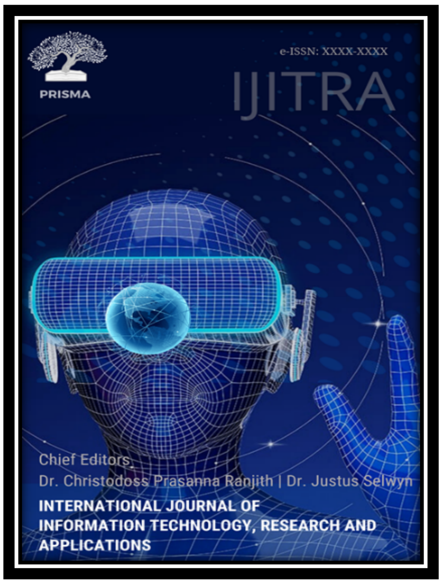

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Effects of Chemical Reaction and free convection on MHD Flow of a non-Newtonian (Rivlin Ericksen) Two-Phase Fluid Through Porous Medium with Time-Dependent Exponentially Reduced Velocities of the channel plates.

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ABSTRACT

The present investigation is a theoretical analysis of chemical reaction and MHD free convection effects on flow of a non-Newtonian (Rivlin Erickson type) duty gas through a porous medium induced in the motion of a semi-infinite flat plate moving with velocity decreasing exponentially with time. The magnetic field is applied normally to the system of flow. The dust particles in the mixed flow are chemically non-reactive but fluid species are reacting and the homogeneous chemical reaction of the first order is under the consideration. The two-phase flow model is governed by coupled partial differential equations. The governing PDEs are reduced to ODEs using assumed solutions. The results are carried out for the velocity profiles for the duty fluid, dust particles, concentration profile, and temperature distribution. The effect of various parameters like magnetic field parameter M, permeability parameter K, Prandtl number Pr, visco-elastic parameter β_0, and Schmidt number Sc on the velocity profiles for both the phase the dusty fluid as well as dust particles, temperature distribution, and concentration profile are investigated analytically and graphical representation is used to explain.

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I. INTRODUCTION

The applications of chemical reactions are in fluid flow systems are taken more in focus by several researchers due to their practical importance. The chemical reactions are observed in thermonuclear fusions, cooling of nuclear reactors for fluid metal, metal casting with electromagnetic process etc. The chemical reactions impacts as per their process (homogeneous / heterogeneous) of happening and order $\left(\frac{dc}{dt}\alpha C^n\right)$of reactions. In early experimental study was carried out by (Chamber and Young, 1958) on diffusions due to chemical reactions in boundary layer flows. Chemical reaction of first order is considered that is homogeneous in nature is taking place between the fluid species. The fluid mechanics problems where multiphase systems are in practical importance some non-Newtonian fluids like human blood, honey, soup are also in use. These fluids and fluid species are having destructive /constructive chemical reactions of first order takes place.

II. MATHEMATICAL FORMULATION

The governing equations of the flow are under following assumptions:

(i) The flow is along *x*-axis and the motion in the flat plate along *x*-axis is cause of flow of dusty fluid.

(ii) The physical quantities are depending on *y* and *t*.

Basic set of governing PDEs as per Saffman (1962) that models the flow of two phase flow along *x*-axis is

$$\frac{\partial u}{\partial t} = \upsilon\frac{\partial^2 u}{\partial y^2} + \frac{K_0 N_0}{\rho}(v-u) \tag{1}$$

$$\frac{\partial v}{\partial t} = \frac{K_0}{m}(u-v) \tag{2}$$

$$\frac{\partial T}{\partial t} = \frac{K_t}{\rho C_p}\frac{\partial^2 T}{\partial y^2} \tag{3}$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial y^2} - K(C - C_\infty) \tag{4}$$

Where u, v denote the fluid and particle velocity; υ - kinematic coefficient of viscosity ; K_0 - desistence coefficient; N_0 - dusty parameters density, ρ - density of the fluid ; m - mass of a dust particle; K_t - thermal conductivity, C_p - specific level a constant pressure.

Introducing chemical reaction parameter, concentration difference, magnetic and porosity parameters and no-Newtonian (Rivlin Ericksen type) dusty fluid, the equation of motion (1) reduced to:

$$\frac{\partial u}{\partial t} = \left(\upsilon + \beta\frac{\partial}{\partial t}\right)\frac{\partial^2 u}{\partial y^2} + \frac{K_0 N_0}{\rho}(v-u) - \left(\frac{\sigma B_0^2}{\rho} + \frac{\upsilon}{K}\right)u + g\beta_T\theta + g\beta_c\phi \tag{5}$$

Where, $\theta = (T - T_\infty)$, $\phi = (C - C_\infty)$

The governing boundary conditions given as:

$$\theta = \upsilon e^{-\lambda^2 t} \quad \phi = \upsilon e^{-\lambda^2 t} \quad u = \upsilon e^{-\lambda^2 t} \quad at\ \ y = 0$$
$$\theta \to 0, \quad \phi \to 0 \quad u \to 0, \quad as\ \ y \to \infty$$

Let us introduce the non-dimensional variables,

$$y^* = \frac{y}{(\upsilon\tau)^{1/2}},\ u^* = \frac{u}{\upsilon},\ v^* = \frac{v}{\upsilon},\ t^* = \frac{t}{\tau},\ \tau = \frac{m}{K0},\ \theta^* = \frac{\theta}{\upsilon},\ \phi^* = \frac{\phi}{\upsilon}$$

The reduced respective equations after using non-dimensional variables and dropping stars are:

$$\frac{\partial u}{\partial t} = \left(1 + \beta_0\frac{\partial}{\partial t}\right)\frac{\partial^2 u}{\partial y^2} + f(v-u) - \left(M + \frac{1}{K_1}\right)u + \beta_T\theta + \beta_c\phi \tag{6}$$

$$\frac{\partial v}{\partial t} = (u - v) \tag{7}$$

$$\frac{\partial \theta}{\partial t} = \frac{v}{Pr}\left(1 + \beta_0\frac{\partial}{\partial t}\right)\frac{\partial^2 \theta}{\partial y^2} \tag{8}$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc}\left(1 + \beta_1\frac{\partial}{\partial t}\right)\frac{\partial^2 \phi}{\partial y^2} - k_1\phi \tag{9}$$

Where f - dust particles mass concentration; M - magnetic parameter; β_0, β_1- visco-elastic , volumetric expansion parameter; Pr - Prandtl number; K_1 - permeability parameter.

$$f = \frac{mN_0}{\rho},\quad M = \frac{m\sigma B_0^2}{K_0\rho},\ \beta_1 = g\beta t,\ \beta_o = \frac{\beta}{\tau\upsilon}, Pr = \frac{\rho\upsilon C_P}{K_T},\quad \frac{1}{K_1} = \frac{\upsilon\tau}{K}$$

The boundary conditions are reduced to

$$\theta = e^{-\lambda^2 t},\ \phi = e^{-\lambda^2 t},\quad u = e^{-\lambda^2 t} \quad at\ \ y = 0$$
$$\theta \to 0, \quad \phi = 0, \quad u \to 0, \quad as\ \ y \to \infty$$

Assumed solutions for equations (6)- (9) respectively are,

$$u = F(y)e^{-\lambda^2 t},\ v = G(y)e^{-\lambda^2 t},\ \theta = H(y)e^{-\lambda^2 t},\ \phi = I(y)e^{-\lambda^2 t} \tag{10}$$

The boundary conditions are transformed as:

$$H = 1,\quad I \to 1,\quad F = 1 \quad at\ \ y = 0$$
$$H \to 0,\quad I \to 0,\quad F \to 0,\quad as\ \ y \to \infty$$

Introducing the assumed solutions to the equations (6) –(9) in view of (10) reduced to,

$$\frac{d^2F}{dy^2}(1 - \lambda^2\beta_0) + F\left[\lambda^2 - f - M - \frac{1}{K_1}\right] + fG = -\beta_T H - \beta_C I \tag{11}$$

$$G(1 - \lambda^2) = F \tag{12}$$

$$\frac{d^2H}{dy^2} + m^2 H = 0 \tag{13}$$

$$\frac{d^2I}{dy^2} + {n_4}^2 I = 0 \tag{14}$$

Eliminating G from and we get

$$\frac{d^2F}{dy^2} + n_1^2 F = -n_2 H - n_3 I \quad (15)$$

From the equation (13) and (14) we get

$$H = e^{-imy}, I = e^{-in_4 y} \quad (16)$$

Equation (15) solved with boundary conditions as,

$$F = \left[e^{-in_1 y} + \frac{n_2}{m^2 - n_1^2} e^{-imy} + \frac{n_3 e^{-in_3 y}}{n_4^2 - n_1^2}\right] \quad (17)$$

Equation (12) gives,

$$G = \frac{1}{1-\lambda^2}\left[e^{-in_1 y} + \frac{n_2}{m^2 - n_1^2} e^{-imy} + \frac{n_3 e^{-in_3 y}}{n_4^2 - n_1^2}\right] \quad (18)$$

The dusty fluid velocity is given by,

$$u = \left[e^{-in_1 y} + \frac{n_2}{m^2 - n_1^2} e^{-imy} + \frac{n_3 e^{-in_3 y}}{n_4^2 - n_1^2}\right] e^{-\lambda^2 t} \quad (19)$$

Real part of u is given by

$$u = \left[\cos n_1 y \; e^{-\lambda^2 t} + \left\{\frac{n_2}{m^2 - n_1^2}(\cos n_1 y - \cos my) + \frac{n_3}{n_4^2 - n_1^2}(\cos n_1 y - \cos n_4 y)\right\} e^{-\lambda^2 t}\right] \quad (20)$$

Real Part for dust particle velocity v is given by

$$v = \frac{1}{(1-\lambda^2)}\left[\cos n_1 y \; e^{-\lambda^2 t} + \left\{\frac{n_2}{m^2 - n_1^2}(\cos n_1 y - \cos my) + \frac{n_3}{n_4^2 - n_1^2}(\cos n_1 y - \cos n_4 y)\right\} e^{-\lambda^2 t}\right] \quad (21)$$

And temperature and concentration distribution is given by

$$\theta = e^{-imy} e^{-\lambda^2 t}, \phi = e^{-in_4 y} e^{-\lambda^2 t} \quad (22)$$

The real part of θ, ϕ is given by $\theta = \cos(m\,y) e^{-\lambda^2 t}, \; \phi = \cos(n_4\, y) e^{-\lambda^2 t}$. (23)

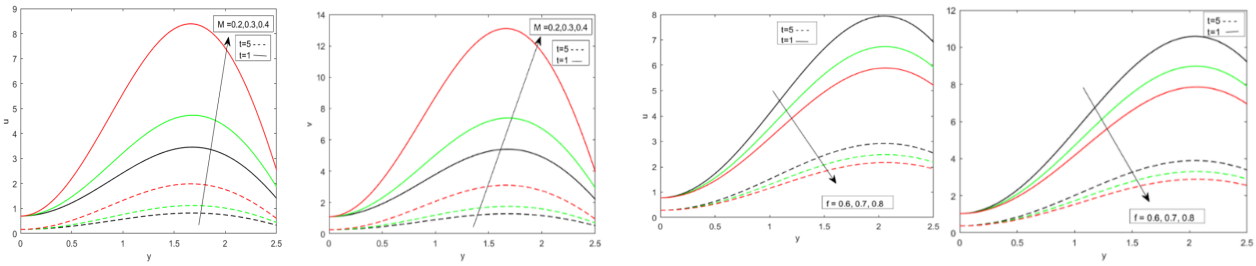
III. RESULTS AND DISCUSSION:

The present investigation is carried out for the two phase visco-elastic (Rivlin Erickson) fluid flowing through a rectangular channel. The heat transfers and chemical reaction for first order in fluid species is under consideration. The fluid is of second order with non-reactive dust particles. The magnetic field is applied to the flow. The governing coupled partial differential equations are solved analytically by reducing in to ordinary differential equations. The results obtained are plotted through Software MATLAB. Velocity profiles for both the phases, concentration profile, and temperature distribution are evaluated that are displayed through figures 1 to 4. The fixed values considered for the different parameter used to obtain the numerical results are mass concentration parameter f = 0.5, $\boldsymbol{\beta_1} = \mathbf{5}$, Pr=1.5, $\boldsymbol{\lambda} = \mathbf{0.5}$, and t=*1* and t = 5.

Figures 1a and 1b are plotted for velocity profile for dusty fluid as well as dust particle for different values of magnetic field parameter M=0.2, 0.3, 0.4. Increasing values of magnetic field influencing as enhanced the velocity for both the phases dusty fluid and dust particles. The flow is started by giving velocity to the channel plate. The velocities are showing drastic reduction in the pattern for higher values of time t. Figures 1c and 1d are plotted for velocity profile for dusty fluid as well as dust particle for different values of particle mass concentration parameter f (0.6, 0.7, 0.8). Increasing concentration parameter reduces the velocity for both the phases dusty fluid as well as dust particles. In presence of mass concentration parameter flow is investigated for time t=*1* and t=*5*. Increasing time values are reducing the velocities. Figures 2a and 2b are plotted for velocity profile for dusty fluid as well as dust particle for different values of porosity parameter K (8, 10, 12). The enhanced values of K reducing the velocity profiles for both the phases of dusty fluid as well as dust particles. In presence of mass concentration parameter flow is investigated for time t=*1* and t=*5*. Increasing time values are reducing the velocities. Figures 2c and 2d are plotted for velocity profile for dusty fluid as well as dust particle for different values of visco-elastic parameter $\boldsymbol{\beta_0}$ (0.4, 0.7, 1.0). The enhanced values of visco-elastic parameter $\boldsymbol{\beta_0}$ increases the velocity profiles for both the phases of dusty fluid as well as dust particles. In presence of visco-elastic parameter $\boldsymbol{\beta_0}$ flow is investigated for time *t=1* and *t=5*. Increasing time values are reducing the velocities.

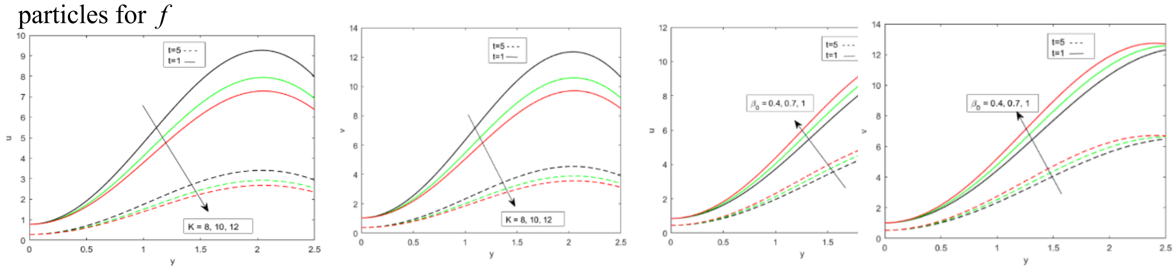
Heat transfer in the two-phase real fluid mixed with fine dusty particles which are non-reactive to the fluid species is investigated for the different parameters that are displayed through figure 3. Figures 3a is plotted for the temperature field for dusty fluid as well as dust particle for different values of Prandtl number *Pr* (1.0, 1.3, 1.5). Increasing values of Prandtl number reducing the temperature field for both the phases dusty fluid and fine mixture of particles. Figure 3b is plotted for the temperature field for dusty fluid for different values of visco-elastic parameter $\boldsymbol{\beta_0}$ (0.4, 0.7, 1.0). Increasing values of visco-elastic parameter reducing the temperature field for both the phases dusty fluid and fine mixture of particles. In the investigation it is in assumption that particles are non-reactive but fluid species are having homogeneous chemical reactions of first order.

In view of that concentration profile is obtained and plotted through the graphs 4a-4c Figures 4a is plotted for concentration profile for dusty fluid for different values of Schmidt number *Sc* (0.3, 0.5, 0.7). Increasing Schmidt number reduces the concentration profile of the dusty fluid. Figures 4b is plotted for concentration profile for dusty fluid for different values of chemical reaction parameter $\boldsymbol{K1}$ (0.2, 0.4, 0.6). Increasing values of K1 enhances the concentration profile of the dusty fluid. Figures 4c is plotted for concentration profile for dusty fluid for different values of visco-elastic parameter $\boldsymbol{\beta_0}$ (0.4, 0.7, 1.0). Increasing visco-elastic parameter reduces the concentration profile of the dusty fluid.



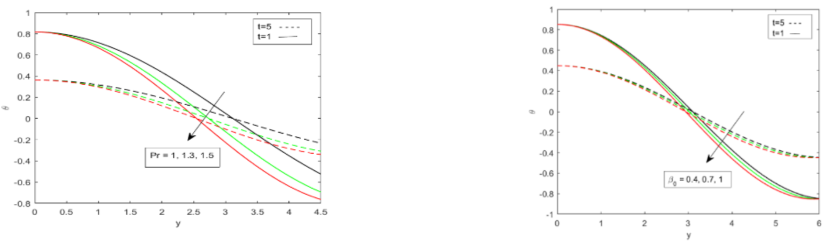
(a) (b) (c) (d)

Figure 1: Velocity Profile for a) dusty fluid for *M* b) dust particles for *M* c) dusty fluid for *f* d) dust particles for *f*



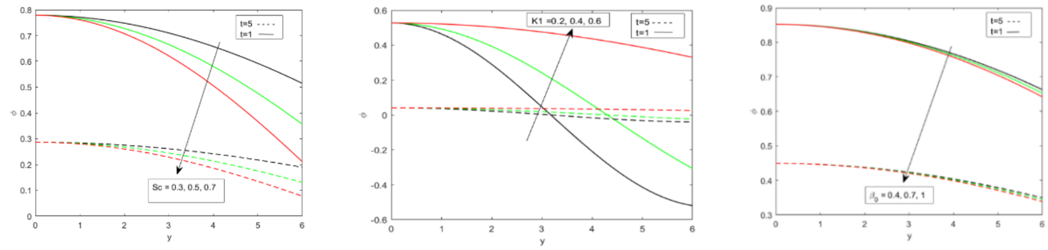
(a) (b) (c) (d)

Figure 2: Velocity Profile for a) dusty fluid for *K* b) dust particles for *K* c) dusty fluid for β_0 d) dust particles for β_0



(a) (b)

Figure 3: Temperature Profile for a) *K* b) β_0



(a) (b) (c)

Figure 4: Concentration Profile for a) *Sc* b) *K1* c) β_0

IV. CONCLUSION

The present investigation of chemical reaction with various parameters on two phase viscoelastic (Rivlin Ericksen) fluid is concluded as:

(i) The high intensity of magnetic field parameter enhances the velocity of both phases the dusty fluid along with dust particles.

(ii) The rising values of concentration parameter *f*, porosity parameter *K*, and viscoelastic parameter β_0 decreases the velocity of both the phases dusty fluid as well as dust particles.

(iii) Dust particles are showing less velocity compared to dusty fluid because dust particles get motion due to the motion of the fluid. It is also observed if the nonreactive dust particle is flowing with fluid their flow pattern is the same as that of the fluid.

(iv) The increasing viscoelastic parameter β_0 and Prandtl number *Pr* decreases the temperature field.

(v) Increasing chemical reaction parameter *K1* increase the concentration profile.

(vi) The velocity for both the phase (*u*, *v*), temperature field θ, concentration profile ϕ reduced exponentially with increasing time.

(vii) The increasing Schmidt number Sc and the viscoelastic parameter β_0 decreases the concentration profile ϕ of both the phases the dusty fluid as well as the dust particle.

The results are investigated theoretically subject to be verified with experimental results for the very specific viscoelastic fluid for purpose of industrial applications.

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