Effect of Chemical Reaction on MHD Heat and Mass Transfer Viscous Fluid with Temperature Dependent Heat source

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Abstract: Effects of chemical reaction on MHD heat and mass transfer flow of a viscous incompressible and electrically conducting fluid through a non homogeneous porous medium in the presence of heat source oscillatory suction velocity has been studied. The governing equations are solved by a simple perturbation technique. The results are obtained for primary velocity, secondary velocity, temperature distribution, mass concentration, skin friction, rate of heat and mass transfer. The effects of various parameters are discussed on flow variables and presented by graphs.

Key words: chemical reaction, variable suction, non-homogeneous porous medium, MHD, heat and mass transfer.

Introduction:

Coupled heat and mass transfer by free convection in a porous medium has attracted considerable attention in the last several decades. Due to its importance , the process of heat and mass transfer is encountered in aeronautics, fluid fuel nuclear reactor, chemical process industries, geophysical applications such as geothermal reservoirs and many engineering applications in which the fluid is the working medium. Chemical reactions take place between a foreign mass and the working fluid which moves. The order of chemical reaction depends on several factors. One of the simplest chemical reaction 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. In many situations there may be an appreciable temperature difference between the surface and ambient fluid. This requires the consideration of temperature dependent heat sources or sinks which may exert strong influence on the heat transfer characteristics. Chemical reaction effects on heat and mass transfer viscous flow have been studied by many authors in different situations. The heat source/sink effects in thermal convection, are significant where there may exist a high temperature differences between the surface (e.g. space craft body) and the ambient fluid. Heat generation is also important in the context of exothermic or endothermic chemical reactions.

Kafousias and Raptis [1]have studied the mass transfer effect of unsteady free convection flow of an incompressible viscous fluid past an infinite vertical accelerated porous plate. Mohapatra and Senapati [3] have been analyzed magneto hydrodynamic free convection flow with mass transfer past a vertical plate. Chen [7] has studied heat and mass transfer in MHD flow by natural convection from a permeable, inclined surface with variable wall temperature and concentration. Gokhale et al. [5] studied effects of mass transfer on the transient free convection flow of a dissipative fluid along a semi infinite vertical plate with constant heat flux. Israel-Cookey et al [6] discussed influence of viscous dissipation on unsteady MHD free convection flow past an infinite heated vertical plate in porous medium with time dependent suction. Kim [4] discussed unsteady MHD convective heat transfer past a semi infinite vertical porous moving plate with variable suction. In their study Raju et al [9] considered unsteady MHD free convection oscillatory couette flow through a porous medium with periodic wall temperature. Raptis et al [2] discussed magneto hydrodynamic free convection flow and mass transfer through a porous medium bounded by an infinite vertical porous plate with constant heat flux. Heat transfer effects on flow of viscous fluid through non homogeneous porous medium are studied by Singh et al [8]. Senapati et.al[10] have studied magnetic effect on mass and heat transfer of a hydrodynamic flow past a vertical oscillating plate in presence of chemical reaction. Senapati et.al[11,12] also discussed the chemical effects on mass and heat transfer on MHD free convection flow of fluids in vertical plates and in between parallel plates for slip flow regions and poiseuille flow respectively. Ravi kumar et.al[13] have studied heat and mass transfer effects on MHD flow of viscous fluid through non-homogeneous porous medium in presence of temperature dependent heat source.

It is proposed to study the effect of chemical reaction on MHD heat and mass transfer viscous rotating fluid with temperature dependent heat source past an infinite isothermal vertical porous plate.

Formulation of the problem:

An unsteady free convention, incompressible and electrically conducting viscous rotating fluid through porous medium past an infinite isothermal, vertical porous plate with constant heat source, the presence of chemical reaction and variable suction is considered. A uniform magnetic field is applied perpendicular to the plate. Let (X, Y, Z) be the Cartesian coordinates system, and let us assume that X-axis & Z-axis in the plane of the plate and Y-axis is normal to the plate with velocity components (u', v', w') in X, Y, Z directions respectively. Both the liquid and the plate are considered in a state of rigid body rotation about Y-axis with uniform angular velocity Ω. Initially surrounding fluid is at rest and the temperature is T'_∞ and mass concentration is C'_∞ at all points. As the plate temperature and mass concentration are considered infinite along X' direction; all physical quantities will be independent of x'. In this analysis of the flow, it is assumed that the magnetic Reynolds number is very small and hence the induced magnetic field is negligible in comparison to the applied magnetic field. It is also assumed that there is no applied voltage which implies the absence of an electric field. Viscous dissipation and joule heating terms are neglected as small velocity usually encountered in free convection flows and constant heat source 'Q' is assumed at y=0. Then neglecting viscous dissipation and assuming variation of density in the body force term and by usual boussinesq's approximation the unsteady flow is governed by the following equations:

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

which is satisfied with $v' = -v_0(1 + \epsilon A e^{i\omega' t'})$=variable sunction/injection.

Momentum equation:

X-component:

$$\frac{\partial u'}{\partial t'} - v_0\left(1 + \epsilon A e^{i\omega' t'}\right)\frac{\partial u'}{\partial y'} - 2\Omega w' = \nu\frac{\partial^2 u'}{\partial y'^2} + g\beta\left(T' - T_\infty'\right) + g\beta_c(c' - c_\infty') - \frac{\nu u'}{k_0(1+\epsilon e^{i\omega' t'})} - \frac{\sigma B_0{}^2 u'}{\rho} \quad (2)$$

Z-component:

$$\frac{\partial w'}{\partial t'} - v_0\left(1 + \epsilon A e^{i\omega' t'}\right)\frac{\partial w'}{\partial y'} + 2\Omega u' = \nu\frac{\partial^2 w'}{\partial y'^2} - \frac{\nu w'}{k_0(1+\epsilon e^{i\omega' t'})} - \frac{\sigma B_0{}^2}{\rho}w' \quad (3)$$

The energy equation:

$$\frac{\partial T'}{\partial t'} - v_0\left(1 + \epsilon A e^{i\omega' t'}\right)\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y'^2} - \frac{q}{\rho C_p}(T' - T'_\infty) \quad (4)$$

Mass concentration equation:

$$\frac{\partial C'}{\partial t'} - v_0\left(1 + \epsilon A e^{i\omega' t'}\right)\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - R'(C' - C_\infty') \quad (5)$$

With corresponding boundary conditions

$$u' = 0, w' = 0, T' = T_w{}' + \epsilon\left(T_w{}' - T_\infty{}'\right)e^{i\omega' t'}, C' = C_w{}' + \epsilon\left(C_w{}' - C_\infty{}'\right)e^{i\omega' t'} at\ y' = 0$$

$$u' \to 0, w' \to 0, T' \to T_\infty{}', C' \to C_\infty{}' as\ y' \to \infty \quad (6)$$

Now introducing the following non dimensional quantities

$$y = \frac{y' v_0}{\nu}, t = \frac{t' v_0{}^2}{4\nu}, u = \frac{u'}{v_0}, w = \frac{w'}{v_0}, \theta = \frac{T' - T'_\infty}{T_w{}' - T'_\infty}, \varphi = \frac{C' - C_\infty{}'}{C_w{}' - C_\infty{}'},$$

$$Sc = \frac{\nu}{D}, Pr = \frac{\mu C_p}{k}, R = \frac{R'\nu}{v_0{}^2}, K = \frac{k_0 v_0{}^2}{\nu^2}, M = \frac{\sigma B_0{}^2 \nu}{\rho v_0{}^2}, E = \frac{\Omega \nu}{v_0{}^2},$$

$$Q = \frac{q\nu}{\rho C_p v_0{}^2}, \omega = \frac{4\nu\omega'}{v_0{}^2}, Gr = \frac{\nu g\beta\,(T_w{}' - T'_\infty)}{v_0{}^2}, Gm = \frac{\nu g\beta_c(C_w{}' - C'_\infty)}{v_0{}^2} \quad (7)$$

the governing equations in the non dimensional form are given by

$$\frac{1}{4}\frac{\partial u}{\partial t} - \left(1 + \epsilon A e^{i\omega t}\right)\frac{\partial u}{\partial y} - 2Ew = \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gm\varphi - \frac{u}{k(1+\epsilon A e^{i\omega t})} - Mu \tag{8}$$

$$\frac{1}{4}\frac{\partial w}{\partial t} - \left(1 + \epsilon A e^{i\omega t}\right)\frac{\partial w}{\partial y} + 2Eu = \frac{\partial^2 w}{\partial y^2} - \frac{w}{k(1+\epsilon A e^{i\omega t})} - Mw \tag{9}$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t} - \left(1 + \epsilon A e^{i\omega t}\right)\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} - Q\theta \tag{10}$$

$$\frac{1}{4}\frac{\partial \varphi}{\partial t} - \left(1 + \epsilon A e^{i\omega t}\right)\frac{\partial \varphi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \varphi}{\partial y^2} - R\varphi \tag{11}$$

Taking p=u + iw , equations (8) and equation (9) can be changed to

$$\frac{1}{4}\frac{\partial p}{\partial t} - \left(1 + \epsilon A e^{i\omega t}\right)\frac{\partial p}{\partial y} + 2Eip = \frac{\partial^2 p}{\partial y^2} + Gr\theta + Gm\varphi - \frac{p}{k(1+\epsilon A e^{i\omega t})} - Mp \tag{12}$$

The boundary conditions to the problem in the dimensionless form are

$$p \to 0,\ \theta = 1 + \epsilon e^{i\omega t},\ \varphi = 1 + \epsilon e^{i\omega t} \qquad \text{at } y = 0$$

$$p \to 0,\ \ \theta \to 0,\ \varphi \to 0 \qquad \text{at } y = \infty \tag{13}$$

Solution of the problem:

In order to solve the equations we assume the velocity p(y, t), temperature θ(y, t) and concentration φ(y, t) as

$$\left.\begin{aligned} p(y,t) &= p_0(y) + \epsilon p_1(y) e^{i\omega t} \\ \theta(y,t) &= \theta_0(y) + \epsilon \theta_1(y) e^{i\omega t} \\ \varphi(y,t) &= \varphi_0(y) + \epsilon \varphi_1(y) e^{i\omega t} \end{aligned}\right\} \tag{14}$$

Using equation (14) into equations (10) to (13) we get the following set of equations

$$\frac{\partial^2 p_0}{\partial y^2} + \frac{\partial p_0}{\partial y} - \left(2iE + \frac{1}{k} + M\right)p_0 = -Gr\theta_0 - Gm\varphi_0 \tag{15}$$

$$\frac{\partial^2 p_1}{\partial y^2} + \frac{\partial p_1}{\partial y} - \left(2iE + \frac{1}{k} + M + \frac{1}{4}i\omega\right)p_1 = -\frac{Ap_0}{k} - \frac{A\partial p_0}{\partial y} - Gr\theta_1 - Gm\varphi_1 \tag{16}$$

$$\frac{\partial^2 \theta_0}{\partial y^2} + Pr\frac{\partial \theta_0}{\partial y} - \alpha_0\theta_0 = 0 \tag{17}$$

$$\frac{\partial^2 \theta_1}{\partial y^2} + Pr\frac{\partial \theta_1}{\partial y} - (\frac{1}{4}i\omega Pr + \alpha_0)\theta_1 = -APr\frac{\partial \theta_0}{\partial y} \tag{18}$$

$$\frac{\partial^2 \varphi_0}{\partial y^2} + Sc\frac{\partial \varphi_0}{\partial y} - RSc\varphi_0 = 0 \tag{19}$$

$$\frac{\partial^2 \varphi_1}{\partial y^2} + Sc\frac{\partial \varphi_1}{\partial y} - Sc(\frac{1}{4}i\omega + R)\varphi_1 = -ASc\frac{\partial \varphi_0}{\partial y} \tag{20}$$

Corresponding boundary conditions are

$p_0 = p_1 = 0, \theta_0 = \theta_1 = 1, \varphi_0 = \varphi_1 = 1 \; at \; y = 0$

$$p_0 = p_1 = 0, \theta_0 = \theta_1 = 0, \varphi_0 = \varphi_1 = 0 \; at \; y = \infty \tag{21}$$

Solving the equations (15) to (20) under the above boundary conditions (21), we have

$$\theta = e^{\lambda_2 y} + \epsilon((1-k_1)e^{\lambda_4 y} + k_1 e^{\lambda_2 y})e^{i\omega t} \tag{22}$$

$$\varphi = e^{\lambda_6 y} + \epsilon((1-k_2)e^{\lambda_8 y} + k_2 e^{\lambda_6 y})e^{i\omega t} \tag{23}$$

$$p = (-k_3 - k_4)e^{\lambda_{10} y} + k_3 e^{\lambda_2 y} + k_4 e^{\lambda_6 y} + \epsilon(k_{15} e^{\lambda_{12} y} + k_{16} e^{\lambda_{10} y} + k_{17} e^{\lambda_2 y} + k_{18} e^{\lambda_6 y} + k_{11} e^{\lambda_4 y} + k_{13} e^{\lambda_8 y})e^{i\omega t} \tag{24}$$

Skin friction: The skin friction (τ_p) due to primary velocity and skin-friction due to secondary velocity at the plate are obtained as follows:

$$\tau_p = \left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{25}$$

$$\tau_s = \left(\frac{\partial w}{\partial y}\right)_{y=0} \tag{26}$$

Rate of heat transfer: The rate of heat transfer in terms of Nusselt number Nu is given by

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \lambda_2 + \epsilon e^{i\omega t}((1-k_1)\lambda_4 + k_1\lambda_2) \tag{27}$$

Rate of mass transfer: Mass transfer coefficient (Sh) at the plate in terms of amplitude and phase is given by

$$Sh = \left(\frac{\partial \varphi}{\partial y}\right)_{y=0} = \lambda_6 + \epsilon e^{i\omega t}((1-k_2)\lambda_8 + k_2\lambda_6) \tag{28}$$

Where $\lambda_2 = \frac{-(Pr+\sqrt{Pr^2+4\alpha_0})}{2}$, $\lambda_4 = \frac{-(Pr+\sqrt{Pr^2+i\omega Pr+4\alpha_0})}{2}$, $\lambda_6 = \frac{-(Sc+\sqrt{Sc^2+4RSc})}{2}$

$\lambda_8 = \frac{-(Sc+\sqrt{Sc^2+i\omega+4R})}{2}$, $\lambda_{10} = \frac{-(1+\sqrt{1+4(2iE+\frac{1}{k}+M)})}{2}$,

$k_1 = \frac{-\lambda_2 APr}{\lambda_2{}^2+Pr\lambda_2-\left(\frac{1}{4}i\omega Pr+\alpha_0\right)}$, $k_2 = \frac{-\lambda_2 ASc}{\lambda_6{}^2+Sc\lambda_6-\left(\frac{1}{4}i\omega+R\right)}$, $k_3 = \frac{-Gr}{\lambda_2{}^2+\lambda_2-\left(2iE+\frac{1}{k}+M\right)}$

$k_4 = \frac{-Gm}{\lambda_6{}^2+\lambda_6-\left(2iE+\frac{1}{k}+M\right)}$, $k_5 = \frac{1}{k}\frac{A(k_3+k_4)}{\lambda_{10}{}^2+\lambda_{10}-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$, $k_6 = \frac{1}{k}\frac{-Ak_3}{\lambda_2{}^2+\lambda_2-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$,
$k_7 = \frac{1}{k}\frac{-Ak_4}{\lambda_6{}^2+\lambda_6-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$ $k_8 = \frac{A(k_3+k_4)\lambda_{10}}{\lambda_{10}{}^2+\lambda_{10}-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$, $k_9 = \frac{-Ak_3\lambda_2}{\lambda_2{}^2+\lambda_2-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$

$k_{10} = \frac{-Ak_4\lambda_6}{\lambda_6{}^2+\lambda_6-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$, $k_{11} = \frac{-Gr(1-k_1)}{\lambda_4{}^2+\lambda_4-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$, $k_{12} = \frac{-Gr\,k_1}{\lambda_2{}^2+\lambda_2-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$,
$k_{13} = \frac{-Gm(1-k_2)}{\lambda_8{}^2+\lambda_8-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$, $k_{14} = \frac{-Gm\,k_2}{\lambda_6{}^2+\lambda_6-\left(2iE+\frac{1}{k}+M+\frac{1}{4}i\omega\right)}$,

$$k_{15} = -k_5 - k_6 - k_7 - k_8 - k_9 - k_{10} - k_{11} - k_{12} - k_{13} - k_{14}$$

$$k_{16} = k_5 + k_8\ ,\ k_{17} = k_6 + k_9 + k_{12}\ ,\ k_{18} = k_7 + k_{10} + k_{14}$$

Results and Discussion: Here the effects of the parameters M, Gm, Sc, E, K, Pr, Gr, R on flow characteristics have been studied and shown by means of graphs. In order to have physical correlations we choose suitable values of flow parameters.

*Primary velocity profiles are depicted in fig.1 to fig3***.**

Fig.1 shows the effects of parameters M, Sc and Gm on the primary velocity at any point of fluid while other parameters remain constant. It is noticed that the primary velocity decreases with the increase of magnetic parameter (M) and Schmidt number (Sc) whereas it increases with the increase of modified Grashof number (Gm).

Fig.2 shows the effects of parameters E, k and Pr on the primary velocity at any point of fluid where the other parameters remain constant. It is noticed that the primary velocity decreases with the increase of Eckert number (E) and Prandtl number (Pr) whereas it increases with the increase of k.

Fig.3 shows the effect of parameters Gr and R while the other parameters remain constant. It is noticed that the primary velocity decreases with the increase of R and it increases with the increase of Gr.

Secondary velocity profiles are depicted in fig.4 to fig.6.

Fig.4 shows the effects of the parameters M, Sc and Gm on the secondary velocity at any point of the fluid while the other parameters remain constant. It is observed that the secondary velocity at any point of fluid increases as each of the parameters M and Sc increase. But the secondary velocity decreases with the increase of Gm.

Fig.5 shows that the increase in the parameter R increases the secondary velocity at any point of the fluid. Again it is seen that increase in the parameter Gr decreases the secondary velocity at any point of the fluid.

Fig.6 shows the effects of the parameters E, K, Pr on the secondary velocity at any point of the fluid. It is observed that secondary velocity at any point of fluid increases with the increase of Pr whereas it decreases with the increase of K and E.

Temperature : Mean temperature profiles are shown in the fig.15.This shows that the temperature falls with the increase of the prandtl number Pr.

Concentration : Mean concentration profiles are depicted in fig.13. This shows that the increase in the parameters Sc and R results a decrease in the concentration.

Coefficients of skin friction profiles are depicted in fig.7 to fig.12:

Fig.7 shows the effects of parameters M, Sc and Gm on coefficient of skin friction due to primary velocity. It is noticed that coefficient of skin friction increases with the increase of the parameter Gm while it decreases with the increase of M and Sc.

Fig.8 shows the effects of parameters E, K and Pr on the coefficient of skin friction (τ_p) due to primary velocity.τ_p increases with an increase in K whereas it shows the reverse effect in case of E and Pr.

Fig.9 depicts the effects of parameters Gr and R on τ_p . As Gr increases, τ_p increases and the effects of increasing value of R results a decrease in τ_p.

Fig.10 shows the effects of parameters M, Sc, Gm on coefficient of skin friction due to secondary velocity (τ_s). It is observed that these parameters show opposite effects as in the fig.7 i.e. for τ_p.

Fig.11 depicts the effects of E, K, and Pr on τ_s. It is noticed that the increase of the parameters E and K results a decrease in τ_s . But when Pr increases τ_s also increases.

Fig.12 shows that the increase in R helps to increase τ_s but τ_s decreases when Gr increases.

Sherwood number: It is shown in fig.14. Here we see that with the increase of the parameters R and Sc, Sherwood number increases.

Nusselt number: From fig.16, we get that the Nusselt number increases with the increase of prandtl number.

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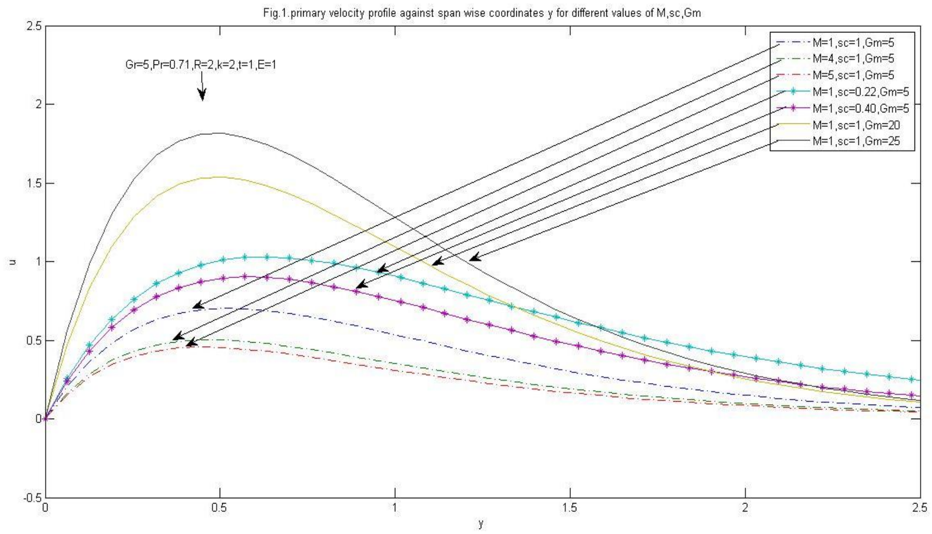


Fig.1.primary velocity profile against span wise coordinates y for different values of M,sc,Gm
Gr=5,Pr=0.71,R=2,k=2,t=1,E=1
M=1,sc=1,Gm=5
M=4,sc=1,Gm=5
M=5,sc=1,Gm=5
M=1,sc=0.22,Gm=5
M=1,sc=0.40,Gm=5
M=1,sc=1,Gm=20
M=1,sc=1,Gm=25
u
y

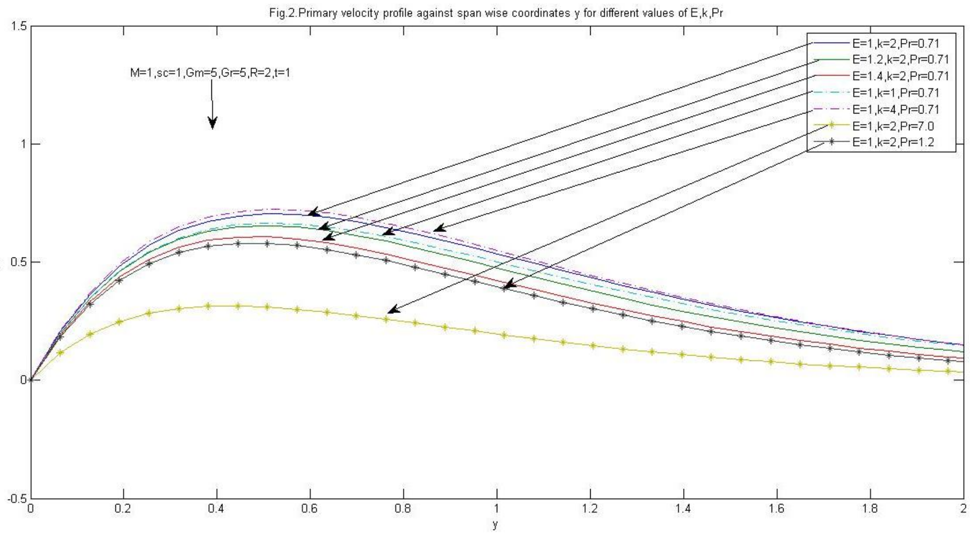


Fig.2.Primary velocity profile against span wise coordinates y for different values of E,k,Pr
M=1,sc=1,Gm=5,Gr=5,R=2,t=1
E=1,k=2,Pr=0.71
E=1.2,k=2,Pr=0.71
E=1.4,k=2,Pr=0.71
E=1,k=1,Pr=0.71
E=1,k=4,Pr=0.71
E=1,k=2,Pr=7.0
E=1,k=2,Pr=1.2
u
y

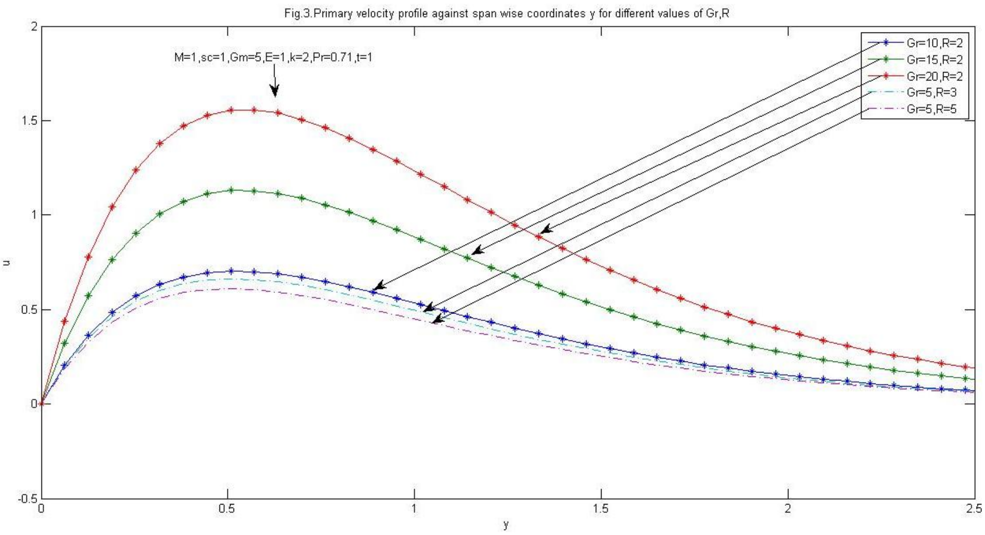


Fig.3.Primary velocity profile against span wise coordinates y for different values of Gr,R
M=1,sc=1,Gm=5,E=1,k=2,Pr=0.71,t=1
Gr=10,R=2
Gr=15,R=2
Gr=20,R=2
Gr=5,R=3
Gr=5,R=5
u
y

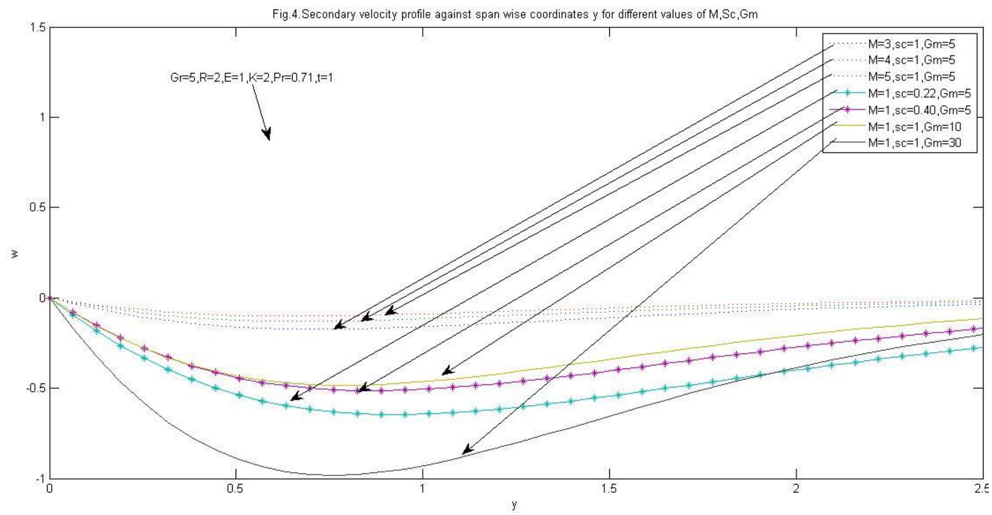


Fig.4.Secondary velocity profile against span wise coordinates y for different values of M,Sc,Gm
Gr=5,R=2,E=1,K=2,Pr=0.71,t=1
M=3,sc=1,Gm=5
M=4,sc=1,Gm=5
M=5,sc=1,Gm=5
M=1,sc=0.22,Gm=5
M=1,sc=0.40,Gm=5
M=1,sc=1,Gm=10
M=1,sc=1,Gm=30
w
y

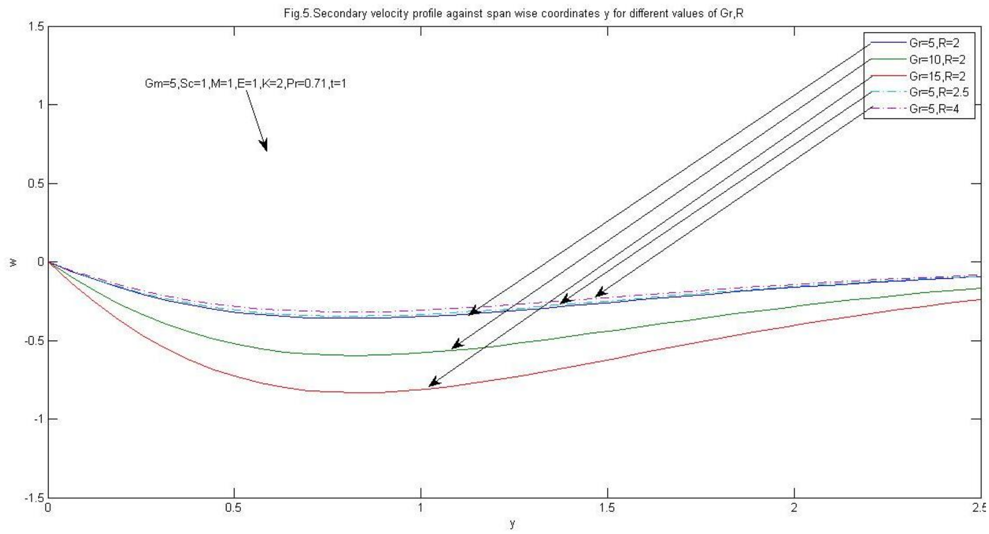


Fig.5.Secondary velocity profile against span wise coordinates y for different values of Gr,R
Gm=5,Sc=1,M=1,E=1,K=2,Pr=0.71,t=1
Gr=5,R=2
Gr=10,R=2
Gr=15,R=2
Gr=5,R=2.5
Gr=5,R=4
w
y

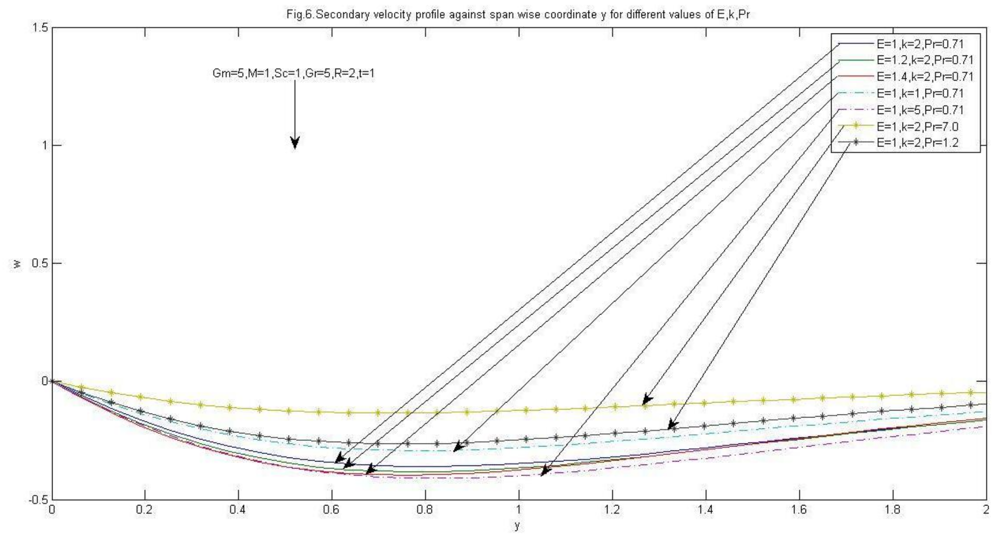


Fig.6.Secondary velocity profile against span wise coordinate y for different values of E,k,Pr
Gm=5,M=1,Sc=1,Gr=5,R=2,t=1
E=1,k=2,Pr=0.71
E=1.2,k=2,Pr=0.71
E=1.4,k=2,Pr=0.71
E=1,k=1,Pr=0.71
E=1,k=5,Pr=0.71
E=1,k=2,Pr=7.0
E=1,k=2,Pr=1.2
w
y

Fig.7.Coefficient of Skin friction (due to primary velocity)profiles for various values of M,Sc,GM

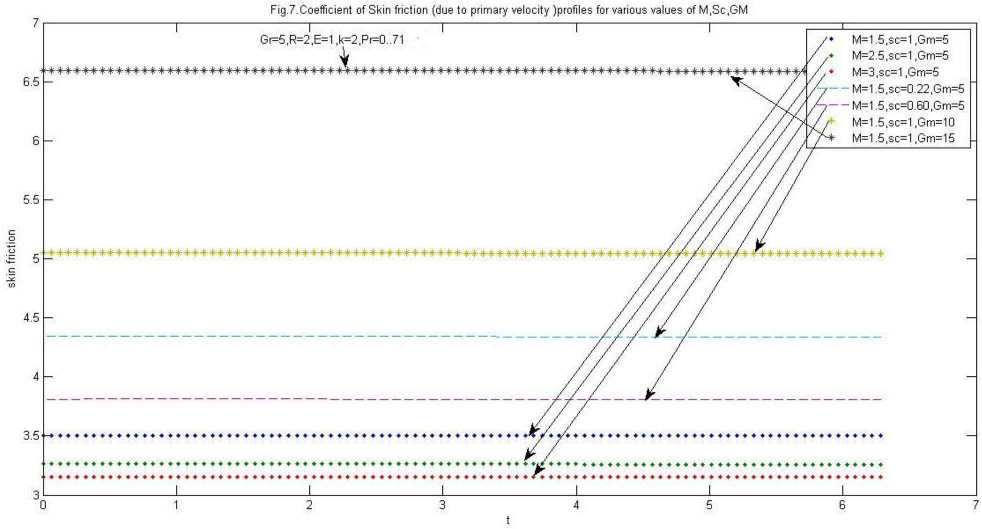


Fig.8.Coefficient of skin friction(due to primary velocity) profiles for various values of E,k,Pr

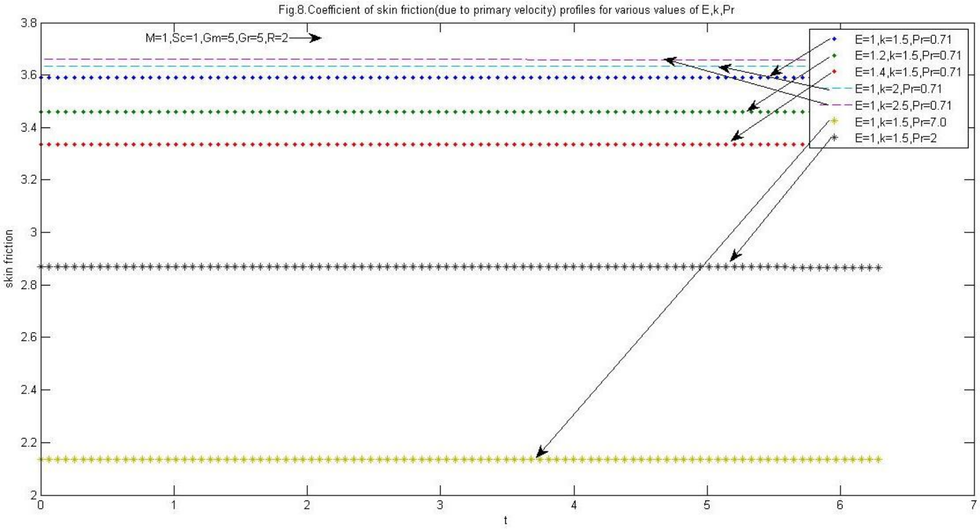


Fig.9.Coefficient of skin friction(due to primary velocity)profiles for various values of Gr,R

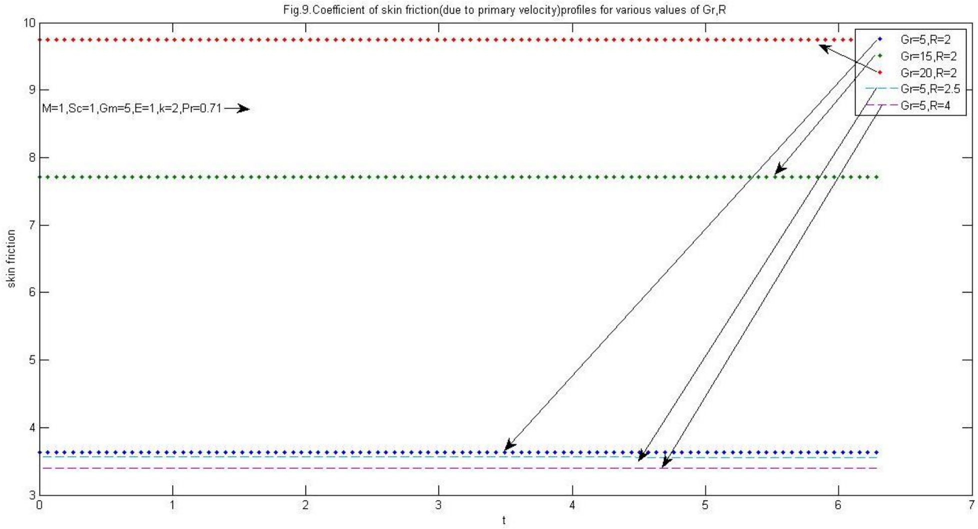


Fig.10.Coefficient of skin friction (due to secondary velocity)profiles for various values of M,Sc,Gm

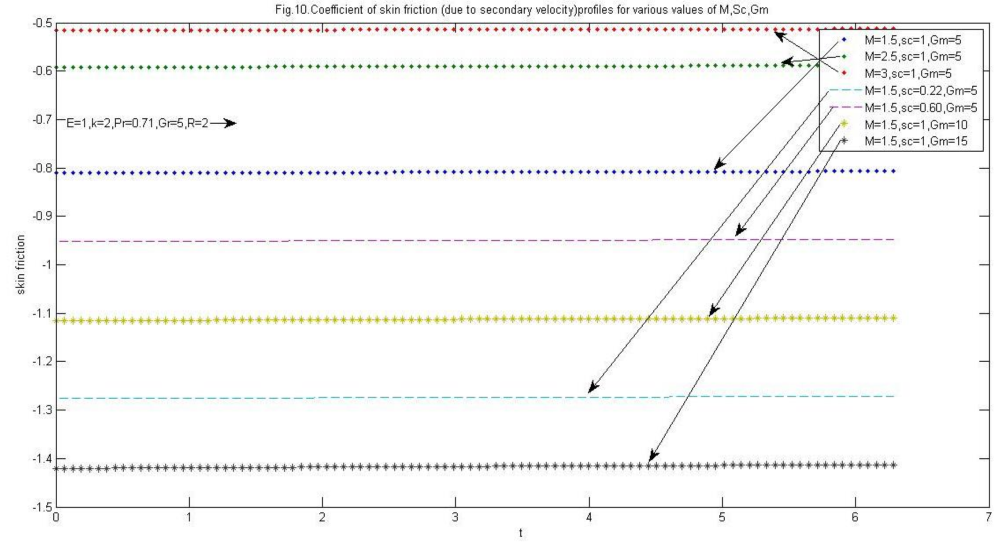


Fig.11.Coefficient of skin friction (due to secondary velocity)profiles for various values of E,k,Pr

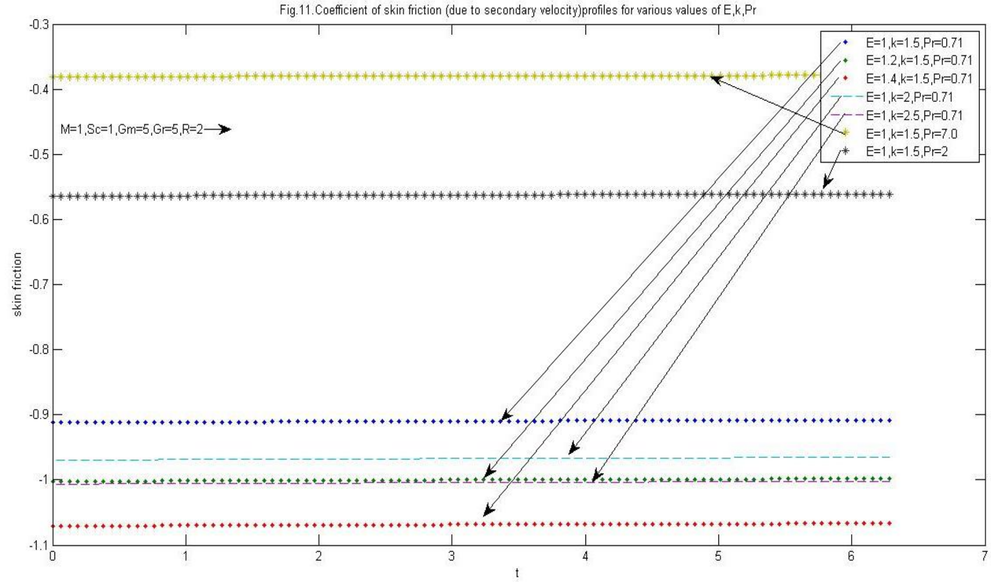


Fig.12.Coefficient of skin friction(due to secondary velocity)for various values of Gr,R

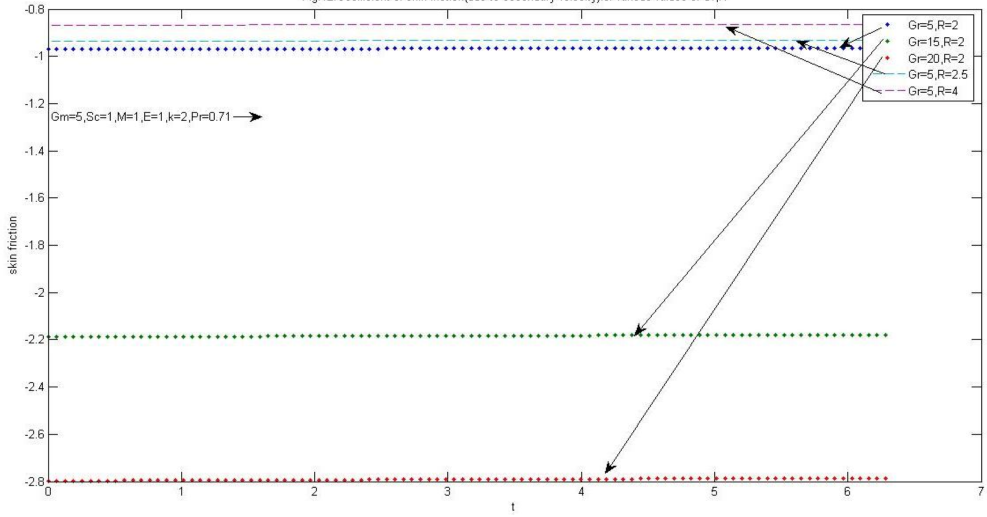
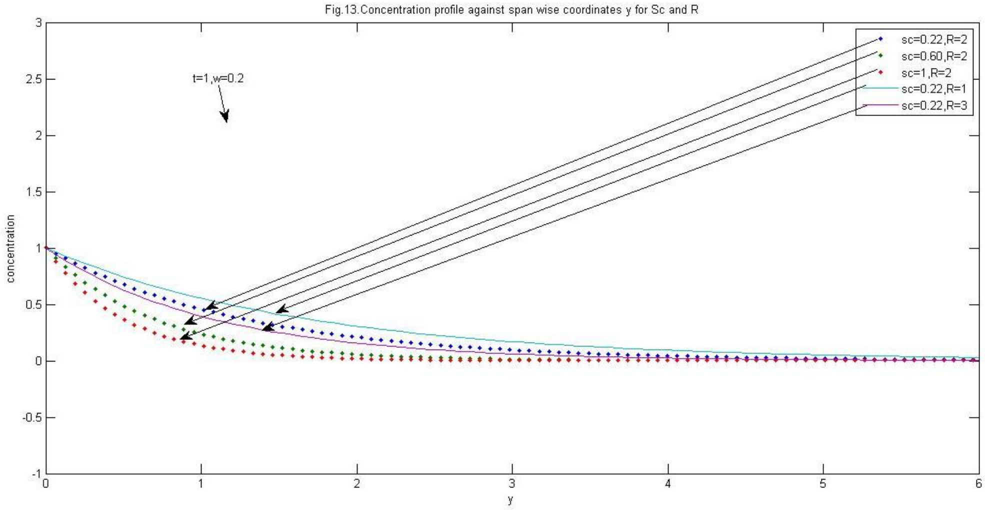


Fig.13.Concentration profile against span wise coordinates y for Sc and R



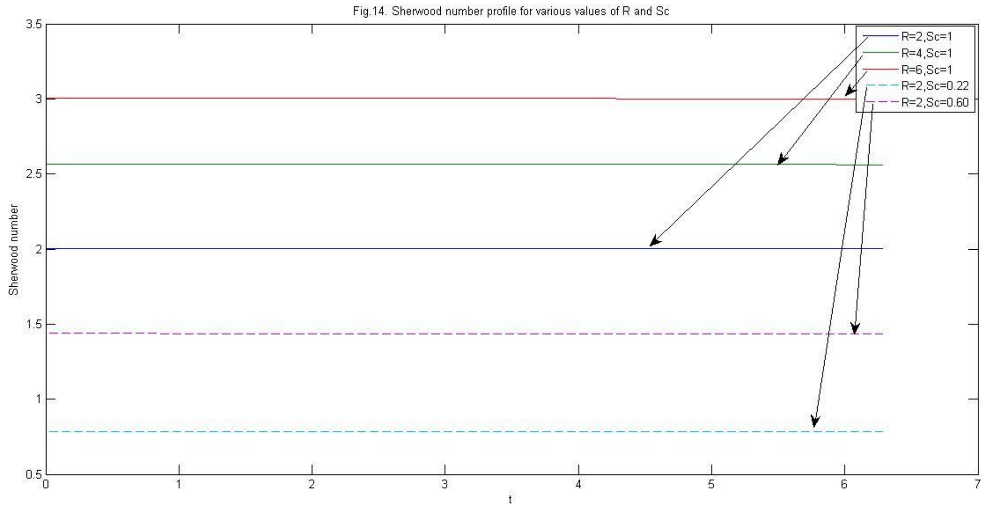


Fig.14. Sherwood number profile for various values of R and Sc
Sherwood number
t
R=2,Sc=1
R=4,Sc=1
R=6,Sc=1
R=2,Sc=0.22
R=2,Sc=0.60

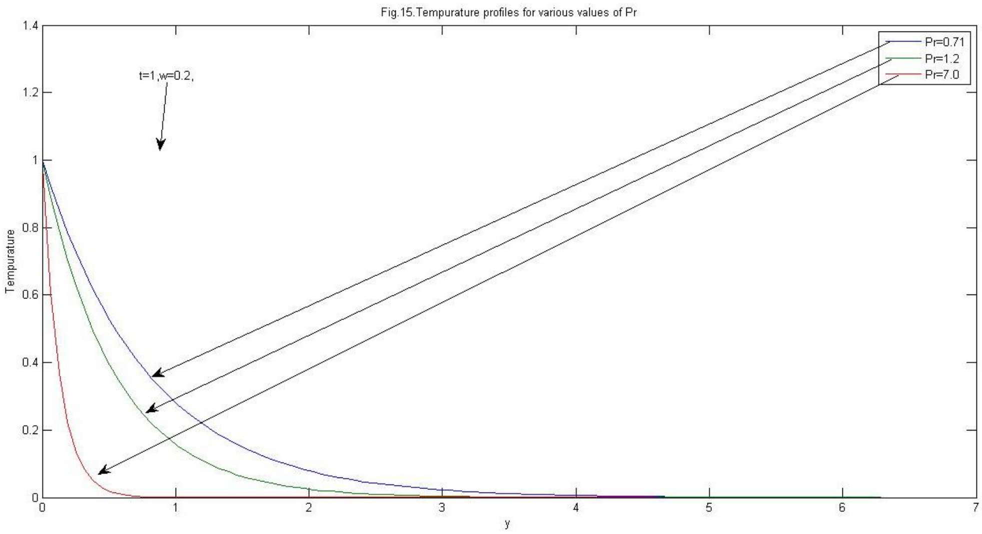


Fig.15.Tempurature profiles for various values of Pr
Tempurature
y
t=1,w=0.2,
Pr=0.71
Pr=1.2
Pr=7.0

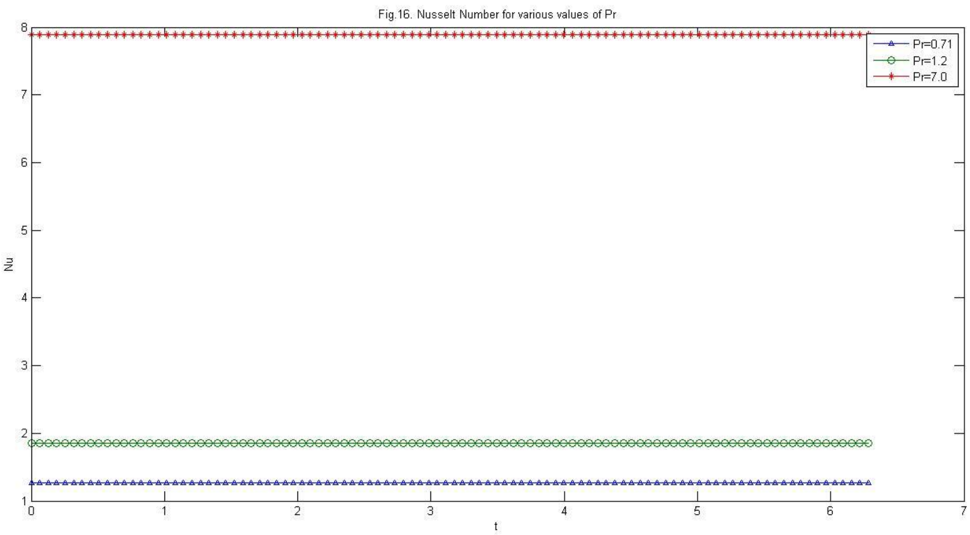


Fig.16. Nusselt Number for various values of Pr
Nu
t
Pr=0.71
Pr=1.2
Pr=7.0