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Forced Convective Second Grade Fluid Flow in a Rotating System with Hall Effects

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Abstract

The unsteady hydromagnetic forced convection from an infinite horizontal porous plate with energy dissipation flow of a second grade and electrically conducting fluid in a rotating system taking Hall current into account with constant suction in presence of transverse magnetic field is studied. The entire system is rotates with a constant angular velocity about the normal to the plate. The governing equations are solved by using multi parameter-perturbation technique. The analytical expressions for the velocity, temperature field, skin friction, the rate of heat transfer at the plates in terms of Nusselt number have been obtained. The effects of visco-elastic parameter, on the velocity, temperature and skin friction, Nusselt number have been illustrated graphically, in combination with other flow parameters involved in the solution. The problem has some relevance in the geophysical and astrophysical studies.

Keywords: Visco-elastic, MHD, Hall effect, Forced convection, skin friction, Rotating system.

2000 AMS Mathematics subject classification: 76A05, 76A10.

1. INTRODUCTION

The study of fluid flow through porous media and heat transfer is fundamental in nature. It is of great practical importance in view of several physical problems such as seepage of water in river beds, porous heat exchangers, cooling of nuclear reactors, filtration and purification process. Because of its industrial importance, problem of flow and heat transfer in porous medium in the presence of magnetic field has been the subject of many experimental and analytical studies. The investigations considering rotational effects are also very important, and the reason for studying flow in a rotating porous medium or rotating flow of a fluid overlying a porous medium in the presence of a magnetic field is fundamental because of its numerous applications in industrial, astrophysical and geophysical problems.

The influence of magnetic field on electrically conducting visco-elastic incompressible fluid is of importance in many applications such as extrusion of plastics in the manufacture of rayon and nylon, the purification of crude oil, and the textile industry, etc. In many process industries the cooling of threads or sheets of some polymer materials is important in the production line. The rate of the cooling can be controlled effectively to achieve final products of desired characteristics by drawing threads, etc., in the presence of an electrically conducting fluid subjected to magnetic field. The study of magneto hydrodynamic (MHD) plays an important role in agriculture, engineering and petroleum industries. The MHD has also its own practical applications. For instance, it may be used to deal with problems such as the cooling of nuclear reactors by liquid sodium and induction flow meter, which depends on the potential difference in the fluid in the direction perpendicular to the motion and to the magnetic field.MHD in the present form is due to the pioneer contribution of several authors like Alfven[1],Cowling[2], Ferraro and Pulmpton[3], Shercliff[4] and Crammer and Pai[5].

When the strength of the applied magnetic field is sufficiently large, Ohm’s law needs to be modified to include Hall current and this fact was emphasized by Cowling[2]. The Hall Effect is due merely to the sideways magnetic force on the drafting free charges .The electric field has to have a component transverse to the direction of the current density to balance this force. In many works of plasma physics, it is not paid much attention to the effect caused due to Hall current. However, the Hall Effect cannot be completely ignored if the strength of the magnetic field is high and number of density of electrons is small as it is responsible for the change of the flow pattern of an ionized gas. Hall Effect results in a development of an additional potential difference between opposite surfaces of a conductor for which a current is induced perpendicular to both the electric and magnetic field. This current is termed as Hall current. The effect of Hall current on MHD convection flow problems have been carried out by Pop[6],Kinyanjui et al.[7],Archrya et al.[8], Dutta et al.[9] and Maleque and Sattar[10], Naik et al.[11] are some of them.

The study of rotating flow problems are also important in the solar physics dealing with sunspot development, the solar cycle and the structure of rotating magnetic stars.It is well known that a number of astronomical bodies possesses fluid interiors and magnetic fields. Changes that take place in the rate of rotation, suggest the possible importance of hydro magnetic spin-up. Debnath [12],Singh [13] and Takhar et al. [14] have studied the problems of spin-up in MHD under different conditions.

In this study, an attempt has been made to extend the problem studied by Ahmed et al.[15] to the case of visco-elastic fluid characterized by second-order fluid [Coleman and Noll] [16] and [Coleman and Markovitz (1964)][17].

2. MATHEMATICAL FORMULATION

The equations governing the motion of an incompressible visco-elastic electrically conducting fluid in a rotating system in presence of a magnetic field are as follows.

Equation of continuity: $\vec{\nabla}.\vec{q} = 0$ (2.1)

Momentum equation: $\rho\left[\frac{\partial \vec{q}}{\partial \bar{t}} + 2\vec{\Omega}\times\vec{q} + \vec{\Omega}\times(\vec{\Omega}\times\vec{r}) + (\vec{q}.\vec{\nabla})\vec{q}\right] = -\vec{\nabla}p + \vec{J}\times\vec{B} + \mu\nabla^2\vec{q}$ (2.2)

Energy equation: $\rho C_p\left[\frac{\partial \bar{T}}{\partial \bar{t}} + (\vec{q}.\vec{\nabla})\bar{T}\right] = K\nabla^2\bar{T} + \phi$ (2.3)

Gauss's law of magnetism: $\vec{\nabla}.\vec{B} = 0$ (2.4)

Kirchhoff's first law: $\vec{\nabla}.\vec{J} = 0$ (2.5)

General Ohm's law: $\vec{J} + \frac{\omega_e \tau_e}{B_0}(\vec{J}\times\vec{B}) = \sigma\left[\vec{E} + \vec{q}\times\vec{B} + \frac{1}{e\eta_e}\vec{\nabla}p_e\right]$ (2.6)

We now consider an unsteady visco-elastic fluid past a porous horizontal plate with constant suction velocity $-w_0$ (say).Choose the origin on the plate and the $\bar{x}$ -axis parallel to the direction of the flow and the $\bar{y}$ -axis along the width of the plate. The $\bar{z}$ -axis is considered perpendicular to the plate and directed into the fluid region and it is the axis of rotation about which the fluid rotates with angular velocity $\overline{\Omega}$. A uniform magnetic field is applied in the transverse direction of the flow.Let $(\bar{u},\bar{v},\bar{w})$ be the fluid velocity at a point $(\bar{x},\bar{y},\bar{z})$.

Our investigation is restricted to the following assumptions:

i) All the fluid properties are constants and the buoyancy force has no effect on the flow.

ii) The plate is electrically non- conducting.

iii) The entire system is rotating with angular velocity $\overline{\Omega}$ about the normal to the plate and $|\overline{\Omega}|$ is so small that $|\overline{\Omega}\times(\overline{\Omega}\times\bar{r})|$.

iv) The magnetic Reynolds number is so small that the induced magnetic field can be neglected.

v) p_e is constants.

vi) $\vec{E} = 0$

The equation of continuity gives

$$\frac{\partial \overline{\omega}}{\partial z}=0\text{, with } \overline{\omega} = -\omega_0 \text{ =a constant=suction velocity.} \quad (2.7)$$

With the foregoing assumptions and under the usual boundary layer approximations, the equations governing the flow and heat transfer are

$$\frac{\partial \overline{u}}{\partial \overline{t}}=\frac{\partial \overline{U}}{\partial \overline{t}}+2\overline{\Omega}\overline{v}+w_0\frac{\partial \overline{u}}{\partial \overline{z}}+\frac{\sigma B_0^2}{\rho(1+m^2)}((\overline{U}-\overline{u})+m\overline{v})+\nu_1\frac{\partial^2 \overline{u}}{\partial \overline{z}^2}+\nu_2(\frac{\partial^3 \overline{u}}{\partial \overline{z}^2\partial \overline{t}}-w_0\frac{\partial^3 \overline{u}}{\partial \overline{z}^3}) \quad (2.8)$$

$$\frac{\partial \overline{v}}{\partial \overline{t}}=\nu_1\frac{\partial^2 \overline{v}^2}{\partial \overline{z}^2}+2\overline{\Omega}(\overline{U}-\overline{u})+w_0\frac{\partial \overline{v}}{\partial \overline{z}}-\frac{\sigma B_0^2}{\rho(1+m^2)}(m(\overline{u}-\overline{U})+\overline{v})++\nu_2(\frac{\partial^3 \overline{v}}{\partial \overline{z}^2\partial \overline{t}}-w_0\frac{\partial^3 \overline{v}}{\partial \overline{z}^3}) \quad (2.9)$$

$$\frac{\partial \overline{T}}{\partial \overline{t}}-w_0\frac{\partial \overline{T}}{\partial \overline{z}}=\frac{\partial^2 \overline{T}}{\partial \overline{z}^2}+\frac{\nu_1}{C_p}\left[\left(\frac{\partial \overline{u}}{\partial \overline{z}}\right)^2+\left(\frac{\partial \overline{v}}{\partial \overline{z}}\right)^2\right]+\frac{\nu_2}{C_p}\left[\begin{array}{l}\frac{\partial \overline{v}}{\partial \overline{z}}\left(\frac{\partial^2 \overline{v}}{\partial \overline{z}\partial \overline{t}}-w_0\frac{\partial^2 \overline{v}}{\partial \overline{z}^2}\right)\\+\frac{\partial \overline{u}}{\partial \overline{z}}\left(\frac{\partial^2 \overline{u}}{\partial \overline{z}\partial \overline{t}}-w_0\frac{\partial^2 \overline{u}}{\partial \overline{z}^2}\right)\end{array}\right] \quad (2.10)$$

The relevant boundary conditions are

$$\begin{array}{l} at\ z=0;\overline{u}=0,\overline{v}=0,\overline{T}=\overline{T}_w+\varepsilon\left(\overline{T}_w-\overline{T}_\infty\right)e^{i\omega\overline{t}} \\ at\ z\to\infty;\overline{u}=\overline{U}=U_0(1+\varepsilon e^{i\omega\overline{t}}),\overline{v}=0,\overline{T}=\overline{T}_\infty \end{array} \quad (2.11)$$

We introduce the following non-dimensional quantities:

$$u=\frac{\overline{u}}{U_0},v=\frac{\overline{v}}{U_0},U=\frac{\overline{U}}{U_0},t=\frac{\overline{t}\,\omega_0^2}{\nu_1},\omega=\frac{\nu_1\overline{\omega}}{\omega_0^2},\Omega=\frac{2\overline{\Omega}\nu_1}{\omega_0^2},z=\frac{\overline{z}\omega_0}{\nu_1},M=\frac{\sigma B_0^2\nu_1}{\rho\omega_0^2},P_r=\frac{\nu_1}{\alpha}.$$

$$T=\frac{\overline{T}-\overline{T}_\infty}{\overline{T}_W-\overline{T}_\infty},E=\frac{U_0^2}{C_P\left(\overline{T}_W-\overline{T}_\infty\right)},d=\frac{\nu_2\omega_0^2}{\nu_1^2}$$

The non-dimensional governing equations and boundary conditions are

$$\frac{\partial u}{\partial t}=\frac{\partial U}{\partial t}+\Omega v+w_0\frac{\partial u}{\partial z}+\frac{M}{(1+m^2)}(mv-(u-U))+\frac{\partial^2 u}{\partial z^2}+d(\frac{\partial^3 u}{\partial z^2\partial t}-w_0\frac{\partial^3 u}{\partial z^3}) \quad (2.12)$$

$$\frac{\partial v}{\partial t}=\frac{\partial^2 v}{\partial z^2}+\Omega(U-u)+\frac{\partial v}{\partial z}-\frac{M}{1+m^2}(m(u-U)+v)++Dd(\frac{\partial^3 v}{\partial z^2\partial t}-w_0\frac{\partial^3 v}{\partial z^3}) \quad (2.13)$$

$$P_r \frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial z^2} + P_r \frac{\partial T}{\partial z} + EP_r \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right] + \frac{dEP_r}{2} \left| \begin{matrix} \frac{\partial}{\partial t} \left(\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right) \\ - \frac{\partial}{\partial t} \left(\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right) \end{matrix} \right| \quad (2.14)$$

Subject to the boundary conditions

$$\begin{aligned} & z = 0 : u = 0, v = 0, T = 1 + \varepsilon e^{i\omega t} \\ & z \to \infty : u = U = 1 + \varepsilon e^{i\omega t}, v = 0, T = 0 \end{aligned} \quad (2.15)$$

3. SOLUTION OF THE PROBLEM

Let us introduce the complex variable q defined by q=u+iv where $i^2=-1$. The non-dimensional forms of the equation governing the flow can be rewritten as

$$\frac{\partial q}{\partial t} = \frac{\partial^2 q}{\partial z^2} + \frac{\partial U}{\partial t} + \frac{\partial q}{\partial z} + \left(\frac{M}{1+m^2} + i\Omega\right)(U - q) - \frac{imM}{1+m^2}(q - U) + d\left(\frac{\partial^3 q}{\partial z^2 \partial t} - \frac{\partial^3 q}{\partial z^3}\right) \quad (3.1)$$

$$P_r \frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial z^2} + P_r \frac{\partial T}{\partial z} + EP_r \left(\left| \frac{\partial q}{\partial z} \right|^2 \right) + \frac{dEP_r}{2} \left(\left| \frac{\partial^2 q}{\partial z \partial t} \right|^2 - \left| \frac{\partial^2 q}{\partial z^2} \right|^2 \right) \quad (3.2)$$

subject to the boundary conditions:

$$\begin{aligned} & z = 0 : q = 0, T = 1 + \varepsilon e^{i\omega t} \\ & z \to \infty : q = 1 + \varepsilon e^{i\omega t}, T = 0 \end{aligned} \quad (3.3)$$

Assuming the small amplitude oscillation ε<<1, we represent the velocity q and the temperature T as

$$q = q_0(z) + \varepsilon e^{i\omega t} q_1(z) + o(\varepsilon^2) \quad (3.4)$$

$$T = T_0(z) + \varepsilon e^{i\omega t} T_1(z) + o(\varepsilon^2) \quad (3.5)$$

Substituting the expressions form (3.4) and (3.5) in equations (3.1) and (3.2) and by equating the harmonic terms and neglecting ε^2 the following differential equations are obtained:

$$q_0'' + q_0' - \left(\frac{M}{1+m^2} + i\Omega + i\frac{mM}{1+m^2}\right) q_0 = -\left(\frac{M}{1+m^2} + i\Omega + i\frac{mM}{1+m^2}\right) \quad (3.6)$$

$$q_1'' + q_1' - \left(\frac{M}{1+m^2} + i\Omega + i\frac{mM}{1+m^2} + i\omega\right) q_1 + d(i\omega q_1'' - q_1''') = -\left(\frac{M}{1+m^2} + i\Omega + i\frac{mM}{1+m^2} + i\omega\right) \quad (3.7)$$

$$T_0'' + P_r T_0' = -EP_r \left| \frac{dq_0}{dz} \right|^2 + \frac{1}{2} dE \Pr \left| \frac{d^2 q_0}{dz^2} \right|^2 \tag{3.8}$$

$$T_1'' + P_r T_1' - i\omega P_r T_1 = -EP_r (q_0' \bar{q}_1' + q_1' \bar{q}_0') - dEP_r \left[\frac{1}{2} \left| i\omega q_1'' \right|^2 - \frac{1}{2} (q_0'' \bar{q}_1'' + q_1'' \bar{q}_0'') \right] \tag{3.9}$$

The relevant boundary conditions are:

$$\begin{aligned} &z = 0 : q_0 = 0, q_1 = 0, T_0 = 1, T_1 = 1 \\ &z \to \infty : q_0 = 1, q_1 = 1, T_0 = 0, T_1 = 0 \end{aligned} \tag{3.10}$$

Here, $\bar{q}_0$ and $\bar{q}_1$ indicate the conjugate of the complex numbers q_0 and q_1 respectively.

Again to solve the equation (3.7) we use the multi-perturbation technique and the velocity components are expanded in the power of visco-elastic parameter d as d<<1 for small shear rate. Thus the expressions for velocity components are considered as

$$q_1 = q_{10} + dq_{11} \tag{3.11}$$

Applying (3.11), in equations (3.7) equating the like powers of d we obtain the following set of differential equations :

$$q_{10}'' + q_{10}' - \left(\frac{M}{1+m^2} + i\Omega + i\frac{mM}{1+m^2} + i\omega\right) q_{10} = -\left(\frac{M}{1+m^2} + i\Omega + i\frac{mM}{1+m^2} + i\omega\right) \tag{3.12}$$

$$q_{11}'' + q_{11}' - \left(\frac{M}{1+m^2} + i\Omega + i\frac{mM}{1+m^2} + i\omega\right) q_{11} + i\omega q_{10}'' - q_{10}''' = 0 \tag{3.13}$$

The relevant boundary conditions are:

$$\begin{aligned} &z = 0 : q_{10} = 0, q_{11} = 0 \\ &z \to \infty : q_{10} = 1, q_{11} = 0 \end{aligned} \tag{3.14}$$

The solutions of the equations (3.6),(3.8),(3.9),(3.12) and (3.13) subject to the boundary conditions (3.10) and (3.14) are

$$q_0 = 1 - e^{-A_1 z}$$

$$q_{10} = 1 - e^{-A_2 z}$$

$$q_{11} = \left(D + \frac{i\omega A_2^2 + A_2^3}{1 - 2A_2}\right) z e^{-A_2 z}$$

$$T_0 = B_2 e^{-P_r z} - \frac{P_r E A_1 \bar{A}_1 e^{-(A_1 + \bar{A}_1) z}}{(A_1 + \bar{A}_1)^2 - (A_1 + \bar{A}_1)}$$

$$T_1 = e^{-C_5 z} - \begin{bmatrix} \dfrac{C_1((A_1+\overline{A}_2)^2 - P_r(A_1+\overline{A}_2))(e^{-C_5 z} + e^{-(A_1+\overline{A}_2)z})}{((A_1+\overline{A}_2)^2 - P_r(A_1+\overline{A}_2))^2 + \omega^2 P_r^{\,2}} + \\ \dfrac{C_2((\overline{A}_1+A_2)^2 - P_r(\overline{A}_1+A_2))(e^{-C_5 z} + e^{-(\overline{A}_1+A_2)z})}{((\overline{A}_1+A_2)^2 - P_r(\overline{A}_1+A_2))^2 + \omega^2 P_r^{\,2}} - \\ \dfrac{C_3((A_2+\overline{A}_1)^2 - P_r(A_2+\overline{A}_1))(e^{-C_5 z} + e^{-(A_2+\overline{A}_1)z})}{((A_2+\overline{A}_1)^2 - P_r(A_2+\overline{A}_1)) + \omega^2 P_r^{\,2}} + \end{bmatrix} +$$

$$i\omega P_r \begin{bmatrix} \dfrac{C_1(e^{-C_5 z} + e^{-(A_1+\overline{A}_2)z})}{((A_1+\overline{A}_2)^2 - P_r(A_1+\overline{A}_2))^2 + \omega^2 P_r^{\,2}} + \dfrac{C_2(e^{-C_5 z} + e^{-(\overline{A}_1+A_2)z})}{((\overline{A}_1+A_2)^2 - P_r(\overline{A}_1+A_2))^2 + \omega^2 P_r^{\,2}} - \\ \dfrac{C_3(e^{-C_5 z} + e^{-(A_2+\overline{A}_1)z})}{((A_2+\overline{A}_1)^2 - P_r(A_2+\overline{A}_1)) + \omega^2 P_r^{\,2}} \end{bmatrix}$$

4. VELOCITY AND TEMPERATURE FIELD

The non-dimensional velocity Field is given by

$$q = q_0(z) + \varepsilon e^{i\omega t} q_1(z)$$

By splitting in to real and imaginary parts the primary and secondary velocity components are derived as

$$u = u_0 + \varepsilon |q_1| \cos(\omega t + \alpha)$$
$$v = v_0 + \varepsilon |q_1| \sin(\omega t + \alpha)$$

where

$$u_0 + iv_0 = q_0, \alpha = \arg(q_1)$$

The temperature in non-dimensional form is given by

$$T = T_0(z) + \mathrm{Re}\,al\ part\ of\,(\varepsilon e^{i\omega t} T_1(z))$$
$$= T_0(z) + \varepsilon |T_1| \cos(\omega t + \beta)$$

Where $\beta = \arg(T_1(z))$

5. SKIN-FRICTION

The skin-friction at the plate in the direction of primary and secondary velocities are respectively given by

$$\tau_{xz} = \frac{\partial u}{\partial z} + d\left[\frac{\partial^2 u}{\partial z \partial t} - \frac{\partial^2 u}{\partial z^2}\right]$$

$$\tau_{yz} = \frac{\partial v}{\partial z} + d\left[\frac{\partial^2 v}{\partial z \partial t} - \frac{\partial^2 v}{\partial z^2}\right]$$

6. COEFFICIENT OF HEAT-TRANSFER

The rate of heat transfer in terms of Nusselt number from the plate to the fluid is given by

$$Nu = -T_0'(0) - \varepsilon\left|T_1'(0)\right|\cos(\omega t + \psi)$$

where $\psi = \arg(T_1'(0))$

7. RESULTS AND DISCUSSIONS:

The objective of the present paper is to investigate the effects of Hall current andmagnetic field on visco-elastic fluid flow past an infinite horizontal porous plate with dissipative heat in a rotating system due to importance of such problem in many spaceand temperature related phenomena.

In order to get physical insight of the effects of flow parameters on the flow problems under considerations we make graphical illustrations for velocity field, temperature field, shearing stress and coefficient of heat transfer i,e, Nusselt number. The parameters ε=0.01, Ω =0.5, ω =0.5, t=1 are kept fixed throughout the discussion. The non-zero valuesof the parameter d characterize the visco-elastic fluid and d=0 represent the Newtonian fluid flow phenomenon.

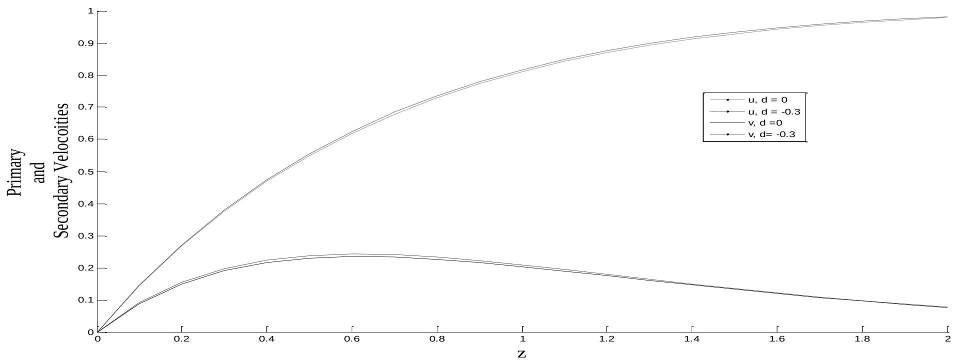

Figure 1: m=2, M=2, ε =0.01, Ω =0.5, ω =0.5, t=1, d=-0.3, Pr=7

Figure 1 reveal the effects of the visco-elastic parameter d on the fluid velocity components u and v. It has been observed from the figure that both primary velocity(u)and secondary velocity(v) increases with the increasing values of the visco-elasticparameter d for fixed Hall parameter(m), Prandtl number(Pr) and Magnetic parameter(M).

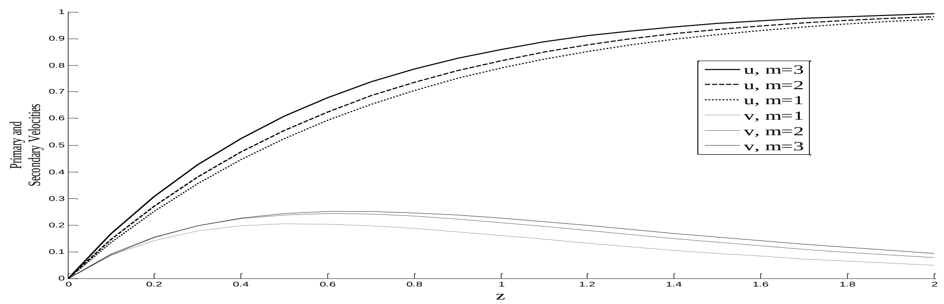

Figure 2: d=-0.3, M=2, ε =0.01, Ω =0.5, ω =0.5, t=1, d=-0.3, Pr=7

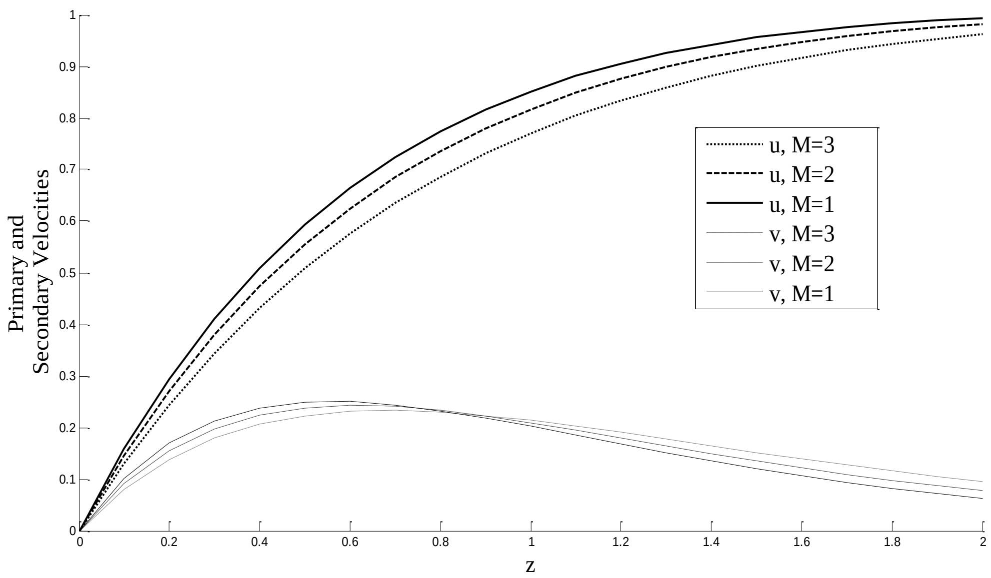

Figure 3: d=-0.3, m=2, ε =0.01, Ω =0.5, ω =0.5, t=1, d=-0.3, Pr=7

Figure 2 exhibit the effects of the Hall parameter(m) on the fluid velocity. It has been observed from the figure that both primary velocity(u) and secondary velocity(v) increases with the increasing values of Hall parameter(m).In general, application of transverse magnetic field has the tendency to decrease the velocity due to resistive Lorentz force. It has been observed from figure 3 that the growth of Magnetic parameter(M) shift the fluid velocity in downward direction for both primary velocity (u) and secondary velocity(v).

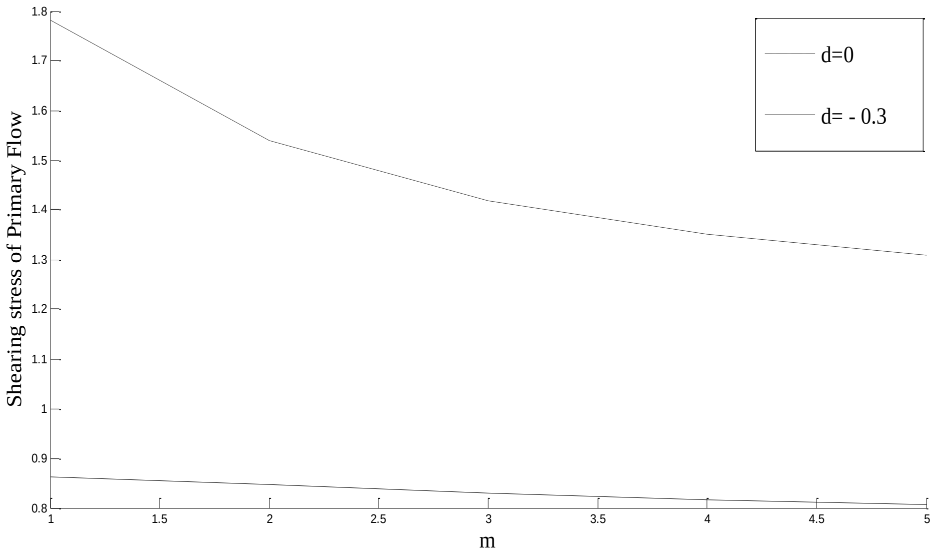

Figure 4: M=2, ε =0.01, Ω =0.5, ω =0.5, t=1, Pr=7

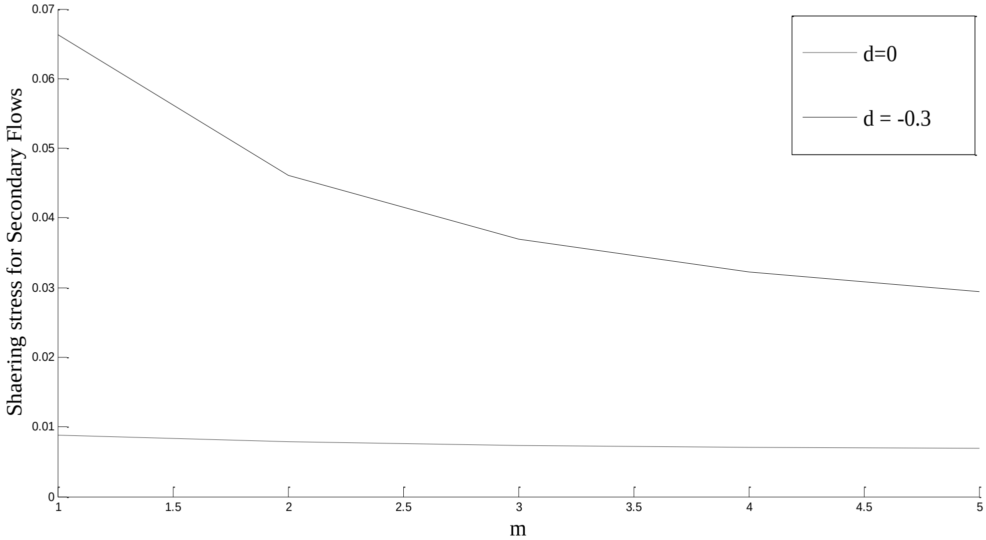

Figure 5: M=2, ε =0.01, Ω =0.5, ω =0.5, t=1, Pr=7

Figure 4 and 5 displays the shearing stress for both primary and secondary flow against the Hall parameter(m). It demonostrates that the shearing stress for both primary and secondary flow decreasing with the increasing values of Hall parameter(m). It is also observed that with the increasing values of visco-elastic parameter shearing stressdecreases for the primary flow and increases for secondary flow.

Figure 6 and 7 displays the temperature T against z for various values of Prandtl number(Pr) and Hall parameter(m). It is observed from the figures that temperature decreases with increase of Prandtl number(Pr) and Hall parameter(m).

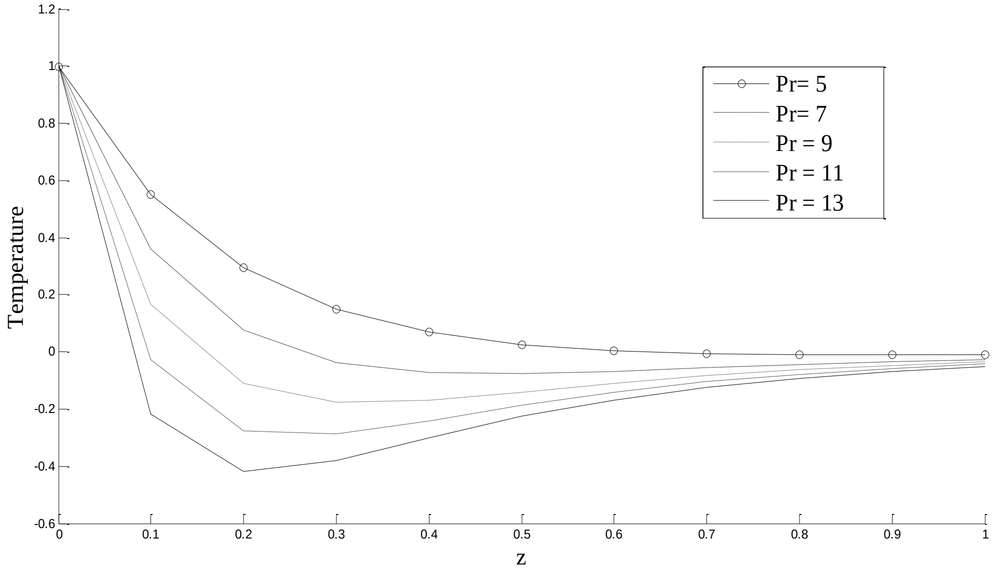

Figure 6: m=2, M=2, ε =0.01, Ω =0.5, ω =0.5, t=1, d=-0.3, E=0.2

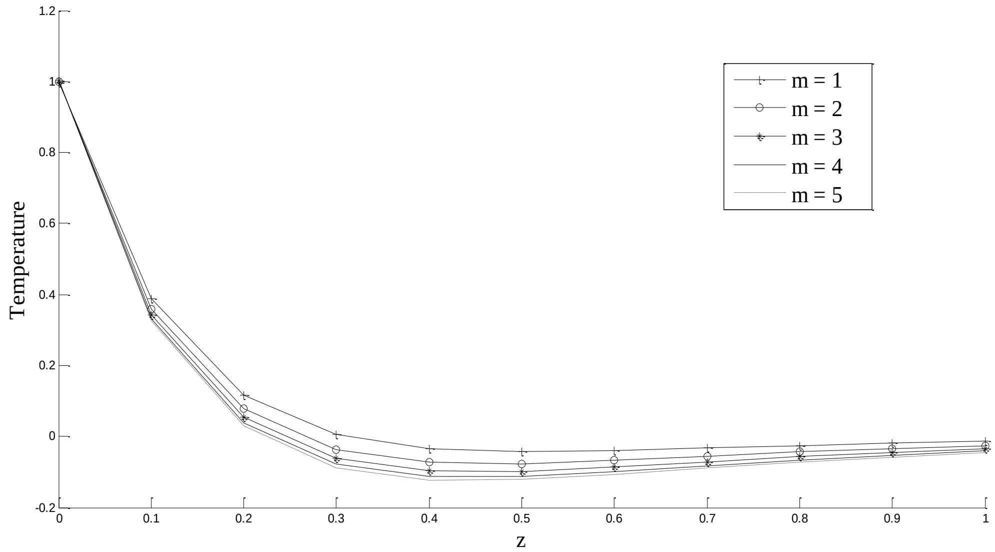

Figure 7: M=2, ε =0.01, Ω =0.5, ω =0.5, t=1, d=-0.3, E=0.2, Pr = 7

Figure 8 and 9 depict the behaviours of coefficient of heat transfer i,e, Nusselt number against Hall parameter m and Prandtl number(Pr).It is noticed that in Figure 10 Nusseltnumber increases with the decrease of visco-elastic parameter d and increases with the increase of Prandtl number(Pr).Also it is noticed that in figure 11 the coefficient of heat transfer i,e, Nusselt number increases with the increase of Prandtl number (Pr) and Eckert number(E).

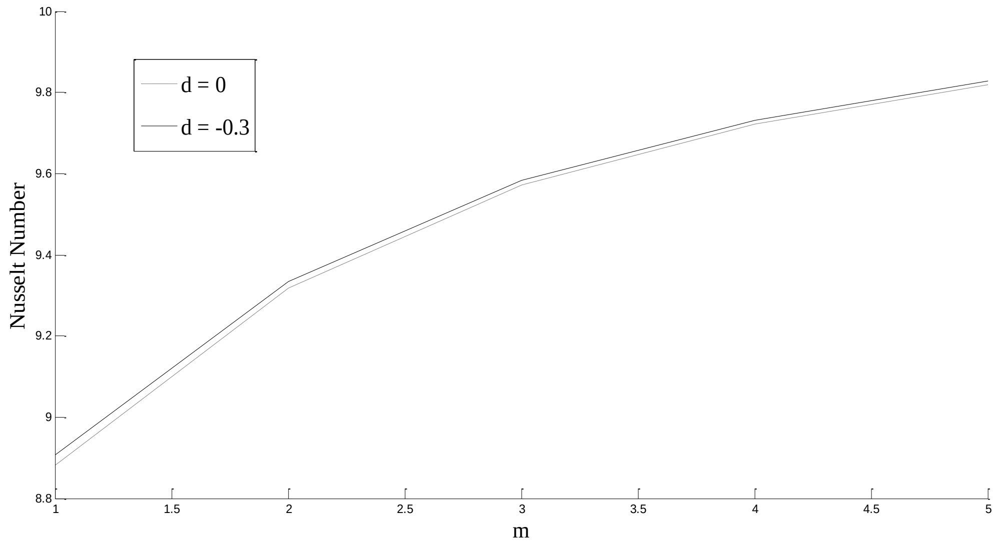

Figure 8: M=2, ε =0.01, Ω =0.5, ω =0.5, t=1, Pr=7, E =0.2

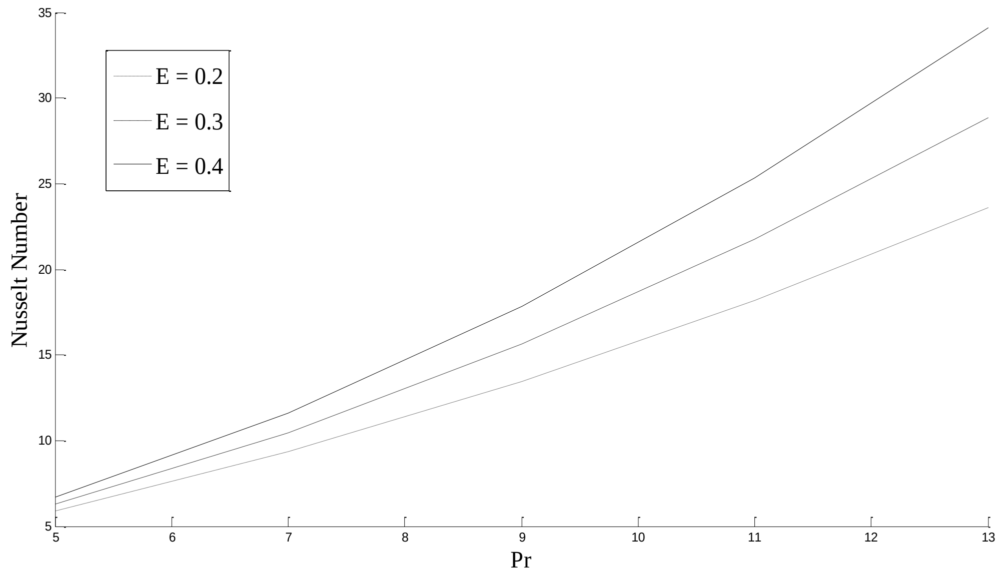

Figure 9: m=2, M=2, ε =0.01, Ω =0.5, ω =0.5, t=1, d = - 0.3.

8. CONCLUSION

The forced convective second order fluid flow in a rotating system with Hall effects inpresence of heat transfer are studied in this paper. Some of the important conclusions of this paper are as follows

i. The flow field is significantly affected with the variation of visco-elastic parameter.

ii. The effect of Hall parameter and magnetic parameter on velocity is prominent throughout the flow in presence of other flow parameter.

iii. The temperature field is significantly affected with the variation of Hall parameter and Prandtl number.

iv. The rate of heat transfer that is Nusselt number is significantly affected during the variation of visco-elastic parameter throughout the fluid flow phenomenon.

v. The primary and secondary components of shearing stress are prominently affected by the visco-elastic parameter.

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Nomenclature

$\vec{q}$ is the velocity vector

$\overline{\Omega}$ is the angular velocity of the fluid

ρ is the fluid density

$\vec{r}$ is the position vector of the fluid particle 7.

p is the pressure

$\vec{J}$ is the current density

$\vec{B}$ is the magnetic induction vector

μ is the co-efficient of viscosity

σ is the electrical conductivity

$\bar{t}$ is the time

B_o is the strength of the applied magnetic field

Cp is the specific heat at constant pressure

$\overline{T}$ is the temperature

K is the thermal conductivity

φ is the frictional heat

ω_e is the electron frequency

τ_e is the electron collision time

e is the electron charge

η_e is the number density of electron

p_e is the electron pressure

$\vec{E}$ is the electric field

v is the kinematic viscosity

m is the Hall parameter

U is the dimensional free stream velocity

α is the thermal diffusivity

u is the non-dimensional primary velocity

v is the non-dimensional secondary velocity

$\overline{\omega}$ is the frequency of oscillation

M is the Hartmann number

Pr is the Prandtl number

E is the Eckert number

d is the visco-elastic parameter

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