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Radiation Effects on MHD Free Convective Rotating Flow with Hall Effects

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ABSTRACT
In this paper, we have studied the unsteady an incompressible MHD rotating free convection flow of Visco-elastic 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. 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 flow parameters with the help of graphs. The skin friction, the Nusselt number and the Sherwood number are also obtained and their behaviour discussed.
Keywords: Heat and mass transfer, MHD flows, porous medium, unsteady flows and visco-elastic fluids.

I. INTRODUCTION

In the recent past a considerable attention has been gained by the magnetohydrodynamic (MHD) rotating flows of electrically conducting, visco-elastic incompressible fluids due to its numerous applications in the cosmic and geophysical fluid dynamics. The subject of geophysical dynamics nowadays has become an important branch of fluid dynamics due to the increasing interest to study environment. In astrophysics it is applied to study the stellar and solar structure, inter planetary and inter stellar matter, solar storms and flares etc. During the last few decades it also finds its application in engineering. Among the applications of rotating flow in porous media to engineering disciplines, one can find the food processing industry, chemical process industry, centrifugation and filtration processes and rotating machinery. In recent years a number of studies have also appeared in the literature on the fluid phenomena on earth involving rotation to a greater or lesser extent viz. Vidya nidhu and Nigam [1],Gupta [2],Jana and Datta [3]. Mazumder[4] obtained an exact solution of an oscillatory Couette flow in a rotating system. Thereafter Ganapathy[5] presented the solution for rotating Couette flow. Singh[6] analyzed the oscillatory magneto hydro dynamic (MHD) Couette flow in a rotating system in the presence of transverse magnetic field. Singh[7] also obtained an exact solution of magneto hydro dynamic (MHD) mixed convection flow in a rotating vertical channel with heat radiation. Hossanien and Mansour[8]investigated unsteady magnetic flow through a porous medium between two infinite parallel plates. The study of the flows of visco-elastic fluids is important in the fields of petroleum technology and in the purification of crude oils. In recent years, flows of visco-elastic fluids attracted the attention of several scholars in view of their practical and fundamental importance associated with many industrial applications. Literature is replete with the various flow problems considering variety of geometries such as Rajgopal[9], Rargopal and Gupta [10], Ariel [11], Pop and Gorla [12]. Hayat et al [13] discussed periodic unsteady flow of a non-Newtonian fluid. Choudhury and Das [14] studied the oscillatory viscelastic flow in a channel filled with porous medium in the presence of radiative heat transfer. Singh [15] analyzed viscoelastic mixed convection MHD oscillatory flow through a porous medium filled in a vertical channel. Taking the rotating frame of reference into account, Puri [16] investigated rotating flow of an elastic-viscous fluid on an oscillating plate. Keeping the above mentioned facts, in this paper, we have considered the unsteady an incompressible MHD rotating free convection flow of Visco-elastic 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.

II. FORMULATION AND SOLUTION OF THE PROBLEM

We consider the unsteady an incompressible MHD free convection rotating 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. In the initial undisturbed state both the plate and the fluid rotate with the same angular velocity Ω . 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.

Figure 1: Physical configuration of the problem

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

$$\frac{\partial w}{\partial z} = 0 \tag{1}$$

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

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial v}{\partial t} + w\frac{\partial v}{\partial z} + 2\Omega u = \nu\frac{\partial^2 v}{\partial z^2} - \left(1+\lambda\frac{\partial}{\partial t}\right)\left(-B_0 J_x + \frac{\nu}{k}v\right) \tag{3}$$

$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z} = \alpha\frac{\partial^2 T}{\partial z^2} - \frac{\partial q_r}{\partial z} \tag{4}$$

$$\frac{\partial C}{\partial t} + w\frac{\partial C}{\partial z} = D\frac{\partial^2 C}{\partial z^2} \tag{5}$$

Where, u, v are the velocity components along x and y directions; T and C are the temperature and concentration components, ν is the kinematic viscosity, ρ is the density, σ is the electric conductivity, B_0 is the magnetic induction, k is the permeability of the porous medium, g is the acceleration due to gravity, β is the thermal expansion co-efficient, β^* is the concentration expansion co-efficient, α is the thermal conductivity and D is the concentration diffusivity q_r is the radiation heat flux. Using Rosseland approximation for radiation,

$$\frac{\partial q_r}{\partial z} = 4\alpha^2(T-T_\infty) \tag{6}$$

The corresponding boundary conditions are

$$u = v = 0, T = T_w, C = C_w \ \text{ at } \ z = 0 \tag{7}$$

$$u = v = 0, T = T_\infty, C = C_\infty \ \text{ at } \ z \to \infty \tag{8}$$

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

$$J + \frac{\omega_e \tau_e}{B_O}(J \times B) = \sigma\left[E + V \times B + \frac{1}{e\eta_e}\nabla P_e\right] \tag{9}$$

Where ω_e is the cyclotron frequency of the electrons, τ_e is the electron collision time, σ is the electrical conductivity, e is the electron charge and P_e is the electron pressure. The ion-slip and thermo electric effects are not included in equation (9). Further it is assumed that $\omega_e \tau_e$ ~ O(1) and $\omega_i \tau_i << 1$, where ω_i and τ_i are the cyclotron frequency and collision time for ions respectively. In 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

$$J_x + m J_y = \sigma B_0 v \tag{10}$$

$$J_y - m J_x = -\sigma B_0 u \tag{11}$$

Where $m = \tau_e \omega_e$ is the hall parameter.
On solving equations (10) and (11) we obtain

$$J_x = \frac{\sigma B_0}{1+m^2}(v + mu) \tag{12}$$

$$J_y = \frac{\sigma B_0}{1+m^2}(mv - u) \tag{13}$$

Substituting the equations (12) and (13) in (3) and (2) respectively, we obtain

Combining the equations (2) and (3), we obtain

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial q}{\partial t} + w\frac{\partial q}{\partial z} + 2i\Omega q = \nu\frac{\partial^2 q}{\partial z^2} - \left(1+\lambda\frac{\partial}{\partial t}\right)\left(\frac{\sigma B_0^2}{\rho(1+m^2)} + \frac{\nu}{k}\right)q + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) \tag{14}$$

We introduce the non-dimensional variables,

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

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

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial q}{\partial t} - \frac{\partial q}{\partial z} + 2iEq = \frac{\partial^2 q}{\partial z^2} - \left(1+\lambda\frac{\partial}{\partial t}\right)\left(\frac{M^2}{1+m^2} + \frac{1}{K}\right)q + Gr(\theta + \phi C) \tag{15}$$

$$\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial z} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial z^2} - R\theta \tag{16}$$

$$\frac{\partial C}{\partial t} - \frac{\partial C}{\partial z} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} \tag{17}$$

The corresponding non-dimensional boundary conditions are

$$q = 0, \theta = 1, C = 1 \quad \text{at} \quad z = 0 \tag{18}$$

$$q = 0, \theta = 0, C = 0 \quad \text{at} \quad z \to \infty \tag{19}$$

Where, $M^2 = \frac{\sigma B_0^2 \nu}{\rho W_0^2}$ is the Hartmann number, $K = \frac{kW_0^2}{\nu^2}$ is the permeability parameter, $E = \frac{\Omega \nu}{W_0^2}$ is the Rotation parameter, $R = \frac{4\alpha^2 W_0^2}{\nu}$ is the Radiation parameter, $\Pr = \frac{\nu}{\alpha}$ is the Prandtl number, $\text{Sc} = \frac{\nu}{D}$ is the Schmidt number, $\lambda = \frac{\lambda W_0^2}{\nu}$ is the Visco-elastic parameter, $\phi = \frac{\beta^*(C_w - C_\infty)}{\beta(T_w - T_\infty)}$ is the Buoyancy ratio .
We assume the solutions of the equations (15) to (17) as,

$$q = q_0(t)e^{i\omega t}, \theta = \theta_0(t)e^{i\omega t}, C = C_0(t)e^{i\omega t} \tag{20}$$

Using the equations (20), the equations (15) to (17) reduces to

$$\frac{d^2 q_0}{dz^2} + \frac{dq_0}{dz} - \left(2iE + \left(\frac{M^2}{1+m^2} + \frac{1}{K} - i\omega\right)(1 - i\omega\lambda)\right)q_0 = -Gr(\theta_0 + \phi C_0) \tag{21}$$

$$\frac{d^2\theta_0}{dz^2} + \Pr\frac{d\theta_0}{dz} + \Pr(i\omega - R)\theta_0 = 0 \tag{22}$$

$$\frac{d^2 C_0}{dz^2} + \text{Sc}\frac{dC_0}{dz} + \text{Sc}\, i\omega C_0 = 0 \tag{23}$$

The corresponding boundary conditions are

$$q_0 = 0, \theta_0 = 1, C_0 = 1 \quad \text{at} \quad z = 0 \tag{24}$$

$$q_0 = 0, \theta_0 = 0, C_0 = 0 \quad \text{at} \quad z \to \infty \tag{25}$$

Solving the equations (21) to (23) making use of the boundary conditions (24) and (25),

$$q_0 = (a_1 + a_2)\mathrm{e}^{-m_1 z} - a_1\mathrm{e}^{-m_2 z} - a_2\mathrm{e}^{-m_3 z} \tag{26}$$

$$\theta_0 = \mathrm{e}^{-m_2 z} \tag{27}$$

$$C_0 = \mathrm{e}^{-m_3 z} \tag{28}$$

Substituting the equations (26) to (28) in the equations (20), we obtained the velocity, temperature and concentration distributions.

Skin friction:

$$\tau = \left(\frac{\partial q}{\partial z}\right)_{z=0} = -\left(m_1(a_1 + a_2) + a_1 m_2 + a_2 m_3\right) e^{i\omega t} \tag{29}$$

Nusselt number:

$$Nu = -\left(\frac{\partial \theta}{\partial z}\right)_{z=0} = m_2\, e^{i\omega t} \tag{30}$$

Sherwood number:

$$Sh = -\left(\frac{\partial C}{\partial z}\right)_{z=0} = m_3\, e^{i\omega t} \tag{31}$$

III. 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 flow parameters as shown in the line graphs (Fig. 2-19) using Mathematica.

We noticed that, the magnitude of the velocity components *u* increases and *v* reduces with increasing Rotation parameter E being the other parameters fixed (Figures 2). From the Figures (3, 9-10), we noticed that the magnitude of the velocity components *u* and *v* reduces with increasing the intensity of the magnetic field or Prandtl number Pr or Schimdt 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 ϕ (Figures 6 & 7). The Figures (4-5 & 11) 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 (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* (Figure 8 and 12).

Figures (13) 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 (14) 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.

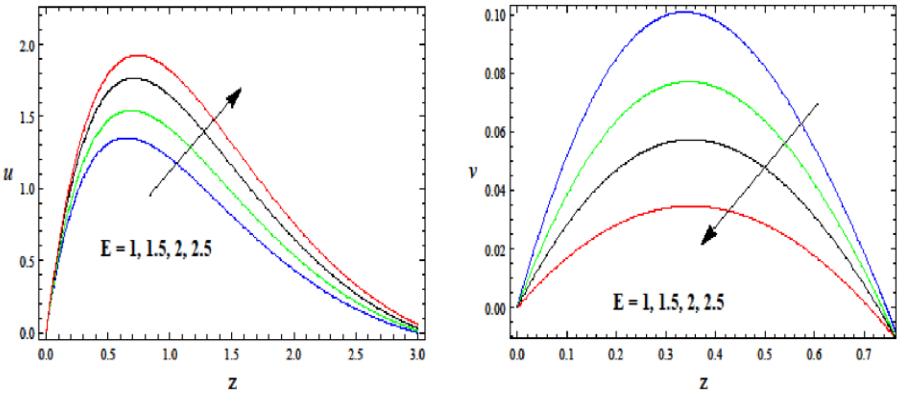

Figure 2. The velocity Profiles for *u* and *v* against E

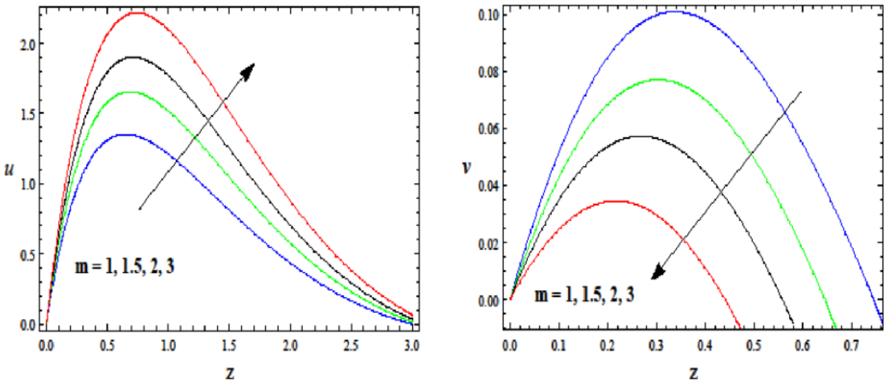

Figure 3. The velocity Profiles for *u* and *v* against m

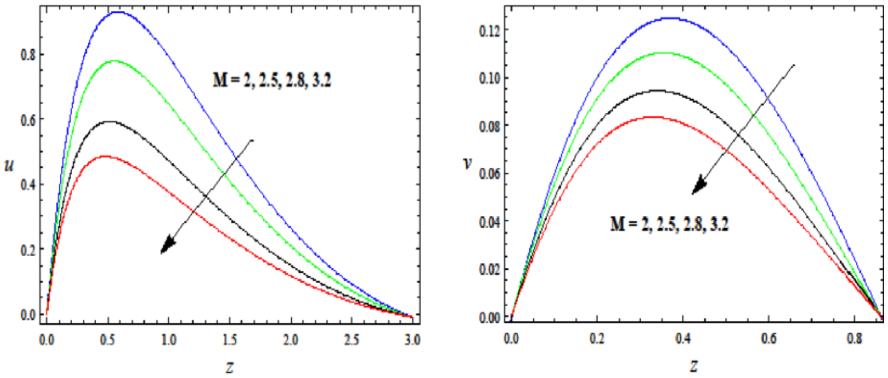

Figure 4. The velocity Profiles for *u* and *v* against M

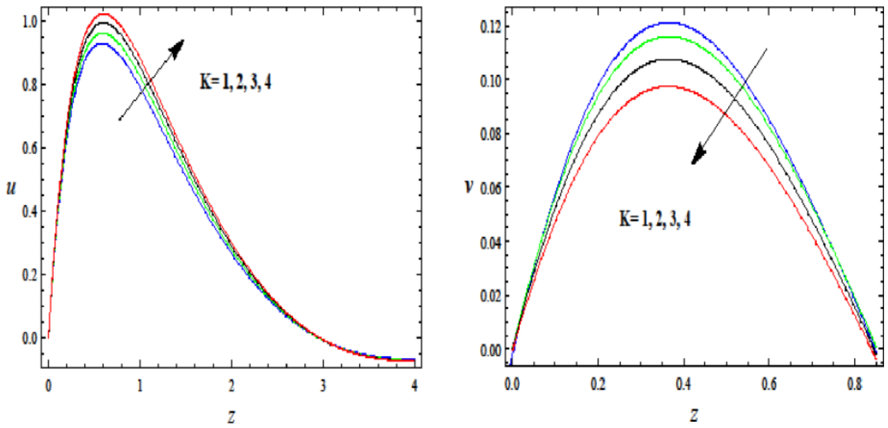

Figure 5. The velocity Profiles for *u* and *v* against K

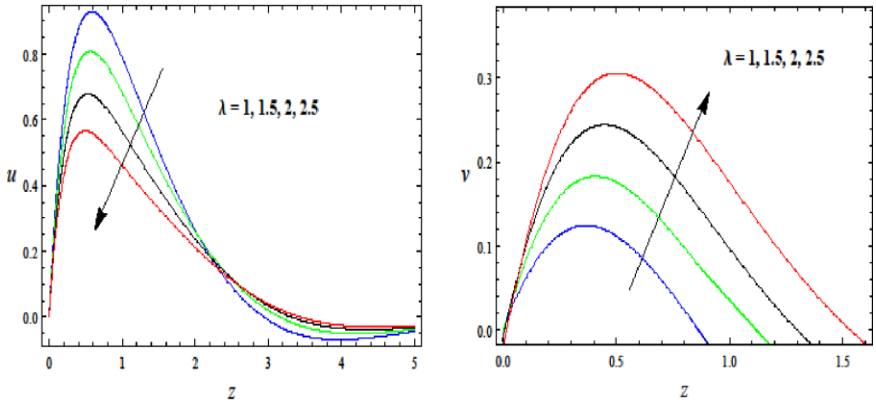

Figure 6. The velocity Profiles for *u* and *v* against λ

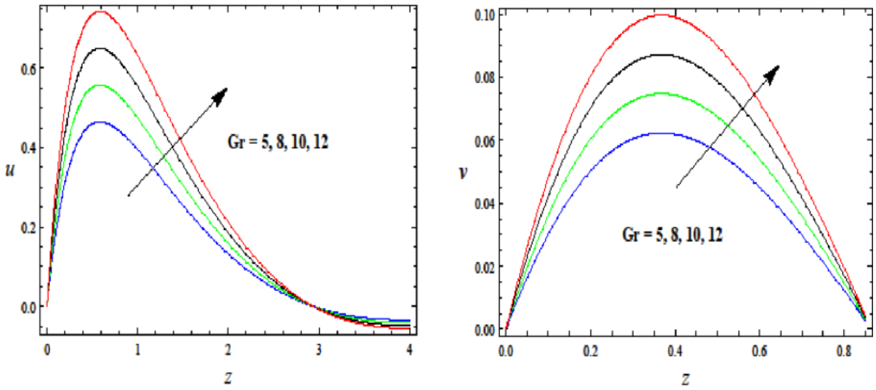

Figure 7. The velocity Profiles for *u* and *v* against Gr

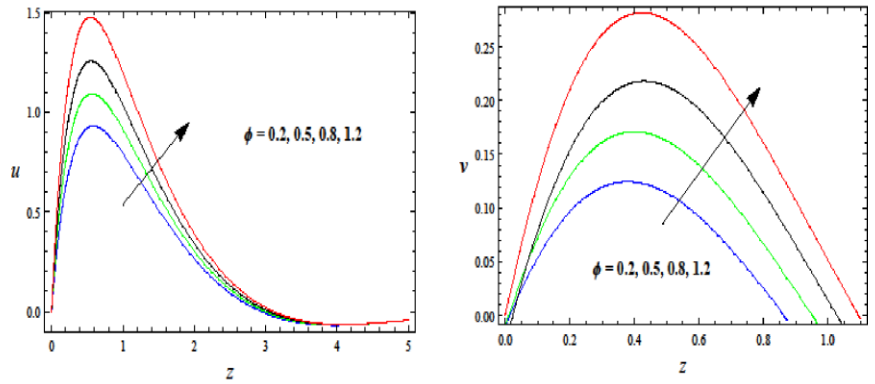

Figure 8. The velocity Profiles for *u* and *v* against ϕ

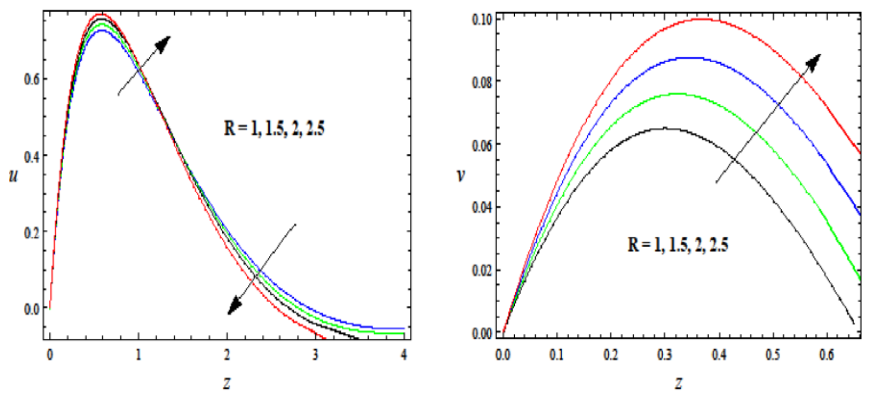

Figure 9. The velocity Profiles for *u* and *v* against R

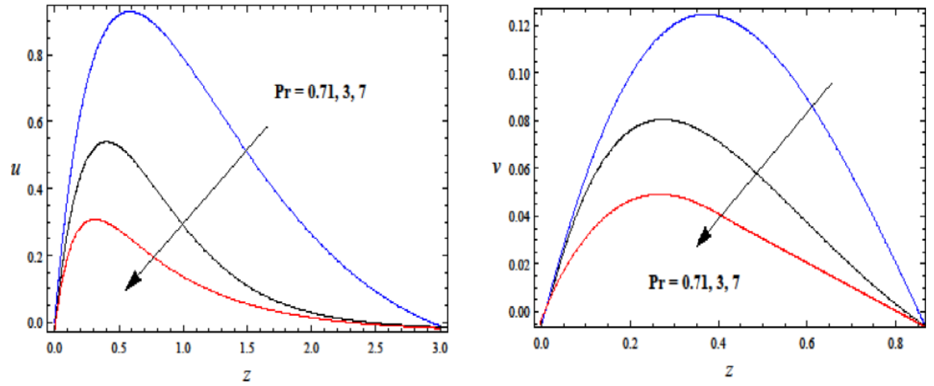

Figure 10. The velocity Profiles for *u* and *v* against Pr

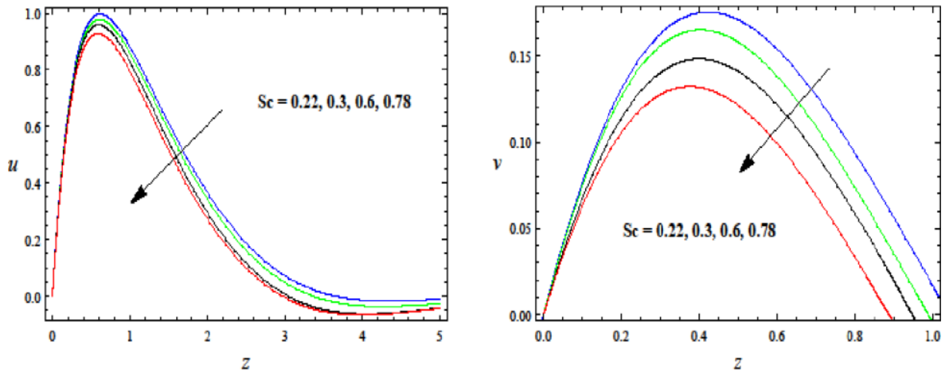

Figure 11. The velocity Profiles for *u* and *v* against Sc

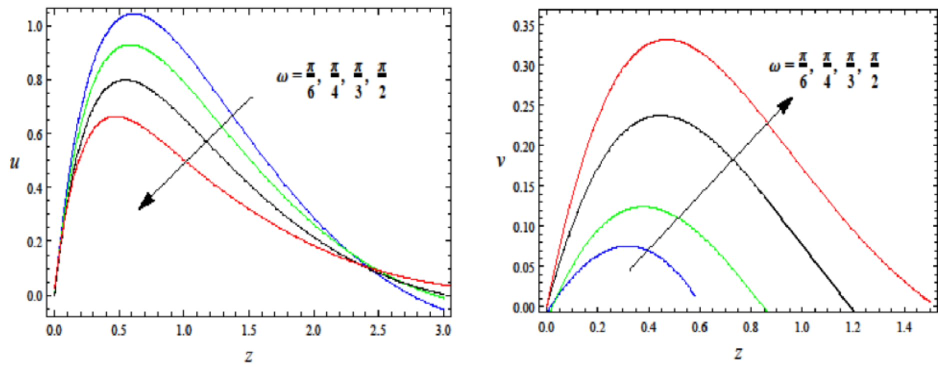

Figure 12. The velocity Profiles for *u* and *v* against ω

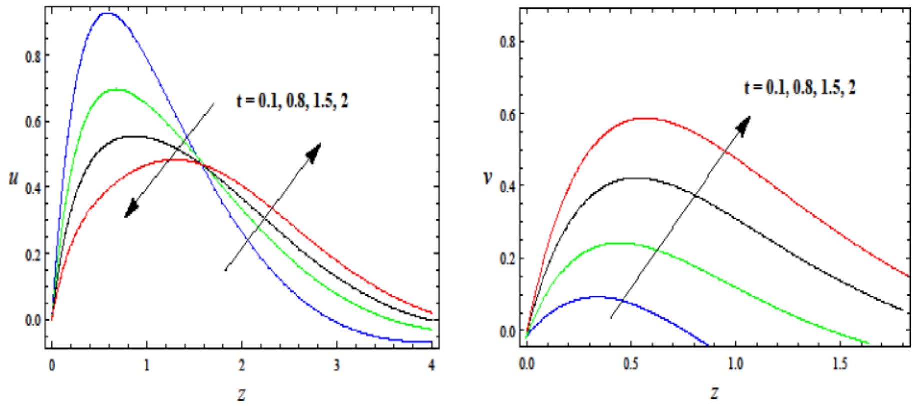

Figure 13. The velocity Profiles for *u* and *v* against t

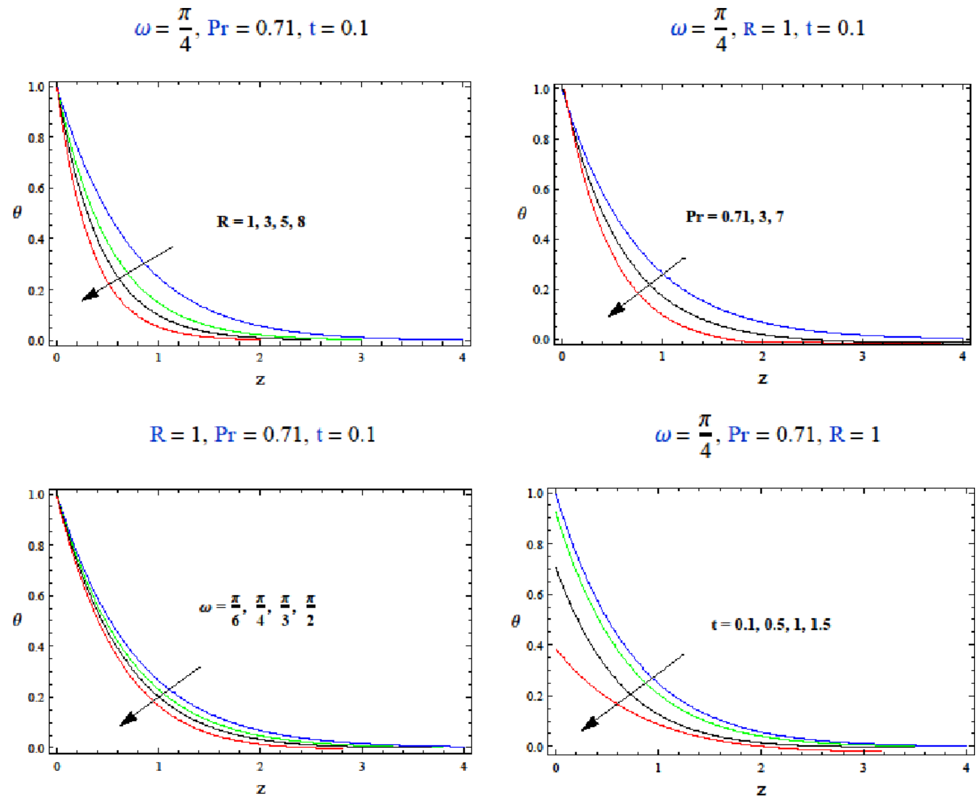

Figure 14. Temperature Profiles for θ with R, Pr, ω and t

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 ϕ, but it is interesting to note that the skin friction decreases with the increase in Hartmann number M, Radiation parameter R, visco-elastic parameter λ, the frequency of oscillation ω, Prandtl number Pr, Schimdt 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 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.

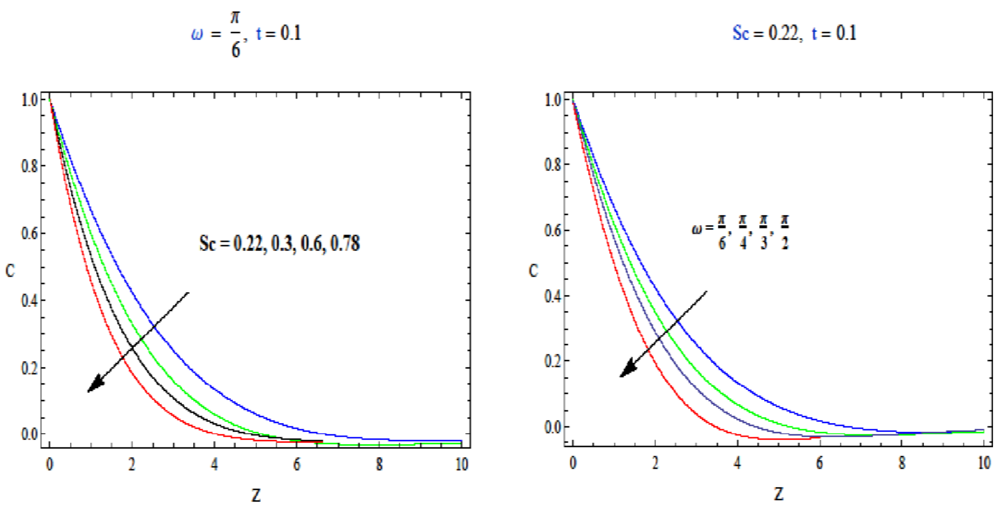

Figure 15. The Concentration Profiles for C with Sc and ω

IV. 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*, Rotation parameter E, 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, Gr and ϕ, reduces with the increase in M, λ, ω, Pr, R, 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.

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Appendix:

$$m_1 = \frac{1+\sqrt{1+4\left[2iE+\left(\frac{M^2}{1+m^2}+\frac{1}{K}-i\omega\right)(1-i\omega\lambda)\right]}}{2},$$

$$m_2 = \frac{\Pr+\sqrt{\Pr^2-4\Pr(i\omega-R)}}{2}, \quad m_3 = \frac{Sc+\sqrt{Sc^2-4Sc\,i\omega}}{2}$$

$$a_1 = \frac{\mathrm{Gr}}{m_2^2-m_2-\left(2iE+\left(\frac{M^2}{1+m^2}+\frac{1}{K}-i\omega\right)(1-i\omega\lambda)\right)},$$

$$a_2 = \frac{\mathrm{Gr}\,\phi}{m_3^2-m_3-\left[2iE+\left(\frac{M^2}{1+m^2}+\frac{1}{K}-i\omega\right)(1-i\omega\lambda)\right]}$$

Table. 1. Skin Friction

τ	E	m	t	ω	Sc	ϕ	Gr	Pr	R	λ	K	M
6.406991	**1**	**1**	**0.1**	$\pi/4$	**0.22**	**0.2**	**10**	**0.71**	**1**	**1**	**1**	**2**
5.515753	1	1	0.1	$\pi/4$	0.22	0.2	10	0.71	1	1	1	**2.5**
4.757022	1	1	0.1	$\pi/4$	0.22	0.2	10	0.71	1	1	1	**3**
	1	1	0.1	$\pi/4$	0.22	0.2	10	0.71	1	1	**2**	2
7.064886	1	1	0.1	$\pi/4$	0.22	0.2	10	0.71	1	1	**3**	2
6.202688	1	1	0.1	$\pi/4$	0.22	0.2	10	0.71	1	**1.5**	1	2
6.069719	1	1	0.1	$\pi/4$	0.22	0.2	10	0.71	1	**2**	1	2
6.101300	1	1	0.1	$\pi/4$	0.22	0.2	10	0.71	**2**	1	1	2
5.627370	1	1	0.1	$\pi/4$	0.22	0.2	10	0.71	**3**	1	1	2
3.920567	1	1	0.1	$\pi/4$	0.22	0.2	10	**3**	1	1	1	2
2.644119	1	1	0.1	$\pi/4$	0.22	0.2	10	**7**	1	1	1	2
9.610487	1	1	0.1	$\pi/4$	0.22	0.2	**15**	0.71	1	1	1	2
12.81398	1	1	0.1	$\pi/4$	0.22	0.2	**20**	0.71	1	1	1	2
8.299571	1	1	0.1	$\pi/4$	0.22	**0.5**	10	0.71	1	1	1	2
9.561291	1	1	0.1	$\pi/4$	0.22	**0.7**	10	0.71	1	1	1	2
6.147386	1	1	0.1	$\pi/4$	**0.6**	0.2	10	0.71	1	1	1	2
6.062867	1	1	0.1	$\pi/4$	**0.78**	0.2	10	0.71	1	1	1	2
6.122192	1	1	0.1	$\pi/3$	0.22	0.2	10	0.71	1	1	1	2
5.379949	1	1	0.1	$\pi/2$	0.22	0.2	10	0.71	1	1	1	2
6.338017	1	1	**0.5**	$\pi/4$	0.22	0.2	10	0.71	1	1	1	2
5.876448	1	1	**0.8**	$\pi/4$	0.22	0.2	10	0.71	1	1	1	2
7.546339	1	**2**	0.1	$\pi/4$	0.22	0.2	10	0.71	1	1	1	2
7.599155	1	**3**	0.1	$\pi/4$	0.22	0.2	10	0.71	1	1	1	2
6.061074	1.5	1	0.1	$\pi/4$	0.22	0.2	10	0.71	1	1	1	2
5.368135	2	1	0.1	$\pi/4$	0.22	0.2	10	0.71	1	1	1	2

Table 2: Nusselt number

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

Table 3: Sherwood number

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