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Visco-Elastic Effects On Mhd Free Convective Flow Past An Oscillating Porous Plate Through Porous Medium With Heat source

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Abstract: An analysis is presented with MHD free convective visco-elastic flow of a fluid through a porous medium bounded by an oscillating porous plate in the slip flow regime in presence of heat source .The porous plate is subjected to a transverse suction velocity .The fluid is characterized by Rivlin –Ericksen Second-order model. Effects of heat and mass transfer are analyzed in this paper .Approximate solution of the problem is obtained by regular perturbation technique .The analytical expressions for the velocity, temperature and concentration fields have been obtained and illustrated graphically to observe the visco-elastic effects .It is noticed that the considered flow field is significantly affected by visco-elastic parameter in comparison with Newtonian fluid flow phenomena.

Keywords: Visco -elastic, Free-convective, MHD, skin friction, porous medium, slip flow.
2010 Mathematics subject classification: 76A10

I. INTRODUCTION

The analysis of hydro magnetic convective flow involving heat and mass transfer in porous medium has attracted the researcher for its possible applications in diverse fields of science and technology viz. Geophysics, Astrophysics, Biological system, Aerodynamics, Aeronautics etc. On the strength of this phenomenon, Messiha [1] has viewed the problem of laminar boundary layers in oscillatory flow along an infinite flat plate with variable suction. The unsteady MHD free convective flow through a porous medium between two infinite vertical parallel oscillating porous plates with different amplitude has been discussed by Singh *et al*. [2]. Devi and Jothimani [3] thoroughly have studied the flow of heat in unsteady oscillatory MHD flow. The effects of free convection on MHD flow past an infinite vertical oscillating plate with constant heat flux has been explained by Deka *et al*. [4] . The hydrodynamic flow in slip flow regime with time dependent suction has been solved by Taneja and Jain [5]. Singh *et al*. [6] have investigated the heat and mass transfer in MHD flow of a viscous fluid past a vertical plate under oscillatory suction velocity.
The oscillatory MHD slip flow along a porous vertical wall in a medium with variable suction in presence of radiation using finite difference method has been numerically solved by Ogulu and Prakash [7].Singh and Gupta [8] have analyzed the MHD free convective flow of a viscous fluid through a porous medium bounded by an oscillating porous plate in slip flow regime with mass transfer. The unsteady MHD flow of stratified fluid through porous medium over a moving plate in slip flow regime has been discussed by Khandelwal and Jain [9]. A simulation of heat transfer of oscillatory blood flow in an indented porous tube has been introduced by Ogulu and Abbey [10]. Das *et al.* [11] have studied the mass transfer effects on free convective MHD flow of a viscous fluid bounded by an oscillating porous plate in the slip flow regime with heat source. The unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and heat generation has been examined by Sharma and Singh [12].The hydromagnetic convective flow past a vertical porous plate through a porous medium with suction and heat source for Newtonian fluid has been analyzed by Das *et al.* [13]. Das *et al.* [14] have also studied the mass transfer effects on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source.
The mechanism of visco- elastic fluid flows in modern technology have generated considerable interest in view of their applications in various manufacturing processes. Authors like Asghar *et al.* [15], Hayat *et al.* [16]. Krishna *et al.*

[17] ,Choudhury and Mohanta [18,19] ,Choudhury and Dey [20] ,Choudhury and Das [21,22,23,24] etc have analyzed some problems of physical interest in this field.

The object of this study is to investigate the visco-elastic effects of free convective flow past through porous medium bounded by an oscillating porous plate in presence of transverse magnetic field. The effects of heat and mass transfer are also considered. In this paper, visco-elastic fluid flow is characterized by Second –order fluid model.

The constitutive equation of the second order fluid model is

$$\sigma_{ij} = -p\delta_{ij} + \mu_1 A_{(1)ij} + \mu_2 A_{(2)ij} + \mu_3 A_{(1)i,\alpha} A_{(1),j}^{\alpha}$$
$$A_{(1)ij} = v_{i,j} + v_{j,i}$$
$$A_{(2)ij} = a_{i,j} + a_{j,i} + 2v_{m,i} v^{m}_{,j} \qquad (1)$$
$$a_i = \frac{\partial v_i}{\partial t} + v_j v_{i,j}$$

where σ_{ij} is the stress tensor, p is isotropic pressure, δ_{ij} is the Kronakar delta , μ_1, μ_2, μ_3 are material constants and $\mu_2 < 0, \mu_1, \mu_3 > 0$

II. MATHEMATICAL FORMULATION

Consider the free convective electrically conducting second-order fluid bounded by a oscillating porous plate through porous medium in the slip flow regime .The magnetic field B_0 is applied in the transverse direction in the plate and pressure in the flow field is assumed to be constant. The magnetic Reynolds number is taken so small that the induced magnetic field on account of flow is neglected. Here we choose $\bar{x}$ -axis along the porous plate and $\bar{y}$- axis is normal to it. Let u and v be the components of velocity in $\bar{x}$ and $\bar{y}$ directions respectively. If suction/injection velocity is denoted by v_0 , the equation governing equations of motion are given as follows:

The equation of continuity:

$$\frac{\partial \bar{v}}{\partial \bar{y}} = 0 \qquad (2)$$

under the condition

$$\bar{v} = \bar{v}_0\left(1 + \varepsilon e^{i\overline{wt}}\right)$$

The momentum equation:

$$\frac{\partial \bar{u}}{\partial \bar{t}} - \bar{v}_0\left(1 + \varepsilon e^{i\bar{\omega}\bar{t}}\right)\frac{\partial \bar{u}}{\partial \bar{y}} = \nu_1 \frac{\partial^2 \bar{u}}{\partial \bar{y}^2} + \nu_2\left(\frac{\partial^3 \bar{u}}{\partial \bar{t}\,\partial \bar{y}^2} - \bar{v}_0\left(1 + \varepsilon e^{i\bar{\omega}\bar{t}}\right)\frac{\partial^3 \bar{u}}{\partial \bar{y}^3}\right) + g\beta(\bar{T} - \bar{T}_\infty) + g\beta^*(\bar{C} - \bar{C}_\infty) - \frac{\nu_1}{K_p}\bar{u} - \frac{\sigma B_0}{\rho}$$
(3)

The energy equation:

$$\frac{\partial \bar{T}}{\partial \bar{t}} - \bar{v}_0\left(1 + \varepsilon e^{i\bar{\omega}\bar{t}}\right)\frac{\partial \bar{T}}{\partial \bar{y}} = k\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} + S(\bar{T} - \bar{T}_\infty)$$
(4)

The concentration equation:

$$\frac{\partial \bar{C}}{\partial \bar{t}} - \bar{v}_0\left(1 + \varepsilon e^{i\bar{\omega}\bar{t}}\right)\frac{\partial \bar{C}}{\partial \bar{y}} = \frac{1}{D}\frac{\partial^2 \bar{C}}{\partial \bar{y}^2} \qquad (5)$$

Here $\nu = \frac{\mu_i}{\rho}$

The relevant boundary conditions are:

$$\bar{y} = 0: \bar{u} = U_0 \varepsilon e^{i\bar{\omega}\bar{t}} + L_1\frac{\partial \bar{u}}{\partial \bar{y}}, \bar{T} = \bar{T}_\infty, \bar{C} = \bar{C}_\infty \qquad (6)$$

$$\bar{y} \to \infty: \bar{u} = 0, \bar{T} \to \bar{T}_\infty, \bar{C} \to \bar{C}_\infty$$

where $L = \mu\left(\frac{pi}{2p\rho}\right)^{\frac{1}{2}}$ and $L_1 = \frac{(2-m)}{m}L$ is the mean free path and m is the Maxwell's reflexion coefficient.

We introduce the following dimensionless quantities:

$$y = U_0 \frac{\bar{y}}{\nu_1}, u = \frac{\bar{u}}{U_0}, T = \frac{\bar{T}-\bar{T}_\infty}{\bar{T}_w-\bar{T}_\infty}, C = \frac{\bar{C}-\bar{C}_\infty}{\bar{C}_w-\bar{C}_\infty}, M = \frac{B_0}{U_0}\left(\frac{\nu_1\sigma}{\rho}\right), S = \frac{\nu_1\bar{S}}{U_0^2}, t = U_0^2\frac{\bar{t}}{\nu_1}, \omega = \frac{\bar{\omega}\nu_1}{U_0^2}$$

$$P_r = \frac{\nu_1}{k}, K_p = \frac{K_0 U_0^2}{\nu_1}, G_r = \nu_1 g\beta\frac{\bar{T}_w-\bar{T}_\infty}{U_0^3}, G_m = \nu_1 g\beta^*\frac{(\bar{C}_w-\bar{C}_\infty)}{U_0^3}, S_c = \frac{\nu_1}{D} \quad (7)$$

in the equations (5), (6) and (7) and obtain the equations:

$$\frac{\partial u}{\partial t} - v_0(1+\varepsilon e^{i\omega t})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + \alpha\left(\frac{\partial^3 u}{\partial t\,\partial y^2} - v_0(1+\varepsilon e^{i\omega t})\frac{\partial^3 u}{\partial y^3}\right) + G_r T + G_m C - \left(M^2 + \frac{1}{K_p}\right)u \quad (8)$$

$$\frac{\partial T}{\partial t} - v_0(1+\varepsilon e^{i\omega t})\frac{\partial T}{\partial y} = \frac{1}{P_r}\frac{\partial^2 T}{\partial y^2} + ST \quad (9)$$

$$\frac{\partial C}{\partial t} - v_0(1+\varepsilon e^{i\omega t})\frac{\partial C}{\partial y} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} \quad (10)$$

The modified boundary conditions are:

$$y = 0: u = \varepsilon e^{i\omega t} + R\frac{\partial u}{\partial y}, T = 1, C = 1 \quad (11)$$

$$y \to \infty: u \to 0, T \to 0, C \to 0$$

where P_r is the Prandtl number , R is the rarefaction parameter ,K_p is the permeability parameter , G_r is the Grashof number for heat transfer , G_m is the Grashof number for mass transfer , M is the magnetic parameter , S is the heat source parameter, v_0 is the suction velocity, Sc is the Schmidt number and α is the visco-elastic parameter .

III. METHOD OF SOLUTION

The equations (8), (9) and (10) are to be solved subject to the boundary conditions (11). To solve these equations we make the following substitution for the non-dimensional velocity, temperature and concentration of the flow field for $\varepsilon \ll 1$, as follows

$$u(y,t) = u_0(y) + \varepsilon e^{i\omega t}u_1(y) \quad (12)$$

$$T(y,t) = T(y) + \varepsilon e^{i\omega t}T_1(y) \quad (13)$$

$$C(y,t) = C_0(y) + \varepsilon e^{i\omega t}C_1(y) \quad (14)$$

Substituting (12) to (14) in the equations (8) to (9) and equating the co-efficient of like powers of ε and neglecting ε^2 and higher powers we get the following differential equations:

$$u_0'' + v_0 u_0' - \alpha v_0 u_0''' - \left(M^2 + \frac{1}{K_p}\right)u_0 = -G_r T_0 - G_m C_0 \quad (15)$$

$$u_1'' + i\alpha\omega u_1'' - \alpha v_0 u_0''' - \alpha v_0 u_1''' + v_0 u_1' - \left(M^2 + \frac{1}{K_p} + i\omega\right)u_1 = -G_r T_1 - G_m C_1 \quad (16)$$

$$T_0'' + v_0 P_r T_0' + S P_r T_0 = 0 \quad (17)$$

$$T_1'' + v_0 P_r T_0' + v_0 P_r T_1' + (S - i\omega)T_0 = 0 \quad (18)$$

$$C_0'' + v_0 S_c C_0' = 0$$

$$C_1'' + v_0 S_c C_1' - S_c i\omega C_1 + v_0 S_c C_0' = 0 \quad (20)$$

The corresponding boundary conditions are:

$$y = 0: u_0 = R\frac{\partial u_0}{\partial y}, u_1 = 1 + R\frac{\partial u_1}{\partial y}, T_0 = 1, T_1 = 0, C_0 = 1, C_1 = 0 \quad (21)$$

$$y \to \infty: u_0 \to 0, u_1 \to 0, T_0 \to 0, T_1 \to 0, C_0 \to 0, C_1 \to 0$$

where dash denotes differentiation with respect to y.

The equations (18) and (19) are still coupled .to solve them, we note that $\alpha \ll 1$ for small shear rate and we assume that

$$u_0 = u_{00} + \alpha u_{01} \quad (22)$$

$$u_1 = u_{10} + \alpha u_{11}$$

(23)

Using (22) and (23) in the equations (18) and (19) and by equating the coefficients of like powers of α and also neglecting those of α^2 we obtain the following equations;

$$u_{00}'' + v_0 u_{00}' - \left(M^2 + \frac{1}{K_p}\right) u_{00} = -G_r T_0 - G_m C_0$$

(24)

$$u_{01}'' + v_0 u_{01}' - v_0 u_{00}''' - \left(M^2 + \frac{1}{K_p}\right) = 0$$

(25)

$$u_{10}'' + v_0 u_{10}' - \left(M^2 + \frac{1}{K_p} + i\omega\right) u_{00} = -G_r T_0 - G_m C_0 - v_0 u_{00}'$$

(26)

$$u_{11}'' + i\omega u_{10}'' - v_0 u_{00}' - u_{10}''' + v_0 u_{11}' + v_0 u_{01}' - \left(M^2 + \frac{1}{K_p} + i\omega\right) u_{11} \quad (27)$$

with relevant boundary conditions:

$$y = 0: u_{00} = R\frac{\partial u_{00}}{\partial y}, u_{01} = R\frac{\partial u_{00}}{\partial y}, u_{10} = 1 + R\frac{\partial u_{10}}{\partial y}, u_{11} = R\frac{\partial u_{11}}{\partial y} \quad (28)$$

$$y \to \infty: u_{00} \to 0, u_{01} \to 0, , u_{10} \to 0\ , , u_{11} \to 0$$

Solving the equations (15) to (17) and (24)-(27) under the boundary conditions (28), we obtain the following solutions:

$$T_0 = e^{-m_1 y} \quad (29)$$

$$T_1 = B_1 e^{-m_2 y} - B_1 e^{-m_1 y} \quad (30)$$

$$C_0 = e^{-S_c v_0 y} \quad (31)$$

$$C_1 = A_1 e^{-m_3 y} - A_1 e^{-S_c v_0 y} \quad (32)$$

$$u_{00} = A_4 e^{-m_4 y} - A_2 e^{-m_1 y} - A_3 e^{-S_c v_0 y} \quad (33)$$

$$u_{01} = A_7 e^{-m_4 y} + A_8 y e^{-m_4 y} - A_5 e^{-m_1 y} - A_6 e^{-S_c v_0 y} \quad (34)$$

$$u_{10} = A_{10} e^{-m_5 y} - A_{12} e^{-m_2 y} + A_{13} e^{-m_1 y} - A_{14} e^{-m_4 y} - A_{15} e^{-m_3 y} + A_{18} e^{-S_c v_0 y} \quad (35)$$

$$u_{11} = A_{31} e^{-m_5 y} + A_{25} y e^{-m_5 y} + A_{26} e^{-m_4 y} + A_{27} e^{-m_3 y} + A_{28} e^{-m_2 y} + A_{29} e^{-m_1 y} + A_{30} e^{-S_c v_0 y} + A_{33} y^2 e^{-m_4 y} + A_{34} y e^{-m_4 y} \quad (36)$$

Thus the respective velocity, temperature and concentration are given by

$$u = D_1 e^{-m_4 y} + D_0 y e^{-m_4 y} - D_2 e^{-m_1 y} - D_3 e^{-S_c v_0 y} + \varepsilon e^{-i\omega t}(D_4 e^{-m_5 y} - D_5 e^{-m_2 y} - D_6 e^{-m_3 y} - D_7 e^{-m_2 y} +$$
D8e−m1y+ D9e−Scv0y+D10ye−m5y+D12ye−m4y+D11y2e−m4y (37)

$$T = e^{-m_1 y} + \varepsilon e^{i\omega t}(B_1 e^{-m_2 y} - B_1 e^{-m_1 y}) \quad (38)$$

$$C = e^{-S_c v_0 y} + \varepsilon e^{i\omega t}(A_1 e^{-m_3 y} - A_1 e^{-S_c v_0 y}) \quad (39)$$

The non dimensional shearing stress σ at the plate (y=0) is given by

$$\sigma = E_1 + \varepsilon e^{i\omega t} E_2 - v_0(1 + \varepsilon e^{i\omega t}) E_3 \quad (40)$$

Again, the non –dimensional heat flux coefficient at the plate in terms of Nusselt number Nu is given by

$$Nu = \left(\frac{\partial T}{\partial y}\right)_{y=0} = m_1 + \varepsilon e^{i\omega t}(B_1 m_2 - B_1 m_1) \quad (41)$$

The mass transfer coefficient in terms of Sherwood number Sh is given by

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = -S_c v_0 + \varepsilon e^{i\omega t}(A_1 S_c v_0 - A_1 m_3) \quad (42)$$

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The constants are obtained but not given here for the sake of brevity.

IV. DISCUSSION OF THE RESULTS

The objective of this paper is to bring out the effects of visco-elastic parameter α on the hydromagnetic oscillatory porous plate in presence of heat source .The visco-elastic effect is explained through the non dimensional parameter α .The non zero values of the parameter α characterized the visco-elastic fluid and α=0 represents the Newtonian fluid flow phenomenon . Also the real part is implied throughout the problem.

In order to get physical insight into the problem the velocity field, temperature field, shearing stress, the rate of heat transfer and the rate of mass transfer have been obtained numerically for various combinations of flow parameters involved in the problem

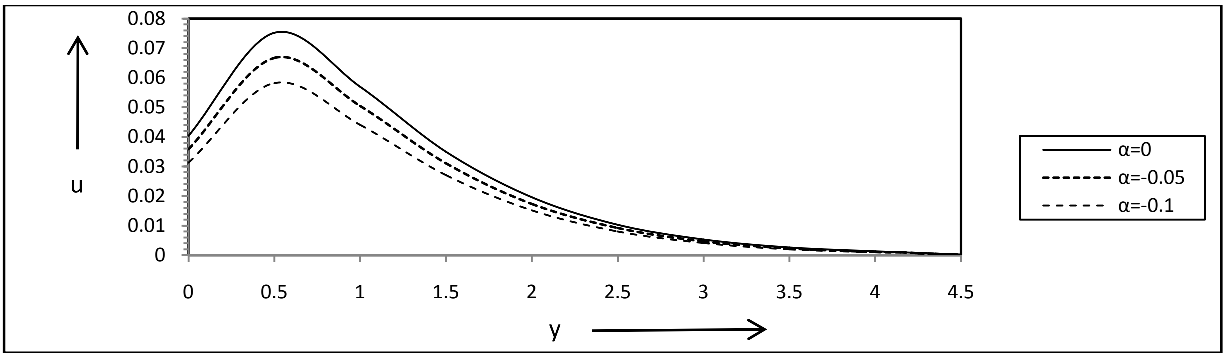

Fig 1: Fluid velocity u against y for S=0.5

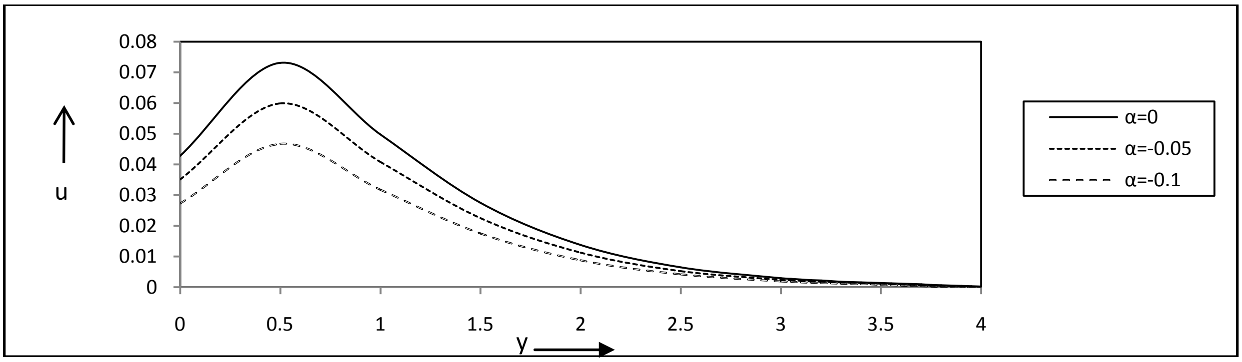

Fig 2: Fluid velocity against y for S= -0.5

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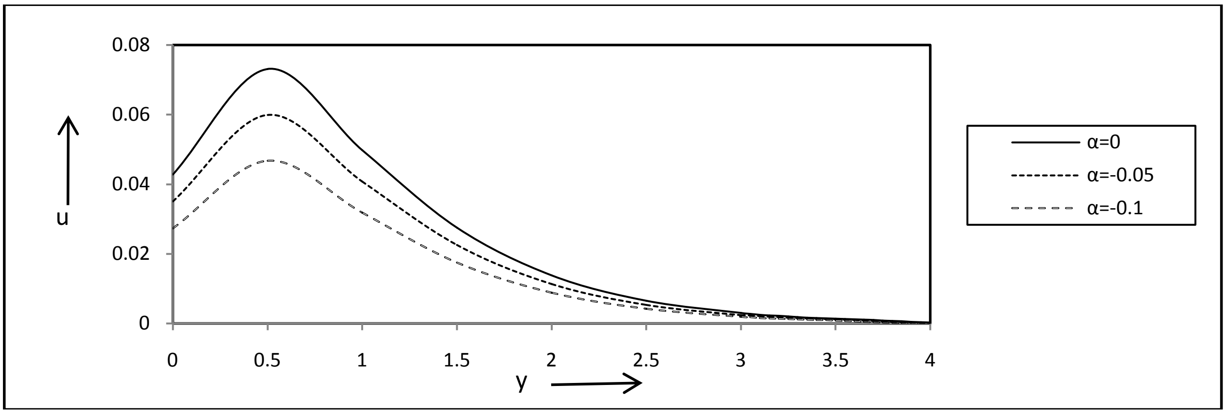

Fig 3: Fluid velocity u against y for M=0.5

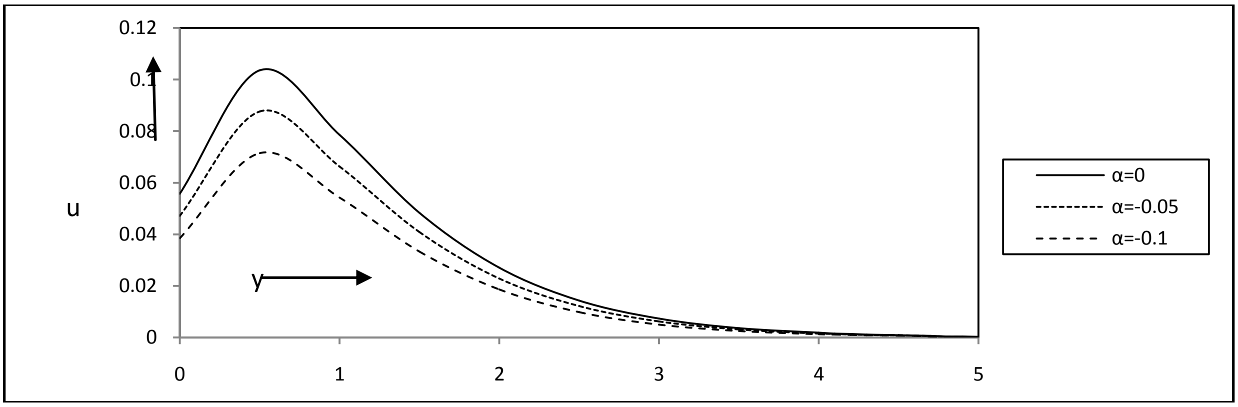

Fig 4: Fluid velocity u against y for M=2

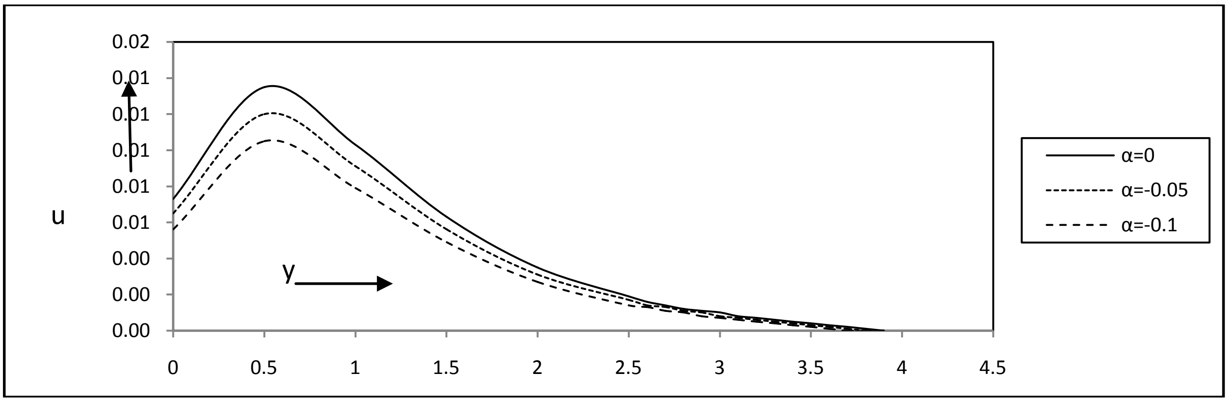

Fig 5: Fluid velocity u against y for Gr=0.9

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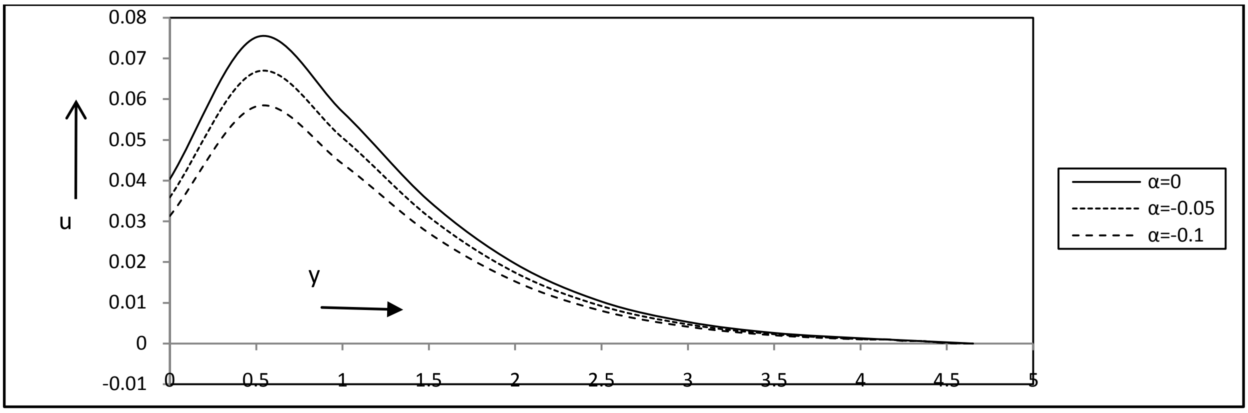

Fig 6: Fluid velocity u against y for Gr=0.5

The figure 1-6 depict the behavior of the fluid velocity u against y under the influence of different velocity of heat source parameter S (=.5,-.5) , Magnetic parameter M(=.5 ,2) and Grashof number for heat transfer Gr(=.5 ,.9) and fixed values Grashof number for Mass transfer Gm(=.5) ,permeability parameter Kp(=2) Rarefaction parameter R(=0.2), Prandtl number Pr(=0.8), schmidth number Sc(=4),ε=.02 , $\omega t = \frac{\pi}{2}$, $\omega = 2$.

These figures indicate that the fluid velocity exhibits decelerating trends throughout the fluid region under consideration with the growing effect of the absolute value of visco-elastic parameter |α| (α=0, - 0. 05,-0.1) and reveal rising effect against y up to y=0.5 and then begin to decelerate in both Newtonian and non-Newtonian cases . The variations of the heat source parameter S(fig. 1,2) or the magnetic parameter (fig. 3,4) or the Grashof number for heat transfer (fig. 5,6) do not change the pattern of the profiles .

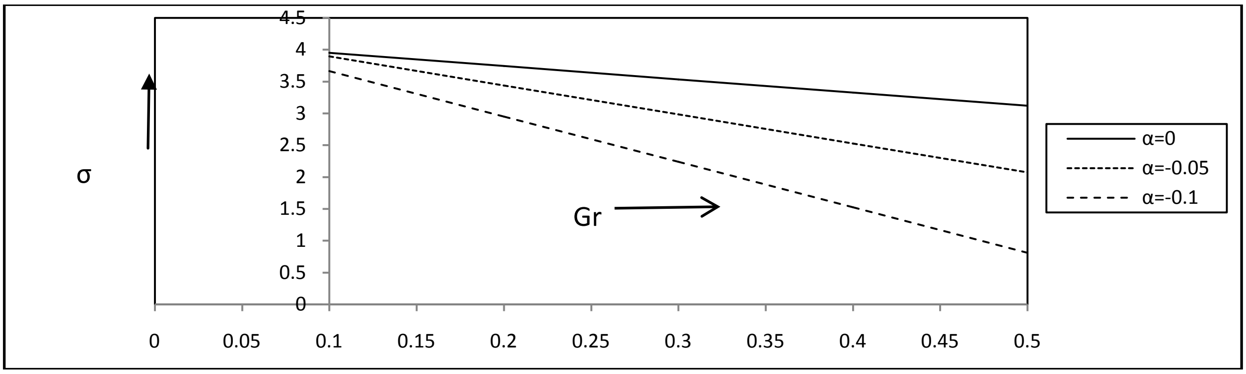

Fig 7: Shearing stress against Grashof number

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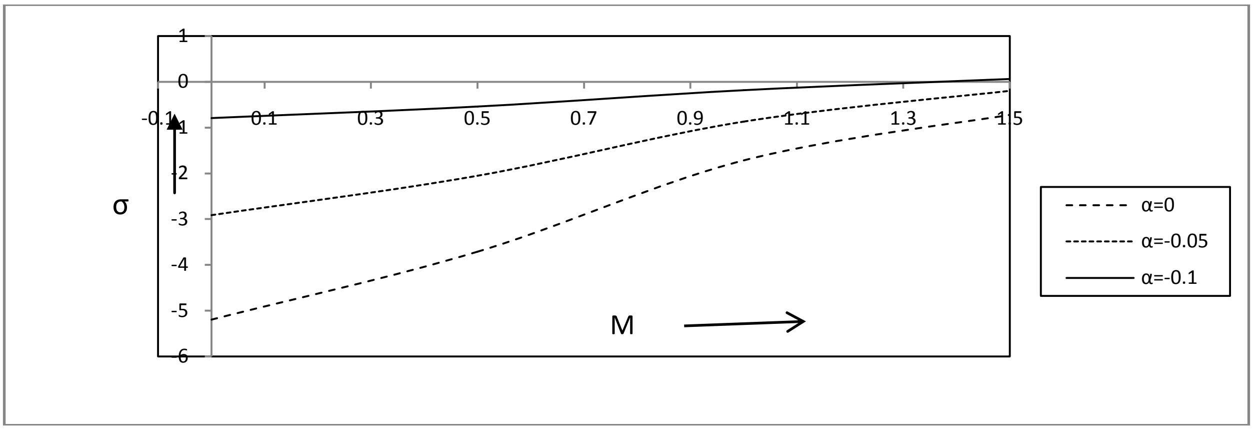

Fig 8: Shearing stress against Magnetic parameter

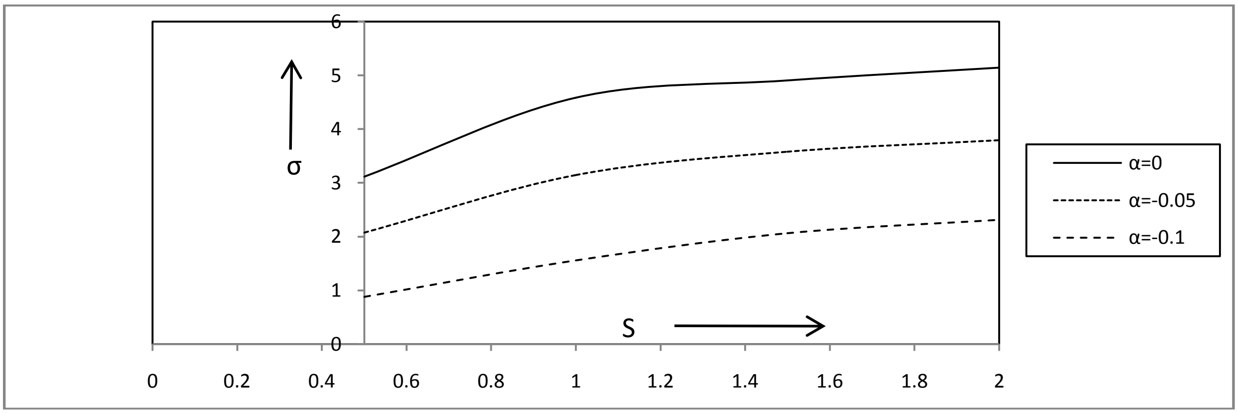

Fig 9: Shearing stress against Heat source parameter

The shearing stress σ against the Grashof number Gr for externally cooled plate (Gr>0) is illustrated in the figure 7. It is noticed from the figure that the shearing stress shows a decelerating trend in both Newtonian and non-Newtonian cases for increasing values of Gr. Also the growth of visco-elastic parameter | α| represent decelerating pattern in comparison with Newtonian fluid (α=0).

The effects of magnetic parameter M with visco-elasticity have been represented in the figure 8.The figure shows that the enhancement of | α| diminishes the shearing stress in the fluid flow region with the rising values of the magnetic parameter.

The behavior of the shearing stress against the heat source parameter S is demonstrated in the figure 9. The increasing values of heat source parameter S reveals that the shearing stress accelerate in both Newtonian and non –Newtonian cases. Again σ diminishes under the influence of | α| in comparison with Newtonian fluid.

It is also noted that the rate of heat transfer in the form of Nusselt number and the rate of mass transfer in the form of Sherwood number are not significantly affected by the non –zero values of α.

V. CONCLUSION

An analysis of visco-elastic effects on MHD free convective flow past an oscillating porous plate in presence of heat source and mass transfer has been presented. From this study we make the following conclusions.

- The velocity field is significantly affected at every point of the fluid flow region by the visco-elastic parameter.
- The rising trend of the absolute value of visco – elastic parameter decelerates fluid velocity of the flow field at all points.

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- The shearing stress experiences a decreasing trend with the amplified magnitude of Grashof number but reverse pattern is observed for magnetic parameter and heat source parameter in both Newtonian and non-Newtonian cases.
- The temperature and concentration fields are not significantly affected by the non-Newtonian parameter.

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