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FREE CONVECTIVE MHD FLOW OF A VISCO-ELASTIC FLUID PAST A VERTICAL POROUS PLATE THROUGH A POROUS MEDIUM WITH CONSTANT SUCTION AND HEAT SOURCE

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KEYWORDS:

Free convective,
MHD,
Visco-elastic,
Porous medium,
Shearing stress,
Nusselt number.

ABSTRACT

The hydromagnetic free convective flow of a visco-elastic electrically conducting fluid past a vertical porous plate through a porous medium with constant suction and heat source in presence of transverse magnetic field has been studied. The induced magnetic field and Joulean heat dissipation are neglected in this problem. Also, Boussinesq approximation has been used to find the governing equations of the flow field in presence of energy dissipation. The governing equations are solved by using multi parameter-perturbation technique. The analytical expressions for the velocity, temperature fields shearing stress, 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, Nusselt number, and shearing stress 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

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1. INTRODUCTION

In modern engineering, whether it is electrical, mechanical, chemical or atomic, the transfer of energy in the form of is an operation frequently encountered in all phases. So, in recent years, the study of heat transfer by laminar flow of viscous incompressible fluids, based on linear stress-strain rate relation, has gained considerable interest. The problem of free convection under the influence of the magnetic field has attracted the interest of many researchers in view of its applications in geophysics and astrophysics. 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.

Sahoo *et al.*[1] have studied the unsteady free convective MHD flow past an infinite vertical plate with constant suction and heat sink. Makinde *et al*.[2] have analyzed the unsteady free convective flow with suction on an accelerating porous plate. Hasimoto[3] has estimated the boundary layer growth on a flat plate with suction and injection. Sharma and Pareek[4] have studied the behaviour of steady free convective MHD flow past a vertical porous moving surface. Singh *et al.*[5] has discussed the effects of heat and mass transfer in MHD flow of a viscous fluid past a vertical plate under oscillatory suction velocity. Raptis and Singh[6] has discussed free convection flow past an accelerated vertical plate in presence of a transverse magnetic field. Singh and Sacheti[7] have reported the unsteady hydromagnetic free convection flow with constant heat flux employing finite difference scheme. Sarangi and Jose[8] have investigated unsteady free convection MHD flow mass transfer past a vertical porous plate with variable temperature. Ogulu and Prakash[9] have discussed the heat transfer to unsteady magneto-hydrodynamic flow past an infinite vertical moving plate with variable suction. The hydromagnetic convective flow past a vertical porous plate through a porous medium with suction and heat source has been studied by Das *et al.*[10].

In this study, an attempt has been made to extend the problem studied by Das *et al*.[10] to the case of visco-elastic fluid characterized by Walters liquid (Model B′)[11]

2. FORMULATION OF THE PROBLEM:

Consider the unsteady free convective flow of a visco-elastic electrically conducting fluid past an infinite vertical porous plate in presence of transverse magnetic field with constant suction and heat flux. Let x-axis be taken in vertically upward direction along the plate and y-axis normal to it. Neglecting the induced magnetic field and Joulean heat dissipation and applying Boussinesq's approximation the governing equations of the flow field with energy dissipation are given by:

Continuity Equation:

$$\frac{\partial v'}{\partial y'} = 0$$
$$\Rightarrow v' = -v'_0 \tag{2.1}$$

Momentum Equation :

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \nu_1 \frac{\partial^2 u'}{\partial y'^2} - \frac{k_0}{\rho}\left(\frac{\partial^2 u'}{\partial t' \partial y'^2} + v'\frac{\partial^3 u'}{\partial y'^3}\right) + g\beta(T' - T'_\infty) - \frac{\sigma B_0^2 u'}{\rho} - \nu_1 \frac{u'}{k'} \tag{2.2}$$

Energy Equation:

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = k\frac{\partial^2 T'}{\partial y'^2} + \frac{1}{c_p}\left\{\nu_1 \frac{\partial u'}{\partial y'} - \frac{k_0}{\rho}\left(\frac{\partial^2 u'}{\partial t' \partial y'^2} + v'\frac{\partial^2 u'}{\partial y^{2'}}\right)\right\} + S'(T' - T'_\infty) \tag{2.3}$$

The boundary conditions of the problem are:

$$\left.\begin{aligned} &u' = 0,\ v' = -v'_0,\ T' = T'_w + \varepsilon(T'_w - T'_\infty)e^{i\omega t} \quad at\ y' = 0 \\ &u' \to 0,\ T' \to T'_\infty \qquad as\, y' \to \infty \end{aligned}\right\} \tag{2.4}$$

Introducing the following non-dimensional variables and parameters:

$$y = \frac{y' v_0'}{v},\ t = \frac{t' v_0'^2}{4v},\ \omega = \frac{4v\omega'}{v_0'^2},\ u = \frac{u'}{v_0'}, v_1 = \frac{\eta_0}{\rho}, T = \frac{T' - T_\infty'}{T_w' - T_\infty'},$$

$$M = \frac{\sigma B_0^2}{\rho}\frac{v}{v_0'^2},\quad Magnetic\ parameter \qquad P_r = \frac{v}{k}, \Pr andtl number$$

$$K_p = \frac{v_0^2 K'}{v^2},\quad the\ permeabilty\ parameter \qquad G_r = \frac{vg\beta(T_w' - T_\infty')}{v_0'^3}, the\ Grashof number$$

$$S = \frac{4S'v}{v_0'^2}, the\ heat\ source\ parameter \qquad E_c = \frac{v_0'^2}{c_p(T_w' - T_\infty')}, the Eckert\ number$$

$$d = \frac{k_0 v_0'^2}{\rho v_1^2}, the\ visco-elastic parameter$$

where g is the acceleration due to gravity, ρ is the density, σ is the electrical conductivity, β is the volumetric co-efficient of expansion for heat transfer, ω is the angular frequency, η_0 is the coefficient of viscosity, k is the thermal diffusivity, T is the temperature, T_w is the temperature at the plate, T_∞ is the temperature at infinity, C_p is the specific heat at constant pressure.

Using the above substitutions in equations (2) and (3), we get the following equations in non-dimensional form:

$$\frac{1}{4}\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - k_1\left[\frac{1}{4}\frac{\partial^3 u}{\partial t \partial y^2} - \frac{\partial^3 u}{\partial y^3}\right] + GrT - Mu - \frac{u}{k_p} \tag{2.5}$$

$$\frac{1}{4}\frac{\partial T}{\partial t} - \frac{\partial T}{\partial y} = \frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2} + E_C\left(\left(\frac{\partial u}{\partial y}\right)^2 - k_1\frac{\partial u}{\partial y}\left(\frac{\partial^2 u}{\partial t \partial y} - \frac{\partial^2 u}{\partial y^2}\right)\right) + \frac{1}{4}ST \tag{2.6}$$

The corresponding boundary conditions are:

$$\left.\begin{array}{l} u = 0, T = 1 + \varepsilon e^{i\omega t}\ \ at\ y = 0, \\ u \to 0, T \to 0\ as\ \ y \to \infty. \end{array}\right\} \tag{2.7}$$

3.METHOD OF SOLUTION:

To solve the equations (2.5) and (2.6), we assume ε to be very small and the velocity and temperature in the neighbourhood of the plate as

$$\left.\begin{array}{l} u(y,t) = u_0(y) + \varepsilon\, e^{i\omega t} u_1(y) \\ T(y,t) = T_0(y) + \varepsilon\, e^{i\omega t} T_1(y) \end{array}\right\} \tag{3.1}$$

Substituting (3.1) in equations (2.5) and (2.6) respectively, equating the harmonic and non-harmonic terms and neglecting the coefficients of ε^2, we get

Zeroth order equations:

$$\alpha u_0''' + u_0'' + u_0' - (M + \frac{1}{k_p})u_0 = -GrT_0 \quad (3.2)$$

$$T_0'' + \Pr T_0' + \frac{1}{4} S T_0 \Pr = -\Pr Ec(u_0'^2 + k_1 u_0'' u_0') \quad (3.3)$$

Subject to boundary conditions:

$$\left.\begin{array}{l} u_0 = 0,\ T_0 = 1,\ at\ y = 0 \\ u_0 \to 0,\ T_0 \to 0\ \ as\ y \to \infty \end{array}\right\} \quad (3.4)$$

First-order Equations:

$$u_1'' + u_1' - d\left(\frac{1}{4} i\omega u_1'' - u_1'''\right) - \left(M + \frac{1}{k_p}\right)u_1 - \frac{i\omega u_1}{4} = -GrT_1 \quad (3.5)$$

$$T_1'' + \Pr T_1' - \frac{\Pr}{4}(i\omega - S)T_1 = -\Pr Ec\left(2u_0'u_1' - d\left(i\omega u_0'u_1' - u_0'u_1'' - u_0''u_1'\right)\right) \quad (3.6)$$

The relevant boundary conditions are:

$$\left.\begin{array}{l} u_1 = 0,\ T_1 = 1,\ at\ y = 0 \\ u_1 \to 0,\ T_1 \to 0\ \ as\ y \to \infty \end{array}\right\} \quad (3.7)$$

To solve the equations (3.2)-(3.3) and (3.5)-(3.6) the physical variables u_0, u_1, T_0, T_1 are expanded in the powers of Eckert number (E_c) as E_c is very small as compared to unity for incompressible fluid. Thus the expressions for velocity, temperature are expressed as follows:

$$\left.\begin{array}{ll} u_0 = u_{00} + Ecu_{01}, & u_1 = u_{10} + Ecu_{11} \\ T_0 = T_{00} + EcT_{01}, & T_1 = T_{10} + EcT_{11} \end{array}\right\} \quad (3.8)$$

Using (3.8) in equations (3.2-3.3) and (3.5-3.6) and equating the co-efficients of like powers of E_c, we obtain the following set of differential equations

Zeroth-order equations:

$$\alpha u_{00}''' + u_{00}'' + u_{00}' - \left(M + \frac{1}{K_p}\right)u_{00} = -GrT_{00} \tag{3.9}$$

$$u_{10}'' + u_{10}' - \alpha\left(\frac{1}{4}i\omega u_{10}'' - u_{10}'''\right) - \left(M + \frac{1}{K_p}\right)u_{10} - \frac{i\omega u_{10}}{4} = -GrT_{10} \tag{3.10}$$

$$T_{00}'' + \Pr T_{00}' + \frac{1}{4}S\Pr T_{00} = 0 \tag{3.11}$$

$$T_{10}'' + \Pr T_{10}' - \frac{1}{4}\Pr(i\omega - S)T_{10} = 0 \tag{3.12}$$

Subject to boundary conditions :

$$\left.\begin{array}{l} u_{00} = 0,\ T_{00} = 1, u_{10} = 0,\ T_{10} = 1, at\ \ y = 0 \\ u_{00} \to 0,\ T_{00} \to 0, u_{10} \to 0,\ T_{10} \to 0, as\ \ y \to \propto \end{array}\right\} \tag{3.13}$$

First order equations:

$$\alpha u_{01}''' + u_{01}'' + u_{01}' - \left(M + \frac{1}{K_p}\right)u_{01} = -GrT_{01} \tag{3.14}$$

$$u_{11}'' + u_{11}' - d\left(\frac{1}{4}i\omega u_{11}'' - u_{11}'''\right) - \left(M + \frac{1}{K_p}\right)u_{11} - \frac{i\omega u_{11}}{4} = -GrT_{11} \tag{3.15}$$

$$T_{01}'' + \Pr T_{01}' + \frac{1}{4}S\Pr T_{01} = -\Pr\left(u_{00}'^{\,2} + \alpha u_{00}' u_{00}''\right) \tag{3.16}$$

$$T_{11}'' + \Pr T_{11}' - \frac{1}{4}\Pr(i\omega - S)T_{11} = -\Pr(2u_{00}' u_{10}' - d(i\omega u_{00}' u_{10}' - u_{00}' u_{10}'' - u_{00}'' u_{10}')) \tag{3.17}$$

The modified boundary conditions are:

$$\left.\begin{array}{l} u_{01} = 0,\ T_{01} = 1, u_{11} = 0,\ T_{11} = 1, at\ \ y = 0 \\ u_{01} \to 0,\ T_{01} \to 0, u_{11} \to 0,\ T_{11} \to 0, as\ \ y \to \propto \end{array}\right\} \tag{3.18}$$

Again to solve the equations (3.9)-(3.10) and (3.14)-(3.15), we use the multi-perturbation technique and the velocity and temperature components and expanded 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

$$\left.\begin{array}{l} u_{00} = u_{000} + du_{001}, \\ u_{10} = u_{100} + du_{101}, \\ u_{01} = u_{010} + du_{011}, \\ u_{11} = u_{110} + du_{111}, \end{array}\right\} \tag{3.19}$$

Applying (3.19), in equations (3.9)-(3.10), (3.14)- (3.15) equating the like powers of k_1 we obtain the following set of differential equations :

Zeroth order equations:

$$u''_{000} + u'_{000} - \left(M + \frac{1}{K_p}\right)u_{000} = -GrT_{00} \tag{3.20}$$

$$u''_{100} + u'_{100} - \left(M + \frac{1}{K_p}\right)u_{100} - \frac{i\omega u_{100}}{4} = -GrT_{10} \tag{3.21}$$

$$u''_{010} + u'_{010} - \left(M + \frac{1}{K_p}\right)u_{100} = -GrT_{01} \tag{3.22}$$

$$u''_{110} + u'_{110} - \left(M + \frac{1}{K_p}\right)u_{110} - \frac{i\omega u_{110}}{4} = -GrT_{11} \tag{3.23}$$

Subject to boundary conditions are:

$$\left.\begin{array}{l} u_{000} = 0,\ u_{100} = 0, u_{010} = 0,\ u_{110} = 0,\ at\ y = 0 \\ u_{000} \to 0,\ u_{100} \to 0, u_{010} \to 0,\ u_{110} \to 0,\ as\ y \to \propto \end{array}\right\} \tag{3.24}$$

First order equations:

$$u''_{001} + u'_{001} - \left(M + \frac{1}{K_p}\right)u_{001} + u'''_{000} = -GrT_{00} \tag{3.25}$$

$$u''_{101} + u'_{101} - \left(M + \frac{1}{K_p}\right)u_{101} - \frac{i\omega u_{101}}{4} - \left[\frac{i\omega u''_{100}}{4} - u'''_{100}\right] = -GrT_{10} \tag{3.26}$$

$$u''_{011} + u'_{011} - \left(M + \frac{1}{K_p}\right)u_{011} + u'''_{010} = -GrT_{01} \tag{3.27}$$

$$u''_{111} + u'_{111} - \left(M + \frac{1}{K_p}\right)u_{111} - \frac{i\omega u''_{111}}{4} - \left[\frac{i\omega u''_{110}}{4} - u'''_{110}\right] = -GrT_{11} \tag{3.28}$$

The relevant boundary conditions are:

$$\left.\begin{array}{l} u_{001} = 0,\ u_{101} = 0, u_{011} = 0,\ u_{111} = 0,\ at\ y = 0 \\ u_{001} \to 0,\ u_{101} \to 0, u_{011} \to 0,\ u_{111} \to 0,\ as\ y \to \propto \end{array}\right\} \tag{3.29}$$

3. Results and Discussions:

The dimensionless skin-friction at the wall is given by

$$\tau_w = \frac{\sigma_{xy}}{\rho v_0^2} = \frac{du}{dy} - d\left(\frac{d^2u}{dtdy} - \frac{d^2u}{dy^2}\right)$$

The heat flux at the wall in terms of Nusselt number is given by

$$N_u = \left(\frac{\partial T}{\partial y}\right)_{y=0}$$

$$= -A_2 + Ec(A_{21}A_{19} - A_{20}A_{22} + \Pr(\frac{8A_{23}A_6}{16A_6^2 - 8\Pr A_6 + S} + \frac{8A_{24}}{16A_2^2 - 8\Pr A_2 + S} +$$

$$\frac{4A_{25}(A_6 + A_2)}{16(A_6 + A_2)^2 - 8\Pr(A_6 + A_2) + S})) + +\varepsilon e^{i\omega t}(-A_{10} + Ec(-A_{10}A_{66} + 4\Pr(\frac{A_{57}(A_6 + A_{14})}{4(A_6 + A_{14})^2 - 4\Pr(A_6 + A_{14}) - \Pr(i\omega - S)}$$

$$+ \frac{A_{58}}{4(A_6 + A_{10})^2 - 4\Pr(A_6 + A_{10}) - \Pr(i\omega - S)})))$$

The purpose of this study is to bring out the effects of visco-elastic parameter on hydromagnetic and heat transfer characteristics as the effects of other parameter have been discussed by Das *et al.(*18)The non-Newtonian effect is exhibited through the parameter k. The corresponding results for Newtonian fluid is obtained by setting k=0 and it is worth mentioning that these results show conformity with earlier results.

In order to understand the physics of the problem, analytical results are discussed with the help of graphical illustrations.

The figures 1 to 5 depict the variations of the velocity profile u against the displacement y.

In order to understand the physics of the problem, analytical results are discussed with the help of graphical illustrations.

Figure 1 illustrates the effect of velocity profile for different values of visco-elastic parameter d. It is observed that the velocity increases with an increasing absolute values of the visco-elastic parameter d.

Figure 2 reveals the effects of Magnetic parameter (M) on velocity profile. It is observed from the figure that the velocity decreases with the increase of the magnetic parameter (M). Physically, it is justified because the application of transverse magnetic field always results in a resistive type of force called Lorentz force and tends to resist the fluid motion, finally reducing the velocity.

Figure 3, illustrate the effect of velocity profile for different values of Grashof number(Gr). It is observed that the velocity increases with the increase in the value of Grashof number due to enhancement in buoyancy force. Actually, Grashof number signifies the relative importance of buoyancy force to viscous hydrodynamic force. Increase of Grashof number indicates small viscous effects in momentum equation and consequently causes increase in velocity profile.

Figure 4, illustrate the effect of velocity profile for different values of heat source parameter(S). It is observed that the velocity increases with the increase in the heat source parameter(S).

Figure 5, shows the variation of velocity distribution with different values of permeability parameter(K_p). It is observed that the velocity increases with the increase in the permeability parameter(K_p).

The study of skin friction experienced by the governing fluid flow gives the significance of the concerned problem. So, knowing the velocity field, the shearing stress at the plate is obtained for various values of visco- elastic parameter.

Figure 6 and 7 depict the behaviours of co-efficient of heat transfer i,e Nusselt number against Grashof number and Prandtl number respectively. It is noticed that the Nusselt number decreases with the rise of visco- elastic parameter d in both Newtonian and non-Newtonian cases. Again, with the rising values of Grashof number and Prandtl number it is seen that the profile of Nusselt number decrease for the growth of non-Newtonian parameter in comparison with Newtonian fluid.

Figure 8 depicts the behaviours of the shearing stress C_f against Grashof number Gr. at the shearing stress increased at every point of the flow field in both Newtonian and non-Newtonian cases. Also the enhancement of visco-elastic parameter reveal the diminishing trend of the shearing stress.

Figure 9 and 10 depict the behaviours of the shearing stress C_f against magnetic parameter (M) at a cooled plate and at a heated plate. It is noticed that due to cooled plate (Gr>0) the shearing stress decreases in the flow field with the rise of visco-elastic parameter d but the reverse pattern is seen in case of heated plate (Gr<0).

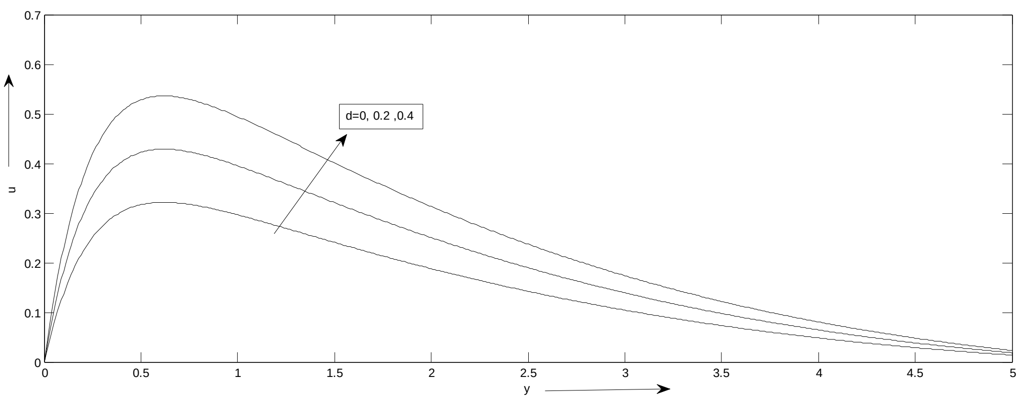

Figure 1: The velocity profile u against the variable y for M=3, Pr=0.71 , Gr=6, E_c=.001 , S=.1, ε=.2,$\omega t=\pi/2$, K_p=1, t=1.

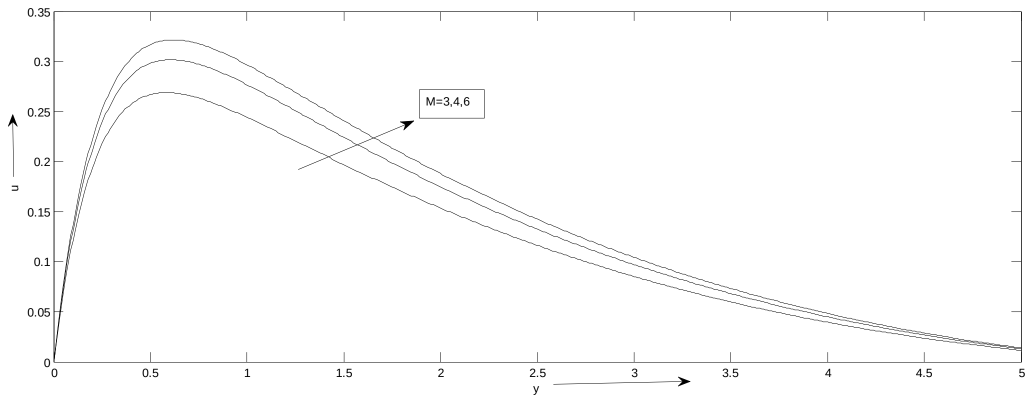

Figure 2: The velocity profile u against the variable y for d=.2, Pr=0.71 , Gr=6, E_c=.001 , S=.1, ε=.2,ωt=π/2, K_p=1, t=1.

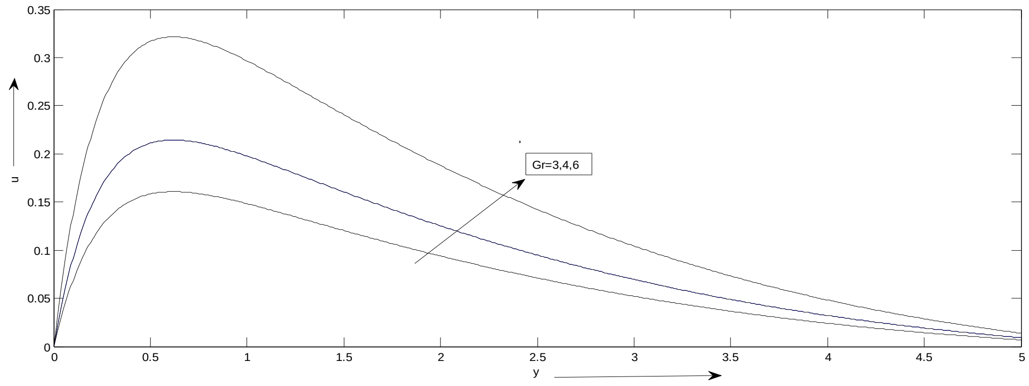

Figure 3: The velocity profile u against the variable y for d=.02, M=3,Pr=0.71,E_c=.001 , S=.1,ε=.2,ωt=π/2, K_p=1, t=1.

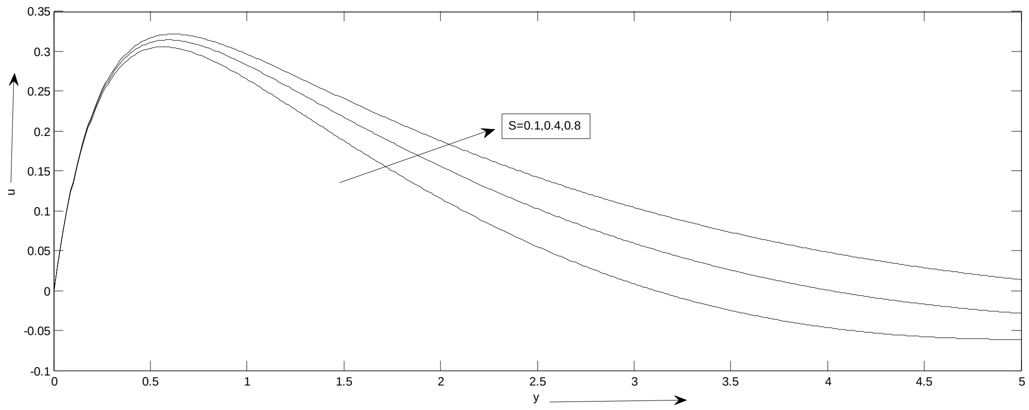

Figure 4: The velocity profile u against the variable y for d=0.2,M=3, Pr=0.71 , Gr=6, E_c=.001, ε=.2,ωt=π/2, K_p=1, t=1.

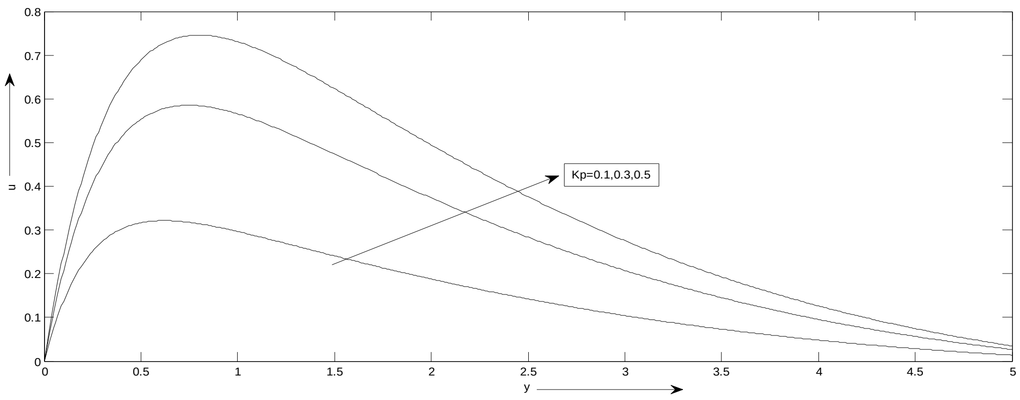

Figure 5: The velocity profile u against the variable y for d=0.2,M=3, Pr=0.71, Gr=6, E_c=.001 , S=.1,ε=.2,ωt=π/2, t=1.

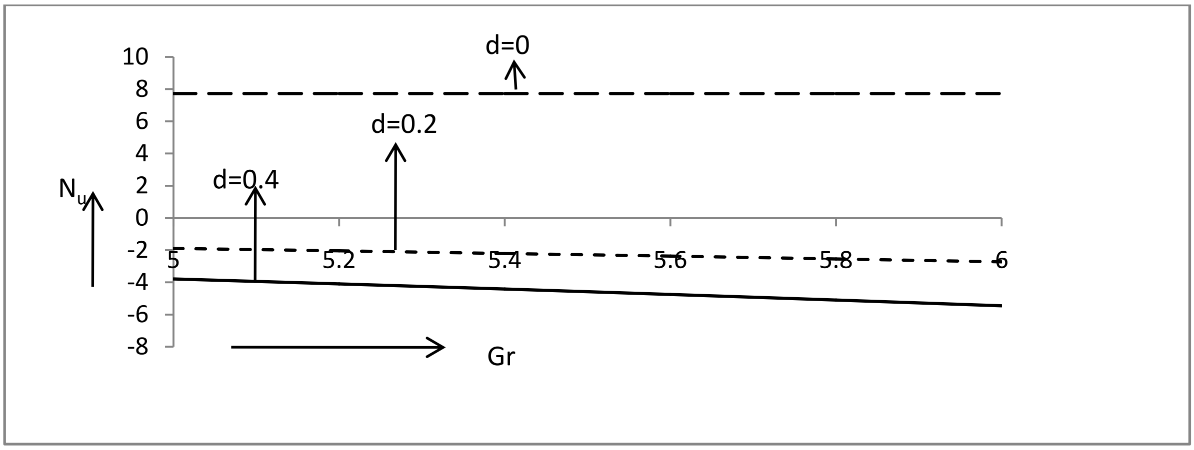

Figure 6: Nusselt number (Nu) Profile against Gr for M=3, Pr=0.71,E_c=.001 ,S=.1, ε=.2,ωt=π/2, K_p=1, t=1.

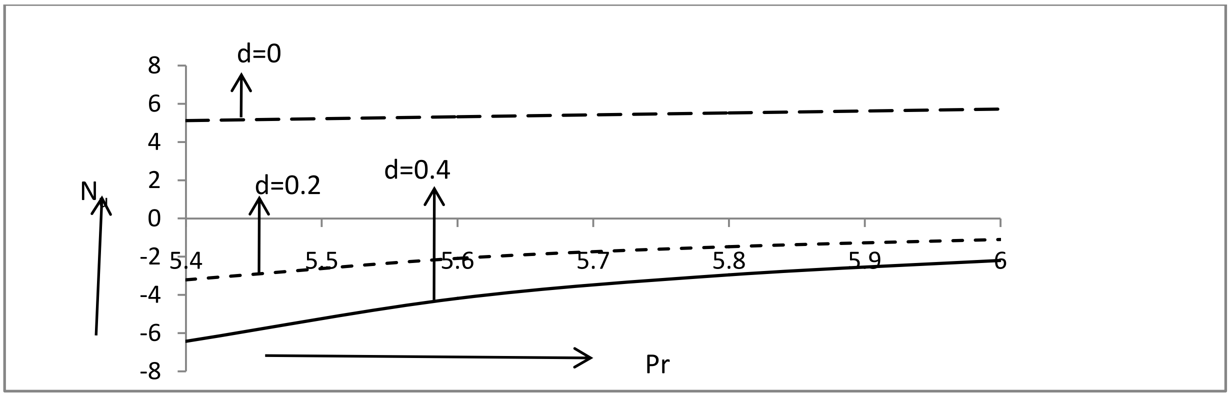

Figure 7: Nusselt number Transfer Profile against Pr for M=3, Gr=6, E_c=.001,S=.1, ε=.2,ωt=π/2, K_p=1, t=1.

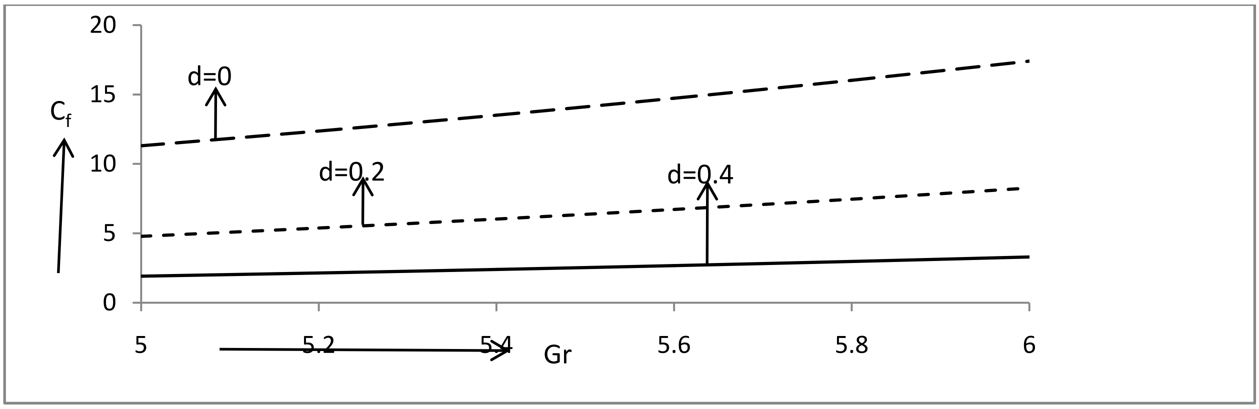

Figure8: The Shearing Stress Profile against M=3, Pr=0.71 , Gr=6, E_c=.001 , S=.1, ε=.2,ωt=π/2, K_p=1, t=1.

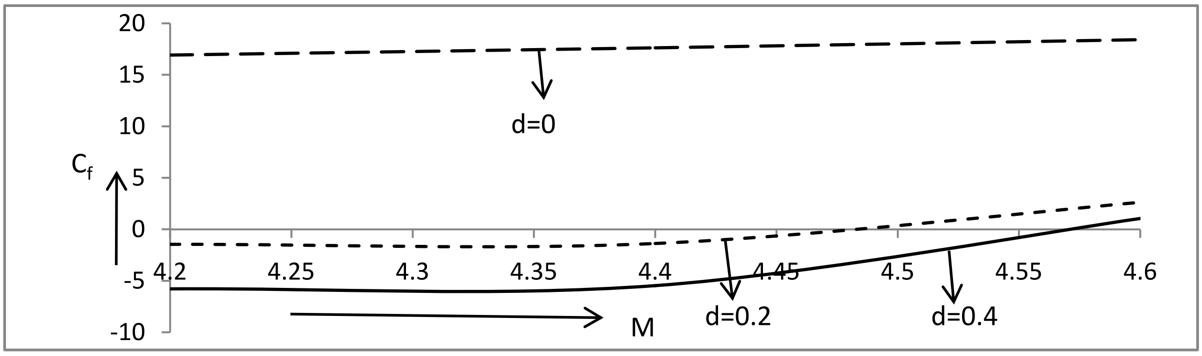

Figure 9: The Shearing Stress Profile against M for Pr=0.71 , Gr=6, E_c=.001 , S=.1, ε=.2,ωt=π/2, K_p=1, t=1.

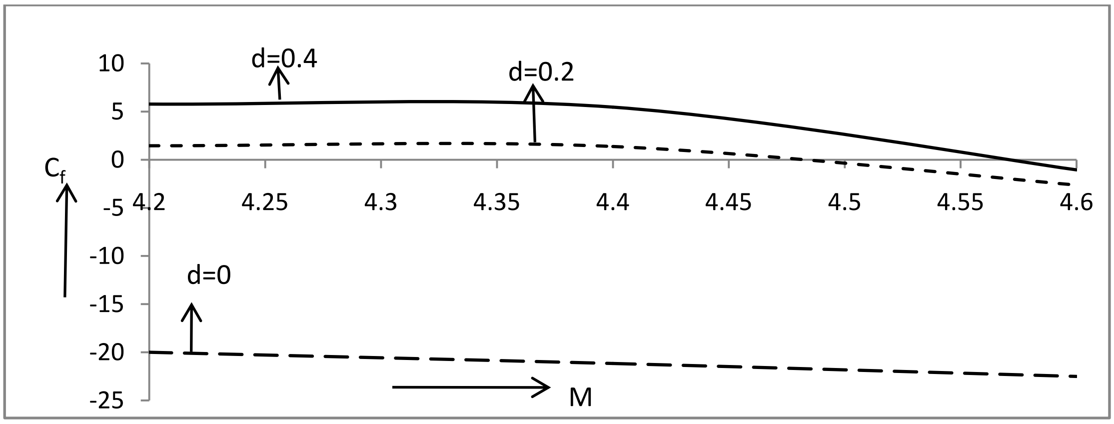

Figure 10: The Shearing Stress Profile against M for Pr=0.71 , Gr=-6, E_c=.001 , S=.1, ε=.2,ωt=π/2, K_p=1, t=1.

4. CONCLUSION

The unsteady two dimensional MHD heat and mass transfer flow of an electrically conducting visco-elastic fluid past a permeable vertical flat plate through a porous medium has ben studied. From this study, we make the following conclusions:

- The rising trend of the visco-elastic parameter leads to a rising trend in velocity at each point of the fluid flow.
- Increase of Grashof number,Permeability parameter, heat source parameter depict a rising trend of the velocity profile but reverse is the phenomena for Magnetic parameter.
- Increase of Grashof number and Prandtl number depict a diminishing trend of the heat transfer when the visco-elastic parameter increases in compared to the Newtonian fluid.
-
- The shearing stress decreases with the increasing values of visco-elastic parameter in comparison with Newtonian fluid flow phenomenon in case of rising values of Grashof number.
- Increase of magnetic parameter on the externally cooled plate increase the shearing stress for the growth of visco-elastic parameter but the reverse nature is observed on the externally heated plate.

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