Thermal Radiation and Chemical Reaction Effects on Unsteady Laminar Hydro Magnetic Free Convective Flow of Oldroyd Fluid Through Porous Medium Along a Moving Vertical Plate with Thermal Diffusion

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***Abstract**: In this chapter the effect of Oldroyd fluid on unsteady laminar free convective flow through porous medium along a moving vertical plate in the presence of Heat source, Chemical reaction and thermal Radiation is studied. The dimensionless governing equations of the flow field are solved analytically. The expressions for velocity, temperature, concentration, skin friction, nusselt number and Sherwood number has been analyzed through graphs and tables.*

Keywords- *Oldroyd fluid, Heat source, Thermal Radiation, Chemical reaction.*

1 INTRODUCTION

The study of non-Newtonian fluid flow has gained the attention of engineers and scientists in recent times due to its important application in various branches of science, engineering and technology: particularly in chemical and nuclear industries, material processing, geophysics, and bio-engineering. In view of these applications an extensive range of mathematical models have been developed to simulate the diverse hydrodynamic behaviour of these non- Newtonian fluids. In particular, different visco-elastic fluid model (like the Rivlin-Ericksen second order model, Oldroyd model, Johnson-Seagalman model).Szeri and Rajagopal [19] examined the flow of a non-Newtonian fluid between heated parallel plates. Singh and Singh [15] have studied MHD heat transfer flow of a dusty visco-elastic liquid down an inclined channel in porous medium. The effect of Oldroyd fluid on unsteady laminar free convective flow through porous medium along a moving porous hot vertical plate in the presence of heat source and thermal diffusion with mass transfer studied by virendraprasad et al [20]. Makinde and Sibanda [7] investigated MHD mixed convection flow with heat and mass transfer past a vertical plate embedded in a uniform porous medium with constant wall suction in the presence of uniform transverse magnetic field. Prakash et al [9] have studied heat transfer MHD flow of viscoelastic (Walters' liquid model – B) stratified fluid in porous medium under variable viscosity.

The visco-elastic MHD convection flow problems are very important in both theoretical and experimental studies as they have overwhelming implications in various fields as petroleum industries, cooling of nuclear reactors, boundary layer control in aerodynamics, crystal growth etc. Again, diffusion rates can be changed tremendously with chemical reactions. A few representative areas of interest in which heat and mass transfer combined along with the chemical reaction play significant role in chemical industries like in food processing and polymer production. The idea of first order chemical reaction where the rate of reaction is directly proportional to the concentration itself has been analysed by Cussler[1]. Patil et al. [8] studied double diffusive mixed convection flow over a moving vertical plate in the presence of internal heat generation and chemical reaction. Sonth*et al.* [16] examined the heat and mass transfer flow of a viscoelastic fluid over an accelerated surface with heat source/sink and viscous dissipation.

The importance of thermal-diffusion and diffusion-thermo effects for various fluid flows has been studied by Eckert and Drake [3]. Saxena and Dubey [13] have analyzed the flow behaviour 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. A Soret effect due to natural convection between heated inclined plates with magnetic field was studied by Raju et al. [10,11].

The role of thermal radiation is of major importance in the design of many advanced energy convection systems operating at high temperature and knowledge of radiative heat transfer becomes very important in nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles and space vehicles. Grosan and Pop [5], Joshi and Kumar [6] and Srinivas and Muthuraj [18] have made investigations of fluid flow with thermal radiation. Ghosh [4] investigated the hydrodynamic fluctuating flow of a viscoelastic fluid in a porous channel, where the channels oscillate with a given velocity in their own planes. Shateyi*et al.* [14] investigated the effects of thermal Radiation, Hall currents, Soret and Dufour on MHD flow by mixed convection over vertical surface in porous medium. Das [2] has analysed viscoelastic effects on unsteady two-dimensional and mass transfer of a viscoelastic fluid in a porous channel with radiative heat transfer.

The main objective of the present chapter is to study the effect of oldroyd fluid on unsteady laminar free convective flow along a moving porous hot vertical plate with thermal diffusion and mass transfer. Approximate solutions have been derived for the mean velocity, mean temperature and mean concentration using perturbation technique and these are presented in graphical form.

2 MATHEMATICAL FORMULATION

In this chapter an unsteady viscous incompressible laminar flow of electrically conducting dusty fluid of oldroyd model through a highly porous medium over an infinite moving vertical plate is considered. A Cartesian coordinate system is considered withX'-axis along plate and Y'-axis taken normal to it. A uniform magnetic field is applied perpendicular to the fluid flow direction.

We made the following assumptions

i. Plate is long enough in thex' direction and hence all the physical quantities are independent of X' only

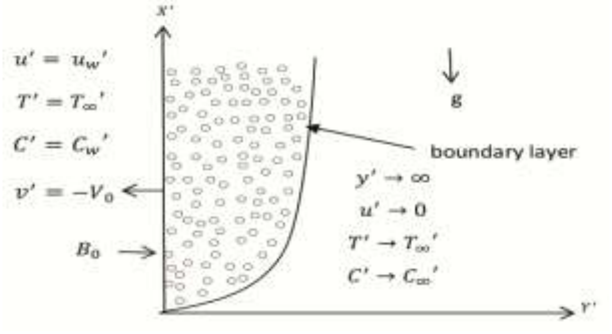
ii. The dust particles are non-conducting, solid, spherical, and equal in size, uniformly and symmetrically distributed in the flow field and their number density is constant throughout the motion.

iii. The electric field and induced magnetic field are neglected [12, 17]

iv. Dissipation effects are neglected

v. Hall effects are neglected

vi. Thermal diffusion, thermal radiation and chemical reaction effects are taken in to account.



Physical Model

Under these assumptions and using Boussinesq's approximation the equations governing the flow are

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

$$v' = -V_0 \qquad (2)$$

$$\left(1 + k_1{}' \frac{\partial}{\partial t'}\right)\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \vartheta\left(1 + k_2{}' \frac{\partial}{\partial t'}\right)\frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T_\infty) + g\beta'(C' - C_\infty) - \frac{\sigma_e {B_0}^2}{\rho}(1 + k_1{}' \frac{\partial}{\partial t'})u' + \frac{K_1 N_0}{\rho}(1 + k_1{}' \frac{\partial}{\partial t'})(V' - u') - \frac{\vartheta}{K'}u' \qquad (3)$$

$$m_1 \frac{\partial V'}{\partial t'} = K_1(u' - V') \qquad (4)$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} + \frac{Q_0}{\rho C_p}(T' - T_\infty') - \frac{1}{\rho C_p}\frac{\partial q_r{}'}{\partial y'} \qquad (5)$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} + D_1\frac{\partial^2 T'}{\partial y'^2} + K_1{}'(C' - C_\infty) \qquad (6)$$

The boundary conditions at the wall and in the free stream are

$$u' = u_w{}', T' = T_w{}', C' = C_w{}' \quad at\ y' = 0, t' \le 0$$
$$u' \to 0, T' \to T_\infty{}', C' \to C_\infty{}' \quad at\ y' \to \infty, t' > 0 \qquad (7)$$

The radiative heat flux is given by

$$q_r{}' = -\frac{4\sigma^*}{3K_s}\frac{\partial T'^4}{\partial y'} \qquad (8)$$

Where $\sigma'\ and\ K_s$are the Stefan-Boltzmann constant and the Roseland mean absorption coefficient, respectively. We assume that the temperature differences within the flow are sufficiently small such that T'^4 may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor series about T'^4 and neglecting higher order terms, thus

$$T'^4 \cong 4T_\infty'^3 T^* - 3T_\infty'^4$$

(9)

Using (5.8) and (5.9) in the last term of equation (5.5), we obtain

$$\frac{\partial q_r'}{\partial y'} = -\frac{16\sigma^* T_\infty'^3}{3K_s}\frac{\partial^2 T'}{\partial y'^2} \qquad (10)$$

Introducing the non-dimensional quantities

$$u = \frac{u'}{v_0}, v = \frac{V'}{v_0}, y = \frac{y' V_0}{\vartheta},$$

$$\theta = \frac{T' - T_\infty}{T_w' - T_\infty}, \emptyset = \frac{C' - C_\infty}{C_W' - C_\infty}, Pr = \frac{\mu C_p}{k},$$

$$Sc = \frac{\vartheta}{D}, M = \frac{\sigma_e B_0^2 \vartheta}{\rho V_0^2}, \ Gr = \frac{\vartheta g\beta\,(T_w' - T_\infty)}{V_0^3},$$

$$Gc = \frac{\vartheta g\beta'(C_w' - C_\infty)}{V_0^3},$$

$$Q = \frac{\vartheta^2 Q_0}{kV_0^2}, So = \frac{D_1(T_w' - T_\infty)}{\vartheta(C_w' - C_\infty)}, Q_1 = \frac{u_w}{v_0},$$

$$B = \frac{m_1 V_0^2}{\vartheta K_1},$$

$$B_1 = \frac{\vartheta K_1 N_0}{\rho V_0^2}, k_1 = \frac{k_1' V_0^2}{\vartheta}, k_2 = \frac{k_2' V_0^2}{\vartheta},$$

$$R = \frac{4\sigma^* T_\infty'^3}{K_T K_s}, \ K = \frac{K' V_0^2}{\vartheta^2} \qquad (11)$$

Using equation (11) in to equations (3) to(6), we get following equations in non-dimensional form

$$\left(1 + k_2\frac{\partial}{\partial t}\right)\frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y} - \left(1 + k_1\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t} + B_1\left(1 + k_1\frac{\partial}{\partial t}\right)(v - u)$$

$$-\left(M(1 + k_1\frac{\partial}{\partial t}) + \frac{1}{K}\right)u = -Gr\theta - Gc\emptyset$$

(12)

$$B\frac{\partial v}{\partial t} = u - v$$

(13)

$$Pr\frac{\partial\theta}{\partial t} - Pr\frac{\partial\theta}{\partial y} = (1 + \frac{4R}{3})\frac{\partial^2\theta}{\partial y^2} + Q\theta \qquad (14)$$

$$\frac{\partial^2\emptyset}{\partial y^2} + Sc\frac{\partial\emptyset}{\partial y} - Sc\frac{\partial\emptyset}{\partial t} + SoSc\frac{\partial^2\theta}{\partial y^2} + ScKr\emptyset = 0$$

(15)

The corresponding boundary conditions in non-dimensional form

$$u = Q_1, \ \theta = 1, \emptyset = 1 \ \ at \ \ y = 0, t \le 0$$

$$u \to 0, \theta_0 \to 0, \emptyset_0 \to 0 \ \ \ as\ y \to \infty, t > 0$$

(16)

3 SOLUTION OF THE PROBLEM

Equations (12)-(15) represent a set of partial differential equations that cannot be solved in closed form. However, these equations can be solved analytically.

$$u(y,t) = u_0\,(y)e^{-nt}$$

$$v(y,t) = v_0\,(y)e^{-nt}$$

$$\theta(y,t) = \theta_0\,(y)e^{-nt}$$

$$\emptyset(y,t) = \emptyset_0\,(y)e^{-nt} \qquad (17)$$

Substitute equation (17) in equations (12)-(15), we get

$$(1 - nk_2)u_0'' + u_0' + k_3 u_0 = (nB_1k_1 - B_1)v_0 - Gr\theta_0 - Gc\emptyset_0$$

(18)

$$v_0 = \frac{1}{1-nB}u_0 \qquad (19)$$

$$\left(1 + \frac{4R}{3}\right)\theta_0'' + Pr\theta_0' + (nPr + Q)\theta_0 = 0 \qquad (20)$$

$$\emptyset_0'' + Sc\emptyset_0' + (nSc + ScKr)\emptyset_0 = -SoSc\theta_0'' \ (21)$$

The corresponding boundary conditions are

$$u_0 = Q_1, \theta_0 = 1, \emptyset_0 = 1 \ \ at \ \ y = 0$$

$$u_0 \to 0, \theta_0 \to 0, \emptyset_0 \to 0 \ \ \ as\ y \to \infty$$

(22)

On solving equations (18)-(21) which are ordinary differential equations in $u_0, v_0, \theta_0, \emptyset_0$ with boundary conditions (22), we get the values of $u, v, \theta, \emptyset$ as

$$u = (k_7e^{-a_6y} - k_4e^{-a_2y} - k_5e^{-a_4y} + k_6e^{-a_2y})e^{-nt}$$

(23)

$$v = \frac{1}{1-nB}(k_7 e^{-a_6 y} - k_4 e^{-a_2 y} - k_5 e^{-a_4 y} + k_6 e^{-a_2 y})e^{-nt} \tag{24}$$

$$\theta = e^{-a_2 y} e^{-nt} \tag{25}$$

$$\emptyset = ((1 + b_2)e^{-a_4 y} - b_2 e^{-a_2 y})e^{-nt} \tag{26}$$

SKINFRICTION

Skinfriction coefficient at the plate is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = (-k_7 a_6 + k_4 a_2 + k_5 a_4 - k_6 a_2)e^{-nt} \tag{27}$$

NUSSELT NUMBER

Rate of heat transferinterms of Nusselt number at the plate is given by

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = a_2 e^{-nt} \tag{28}$$

SHERWOOD NUMBER

Rate of mass transfer interms of Sherwood number at the plate is given by

$$Sh = -\left(\frac{\partial \emptyset}{\partial y}\right)_{y=0} = ((1 + b_2)a_4 - k_2 a_2)e^{-nt} \tag{29}$$

4 RESULTS AND DISCUSSION

Numerical calculations are carried out for different values of dimensionless parameters and representative set of results is reported graphically in Figures. 1-20 These results are obtained to illustrate the influence of the Chemical reaction parameter Kr, Dufour number Df, Magnetic field parameter M, Schmidt number Sc, Soret number So, Grashof number Gr, modified Grashof number Gc on the velocity, temperature and concentration profiles, while the values of the physical parameters are fixed at real constants.

Figure.1 shows results for concentration profiles for different values of Chemical reaction parameter Kr. It is seen that concentration decreases with increasing values of the Chemical reaction parameter Kr. Figure. 2 illustrate the influence of the Schmidt number Sc on concentration field in the boundary layer. It is noticed concentration decreases as Schmidt number Sc increases. Figure.3 illustrate the influence of the Soret number So onconcentration profiles. It is seen that concentration increases as Soret number So increases. Figure. 4 shows results for concentration profiles for different values of Heat source parameter Q. It is observed that concentration increases with increasing values of the Heat source parameter S.

For different values of the thermal Radiation parameter R, the temperature profiles are plotted in Figure.5. It is seen that as thermal Radiation parameter R increases, the temperature profiles increases. Figure..6 shows the temperature profiles for different values of Prandtl number Pr. We noticed that the temperature decreases with increasing values of Prandtl number Pr.

For different values of the thermal Radiation parameter R, the velocity profiles are plotted in Figure .7. It is seen that as thermal Radiation parameter R increases, velocity profiles increases. Figure.8 shows the velocity profiles for different values of Permeability parameter K. It is observed that as Permeability parameter K increases, the velocity increases. Figure.9 illustrates the effect of Grashof number Gr on velocity profile. It is observed that as the Grashof number Gr increases, the velocity also increases. The velocity profile for different values of modified Grashof number Gc are shown in figure.10. This shows that the velocity increases for $y \leq 2$ near the plate and decreases for $y > 2$with increasing values of modified Grashof number Gc.

Figure. 11 shows the velocity profiles for different values of Magnetic field parameter M. It is obvious that as the Magnetic field parameter M increases, the velocity decreases. Figure.12 illustrates the effect of Prandtl number Pr on velocity profiles. It is observed that as the Prandtl number Pr increases, the velocity also decreases. The velocity profiles for different values of Visco-elastic parameter $k_2$are shown in Figure.13. It is observed that as visco-elastic parameter increases, velocity decreases.The velocity profiles for different values of Visco-elastic parameter $K_1$are shown in Figure.14. It is observed that as visco-elastic parameter increases, velocity decreases. Figure.15 illustrate the influence of the Soret number So on velocity profiles. It is seen that velocity increases as Soret number So increases. Figure.16 shows results for velocity profiles for different values of Chemical reaction parameter Kr. It is seen that velocity decreases with increasing values of the Chemical reaction parameter Kr.

Figure.17 shows the velocity profiles for dust particle for different values of Magnetic field parameter M. It is obvious that as the Magnetic field parameter M increases, the velocity decreases. Figure.18 shows the velocity profiles for dust particle for different values of Permeability parameter K. It is observed that as Permeability parameter K increases, the velocity increases. Figure.19 and.20 display the effect of Visco-elastic parameters K_1 *and* K_2 on velocity profiles for dust particle. It is observed that dust particle velocity increases as K_1 while decreases as K_2 increases.

Table.1 shows the numerical values of mass transfer coefficient in terms of Sherwood number (*Sh*) for various values ofand Chemical reaction parameter Kr, Schmidt number Sc, Soret number *So*, and Prandtl number *Pr*. It isobserved that as Chemical reaction Kr and Schmidt number Sc increases, Sherwood number increases,as Soret number So and Prandtl number Pr increases,Sherwood number decreases.

Table.2 shows the numerical values of heat transfer coefficient in terms of nusselt number (*Nu*) for various values ofPrandtl number Prand Radiation parameter R. It isobserved that nusselt number increases for increasing values of Pr and decrease for increasing values of Radiation parameter R.

Table.3 shows the numerical values of skinfrictionfor various values ofSoret number *So*, Chemical reaction parameter Kr, Radiation parameter R, Heat source parameter Q, Grashof number Gr, modified Grashof number Gc.It isobserved that as Soret number So, Radiation parameter R, Grashof number Gr, modified Grashof number Gc increase, skinfriction for dusty fluid and dust particle increase. As Chemical reaction Kr and Heat source parameter S increase, skinfriction decrease for dusty fluid and dust particle.

5 CONCLUSIONS

In this chapter we studied Chemical reaction and thermal Radiation effects on unsteady laminar hydro magnetic free convective flow of Oldroyd fluid through porous medium along a moving vertical plate with thermal diffusion. The governing equations are solved analytically. From this investigation, the following observations have been drawn

1. Velocities of dustyfluid and dust particles increase with the increase in Porosity parameter while decrease with the increase in Magnetic field parameter.
2. Temperature increases with increasing values of Radiation parameter while decreases with increasing values of Prandtl number
3. Concentration decreases with increasing values of Chemical reaction parameter and Schmidt number while increases with increasing values of Soret number
4. Skinfriction increases for dusty fluid and dust particles with the increase in Soret number while decreases with Heat source parameter.
5. Nusselt number increases with increasing values of Prandtl number while decreases with increasing values of Radiation parameter.
6. Sherwood number increases with increasing values of Chemical reaction parameter while decreases with increasing values of Soret number.

GRAPHS AND TABLES

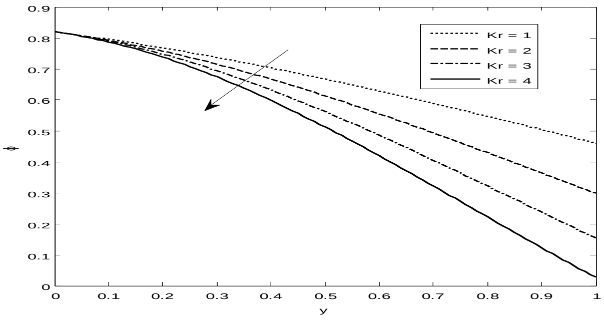


Fig.1. Concentration profiles for different values ofKr with t=2, n=0.1, R=1, Pr=0.71, Q=0.05, Sc=0.6

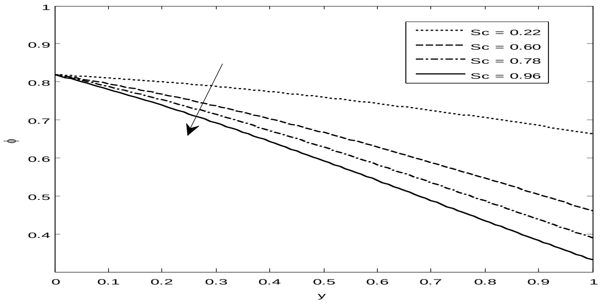


Fig.2. Concentration profiles for different values ofSc with t=2, n=0.1, R=1, Pr=0.71, Q=0.05, Kr=1, So=1

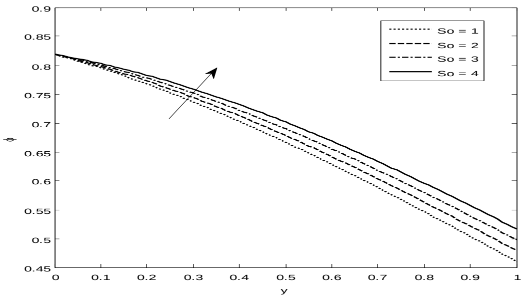


Fig.3. Concentration profiles for different values of So with t=2,n=0.1, R=1, Pr=0.71, Q=0.05, Sc=0.6, Kr=1

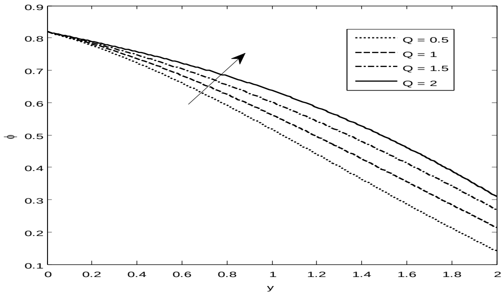


Fig.4. Concentration profiles for different values of Q with t=2, n=0.1, R=1, Pr=0.71, Sc=0.6, So=1, Kr=1

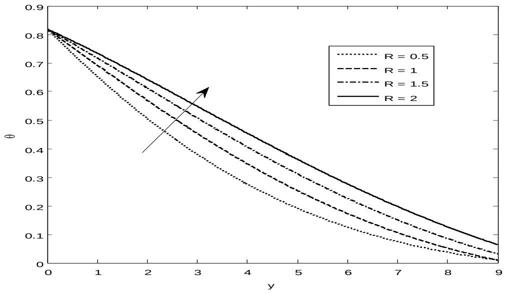


Fig. 5 Temperature profiles for different values of R with t=2, n=0.1, Kr=1, Pr=0.71, Q=0.05, Sc=0.6, So=1

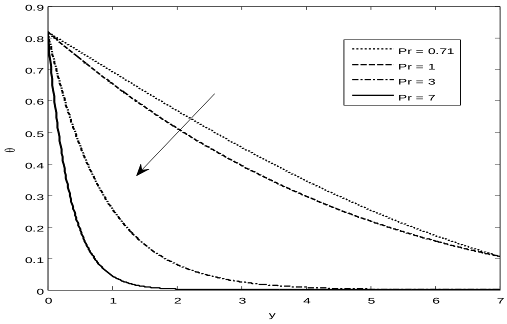


Fig.6 Temperature profiles for different values of Pr with t=2, n=0.1, Kr=1, R=1, Q=0.05, Sc=0.6, So=1

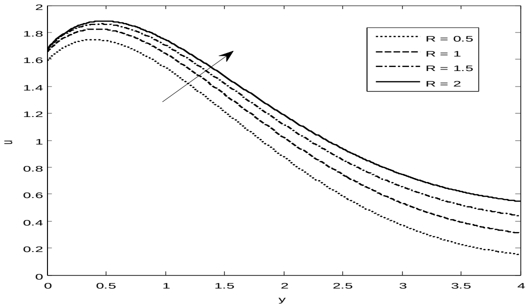


Fig.7 Velocity profiles for different values of R with t=2, n=0.1, Kr=1, Pr=0.71, S=0.05, Sc=0.6, A=1, So=1

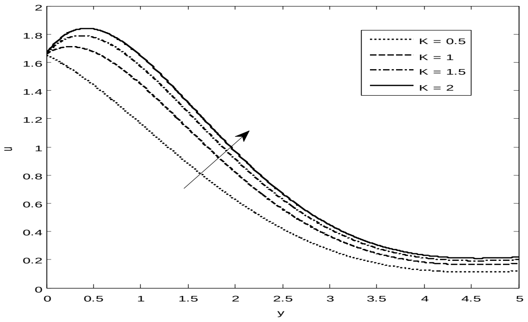


Fig. 8Velocity profiles for different values of K with t=2, n=0.1, Kr=1, Pr=0.71, Q=0.05, Sc=0.6, So=1

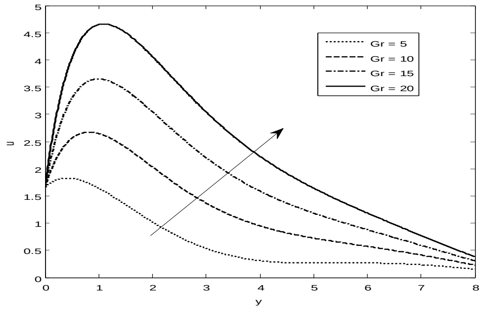


Fig.9 Velocity profiles for different values of Gr with t=2, n=0.1, Kr=1, Pr=0.71, Q=0.05, Sc=0.6, So=1

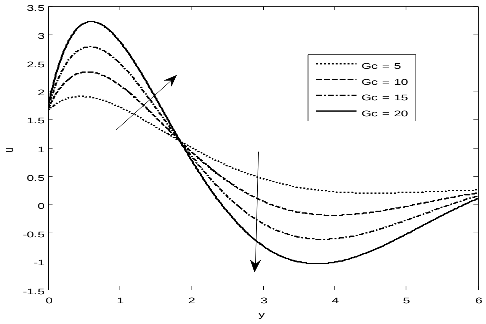


Fig.10 Velocity profiles for different values of Gc with t=2, n=0.1, Kr=1, Pr=0.71, Q=0.05, Sc=0.6, So=1

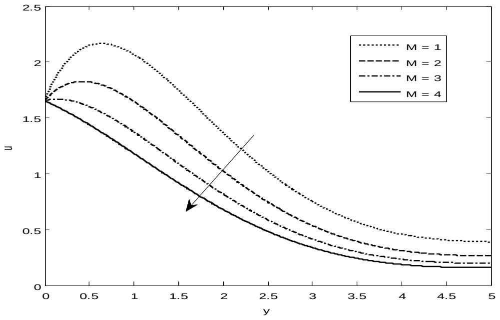


Fig.11 Velocity profiles for different values of M with t=2, n=0.1, Kr=1, Pr=0.71, Q=0.05, Sc=0.6, So=1

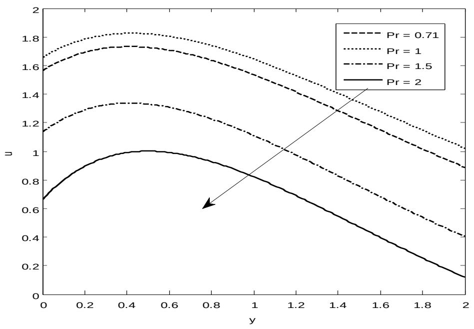


Fig.12 Velocity profiles for different values of Pr with t=2, n=0.1, Kr=1,Pr=0.71, Q=0.05, Sc=0.6, So=1

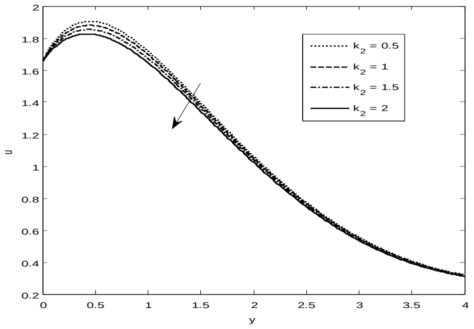


Fig.13 Velocity profiles for different values of $k_1$with t=2, n=0.1,Kr=1, Pr=0.71, Q=0.05, Sc=0.6, So=1

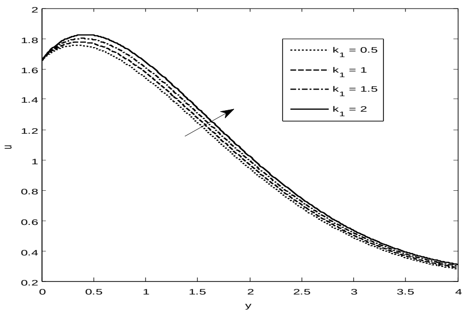


Fig.14 Velocity profiles for different values of $k_2$with t=2, n=0.1, Kr=1, Pr=0.71, Q=0.05, Sc=0.6, So=1

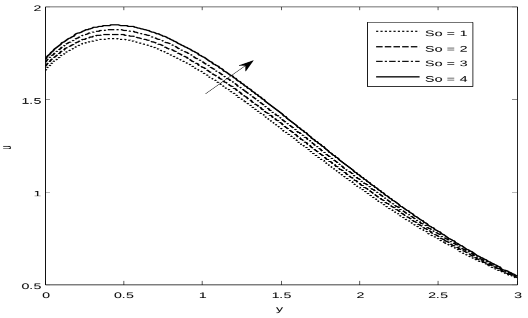


Fig.15 Velocity profiles for different values of So with t=2, n=0.1, Kr=1, Pr=0.71, S=0.05, Sc=0.6, So=1

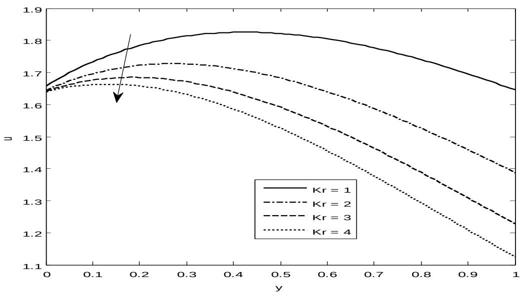


Fig.16 Velocity profiles for different values of Kr with t=2, n=0.1, Pr=0.71,Q=0.05, Sc=0.6, So=1

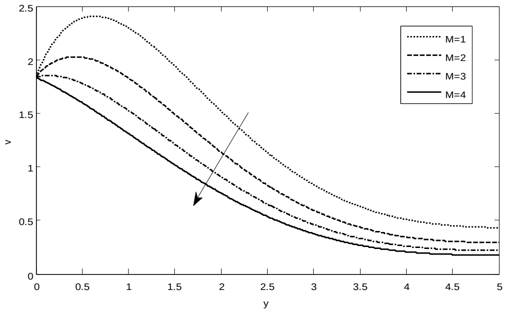


Fig.17 Velocity profiles for dust particle for different values of M with t=2,n=0.1, Kr=1, Pr=0.71, Q=0.05, Sc=0.6, So=1

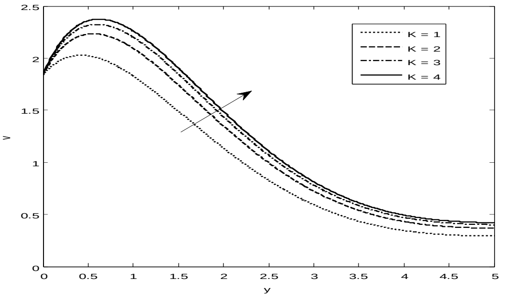


Fig.18 Velocity profiles for dust particle for different values of K with t=2, n=0.1, Kr=1, Pr=0.71,Q=0.05, Sc=0.6, So=1

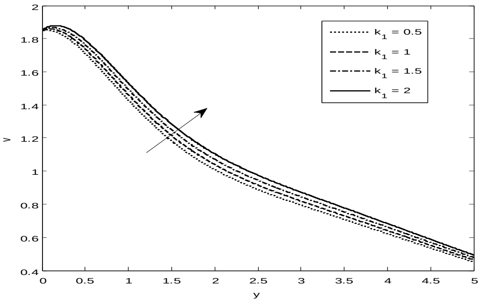


Fig.19 Velocity profiles for dust particle for different values of k_1 witht=2, n=0.1, Kr=1, Pr=0.71,Q=0.05, Sc=0.6, A=1, So=1

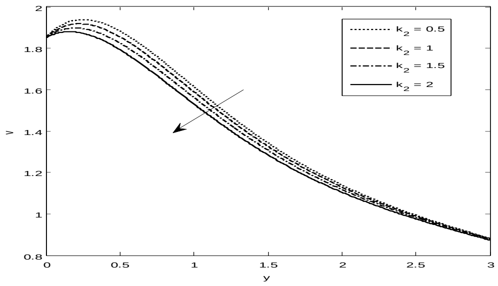


Fig.20 Velocity profiles for dust particle for different values of $k_2$with t=2, n=0.1, Kr=1, Pr=0.71,Q=0.05, Sc=0.6, So=1

Table. 1

Sherwood number for different values of Chemical reaction Kr, Schmidt number Sc, Soret number So, Prandtl number Pr

Kr	**Sc**	**So**	**Pr**	**Sh**
1	0.60	1	0.71	0.2184
2	0.60	1	0.71	0.2254
3	0.60	1	0.71	0.2287
1	0.78	1	0.71	0.2876
1	0.96	1	0.71	0.3575
1	0.60	2	0.71	0.1913
1	0.60	3	0.71	0.1641
1	0.60	1	1	0.2153
1	0.60	1	7	-1.2138

Table. 2

Nusselt number for different values of Prandtl number Pr, Radiation R

Pr	**R**	**Nu**
0.71	1	0.1246
1	1	0.1754
7	1	2.3067
0.71	2	0.0793
0.71	3	0.0581

Table. 3

Skinfriction for different values of Soret number So, Chemical reaction Kr, Radiation R, Heat source S, Grashof number Gr, modifiedGrashof number Gc

So	**Kr**	**R**	**Q**	**Gr**	**Gc**	τ_f	τ_p
1	1	1	0.05	5	4	0.8928	0.9920
2	1	1	0.05	5	4	0.9015	1.0016
3	1	1	0.05	5	4	0.9101	1.0113
1	2	1	0.05	5	4	0.6594	0.7327
1	3	1	0.05	5	4	0.4921	0.5468
1	1	2	0.05	5	4	0.9811	1.0901
1	1	3	0.05	5	4	1.0468	1.1632
1	1	1	0.07	5	4	0.8494	0.9438
1	1	1	0.09	5	4	0.8042	0.8936
1	1	1	0.05	10	4	3.1410	3.4901
1	1	1	0.05	15	4	5.3893	5.9881
1	1	1	0.05	5	2	0.2727	0.3030
1	1	1	0.05	5	3	0.5827	0.6475

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