$$T_0'' + \Pr T_0' + \Pr S T_0 = 0 \tag{20}$$

$$T_1'' + \Pr T_1' + P\left(S - \frac{i\omega}{4}\right)T_1 = -\Pr T_0' \tag{21}$$

$$C_0'' + \mathrm{Sc} C_0' = 0 \tag{22}$$

$$C_1'' + \mathrm{Sc} C_1' - \frac{i\omega}{4}\mathrm{Sc}\, T_1 = -\mathrm{Sc}\, C_0' \tag{23}$$

The boundary conditions reduce to

$$\begin{aligned} &u_0 = u_1 = 0,\ T_0 = T_1 = 1,\ C_0 = C_1 = 0 \quad \text{at} \quad y = 0, \\ &u_0 = u_1 \to 0,\ T_0 = T \to 0,\ C_0 = C_1 \to 0, \quad \text{as} \quad y \to \infty \end{aligned} \tag{24}$$

Eqs. (18) and (19) are of third order but two boundary conditions are available. Therefore the perturbation method has been applied using $Rc\left(Rc \ll 1\right)$, the elastic parameter as the perturbation parameter.

$$\begin{aligned} u_0 &= u_{00}(y) + \mathrm{Rc}\, u_{01}(y) + O\left(\mathrm{Rc}^2\right), \\ u_1 &= u_{10}(y) + \mathrm{Rc}\, u_{11}(y) + O\left(\mathrm{Rc}^2\right) \end{aligned} \tag{25}$$

Inserting Eq. (25) into (18) and (19) and equating the coefficients of Rc^0 and Rc to zero we have following sets of ordinary differential equations zeroth order and first or der;

$$u_{00}'' + u_{00}' - \left(M^2 + 2iE + \frac{1}{K}\right)u_{00} = -\mathrm{Gr}\, T_0 - \mathrm{Gc}\, C_0 \tag{26}$$

$$u_{01}'' + u_{01}' - \left(M^2 + 2iE + \frac{1}{K}\right)u_{01} = u_{00}''' \tag{27}$$

$$\begin{aligned} &u_{10}'' + u_{10}' - \left(M^2 + 2iE + \frac{1}{K}\right)u_{10} \\ &\quad = -u_{00}' - \mathrm{Gr}\, T_1 - \mathrm{Gc}\, C_1 - \frac{u_{00}}{K} \end{aligned} \tag{28}$$

$$\begin{aligned} &u_{11}'' + u_{11}' - \left(M^2 + 2iE + \frac{1}{K}\right)u_{11} \\ &\quad = -u_{10}''' - i\omega u_{10}'' - u_{00}''' - \frac{u_{01}}{K} \end{aligned} \tag{29}$$

The corresponding boundary conditions are:

$$\begin{aligned} &u_{00} = u_{01} = 0, \quad \text{as} \quad y = 0, \\ &u_{10} = u_{11} \to 0, \quad \text{as} \quad y \to \infty \end{aligned} \tag{30}$$

Solving these differential equations with the help of boundary conditions we get,

$$\begin{aligned} q(y,t) = &\left\{\left(a_1 + a_2 - \frac{P_o}{M^2 + 2iE + \frac{1}{K}}\right)e^{-m_4 y}\right. \\ &- a_1 e^{-m_1 y} - a_2 e^{-\mathrm{Sc}\, y} + \frac{P_o}{\left(M^2 + 2iE + \frac{1}{K}\right)} \\ &\left.- R_c(a_3 + a_4 + a_5)e^{-m_4 y} + a_3 e^{-m_4 y} + a_4 e^{-m_1 y} + a_5 e^{-\mathrm{Sc}\, y})\right\} \\ &+ \varepsilon\left\{\left(\left(\left(a_{18} - \frac{P_1}{a_6}\right)e^{-m_5 y} + a_{12} e^{-m_4 y} - a_{13} e^{-m_3 y}\right.\right.\right. \\ &\left. - a_{14} e^{-m_1 y} - a_{15} e^{-\mathrm{Sc}\, y} + a_{16} e^{-m_2 y} - a_{17} + \frac{P_1}{a_6}\right) \\ &+ Rc\left((a_{25} + a_{31})e^{-m_5 y} + a_{26} e^{-m_4 y} + a_{27} e^{-m_3 y}\right. \\ &\left.\left. + a_{25} e^{-m_2 y} + a_{29} e^{-m_1 y} + a_{30}\, e^{-\mathrm{Sc}\, y}\right)\right\} e^{i\omega t} \end{aligned} \tag{31}$$

$$\theta(y,t) = e^{-m_1 y} + \varepsilon\left(e^{-m_3 y} + \frac{4im_1}{\omega}\left(e^{-m_1 y} - e^{-m_3 y}\right)\right)e^{i\omega t} \tag{32}$$

$$\phi(y,t) = e^{-S_c y} + \varepsilon\left(\left(1 - \frac{4iS_c}{\omega}\right)e^{-m_2 y} + \frac{4iS_c}{\omega}e^{-S_c y}\right)e^{i\omega t} \tag{33}$$

The skin friction at the plate in terms of amplitude and phase angle is given by

$$\tau = \left.\frac{\partial u_0}{\partial y}\right|_{y=0} + \varepsilon e^{i\omega t}\left.\frac{\partial u_1}{\partial y}\right|_{y=0} = \left.\frac{\partial u_0}{\partial y}\right|_{y=0} + \varepsilon|N|\cos\left(\omega t + \alpha\right) \tag{34}$$

Where, $N = N_r + iN_i, \tan\alpha = \frac{N_i}{N_r}$

The rate of heat transfer, i.e. heat flux at the (Nu) in terms of amplitude and phase is given by,

$$\begin{aligned} N_u &= -\left[\left.\frac{\partial T_0}{\partial y}\right|_{y=0} + \varepsilon e^{i\omega t}\left.\frac{\partial T_1}{\partial y}\right|_{y=0}\right] \\ &= -\left[\left.\frac{\partial T_0}{\partial y}\right|_{y=0} + \varepsilon|R|\cos\left(\omega t + \delta\right)\right] \end{aligned} \tag{35}$$

$$R = R_r + iR_i, \tan\delta = \frac{R_i}{R_r}$$

The mass transfer coefficient, i.e, the Sherwood number (Sh) at the plate in terms of amplitude and phase is given by

$$S_h = -\left[\left.\frac{\partial C_0}{\partial y}\right|_{y=0} + \varepsilon e^{i\omega t}\left.\frac{\partial C_1}{\partial y}\right|_{y=0}\right] \tag{36}$$

$$= -\left[\left.\frac{\partial C_0}{\partial y}\right|_{y=0} + \varepsilon |Q| \cos(\omega t + \gamma)\right]$$

Where, $Q = Q_r + iQ_i, \tan\gamma = \dfrac{Q_i}{Q_r}$

4. RESULTS AND DISCUSSION

The present study considers the effect of mass transfer on free convective rotating flow and heat transfer of a visco-elastic incompressible electrically conducting fluid past a vertical plate through a porous medium with time dependent suction in presence of a constant transverse magnetic field and heat source. The significance of the present study is to bring out the effect of oscillatory characteristics of suction velocity, plate temperature and concentration. The common feature of the velocity profile is parabolic with picks near the plate. It is interesting to note that due to dominating effect of heat source no oscillatory behaviour of the profile is exhibited but in the presence of sink an oscillation in the profile is well marked. The result of the present study is verified by comparing with that of Das et al. [19] for viscous case Rc = 0. The effect of Rc is to thinning of velocity boundary layer which may be attributed due to elastic property of the fluid under consideration. Our result is in conformity with the result of Das et al. [19].

The flow governed by the non-dimensional parameters Hartmann number M, permeability parameter K, rotation parameter E, thermal Grashof number Gr, mass Grashof number Gc, Elastic parameter Rc, ω the frequency of oscillation, Schmidt number Sc, Prandtl number Pr, Heat source parameter S, time *t.* The velocity, temperature and concentration profiles are shown on Figures (2-12), Figures (13-16) and Figures (17-18) respectively. Tables (1-3) represent the skin friction, Nusselt number and Sherwood number for different variations in the governing parameters.

We noticed that from the Fig. 2, the velocity components *u* and *v* reduce with increasing the Hartmann number *M*. Further, due to interaction of applied magnetic field with conducting fluid the current is generated. Consequently, it gives rise to an induced magnetic field and ponders motive force. That force acts opposite to the direction of the flow and unless an additional electric field is applied to counter act. In the present study the Lorentz force decelerates the fluid flow consequently resulted in thinning of boundary layer. The resultant velocity is also reduces with increasing the intensity of the magnetic field. Both the velocity components *u* and *v* enhance with increasing permeability parameter K. i.e., both the real and imaginary parts of the velocity enhance with increasing the permeability parameter *K* throughout the fluid region. We also observe that lower the permeability lesser the fluid speed in the entire fluid medium (Fig. 3). The similar behaviour is observed with increasing the thermal Grashof number Gr, mass Grashof number Gc or rotation parameter *E* (Figs. 4-6). It is also observed that, from the Figures (7-8) both the velocity components continuously retardation in its magnitude with increasing elastic parameter Rc or the frequency of oscillation ω. The figure (9) reveals that, the primary velocity component *u* reduces and secondary velocity component *v* increases for $z \geq 2$ and the gradually reduces with increasing Schmidt number Sc. Likewise, from the figures (10 & 11) both the velocity components *u* and *v* reduces with increasing Heat source parameter S or Prandtl number Pr. The resultant velocity is also reduces with increasing S or Pr. The effect of source parameter is well marked from Fig. (10). Presence of source reduces the velocity, significantly in all the layers. Most interesting case is due to the presence of sink which gives rise to a span wise oscillatory flow after a few layers from the plate. This is due to depletion of thermal energy causing a sudden reduction of velocity. Again it is compensated due to buoyancy effect. Finally with increasing time the velocity components *u*, *v* and resultant velocity enhance throughout the fluid region Figs. 12). Hence we observed that the free convection due to thermal buoyancy, mass buoyancy and porosity of the medium enhances the fluid velocity whereas Schmidt number and Prandtl number reduce it. Kumar et al. [17] observed that the velocity profile increases with increase of thermal Grashof number and Solutal Grashof number and they have also observed that the velocity decreases with increase in magnetic parameter. Hence our observation in respect of these parameters agree with [17] in the absence of porous medium. Thus, the above result indicates that heavier species with lower thermal conductivity reduces the fluid flow.

Figs. (13-16) exhibits the effects of Prandtl number (Pr), source/sink parameter S, the frequency of oscillation and time on temperature field. The variation is asymptotic in nature. Sharp fall of temperature is noticed in case of water (Pr = 7.0) for both source/sink. Absence of source contributes to increase the thickness of thermal boundary layer. Higher Prandtl number fluid causes lower thermal diffusivity and hence reduces the temperature at all points. It is interesting to note that the effect of source is to lower down the temperature than the effect of sink. The temperature increases with increasing frequency of oscillation and time throughout the fluid region. From Figs. (17-19), it is observed that the concentration distribution asymptotically decreases with the heavier species. This result is in good agreement with Das et al. [19]. Likewise the concentration enhances with increasing frequency of oscillation and time throughout the fluid region.

We noticed from the Table (1) we present the values of skin friction. The increase of visco-elastic parameter (Rc) leads to decrease the skin friction. Further, it is to note that an increase in Gr, Gc, Pr, ω and K leads to exert greater skin friction on the boundary whereas Sc, M, S, *t* and Rc reduce it.

From the Table 2 it is seen that an increase in Pr or S leads to an increase in Nusselt number. Nusselt number reduces with increasing the frequency of oscillation. There is no effect of time on Nusselt number.

It is noticed from the table (3) that the Schmidt number i.e. mass transfer coefficient affects Sherwood number in a

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similar manner as that of Prandtl number, the frequency of oscillation and time in heat transfer.

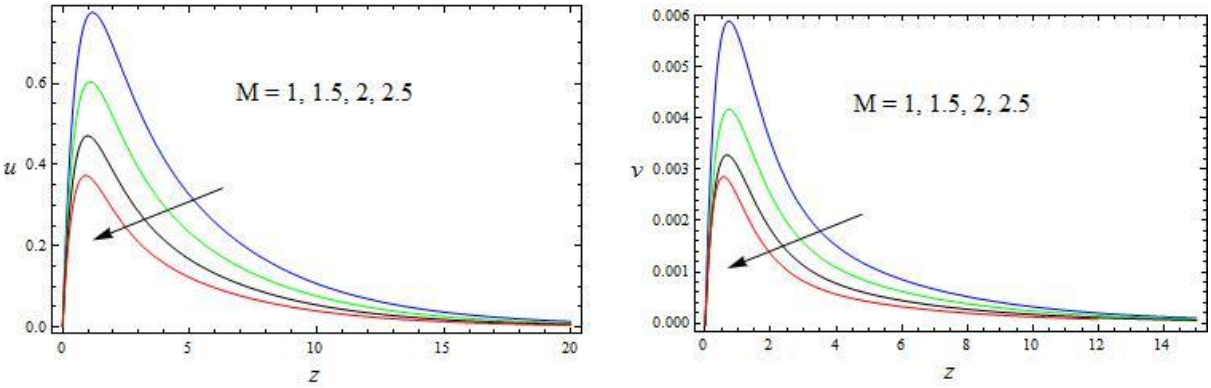

Fig. 2 The velocity profiles for the components *u* and *v* against *M*

$$K = 0.5, E = 0.5, \mathrm{Gr} = 5, \mathrm{Gc} = 3, \mathrm{Rc} = 0.01, \omega = \pi / 6, S = 0.5, \mathrm{Sc} = 0.22, \mathrm{Pr} = 0.71, t = 0.1$$

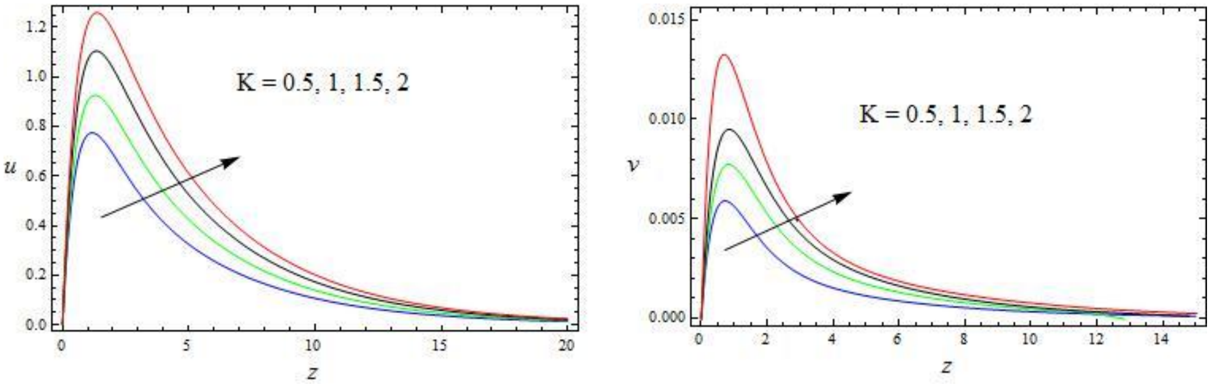

Fig. 3 The velocity profiles for the components *u* and *v* against *K*

$$M = 1, E = 0.5, \mathrm{Gr} = 5, \mathrm{Gc} = 3, \mathrm{Rc} = 0.01, \omega = \pi / 6, S = 0.5, \mathrm{Sc} = 0.22, \mathrm{Pr} = 0.71, t = 0.1$$

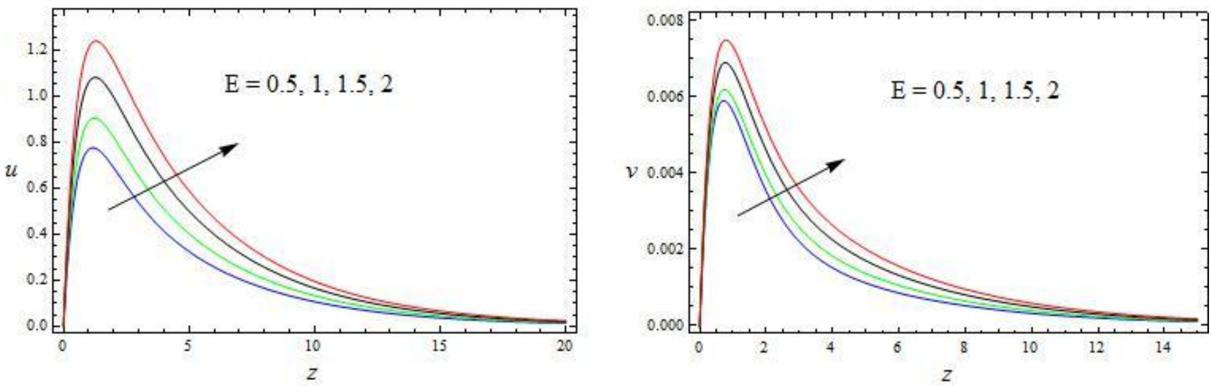

Fig. 4 The velocity profiles for the components *u* and *v* against *E*

$$M = 1, K = 0.5, \mathrm{Gr} = 5, \mathrm{Gc} = 3, \mathrm{Rc} = 0.01, \omega = \pi / 6, S = 0.5, \mathrm{Sc} = 0.22, \mathrm{Pr} = 0.71, t = 0.1$$

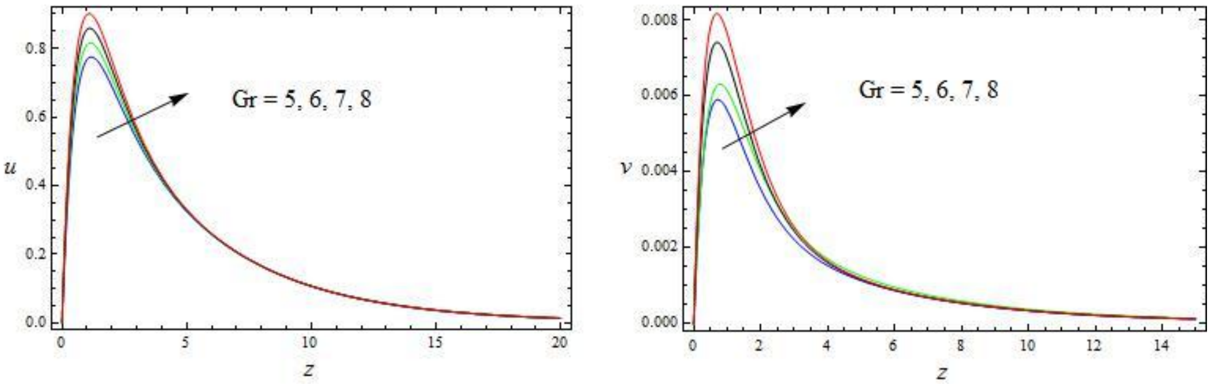

Fig. 5 The velocity profiles for the components *u* and *v* against Gr

$$M = 1, K = 0.5, E = 0.5, \mathrm{Gc} = 3, \mathrm{Rc} = 0.01, \omega = \pi / 6, S = 0.5, \mathrm{Sc} = 0.22, \mathrm{Pr} = 0.71, t = 0.1$$

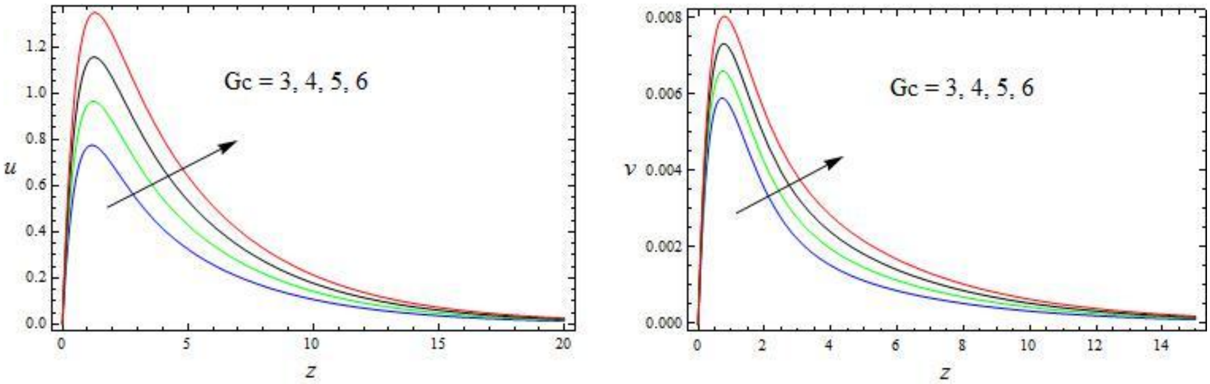

Fig. 6 The velocity profiles for the components *u* and *v* against Gc

$$M = 1, K = 0.5, E = 0.5, \mathrm{Gr} = 5, \mathrm{Rc} = 0.01, \omega = \pi / 6, S = 0.5, \mathrm{Sc} = 0.22, \mathrm{Pr} = 0.71, t = 0.1,$$

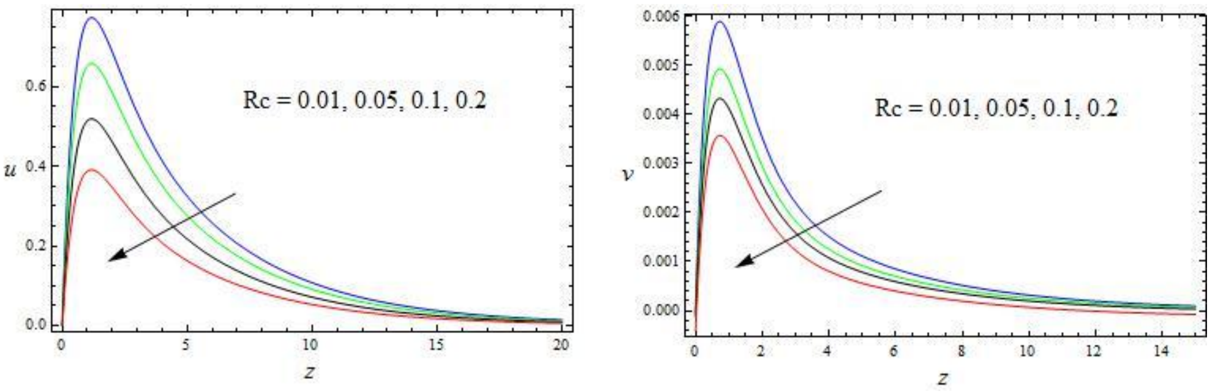

Fig. 7 The velocity profiles for the components *u* and *v* against Rc

$$M = 1, K = 0.5, E = 0.5, \mathrm{Gr} = 5, \mathrm{Gc} = 3, \omega = \pi / 6, S = 0.5, \mathrm{Sc} = 0.22, \mathrm{Pr} = 0.71, t = 0.1$$

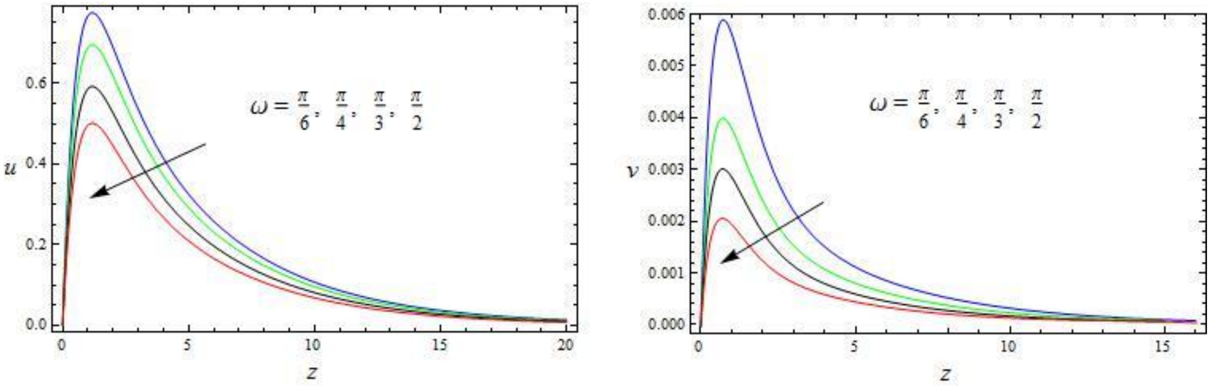

Fig. 8 The velocity profiles for the components *u* and *v* against ω

$M = 1, K = 0.5, E = 0.5, \mathrm{Gr} = 5, \mathrm{Gc} = 3, \mathrm{Rc} = 0.01, S = 0.5, \mathrm{Sc} = 0.22, \Pr = 0.71, t = 0.1$

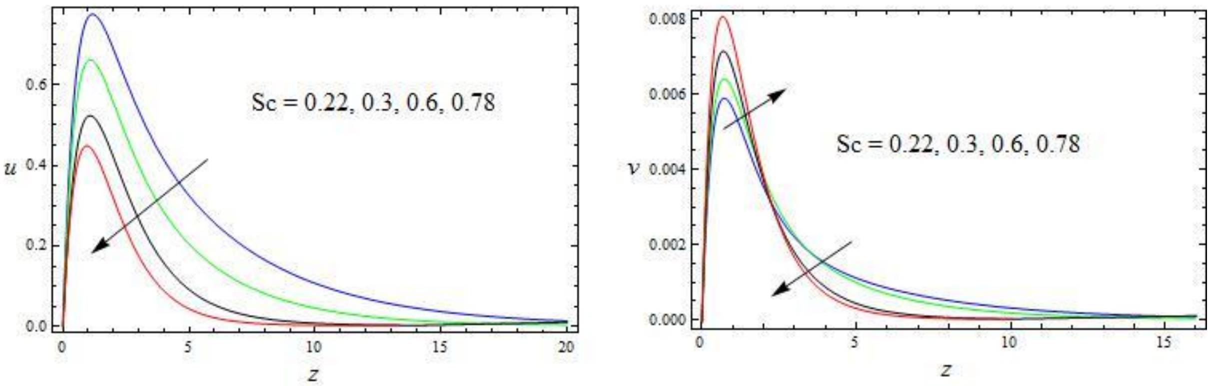

Fig. 9 The velocity profiles for the components *u* and *v* against Sc

$M = 1, K = 0.5, E = 0.5, \mathrm{Gr} = 5, \mathrm{Gc} = 3, \mathrm{Rc} = 0.01, S = 0.5, \mathrm{Sc} = 0.22, \Pr = 0.71, t = 0.1$

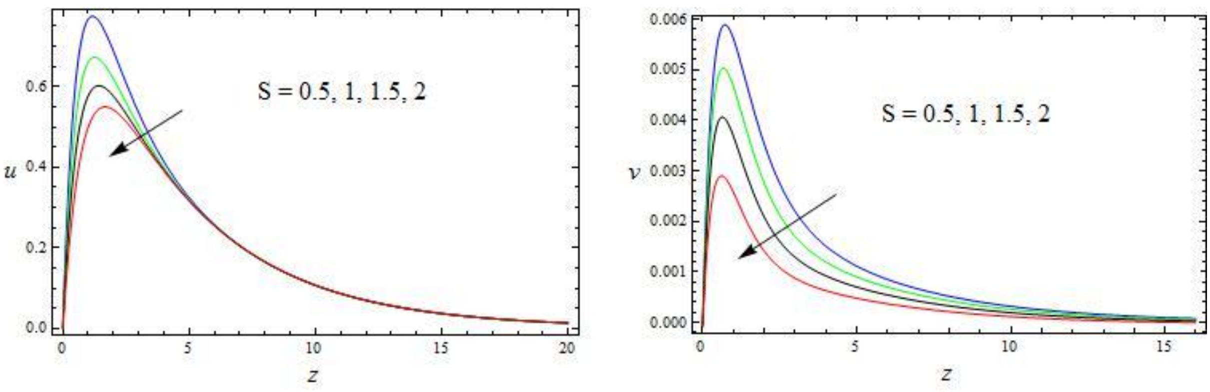

Fig. 10 The velocity profiles for the components *u* and *v* against *S*

$M = 1, K = 0.5, E = 0.5, \mathrm{Gr} = 5, \mathrm{Gc} = 3, \mathrm{Rc} = 0.01, \omega = \pi / 6, \mathrm{Sc} = 0.22, \Pr = 0.71, t = 0.1,$

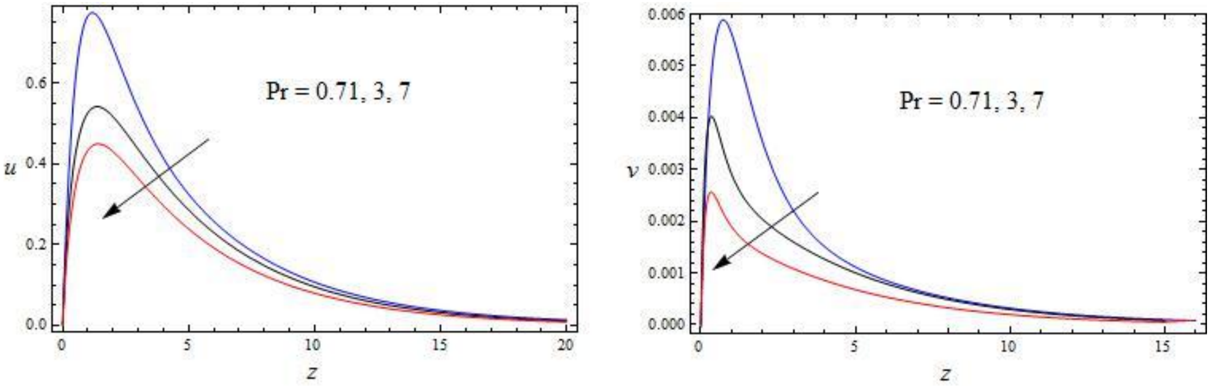

Fig. 11 The velocity profiles for the components *u* and *v* against Pr

$M = 1, K = 0.5, E = 0.5, \mathrm{Gr} = 5, \mathrm{Gc} = 3, \mathrm{Rc} = 0.01, \omega = \pi / 6, S = 0.5, \mathrm{Sc} = 0.22, t = 0.1$

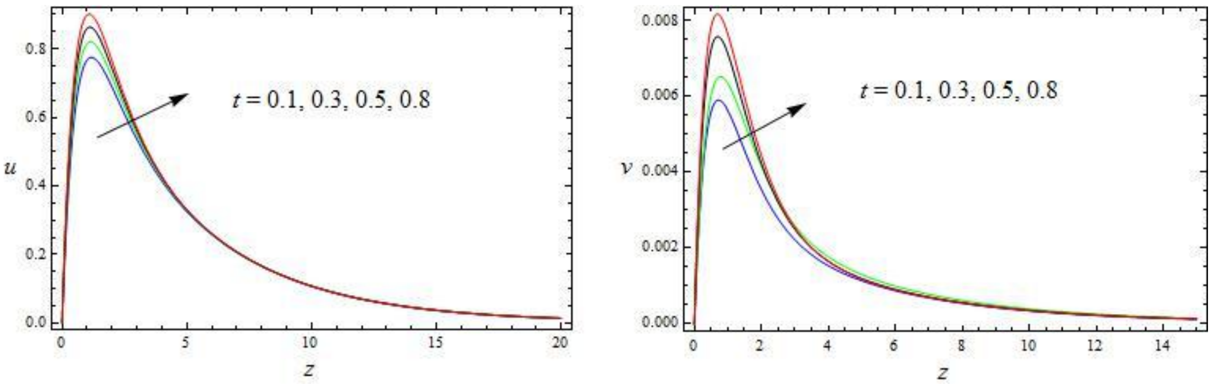

Fig. 12 The velocity profiles for the components *u* and *v* against *t*

$M = 1, K = 0.5, E = 0.5, \mathrm{Gr} = 5, \mathrm{Gc} = 3, \mathrm{Rc} = 0.01, \omega = \pi / 6, S = 0.5, \mathrm{Sc} = 0.22, \mathrm{Pr} = 0.71$

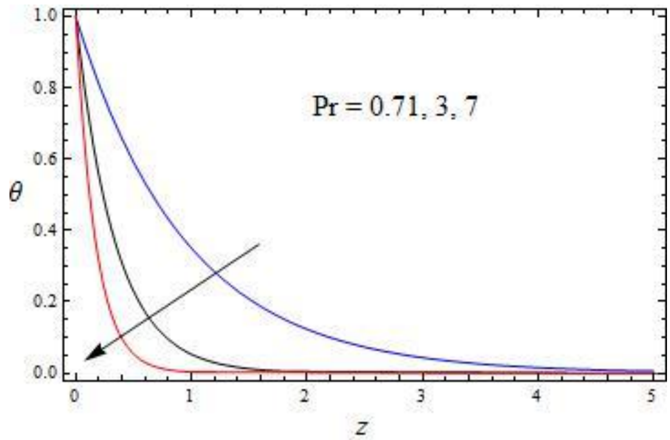

Fig. 13 The temperature profiles for θ against Pr with $\varepsilon = 0.01, \omega = \pi / 6, S = 0.5, t = 0.1$

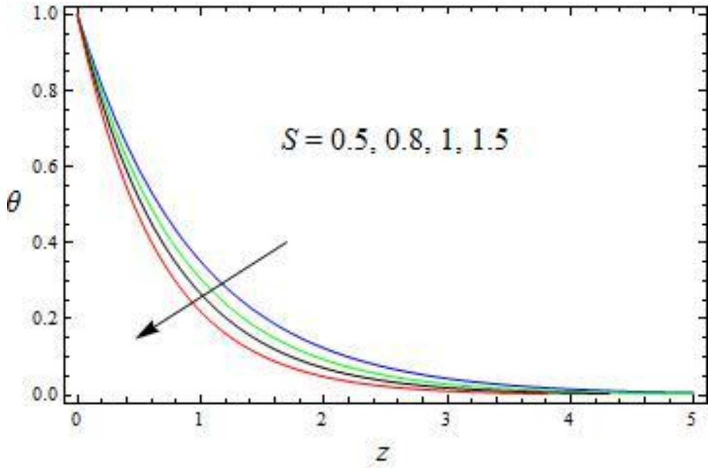

Fig. 14 The temperature profiles for θ against S with $\varepsilon = 0.01, \omega = \pi / 6, \mathrm{Pr} = 0.71, t = 0.1$

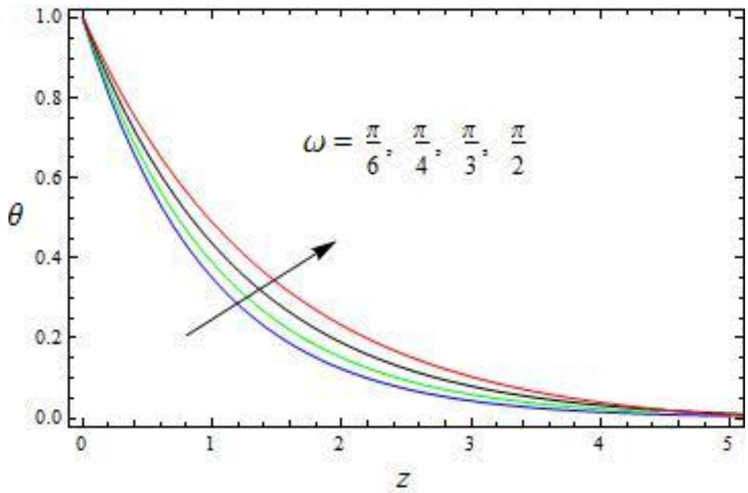

Fig. 15 The temperature profiles for θ against ω with $\varepsilon = 0.01, S = 0.5, \mathrm{Pr} = 0.71, t = 0.1$

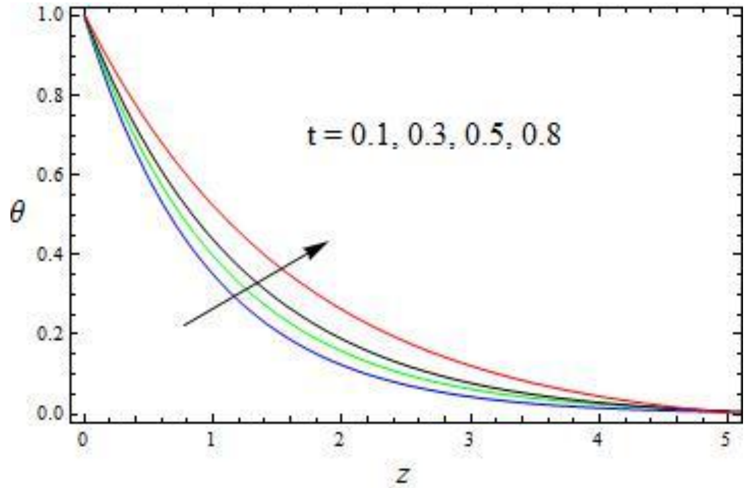

Fig. 16 The temperature profiles for θ against t with $\varepsilon = 0.01, \omega = \pi / 6, S = 0.5, \mathrm{Pr} = 0.71$

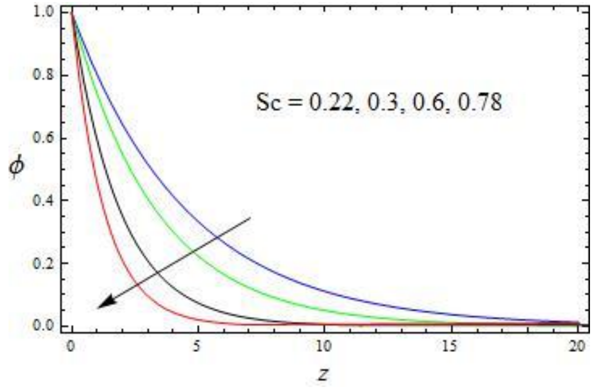

Fig. 17 The Concentration profiles for ϕ against *t* with $\varepsilon = 0.01, \omega = \pi/6, \mathrm{Sc} = 0.22, t = 0.1$

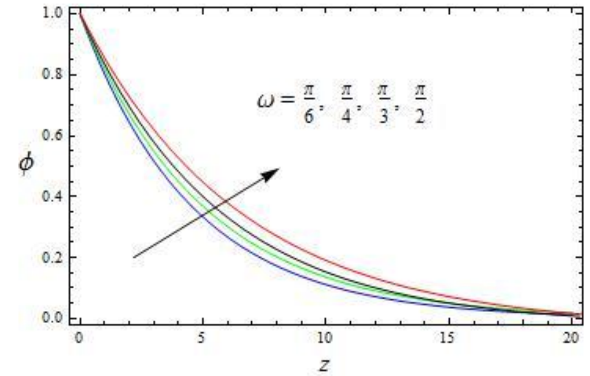

Fig. 18 The Concentration profiles for ϕ against *t* with $\varepsilon = 0.01, \mathrm{Sc} = 0.22, t = 0.1$

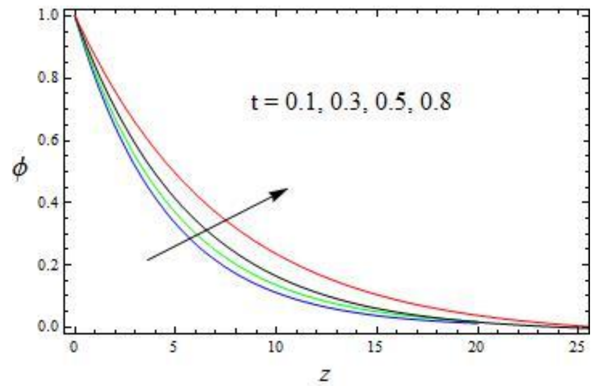

Fig. 19 The Concentration profiles for ϕ against *t* with $\varepsilon = 0.01, \omega = \pi/6, \mathrm{Sc} = 0.22$

Table 1: Shear stresses

M	K	S	Gr	Gc	Sc	ω	Rc	Pr	t	τ
1	**0.5**	**0.5**	**5**	**3**	**0.22**	$\pi/6$	**0.001**	**0.71**	**0.1**	0.647996
1.5										0.509526
2										0.400457
	1									0.714341
	1.5									0.749688
		1								0.601219
		1.5								0.579154
			6							0.651212
			7							0.653632
				4						0.666612
				5						0.682836
					0.3					0.621506
					0.6					0.544473
						$\pi/4$				0.913730
						$\pi/3$				1.135170
							0.01			0.647996
							0.05			0.647996
								3		2.666330
								7		-0.11972
									0.5	0.438557
									0.8	0.281477

Table 2: Nusselt number

Pr	ω	t	S	Nu
0.71	$\pi/6$	**0.1**	0.5	1.049300
3				3.443800
7				7.491330
	$\pi/4$			1.049020
	$\pi/3$			1.048870
		0.5		1.049300
		0.8		1.049300
			0.8	1.189220
			1	1.270730

Table 3: Sherwood number

Sc	ω	t	Sh
0.22	$\pi/6$	**0.1**	0.220035
0.3			0.300029
0.6			0.600013
	$\pi/4$		0.220062
	$\pi/3$		0.220087
		0.5	0.220035
		0.8	0.220035

4. CONCLUSIONS

We have considered the effect of heat and mass transfer on free convective rotating flow of a visco-elastic incompressible electrically conducting fluid past a vertical porous plate through a porous medium with time dependent suction in presence of a uniform transverse magnetic field and heat source. The conclusions are made as the following.

1. Presence of heat source prevents the oscillatory flow whereas the sink favours it. Elasticity of the fluid is responsible for thinning of the boundary layer.
2. Application of magnetic field decelerates the fluid flow.
3. The heavier species with low conductivity reduces the flow within the boundary layer.
4. An increase in elasticity of the fluid leads to decrease the velocity which is an established result.
5. The concentration distribution asymptotically decreases with the heavier species.
6. Elasticity's of the fluid and heat source reduce the skin friction providing a favourable condition for stretching.

Appendix:

$$a_1 = \frac{\mathrm{Gr}}{m_1^2 - m_1 - \left(M^2 + 2iE + \frac{1}{K}\right)},$$

$$a_2 = \frac{\mathrm{Gc}}{\mathrm{Sc}^2 - \mathrm{Sc} - \left(M^2 + 2iE + \frac{1}{K}\right)}$$

$$a_3 = \frac{-(a_1 + a_2)m_4^3}{m_4^2 - m_4 - \left(M^2 + 2iE + \frac{1}{K}\right)},$$

$$a_4 = \frac{\mathrm{Gr}a_1\ m_1^3}{m_1^2 - m_1 - \left(M^2 + 2iE + \frac{1}{K}\right)}$$

$$a_5 = \frac{\mathrm{Gc}\,a_2\,\mathrm{Sc}^3}{\mathrm{Sc}^2 - \mathrm{Sc} - \left(M^2 + 2iE + \frac{1}{K}\right)},$$

$$a_6 = M^2 + 2iE + \frac{1}{K}, \quad a_7 = m_4(a_1 + a_2)$$

$$a_8 = \frac{4im_1}{\omega}, \quad a_9 = 1 - \frac{4i\mathrm{sc}}{\omega}, \quad a_{10} = \frac{4i\mathrm{sc}}{\omega},$$

$$a_{11} = \frac{a_1 + a_2}{k}, \quad a_{12} = \frac{a_7 + a_{11}}{m_4^2 - m_4 - a_6}$$

$$a_{13} = \frac{\mathrm{Gr}(1 - a_8)}{m_3^2 - m_3 - a_6}, \quad a_{14} = \frac{Gr.a_8}{m_1^2 - m_1 - a_6},$$

$$a_{15} = \frac{\mathrm{Gc}a_{10}}{\mathrm{Sc}^2 - \mathrm{Sc} - a_6}, \quad a_{16} = \frac{\mathrm{Gc}a_9}{m_2^2 - m_2 - a_6}$$

$$a_{17} = \frac{a_{11}}{a_6}, \quad a_{18} = -a_{12} + a_{13} + a_{14} + a_{15} - a_{16} + a_{17},$$

$$a_{19} = (a_{18}m_5^3 - i\omega a_{18}m_5^2)$$

$$a_{20} = a_{12}m_4^3 - i\omega a_{12}m_4^2 + (a_1 + a_2)m_4^3 + \left(\frac{a_3 + a_4 + a_5}{k}\right),$$

$$a_{21} = -a_{13}m_3^3 + i\omega a_{13}m_3^2$$

$$a_{22} = a_{16}m_2^3 - i\omega a_{16}m_2^2,$$

$$a_{23} = -a_{14}m_1^3 + i\omega a_{14}m_1^2 - \mathrm{Gr}a_1m_1^3,$$

$$a_{24} = -a_{15}\mathrm{Sc}^3 + i\omega a_{15}\mathrm{Sc}^2 - \mathrm{Gc}a_2\mathrm{Sc}^3$$

$$a_{25} = \frac{a_{19}}{m_5^2 - m_5 - a_6}, \quad a_{26} = \frac{a_{20}}{m_4^2 - m_4 - a_6},$$

$$a_{27} = \frac{a_{21}}{m_3^2 - m_3 - a_6}, \quad a_{28} = \frac{a_{22}}{m_2^2 - m_2 - a_6}$$

$$a_{29} = \frac{a_{23}}{m_1^2 - m_1 - a_6}, \quad a_{30} = \frac{a_{24}}{\mathrm{Sc}^2 - \mathrm{Sc} - a_6},$$

$$a_{31} = -(a_{25} + a_{26} + a_{27} + a_{28} + a_{29} + a_{30})$$

$$m_1 = \frac{\mathrm{Pr} + \sqrt{\mathrm{Pr}^2 + 4\,\mathrm{Pr}\,S}}{2}, \quad m_2 = \frac{\mathrm{Sc} + \sqrt{\mathrm{Sc}^2 + i\,\omega\,\mathrm{Sc}}}{2},$$

$$m_3 = \frac{\mathrm{Pr} + \sqrt{\mathrm{Pr}^2 + 4S + i\,\omega\,\mathrm{Pr}}}{2},$$

$$m_4 = \frac{1 + \sqrt{1 + \left(M^2 + 2iE + \frac{1}{K}\right)}}{2}, \quad m_5 = \frac{1 + \sqrt{1 + 4a_6}}{2}$$

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