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EFFECTS OF THERMAL RADIATION AND HALL EFFECTS ON MHD FREE CONVECTION FLOW OF VISCO-ELASTIC FLUID THROUGH POROUS MEDIUM PAST AN INFINITE VERTICAL POROUS PLATE

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ABSTRACT

This study investigates on unsteady MHD free convection flow of a viscous, incompressible and electrically conducting visco-elastic fluid through a porous medium with simultaneous heat and mass transfer near an infinite vertical porous plate under the influence of uniform transverse magnetic field and taking hall current into account. To check the accuracy of the numerical solutions for energy, state and momentum equations are obtained by using the perturbation method for small elastic parameter. The expressions for the velocity, temperature and concentration have been derived analytically and also its behaviour is computationally discussed. The effect of various governing parameters controlling the physical situation is discussed with the aid of line graphs. Significant results from this study are obtained for that velocity, temperature and concentration. The skin friction on the boundary, the heat flux in terms of the Nusselt number, and the rate of mass transfer in terms of the Sherwood number are also obtained and their behaviour computationally discussed. During the course of numerical computation, an excellent agreement was found between the profiles with z and time series profiles.

Keywords: *Hall effects, Heat and mass transfer, MHD flows, porous medium, unsteady flows and visco-elastic fluids.*

INTRODUCTION

The study of hydro magnetic free convection flow finds applications in science and engineering, in areas such as geophysical exploration, solar physics, and astrophysical studies. The convection problem in a porous medium has important applications in geothermal reservoirs and geothermal extractions. The process of heat and mass transfer is encountered in aeronautics, fluid fuel nuclear reactor, chemical process industries and many engineering applications in which the fluid is the working medium. When the strength of the magnetic field is strong, one cannot neglect the effect of Hall current. It is of considerable importance and interest to study how the results of the hydro dynamical problems get modified by the effect of Hall currents. Hall currents give rise to a cross flow making the flow three dimensional.

Azzam [1] reported a study on the radiation effects on the Magnetohydrodynamic (MHD) mixed free-forced convection flow past a semi-infinite moving vertical plate for high temperature differences. Unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption was reported by Chamkha [3]. A few other works of interest in this area include Kim [10], Makinde [11], Ogulu and Prakash [12]. Chaughan and Rastogi [4] studied steady state MHD Couette flow of a viscous, incompressible and electrically conducting fluid flow between two infinite parallel plates in the presence of an inclined magnetic field. Hazem [8 & 9] reported unsteady magnetohydromagnetic Couette flow of an electrically conducting incompressible non-Newtonian viscoelastic fluid between two parallel horizontal non-conducting porous plates with heat transfer. Salama [14] investigated flow formation in magnetohydrodynamics with time varying suction and taking into account the effects of heat and mass transfer. Farhad *et al.*, [7] investigated the hydromagnetic rotating flow of viscous fluid through a porous space under slip condition. Baoku *et al.*, [2] studied the problem of steady hydromagnetics Couette flow of a high viscous fluid through a porous channel in the presence of an applied uniform transverse magnetic field and thermal radiation. Cheng and Lau [5] and Cheng and Teckchandani [6] obtained numerical solutions for the convective flow in a porous medium bounded by two isothermal parallel plates in the presence of the withdrawal of the fluid. In all the above mentioned studies, the effect of porosity, permeability and the thermal resistance of the medium is ignored or treated as constant. Rakesh [13] studied effect of slip conditions and Hall current on unsteady MHD flow of a visco-elastic fluid past an infinite vertical porous plate through porous medium. Veera Krishna.M and G.Dharmaiah [15] discussed Heat Transfer on unsteady MHD Couette flow of a Bingham fluid through a Porous medium in a parallel plate channel with uniform suction and injection under the effect of inclined magnetic field and taking Hall currents. Veera Krishna.M and Devika Rani [16] investigated unsteady MHD mixed convection oscillatory flow of viscous incompressible fluid in a rotating vertical channel with radiation effects. Radiative heat transfer on unsteady MHD oscillatory visco-elastic flow through porous medium in a parallel plate channel was studied by Veera Krishna *et al.*, [17].

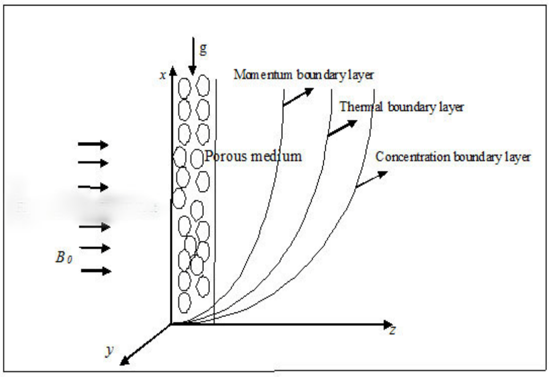
The present work is motivated to study the heat and mass transfer unsteady MHD free convection flow of a viscous, incompressible and electrically conducting visco-elastic fluid through a porous medium near an infinite vertical porous plate under the influence of uniform transverse magnetic field and taking hall current into account.

FORMULATION AND SOLUTION OF THE PROBLEM

We consider the unsteady flow of an incompressible MHD free convection flow of Visco-elastic fluid through a porous medium with simultaneous heat and mass transfer near infinite vertical oscillating porous plate under the influence of uniform transverse magnetic field and taking hall current into account. The plate temperature is constant to be maintained. The Visco-elastic and Darcy's resistance terms are taken into account with constant permeability of the porous medium. The physical configuration of the problem is shown in Figure 1.

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 under the influence of uniform transverse magnetic field is governed by the following system of Equations

Figure-1: Physical configuration of the Problem



Equation of continuity:

$$\frac{\partial w}{\partial z} = 0 \tag{2.1}$$

Equation of Momentum:

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t} + w\frac{\partial u}{\partial z} = \nu\frac{\partial^2 u}{\partial z^2} + \left(1+\lambda\frac{\partial}{\partial t}\right)\left(B_0 J_y - \frac{\nu}{k}\right)u + g\beta(T-T_\infty) + g\beta^*(C-C_\infty) \tag{2.2}$$

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial v}{\partial t} + w\frac{\partial v}{\partial z} = \nu\frac{\partial^2 v}{\partial z^2} - \left(1+\lambda\frac{\partial}{\partial t}\right)\left(B_0 J_x + \frac{\nu}{k}\right)v \tag{2.3}$$

Equation of Energy:

$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z} = \alpha\frac{\partial^2 T}{\partial z^2} - \frac{\partial q_r}{\partial z} \tag{2.4}$$

Equation of Concentration:

$$\frac{\partial C}{\partial t} + w\frac{\partial C}{\partial z} = D\frac{\partial^2 C}{\partial z^2} \tag{2.5}$$

Using Rosseland approximation for radiation,

$$\frac{\partial q_r}{\partial z} = 4\alpha^2(T-T_\infty) \tag{2.6}$$

The corresponding boundary conditions are

$$u = v = 0, T = T_w, C = C_w \ \ at \quad z = 0 \tag{2.7}$$

$$u = v = 0, T = T_\infty, C = C_\infty \ \ at \quad z \to \infty \tag{2.8}$$

When the strength of the magnetic field is very large, the generalized ohm's law is modified to include the hall current so that

$$J + \frac{\omega_e \tau_e}{B_O}\left(J \times B\right) = \sigma\left[E + V \times B + \frac{1}{e\eta_e}\nabla P_e\right] \tag{2.9}$$

We also assume that the electric field *E=0* under assumptions reduces to

$$J_x + m\ J_y = \sigma B_0 v \tag{2.10}$$

$$J_y - m\ J_x = -\sigma B_0 u \tag{2.11}$$

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

On solving equations (2.10) and (2.11) we obtain

$$J_x = \frac{\sigma B_0}{1+m^2}(v + mu) \tag{2.12}$$

$$J_y = \frac{\sigma B_0}{1+m^2}(mv - u) \tag{2.13}$$

Substituting the equations (2.12) and (2.13) in (2.3) and (2.2) respectively, we obtain

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t} + w\frac{\partial u}{\partial z} = \nu\frac{\partial^2 u}{\partial z^2} + \left(1+\lambda\frac{\partial}{\partial t}\right)\left(\frac{\sigma B_0^2}{1+m^2}(mv-u) - \frac{\nu}{k}\right)u$$
$$+ g\beta(T - T_\infty) + g\beta^*(C - C_\infty) \tag{2.14}$$

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial v}{\partial t} + w\frac{\partial v}{\partial z} = \nu\frac{\partial^2 v}{\partial z^2} - \left(1+\lambda\frac{\partial}{\partial t}\right)\left(\frac{\sigma B_0^2}{1+m^2}(v+mu) + \frac{\nu}{k}\right)v \tag{2.15}$$

We choose, $q = u + iv$ and taking into consideration, the momentum equation (2.14) and (2.15) can be written as, we obtain

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial q}{\partial t} + w\frac{\partial q}{\partial z} = \nu\frac{\partial^2 q}{\partial z^2} - \left(1+\lambda\frac{\partial}{\partial t}\right)\left(\frac{\sigma B_0^2}{\rho(1+m^2)} + \frac{\nu}{k}\right)q + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) \tag{2.16}$$

We introduce the non-dimensional variables,

$$u^* = \frac{u}{W_0}, v^* = \frac{v}{W_0}, t^* = \frac{tW_0^2}{\nu}, z^* = \frac{zW_0}{\nu}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, C^* = \frac{C - C_\infty}{C_w - C_\infty}$$

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

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial q}{\partial t} - \frac{\partial q}{\partial z} = \frac{\partial^2 q}{\partial z^2} - \left(1+\lambda\frac{\partial}{\partial t}\right)\left(\frac{M^2}{1+m^2} + \frac{1}{K}\right)q + Gr(\theta + \phi C) \tag{2.17}$$

$$\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial z} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial z^2} - R\theta \tag{2.18}$$

$$\frac{\partial C}{\partial t} - \frac{\partial C}{\partial z} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} \tag{2.19}$$

The corresponding non-dimensional boundary conditions are

$$q = 0, \theta = 1, C = 1 \ \ at \quad z = 0 \tag{2.20}$$

$$q = 0, \theta = 0, C = 0 \ \ at \quad z \to \infty \tag{2.21}$$

We assume the solutions of the equations (2.17) to (2.19) as,

$$q(z,t) = q_0(t)\,e^{i\omega t}, \quad \theta(z,t) = \theta_0(t)\,e^{i\omega t}, \quad C(z,t) = C_0(t)\,e^{i\omega t} \tag{2.22}$$

Using the equations (2.22), the equations (2.10) to (2.12) reduces and Solving making use of the boundary conditions, ,we obtained the velocity, temperature and concentration distributions.

$$q = ((a_1 + a_2)e^{-m_1 z} - a_1 e^{-m_2 z} - a_2 e^{-m_3 z})e^{i\omega t} \tag{2.23}$$

$$\theta = e^{-m_2 z}\, e^{i\omega t} \tag{2.24}$$

$$c = e^{i\omega t} \tag{2.25}$$

SKIN FRICTION

The skin friction at the plate is given by

$$\tau = \left(\frac{\partial q}{\partial z}\right)_{z=0} = -\left(m_1(a_1 + a_2) + a_1 m_2 + a_2 m_3\right)\, e^{i\omega t} \tag{2.26}$$

NUSSELT NUMBER

The rate of heat transfer, that is, the heat flux at the plate Z=0 in terms of the Nusselt number, is given by

$$Nu = -\left(\frac{\partial \theta}{\partial z}\right)_{z=0} = m_2\, e^{i\omega t} \tag{2.27}$$

SHERWOOD NUMBER

The rate of mass transfer at the plate Z=0 in terms of the Sherwood number is given by

$$Sh = -\left(\frac{\partial C}{\partial z}\right)_{z=0} = m_3\, e^{i\omega t} \tag{2.28}$$

RESULTS AND DISCUSSION

We have considered the unsteady MHD free convection flow of a viscous, incompressible and electrically conducting visco-elastic fluid through a porous medium with simultaneous heat and mass transfer near an infinite vertical porous plate under the influence of uniform transverse magnetic field and taking hall current into account. The plate temperature is constant to be maintained. The visco-elastic and Darcy's resistance terms are taken into account with constant permeability of the porous medium. The governing equations of the flow field are solved by a regular perturbation method for small elastic parameter. The expressions for the velocity, temperature, concentration have been derived analytically and also its behaviour is computationally discussed with reference to different m, M, K, λ, Gr, Sc, R, ω, ϕ , parameters as shown in the line graphs using Mathematica.

We noticed that, the magnitude of the velocity components *u* increases and *v* reduces with increasing hall parameter *m* being the other parameters fixed (Figures 2). But the resultant velocity enhances with increasing hall parameter *m*. The Figure (3) 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 λ or the frequency of oscillation ω. 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* (Figure 4). Figure (5) showed the effect of Radiation parameter R, the Prandtl number Pr, and the frequency of oscillation ω and time *t* on the temperature of the flow field. We noted that the temperature of the flow field 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. Figures (6) depict the effect of the Schmidt number Sc and the frequency of oscillation ω on concentration distribution. The concentration distribution decreases at all points of the flow field with the increase in the Schmidt number Sc. This shows that the heavier diffusing species have a greater retarding effect on the concentration distribution of the flow field. Also, it is observed that presence of the frequency of oscillation ω reduces the concentration distribution.

From the time series profiles7, 8, 9 the behaviour of the results for the velocity are found in good agreement between the profiles with *z* and time series profiles with magnetic field parameter M. Similarly, we obtained time series profiles for temperature with radiation parameter R and for Concentration with frequency of oscillation ω.

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, Radiation parameter R and Buoyancy ratio ϕ, but it is interesting to note that the skin friction decreases with the increase in Hartmann number M, visco-elastic parameter λ, the frequency of oscillation ω, Prandtl number Pr, thermal Grashof number Gr, Schimdt number Sc 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 ω 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 ω and time *t* increase the rate of mass transfer at the surface of the plate.

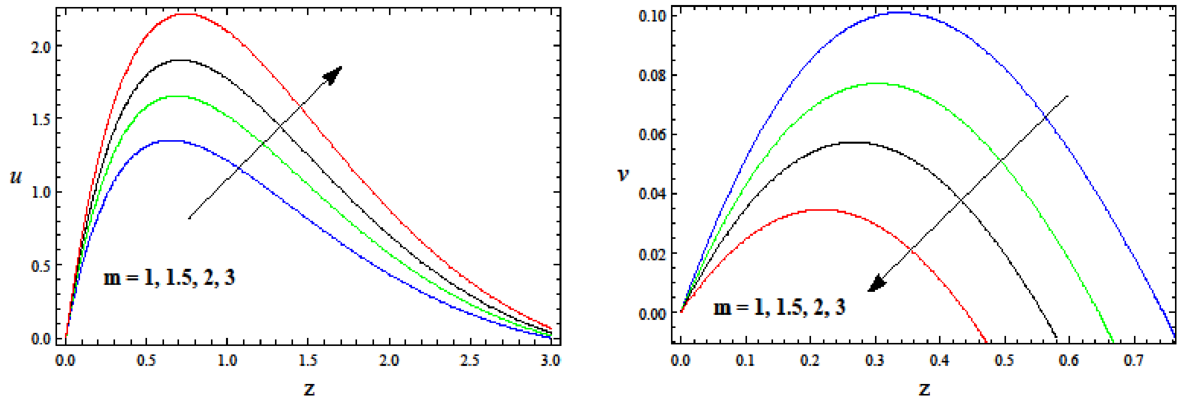


Figure -2: The velocity Profiles for *u* and *v* against *m*

M=1.5, K=1, Pr =0.71, Sc=0.78, R=1, Gr =10, $\lambda=1$, $\phi=0.2$, $\omega=\pi/4$, t =0.1

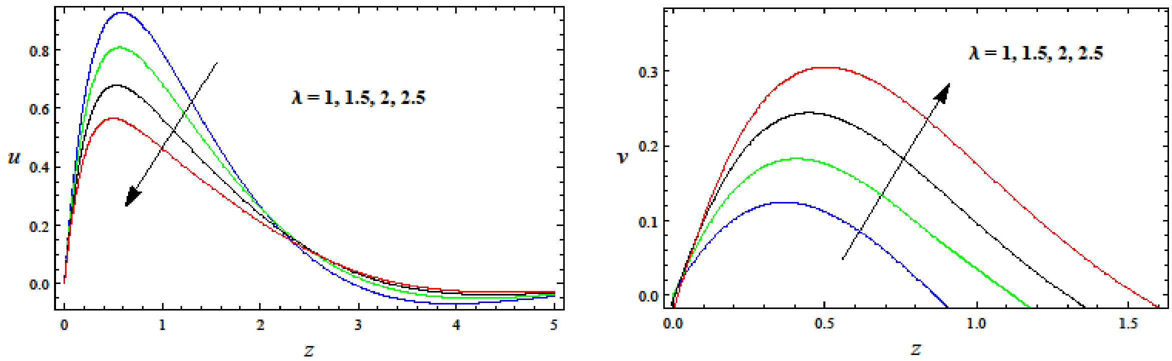


Figure -3: The velocity Profiles for *u* and *v* against λ

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

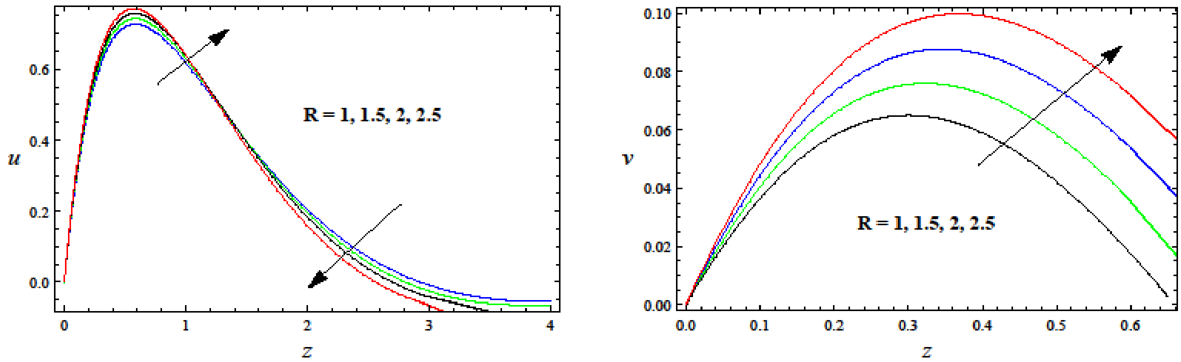


Figure -4: The velocity Profiles for *u* and *v* against R

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

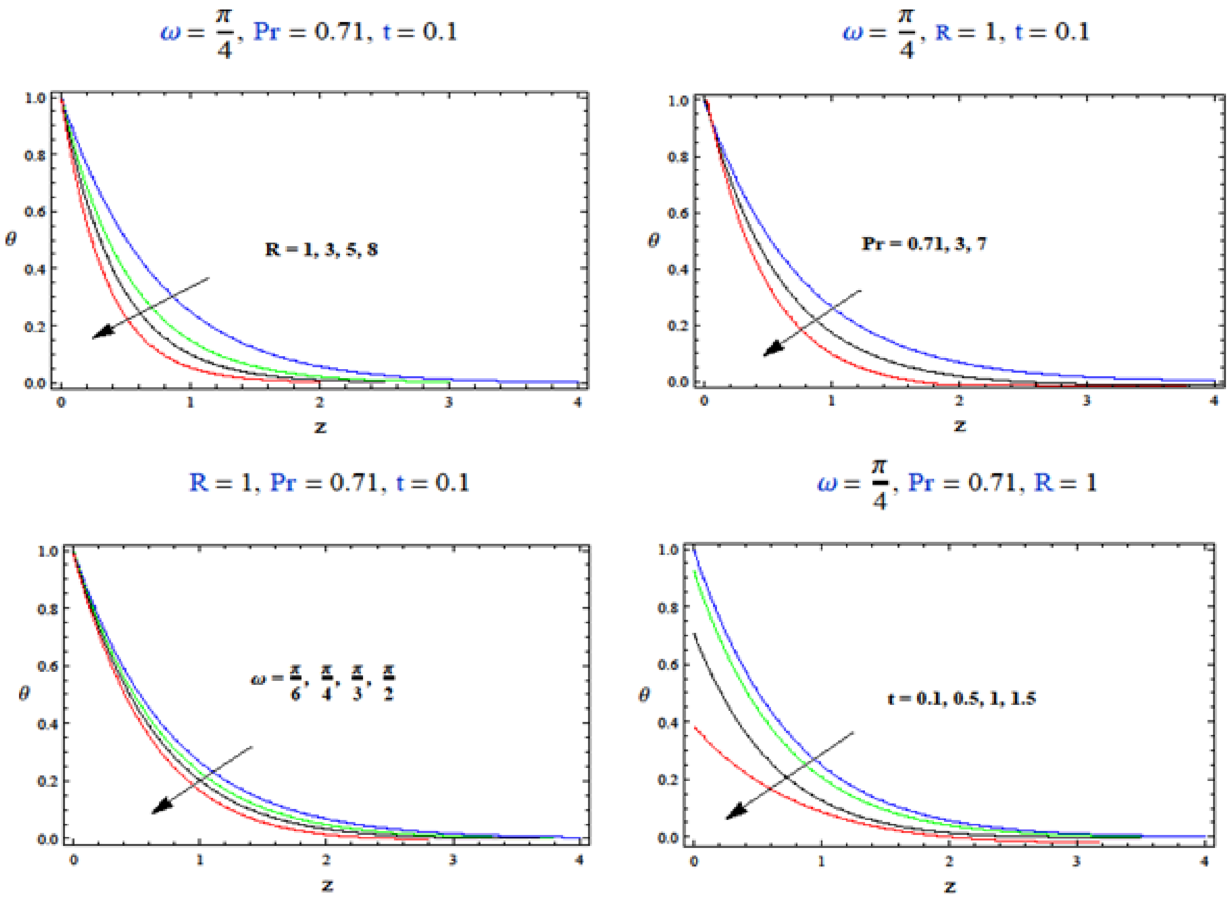


Figure -5: The Temperature Profiles for θ with R, Pr, ω and t

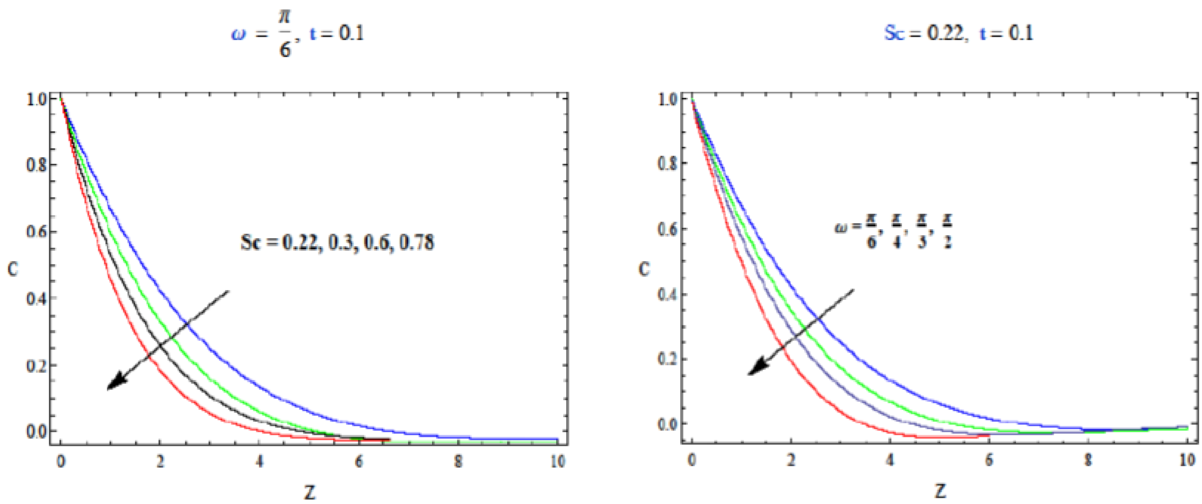


Figure -6: The Concentration Profiles for C with Sc and ω

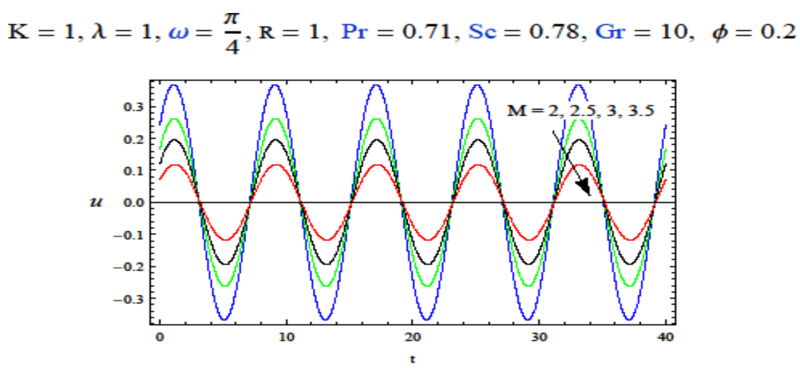


Figure -7: Time series profile for u with Hartmann number M

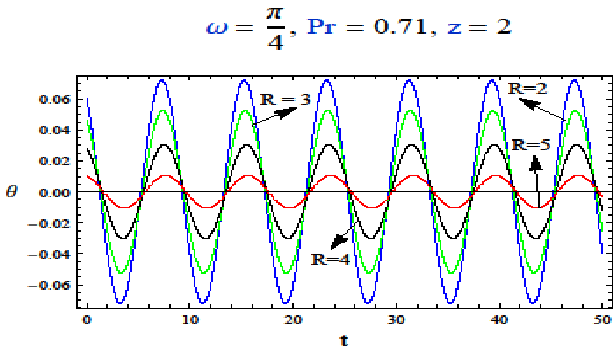


Figure - 8: Time series profile for θ with Radiation parameter R

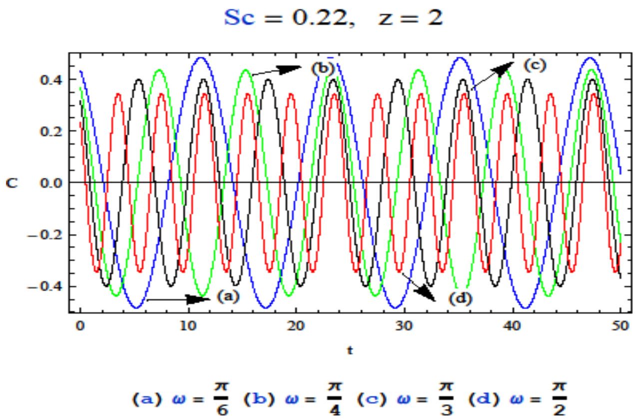


Figure - 9: Time series profile for concentration C with ω

Table-1: Skin Friction

M	K	λ	R	Pr	Gr	ϕ	Sc	ω	t	m	τ
2	**1**	**1**	**1**	**0.71**	**10**	**0.2**	**0.22**	$\pi/4$	**0.1**	**1**	5.923870
2.5	1	1	1	0.71	10	0.2	0.22	$\pi/4$	0.1	1	5.090920
3	1	1	1	0.71	10	0.2	0.22	$\pi/4$	0.1	1	4.423994
2	**2**	1	1	0.71	10	0.2	0.22	$\pi/4$	0.1	1	6.445740
2	**3**	1	1	0.71	10	0.2	0.22	$\pi/4$	0.1	1	6.651547
2	1	**1.5**	1	0.71	10	0.2	0.22	$\pi/4$	0.1	1	5.484708
2	1	**2**	1	0.71	10	0.2	0.22	$\pi/4$	0.1	1	4.973461
2	1	1	**2**	0.71	10	0.2	0.22	$\pi/4$	0.1	1	6.105673
2	1	1	**3**	0.71	10	0.2	0.22	$\pi/4$	0.1	1	6.960908
2	1	1	1	**3**	10	0.2	0.22	$\pi/4$	0.1	1	3.643617
2	1	1	1	**7**	10	0.2	0.22	$\pi/4$	0.1	1	2.357887
2	1	1	1	0.71	**15**	0.2	0.22	$\pi/4$	0.1	1	3.536831
2	1	1	1	0.71	**20**	0.2	0.22	$\pi/4$	0.1	1	2.715774
2	1	1	1	0.71	10	**0.5**	0.22	$\pi/4$	0.1	1	7.428604
2	1	1	1	0.71	10	**0.7**	0.22	$\pi/4$	0.1	1	8.431760
2	1	1	1	0.71	10	0.2	**0.6**	$\pi/4$	0.1	1	5.794396
2	1	1	1	0.71	10	0.2	**0.78**	$\pi/4$	0.1	1	5.738639
2	1	1	1	0.71	10	0.2	0.22	$\pi/3$	0.1	1	5.415466
2	1	1	1	0.71	10	0.2	0.22	$\pi/2$	0.1	1	4.351939
2	1	1	1	0.71	10	0.2	0.22	$\pi/4$	**0.5**	1	5.368414
2	1	1	1	0.71	10	0.2	0.22	$\pi/4$	**0.8**	1	4.601975
2	1	1	1	0.71	10	0.2	0.22	$\pi/4$	0.1	**2**	7.464147
2	1	1	1	0.71	10	0.2	0.22	$\pi/4$	0.1	**3**	8.301656

Table-2: Nusselt number

R	Pr	ω	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	ω	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

CONCLUSIONS

The unsteady flow of an incompressible MHD free convection flow of Visco-elastic Kuvshinshiki fluid through a porous medium with simultaneous heat and mass transfer near an infinite vertical oscillating porous plate under the influence of uniform transverse magnetic field has been discussed. The influence of the dimensionless parameters on velocity temperature, Concentration, skin friction, Nusselt number and Sherwood number is demonstrated on figures and discussed. From the results obtained, the findings are:

1. The magnitude of the resultant velocity reduces with increasing the intensity of the magnetic field or Prandtl number Pr or Schimdt number Sc.
2. The resultant velocity enhance with increasing Hall parameter *m* or Grashof number Gr or Buoyancy ratio ϕ.
3. The resultant velocity enhances 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.
4. The reversal behaviour is observed with increasing visco-elastic parameter λ or the frequency of oscillation ω.
5. The magnitude of the resultant velocity 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*.
6. The magnitude of the temperature of the flow field diminishes as the Prandtl number or time or the frequency of oscillation.
7. The concentration reduces at all points of the flow field with the increase in the Schmidt number Sc, and presence of the frequency of oscillation ω reduces the concentration distribution.
8. Also, the skin friction increases with the increase in *m*, K, R and ϕ, reduces with the increase in M, λ, ω, Pr, Gr, Sc and *t*.
9. The rate of heat transfer (Nusselt number Nu) at the surface of the plate increase R, Pr or ω, and reduces with increasing time *t*.
10. The Schmidt number Sc, ω and time *t* increase the rate of mass transfer (Sh) at the surface of the plate.
11. Moreover, the time required for the velocity and temperature fields, skin-friction, Nusselt number and mass Grashof number to attain maximum rests on the dimensionless parameters.
12. The results for the velocity are found in good agreement between the profiles with *z* and time series profiles with magnetic field parameter. Similarly, we obtained temperature with R and Concentration with frequency of oscillation.

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