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RADIATION AND CHEMICAL REACTION EFFECTS ON UNSTEADY VISCOELASTIC FLUID FLOW THROUGH POROUS MEDIUM

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ABSTRACT

In this paper, we attempt to analyze the effects of radiation and chemical reactions on laminar boundary layer flow of an electrically conducting unsteady viscoelastic incompressible fluid flow along a vertical semi-infinite plate passing through porous channel. The coupled nonlinear partial differential equations for energy, momentum, and mass diffusions are solved analytically with the use of perturbation technique. Moreover, the analytical expressions for fluid velocity, temperature, and concentration distributions are obtained and interpreted using the software MATLAB. The enhancement of velocity is prominent with the growth of G_r, G_m, N_r and Kr but a reverse pattern is observed with the rise of P_r. The physical values of skin friction coefficient, Nusselt number and Sherwood number are estimated remembering their importance in engineering and technology fields. The graphical augmentation are instituted in possible cases for various viscoelastic parameters in combination of other dimensionless flow parameters. The simulations presented here relate to metal extraction in chemical and polymer processes.

Keywords: *Viscoelastic, chemical reaction, radiation, porous medium*

1. INTRODUCTION

In the past few decades, the application of boundary layer flow for non-Newtonian fluids has been continuously increasing, as it plays an important role in different fields like engineering, processing, metal extraction, aerospace, polymer processing, and contemporary technology. Non-Newtonian fluid flow can also be practically applicable in bio-engineering, for instance, there are various viscoelastic fluid models to describe the blood circulation process through animal arteries, then also to understand the mechanism of dialysis of blood through artificial kidneys one can study viscoelastic pulsatile flow.

There are many hydrometallurgical industries and transport affairs which are governed by the combined effect of buoyancy forces due to mass diffusion and thermal energy in presence of radiation and chemical reaction effects. Further, these processes occur in the combustion system, solar collectors, nuclear reactor safety and chemical engineering, etc.

MHD flow through an exponentially extending sheet with a heat sink: chemical reaction and radiation impact has been first studied by (Khalili et al., 2017). Many researchers have studied various problems related to Walters B$^{/}$ liquid model. To mention a few, the simultaneous investigation of heat and mass transfer, as well as magnetohydrodynamic (MHD) flow through a vertically oscillating plate contained in a porous medium, was investigated using Walters Liquid Model-B$^{/}$ given by (Abro and Khan, 2018). The constitutive equations of some non-Newtonian fluid flows, with short memories, have been studied by (Walters, 1964) and (Bread and Walters, 1964). On an unstable MHD heat and mass transfer flow across an accelerated inclined vertical plate, finite element Soret Dufour impacts have been investigated by Bejawada et al. (2021).

Again, heat and mass transmission effects on unsteady MHD free convection flow past an infinite vertical plate, a numerical solution has been studied by (Kumari et al., 2021). Chemical reaction and hall effect in heat and mass transfer of MHD Casson fluid under radiation over an exponentially permeable stretching sheet was analyzed by (Ganesh et al., 2021). In the presence of thermal radiation and chemical reaction with suction, MHD boundary layer flow of nanofluid and heat transfer across a porous exponentially stretched sheet have been suitably illustrated by (Reddy et al., 2017) in presence of first-order chemical reaction and Joule heating. Also, the effects of thermal diffusion and chemical reaction on MHD flow on a vertical surface with a generation of heat has been discussed by (Bhavana et al., 2018). The hydromagnetic oscillatory slip flow effects on viscoelastic fluid have been studied by (Dey and Choudhury, 2019). The effects of Chemical Reaction and Suction/Blowing MHD Boundary Layer Flow of Nanofluid and Heat Transfer Over a Nonlinear Stretching sheet was illustrated by (Reddy, et al., 2018) for nanofluids. Analysis of heat transfer and mass transfer results on MHD viscoelastic fluid flow on a stretching- sheet in presence of a chemical reaction was done by (Nayak et al., 2016). (Reddy et al., 2018) have discussed the effects of thermal diffusion and radiation on MHD dusty viscoelastic fluids between two parallel moving plates. (Jonnadula, 2015) have examined the influence of chemical reactions and thermal radiation on MHD viscous fluid flow. The unsteady viscous fluid flow in presence of chemical reaction and radiation has been analyzed by (Mishra et al., 2014). Chemical reaction over a curved surface with nonlinear thermal radiation and slip condition has been analyzed for nanofluids by (Ramzan et al., 2020). (Sivaraj and Kumar, 2013) have found the analytical solution for chemically reacting dusty viscoelastic fluid in presence of MHD. They show that convective boundary conditions and thermal radiation have a more significant effects on the dusty fluid in their regular porous channel. The combined effects of Soret-Dufour on unsteady MHD flow of dusty fluid flow over inclined porous

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medium has been investigated by (Pandya et al., 2017). (Choudhury and Dey, 2019) have studied the unsteady thermal radiation effects on MHD connective ship flow of viscoelastic fluid. Furthermore, (Srinivasacharya and Reddy, 2016) have successfully illustrated mixed convection heat and mass transport over a vertical plate in a power-law fluid-saturated saturated porous medium: chemical reaction and radiation impacts. The survey of literature pacifies that, flow of viscoelastic fluid through porous medium for various outlook have been demonstrated by many researchers and the details engrossed readers are referred to the references.

In most of the above studies, chemical reaction and radiation effects on fluid flow are discussed for both Newtonian and non-Newtonian fluids. But in many practical situations, it has been seen that models based on natural non-Newtonian fluid flow are extensively applicable in many engineering and industrial applications. In presence of chemical reaction or thermal radiation, some models based on viscoelastic fluid flows through porous medium are found in the works of many researchers. The combined effects of chemical reaction and thermal radiation on unsteady viscoelastic fluid flow through porous media is considered here. In the present study, the inclusion of porous media is important since it greatly prevents heat loss in heat transport processes and also accelerates the process of heating/cooling. Also, the fluids may be chemically reactive so for the mass transport equation chemical reaction term is vital.

2. Formulation of the problem

We consider an incompressible, unsteady, laminar, electrically conducting, boundary layer flow of a viscoelastic fluid through a vertical semi-infinite plate via a porous medium in presence of radiation and chemical reactions. Further, the time-dependent suction is also considered. The physical configuration of the problem is shown in figure-1

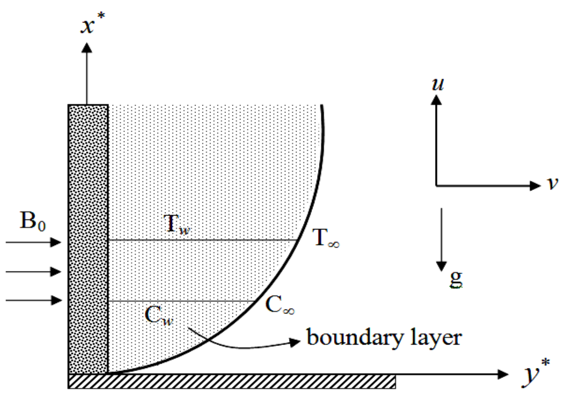

Figure-1: Physical model

Flow variables are functions of y^* and t^* only, as the plate is of infinite length along x^*-direction. The governing equations of flow field are:

Equation of continuity: $\frac{\partial v^*}{\partial y^*} = 0$ (1)

Momentum equation:

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = \nu \frac{\partial^2 u^*}{\partial y^{*2}} - k_0 \nu \frac{\partial^3 u^*}{\partial y^{*3}} + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) - \frac{\nu}{K^*} u^* + \frac{\sigma B_0^2}{\rho} u^* \quad (2)$$

Equation of energy: $\frac{\partial T}{\partial t^*} + v^* \frac{\partial T}{\partial y^*} = \frac{K}{\rho C_p} \frac{\partial^2 T}{\partial y^{*2}} + \frac{1}{\rho C_p} \frac{\partial q_r}{\partial y^*}$ (3)

Energy of mass diffusion: $\frac{\partial C}{\partial t^*} + v^* \frac{\partial C}{\partial y^*} = D \frac{\partial^2 C}{\partial y^{*2}} - K_r(C - C_\infty)$ (4)

For radiation, the Rosseland approximation can be taken as

$$q_r = -\frac{4\sigma^*}{3k^*} \frac{\partial T^4}{\partial y^*} \quad (5)$$

Using Taylor's series T^4 can be expanded linearly about the free-stream temperature T_∞ and neglecting all higher order teams we get

$$T^4 \cong 4TT_\infty^3 - 3T_\infty^4 \quad (6)$$

Using equations (5) and (6), the energy equation reduces to

$$\frac{\partial T}{\partial t^*} + v^* \frac{\partial T}{\partial y^*} = \frac{K}{\rho C_p} \frac{\partial^2 T}{\partial *^2} + \frac{16\sigma^* T_\infty^3}{3\rho C_p} \frac{\partial^2 T}{\partial y^{*2}} \quad (7)$$

From equation (1), it can be assumed that suction is only dependent on time and can be assume as follows:

$$v^* = -V_0\left(1 + \epsilon A e^{n^* t^*}\right), \text{ where } \epsilon A \ll 1 \quad (8)$$

the negative sign, specifies that the suction is towards the plate.

To get dimensionless partial differential equation, we introduce the following dimensionless parameters

$$u = \frac{u^*}{U_0}, \; y = \frac{U_0}{\nu} y^*, t = \frac{U_0^2}{\nu} t^*, n = \frac{\nu n^*}{U_0^2}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, \; \varphi = \frac{C - C_\infty}{C_w - C_\infty},$$

$$k_r = \frac{k_r^* \nu}{U_0^2}, K = \frac{K^* U_0^2}{\nu^2}, N_r = \frac{16\rho^* T_\infty^3}{3k/k}, P_r = \frac{\rho \nu C_p}{k}, S_c = \frac{\nu}{D},$$

$$G_r = \frac{\nu g \beta (T_w - T_\infty)}{U_0^3}, G_m = \frac{\nu g \beta^* (C_w - C_\infty)}{U_0^3}$$

Making use of the above dimensionless parameters in equations (2), (7) and (4), the governing equations reduce to

$$\frac{\partial u}{\partial t} - (1 + \epsilon A e^{nt}) \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - k_1 \frac{\partial^3 u}{\partial y^3} + G_r \theta + G_m \phi + (M - \frac{1}{K}) u,$$

$$\text{where } k_1 = \frac{k_0 V_0}{\nu^2} \quad (9)$$

$$\frac{\partial \theta}{\partial t} - (1 + \epsilon A e^{nt}) \frac{\partial \theta}{\partial y} = \left(\frac{1 + N_r}{P_r}\right) \frac{\partial^2 \theta}{\partial y^2} \quad (10)$$

$$\frac{\partial \phi}{\partial t} - (1 + \epsilon A e^{nt}) \frac{\partial \phi}{\partial y} = \frac{D}{\nu} \frac{\partial^2 \phi}{\partial y^2} - K_r \phi \quad (11)$$

The boundary conditions are

$$\left.\begin{array}{l} y = 0: u = 1, \; \theta = 1 + \epsilon e^{nt}, \; \varphi = 1 + \epsilon e^{nt} \\ y \to \infty: u \to U_0, \theta \to 0, \; \varphi \to 0 \end{array}\right\} \quad (12)$$

3. Method of Solution

The nonlinear coupled differential equations (9) to (11) with the relevant boundary conditions (12) can be solved analytically. As the amplitude ($\epsilon \ll 1$) is very small, so u, θ and φ can be taken as

$$u(y,t) = u_0(y) + \epsilon e^{nt} u_1(y) + 0(\epsilon^2) \quad (13)$$

$$\theta(y,t) = \theta_0(y) + \epsilon e^{nt} \theta_1(y) + 0(\epsilon^2) \quad (14)$$

$$\phi(y,t) = \phi_0(y) + \epsilon \epsilon \phi_1(y) + 0(\epsilon^2) \quad (15)$$

Substituting equations (13) to (15) into equations (9) to (11) respectively and equating harmonic, non-harmonic terms with the neglect of second and higher orders, we get zeroth and first order differential equations.

Zeroth-order equations:

$$k_1 u_0''' - u_0'' - u_0' - \left(M - \frac{1}{K}\right) u_0 = G_r \theta_0 + G_m \phi_0 \quad (16)$$

$$\theta_0'' + \alpha \theta_0' = 0, \alpha = \frac{P_r}{1 + N_r} \quad (17)$$

$$\phi_0'' + S_c \phi_0' = S_c K_r \phi_0 \quad (18)$$

First-order equations:

$$k_1 u_1''' - u_1'' - u_1' - \left(n - M + \frac{1}{K}\right) u_1 = A u_0' + G_r \theta_1 + G_m \phi_1 \quad (19)$$

$$\theta_1'' - n\alpha \theta_1 + \alpha \theta_1' + A\alpha \theta_0' = 0 \quad (20)$$

$$\phi_1'' + S_c\phi_1' - (n + K_r)\phi_1 + AS_c\phi_0' = 0 \quad (21)$$

The corresponding boundary conditions are

$$y = 0: u_0 = 1, u_1 = 0;\ \theta_0 = 1, \theta_0 = 1; \phi_0 = 1, \phi_1 = 1$$
$$y \to \infty: u_0 \to 1, u_1 \to 0;\ \theta_0 \to 0, \theta_0 \to 0; \phi_0 \to 0, \phi_1 \to 0 \quad (22)$$

Solving equations (17), (18) and (20) and (21) subject to the boundary conditions (22) we get

$$\theta_0 = e^{-\alpha y} \quad (23)$$

$$\theta_1 = c_4 e^{-a_2 y} - \frac{A\alpha}{n} e^{-\alpha y} \quad (24)$$

$$\phi_0 = e^{-a_4 y} \quad (25)$$

$$\phi_1 = (1 - a_7)e^{-a_6 y} + a_7 e^{-a_4 y} \quad (26)$$

To solve equations (16) and (19), we are to use multiparameter perturbation scheme for small shear rate on k_1 ($\ll 1$) as

$$u_0 = u_{00} + k_1 u_{01} + O(k_1^2) \quad (27)$$

$$u_1 = u_{10} + k_1 u_{11} + O(k_1^2) \quad (28)$$

Substituting equations (27) and (28) in equations (16) and (19) respectively, then comparing the like powers of k_1 and neglecting second and higher order terms we get

Zeroth-order equations:

$$u_{00}'' + u_{00}' + \left(M - \frac{1}{K}\right)u_{00} = -(G_r\theta_0 + G_m\phi_0) \quad (29)$$

$$u_{10}'' + u_{10}' - \left(n - M + \frac{1}{K}\right)u_{10} = -(G_r\theta_1 + G_m\phi_1 + Au_{00}'') \quad (30)$$

First-order equations:

$$u_{00}''' - u_{01}'' - u_{01}' + \left(M - \frac{1}{K}\right)u_{01} = G_r\theta_0 + G_m\phi_0 \quad (31)$$

$$u_{10}''' - u_{11}'' - u_{11} + \left(n - M + \frac{1}{K}\right)u_{11} = Au_{01}' + G_r\theta_1 + G_m\phi_1 \quad (32)$$

corresponding boundary conditions are:

$$y = 0: u_{00} = 1, u_{01} = 0, u_{10} = 0, u_{11} = 0 \quad (33)$$
$$y \to \infty: u_{00} \to 0, u_{01} \to 0, u_{10} \to 0, u_{11} \to 0$$

The solutions of the equations (29) to (32), under the boundary conditions (33) are obtained as

$$u_{00} = (1 + a_{10} + a_{11})e^{-a_9 y} - a_{10}e^{-\alpha y} - a_{11}e^{-a_4 y} \quad (34)$$

$$u_{10} = a_{19}e^{-a_{13}y} - a_{14}e^{-a_2 y} + a_{15}e^{-\alpha y} - a_{16}e^{-a_6 y} - a_{17}e^{-a_4 y} - a_{18}e^{-a_9 y} \quad (35)$$

$$u_{01} = a_{24}e^{-a_9 y} + a_{25}e^{-\alpha y} + a_{26}e^{-a_4 y} \quad (36)$$

$$u_{11} = a_{37}e^{-a_{13}y} + a_{32}e^{-a_9 y} + a_{33}e^{-\alpha y} + a_{34}e^{-a_4 y} - a_{34}e^{-a_2 y} - a_{36}e^{-a_6 y} \quad (37)$$

With the help of the above solutions, we can find the expressions for velocity, temperature and concentration as follows:

$$u = (a_{38}e^{-a_9 y} + a_{39}e^{-\alpha y} + a_{40}e^{-a_4 y}) + \epsilon e^{nt}(a_{41}e^{-a_{13}y} - a_{42}e^{-a_2 y} - a_{44}e^{-a_6 y} - a_{45}e^{-a_4 y} + a_{46}e^{-a_9 y}) \quad (38)$$

$$\theta = e^{-\alpha y} + \epsilon e^{nt}\left(c_4 e^{-a_2 y} - \frac{A\alpha}{n} e^{-a_2 y}\right) \quad (39)$$

$$\phi = e^{-a_4 y} + \epsilon\{(1 - a_7)e^{-a_6 y} - a_7 e^{-a_4 y}\} \quad (40)$$

The dimensionless form of the physical quantities, Skin-friction τ along x-axis, Nusselt number N_u and Sherwood number S_h are:

$$\tau = \left.\frac{\partial u}{\partial y}\right]_{y=0} = -(a_{38}a_9 + a_{39}\alpha + a_{40}a_4) - \epsilon e^{nt}\{-(a_{41}a_{13} + a_{42}a_2) - a_{43}\alpha + a_{44}a_6 + a_{45}a_4 + a_{46}a_9\} \quad (41)$$

$$N_u = \left.\frac{\partial \theta}{\partial y}\right]_{y=0} = -\alpha + \epsilon e^{nt}\left(-a_2 C_4 + \frac{A\alpha^2}{n}\right) \quad (42)$$

$$S_h = \left.\frac{\partial \phi}{\partial y}\right]_{y=0} = -a_4 + \epsilon e^{nt}\left(-a_2 C_4 + \frac{A\alpha^2}{n}\right) \quad (43)$$

4. Results and Discussion

The goal of our present analysis is to highlight the effects of chemical reaction and radiation on unsteady viscoelastic fluid flow through a porous medium. The analytical outcomes are discussed in the previous section. In the present section, the simulation of divergent flow parameters has been analyzed using MATLAB code. The consequences of physical parameters, such as viscoelastic parameter k_1, Grashof number G_r, modified/solutal Grashof number G_m, N_r the radiation parameter, Schmidt number S_c, chemical reaction parameter k, porosity parameter K on fluid flow variables like velocity, skin friction, concentration, and temperature have been analyzed using simulation and explained graphically in figures 2 to 10. Attention is directed towards the zero and non-zero values of the viscoelastic parameter, where the zero value of viscoelastic parameter k_1 acts for the Newtonian fluid motion and the non-zero value of k_1 (0.05, 0.10, 0.15) characterizes the viscoelastic fluid motion. The numerical computations are executed by taking n=0.1, ϵ=0.001, A=0.3, t=0.1, M=1.7, K=1/0.001, P_r=1.2, N_r=0.5, Sc=0.2, K_r=0.5, G_r=3, G_m=4 unless otherwise stated. Figures 2 to 5 illustrate the velocity distribution u (y, t) against y for different flow parameters involved in the fluid motion. From figures 2 to 5, it has been observed that the velocity increases sharply up to y= 1.25 near the plate, which gradually decreases and approaches zero as y increases. The variations of flow parameters in figures 3 to 5 do not change the flow pattern of velocity both in Newtonian and viscoelastic fluids. Moreover, with the increase of viscoelastic parameter k_1, the speed of the fluid velocity enhances. In all the figures k1 means k_1.

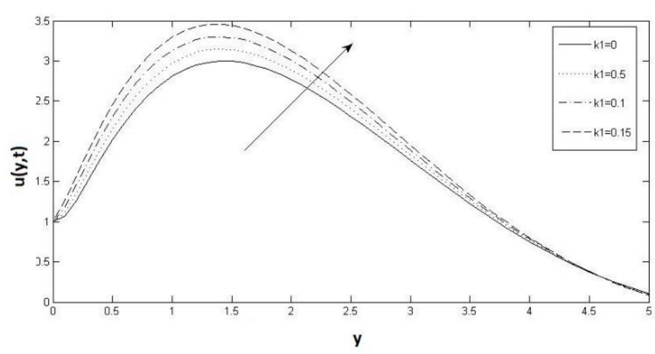

Figure: 2 Velocity distribution for different flow parameters n=0.1, t=0.1, P_r=1.2, M=1.7, N_r=0.5, Sc=0.2, K_r=0.5, ϵ=0.001, A=0.3, K=1/0.001, G_r=3, G_m=6

In chemical reaction and radiation flow problems, heat transfer plays an important role and consequently the significance of Grashof number comes into account. In fluid dynamics G_r estimates the ratio of buoyancy force to viscous force. Physically, the viscosity or resistance between fluid particles decreases as Grashof number grows (Grashof number is inversely related to viscosity), and speed increases as a result.

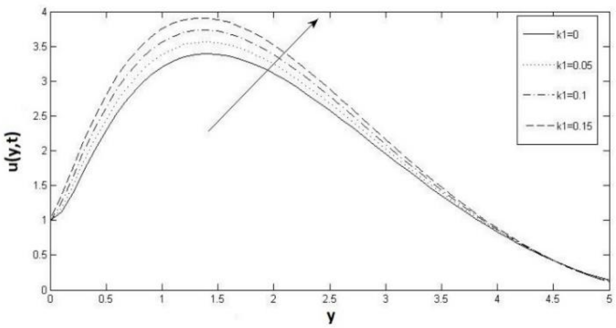

Figure: 3 Velocity distribution for diverse G_r
n=0.1, t=0.1, P_r=1.2, M=1.7, N_r=0.5, Sc=0.2, K_r=0.5, ϵ=0.0001, A=0.3, K=1/0.001, G_r=5, G_m=6

Throughout the study, Grashof number is considered to be non-zero and positive i.e., the fluid passes through a cooled plate(external). Figures 2 and 3 depict the effect of G_r on the velocity profile. It has also been found that with the enhancement of Grashof number, viscosity of a fluid diminishes which results a sharp hike in fluid velocity for both the fluids.

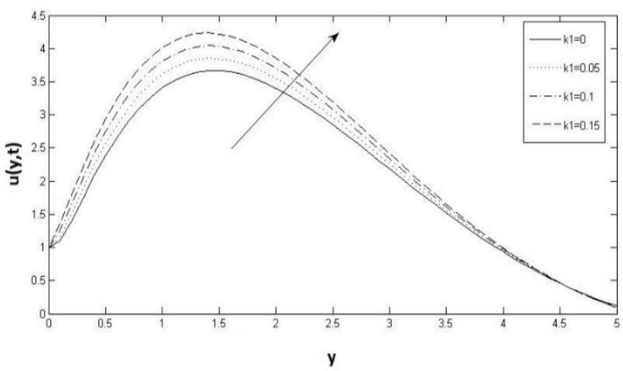

Figure: 4 Velocity distribution for diverse G_m
n=0.1, t=0.1, P_r=1.2, M=1.7, N_r=0.5, Sc=0.2, K_r=0.5, ϵ=0.0001, A=0.3, K=1/0.001, G_r=3, G_m=8

The Grashof number has a favourable effect on velocity since it minimises frictional power. As a result, the Grashof number may be raised to lessen the effect of friction. Again, ejection of mass occurs due to the fluid motion relation with mass transfer. The free convective parameter for mass transfer is represented by G_m. The positive non-zero value of G_m implies that the concentration at the boundary surface is more than the free stream concentration. Figures 2 and 4 indicates that with the increased value of G_m, fluid viscosity enhances and which amplifies the velocity furthermore.

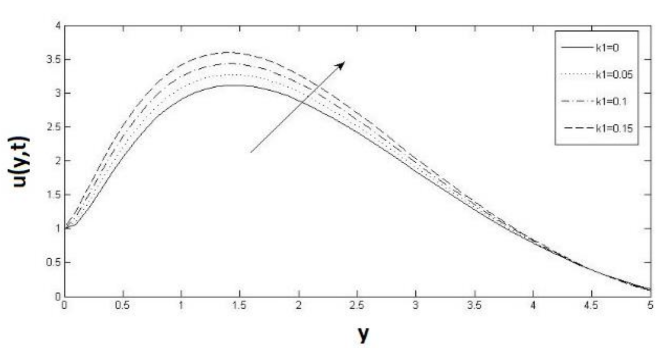

Figure: 5 Velocity distribution for diverse N_r
n=0.1, t=0.1, P_r=1.2, M=1.7, N_r=0.8, Sc=0.2, K_r=0.5, ϵ=0.001, A=0.3, K=1/0.001, G_r=3, G_m=6

From figures 2 and 5, it is observed that with the grow of thermal radiation parameter (N_r) there is a rising trend in the fluid velocity in both Newtonian and viscoelastic fluid which is due to the internal heat generation.

Effect of chemical reaction parameter (K_r) is shown in figures 2 and 6. It has been noticed that with the enhancement value of K_r, a considerable amount of growth in velocity is observed.

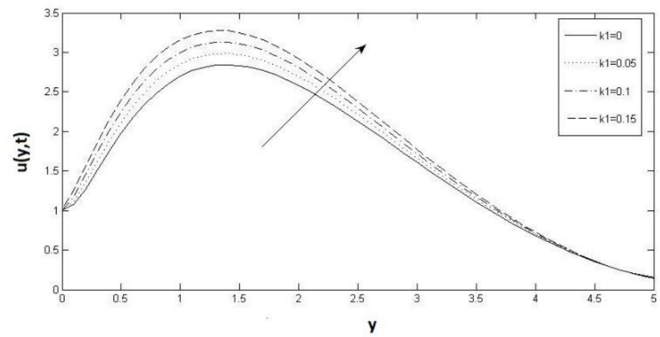

Figure: 6 Velocity distribution for diverse K_r
n=0.1, t=0.1, P_r=1.2, M=1.7, N_r=0.8, Sc=0.2, K_r=0.7, ϵ=0.001, A=0.3, K=1/0.001, G_r=3, G_m=6

The Prandtl number signifies the effect of thermal diffusion and momentum in the heat transfer problems, so its effects can't be ignored. From 2 and 7 it is clear that with the growing value of P_r, the fluid velocity diminishes in the respective fluids.

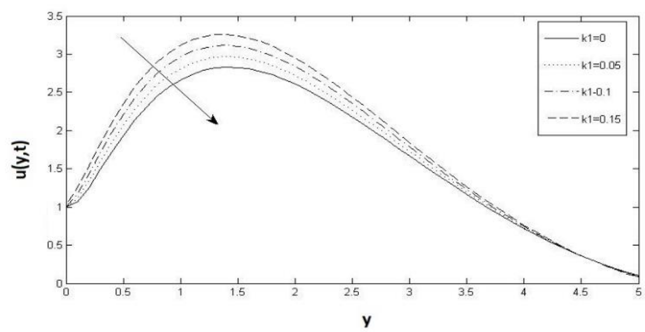

Figure-7 Velocity distribution for diverse P_r
n=0.1, t=0.1, P_r=1.4, M=1.7, N_r=0.5, Sc=0.2, K_r=0.5, ϵ=0.001, A=0.3, K=1/0.001, G_r=3, G_m=6

Figures 8 to 10 characterize the behavior of the shearing stress against the flow parameters such as Grashof number (G_r), solutal Grashof number (G_m) and magnetic parameter (M) respectively. It has been noticed that shearing stress enhances with the increase of G_r, but decreasing trend in shearing stress is observed with the growth of G_m and M in both Newtonian and viscoelastic fluids. Unlike fluid velocity, we observe a reverse trend in shearing stress. With the rise of viscoelastic parameter k_1 the shearing stress for viscoelastic fluids declines in comparison to Newtonian fluid.

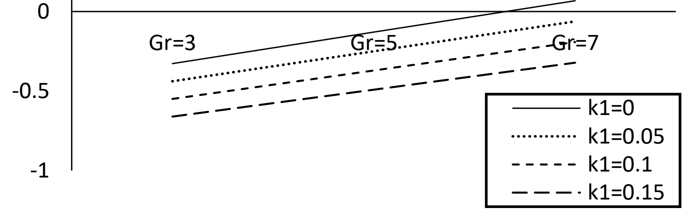

Figure-8 Effect of shearing stress against G_r

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Table-1: Values of Sherwood and Nusselt number for different parameters

k_1	P_r	N_r	S_c	K_r	M	G_m	G_r	S_h	N_u
0	1.2	0.5	0.2	0.5	1.7	3	6	-0.5654	-0.9245
0.05	1.2	0.5	0.2	0.5	1.7	3	6	-0.5654	-0.9245
0.1	1.2	0.5	0.2	0.5	1.7	3	6	-0.5654	-0.9245
0.15	1.2	0.5	0.2	0.5	1.7	3	6	-0.5654	-0.9245
0	1.4	0.5	0.2	0.5	1.7	3	6	-0.5654	-1.0786
0.05	1.4	0.5	0.2	0.5	1.7	3	6	-0.5654	-1.0786
0.1	1.4	0.5	0.2	0.5	1.7	3	6	-0.5654	-1.0786
0.15	1.4	0.5	0.2	0.5	1.7	3	6	-0.5654	-1.0786
0	1.6	0.5	0.2	0.5	1.7	3	6	-0.5654	-1.2327
0.05	1.6	0.5	0.2	0.5	1.7	3	6	-0.5654	-1.2327
0.1	1.6	0.5	0.2	0.5	1.7	3	6	-0.5654	-1.2327
0.15	1.6	0.5	0.2	0.5	1.7	3	6	-0.5654	-1.2327
0	1.2	0.3	0.2	0.5	1.7	3	6	-0.5654	-0.9245
0.05	1.2	0.3	0.2	0.5	1.7	3	6	-0.5654	-0.9245
0.1	1.2	0.3	0.2	0.5	1.7	3	6	-0.5654	-0.9245
0.15	1.2	0.3	0.2	0.5	1.7	3	6	-0.5654	-0.9245
0	1.2	0.7	0.2	0.5	1.7	3	6	-0.5654	-0.7070
0.05	1.2	0.7	0.2	0.5	1.7	3	6	-0.5654	-0.7070
0.1	1.2	0.7	0.2	0.5	1.7	3	6	-0.5654	-0.7070
0.15	1.2	0.7	0.2	0.5	1.7	3	6	-0.5654	-0.7070
0	1.2	0.9	0.2	0.5	1.7	3	6	-0.5654	-0.6326
0.05	1.2	0.9	0.2	0.5	1.7	3	6	-0.5654	-0.6326
0.1	1.2	0.9	0.2	0.5	1.7	3	6	-0.5654	-0.6326
0.15	1.2	0.9	0.2	0.5	1.7	3	6	-0.5654	-0.6326
0	1.2	0.5	0.5	0.5	1.7	3	6	-0.8093	-0.8013
0.05	1.2	0.5	0.5	0.5	1.7	3	6	-0.8093	-0.8013
0.1	1.2	0.5	0.5	0.5	1.7	3	6	-0.8093	-0.8013
0.15	1.2	0.5	0.5	0.5	1.7	3	6	-0.8093	-0.8013
0	1.2	0.5	0.7	0.5	1.7	3	6	-1.0382	-0.8013
0.05	1.2	0.5	0.7	0.5	1.7	3	6	-1.0382	-0.8013
0.1	1.2	0.5	0.7	0.5	1.7	3	6	-1.0382	-0.8013
0.15	1.2	0.5	0.7	0.5	1.7	3	6	-1.0382	-0.8013
0	1.2	0.5	0.9	0.5	1.7	3	6	-1.2592	-0.8013
0.05	1.2	0.5	0.9	0.5	1.7	3	6	-1.2592	-0.8013
0.1	1.2	0.5	0.9	0.5	1.7	3	6	-1.2592	-0.8013
0.15	1.2	0.5	0.9	0.5	1.7	3	6	-1.2592	-0.8013
0	1.2	0.5	0.2	0.4	1.7	3	6	-0.6000	-0.8013
0.05	1.2	0.5	0.2	0.4	1.7	3	6	-0.6000	-0.8013
0.1	1.2	0.5	0.2	0.4	1.7	3	6	-0.6000	-0.8013
0.15	1.2	0.5	0.2	0.4	1.7	3	6	-0.6000	-0.8013
0	1.2	0.5	0.2	0.6	1.7	3	6	-0.6622	-0.8013
0.05	1.2	0.5	0.2	0.6	1.7	3	6	-0.6622	-0.8013
0.1	1.2	0.5	0.2	0.6	1.7	3	6	-0.6622	-0.8013
0.15	1.2	0.5	0.2	0.6	1.7	3	6	-0.6622	-0.8013
0	1.2	0.5	0.2	0.8	1.7	3	6	-0.5276	-0.8013
0.05	1.2	0.5	0.2	0.8	1.7	3	6	-0.5276	-0.8013
0.1	1.2	0.5	0.2	0.8	1.7	3	6	-0.5276	-0.8013
0.15	1.2	0.5	0.2	0.8	1.7	3	6	-0.5276	-0.8013
0	1.2	0.5	0.2	0.5	1.7	3	3	-0.4316	-0.8013
0.05	1.2	0.5	0.2	0.5	1.7	3	3	-0.4316	-0.8013
0.1	1.2	0.5	0.2	0.5	1.7	3	3	-0.4316	-0.8013
0.15	1.2	0.5	0.2	0.5	1.7	3	3	-0.4316	-0.8013
0	1.2	0.5	0.2	0.5	1.7	3	5	-0.4316	-0.8013
0.05	1.2	0.5	0.2	0.5	1.7	3	5	-0.4316	-0.8013
0.1	1.2	0.5	0.2	0.5	1.7	3	5	-0.4316	-0.8013
0.15	1.2	0.5	0.2	0.5	1.7	3	5	-0.4316	-0.8013
0	1.2	0.5	0.2	0.5	1.7	3	7	-0.4316	-0.8013
0.05	1.2	0.5	0.2	0.5	1.7	3	7	-0.4316	-0.8013
0.1	1.2	0.5	0.2	0.5	1.7	3	7	-0.4316	-0.8013
0.15	1.2	0.5	0.2	0.5	1.7	3	7	-0.4316	-0.8013

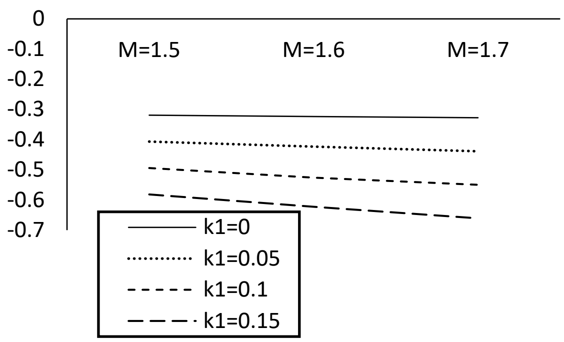

Figure: 9 Effect of shearing stress against G_m

The Nusselt and Sherwood number which characterizes the rate of heat and mass transfer respectively are not notably affected by the changed values of viscoelastic parameters k_1. Also, from the expressions (39) and (40) it is clear that the influence of viscoelastic parameter on temperature and concentration profile has no significance, although they are

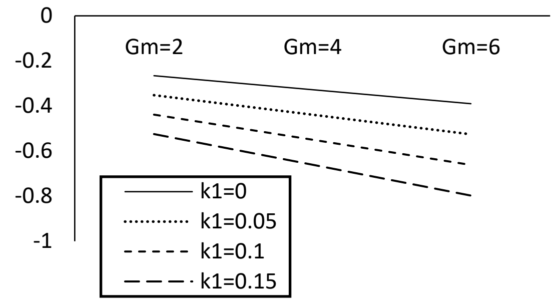

Figure: 10 Effect of shearing stress against M

considerably affected by Newtonian fluid. Since our prime focus is to find the effects of viscoelasticity on the Sherwood number, and the Nusselt number, and these are not affected by the parameter $k_{1,}$ so instead of graphical representation, we are expressing their values for different parameters in tabular form (Table-1). To ensure the validity of our findings, we compared them to previously published work for viscous fluid (Mishra et al., 2014) and found significant.

3. CONCLUSIONS

The key aspects of this study are highlighted here. The final ordinary differential equations are facilitated with some flow parameters and almost every parameter plays an effective role in the fluid flow region. The conclusion of this study is as follows

- The fluid velocity enhances sharply near the plate then decreases gradually and approaches to zero after attaining the peak.
- The speed of the fluid flow increases at each point with the growth of viscoelastic parameter in the flow region.
- Fluctuation of shearing stress is observed significantly for different flow parameters both in Newtonian and viscoelastic fluid.
- The Sherwood and the Nusselt number are not affected considerably with the change of viscoelastic parameter.
- No significant change is observed in the concentration and temperature profile by viscoelastic parameter due to constraining effects of elasticity.

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NOMENCLATURE

x, y	Cartesian coordinates
u, v	Velocity along x and y directions
g	Acceleration due to gravity
T	Dimensional temperature
C	Dimensional concentration
Cp	Specific heat at constant pressure
t	Time
B_o	Magnetic field intensity
K	Porous permeability
k	Thermal conductivity
N_r	Radiation parameter
A	Suction parameter
n	Exponential index, a constant
D	Molar diffusivity
P_r	Prandtl number
Gr	Grashof number
Gm	Solutal Grashof number

Greek symbols

ρ	Fluid density
σ	Electrical conductivity
β, β'	Volumetric expansion due to temperature and concentration
ϵ	Reference parameter (<<1)

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