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EFFECT OF CHEMICAL REACTION ON MHD FREE CONVECTION FLOW PAST AN EXPONENTIALLY ACCELERATE POROUS PLATE WITH VARIABLE TEMPERATURE EMBEDDED IN POROUS MEDIUM

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ABSTRACT

Free convection MHD flow of a viscous incompressible fluid past an accelerating infinite vertical plate with variable temperature and mass transfer has been studied. The dimensionless governing equations are solved using Laplace Transformation technique .The temperature and species concentration near the plate are assumed to vary with respect to time. The influences of the various parameters on the flow field, skin friction, rate of heat transfer, rate of mass transfer and Temperature field are extensively discussed from graphs.

KEYWORDS: MHD, Free Convection, Vertical Plate, Acceleration, Heat Transfer, Mass Transfer, Variable Temperature, Chemical Reaction and Porous Medium

INTRODUCTION

Coupled heat and mass transfer by natural convection in a fluid –saturated porous medium has attracted considerable attention in the last few years due to many important engineering and geophysical applications. It occurs not only due to temperature difference, but also due to concentration difference as well as different geophysical situations. Its application in many process industries like extrusion of plastic in the manufacture of Rayon and Nylon, purification of crude oil, pulp, paper industries, Radio propagation through the ionosphere. The phenomenon of mass transfer is a common theory of stellar structure. Also observable effects are detected on the solar surface.

Free convection effect on flow past a vertical surface studied by Vajnvelu et al [2], Vedhanayagam [3] and others with different boundary conditions. Revankar et al [6] and many workers have studied hydro magnetic natural convection flow past a vertical surface.

Convective heat transfer through porous media has been a subject of great interest for the last three decades. Kim et al [10] and Harris et al [12] have studied the problem of natural convection flow through porous medium past vertical plate. Mishra and Mohapatra [1] have considered the unsteady MHD free convection flow past a vertical porous plate. Raptis et al [7] and Geindreau et al [8] studied the effect of magnetic field in flow through porous medium. Raptis, Tzivonidis and Kafousias [3] and Raptis, Kafousias and Massalas [4] have studied the steady free convection and mass transfer through porous medium. Mohapatra and Senapati [8] have considered the steady MHD free convection flow through a porous medium with mass transfer. Mohapatra and Senapati [9, 11] have investigated the unsteady MHD free convection flow with mass transfer through porous medium past a vertical plate.

Flows past in a vertical exponentially accelerating plate in its own plane in presence of chemical reaction has many industrial applications. Muthucumaraswamy and Ganesan, [13]have studied the effect of the chemical reaction and injection on flow characteristics in an unsteady upward motion of an isothermal plate, Muthucumaraswamy,Sathappan, and Natarajan[14] , have studied mass transfer effect on exponentially accelerated isothermal vertical plate. Senapati and Dhal [16] have considered MHD free convection flow past an exponentially accelerated vertical plate with constant heat flux in the presence of variable mass diffusion and chemical reaction through porous medium. Senapati et al. [15] have studied the Effect of heat and mass transfer on MHD free convection flow past an oscillating vertical Plate with variable temperature embedded in porous medium.

In this problem, It try to investigate the Effect of chemical reaction on MHD free convection flow past an exponentially accelerate porous plate with variable temperature embedded in porous medium

FORMULATION OF PROBLEM

Consider the unsteady free convection two-dimensional flow of an incompressible, electrically conducting viscous fluid along an infinite exponentially accelerate porous plate with variable temperature embedded in porous medium in the presence of chemically reactive species . The X' –axis is taken along the plate in the upward direction growing in the direction of motion and Y' –axis is taken normal to the plate. Assume that the fluid has constant properties and the variation in density and mass concentration is considered only in the body force term. A magnetic field of uniform strength B_0 acts normal to the plate. Initially we assume that the plate and fluid are in the same temperature and concentration at all points. At time t'>0, the plate starts oscillating in its own plane with frequency and temperature of the plate and concentration level are also raised linearly with time. Then by usual Boussinesq's approximation, the unsteady flow is governed by the following equations:

$$\frac{\partial u'}{\partial t'} = \nu \frac{\partial^2 u'}{\partial y'^2} - \frac{\nu}{K'} u' - \frac{\sigma B_0^2 u'}{\rho} + g\beta(T' - T'_\infty) + g\beta_C(C' - C'_\infty) \tag{1}$$

$$\rho C_p \frac{\partial T'}{\partial t'} = k \frac{\partial^2 T'}{\partial y'^2} \tag{2}$$

$$\frac{\partial c'}{\partial t'} = D \frac{\partial^2 C'}{\partial y^2} - R'(C' - C'_\infty) \tag{3}$$

where ν is the kinematic viscosity, k is the thermal diffusivity, K' is the permeability coefficient, β is the volumetric coefficient of expansion for heat transfer, ρ is the density , σ is the electrical conductivity of the fluid , g is the acceleration due to gravity , T' is the temperature, $T'_\infty$is the temperature of the fluid far away from the plate.

With the following boundary conditions

$$\left.\begin{array}{l} t' \le 0, u' = 0, T' = T'_\infty , C' = C'_\infty \;\; for\, all\, y' \\ \left.\begin{array}{l} t' > 0, u' = U_0 e^{A't'} , T' = T'_\infty + (T'_w - T'_\infty)At', \\ \qquad C' = C'_\infty + (C'_w - C'_\infty)At' \;\; at\; y' = 0 \\ t' > 0, u' = 0 , T' \to T'_\infty , C' \to C'_\infty as y' \to \infty \end{array}\right] \end{array}\right] \tag{4}$$

where $A = \frac{U_0^2}{\upsilon}$ exponential parameter.

Let us introduce the dimensionless quantities

$$\left.\begin{array}{l} u = \dfrac{u'}{U_0}, t = \dfrac{t' U_0^2}{\upsilon}, y = \dfrac{y' U_0}{\upsilon}, \theta = \dfrac{T' - T'_\infty}{T'_w - T'_\infty}, C = \dfrac{C' - C'_\infty}{C'_w - C'_\infty}, \omega = \dfrac{\upsilon \omega'}{U_0^2} \\[2ex] Gr = \dfrac{g\beta\upsilon(T'_w - T'_\infty)}{U_0^3}, Gm = \dfrac{g\beta_C\upsilon(C'_w - C'_\infty)}{U_0^3}, Pr = \dfrac{\mu C_p}{k}, Sc = \dfrac{\upsilon}{D}, M = \dfrac{\sigma\nu B_0^2}{\rho U_0^2} \\[2ex] K = \dfrac{U_0^2 K'}{\upsilon^2}, \end{array}\right\} \tag{5}$$

where D is the mass diffusion, Gr is Grashof number, Gm is modified Grashof number ,K is permeability of porous medium, M is magnetic parameter ,Sc is Schmidt number, Pr is Prandtl number, $B_0 = \mu_e H_0$ and R is chemical reaction parameter

Substituting equation (5) in the equations (1), (2) & (3), we have

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + GmC - \left(M + \frac{1}{K}\right)u \tag{6}$$

$$Pr\frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} \tag{7}$$

$$Sc\frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial y^2} - RScC \tag{8}$$

With boundary conditions

$$\left.\begin{array}{l} t \le 0, u = 0, \theta = 0, C = 0 \; for \; y = 0 \\ t > 0, \begin{array}{l} u = e^{At}, \theta = t, C = t \text{ for } y = 0 \\ u = 0, \theta \to 0, C \to 0 \text{ for } y \to \infty \end{array}\Big\} \end{array}\right\} \tag{9}$$

METHOD OF SOLUTION

We solve the governing equation in an exact form by using Laplace transform of equation (6) to (8) using condition (9), we get

$$\frac{d^2\bar{\bar{u}}}{dy^2} - \left(s + \frac{1}{K} + M\right)\bar{u} + Gr\bar{\theta} + Gm\bar{C} = 0 \tag{10}$$

$$\frac{d^2\bar{\bar{\theta}}}{dy^2} - Prs\bar{\bar{\theta}} = 0 \tag{11}$$

$$\frac{d^2\bar{\bar{C}}}{dy^2} - Pr(s + R)\bar{\bar{C}} = 0 \tag{12}$$

Here s is the Laplace transform parameter.

The boundary conditions reduce to

$$\left.\begin{array}{l}\left.\begin{array}{r}\bar{u}=\frac{1}{s-A}\\ \bar{\theta}=\frac{1}{s^2},\bar{C}=\frac{1}{s^2}\end{array}\right\}\text{for } y=0\ \&\ t>0\\ \bar{u}=0,\bar{\theta}=0,\bar{C}=0 \text{ for } y\to\infty\ \&\ t>0\end{array}\right\} \tag{13}$$

By solving equation (10) to (12) using (13), we get

$$\bar{\theta}=\frac{e^{-\sqrt{Prs}y}}{s^2} \tag{14}$$

$$\bar{C}=\frac{e^{-\sqrt{Sc(s+R)}y}}{s^2} \tag{15}$$

$$\bar{u}=$$

$$\left(\frac{1}{s-A}+\frac{Gr}{s^2\left((Prs)-\left(s+\frac{1}{K}+M\right)\right)}+\frac{Gm}{s^2\left(Sc(s+R)-\left(s+\frac{1}{K}+M\right)\right)}\right)e^{-\sqrt{s+\left(\frac{1}{k}\right)+M}y}-\left(\frac{Gr}{s^2\left(Prs-\left(s+\frac{1}{K}+M\right)\right)}\right)e^{-y\sqrt{Prs}}-$$

$$\left(\frac{Gm}{s^2\left(Sc(s+R)-\left(s+\frac{1}{K}+M\right)\right)}\right)e^{-y\sqrt{Sc(s+R)}} \tag{16}$$

Taking inverse Laplace transformation from equation (14)-(16), we get

$$\theta=t\left[(1+2\eta^2Pr)erfc\left(\eta\sqrt{Pr}\right)-\frac{2\eta\sqrt{Pr}}{\sqrt{\pi}}exp(-\eta^2Pr)\right] \tag{17}$$

$$C=\frac{1}{2}\Bigg[t\left(e^{-2\eta\sqrt{RSc}}.erfc\left(\eta\sqrt{Sc}-\sqrt{Rt}\right)+e^{2\eta\sqrt{RSc}}.erfc\left(\eta\sqrt{Sc}+\sqrt{Rt}\right)\right)-\eta\sqrt{\frac{Sct}{R}}\Big(e^{-2\eta\sqrt{RSc}}.erfc\big(\eta\sqrt{Sc}-$$

$$\sqrt{Rt}\big)-e^{2\eta\sqrt{RSc}}.erfc\left(\eta\sqrt{Sc}+\sqrt{Rt}\right)\Big)\Bigg] \tag{18}$$

$$u=\frac{1}{2}\Bigg(e^{At}\left(e^{-2\eta\sqrt{t(A+M')}}.erfc\left(\eta-\sqrt{t(A+M')}\right)+e^{2\eta\sqrt{t(A+M')}}.erfc\left(\eta+\sqrt{t(A+M')}\right)\right)\Bigg)$$

$$+A_1\left(e^{\eta\sqrt{2tM'}}erfc\left(\eta+\sqrt{tM'}\right)+e^{-\eta\sqrt{2tM'}}erfc\left(\eta-\sqrt{tM'}\right)\right)+$$

$$A_2\left(e^{\eta\sqrt{2tM'}}erfc\left(\eta+\sqrt{tM'}\right)-e^{-\eta\sqrt{2tM'}}erfc\left(\eta-\sqrt{tM'}\right)\right)+A_3\Bigg(e^{2\eta\sqrt{\frac{PrtM'}{Pr-1}}}.erfc\left(\eta+\sqrt{\frac{PrtM'}{Pr-1}}\right)+e^{-2\eta\sqrt{\frac{PrtM'}{Pr-1}}}.erfc\Bigg(\eta-$$

$$\sqrt{\frac{PrtM'}{Pr-1}}\Bigg)\Bigg)+A_4\Bigg(e^{2\eta\sqrt{\frac{tSc(M'-R)}{Sc-1}}}.erfc\left(\eta+\sqrt{\frac{tSc(M'-R)}{Sc-1}}\right)+e^{-2\eta\sqrt{\frac{tSc(M'-R)}{Sc-1}}}.erfc\left(\eta-\sqrt{\frac{tSc(M'-R)}{Sc-1}}\right)\Bigg)+$$

$$-\frac{GrPr^2}{2(Pr-1)}\Bigg(2A_5erfc\left(\eta\sqrt{Pr}\right)+A_6\left((2t+4t\eta^2).erfc\left(\eta\sqrt{Pr}\right)-\frac{4\eta t}{\sqrt{\pi Pr}}e^{-\eta^2Pr}\right)+$$

$$A_7e^{\frac{M't}{Pr-1}}\Bigg(e^{2\eta\sqrt{\frac{M'tPr}{Pr-1}}}.erfc\left(\eta\sqrt{Pr}+\sqrt{\frac{M'Pr}{Pr-1}}\right)+e^{-2\eta\sqrt{\frac{M'tPr}{Pr-1}}}.erfc\left(\eta\sqrt{Pr}-\sqrt{\frac{M'Pr}{Pr-1}}\right)\Bigg)\Bigg)-A_8\Big(e^{2\eta\sqrt{RSct}}.erfc\big(\eta\sqrt{Sc}+$$

$$\sqrt{Rt}\big)+e^{-2\eta\sqrt{RSct}}.erfc\left(\eta\sqrt{Sc}-\sqrt{Rt}\right)\Big)-A_9\Bigg(\frac{t}{Sc}\left(e^{2\eta\sqrt{tRSc}}.erfc\left(\eta\sqrt{Sc}+\sqrt{Rt}\right)+e^{-2\eta\sqrt{tRSc}}.erfc\left(\eta\sqrt{Sc}-\sqrt{Rt}\right)\right)+$$

$$\frac{2\eta\sqrt{t}}{\sqrt{RSc}}\left(e^{2\eta\sqrt{tRSc}}.erfc\left(\eta\sqrt{Sc}+\sqrt{Rt}\right)-e^{-2\eta\sqrt{tRSc}}.erfc\left(\eta\sqrt{Sc}-\sqrt{Rt}\right)\right)\Bigg)-A_{10}e^{\frac{t(M'-R)}{Sc-1}}\left(e^{2\eta\sqrt{\frac{(M'-R)Sct}{Sc-1}}}.erfc\left(\eta\sqrt{Sc}+\right.\right.$$

$$\left.\left.\sqrt{\frac{(M'-R)t}{Sc-1}}\right)+e^{-2\eta\sqrt{\frac{(M'-R)Sct}{Sc-1}}}.erfc\left(\eta\sqrt{Sc}-\sqrt{\frac{(M'-R)t}{Sc-1}}\right)\right) \tag{19}$$

The dimensional rate of heat transfer,

$$\mathrm{Nu}=-\left(\frac{\partial\theta}{\partial\eta}\right)_{\eta=0}=\frac{4t\sqrt{Pr}}{\sqrt{\pi}} \tag{20}$$

The dimensionless rate of mass transfer ,

$$Sh=-\left(\frac{\partial C}{\partial\eta}\right)_{\eta=0}=\frac{1}{2}\left[t\left(2\sqrt{Rt}\left(erfc\left(-\sqrt{Rt}\right)-erfc\left(\sqrt{Rt}\right)\right)+4\sqrt{\frac{Sc}{\pi}}exp(-Rt)\right)-\sqrt{\frac{Sct}{R}}\left(erfc\left(\sqrt{Rt}\right)-\right.\right.$$

$$\left.\left.erfc\left(-\sqrt{Rt}\right)\right)\right] \tag{21}$$

The non-dimensional Skin friction at the wall from the equations (19) is given by

$$\tau_0=\left(\frac{\partial u}{\partial\eta}\right)_{\eta=0}=\frac{1}{2}\left(e^{At}\left(2\sqrt{t(A+M')}\left(erfc\left(\sqrt{t(A+M')}\right)-erfc\left(-\sqrt{t(A+M')}\right)\right)-\frac{4}{\sqrt{\pi}}e^{-t(A+M')}\right)\right)+$$

$$A_1\left(\sqrt{2tM'}\left(erfc\left(\sqrt{tM'}\right)-erfc\left(-\sqrt{tM'}\right)\right)-\frac{4}{\sqrt{\pi}}e^{-tM'}\right)+\left(-\frac{Gm\sqrt{t}}{2(ScR-M')\sqrt{M'}}\right)\left(\sqrt{2tM'}\left(erfc\left(\sqrt{tM'}\right)+erfc\left(-\sqrt{tM'}\right)\right)-\right.$$

$$\left.\frac{4}{\sqrt{\pi}}e^{-tM'}\right)+\left(\frac{Gr\sqrt{t}}{2(M')^{\frac{3}{2}}}\right)\left(erfc\left(\sqrt{M't}\right)+erfc\left(-\sqrt{M't}\right)\right)$$

$$+A_3\left(2\sqrt{\frac{PrtM'}{Pr-1}}\left(erfc\left(\sqrt{\frac{PrtM'}{Pr-1}}\right)-erfc\left(-\sqrt{\frac{PrtM'}{Pr-1}}\right)\right)-\frac{4}{\sqrt{\pi}}e^{-\frac{PrtM'}{Pr-1}}\right)+A_4\left(2\sqrt{\frac{tSc(M'-R)}{Sc-1}}\left(erfc\left(\sqrt{\frac{tSc(M'-R)}{Sc-1}}\right)-\right.\right.$$

$$\left.\left.erfc\left(-\sqrt{\frac{tSc(M'-R)}{Sc-1}}\right)\right)-\frac{4}{\sqrt{\pi}}e^{-\frac{tSc(M'-R)}{Sc-1}}\right)-A_8\left(2\sqrt{tScR}\left(erfc\left(\sqrt{Rt}\right)-erfc\left(-\sqrt{Rt}\right)\right)-\frac{4}{\sqrt{\pi}}\sqrt{Sc}\left(e^{-Rt}\right)\right)-$$

$$A_9\left(\frac{1}{Sc}\left(2\sqrt{RtSc}\left(erfc\left(\sqrt{Rt}\right)-erfc\left(-\sqrt{Rt}\right)\right)-\frac{4\sqrt{Sc}}{\sqrt{\pi}}e^{-Rt}\right)+\frac{2\sqrt{t}}{\sqrt{RSc}}\left(erfc\left(\sqrt{Rt}\right)-erfc\left(-\sqrt{Rt}\right)\right)\right)-$$

$$A_{10}\left(e^{\frac{t(M'-R)}{Sc-1}}\left(2\sqrt{\frac{tSc(M'-R)}{Sc-1}}\left(erfc\left(\sqrt{\frac{t(M'-R)}{Sc-1}}\right)-erfc\left(-\sqrt{\frac{t(M'-R)}{Sc-1}}\right)\right)-\frac{4}{\sqrt{\pi}}\sqrt{Sc}e^{-\frac{t(M'-R)}{Sc-1}}\right)\right)-\frac{Gr(Pr)^2}{2(Pr-1)}\left(-\frac{4A_5\sqrt{Pr}}{\sqrt{\pi}}+\right.$$

$$\left.A_6\left(2t\left(1-\frac{2\sqrt{Pr}}{\sqrt{\pi}}\right)\right)-\frac{4t}{\sqrt{\pi Pr}}\right)+A_7e^{\frac{M't}{Pr-1}}\left(2\sqrt{\frac{M'Pr}{Pr-1}}\left(erfc\left(\sqrt{\frac{M'Pr}{Pr-1}}\right)-erfc\left(-\sqrt{\frac{M'Pr}{Pr-1}}\right)\right)-\frac{4\sqrt{Pr}}{\sqrt{\pi}}e^{-\frac{M'Pr}{Pr-1}}\right) \tag{22}$$

Where $A_1=\left(\frac{Gr(3PrM'-Pr^2M'-2)}{2M'^2(M'^2-2)}+\frac{Grt}{2M'}+\frac{Gm(ScM'^2+Sc^2RM'+RM'-R^2Sc-2ScRM')}{2ScM'(M'-R)(ScR-M')^2}-\frac{Gmt}{2(ScR-M')}\right)$

$$A_2=\left(\frac{Gr\eta\sqrt{t}}{2(M')^{\frac{3}{2}}}-\frac{Gm\sqrt{t}}{2(ScR-M')\sqrt{M'}}\right)A_3=\frac{Gr}{2(Pr-1)}e^{\frac{M't}{Pr-1}}A_4=\frac{Gm}{2(Sc-1)}e^{\left(\frac{(M'-RSc)t}{Sc-1}\right)}$$

$$A_5 = -\frac{(Pr-1)^2}{(PrM')^2}, A_6 = \frac{1-Pr}{M'Pr}, A_7 = \frac{(Pr-1)^2}{(PrM')^2}, A_9 = \frac{Gm}{2Sc^3(RSc-M')}, A_{10} = \frac{Gm(Sc-1)}{2Sc^4(RSc-M')^2}$$

$$A_8 = \frac{Gm(2M'^2-R^2Sc-3RSc\,M'-RM'+R^2)}{2R(M'-R)Sc^4(RSc-M')^2} \text{ And } \eta = \frac{y}{2\sqrt{t}}$$

GRAPHICAL RESULTS AND DISCUSSIONS

In this paper we have studied the Effect of chemical reaction on MHD free convection flow past an exponentially accelerate porous plate with variable temperature embedded in porous medium. The effect of the parameters Gr, Gm, M, K, R, Pr, A and Sc 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. The graphs of velocities, heat and mass concentration are taken w.r.t. η and the graphs of Skin friction, Nusselt number and Sherwood Number are taken w.r.t time (t).

Velocity Profiles: The velocity profiles are depicted in Figure 1 3. Figure 1 shows the effect of the parameters M, K and A on velocity at any point of the fluid, when Pr=2,Gr=2,Gm=2, R=2 Sc=2,and t=0.2..It is noticed that the velocity decreases with the increase magnetic parameter (M), where as increases with the increase of permeability of porous medium (K) and exponential parameter (A).

Figure 2 shows the effect of the parameters Gr, Gm and R on velocity at any point of the fluid , when Sc=2,Pr=2,M=2,K=2,A=2 and t=0.2. It is noticed that the velocity increases with the increase of Grashof number (Gr), Modified Grashof number (Gm) and Chemical reaction parameter (R).

Figure 3 shows the effect of the parameters Pr, Sc and t on velocity at any point of the fluid, when M=2,K=2,Gr=2,Gm=2,R=2 and A=2. It is noticed that the velocity decreases with the increase of Schmidt number (Sc) and Prandtl number (Pr) where as increases with time (t).

Heat Profile: Figure 4 shows the effect of the parameters Pr and t on Heat profile at any point of the fluid in the absence of other parameters. it is noticed that the temperature falls in the increase of Prandtl number (Pr), whereas temperature rises with time (t).

Mass Concentration Profile: Figure 5 shows the effect of the parameters Sc, t and R on mass concentration profile at any point of the fluid in the absence of other parameters It is noticed that the mass concentration increases with the increase of Schmidt number (Sc), time (t) and chemical reaction parameter(R).

Skin Friction: The Skin friction are depicted in Figs 6-8.Figure-(6) illustrates the effect of the parameters Gr, Gm and R on Skin friction at plate of the fluid w.r.t. time (t) , when Sc=2,Pr=2,K=2,M=5 and R=2 .It is noticed that Skin friction at plate decreases with the increase of Grashof number (Gr), Modified Grashof number (Gm) and Chemical reaction parameter (R).

`Figure 7 illustrates the effect of the parameters M and K on Skin friction at plate of the fluid w.r.t. time (t), when Sc=2, Pr=2, Gr=2, Gm=2 and R=2. It is noticed that Skin friction at plate decreases with the increase of magnetic parameter (M), where as increases with the increase of permeability of porous medium (K).

Figure 8, illustrates the effect of the parameters Sc, Pr and A on Skin friction at plate of the fluid w.r.t. time (t), when M=2, K=2, Gr=2, Gm=2 and R=2.It is noticed that Skin friction at plate increases with the increase of Schmidt number (Sc) and Prandtl number (Pr) where as decreases with the increase of exponential parameter (A).

Sherwood Number: Figure 9, illustrates the effect of the parameters of Sc and R on Sherwood Number at plate of the fluid w.r.t. time (t) in the absence of other parameters .It is noticed that Sherwood Number at plate increases with the increase of Schmidt number (Sc) ,reaction parameter (R) and time(t).

Nusselt Number: Figure 10 illustrates the effect of the parameters Pr and t on Nusselt number at plate; It is observed that Nusselt number increases at the plate with the increase of time (t) and prandtl number (Pr).

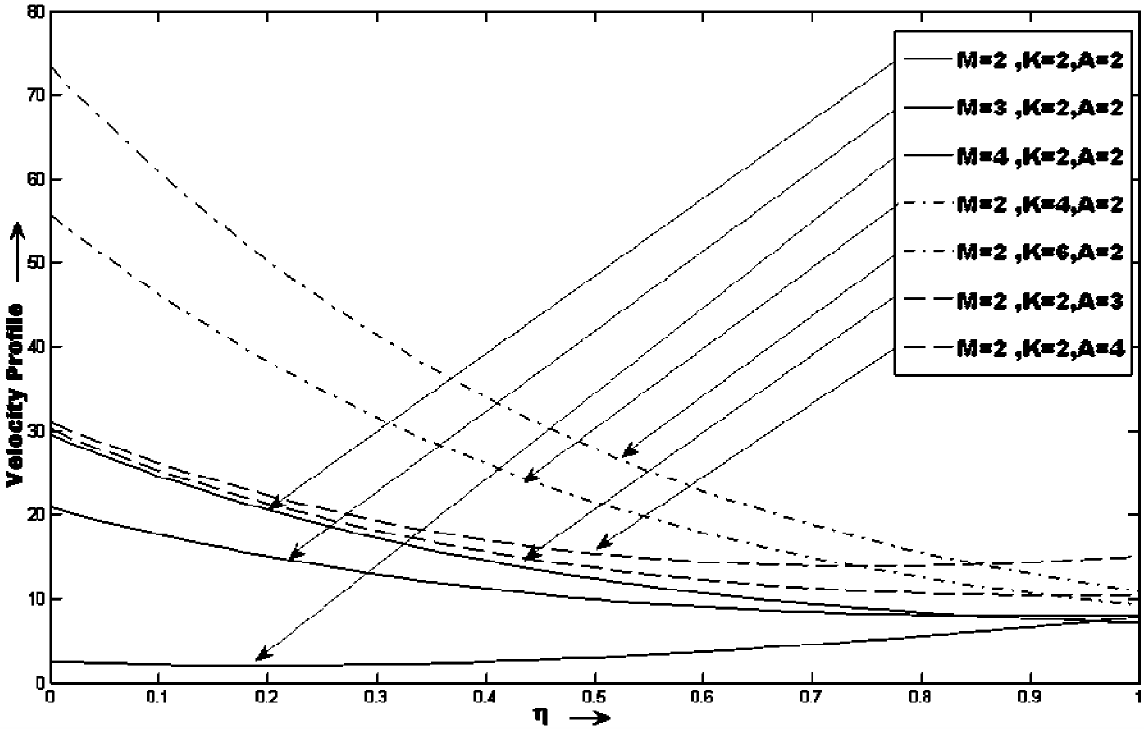

Figure 1: Effect of M, K and A on Velocity Profile when Sc=2, Pr=2, Gr=2, Gm=2, R=2 and t=0.2

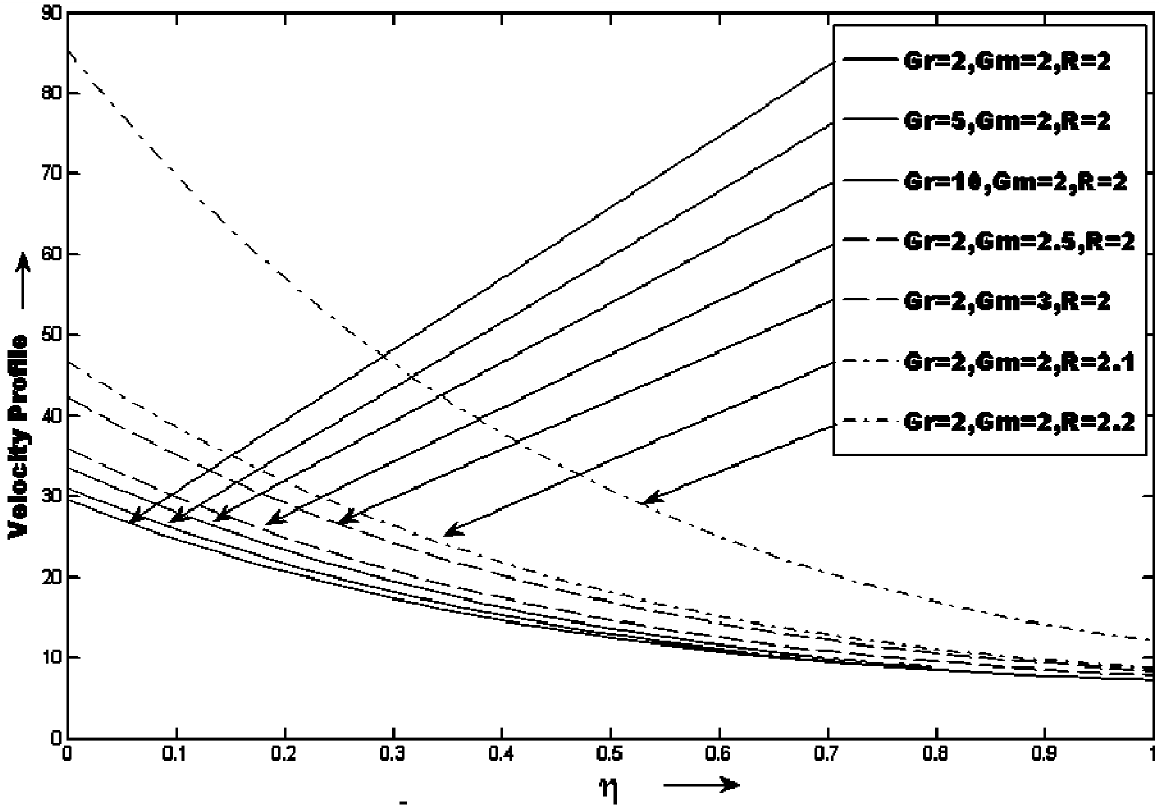

Figure 2: Effect of Gr, Gm and R on Velocity Profile when Sc=2, Pr=2, M=2, K=2, A=2 and t=0.2

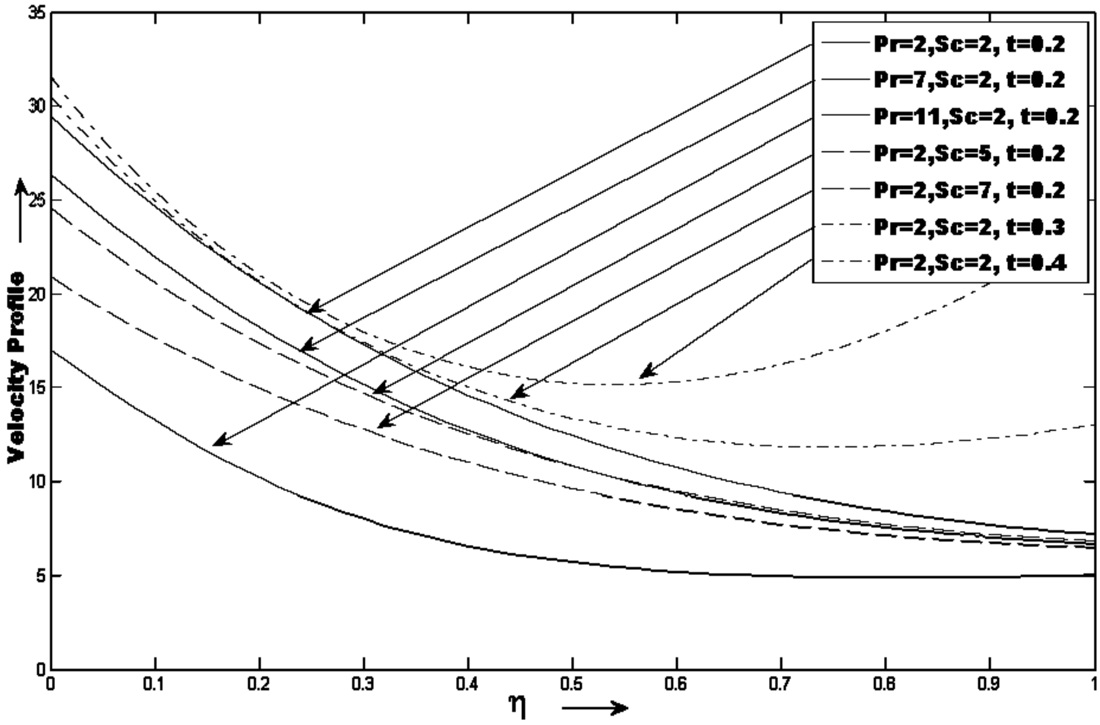

Figure 3: Effect of Pr, Sc and t on Velocity Profile when M=2, K=2, Gr=2, Gm=2, R=2 and A=2

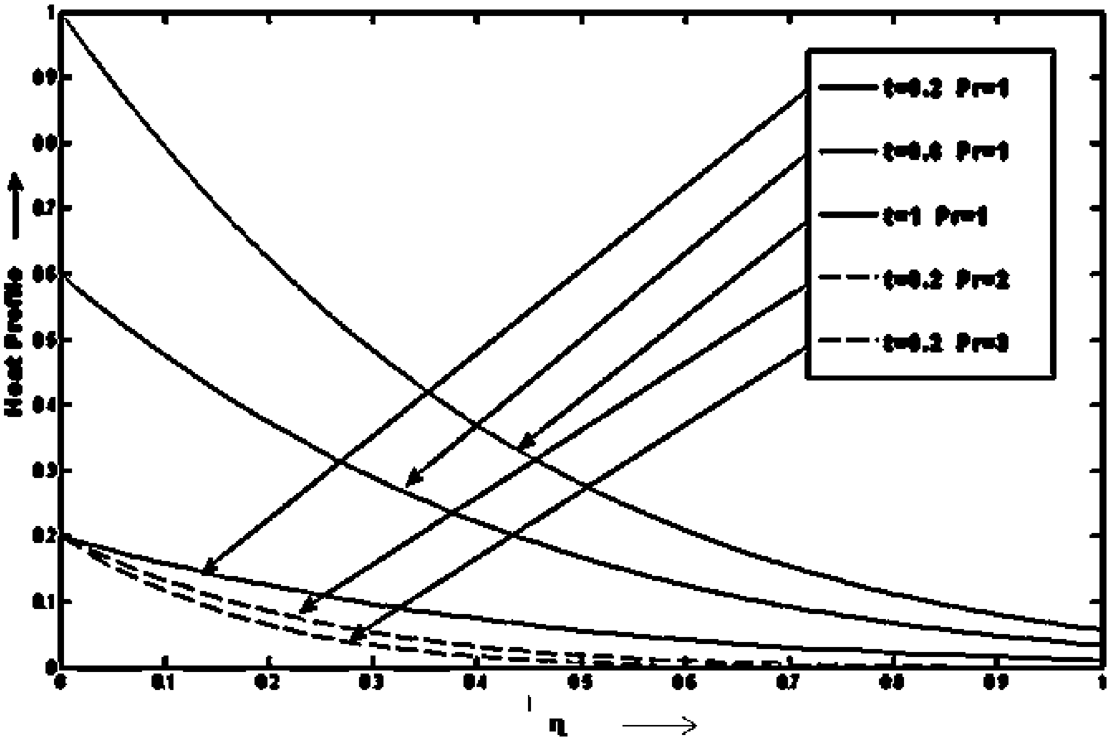

Figure 4: P Effect of Pr and t on Heat Profile in the Absence of Other Parameters

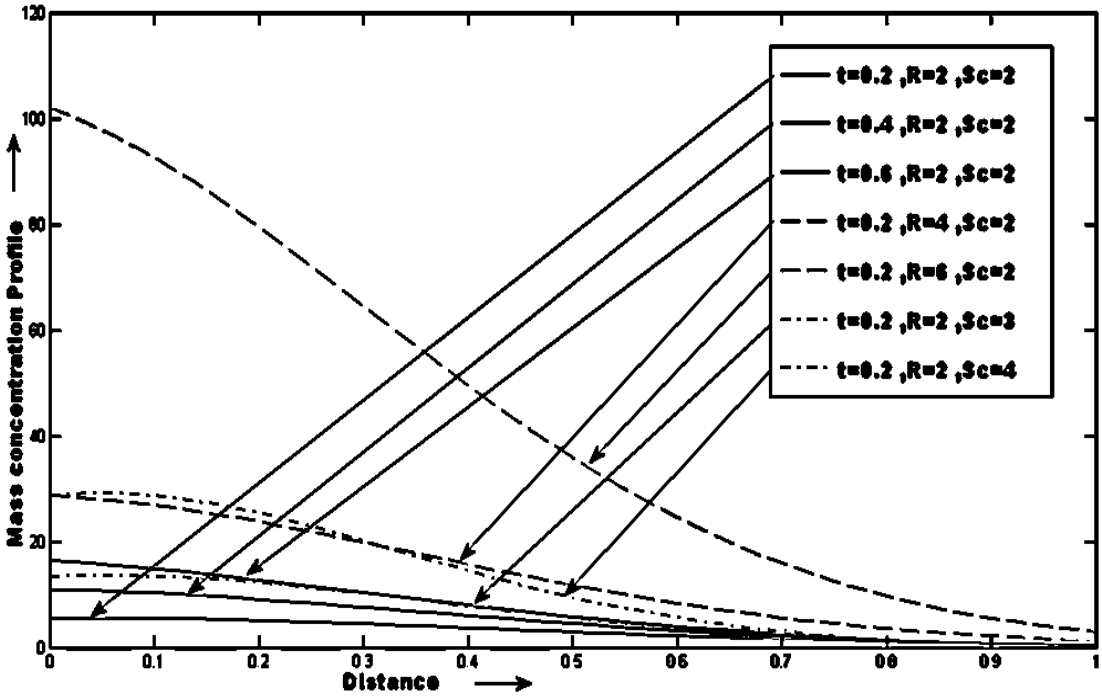

Figure 5: Effect of R, Sc and t on Mass Concentration Profile in the Absence of Other Parameters

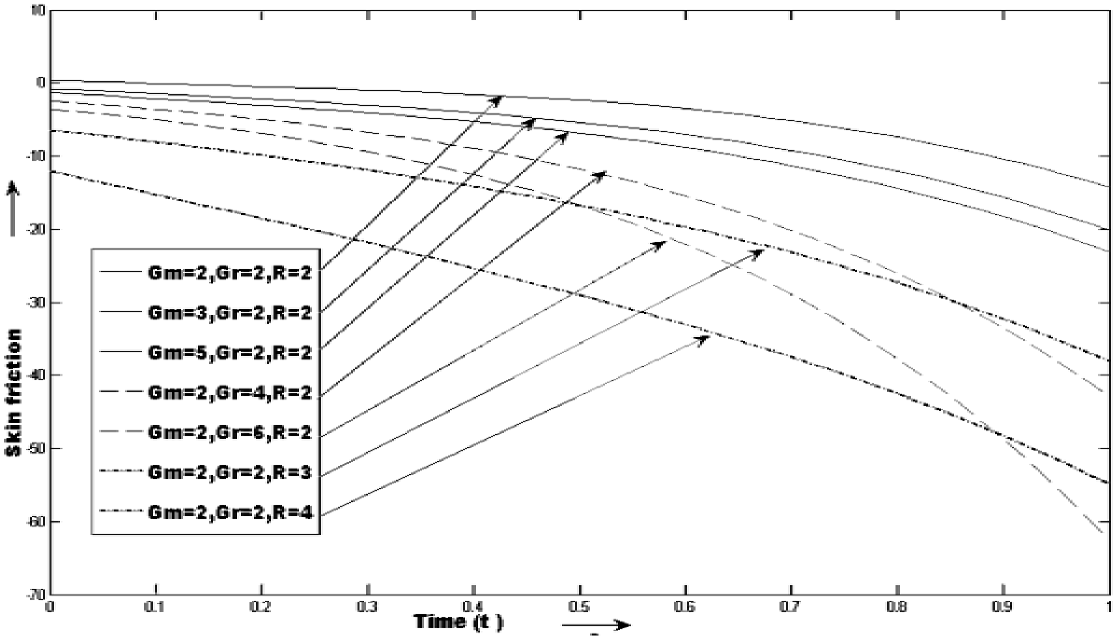

Figure 6: Effect of Gr, Gm and R on Skin Friction When Sc=2, Pr=2, K=2, M=5 and R=2

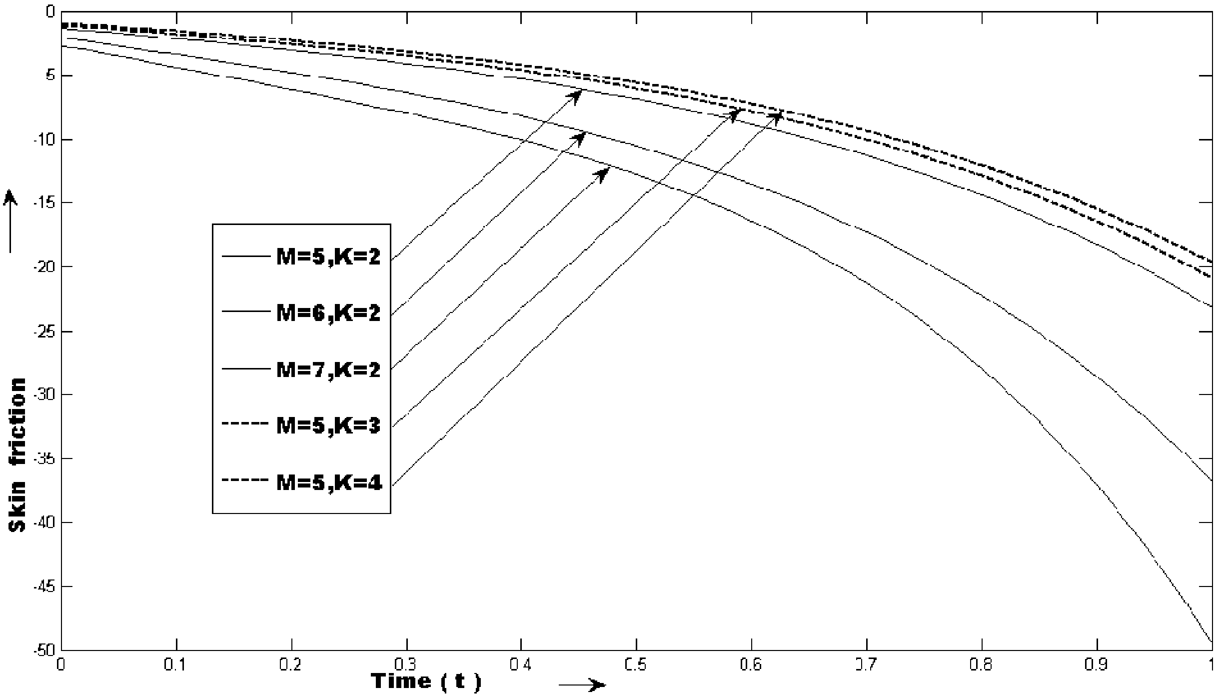

Figure 7: Effect of M and K on Skin Friction When Sc=2, Pr=2, Gr=2, Gm=2 and R=2

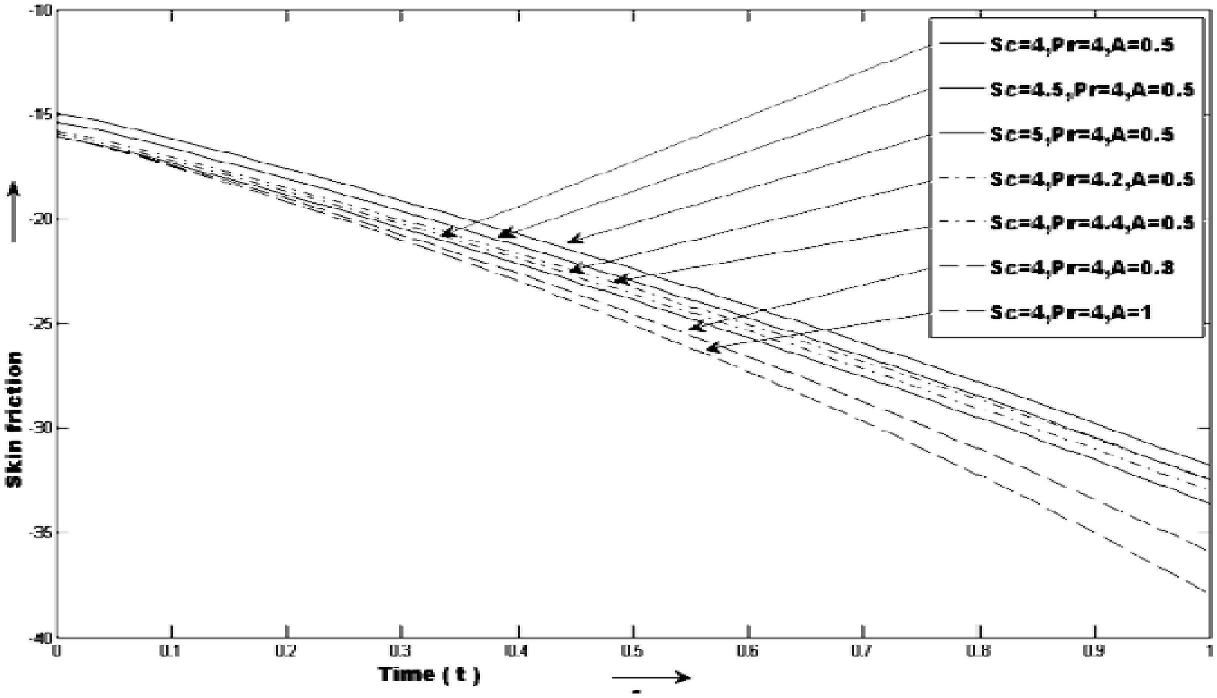

Figure 8: Effect of Sc, Pr and A on Skin Friction when M=2, K=2, Gr=2, Gm=2 and R=2

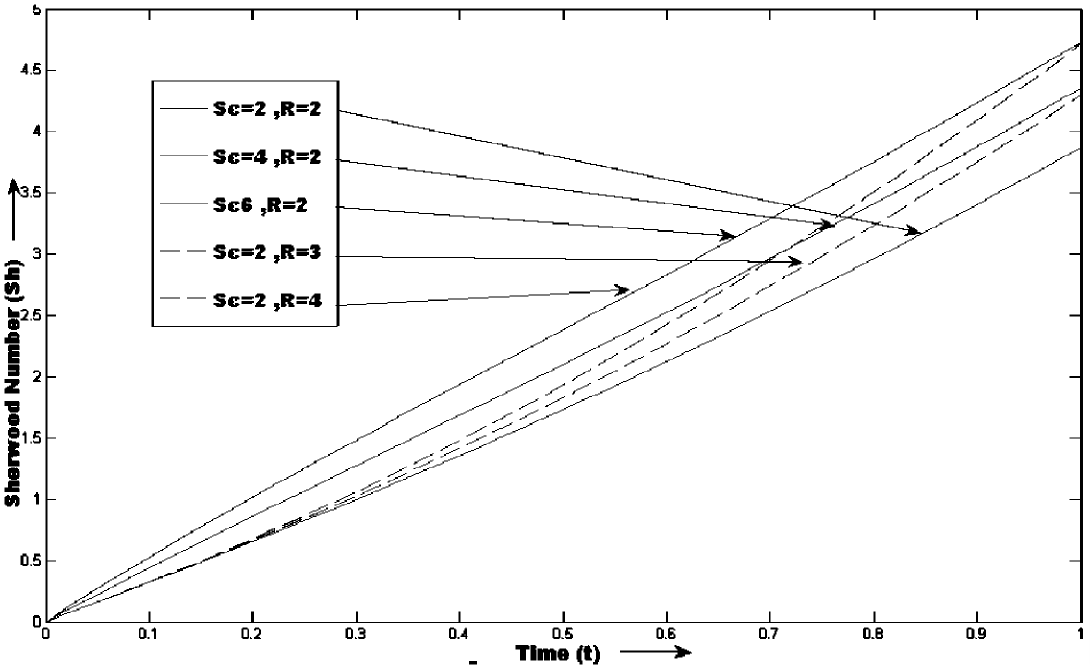

Figure 9: Effect of Sc and R on Sherwood Number in the Absence of Other Parameters

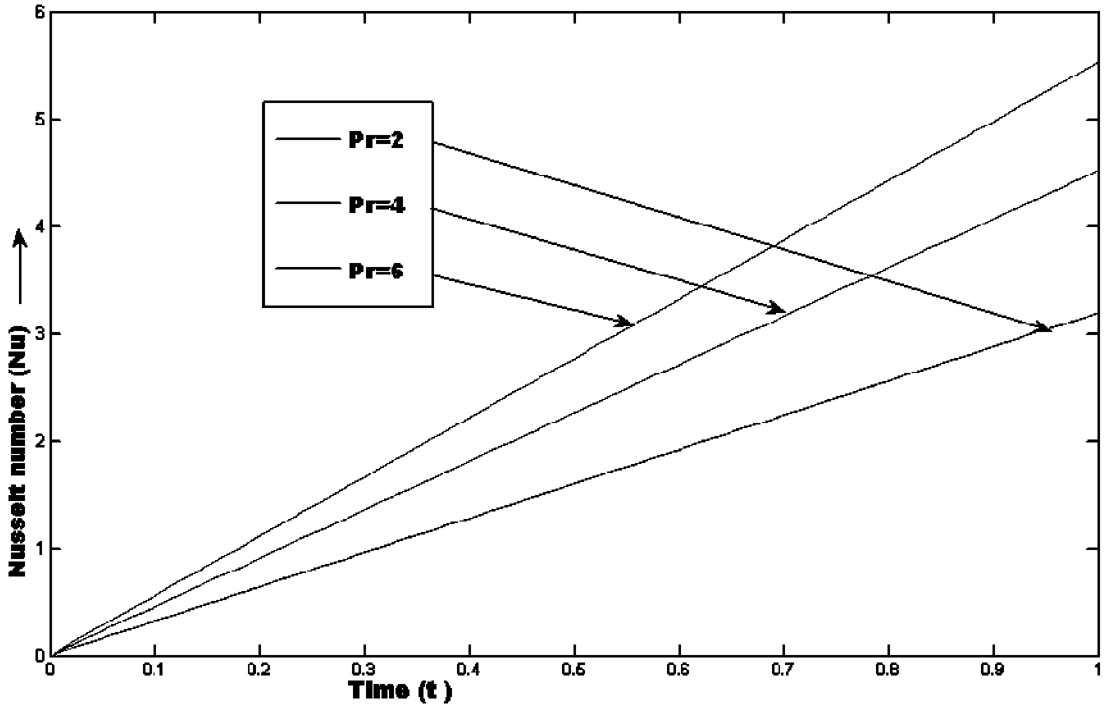

Figure 10: Effect of Pr on Nusselt Number in the Absence of Other Parameters

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