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Visco-Elastic Effects on MHD Free Convection and Mass Transfer for Boundary Layer Flow with Radiation and Transpiration

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Abstract

The two dimensional MHD free convection and mass transfer boundary layer flow of a visco-elastic electrically conducting and chemically reacting fluid flowing along a semi-infinite vertical porous plate with time dependent suction velocity in presence of heat source, thermal and concentration buoyancy effects. The transformed governing equations are solved by multi parameter-perturbation technique. The analytical expressions for the velocity, temperature and species concentration fields have been obtained. The corresponding expressions for the non-dimensional rates of heat transfer and mass transfer have been obtained. The velocity profile and the shearing stress have been illustrated graphically, for various values of flow parameters involved in the solution to observe the effect of visco-elastic parameter.

Keywords: MHD, Free-convection, Electrically conducting, Heat transfer, Mass transfer, visco-elastic, shearing stress.

INTRODUCTION

The applications of hydromagnetic incompressible visco-elastic flow in science and engineering involving heat and mass transfer under the influence of chemical reaction is of great importance to many areas of science and engineering. This frequently occurs in agriculture, engineering, plasma studies and petroleum industries. 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. In recent years the non-Newtonian fluids in the presence of magnetic field find increasing applications in many areas such as chemical engineering, electromagnetic propulsions, nuclear reactor etc. 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. In many chemical engineering processes, chemical reactions take place between a foreign mass and the working fluid which moves due to the stretch of a surface. The order of chemical reaction depends on several factors. One of the simplest chemical reactions is the first order reaction in which the rate of the reaction is directly proportional to the species concentration. Chemical reaction can be classified as either homogeneous or heterogeneous processes, which depends on whether it occurs at an interface or as a single-phase volume reaction. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. Recently, a new idea is added to the study of boundary layer fluid flow and heat transfer in the consideration of the effects of thermal radiation and temperature dependent viscosity. Many process in engineering applications occur at high temperature and the radiate heat transfer becomes very important for the design of the pertinent equipment. Many investigators have studied two-dimensional laminar boundary layer flow and convective heat transfer. But not much attention has been given however to cases where thermal radiation becomes an additional factor. Recently, development in hypersonic flight, missile reentry, rocket combustion chambers, have focused attention on thermal radiation as a mode of energy transfer and emphasized the need for an improved understanding of radiative transfer in these processes.

Radiative effects have important applications in physics and engineering. The radiations heat transfer effects on different flows are very important in space technology and high temperature process. Chen[1] has studied heat and mass transfer in MHD flow by natural convection. Cookey *et al.*[2] have studied MHD free convection and mass transfer flow with radiative heat. Amos *etal.* [3] have studied magnetic effect on pulsatile flow in a constricted axis symmetric table. Soundalgekar [4] has studied free convection effects on hydromagnetic oscillatory flow in the Stokes problem past an infinite porous vertical limiting surface with constant suction. Kim [5] has studied unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Chamkha [6] has studied unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable surface with heat source and sink. Chamkha[7] has studied unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Abel *et al.*[8] have studied buoyancy force and thermal radiation effects in MHD boundary visco-elastic flow over continuously moving stretching surface. Raptis [9] has studied flow of a micropolar fluid past a continuously moving plate by the presence of radiation. Chamkha[10] has studied hydromagnetic three dimensional free convection on a vertical stretching surface with heat generation or absorption. Hossain *et al.* [11] have studied the effect of radiation on free convection from a porous vertical plate. Muthumucumaraswamy *et al.*[12] have studied natural convection on a moving isothermal vertical plate with chemical reaction. Prakash *etal.*[13] have studied unsteady two-dimensional flow of a radiating and chemically reacting MHD fluid with time-dependent suction. Makinde *et al.*[14] have studied free convection flow with thermal radiation mass transfer past a moving vertical porous plate. Das *et al.*[15] have studied MHD free convection flow of a radiating and chemically reacting fluid. Seddek[16] has studied finite element method for the effect of chemical reaction. Das *e tal.*[17] have studied effects of radiation and transpiration on free convection and mass transfer flow through a porous medium of a chemically reacting MHD fluid.

In this study, an attempt has been made to extend the problem studied by Das *et al.*[17] to the case of visco-elastic fluid characterized by second-order fluid.

The constitutive equation for the incompressible Second-order fluid is of the form

$$\sigma = -pI + \mu_1 A_1 + \mu_2 A_2 + \mu_3 (A_1)^3 \quad (1)$$

Where σ is the stress tensor, $A_n(n = 1,2,3)$ are the kinematic Rivlin-Ericksen tensors; μ_1, μ_2, μ_3 are the material coefficients describing the viscosity, elasticity and cross-viscosity respectively. The material coefficients μ_1, μ_2, μ_3 are taken constants with μ_1 and μ_3 as positive and μ_2 as negative [Coleman and Markovitz (1964)] [18].The equation (1) was derived by Coleman and Noll[19] from that of simple fluids by assuming that the stress is more sensitive to the recent deformation than to the deformation that occurred in the distant past.

The governing boundary layer equation for second order fluid is of the form

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = U\frac{dU}{dx} + \nu_1\frac{\partial^2 u}{\partial y^2} + \nu_2\left[\frac{\partial u}{\partial x}\frac{\partial^2 u}{\partial y^2} + u\frac{\partial^3 u}{\partial x\partial y^2} + v\frac{\partial^3 u}{\partial y^3} + \frac{\partial^3 u}{\partial y^3} + \frac{\partial u}{\partial y}\frac{\partial^2 v}{\partial y^2}\right] - \frac{\sigma B_0^2(x)(u - U_\infty)}{\rho} \quad (2)$$

MATHEMATICAL FORMULATION

We consider an unsteady free convection two-dimensional boundary layer flow of a viscous incompressible, electrically conducting fluid through a porous medium with heat source occupying semi-infinite region of space bounded by a semi-infinite vertical plate under the influence of uniform magnetic field B_o applied normal to the direction of flow, in presence of thermal and concentration buoyancy effects. The effect of induced magnetic field is neglected. Further magnetic field is not strong enough to cause Joule heating. Hence, the term due to electrical dissipation is neglected in energy equation. Let x-axis be taken along the vertical plate and Y-axis is taken normal to it. The fluid properties are assumed constant except for the influence of density in the body force term. As the bounding surface/plate is infinite in length, all the variables are the functions of y and t only. Hence, by the usual boundary approximation the basic equations for unsteady flow through porous medium are,

$$\frac{\partial v'}{\partial y'} = 0 \quad (3)$$

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \nu_1\frac{\partial^2 u'}{\partial y'^2} + \nu_2\left[v'\frac{\partial^3 u'}{\partial y'^3}\right] - \frac{\sigma B_0^2 u'}{\rho} + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) \quad (4)$$

$$\frac{\partial T}{\partial t'} + v'\frac{\partial T}{\partial y'} = \frac{\lambda}{\rho C_p}\frac{\partial^2 T}{\partial y'^2} + S(T - T_\infty) - \quad (1)$$

$$\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y'} \quad (5)$$

$$\frac{\partial C}{\partial t'} + v'\frac{\partial C}{\partial y'} = D\frac{\partial^2 C}{\partial y'^2} - K_r'^2(C - C_\infty) \quad (6)$$

where u' and v' are the velocity components in x and y direction respectively; σ is the conductivity of the fluid; ν is the kinematics coefficient of viscosity; ρ is the density of the fluid; C_p is the specific heat at constant pressure; β,β^* are the coefficient of volume expansion due to temperature and concentration; q_r is the radiative flux; S, the coefficient of heat source; λ is the thermal conductivity; D is the chemical diffusivity; K'_r is the chemical reaction rate constant.

By using Rosselant approximation for radiation (vide Raptis[9], Cookey[2], Makinde[14], Prakash and Ogulu[13]), the radiative heat flux q_r is given by,

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \quad (7)$$

where σ^* is the Stefan-Boltzmann constant and k^* the mean absorption coefficient.

Assuming the temperature differences within the flow tube sufficiently small, we can expand T^4 in a Taylor series about T_∞ and neglecting higher order terms we have,

$$T^4 = 4T_\infty^3 T - 3T_\infty^4 \quad (8)$$

Then the energy equation (2.3) becomes,

$$\frac{\partial T}{\partial t'}+v'\frac{\partial T}{\partial y'}=\frac{\lambda}{\rho C_p}\frac{\partial^2 T}{\partial y'^2}+S(T-T_\infty)+\frac{16\sigma^* T_\infty^3}{3\rho C_p k^*}\frac{\partial^2 T}{\partial y'^2} \tag{9}$$

In view of (3), we can take the time-dependent suction (as in Cookey et al,[2]) as,

$$v=-v_0(1+\varepsilon A e^{nt}) \tag{10}$$

where A is the suction parameter and εA<<1. Here the minus sign indicates that the suction istowards the plate.For simplicity, we introduce the following non-dimensional quantities:

$$t=\frac{t' v_0^2}{\nu},\ y=\frac{v_0 y'}{\nu},u=\frac{u'}{v_0},\theta=\frac{T-T_\infty}{T_w-T_\infty},\phi=\frac{C-C_\infty}{C_w-C_\infty},n'=\frac{\nu n}{v_0^2}$$

$$Gr=\frac{g\beta(T_0-T_\infty)}{U_0V_0^2},\quad \textit{Grashoff number for Heat Transfer}$$

$$G_c=\frac{g\beta^*(C_0-C_\infty)}{U_0V_0^2},\quad \textit{Grashoff number for Mass Transfer}$$

$$\Pr=\frac{\mu C_p}{\lambda},\quad \textit{Prandtl number}$$

$$S_c=\frac{v_1}{D},\quad \textit{Schmidt number}$$

$$k=\frac{k' v_0^2}{v_0^2},\quad \textit{Porosity parameter}$$

$$K_r=\frac{K_r'}{v_0}\sqrt{v_1},\quad \textit{Chemical reaction parameter}$$

$$N_r=\frac{16\sigma^* T_\infty^3}{3k^*\lambda},\quad \textit{Thermal Radiation parameter}$$

$$M=\frac{\sigma B_0^2 v_1}{\rho v_0^2},\quad \textit{Hartmann number}$$

$$S'=\frac{Sv}{v_0^2},\quad \textit{Heat source parameter}$$

$$\alpha=\frac{v_2 v_0^2}{v_1},\quad \textit{Visco-elastic parameter}$$

Then using (10) and the above non-dimensional quantities, the (4), (5), (6) reduces to

$$\frac{\partial u}{\partial t}-(1+\varepsilon A e^{nt})\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}-\alpha(1+\varepsilon A e^{nt})\frac{\partial^3 u}{\partial y^3}-(M^2+\frac{1}{k})u+Gr\theta+G_c\phi \tag{11}$$

$$\frac{\partial \theta}{\partial t}-(1+\varepsilon A e^{nt})\frac{\partial \theta}{\partial y}=\frac{(1+N_r)}{P_r}\frac{\partial^2\theta}{\partial y^2}-\alpha(1+\varepsilon A e^{nt})\frac{\partial^2\theta}{\partial y^2}+S\theta \tag{12}$$

$$\frac{\partial \phi}{\partial t}-(1+\varepsilon A e^{nt})\frac{\partial \phi}{\partial y}=\frac{1}{S_c}\frac{\partial^2\phi}{\partial y^2}-K_r^2\phi \tag{13}$$

The corresponding boundary conditions are:

$$\begin{aligned}&u=1,\ \theta=1+\varepsilon e^{nt},\ \phi=1+\varepsilon e^{nt}\ on\ \ y=0\\&u\to 0,\ \theta\to 0,\ \phi\to 0\ as\ y\to\infty\end{aligned} \tag{14}$$

METHOD OF SOLUTION

In order to solve the equations (11) -(13), we assume that the unsteady flow is superimposed on the mean steady flow (Soundalgekar [16]) so that in the neighbourhood of the plate we have,

$$\left.\begin{aligned}u&=u_0(y)+\varepsilon e^{nt}u_1(y)+o(\varepsilon^2)\\ \theta&=\theta_0(y)+\varepsilon e^{nt}\theta_1(y)+o(\varepsilon^2)\\ \phi&=\phi_0(y)+\varepsilon e^{nt}\phi_1(y)+o(\varepsilon^2)\end{aligned}\right\} \tag{15}$$

Substituting (15) in to the equations (11)-(13) and then equating the steady and unsteady parts, we get,

$$\alpha u_0'''-u_0''-u_0'+M_1u_0=Gr\theta_0+G_c\phi_0 \tag{16}$$

$$\alpha A u_1'''-u_1''-u_1'+(M_1+n)u_1=Au_0'-\alpha A u_0'''+Gr\theta_0+G_c\phi_0 \tag{17}$$

$$\theta_0''+h\theta_0'+Sh\theta_0=0 \tag{18}$$

$$\theta_1''+h\theta_1'+(S-n)h\theta_1=-Ah\theta_0' \tag{19}$$

$$\phi_0''+S_c\phi_0'-S_cK_r^2\phi_0=0 \tag{20}$$

$$\phi_1''+S_c\phi_1'-S_c(K_r^2+n)\phi_1=-AS_c\phi_0' \tag{21}$$

where $h=\dfrac{P_r}{1+N_r},\ \ M_1=(M^2+\dfrac{1}{k})$

The relevant boundary conditions are given by:

$$\begin{aligned}&u_0=1,u_1=0,\theta_0=\theta_1=1,\ \phi_0=\phi_1=1\ on\ y=o\\&u_0\to 0,\ \ u_1\to 0,\ \ \theta_0\to 0,\theta_1\to 0,\phi_0\to 0,\ \phi_1\to 0\\&as\ \ y\to\infty\end{aligned} \tag{22}$$

The solution of the equation (18)–(21) subject to the boundary conditions (22) are:

$$\theta_0=e^{-h_2y}$$

$$\theta_1=A_4e^{-h_4y}+\frac{Ahh_2e^{h_2y}}{h_2^2+hh_2+(S-n)^2}$$

$$\phi_0=e^{-h_6y}$$

$$\phi_1=A_8e^{-h_8y}+\frac{Ah_6S_ce^{-h_6y}}{h_6^2-S_ch_6-(K_r+n)S_c}$$

Again to solve the equations (16), (17)we use the multiparameter-perturbation technique and the velocity components are expanded in the power of visco-elastic parameter α as α<<1 for small shear rate. Thus the expressions for velocity components are considered

$$u_0 = u_{00} + \alpha u_{01}, \qquad u_1 = u_{10} + \alpha u_{11} \qquad (23)$$

Applying (23), in equations (16), (17) equating the like powers of α we obtain the following set of differential equations :

$$u''_{00} + u'_{00} - M_1 u_{00} = -Gre^{-h_2 y} - G_c e^{-h_6 y} \qquad (24)$$

$$u''_{01} + u'_{01} - M_1 u_{01} - u'''_{00} = -Gre^{-h_2 y} - G_c e^{-h_6 y} \qquad (25)$$

Subject to boundary conditions are:

$$u_{00} = 1, \;\; u_{01} = 0, \quad at \;\; y = 0$$

$$u_{00} \to 0, \;\; u_{01} \to 0, \quad at \;\; y \to \infty \qquad (26)$$

$$u''_{10} + u'_{10} - (M_1 + n)u_{10} = -Au'_{00} - Gr\theta_1 - G_c\phi_1 \qquad (27)$$

$$u''_{11} + u'_{11} - (M_1 + n)u_{11} = Au'''_{10} - Au'_{01} - Au'''_{00} - Gr\theta_1 - G_c\phi_1 \qquad (28)$$

Subject to boundary conditions are:

$$u_{10} = 1, \;\; u_{11} = 0, \quad at \;\; y = 0$$

$$u_{10} \to 0, \;\; u_{11} \to 0, \quad at \;\; y \to \infty \qquad (29)$$

RESULTS AND DISCUSSION

The expression for the skin friction at the plate y=0 is

$$C_f = \frac{\partial u}{\partial y} + \alpha\left(\frac{\partial^2 u}{\partial t \partial y} - (1 + \varepsilon A e^{nt})\frac{\partial^2 u}{\partial y^2}\right) \quad at\; y = 0 \qquad (30)$$

The rate of heat transfer in terms of Nusselt no(Nu) in non-dimensional form is given by

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

$$= -h_2 + \varepsilon e^{nt}\left(-A_4 h_4 - \frac{Ahh_2^2}{h_2^2 + hh_2 + (S-n)h}\right) \qquad (31)$$

The rate of mass transfer in terms of Sherwood no(S_h) in non-dimensional form is given by

$$S_h = \left(\frac{\partial \phi}{\partial y}\right)_{y=0}$$

$$= -h_6 + \varepsilon e^{nt}\left(-h_8 A_8 - \frac{Ah_6^2 S_c}{h_6^2 - S_c h_6 - (K_r^2 + n)S_c}\right) \qquad (32)$$

The purpose of this study is to bring out the effects of visco-elastic parameter on hydro-magnetic,heat and mass transfer characteristics as the effects of other parameter have been discussed by Das etal.[17]. The non-Newtonian effect is exhibited through the parameter α. The corresponding results for Newtonian fluid is obtained by setting α=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 parameters S=.05,n=.7,A=.3,α=-.03,ε=.02are kept fixed throughout the discussions. visco-elastic parameter α.

Figure 1 illustrate the effect of velocity profile for different values of visco-elastic parameter α. It is observed that the velocity decreases with an increasing absolute values of the visco-elastic parameter α.

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 Prandtl number(Pr). It is observed that the velocity decreases with an increasing the Prandtl number(Pr).

Figure 4, shows that the effect of velocity profile for different values of thermal Grashof number(Gr). It is observed that an increasing in thermal Grashof number(Gr) leads to an increase in the velocity due to the enhancement in buoyancy forces. Actually, the thermal Grashof number signifies the relative importance of buoyancy force to the viscous hydrodynamic force. Increase of Grashof number(Gr) indicates small viscous effects in the momentum equation and consequently causes increase in the velocity profiles.

Figure 5, shows the variation of velocity distribution with different values of Grashof number for mass transfer(Gm). It is observed from the figure that the velocity increases with an increasing the Grashof number for mass transfer.

Figure 6, shows the variation of velocity distribution with different values of thermal radiation parameter(Nr). It is observed that the velocity increases with an increasing the thermal radiation parameter.

Figure 7, reveals the effect of porosity parameter(k) on velocity profile. It is evident that from the figure that the velocity increases with the increasing of porosity parameter.

Figure 8, reveals the effect of porosity parameter (kr) on velocity profile. It is evident that from the figure that the velocity decreases with the increasing of chemical reaction parameter(kr).

Figures9,10displays the shearing stress against time(t). It is observed that shearing stress decrease with time. Further, these figures exhibitthe effects of visco-elastic parameter (α) on the shearing stress at the plate with the combination of other flow parameters. From these figures, it is observed that the shearing stress decreases with the increase of the absolute values of the visco-elastic parameter (α). Also,the shearing stress decreases with the increasing values of magnetic parameter (M) and Prandtl number (Pr).

It is also observed from the expression of θ and ϕ that the temperature field and concentration field are not significantly affected by the visco-elastic parameters.

CONCLUSION

The ofvisco-elastic effects on MHD free convection and mass transfer for boundary layer flow along with radiation and transpiration are studied in this paper. Some of the important conclusions this paper are as follows

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

ii) The shearing stress is prominently affected by the visco-elastic parameter.

iii)The effect of Prandtl number (Pr) and magnetic parameter M) on velocity and shearing stress is prominentthroughout the flow in presence of other flow parameter.

iv) The temperature field and concentration field are not significantly affected by the visco-elastic parameters.

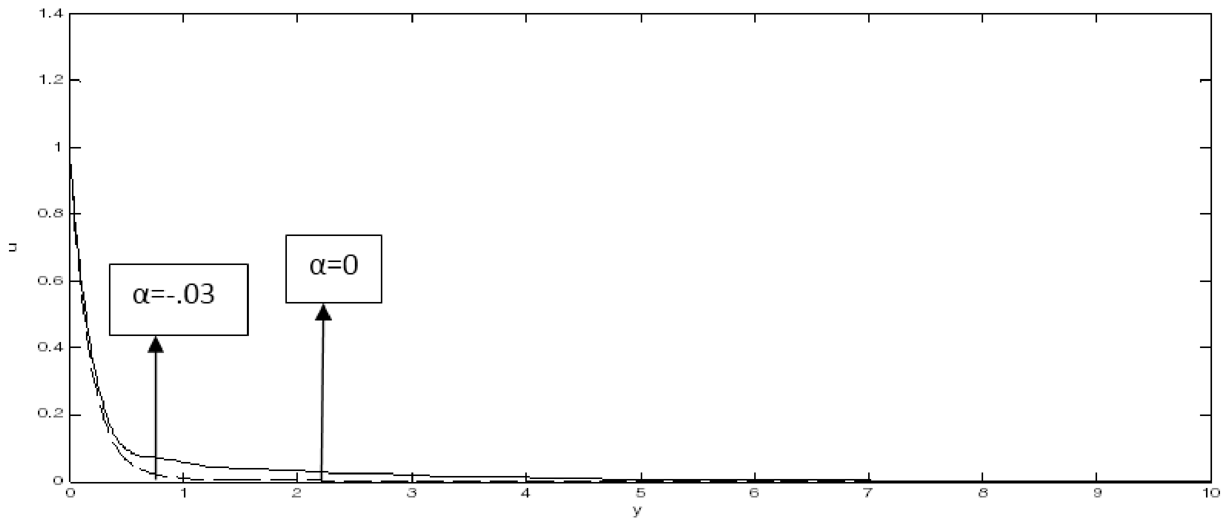

Figure 1: The velocity profile u against the displacement variable y for M=5,Pr=.71,Gr=5,Gm=2,Sc=.3,Kr=.5,Nr=.5,S=.05,n=.7,k=1.5,A=.3,α=-.03,ε=.02

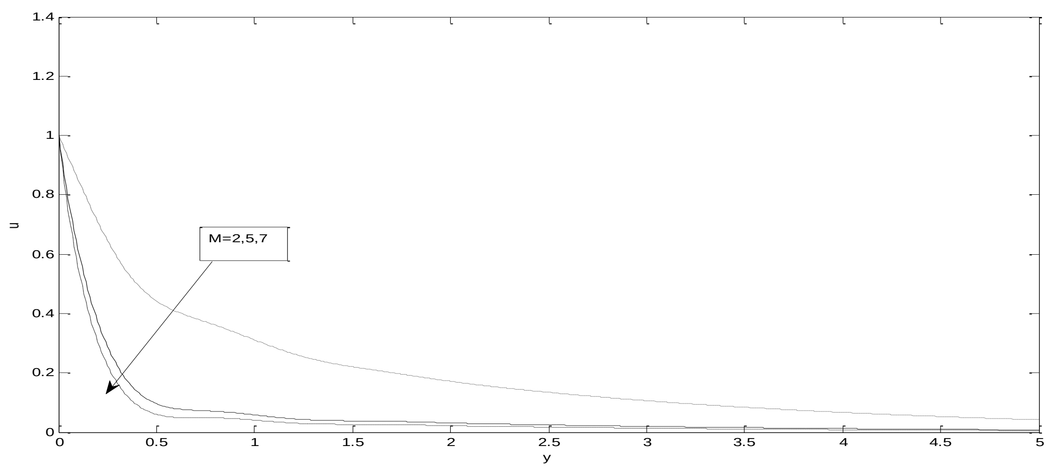

Figure 2: The velocity profile u against the displacement variable y for α=.03,Pr=.71,Gr=5,Gm=2,Sc=.3,Kr=.5,Nr=.5,S=.05,n=.7,k=1.5,A=.3,α=-.03,ε=.02

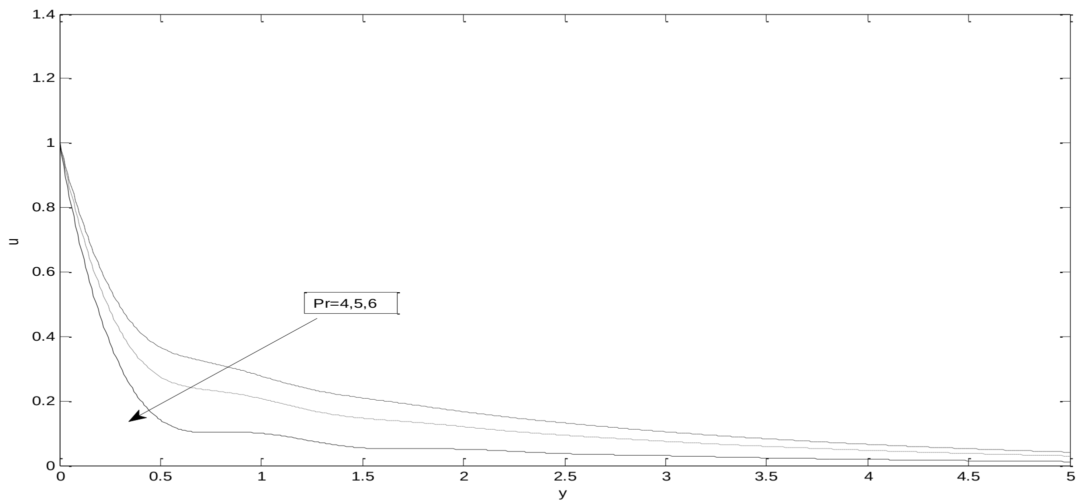

Figure 3: The velocity profile u against the displacement variable y for α=-.03
M=5,Gr=5,Gm=2,Sc=.3,Kr=.5,Nr=.5,S=.05,n=.7,k=1.5,A=.3,α=-.03,ε=.02

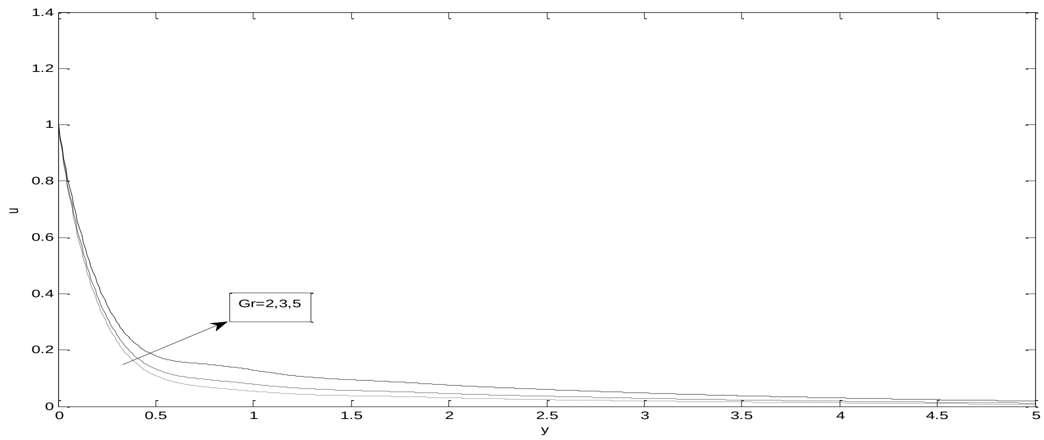

Figure 4: The velocity profile u against the displacement variable y for α=-.03
M=5,Pr=.71,Gm=2,Sc=.3,Kr=.5,Nr=.5,S=.05,n=.7,k=1.5,A=.3,α=-.03,ε=.02.

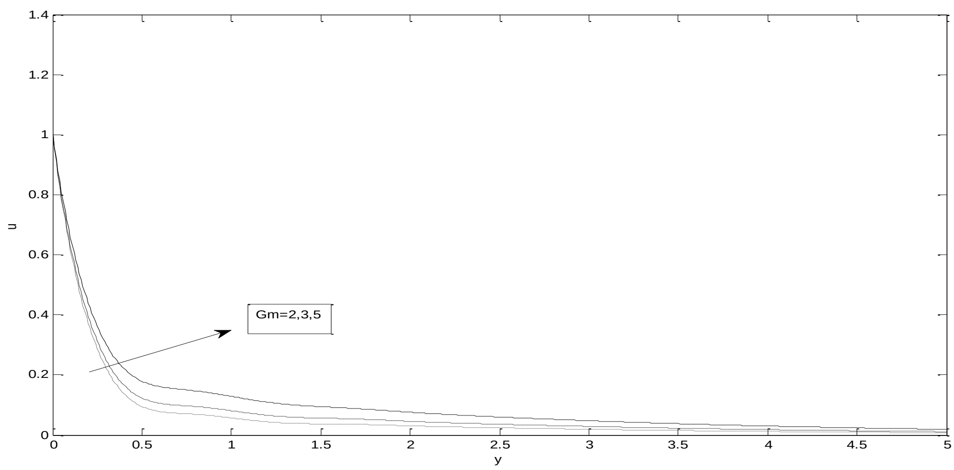

Figure 5: The velocity profile u against the displacement variable y for α=-.03
M=5,Pr=.71,Gr=5,Sc=.3,Kr=.5,Nr=.5,S=.05,n=.7,k=1.5,A=.3,α=-.03,ε=.02.

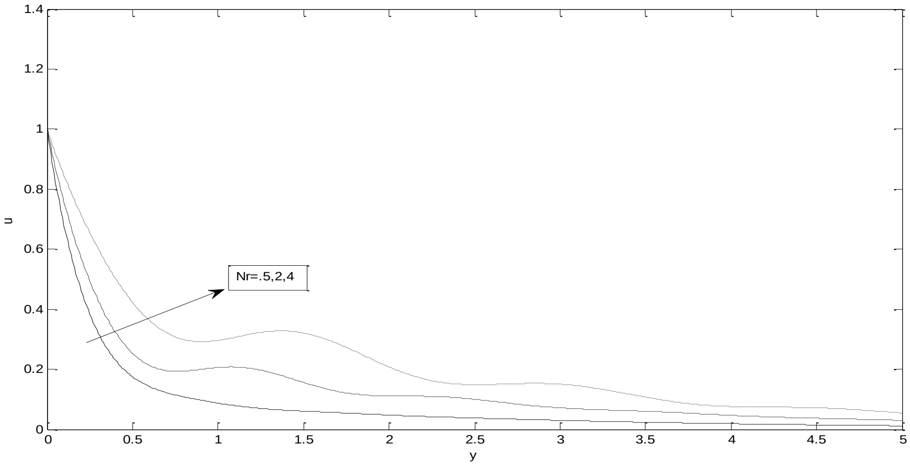

Figure6: The velocity profile u against the displacement variable yfor M=5,Pr=.71,Gr=5,Gm=2,Sc=.3,Kr=.5,,S=.05,n=.7,k=1.5,A=.3,α=-.03,ε=.02

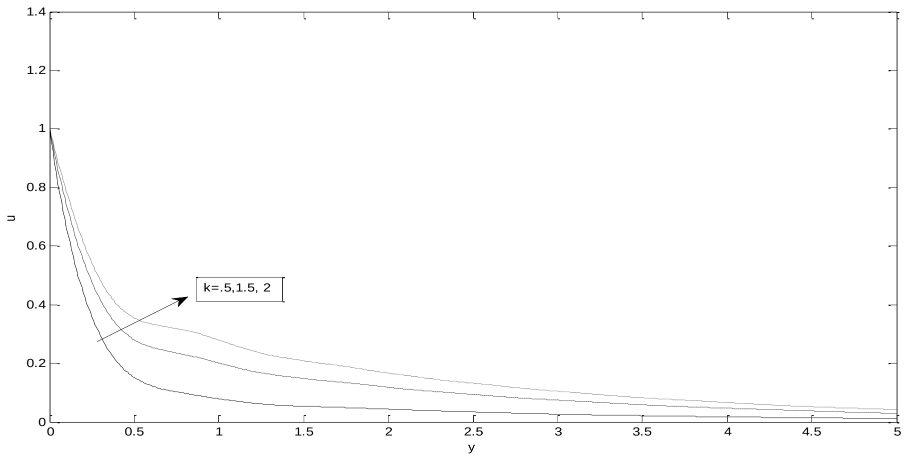

Figure 7: The velocity profile u against the displacement variable y for α=-.03, M=5,Pr=.71,Gr=5,Gm=2,Sc=.3,Kr=.5,Nr=.5,S=.05,n=.7,k=1.5,A=.3,α=-.03,ε=.02.

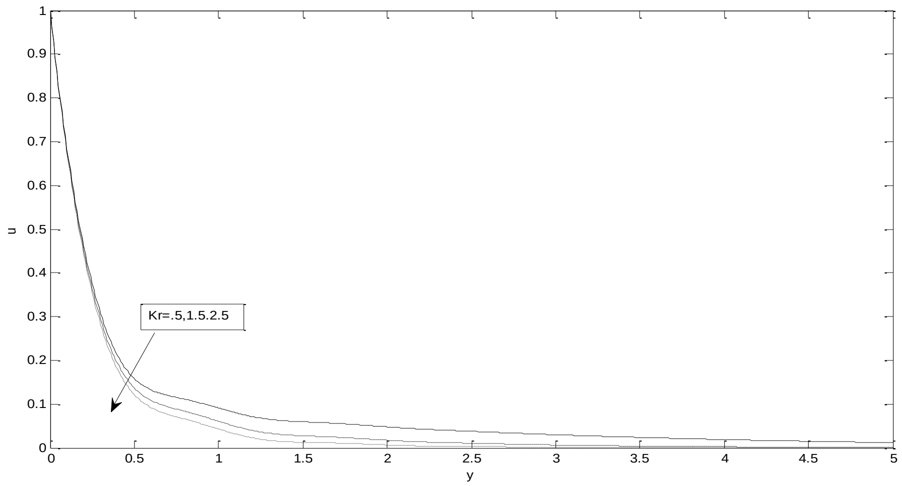

Figure 8: The velocity profile u against the displacement variable y for α=-.03, M=5,Pr=.71,Gr=5,Gm=2,Sc=.3,Nr=.5,S=.05,n=.7,k=1.5,A=.3,α=-.03,ε=.02.

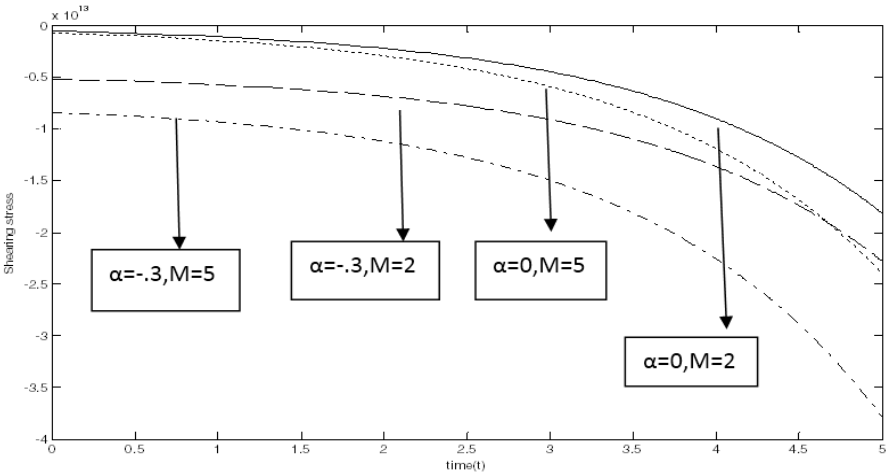

Figure 9: Variation of shearing stress (C_f) against time(t) for α=-.03, Pr=.71,Gr=5,Gm=2,Sc=.3,Kr=.5,Nr=.5,S=.05,n=.7,k=1.5,A=.3,ε=.02

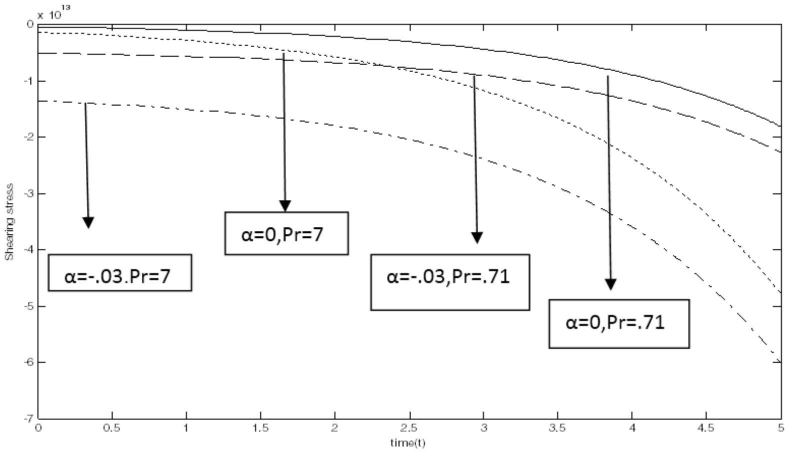

Figure10: Variation of shearing stress (C_f) against time(t) for α=.03, M=2,Gr=5,Gm=2,Sc=.3,Kr=.5,Nr=.5,S=.05,n=.7,k=1.5,A=.3,ε=.02

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