# HEAT SOURCE AND CHEMICAL EFFECTS ON MHD FLOW IN THE PRESENCE OF SORET

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**ABSTRACT -** *The present paper is concerned to analyze the heat source and chemical effects on MHD mixed convective flow in the presence of chemical reaction. Soret is studied. The present theoretical study has been carried out under perturbation approximation technique. The governing equations of the flow field were solved analytically. The expressions for velocity, temperature and concentration fields are obtained. The obtained results are discussed with the help of graph to observe the effect of various parameters like Schmidt number (Sc), Prandtl number (Pr), Magnetic field (M),Eckert number(Ec), Mass Grashof number (Gm), Grashof number(Gr).*

***Keywords:*****Radiation, soret effect, MHD, Heat source, Perturbation.**

## 1. INTRODUCTION

To study the effect of heat source and chemical effects on MHD flow in the presence of soret. Due to the steady two dimensional flow of an incompressible elastically conducting viscous fluid. The objective of this work is analyze the chemical reaction , magnetic field , soret of the heat and mass transfer and may also analyzed the characteristic of the flow.D.A.Nield (2000) have discussed about the modeling fluid flow in a saturated porous medium by heat transfer[1].S.Suneetha , N.Bhaskar Reddy , V. Ramachandra Prasad (2008) have studied the thermal radiation effects with a variable surface temperature effects with a variable surface temperature and concentration in the presence of free convection flow past of an impulsively started vertical plate[2]. M.Sajid, I.Pop , T.Hayat(2010) have studied that flow of a viscoelastic fluid between permeable parallel vertical plate by a fully developed mixed convection flow[3].Dileepsinghchauhan and vikaskumar (2011) have studied the effect of radiation in a mixed convection flow with a partially filled vertical channel. And observed the convection flow and viscous heating with a porous medium[4].A.Bhatacharya, R.K. Deka (2013) has studied the effect on transient free convection flow in radiation and stratification. They have observed flow of an elastio-viscous fluid past an infinite vertical plate[5]. J.PrathaKumar , J.C. Umarathi and Shreedevi kalian(2014) have discussed the effects on mixed convection . They have observed that flow of two immiscible viscous fluids in a vertical channel[6]. K.Govanthan ,K.Kaladhar, G.Nagaraju, B.Balaswamy(2014) have discussed the transpiration cooling in a one side of a long vertical channel embedded in porous medium. And there have been observed the effect of MHD and injection to the vertical walls[7].B.Lavanya, A.LeelaRatnam(2014) studied unsteady flow of free convection through a flow past in a vertical porous plate which is embedded in a porous medium with a heat source/sink and soret effect in a slip flow regime[8].A.K.Mishra , Rajesh Menon. K and Shaima Abdullah Amer Al-shanfari (2015) have discussed the heat and mass transfer flow through porous medium in a vertical channel with heat absorption/generation effect of radiation on free convection flow[9]. K.Sharmila , K.Kannathal (2018) have discussed about the MHD mixed convection flow of inclined magnetic field in the presence of thermal radiation with the effects of chemical reaction and soret embedded in a porous medium[10].

## 2. MAHEMATICAL ANALYSIS

An unsteady flow of an incompressible and electically conducting viscous fluid along an infinite vertical plate is considered. To analyze the flow, consider a Cartesian co-ordinate system with $x^*$ axis along the plate in vertically upward and $y^*$ axis normal to the plate. A uniform magnetic field is applied transversely to the direction of the flow. Under the usual Boussinesq's approximation the mixed convection flow is governed by the following equations of conservation of momentum , thermal energy and concentration in non – dimensional form.

$$\frac{\partial v^*}{\partial y^*} = 0, v^* = -v_0 (v_0 > 0), \qquad (1)$$

$$v^* \frac{d\,u^*}{dy^*} = \nu \frac{d^2 u^*}{dy^{*2}} + g\beta(T^* - T_\infty) + g\beta^*(C^* - C_\infty) - \frac{\sigma {B_0}^2}{\rho} u^*$$

(2)

$$v^*\frac{dT^*}{dy^*}=\frac{k}{\rho C_P}\frac{d^2T^*}{dy^{*2}}+\frac{\nu}{C_P}\left(\frac{du^*}{dy^*}\right)^2+\frac{\sigma B_0{}^2}{\rho C_P}u^{*2}+\frac{Q_0}{\rho C_P}(T^*-T_\infty)\ (3)$$

$$v^*\frac{dC^*}{dy^*}=D\frac{d^2C^*}{dy^{*2}}+D_1\frac{d^2T^*}{dy^{*2}}-k_1(C^*-C_\infty)\qquad(4)$$

Where $u^*$ and $v^*$ are velocity components in $x^*$ and $y^*$ directions respectively , g is the acceleration due to gravity , $\beta$ is the thermal expansioncoefficient , $T^*$ is the temperature of the fluid , $T_w$ is the temperature near the plate , $T_\infty$ is the temperature away from the plate , $\beta^*$ is the mass expansion co-efficient , $C^*$ is the concentration of the fluid , $C_\infty$ is the concentration away from the plate , $C_w$ is the concentration near the plate, $\sigma$ is the magnetic permeability of the fluid , $B_0$ is the coefficient of magnetic field, $\rho$ is the density of the fluid , $\nu$ is the kinematic viscosity , K is the thermal conductivity, $C_p$ is the specific heat at constant pressure, D is the chemical molecule diffusivity , $D_1$ is the thermal diffusivity, $K_1$ is the chemical reaction rate constant.

The boundary conditions for the velocity, temperature and concentration fields are,

$$y^*=0\ :\ u^*=0\ ;\ T^*=T_w;\ C^*=C_w$$

$$y^*\to\infty:\ u^*\to 0\ ;\ T^*\to T_\infty;\ C^*\to C_\infty\quad (I)$$

Introducing the non-dimensional quantities,

$$u=\frac{u^*}{v_0},\ y=\frac{y^*v_0}{\nu},\ \nu=\frac{\mu}{\rho},\ k^*=\frac{\nu}{K_0v_0{}^2},$$

$$Q=\frac{Q_0\nu}{\rho C_P v_0{}^2},$$

$$M^3=\frac{\sigma B_0{}^2\nu}{\rho v_0{}^2},\ \theta=\frac{T^*-T_\infty}{T_w-T_\infty},$$

$$\phi=\frac{C^*-C_\infty}{C_w-C_\infty},\ Gr=\frac{\nu g\beta(T_w-T_\infty)}{v_0{}^3},$$

$$Gm=\frac{\nu g\beta^*(C_w-C_\infty)}{v_0{}^3},$$

$$Pr=\frac{\nu\rho C_P}{k},\ So=\frac{D_1(T_w-T_\infty)}{\nu(C_w-C_\infty)},$$

$$Sc=\frac{\nu}{D},\ Ec=\frac{v_0{}^2}{C_p(T_w-T_\infty)},$$

$$Kr=\frac{\nu k_1}{v_0{}^2}\qquad(5)$$

Where $Gr$ is the Grashof number, $Gm$ is the Mass Grashof number, M is the magnetic parameter, Sc is the Schmidt number, $Pr$ is the Prandtl number, So is the soret number , $Kr$ is the chemical reaction parameter.

By the usage of dimensionless quantities (5) in equation (2), (3) & (4) then the governing equations are reduced in form as,

$$u''+u'-(M^3)\,u=-Gr\theta-Gm\phi\,(i)$$

$$\theta''+Pr\,\theta'+Pr\,Q\theta+Pr\,Ec(u')^2+Pr\,Ec\,M^3u^2=0(ii)$$

$$\phi''+Sc\,\phi'-Sc\,Kr\,\phi+So\,Sc\,\theta''=0\qquad(iii)$$

The boundary conditions are

$$y=0\ :\ u=0\ ;\ \theta=1;\ \phi=1$$

$$y\to\infty\ :\ u\to 0;\ \theta\to 0;\ \phi\to 0\qquad(II)$$

**ANALYTICAL SOLUTION:**

By using Perturbation technique velocity, temperature and concentration of the fluid can be solved analytically. The approximate solutions are as follows,

$$u(y)=u_0(y)+Ec\,u_1(y)+O(Ec^2)\qquad(6)$$

$$\theta(y)=(y)+Ec\,\theta_1(y)+O(Ec^2)(7)$$

$$\phi(y)=\phi_0(y)+Ec\,\phi_1(y)+O(Ec^2)(8)$$

Substitutes (6)-(8) in (i)-(iii) and then equate the like powers to get the equations.

**Zeroth Order:**

$$u_0''+u_0'-(M^3)u_0=-Gr\theta_0-Gm\phi_0(A)$$

$$\theta_0''+Pr\,\theta_0'+Pr\,Q\theta_0=0(B)$$

$$\phi_0''+Sc\,\phi_0'-Sc\,Kr\,\phi_0=-So\,Sc\,\theta_0''\ (C)$$

**First Order:**

$$u_1''+u_1'-(M^3)u_1=-Gr\theta_1-Gm\phi_1\qquad(D)$$

$$\theta_1'' + Pr\,\theta_1' + Pr\,Q\theta_1 - Pr\,(u_0')^2 - Pr\,M^3 u_0^2 \quad \text{(E)}$$

$$\phi_1'' + Sc\,\phi_1' - Sc\,Kr\,\phi_1 = -So\,Sc\,\theta_1'' \quad \text{(F)}$$

The corresponding boundary conditions are

$$y = 0: u_0 = 0, u_1 = 0; \theta_0 = 1, \theta_1 = 0; \phi_0 = 1, \phi_1 = 0$$

$$y \to \infty: u_0 \to 0, u_1 \to 0; \theta_0 \to 0, \theta_1 \to 0; \phi_0 \to 0,$$

$$\phi_1 \to 0 \quad \text{(III)}$$

Apply the boundary conditions are (III) to (A)-(F) then solutions are,

$$u_0 = C_5 e^{-K_3 y} + C_4 e^{-K_2 y} + C_3 e^{-K_1 y} \quad (9)$$

$$\theta_0 = e^{-K_1 y} \quad (10)$$

$$\phi_0 = C_2 e^{-K_2 y} + C_1 e^{-K_1 y} \quad (11)$$

$$u_1 = \begin{pmatrix} C_{29} e^{-Ky} + C_{21} e^{-K_5 y} + C_{22} e^{-K_4 y} + C_{23} e^{-2K_3 y} + C_{24} e^{-2K_2 y} \\ +C_{25} e^{-2K_1 y} + C_{26} e^{-(K_2+K_3)y} + C_{27} e^{-(K_1+K_2)y} + C_{28} e^{-(K_1+K_3)y} \end{pmatrix} \quad (12)$$

$$\theta_1 = \begin{pmatrix} C_{12} e^{-K_4 y} + C_6 e^{-2K_3 y} + C_7 e^{-2K_2 y} + C_8 e^{-2K_1 y} \\ +C_9 e^{-(K_2+K_3)y} + C_{10} e^{-(K_1+K_2)y} + C_{11} e^{-(K_1+K_3)y} \end{pmatrix} \quad (13)$$

$$\phi_1 = \begin{pmatrix} C_{20} e^{-K_5 y} + C_{13} e^{-K_4 y} + C_{14} e^{-2K_3 y} + C_{15} e^{-2K_2 y} + C_{16} e^{-2K_1 y} \\ +C_{17} e^{-(K_2+K_3)y} + C_{18} e^{-(K_1+K_2)y} + C_{19} e^{-(K_1+K_3)y} \end{pmatrix} \quad (14)$$

The mean velocity, mean temperature, mean concentration can be obtained by substituting equation (9)-(14) in equation (6)-(8)

$$U(y) = (C_5 e^{-K_3 y} + C_4 e^{-K_2 y} + C_3 e^{-K_1 y})$$

$$+Ec \begin{pmatrix} C_{29} e^{-K_6 y} + C_{21} e^{-K_5 y} + C_{22} e^{-K_4 y} + C_{23} e^{-2K_3 y} + C e^{-2K_2 y} \\ +C_{25} e^{-2K_1 y} + C_{26} e^{-(K_2+K_3)y} + C_{27} e^{-(K_1+K_2)y} + C_{28} e^{-(K_1+K_3)y} \end{pmatrix} \quad (15)$$

$$\theta(y) = (e^{-K_1 y})$$

$$+Ec \begin{pmatrix} C_{12} e^{-K_4 y} + C e^{-2K_3 y} + C_7 e^{-2K_2 y} + C_8 e^{-2K_1 y} \\ +C_9 e^{-(K_2+K_3)y} + C_{10} e^{-(K_1+K_2)y} + C_{11} e^{-(K_1+K_3)y} \end{pmatrix} \quad (16)$$

$$\phi(y) = (C_2 e^{-K_2 y} + C_1 e^{-K_1 y})$$

$$+Ec \begin{pmatrix} C_{20} e^{-K_5 y} + C_{13} e^{-K_4 y} + C_{14} e^{-2K_3 y} + C_{15} e^{-2K_2 y} + C_{16} e^{-2K_1 y} \\ +C_{17} e^{-(K_2+K_3)y} + C_{18} e^{-(K_1+K_2)y} + C_{19} e^{-(K_1+K_3)y} \end{pmatrix} \quad (17)$$

**Skin Friction**

The Skin friction of the mean velocity profile is given in the form given,

$$Cf = \left(\frac{du}{dy}\right)_{y=0}$$

$$Cf = -(K_3 C_5 + K_2 C_4 + K_1 C_3)$$

$$-Ec \begin{pmatrix} K_6 C_{29} + K_5 C_{21} + K_4 C_{22} + 2K_3 C_{23} + 2K_2 C_{24} + 2K_1 C_{25} \\ +(K_2+K_3) C_{26} + (K_1+K_2) C_{27} + (K_1+K_3) C_{28} \end{pmatrix}$$

(18)

**Nusselt Number**

The Nusselt number of the temperature field is given in the non-dimensional form is,

$$Nu = \left(\frac{d\theta}{dy}\right)_{y=0}$$

$$Nu = -(K_1)$$

$$-Ec \begin{pmatrix} K_4 C_{12} + 2K_3 C_6 + 2K_2 C_7 + 2K_1 C_8 \\ +(K_2+K_3) C_9 + (K_1+K_2) C_{10} + (K_1+K_3) C_{11} \end{pmatrix} \quad (19)$$

**Sherwood Number**

The non-dimensional form of the coefficient of rate of mass transfer is obtained by the mean concentration then the Sherwood number form is given by,

$$Cf = \left(\frac{d\phi}{dy}\right)_{y=0}$$

$$Cf = -(K_1 C_2 + K_1 C_1)$$

$$-Ec \begin{pmatrix} K_5 C_{20} + K_4 C_{13} + 2K_3 C_{14} + 2K_2 C_{15} + 2K_1 C_{16} \\ +(K_2+K_3) C_{17} + (K_1+K_2) C_{18} + (K_1+K_3) C_{19} \end{pmatrix} (20)$$

## 3. RESULT AND DISCUSSION

In order to understand the physical importance of the flow between the two plates, calculations have been carried out for velocity, temperature, concentration field. Effects for different values of Grashof number (Gr), Mass Grashof number (Gm), Magnetic field (M), Soret effect (So), Prandtl number (Pr), Heat generating parameter (Q), Eckert number (Ec), Schmidt number (Sc), chemical reaction (Kr) on velocity, temperature, concentration profiles are shown graphically.

The velocity profiles are shown in figures 1 to 6 for different values of Grashof number (Gr) , Mass Grashof number (Gm) , Magnetic field (M) , Soret number (So) , Heat generating parameter (Q) while all other parameters are kept constant.

In figure 1, Velocity profiles u is presented for different values of Grashof number (Gr) when other parameters are kept constant. It shows the falling trend in the velocity profile.

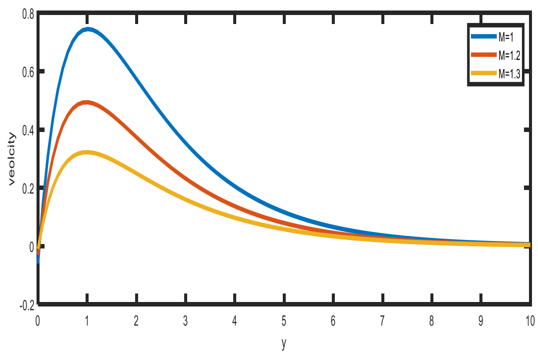


**Figure 1.** Velocity profile for different values of Magnetic field M

The effect of Mass Grashof number on the velocity field has been illustrated in figure.2. It is observed that as the mass grashof number (Gm) increases the velocity field decreases.

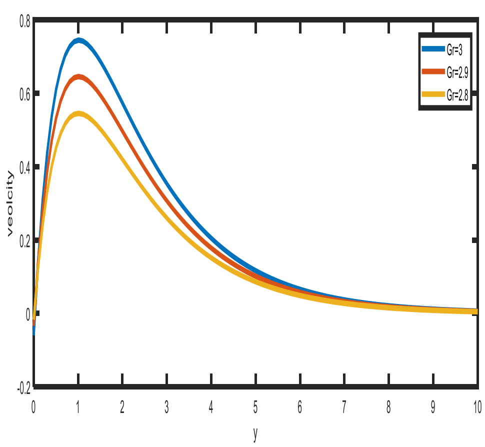


**Figure 2.** Velocity profile for different values of Grashof number

When the applied magnetic field intensity increases, thereseems to be a decreases in the velocity profile. In figure.3 illustrates the effect of magnetic field on the velocity profiles.

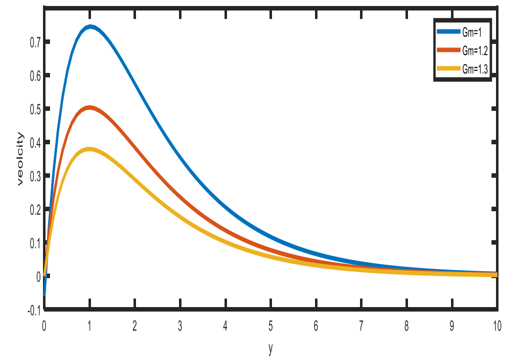


**Figure 3.** Velocity profile for different values Mass Grashof number

Figure.4. illustrates the effect of soret number on the velocity field. It is notified that as the soret number increases, the velocity profile decreases.

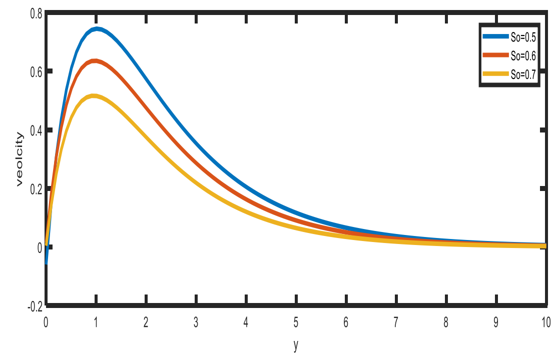


**Figure 4.** Velocity profile for different values of Soret number

It is seen that as the Prandtl number (Pr) increases the velocity profile decreases. The effect of Prandtl number on the velocity field has been illustrated in figure .5.

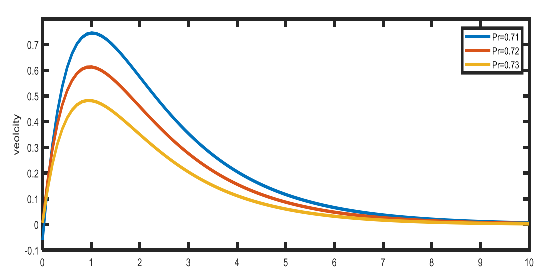


**Figure 5.** Velocity profile for different values of Prandtlnumber

Figure.6 shows that decreases in heat generating parameter to decreases in velocity field when all other parameters that appear in the velocity field are kept constant.

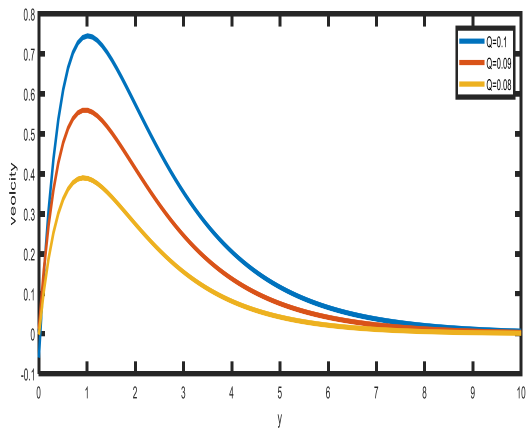


**Figure 6.** Velocity profile for different values of heatgeneration parameter

Figure.7 shows that increases in Prandtl number contributes to decreases in temperature field when all other parameters that appear in the temperature field are kept constant.

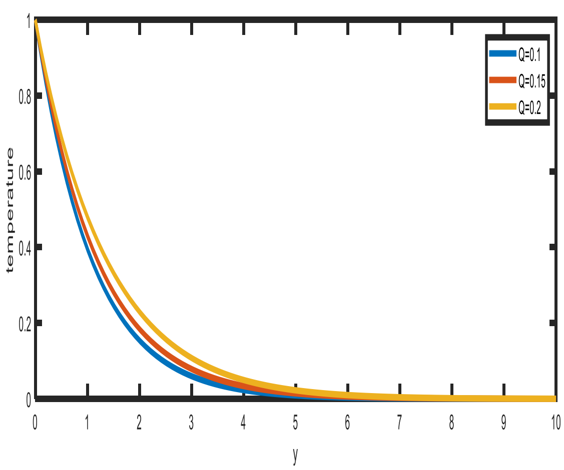


**Figure 7.** Temperature profile for different values of Heat generation parameter

Figure.8 depicts the temperature profile $\theta$ for the different values of heat generating parameter (Q) while other parameter are Gr=3, Gm=1 , M=1,Pr=0.71 , Ec=0.001 , Kr=0.1 , So=0.5 , Sc= 0.6 . The trend shows that the temperature increases with increasing heat generating parameter Q. It is observed there is a rise in temperature in the presence of high generating parameter.

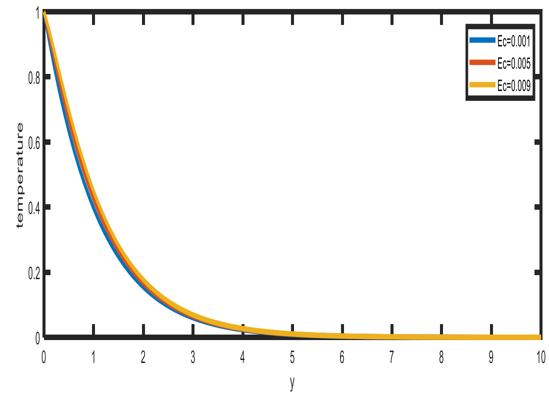


**Figure 8.** Temperature profile for different values of Eckert number

The effect of Eckert number on the temperature field is shown in figure.9. It is observed that an increase in Eckert number (Ec) contributes to increases in the temperature.

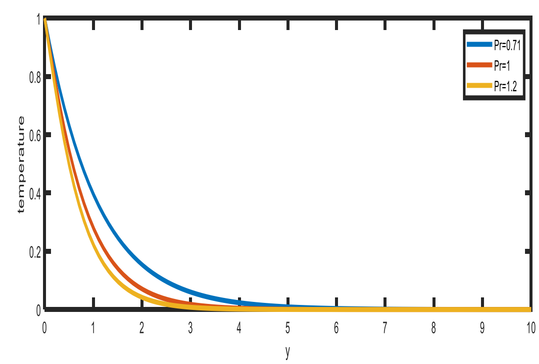


**Figure 9.** Temperature profile for different values of Prandtl number

As the Schmidt number decreases the concentration field is found to be increasing. In figure .10 illustrates the effect of Schmidt number on the concentration profile of the fluid under consideration.

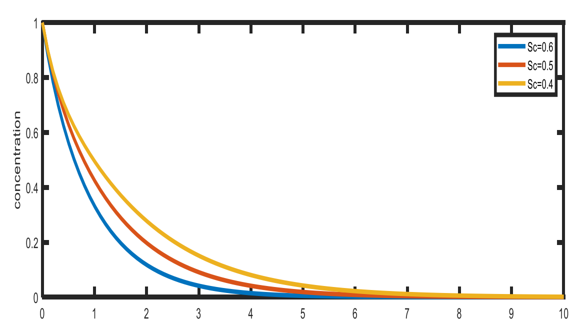


**Figure 10.** Concentration profile for different values of Schmidt number

Figure.11 illustrates the effect of the chemical reaction Kr on the concentration profile of the fluid. As the chemical reaction Kr decreases, the concentration profile increases.

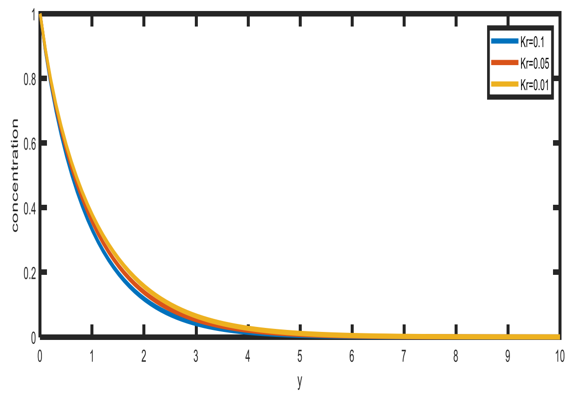


**Figure 11.** Concentration profile for different values of **chemical** reaction

The effect of soret number on the concentration fields is shown in figure.12. It is observed that as the soret number decreases the concentration fields increases.

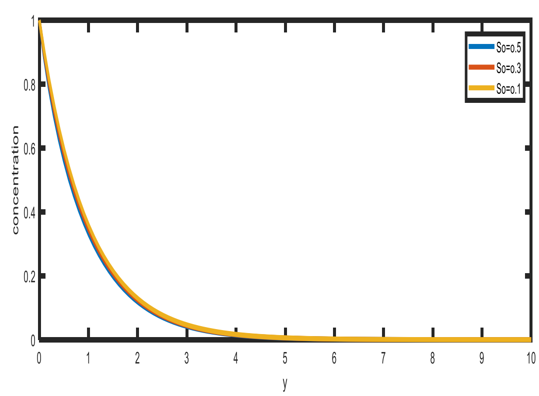


**Figure 12.** Concentration profile for different values of Soret number

## 4. CONCLUSIONS

The analysis brings out the result of the velocity, temperature and concentration distribution of the flow fluid.

1) The velocity field is observed to decreases with an increase in Prandtl number

2) The concentration reduces with increases in Sc or Kr or So.

3) A fall in temperature occurs due to an increase in Pr.

4) The effect of the Prandtl number is very important in the temperature field.

5) In temperature field increases with increase in Q but in velocity profile decreases with decrease in Q.

6) The soret effect in concentration is decrease with increase where as in the velocity profile soret effect is increases with the decrease in the profile.

## 5. APPENDIX

$$K_1 = \frac{Pr + \sqrt{Pr^2 - 4QPr}}{2}$$

$$K_2 = \frac{Sc + \sqrt{Sc^2 + 4\,Kr\,Sc}}{2}$$

$$K_3 = \frac{1 + \sqrt{1 + 4(M^3)}}{2}$$

$$K_4 = \frac{Pr + \sqrt{Pr^2 - 4QPr}}{2}$$

$$K_5 = \frac{Sc + \sqrt{Sc^2 + 4\,Sc\,Kr}}{2}$$

$$K_6 = \frac{1 + \sqrt{1 + 4(M^3)}}{2}$$

$$C_1 = \frac{-So\,Sc\,K_1{}^2}{K_1{}^2 - Sc\,K_1 - Kr\,Sc}$$

$$C_2 = 1 - C_1$$

$$C_3 = \frac{-(C_1\,Gm + Gr)}{K_1{}^2 - K_1 - (M^3)}$$

$$C_4 = \frac{-C_2\,Gm}{K_2{}^2 - K_2 - (M^3)}$$

$$C_5 = -C_3 - C_4$$

$$C_6 = \frac{-\Pr C_5{}^2\,(K_3{}^2 + M^3)}{4\,K_3{}^2 - 2\,Pr\,K_3 + \Pr Q}$$

$$C_7 = \frac{-\Pr C_4{}^2\,(K_2{}^2 + M^3)}{4\,K_2{}^2 - 2\,Pr\,K_2 + \Pr Q}$$

$$C_8 = \frac{-\Pr C_3{}^2\,(K_1{}^2 + M^3)}{4\,K_1{}^2 - 2\,Pr\,K_1 + \Pr Q}$$

$$C_9 = \frac{-2\,\mathrm{Pr}\,C_4 C_5\,(K_2K_3 + M^3)}{(K_2+K_3)^2 - \ Pr\,(K_2+K_3) + \mathrm{Pr}\,Q}$$

$$C_{10} = \frac{-2\,\mathrm{Pr}\,C_3 C_4\,(K_1K_2 + M^3)}{(K_1+K_2)^2 - \ Pr\,(K_1+K_2) + \mathrm{Pr}\,Q}$$

$$C_{11} = \frac{-2\,\mathrm{Pr}\,C_3 C_5\,(K_1K_3 + M)}{(K_1+K_3)^2 - \ Pr\,(K_1+K_3) + \mathrm{Pr}\,Q}$$

$$C_{12} = -C_6 - C_7 - C_8 - C_9 - C_{10} - C_{11}$$

$$C_{13} = \frac{-So\,Sc\,{K_4}^2 C_{12}}{{K_4}^2 - Sc\,K_4 - Kr\,Sc}$$

$$C_{14} = \frac{-4\,So\,Sc\,{K_3}^2 C_6}{4\,{K_3}^2 - 2\,Sc\,K_3 - Kr\,Sc}$$

$$C_{15} = \frac{-4\,So\,Sc\,{K_2}^2 C_7}{4\,{K_2}^2 - 2\,Sc\,K_2 - Kr\,Sc}$$

$$C_{16} = \frac{-4\,So\,Sc\,{h_1}^2 C_8}{4\,{K_1}^2 - 2\,Sc\,K_1 - Kr\,Sc}$$

$$C_{17} = \frac{-So\,Sc\,(K_2+K_3)^2 C_9}{(K_2+K_3)^2 - Sc\,(K_2+K_3) - Kr\,Sc}$$

$$C_{18} = \frac{-So\,Sc\,(K_1+K_2)^2 C_{10}}{(K_1+K_2)^2 - Sc\,(K_1+K_2) - Kr\,Sc}$$

$$C_{19} = \frac{-So\,Sc\,(K_1+K_3)^2 C_{11}}{(K_1+K_3)^2 - Sc\,(K_1+K_3) - Kr\,Sc}$$

$$C_{20} = -C_{13} - C_{14} - C_{15} - C_{16} - C_{17} - C_{18} - C_{19}$$

$$C_{21} = \frac{-C_{20}\,Gm}{{K_5}^2 - K_5 - M^3}$$

$$C_{22} = \frac{(-C_{13}\,Gm - C_{12}\,Gr)}{{K_4}^2 - K_4 - M^3}$$

$$C_{23} = \frac{(-C_{14}\,Gm - C_6\,Gr)}{4\,{K_3}^2 - 2K_3 - M^3}$$

$$C_{24} = \frac{(-C_{15}\,Gm - C_7\,Gr)}{4\,{K_2}^2 - 2K_2 - M^3}$$

$$C_{25} = \frac{(-C_{16}\,Gm - C_8\,Gr)}{4\,{K_1}^2 - 2K_1 - M^3}$$

$$C_{26} = \frac{(-C_{17}\,Gm - C_9\,Gr)}{(K_2+K_3)^2 - (K_2+K_3) - M^3}$$

$$C_{27} = \frac{(-C_{18}\,Gm - C_{10}\,Gr)}{(K_1+K_2)^2 - \ (K_1+K_2) - M^3}$$

$$C_{28} = \frac{(-C_{19}\,Gm - C_{11}\,Gr)}{(K_1+K_3)^2 - \ (K_1+K_3) - M^3}$$

$$C_{29} = -C_{21} - C_{22} - C_{23} - C_{24} - C_{25} - C_{26} - C_{27} - C_{28}$$

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