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RESEARCH ARTICLE

RADIATION AND THERMAL DIFFUSION EFFECTS ON VISCO-ELASTIC FLUID PAST A POROUS PLATE WITH CHEMICAL REACTION AND HEAT GENERATION

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Abstract

A free convective two dimensional MHD boundary layer flow of a non-Newtonian (visco-elastic) fluid past a vertical porous plate have been thoroughly researched in this paper. The thermal diffusion Effects are also analyzed in presence of chemical reaction and radiation. A steady suction pressure is maintained at the plate. A singular perturbation method has been used to solve the problem. The analytical results are obtained for different values of the various dimensionless parameters entering into the flow problem and discussed quantitatively.

Introduction:-

Visco-elastic flow problems have considerable significance in both theoretical and experimental studies as they have numerous applications across various areas like polymer processing (extrusion, injection molding) coating and thin film processes (paints, adhesives), cooling of nuclear reactors, in food processing, in waste water treatment etc. A few illustrative areas of interest in which MHD visco-elastic fluid combined with heat and mass transfer play a vital role in biological and medical industries like in cardio-vascular disease modeling, cancer research viz., metastasis, tumor growth revealing, in wound healing and tissue repair etc. These applications exhibit the significance of visco-elastic fluid flow problems in understanding and solving various challenges of real world.

The behavior of the flow pattern of a first order chemical reaction in the neighborhood of a plate has been analyzed by Chambre and Young (1958). Cussler (1988) has generalized the importance of diffusion-thermo effects for various fluid flow phenomenons. The idea of natural convection flow through a porous medium in presence of radiation has been investigated by Raptis (1998).

Makinde (2005) has investigated free convection flow with thermal radiation and mass transfer past a moving vertical porous plate. Saxena and Dubey (2011) have analyzed the flow behavior of unsteady MHD heat and mass transfer free convection flow of a polar fluid past a vertical moving porous plate in a porous medium with heat generation and thermal diffusion. Kumar et al. (2012) have studied the thermal diffusion and radiation effects on unsteady MHD flow through porous medium with variable temperature and mass diffusion in the presence of heat source/sink. Diffusion thermo effects of visco-elastic fluid past a porous surface in presence of magnetic field and radiation has been examined by Choudhury et al. (2013). Visco-Elastic MHD boundary layer flow with heat and mass transfer over a continuously moving inclined surface in presence of energy dissipation has been analyzed by Choudhury et al. (2013). Das (2014) has investigated the visco-elastic effects on unsteady MHD free convection and mass transfer for visco-elastic fluid flow past a hot vertical porous plate with heat generation/ absorption through porous medium. Choudhury and Dhar (2014) have studied the effects of MHD visco-elastic fluid flow past a moving

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plate with double diffusive convection in presence of heat generation. Magneto -hydrodynamic boundary layer flow with Soret/Dufour effects in presence of heat source and chemical reaction has been studied by Das and Dorjee (2019). Mahato et al. (2020) has examined the Hall effect on MHD transient free convection flow of chemically reactive Casson fluid with heat source/sink past an infinite vertical cylinder. Three-dimensional flow past a porous vertical plate in a porous medium with sinusoidal suction and permeability in the presence of thermal diffusion has been studied by Ahmed et al. (2021). Islam et al. (2021) have generalized the Dufour effect on MHD free convection heat and mass transfer effects flow over an inclined plate embedded in a porous medium. Chiranjeevi et al. (2021) have investigated radiation absorption on MHD free convective laminar flow over a moving vertical porous plate, viscous dissipation and chemical reaction with suction under the influence of transverses magnetic field. MHD free convection from a semi-infinite vertical porous plate with Diffusion-thermo effect has been studied by Bordoloi and Ahmed (2022).

The objective of this paper is to investigate thermal diffusion and radiation effects on hydromagnetic visco-elastic fluid past a vertical porous plate with first order chemical reaction and heat generation. The solutions for velocity, temperature and concentration fields are obtained subject to relevant boundary conditions and discussed graphically.

Mathematical Formulation

An investigation of two dimensional MHD free convective visco-elastic fluid past a porous surface has been examined in presence of radiation and Dufour effect along with chemical reaction. It is assumed that the plate is maintained at a constant suction pressure. A uniform magnetic field of strength B_0 is applied in the lateral direction to the plate. In this paper, we have incorporated the simultaneous heat and mass transfer fluid flow mechanisms in connection with heat generation. Assume that $x^{/}$- axis be taken along the plate in the vertically upward direction and $y^{/}$-axis be taken along the normal to the plate. Then using Boussinesq approximation, the governing equations of motion are as follows:

Equation of continuity:

$$\frac{\partial v'}{\partial y'} = 0 \qquad (1)$$

Equation of momentum:

$$v'\frac{\partial u'}{\partial y'} = g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) + \frac{\eta_0}{\rho}\frac{\partial^2 u'}{\partial y'^2} - \frac{k_0 v'}{\rho}\frac{\partial^3 u'}{\partial y'^3} - \frac{\sigma B_0^2 u'}{\rho} \qquad (2)$$

Energy equation:

$$\rho C_p\left(v'\frac{\partial T'}{\partial y'}\right) = k_T\left(\frac{\partial^2 T'}{\partial y'^2}\right) - \frac{\partial q_r}{\partial y'} + \left[\rho\frac{D_m K_T}{C_s}\frac{\partial^2 C'}{\partial y'^2}\right] + Q_0(T' - T'_\infty) \qquad (3)$$

Concentration equation:

$$v'\frac{\partial C'}{\partial y'} = D\left(\frac{\partial^2 C'}{\partial y'^2}\right) - K_r(C' - C'_\infty) \qquad (4)$$

The relevant boundary conditions are as follows:

$$y' = 0 : u' = U,\ v' = -v_0 = \text{constant},\ T' = T'_w,\ C' = C'_\infty$$
$$y' \to \infty : u' \to 0,\quad T' \to T'_\infty,\quad C' \to C'_\infty \qquad (5)$$

We exhibit the following non-dimensional quantities:

$$u = \frac{u'}{U},\ y = \frac{y'U}{\nu},\ \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty},\ \phi = \frac{C' - C'_\infty}{C'_w - C'_\infty},\ \lambda = \frac{v_0}{U},\ M = \frac{\sigma B_0^2 \nu}{\rho U^2}$$

$$Gr = \frac{\nu g\beta(T'_w - T'_\infty)}{U^3},\ Gm = \frac{\nu g\beta^*(C'_w - C'_\infty)}{U^3},\ Pr = \frac{\eta_0 C_p}{K_T},\ \gamma = \frac{\nu K_r}{U^2}$$

$$Sc = \frac{\nu}{D},\ R = \frac{16a^*\nu^2\sigma {T'_\infty}^3}{k_T U^2},\ k = \frac{k_0 U^2}{\rho\nu^2},\ Du = \frac{D_m K_T(C'_w - C'_\infty)}{C_s C_p \nu(T'_w - T'_\infty)},\ Q = \frac{\nu Q_0}{\rho {V_0}^2 C_p}$$

where k is the visco-elastic parameter, Pr is the Prandtl number, Du is the coefficient of mass diffusivity, Gr is the thermal Grashof number, Gm is the solutal Grashof number, M is the Hartmann number, Sc is the Schmidt number and, R is the radiation parameter, γ is the chemical reaction parameter.

The transformed non-dimensional governing equations of motion (2) to (4) are

$$k\frac{d^3u}{dy^3} + \frac{1}{\lambda}\frac{d^2u}{dy^2} + \frac{du}{dy} + \frac{Mu}{\lambda} = -\left(\frac{Gr\,\theta + Gm\,\phi}{\lambda}\right) \qquad (6)$$

$$\frac{d^2\theta}{dy^2} + \lambda Pr\frac{d\theta}{dy} - (R + Pr.Q)\theta = -Pr.Du\frac{d^2\phi}{dy^2} \quad (7)$$

$$\frac{d^2\phi}{dy^2} + Sc.\lambda\frac{d\phi}{dy} = \gamma.Sc.\phi \quad (8)$$

subject to the boundary conditions:

$y = 0: \quad u = 1, \theta = 1, \phi = 1$

$y \to \infty: \ u \to 0, \ \theta \to 0, \ \phi \to 0$ (9)

Method of Solution:-

The equations (7) and (8) are linear ordinary differential equations of 2nd order and can be easily solvable. The solutions of the equations (7) and (8) are given by

$\theta = C_4 e^{-\beta_4 y} + (1 - C_4)e^{-\beta_2 y}$

$\phi = e^{-\beta_2 y}$

To solve the equation (6), we bring into play the perturbation technique considering k (visco-elastic parameter) as the perturbation parameter as $k \ll 1$ for small shear rate. Consider that the solution of the equation (6) subject to the boundary conditions is of the form

$u = u_0 + ku_1 + o(k^2)$ (10)

Using (10) in the equation (6) and equating the coefficients of like terms of k and neglecting the higher order terms we get, zeroth and first order equations as follows:

$\frac{1}{\lambda}u_0'' + u_0' + \frac{M}{\lambda}u_0 = -\left(\frac{Gr\theta + Gm\phi}{\lambda}\right)$ (11)

$\frac{1}{\lambda}u_1'' + u_1' + \frac{M}{\lambda}u_1 = -u_0'''$ (12)

the transformed boundary conditions are:

$y = 0; \ u_0 = 1, \ \ u_1 = 0$

$y \to \infty; \ u_0 = 0, \ \ u_1 = 0$ (13)

Now the equations (11) and (12) are linear ordinary differential equation which can be easily solvable. Solving the equations (11) and (12) under the boundary condition (13), we get

$u_0 = C_8 e^{-\beta_6 y} + C_9 e^{-\beta_4 y} + (C_{10} + C_{11})e^{-\beta_2 y}$

$u_1 = C_{18} e^{-\beta_4 y} + C_{19} e^{-\beta_2 y} - (C_{18} + C_{19})e^{-\beta_6 y}$

Using the value of u_0, u_1 in (10), we get the velocity of fluid

$u = C_8 e^{-\beta_6 y} + C_9 e^{-\beta_4 y} + C_{20} e^{-\beta_2 y} + k\left(C_{18} e^{-\beta_4 y} + C_{19} e^{-\beta_2 y} - C_{21} e^{-\beta_6 y}\right)$

The shearing stress or viscous drag near the plate in the direction of free stream is given by

$$\tau = \frac{\tau'}{\rho U^2} = [\boldsymbol{u}' + \boldsymbol{k\lambda u}'']_{at\ y=0}$$

$$= -\beta_6 C_8 - \beta_4 C_9 - \beta_2 C_{20} + k(-\beta_4 C_{18} - \beta_2 C_{19} + \beta_6 C_{21}) + k\lambda(\beta_6^2 C_8 + \beta_4^2 C_9 + \beta_2^2 C_{20})$$

The Nusselt number i.e., heat flux from the plate to the fluid is given by

$Nu = (\theta')_{at\ y=0} = -(\beta_4 C_4 + \beta_2 - \beta_2 C_4)$

The mass flux at the wall in terms of Sherwood number is given by

$Sh = (\phi')_{at\ y=0} = -\beta_2$

For the sake of brevity, the constants of the solution are not given here.

Results and Discussions:-

The study of two-dimensional free convective MHD visco-elastic fluid past a vertical porous surface in presence of thermal radiation, chemical reaction and Dufour effect has been investigated in this chapter. The visco-elastic effect is incorporated through the dimension less parameter k. Figures 1 to 3 illustrate the fluid velocity for two values of visco-elastic parameter i.e., k=0 and k=0.1 along with the combination of other flow parameters involved in the problem. The figures exhibit that in case of externally heated plate (Gr < 0), the fluid velocity boost significantly nearer to the plate but in case of externally cooled plate (Gr > 0), the fluid velocity decreases as it deviates from the plate. The physical significance of higher viscosity in the vicinity of the surface has been observed in both

Newtonian fluid (k = 0) and non-Newtonian fluid (k = 0.1). For externally cooled plate (Gr>0), the amplified values of visco-elastic parameter enhance the velocity of non-Newtonian fluid corresponding to the Newtonian fluid but an invert behavior has been observed for the fluid past an externally heated plate (Gr<0).

Figure (1) signifies the behavior of flow patterns in both Gr>0 and Gr<0 values of thermal Grashof number. In case of Gr>0, the speed of fluid traced out a parabolic curve but in case of Gr<0, a reverse flow is observed for $k \leq 0.1$. In figure (2), we observed that the effect of Magnetic parameter (M) on the velocity profile. For externally cooled plate i.e., for Gr>0, the decreasing nature of fluid flow pattern is noticed in both Newtonian as well as non-Newtonian fluid. In thermodynamics, The Dufour effect is a phenomenon specifically in heat and mass transfer flow problems. The Dufour effect, describes the diffusion of matter caused by a temperature gradient in a mixture of gases or liquids. The Dufour effect is denoted through the parameter Du. Figure (3), reveals the effect of Dufour number (Du) on the fluid velocity profile. The increasing values of Du enhanced the fluid velocity of both Newtonian and Non-Newtonian fluids in accordance with the raising values of visco-elastic parameter k.

Shearing stress or viscous drag has much more practical importance in various areas like industry, medical science, engineering etc. Figures (4) to (6) explain the behavior of shearing stress formed near the cooled surface for various values of k , i.e., k =0, k=0.1 and k=0.2. The increasing values of visco-elastic parameter make the fluid thicker and hence the shearing stress will be higher in Non-Newtonian fluid in comparison with Newtonian fluid. Figure (4) and figure (5) illustrate the nature of shearing stress experienced by both Newtonian and Non-Newtonian (visco-elastic) fluid against Dufour number and Prandtl number respectively. In both the cases, increasing values of Dufour number and Prandtl number enhanced the magnitude of shearing stress along with the raising values of k. Figure (6) shows the effect of chemical reaction parameter on the shearing stress. It is observed that during the growth of chemical reaction parameter γ, the magnitude of shearing stress decelerate at the vicinity of the wall of externally cooled surface (Gr>0). Visco-elastic parameter does not affect the rate of heat transfer (Nusselt number) and the rate of mass transfer (Sherwood number) significantly.

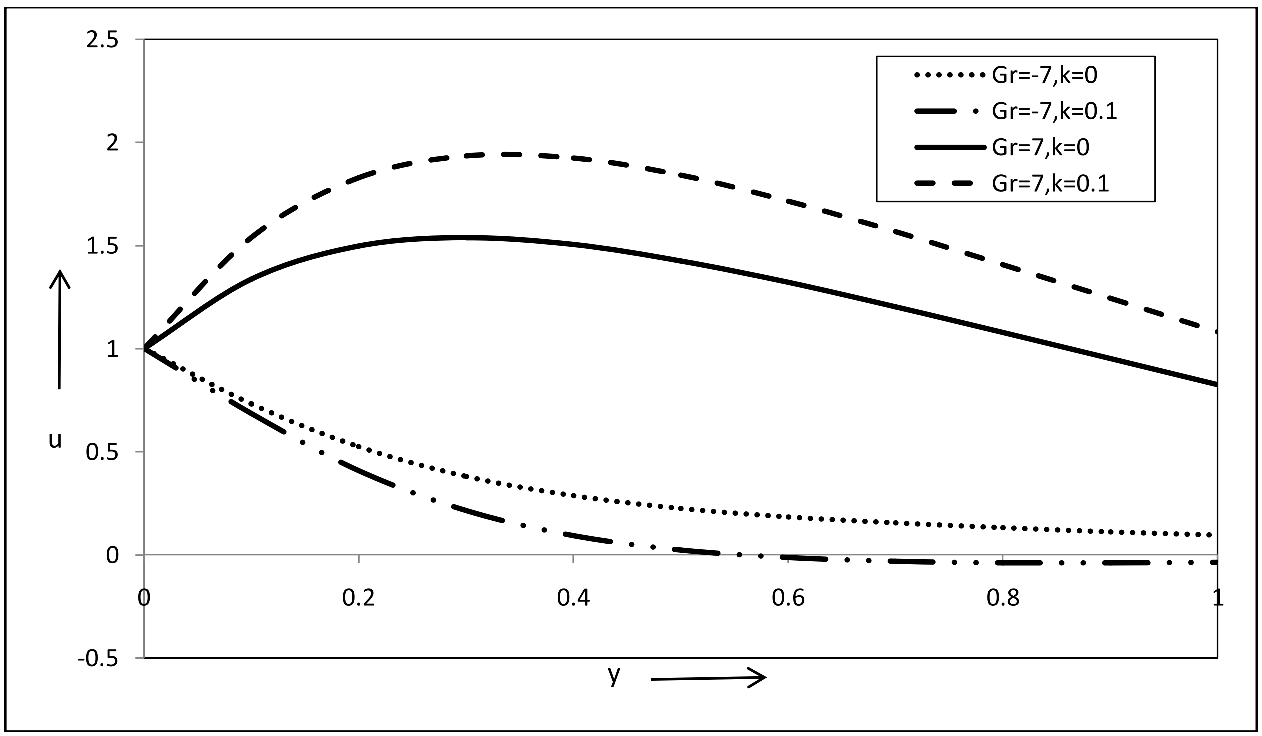

Figure 1:- Velocity u against y for M=1, Gm=10, Sc=5, γ=1, Du=0.5, R=10, Pr=5

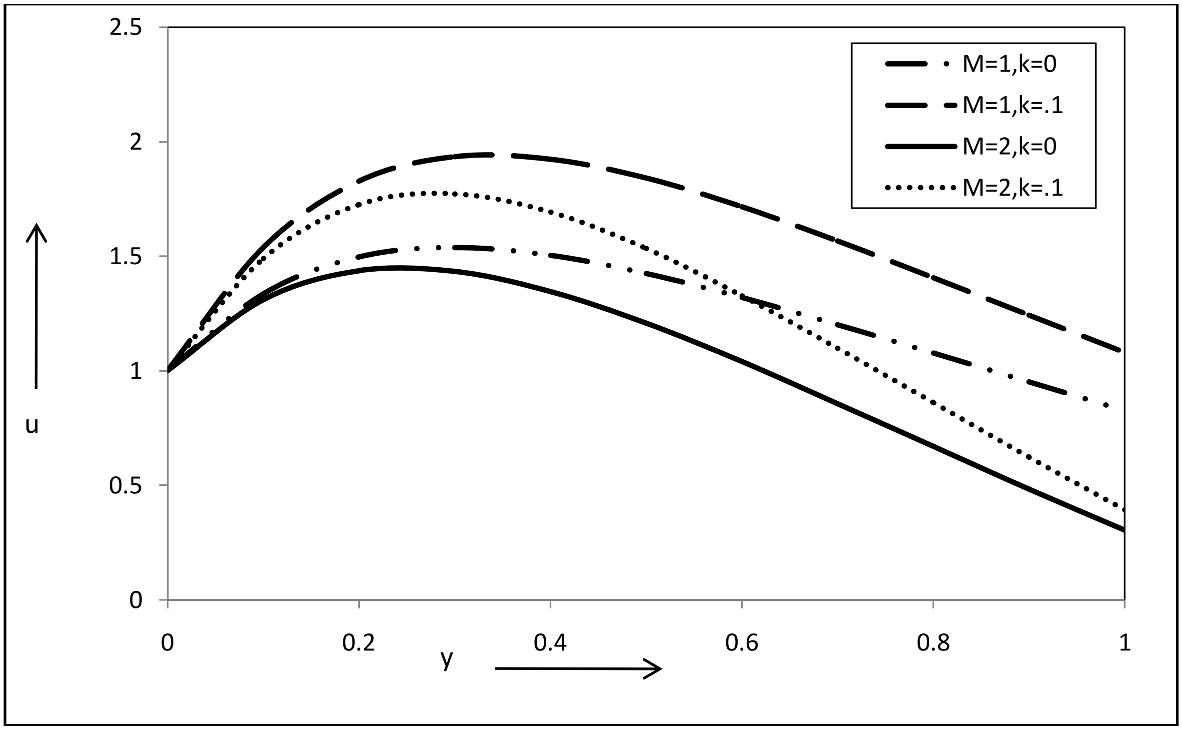

Figure 2:- Velocity u against y for Gr=7, Gm=10, Sc=5
γ=1, Du=0.5, R=10, Pr=5

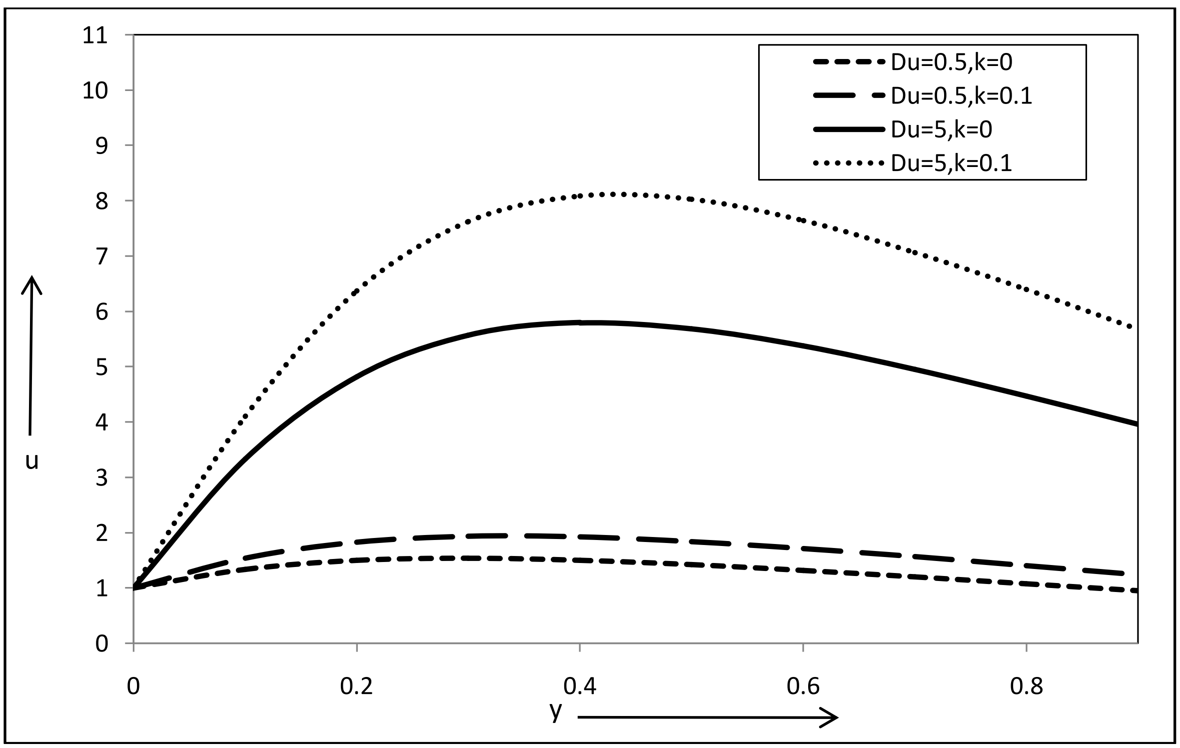

Figure 3:- Velocity u against y for Sc=5, Gm=10, Gr=7
M=1, γ=1, R=10, Pr=5.

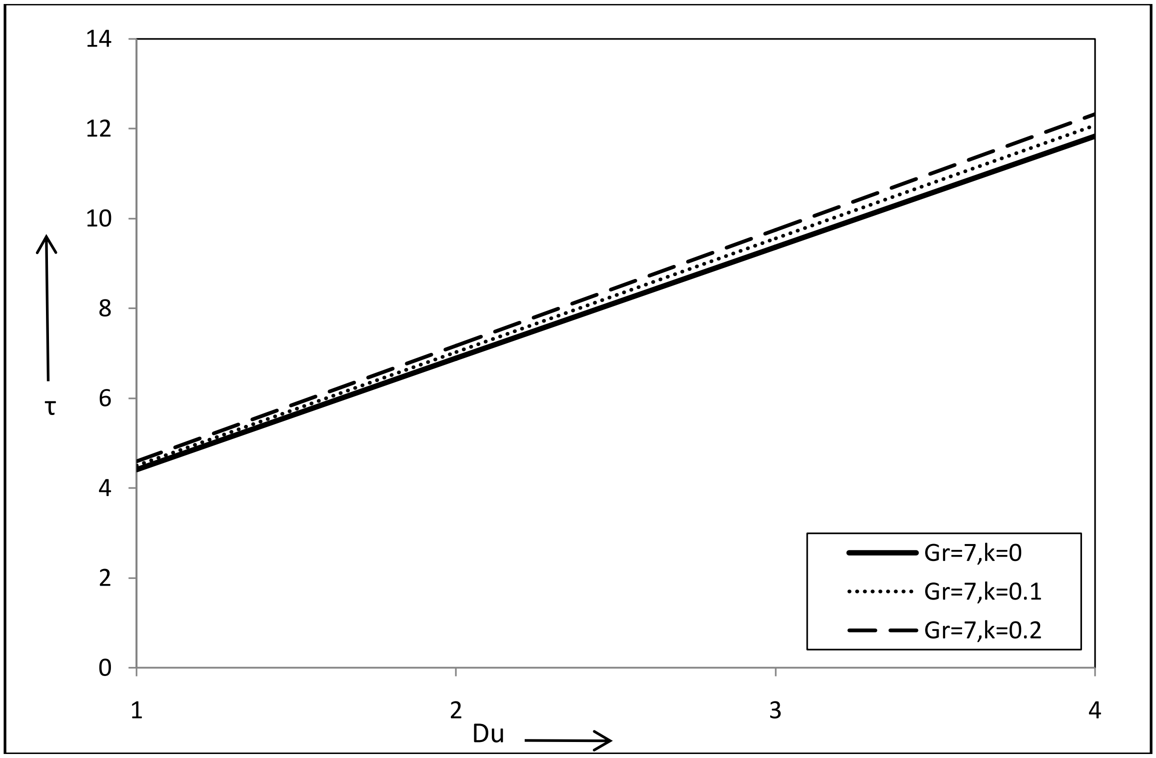

Figure 4:- Shearing stress against Du for M=1, Gm=10, Sc=5
R=10, γ=1, Pr=5

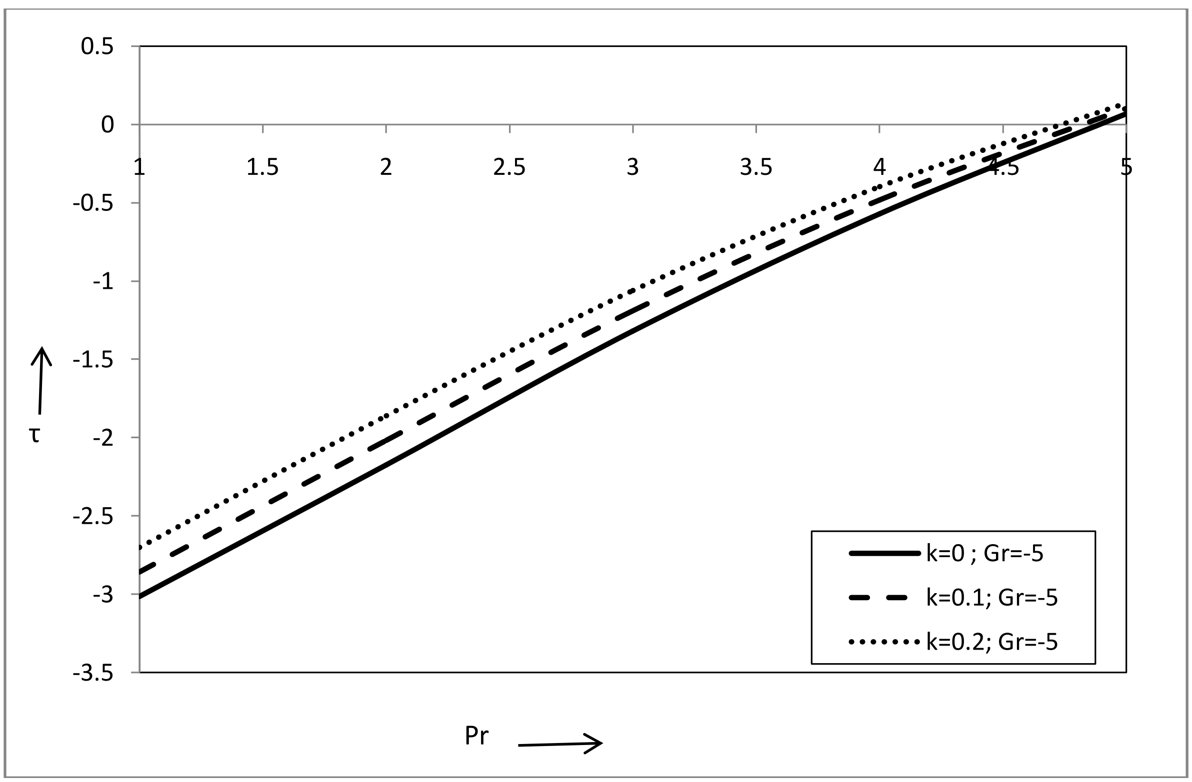

Figure 5:- Shearing stress against Pr for M=1, Gm=10, Sc=5
Du=0.5, R=10, γ=1, Pr=5

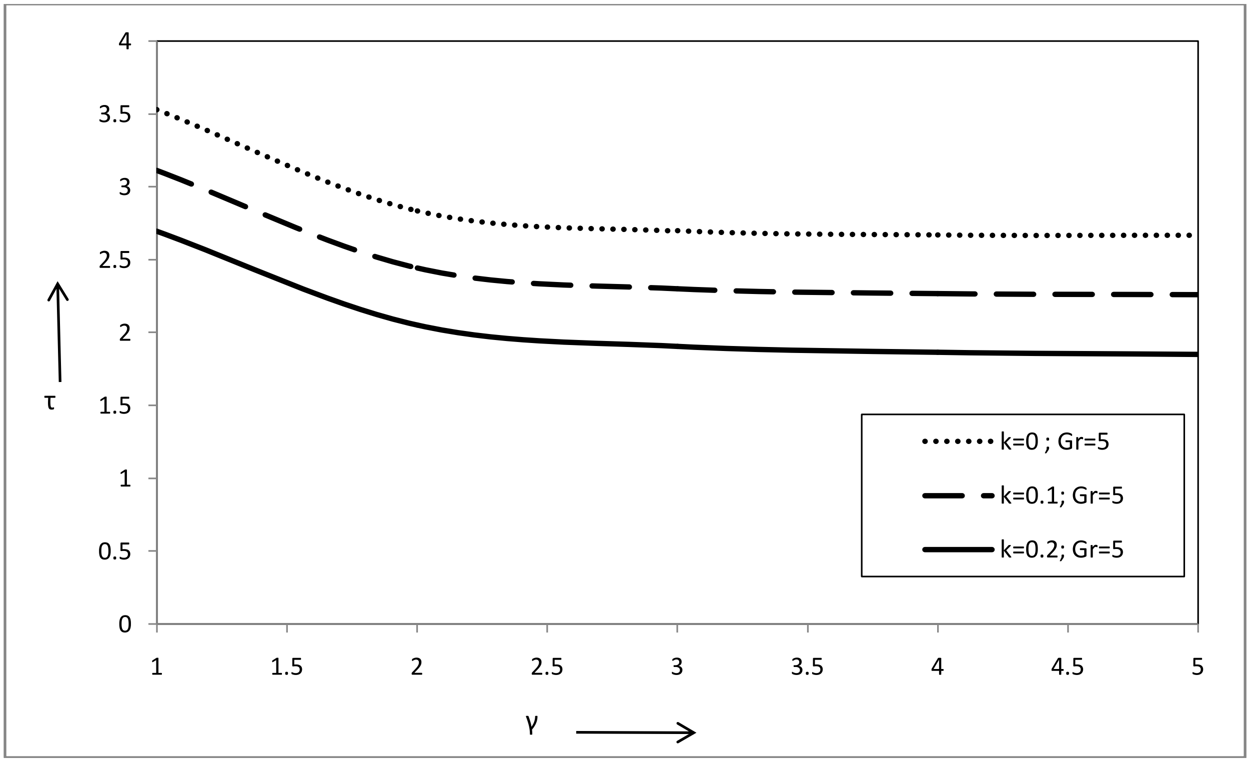

Figure 6:- Shearing stress against γ for M=1, Gm=10, Sc=5
R=10, Du=0.5, Pr=5

Conclusion:-

A study of diffusion-thermo and radiation effects on free convective MHD visco-elastic fluid flow past a vertical porous surface in presence of heat generation is analyzed here. The following conclusions have been made from this study

1. Visco-elastic parameter k affects the velocity profile of the fluid flow region along with other flow parameters.
2. For both Newtonian and non-Newtonian cases, the fluid velocity amplifies in externally cooled plate but decelerates in case of externally heated plate.
3. The effect of magnetic parameter is significant in the velocity field for externally cooled plate.
4. The velocity profile increases with the increasing values of the Dufour number in both Newtonian and non-Newtonian phenomenon.
5. The increasing values of Dufour number and Prandtl number accelerate the magnitude of shearing stress for externally cooled surface in both Newtonian and non-Newtonian fluids.
6. For both Newtonian and non-Newtonian fluid flow phenomenon, the chemical reaction parameter lowers the magnitude of shearing stress for externally cooled surface.
7. The rate of heat transfer (Nu) and the rate of mass transfer (Sh) are not significantly affected by the visco-elastic parameter.

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