where, U is the mean axial velocity,

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

$$\frac{\partial u}{\partial t} = -\frac{\partial p}{\partial x} + \frac{1}{\mathrm{Re}} \frac{\partial^2 u}{\partial z^2} - \frac{M^2 Sin^2 \alpha}{Re(1 + m^2 Sin^2 \alpha)} (u + wmSin\alpha) - \frac{D^{-1}}{Re} u - GrT \tag{2.15}$$

$$\frac{\partial w}{\partial t} = \frac{1}{\mathrm{Re}} \frac{\partial^2 w}{\partial z^2} + \frac{M^2 Sin^2 \alpha}{Re(1 + m^2 Sin^2 \alpha)} (umSin\alpha - w) - \frac{D^{-1}}{Re} w \tag{2.16}$$

$$\frac{\partial T}{\partial t} = \frac{1}{Pe} \frac{\partial^2 T}{\partial z^2} - \frac{R^2}{Pe} \frac{\partial q}{\partial z} \tag{2.17}$$

Where, $\mathrm{Re} = \frac{Ud}{\nu}$ is the Reynolds number

$D = \frac{K}{d^2}$ the permeability parameter (Darcy parameter), $Gr = \frac{g\beta d^2 T_w}{\nu U}$ the Grashoff number

$Pe = \frac{\rho C_p dU}{\nu U}$ the Peclet number , $R = \frac{2\alpha d}{\sqrt{K}}$ the radiation parameter

The corresponding transformed boundary conditions are

$$u = w = T = 0, \quad z = -\frac{1}{2} \tag{2.18}$$

$$u = w = 0, T = Cos\omega t, \qquad z = \frac{1}{2} \tag{2.19}$$

For the oscillatory internal flow, we shall assume that the fluid flows only under the influence of a non-dimensional pressure gradient oscillating in the in the direction of *x*-axis only which is of the form,

$$-\frac{\partial p}{\partial x} = P\, Cos\omega t \tag{2.20}$$

In order to combine equations (2.15) and (2.16) into single equation, we introduce a complex function $F = u + iw$, we obtain

$$\mathrm{Re}\frac{\partial q}{\partial t} = -P\, Cos\omega t + \frac{\partial^2 q}{\partial z^2} - \left( \frac{M^2 Sin^2\alpha}{(1 - imSin\alpha)} + i\omega\, \mathrm{Re} + D^{-1} \right) q - GrT \tag{2.21}$$

The boundary conditions in complex form are

$$q = T = 0, \quad z = -\frac{1}{2} \tag{2.22}$$

$$q = 0, T = e^{i\omega t}, \qquad z = \frac{1}{2} \tag{2.23}$$

In order to solve the equations (2.17) and (2.21) making use of boundary conditions (2.22) and (2.23), we assume in the complex form the solution of the problem as

$$q(z,t) = q_0(z)e^{i\omega t},\ T(z,t) = \theta_0(z)e^{i\omega t},\ -\frac{\partial p}{\partial x} = P\, e^{i\omega t} \tag{2.24}$$

Substituting equations (2.24) in equations (2.16) and (2.21), we get

$$\frac{d^2 q_0}{dz^2} - \lambda^2 q_0 = -P\,\mathrm{Re} - Gr\,\theta_0 \tag{2.24}$$

and

$$\frac{d^2 q_0}{dz^2} - \xi^2 \theta_0 = 0 \tag{2.25}$$

Where, $\lambda^2 = \dfrac{M^2 Sin^2\alpha}{(1-imSin\alpha)} + i\omega \,\mathrm{Re} + D^{-1}$ and $\xi^2 = i\omega Pe + R^2$

The boundary conditions given in equations (2.22) and (2.23) become

$$q_0 = \theta_0 = 0, \quad z = -\frac{1}{2} \tag{2.26}$$

$$q_0 = 0, \theta_0 = 1, \quad z = \frac{1}{2} \tag{2.27}$$

The ordinary differential equations (2.24) and (2.25) are solved under the boundary conditions given in equations (2.26) and (2.27) for the velocity and temperature fields. The solution of the problem is obtained as

$$q(z,t) = \left\{ \frac{P\,\mathrm{Re}}{\lambda^2}\left(1 - \frac{Cosh\lambda z}{Cosh\dfrac{\lambda}{2}}\right) + \frac{Gr}{\lambda^2 - \xi^2}\left(\frac{Sinh\lambda\left(z+\frac{1}{2}\right)}{Sinh\lambda} - \frac{Sinh\xi\left(z+\frac{1}{2}\right)}{Sinh\xi}\right)\right\} e^{i\omega t} \tag{2.28}$$

$$T(z,t) = \frac{Sinh\xi\left(z+\frac{1}{2}\right)}{Sinh\xi}\, e^{i\omega t} \tag{2.29}$$

Now from the velocity field, we can obtain the skin-friction at the left plate in terms of its amplitude and phase angle as

$$\tau_L = \left(\frac{\partial q}{\partial z}\right)_{z=-1/2} = \left(\frac{\partial q_0}{\partial z}\right)_{z=-1/2} e^{i\omega t} = |q|\, Cos(\omega t + \phi)$$

Where $|q| = \sqrt{(\mathrm{Re}\, q)^2 + (\mathrm{Im}\, q)^2}$ and $\phi = Tan^{-1}\left(\dfrac{\mathrm{Re}\, q}{\mathrm{Im}\, q}\right)$

$$\mathrm{Re}\, q + i\,\mathrm{Im}\, q = \frac{P\,\mathrm{Re}}{\lambda^2} Tanh\left(\frac{\lambda}{2}\right) + \frac{Gr}{\lambda^2 - \xi^2}\left[\frac{\lambda}{Sinh\lambda} - \frac{\xi}{Sinh\xi}\right] \tag{2.30}$$

From the temperature field, the rate of heat transfer *Nu* (Nusselt number) at the left plate in terms of its amplitude and phase angle is obtained

$$Nu = \left(\frac{\partial T}{\partial z}\right)_{z=-1/2} = \left(\frac{\partial \theta_0}{\partial z}\right)_{z=-1/2} e^{i\omega t} = |H|\, Cos(\omega t + \psi) \tag{2.31}$$

Where $|H| = \sqrt{(\mathrm{Re}\, H)^2 + (\mathrm{Im}\, H)^2}$ , $\psi = Tan^{-1}\left(\dfrac{\mathrm{Re}\, H}{\mathrm{Im}\, H}\right)$ and $\mathrm{Re}\, H + i\,\mathrm{Im}\, H = \dfrac{\xi}{Sinh\,\xi}$

### 3. Results and Discussion

We consider an incompressible viscous and electrically conducting fluid in a parallel plate channel bounded by a loosely packed porous medium. The fluid is driven by a uniform pressure gradient parallel to the channel plates and the entire flow field is subjected to a uniform inclined magnetic field of strength $H_o$ inclined at an angle of inclination $\alpha$ with the normal to the boundaries in the transverse *xy*-plane. The temperature of one of the plates varies periodically and the temperature difference of the plates is high enough to induce radiative heat transfer. The complete expressions for the velocity, $q(z)$ and temperature, $T(z)$ profiles as well as the skin friction, $\tau$ and the heat transfer rate, *Nu* are given in equations (2.28)-(2.31). In order to understand the physical situation of the problem and hence the manifestations of the effects of the material parameters entering into the solution of problem, To study the effects of these different parameters appearing in the governing flow problem, we have carried out computational and numerical calculations for the velocity field, skin-friction, temperature field and temperature in terms of its amplitude and the phase. The computational results are presented in Figures (2-9) for the velocity profiles (fixing $\alpha = \pi/3$), Figures (10-11) for temperature profiles and also tables (1) for shear stresses at z = -1/2. We noticed that, from Figures (2 & 3) shows the variation of velocity profiles under the influence of the Reynolds parameter *Re*. The magnitude of the velocity *u* increases and *w* decreases with increase in Raynolds number *R*. It is evident from that increasing value of *R*e leads to the increase of resultant velocity. It is interesting to note that from figures (4 & 5) both the magnitude of velocity components *u* and *w* decreases with the increase of intensity of the magnetic field (Hartmann number *M*). This is because of the reason that effect of a inclined magnetic field on an electrically conducting fluid gives rise to a resistive type force (called Lorentz force) similar to drag force and upon increasing the values of *M* increases the drag force which has tendency to slow down the motion of the fluid. The resultant velocity also reduces with increase in the intensity of the magnetic field. The magnitudes of the velocity components *u* and *w* increase with the increase in permeability of the porous medium (*D*) is observed from Figures (6 & 7). Lower the permeability of the porous medium lesser the fluid speed is in the entire fluid region. It is expected physically also because the resistance posed by the porous medium to the decelerated flow due to inclined magnetic field reduces with decreasing permeability *D* which leads to decrease in the velocity. The resultant velocity also increases with increase in *D*. The variation of the velocity profiles with hall parameter *m* is shown in Figures (8 & 9). The magnitudes of the velocity components *u*, *w* and the resultant velocity increases with the increase of hall parameter *m* throughout the channel and there is no significant effect of hall parameter *m* on both the velocity components with the effect of inclined magnetic field.

The temperature profiles are shown in Figure (10-11). The temperature decreases with the increase of radiation parameter *R*, the Peclet number *P*e (Figures 10-11).

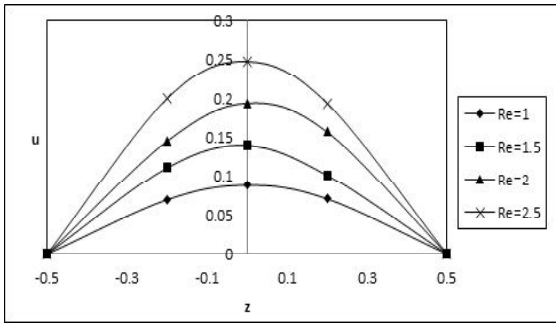



Fig. 2: The velocity Profile for *u* against *Re* with $P=5, Pe=0.7, Gr=1, D=1, R=1, M=5, m=1, \omega=5, t=1$

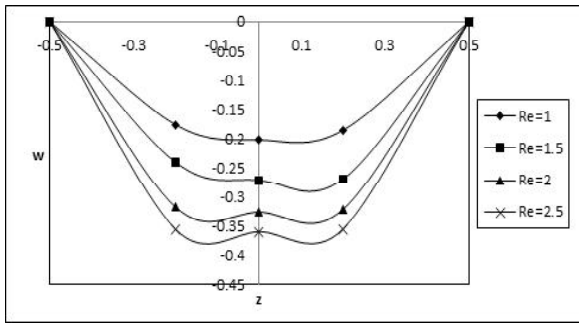



Fig. 3: The velocity Profile for *w* against *Re* with $P=5, Pe=0.7, Gr=1, D=1, R=1, M=5, m=1, \omega=5, t=1$

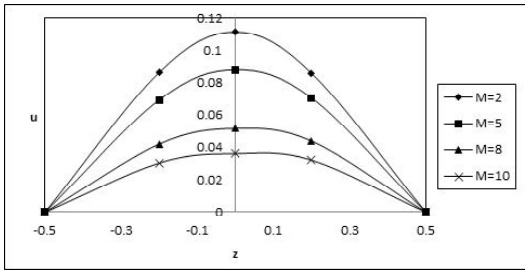



Fig. 4: The velocity Profile for $u$ against $M$ with $P=5, Pe=0.7, \mathrm{Re}=1, Gr=1, D=1, R=1, m=1, \omega=5, t=1$

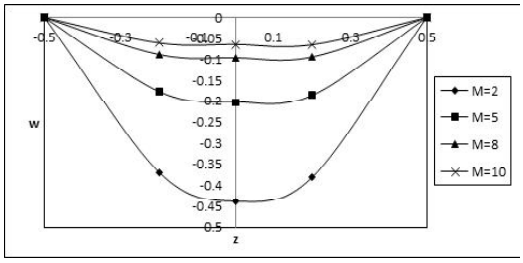



Fig. 5: The velocity Profile for $w$ against $M$ with $P=5, Pe=0.7, \mathrm{Re}=1, Gr=1, D=1, R=1, m=1, \omega=5, t=1$

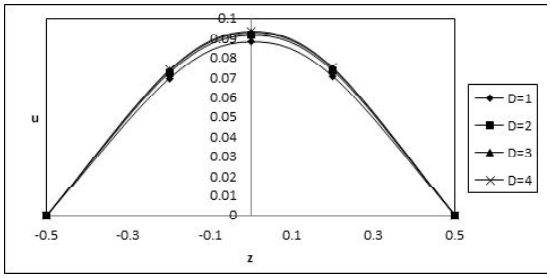



Fig. 6: The velocity Profile for $u$ against $D$ with $P=5, Pe=0.7, \mathrm{Re}=1, Gr=1, R=1, M=5, m=1, \omega=5, t=1$

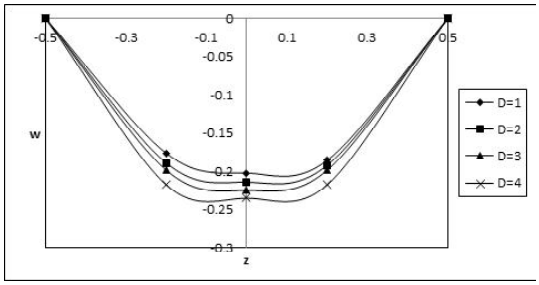



Fig. 7: The velocity Profile for $w$ against $D$ with $P=5, Pe=0.7, \mathrm{Re}=1, Gr=1, R=1, M=5, m=1, \omega=5, t=1$

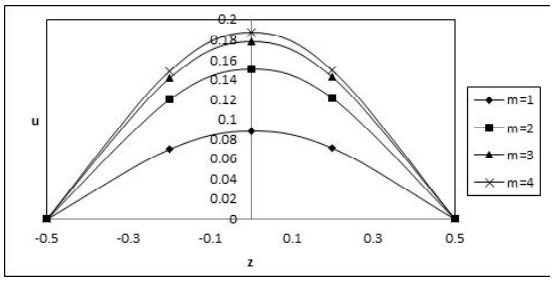



Fig. 8: The velocity Profile for $u$ against $m$ with $P=5, Pe=0.7, \mathrm{Re}=1, Gr=1, D=1, R=1, M=5, \omega=5, t=1$

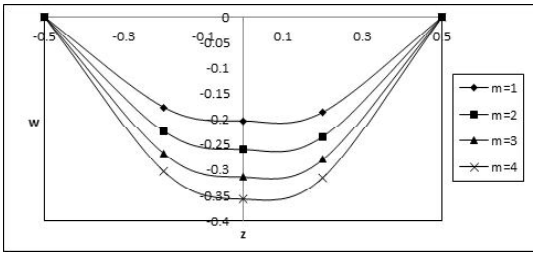



Fig. 9: The velocity Profile for $w$ against $m$ with $P=5, Pe=0.7, \mathrm{Re}=1, Gr=1, D=1, R=1, M=5, \omega=5, t=1$

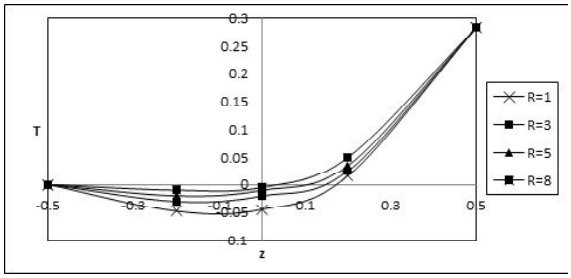



Fig. 10: The Temperature Profile for $T$ against $R$ with $Pe=0.7, \omega=5, t=1$

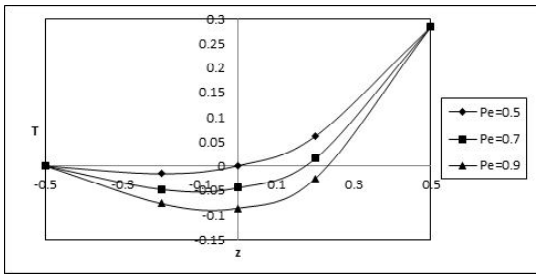



Fig. 11: The Temperature Profile for $T$ against $Pe$ with $R=1, \omega=5, t=1$

The skin-friction at the plate $z = -1/2$ is obtained in terms of its amplitude $|q|$ and the phase angle $\phi$. The amplitude $|q|$ is presented in Table 1. The amplitude $|q|$ increases with increase in Reynolds number Re, pressure gradient $P$, Grashof number $Gr$ and the Hall parameter $m$. The amplitude $|q|$ increases with increase of permeability of the porous medium $D$ for small values of $\omega$ ($\omega \leq 5$) but decreases for large values of $\omega$ ($\omega > 5$). However, the effect of $D$ is insignificant for large values of frequency of oscillations $\omega$. The amplitude $|q|$ decreases with increase in the intensity of the magnetic field (Hartmann number $M$). The amplitude $|q|$ increases with increase in Peclet number $Pe$ or Radiation parameter $R$ for the values of $\omega \leq 15$ but decreases for large values of $\omega \leq 15$. A decrease in $|q|$ is noticed with increasing frequency of oscillations $\omega$.

Table 1: Amplitude ($|q|$) of Skin friction ( $\tau_L$ ) at lower plate

| Re | $M$ | $m$ | $D$ | $Gr$ | $Pe$ | $R$ | $P$ | $\omega = 5$ | $\omega = 10$ | $\omega = 15$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **1** | **1** | **1** | **0.7** | **1** | **10** | 0.74175 | 0.799029 | 0.622992 |
| **1.5** | 2 | 1 | 1 | 1 | 0.7 | 1 | 10 | 1.59843 | 0.879376 | 0.643293 |
| **2** | 2 | 1 | 1 | 1 | 0.7 | 1 | 10 | 1.75104 | 0.90803 | 0.645668 |
| 1 | **5** | 1 | 1 | 1 | 0.7 | 1 | 10 | 0.45904 | 0.356544 | 0.339405 |
| 1 | **8** | 1 | 1 | 1 | 0.7 | 1 | 10 | 0.19977 | 0.173817 | 0.179968 |
| 1 | 2 | **2** | 1 | 1 | 0.7 | 1 | 10 | 1.50641 | 0.859331 | 0.651048 |
| 1 | 2 | **3** | 1 | 1 | 0.7 | 1 | 10 | 1.61843 | 0.900872 | 0.671557 |
| 1 | 2 | 1 | **2** | 1 | 0.7 | 1 | 10 | 1.23184 | 0.770207 | 0.611035 |
| 1 | 2 | 1 | **3** | 1 | 0.7 | 1 | 10 | 1.13851 | 0.739593 | 0.597566 |
| 1 | 2 | 1 | 1 | **3** | 0.7 | 1 | 10 | 1.40054 | 0.863886 | 0.633323 |
| 1 | 2 | 1 | 1 | **5** | 0.7 | 1 | 10 | 1.49245 | 0.930019 | 0.65862 |
| 1 | 2 | 1 | 1 | 1 | **0.9** | 1 | 10 | 1.31844 | 0.803141 | 0.631482 |
| 1 | 2 | 1 | 1 | 1 | **1.2** | 1 | 10 | 1.33554 | 0.812094 | 0.638265 |
| 1 | 2 | 1 | 1 | 1 | 0.7 | **5** | 10 | 1.30839 | 0.850364 | 0.638895 |
| 1 | 2 | 1 | 1 | 1 | 0.7 | **10** | 10 | 1.35168 | 0.862647 | 0.642625 |
| 1 | 2 | 1 | 1 | 1 | 0.7 | 1 | **1** | 0.17854 | 0.021697 | 0.077568 |
| 1 | 2 | 1 | 1 | 1 | 0.7 | 1 | **5** | 0.68079 | 0.365671 | 0.313108 |

## 4. Conclusions

1. The velocity component for primary flow enhances with increasing in Re, $D$, $m$, $Gr$, $Pe$ and $P$; and reduces with increasing in the intensity of the magnetic field M (Hartmann number) and Radiation parameter.
2. The velocity component for secondary flow enhances with increasing in $D$ and $m$; and reduces with increasing in Re, $M$, $Gr$, $Pe$, $P$ and Radiation parameter $R$.
3. The resultant velocity enhances with increasing in Re, $D$, $m$ and $P$; and reduces with increasing in $M$, $Gr$, $Pe$, $R$ and the frequency of oscillation $\omega$.
4. Temperature reduces with increase in R or Pe while it enhances initially and then gradually reduces with increase in frequency of oscillation $\omega$.

## References

1. T. Hayat, Y. Wang and K. Hutter, "Hall effects on the unsteady hydromagnetic oscillatory flow of a second-grade fluid," Int. J. Nonlinear Mech. *39*, 1027-1037 (2004).
2. T. Hayat, N. Ahmed, M. Sajid and S. Asghar, "On the MHD flow of a second grade fluid in a porous channel," Comput. Math. Appl. *54*, 407-414 (2007).

3. T. Hayat, T. Javed and M. Sajid, "Analytic solution for MHD rotating flow of a second grade fluid over a shrinking surface," Phys. Lett. A *372*, 3264-3273 (2008).
4. T. Hayat, S. Iram, T. Javed and S. Asghar, "Shrinking flow of second grade fluid in a rotating frame: an analytic solution," Commun. Nonlinear Sci. Numer. Simulat. *15*, 2932-2941 (2010).
5. M. Ahmad and M. Yaseen, "Hall Effects on Rayleigh-Stokes Problem for Heated Second Grade Fluid," in The 3rd Session of 2012 Workshop of Pakistan Academy of Sciences, Proceedings of the Pakistan Academy of Sciences 49, (Pakistan Academy of Sciences, 2012), pp. 193-198.
6. T. Hayat, S. Nadeem, S. Asghar and A. M. Siddiqui, "Effects of Hall current on unsteady flow of a second grade fluid in a rotating system," Chem. Eng. Comm. *192*, 1272-1284 (2005).
7. W. Tana and T. Masuokaa, "Stokes' first problem for a second grade fluid in a porous half-space with heated boundary," Int. J. Nonlinear Mech. *40*, 515-522 (2005).
8. A. K. Tiwari, "Analytical studies on transient rotating flow of a second grade fluid in a porous medium," Adv. Theor. Appl. Mech *2*, 33-41 (2009).
9. I. Khan, A. Farhad, S. Sharidan and M. Norzieha, "Exact solutions for accelerated flows of a rotating second grade fluid in a porous medium," World Appl. Sci. J. *9*, 55-68 (2010).
10. T. Hayat, T. Javed and Z. Abbas, "Slip flow and heat transfer of a second grade fluid past a stretching sheet through a porous space," Int. J. Heat Mass Tran. *51*, 4528-4534 (2008).
11. M. Khan, S. H. Ali, T. Hayat and C. Fetecau, "MHD Flows of a second grade fluid between two side walls perpendicular to a plate through a porous medium," Int. J. Nonlinear Mech. *43*, 302-319 (2008).
12. Samiulhaq, S. Ahmad, D. Vieru, I. Khan and S. Shafie, "Unsteady magnetohydrodynamic free convection flow of a second grade fluid in a porous medium with ramped wall temperature," PLOS ONE *9*, 1-9 (2014).
13. R. M. Lahurikar, B. On flow past a infinite vertical isothermal plate in a rotating fluid, Marathwada Math. Society *11*, 41-49 (2010).
14. A.R. Vijayalakshmi, "Radiation Effects on Free- Convection Flow Past an Impulsively Started Vertical Plate in a Rotating Fluid," Theoret. Appl. Mech *37*, 79-95 (2010).
15. Veera Krishna. M and B.V. Swarnalathamma, Convective Heat and Mass Transfer on MHD Peristaltic Flow of Williamson Fluid with the Effect of Inclined Magnetic Field," *AIP Conference Proceedings* 1728:020461, 2016 doi: http://dx.doi.org/10.1063/1.4946512
16. Swarnalathamma. B. V. and M. Veera Krishna Peristaltic hemodynamic flow of couple stress fluid through a porous medium under the influence of magnetic field with slip effect *AIP Conference Proceedings* 1728:020603, 2016. doi: http://dx.doi.org/10.1063/1.4946654
17. Veera Krishna. M and M. Gangadhar Reddy MHD free convective rotating flow of Visco-elastic fluid past an infinite vertical oscillating porous plate with chemical reaction, *IOP Conf. Series: Materials Science and Engineering* 149:012217, 2016. doi: http://dx.doi.org/10.1088/1757-899X/149/1/012217.
18. Veera Krishna/M and G. Subba Reddy, Unsteady MHD convective flow of Second grade fluid through a porous medium in a Rotating parallel plate channel with temperature dependent source, *IOP Conf. Series: Materials Science and Engineering*, 149:012216, 2016. doi**:** http://dx.doi.org/10.1088/1757-899X/149/1/012216.
19. Veera Krishna.M., B.V.Swarnalathamma and J. Prakash, "Heat and mass transfer on unsteady MHD Oscillatory flow of blood through porous arteriole, Applications of Fluid Dynamics, Lecture Notes in Mechanical Engineering, vol. XXII, pp. 207-224, 2018. Doi: 10.1007/978-981-10-5329-0_14.
20. Veera Krishna. M, G. Subba Reddy, A.J. Chamkha, "Hall effects on unsteady MHD oscillatory free convective flow of second grade fluid through porous medium between two vertical plates," Physics of Fluids, vol. *30*, 023106 (2018); doi: 10.1063/1.5010863
21. Veera Krishna. M, A.J. Chamkha, Hall effects on unsteady MHD flow of second grade fluid through porous medium with ramped wall temperature and ramped surface concentration, Physics of Fluids *30*, 053101 (2018), doi: https://doi.org/10.1063/1.5025542