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Chemical Reaction and Radiation Effects on Unsteady MHD Free Convection Flow Past an Exponentially Accelerated Vertical Plate Through Porous Medium With Heat Absorption in the Presence of Thermal Diffusion

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Abstract

The present study is aimed at analyzing the effects chemical reaction and thermal radiation on an unsteady MHD free convection flow near a moving vertical plate through a porous medium in presence of heat generation/ absorption. General exact solutions for the partial differential equations governing the flow are obtained with the aid of the usual Laplace transform technique. Also the applications of general solution for the important cases of the flow are discussed. Velocity decreases with the increase in the magnetic parameter or the radiation parameter , the coefficient of heat absorption , the Schmidt number or Prandtl number. The skin friction coefficient increased due to increase in the concentration buoyancy effects while it decreases due to increase the magnetic parameter. The Nusselt number and Sherwood number increases with increasing values of radiation parameter or heat absorption parameter or chemical reaction parameter.

Key wards: MHD, Heat generation/ absorption, Radiation, Chemical reaction, Porous medium, Laplace Transform method.

1 INTRODUCTION:

Gupta et al. [1] studied the viscous dissipation effects on free convection on flow past a linearly accelerated vertical plate in the presence of viscous dissipative heat using perturbation method. Kafousias and Raptis [2] extended this problem to include mass transfer effects subjected to variable suction or injection. Free convection effects on flow past an exponentially accelerated vertical plate was investigated by Singh and Naveen kumar [3]. Soundalgekar et al. [4] considered Mass transfer effects on the flow past an impulsively started infinite vertical plate with variable temperature constant heat flux. The skin friction for accelerated vertical plate has been studied analytically by Hossain and Shayo [5]. Basant kumar Jha et al. [6] analyzed mass transfer effects on exponentially accelerated infinite vertical plate with constant heat flux and uniform mass diffusion. Basant kumar Jha [7] studied MHD free convection and mass transform flow through a porous medium. Muthucumaraswamy et al. [10] studied mass transfer effects on exponentially accelerated isothermal vertical plate. Radiation and mass transfer effects on MHD free convection flow past an exponentially accelerated vertical plate with variable temperature was investigated by Rajesh and Varma [11]. MHD effects on free convection and mass transform flow through a porous medium with variable temperature was investigated by Rajesh and Varma [12]. Muthucumaraswamy and Muralidharan [13] studied Thermal radiation on linearly accelerated vertical plate with variable temperature and uniform mass flux. Rajput U. S and Sahu P.S [14] investigated the effects of rotation and magnetic field on the flow past an exponentially accelerated vertical plate with constant temperature. Muthucumaraswamy and Visalakshi [15] studied radiative flow past an exponentially accelerated vertical plate with variable temperature and mass diffusion. Recently Rajput and Kumar [16] investigated radiation effects on MHD flow past an impulsively started vertical plate with variable heat and mass transfer. Several researchers reported on these issues [17-35]. The present study is aimed at analyzing the effects chemical reaction and radiation on unsteady MHD free convection flow near a moving vertical plate through a porous medium in presence of heat generation/ absorption. A general exact solution for the partial differential equations governing the flow is obtained with the aid of the usual Laplace transform technique. Also the applications of general solution for the important cases of the flow are discussed.

2 NOMENCLATURE

a^*	: Acceleration coefficient	q_r	: Radiative heat flux in the y direction
A	: Constant	θ	: Dimension less time
B_0	: External magnetic field	t^*	: Time
C^*	: Specifies concentration in the Fluid	t	:Dimensionless time
C_w^*	: Fluid concentration of the plate	S_0	: Soret number
C_∞^*	: Fluid concentration far away from the plate	y^*	: Co-ordinate axis normal to the plate
C	: Dimensionless concentration	y	: Dimensionless Co-ordinate axis normal to the plate

C_p	: Specifies heat at constant pressure
H	: Heat absorption Parameter
D	: Chemical molecular Diffusivity
G_m	: mass Grashof number
G_r	: thermal Grashof number
g	: gravitation due to acceleration
k	: non dimensional permeability coefficient of a porous medium
K_C	: Non dimensional rate of chemical reaction
K_c^*	: Rate of chemical reaction
k^*	: permeability of porous medium
Nu	: Nusselt number
P_r	: Prandtl number
S_c	: Schmidt number
T^*	: Temperature fluid near the plate
T_w^*	: Temperature of the plate
T_∞^*	: Temperature of the fluid far away from the plate
u^*, v^*	: velocity components]
u	: non dimensional velocity
F	: radiation parameter
M	: magnetic parameter
Sh	: Non dimensional Sherwood number

GREEK SYMBOLS

κ	: Thermal conductivity of the fluid
ν	: Kinematic viscosity
σ	: Electrical conductivity
μ	: Dynamic viscosity
β_T	:coefficient of volume expansion
α	: thermal conductivity
β_c	: coefficient of volume expansion with concentration
ρ	: fluid density
τ	: non-dimensional skin friction
erf	:Error function
erfc	: Complementary error function

SUBSCRIPTS AND SUPER SCRIPTS

W	: plate
∞	: for away from the plate

Prime denotes differentiation with respect to y.

5.3 FORMULATION OF THE PROBLEM:

We have considered the unsteady flow of an incompressible and electrically conducting viscous fluid past an infinite vertical plate with variable temperature embedded in porous medium in presence of chemical reaction and heat absorption. A magnetic field of uniform strength B_0 is applied transversely to the plate. The induced magnetic field is neglected as the magnetic Reynolds number of the flow is taken to be very small. The viscous dissipation is assumed to be negligible. The flow is assumed to be in x^*-direction which is taken along the vertical plate in the upward direction. The y^*-axis is taken to be normal to the plate. Initially the plate and the fluid are at the same temperature T_∞^* in the stationary condition with concentration level C_∞^* at all points. At time $t^* > 0$ the plate is exponentially accelerated with a velocity $u = u_0 e^{a^* t^*}$ in its own plane and the plate temperature is raised linearly with time t and the level of concentration near the plate is raised to C_w^*. The fluid considered here is a gray, absorbing/emitting radiation but a non-scattering medium.

In this analysis we made the following assumptions:

1. It is assumed that there is no applied voltage which implies the absence of an electrical field.
2. The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and the Hall Effect are negligible.
3. Viscous dissipation and Joule heating terms are neglected.
4. As the plate is infinite in extent, the physical variables are functions of y′ and t′ only.
5. It is assumed that the effect of viscous dissipation is negligible in the energy equation
6. There is a first order chemical reaction between the diffusing species and the fluid.
7. The fluid considered here is a gray, absorbing emitting radiation but a non-scattering medium.
8. Thermo diffusion effect is considered.

Using the above assumptions and the usual Bossinesq's approximation, the unsteady flow is governed by the following equations:

Momentum equation:

$$\frac{\partial u^*}{\partial t^*} = \nu \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_T (T^* - T_\infty^*) + g\beta_C (C^* - C_\infty^*) - \frac{\sigma B_0^2}{\rho} u^* - \frac{\vartheta}{k^*} u^* \tag{5.1}$$

Energy equation:

$$\frac{\partial T^*}{\partial t^*} = \frac{\kappa}{\rho C_P} \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_P} \frac{\partial q_r}{\partial y^*} - \frac{Q}{\rho C_P} \left(T^* - T_\infty^*\right) \tag{5.2}$$

Concentration equation:

$$\frac{\partial C^*}{\partial t^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} + D_1 \left(\frac{\partial^2 T^*}{\partial y^{*2}} \right) - K_c^* (C^* - C_\infty^*) \tag{5.3}$$

The initial and boundary conditions are

$$u^* = 0, \quad T^* = T_\infty^*, \quad C^* = C_\infty^* \quad for\ \ all\ \ y^*, t^* \leq 0$$

$$u^* = u_0\, e^{a^* t^*}, \quad T^* = T_\infty^* + (T_w^* - T_\infty^*)At^*, \quad C^* = C_w^* \quad at\ y^* = 0, t^* > 0$$

$$u^* = 0, \quad T^* = T_\infty^*, \quad C^* = C_\infty^* \quad as y \to \infty, t^* > 0$$

(5.4)

To reduce the above equations into non-dimensional form, we introduce the following dimensionaless variables and parameters

$$y = \frac{U_0 y^*}{\nu},\ u = \frac{u^*}{U_0},\ \theta = \frac{T^* - T_\infty^*}{T_W{}^* - T_\infty^*},\ t = \frac{t^* U_0{}^2}{\nu}$$

$$F = \frac{16\sigma a^* \nu^2 T_\infty^{*3}}{\kappa U_0^2},\ \ C = \frac{C^* - C_\infty^*}{C_W{}^* - C_\infty^*},\ \mathrm{P_r} = \frac{\mu c_p}{\kappa},$$

$$G_r = \frac{\nu g \beta_T (T_W^* - T_\infty^*)}{U_0^3},\ G_m = \frac{\nu g \beta_c (C_W^* - C_0^*)}{U_0^3},\ K_C = \frac{\nu K_C{}^*}{U_0^2},\ M = \frac{\sigma B_0^2 \nu}{\rho U_0^2},\ k = \frac{U_0^2 k^*}{\nu^2},\ a = \frac{a^* \nu}{U_0^2},$$

$$S_c = \frac{\nu}{D},\ \ s_0 = \frac{D_1 (T_W{}^* - T_\infty^*)}{\nu (C_W{}^* - C_\infty^*)},\ \ H = \frac{Q \nu^2}{\kappa U_0^2}$$

(5.5)

Where $A = \frac{u_0^2}{\nu}$, The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y^*} = -4a^* \sigma (T_\infty^{*4} - T^{*4})$$

(5.6)

It is assumed that the temperature differences with in the flow are sufficiently small that T^{*4} may be expressed as a linear function of the temeperature.This is accomplished by expanding T^{*4} in a taylor series about T_∞^* and neglecting the higher order terms, thus

$$T^{*4} = 4T_\infty^{*3} T^* - 3T_\infty^{*4} \tag{5.7}$$

By using equation (5.5) & (5.6), equation (5.2) reduces to

$$\rho C_P \frac{\partial T^*}{\partial t^*} = K\frac{\partial^2 T^*}{\partial y*^2} + 16a^*\sigma T_\infty^{*3}(T_\infty^* - T^*) - Q\left(T^* - T_\infty^*\right) \quad (5.8)$$

With the help of equation (5.8), governing equations (5.1) to (5.3) are reduced to

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} - G_r\theta - G_m C - M_1 u \qquad \text{Where } M_1 = M + \frac{1}{K} \quad (5.9)$$

$$P_r \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} - F_1\theta \qquad \text{Where } F_1 = F + H \quad (5.10)$$

$$S_C \frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial y^2} + S_0 S_c \frac{\partial^2 \theta}{\partial y^2} - K_c S_C C \quad (5.11)$$

The corresponding initial and boundary conditions in non dimensional form are

$$u = 0, \quad \theta = 0, \quad C = 0 \quad \text{for all } y^* \geq 0, t^* \leq 0$$

$$u = e^{at}, \quad \theta = 1, \quad C = 1 \quad \text{at } y = 0, t^* > 0$$

$$u \to 0, \quad \theta \to 0, \quad C \to 0 \quad \text{as } y \to \infty, t^* > 0 \quad (5.12)$$

All the physical parameters are defined in the nomenclature

5.4 SOLUTION OF THE PROBLEM:

We solve the governing equations in exact form by the Laplace transform technique. The Laplace transforms of the equations (5.9)-(5.11) and the boundary conditions (5.12) are given by

$$\frac{d^2\bar{\theta}}{dy^2} - (sP_r + F_1)\bar{\theta} = 0 \quad (5.13)$$

$$\frac{d^2\bar{C}}{dy^2} - (sS_c + K_c S_C)\bar{C} + S_0 S_c (sP_r + F_1)\bar{\theta} = 0 \quad (5.14)$$

$$\frac{d^2\bar{u}}{dy^2} - (M_1 + s)\bar{u} = -G_r\bar{\theta} - G_m\bar{C} \quad (5.15)$$

$$\bar{u} = \frac{1}{s-a}, \qquad \bar{\theta} = \frac{1}{s^2}, \qquad \bar{C} = \frac{1}{s}, \qquad at\ y = 0\ \ t < 0$$

$$\bar{u}=0, \qquad \bar{\theta}=0, \qquad \bar{C}=0, \qquad at\ y\to\infty\ t>0 \tag{5.16}$$

Solving the equations (5.13)-(5.15) with the help of equation (5.16), we get

$$\bar{\theta}(y,s)=\left(\frac{1}{s^2}\right)e^{-y\sqrt{s\,\mathrm{P_r}+F_1}} \tag{5.17}$$

$$\bar{C}(y,s)=\left(\frac{1}{s}-\frac{(b_2+b_4)}{s}-\frac{(b_1+b_3)}{s+a_2}-\frac{b_5}{s^2}\right)e^{-y\sqrt{sS_c+S_cK_c}} + \left(\frac{(b_2+b_4)}{s}+\frac{(b_1+b_3)}{s+a_2}\right)e^{-y\sqrt{s\,\mathrm{P_r}+F_1}} \quad (5.18$$

$$\begin{aligned}\bar{u}(y,s)=&\begin{pmatrix}\dfrac{1}{s-a}-\dfrac{z_{29}}{s}-\dfrac{z_{30}}{s^2}-\dfrac{z_{31}}{s+a_2}\\ -\dfrac{z_{11}}{s+z_2}-\dfrac{z_{28}}{s+z_{13}}\end{pmatrix}e^{-y\sqrt{s+M_1}}\\ &+\begin{pmatrix}\dfrac{z_{10}}{s}+\dfrac{z_8}{s^2}+\dfrac{z_{11}}{s+z_2}+\dfrac{z_4}{s+a_2}\\ -\dfrac{z_{11}}{s+z_2}-\dfrac{z_{28}}{s+z_{13}}\end{pmatrix}e^{-y\sqrt{sS_c+S_cK_c}}\\ &+\left(\frac{z_{26}}{s}+\frac{z_{27}}{s^2}+\frac{z_{28}}{s+z_{13}}+\frac{z_{18}}{s+z_2}\right)e^{-y\sqrt{s\,\mathrm{P_r}+F_1}}\end{aligned} \tag{5.19}$$

Where‘s’ is the Laplace transformation parameter.

On taking inverse Laplace transform of equations (5.17), (5.18) and (5.19), we get Thus, the general solution of the present problem for the temperature $\theta(y,t)$, the velocity $u(y,t)$ and the concentration $C(y,t)$ for $t>0$ are given by

$$u(y,t)=\frac{e^{at}}{2}\left[e^{-y\sqrt{a+M_1}}erfc\left(\eta-\sqrt{(M_1+a)t}\right)+e^{y\sqrt{a+M_1}}erfc\left(\eta+\sqrt{(M_1+a)t}\right)\right]-$$
$$\frac{z_{29}}{2}\left[e^{-y\sqrt{M_1}}erfc\left(\eta-\sqrt{(M_1)t}\right)+e^{y\sqrt{M_1}}erfc\left(\eta+\sqrt{(M_1)t}\right)\right]-$$
$$z_{30}\left[\left(\frac{t}{2}-\frac{y}{4\sqrt{M_1}}\right)\left(e^{-y\sqrt{M_1}}erfc\left(\eta-\sqrt{(M_1)t}\right)\right)++\left(\frac{t}{2}+\frac{y}{4\sqrt{M_1}}\right)\left(e^{y\sqrt{M_1}}erfc\left(\eta+\sqrt{(M_1)t}\right)\right)\right]-$$
$$\frac{z_{31}e^{-a_2 t}}{2}\left[e^{-y\sqrt{M_1-a_2}}erfc\left(\eta-\sqrt{(M_1-a_2)t}\right)+e^{y\sqrt{M_1-a_2}}erfc\left(\eta+\sqrt{(M_1-a_2)t}\right)\right]-$$
$$\frac{z_{11}e^{-z_2 t}}{2}\left[e^{-y\sqrt{M_1-z_2}}erfc\left(\eta-\sqrt{(M_1-z_2)t}\right)+e^{y\sqrt{M_1-z_2}}erfc\left(\eta+\sqrt{(M_1-z_2)t}\right)\right]-$$
$$\frac{z_{28}e^{-z_{13} t}}{2}\left[e^{-y\sqrt{M_1-z_{13}}}erfc\left(\eta-\sqrt{(M_1-z_{13})t}\right)+e^{y\sqrt{M_1-z_{13}}}erfc\left(\eta+\sqrt{(M_1-z_{13})t}\right)\right]+$$
$$\frac{z_{10}}{2}\left[e^{-y\sqrt{S_cK_c}}erfc\left(\eta\sqrt{S_c}-\sqrt{K_ct}\right)+e^{y\sqrt{S_cK_c}}erfc\left(\eta\sqrt{S_c}+\sqrt{K_ct}\right)\right]+$$
$$\frac{z_{11}e^{-z_2 t}}{2}\left[e^{-y\sqrt{S_c(K_c-z_2)}}erfc\left(\eta\sqrt{S_c}-\sqrt{(K_c-z_2)t}\right)+e^{y\sqrt{S_c(K_c-z_2)}}erfc\left(\eta\sqrt{S_c}+\sqrt{(K_c-z_2)t}\right)\right]+$$
$$\frac{z_4e^{-a_2 t}}{2}\left[e^{-y\sqrt{S_c(K_c-a_2)}}erfc\left(\eta\sqrt{S_c}-\sqrt{(K_c-a_2)t}\right)+e^{y\sqrt{S_c(K_c-a_2)}}erfc\left(\eta\sqrt{S_c}+\sqrt{(K_c-a_2)t}\right)\right]+$$
$$z_8\left[\left(\frac{t}{2}-\frac{y\sqrt{S_c}}{4\sqrt{K_c}}\right)\left(e^{-y\sqrt{S_cK_c}}erfc\left(\eta\sqrt{S_c}-\sqrt{K_ct}\right)\right)+\left(\frac{t}{2}+\frac{y\sqrt{S_c}}{4\sqrt{K_c}}\right)\left(e^{y\sqrt{S_cK_c}}erfc\left(\eta\sqrt{S_c}+\sqrt{K_ct}\right)\right)\right]+$$
$$\frac{z_{26}}{2}\left[e^{-y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}-\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)+e^{y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}+\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)\right]+$$
$$z_{27}\left[\left(\frac{t}{2}-\frac{y\,\mathrm{P_r}}{4\sqrt{F_1}}\right)\left(e^{-y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}-\sqrt{\frac{F_1}{\mathrm{Pr}}t}\right)\right)+\left(\frac{t}{2}+\frac{y\,\mathrm{Pr}}{4\sqrt{F_1}}\right)\left(e^{y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}+\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)\right)\right]+$$
$$\frac{z_{28}e^{-z_{13}t}}{2}\left[\left(e^{-y\sqrt{F_1-z_{13}P_r}}erfc\left(\eta\sqrt{\mathrm{P_r}}-\sqrt{\left(\frac{F_1}{\mathrm{P_r}}-z_{13}\right)t}\right)\right)+\left(e^{y\sqrt{F_1-z_{13}Pr}}erfc\left(\eta\sqrt{\mathrm{P_r}}+\sqrt{\left(\frac{F_1}{\mathrm{P_r}}-z_{13}\right)t}\right)\right)\right]+$$
$$\frac{z_{18}e^{-a_2t}}{2}\left[\left(e^{-y\sqrt{F_1-a_2P_r}}erfc\left(\eta\sqrt{\mathrm{P_r}}-\sqrt{\left(\frac{F_1}{\mathrm{P_r}}-a_2\right)t}\right)\right)+\left(e^{y\sqrt{F_1-a_2P_r}}erfc\left(\eta\sqrt{\mathrm{P_r}}+\sqrt{\left(\frac{F_1}{\mathrm{P_r}}-a_2\right)t}\right)\right)\right] \quad (5.20)$$

$$\theta(y,t)=\left[\left(\frac{t}{2}-\frac{y\,\mathrm{P_r}}{4\sqrt{F_1}}\right)\left(e^{-y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}-\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)\right)+\left(\frac{t}{2}+\frac{y\,\mathrm{P_r}}{4\sqrt{F_1}}\right)\left(e^{y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}+\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)\right)\right] \quad (5.21)$$

Where $F_1 = F + H$

$$C(y,t)=\frac{(1-(b_2+b_4))}{2}\left[e^{-y\sqrt{S_cK_c}}erfc\left(\eta\sqrt{S_c}-\sqrt{K_ct}\right)+e^{y\sqrt{S_cK_c}}erfc\left(\eta\sqrt{S_c}+\sqrt{K_ct}\right)\right]-$$
$$\frac{(b_1+b_3)e^{-a_2t}}{2}\left[e^{-y\sqrt{S_c(K_c-a_2)}}erfc\left(\eta\sqrt{S_c}-\sqrt{(K_c-a_2)t}\right)+e^{y\sqrt{S_c(K_c-a_2)}}erfc\left(\eta\sqrt{S_c}+\sqrt{(K_c-a_2)t}\right)\right]-$$
$$b_5\left[\left(\frac{t}{2}-\frac{y\sqrt{S_c}}{4\sqrt{K_c}}\right)\left(e^{-y\sqrt{S_cK_c}}erfc\left(\eta\sqrt{S_c}-\sqrt{K_ct}\right)\right)+\left(\frac{t}{2}+\frac{y\sqrt{S_c}}{4\sqrt{K_c}}\right)\left(e^{y\sqrt{S_cK_c}}erfc\left(\eta\sqrt{S_c}+\sqrt{K_ct}\right)\right)\right]+$$
$$\frac{(b_2+b_4)}{2}\left[e^{-y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}-\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)+e^{y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}+\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)\right]+$$
$$\frac{(b_1+b_3)e^{-a_2t}}{2}\left[\left(e^{-y\sqrt{F_1-a_2P_r}}erfc\left(\eta\sqrt{\mathrm{P_r}}-\sqrt{\left(\frac{F_1}{\mathrm{P_r}}-a_2\right)t}\right)\right)+\left(e^{y\sqrt{F_1-a_2Pr}}erfc\left(\eta\sqrt{\mathrm{P_r}}+\sqrt{\left(\frac{F_1}{\mathrm{P_r}}-a_2\right)t}\right)\right)\right]+$$
$$b_5\left[\left(\frac{t}{2}-\frac{y\mathrm{P_r}}{4\sqrt{F_1}}\right)\left(e^{-y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}-\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)\right)+\left(\frac{t}{2}+\frac{y\mathrm{P_r}}{4\sqrt{F_1}}\right)\left(e^{y\sqrt{F_1}}erfc\left(\eta\sqrt{\mathrm{P_r}}+\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)\right)\right] \quad (5.22)$$

Skin friction

Knowing the velocity field, we now study the effect of t, Pr, F, M, etc. on the skin friction. In the non dimensional form, it is given by

$$\tau=-\left(\frac{\partial u}{\partial y}\right)_{y=0}$$
$$= \quad e^{at}\left[\frac{1}{\sqrt{\pi t}}e^{-(a+M_1)t}+\sqrt{a+M_1}erf\left(\sqrt{(M_1+a)t}\right)\right]+$$
$$z_{29}\left[\frac{1}{\sqrt{\pi t}}e^{-M_1t}+\sqrt{M_1}erf\left(\sqrt{(M_1)t}\right)\right]+$$
$$z_{30}\left[\left(\frac{2tM_1+1}{2\sqrt{M_1}}\right)erf\left(\sqrt{(M_1)t}\right)+\sqrt{\frac{t}{\pi}}e^{-M_1t}\right]+$$
$$z_{31}e^{-a_2t}\left[\sqrt{(M_1-a_2)}erf\left(\sqrt{(M_1-a_2)t}\right)+\frac{1}{\sqrt{\pi t}}e^{-(M_1-a_2)t}\right]+$$

$$z_{11}e^{-z_2 t}\left[\sqrt{(M_1-z_2)}\,erf\left(\sqrt{(M_1-z_2)t}\right)+\frac{1}{\sqrt{\pi t}}e^{-(M_1-z_2)t}\right]+$$
$$z_{28}e^{-z_{13} t}\left[\sqrt{(M_1-z_{13})}\,erf\left(\sqrt{(M_1-z_{13})t}\right)+\frac{1}{\sqrt{\pi t}}e^{-(M_1-z_{13})t}\right]-$$
$$z_{10}\left[\sqrt{\frac{S_c}{\pi t}}e^{-K_c t}+\sqrt{S_c K_c}\,erf\left(\sqrt{K_c t}\right)\right]-$$
$$z_{11}e^{-z_2 t}\left[\sqrt{\frac{S_c}{\pi t}}e^{-(K_c-z_2)t}+\sqrt{S_c(K_c-z_2)}\,erf\left(\sqrt{(K_c-z_2)t}\right)\right]-$$
$$z_{4}e^{-a_2 t}\left[\sqrt{\frac{S_c}{\pi t}}e^{-(K_c-a_2)t}+\sqrt{S_c(K_c-a_2)}\,erf\left(\sqrt{(K_c-a_2)t}\right)\right]-$$
$$z_{8}\left[\left(\frac{2tK_c+\sqrt{S_c}}{2\sqrt{K_c}}\right)erf\left(\sqrt{(K_c)t}\right)+\sqrt{\frac{tS_c}{\pi}}e^{-\sqrt{K_c}t}\right]-$$
$$z_{26}\left[\sqrt{\frac{\mathrm{P_r}}{\pi t}}e^{-\frac{F_1}{\mathrm{P_r}}t}+\sqrt{F_1}\,erf\left(\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)\right]-$$
$$z_{27}\left[\left(\frac{2tF_1+\mathrm{P_r}}{2\sqrt{F_1}}\right)erf\left(\sqrt{(\frac{F_1}{\mathrm{Pr}})t}\right)+\sqrt{\frac{t\,\mathrm{P_r}}{\pi}}e^{-\frac{F_1}{\mathrm{P_r}}t}\right]-$$
$$z_{28}e^{-z_{13}t}\left[\sqrt{\frac{\mathrm{P_r}}{\pi t}}e^{-\left(\frac{F_1}{\mathrm{Pr}}-z_{13}\right)t}+\sqrt{F_1-z_{13}\,P_r}\;erf\left(\sqrt{\left(\frac{F_1}{\mathrm{P_r}}-z_{13}\right)t}\right)\right]-$$
$$z_{18}e^{-a_2 t}\left[\sqrt{\frac{\mathrm{P_r}}{\pi t}}e^{-\left(\frac{F_1}{\mathrm{Pr}}-a_2\right)t}+\sqrt{F_1-a_2\,P_r}\;erf\left(\sqrt{\left(\frac{F_1}{\mathrm{P_r}}-a_2\right)t}\right)\right] \qquad (5.23)$$

Nusselt Number

An important phenomenon in this study is to understand the effect of t, F and H on the Nusselt Number. In non-dimensional form, the rate of heat transfer is given by

$$Nu=-\left(\frac{\partial\theta}{\partial y}\right)_{y=0}=\left(\frac{2tF_1+\mathrm{P_r}}{2\sqrt{F_1}}\right)erf\left(\sqrt{\left(\frac{F_1}{\mathrm{P_r}}\right)t}\right)+\sqrt{\frac{t\,\mathrm{P_r}}{\pi}}e^{-\frac{F_1}{\mathrm{P_r}}t} \qquad (5.24)$$

Sherwood Number

An important phenomenon in this study is to understand the effect of t, S_c *and* K_c on the Sherwood Number. In non-dimensional form, the rate of mass transfer is given by

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

$$\begin{aligned}
= \quad & (1-(b_2+b_4))\left[\sqrt{\frac{S_c}{\pi t}}e^{-K_c t} + \sqrt{S_c K_c}\, erf\left(\sqrt{K_c t}\right)\right] - \\
& (b_1+b_3)e^{-a_2 t}\left[\sqrt{\frac{S_c}{\pi t}}e^{-(K_c-a_2)t} + \sqrt{S_c(K_c-a_2)}\, erf\left(\sqrt{(K_c-a_2)t}\right)\right] - \\
& b_5\left[\left(\frac{2tK_c+\sqrt{S_c}}{2\sqrt{K_c}}\right) erf\left(\sqrt{(K_c)t}\right) + \sqrt{\frac{tS_c}{\pi}}e^{-\sqrt{K_c}t}\right] + \\
& (b_2+b_4)\left[\sqrt{\frac{\mathrm{P_r}}{\pi t}}e^{-\frac{F_1}{\mathrm{P_r}}t} + \sqrt{F_1}\, erf\left(\sqrt{\frac{F_1}{\mathrm{P_r}}t}\right)\right] + \\
& (b_1+b_3)e^{-a_2 t}\left[\sqrt{\frac{\mathrm{P_r}}{\pi t}}e^{-\left(\frac{F_1}{\mathrm{P_r}}-a_2\right)t} + \sqrt{F_1 - a_2 P_r}\; erf\left(\sqrt{\left(\frac{F_1}{\mathrm{P_r}}-a_2\right)t}\right)\right] + \\
& b_5\left[\left(\frac{2tF_1+\mathrm{P_r}}{2\sqrt{F_1}}\right) erf\left(\sqrt{\left(\frac{F_1}{\mathrm{P_r}}\right)t}\right) + \sqrt{\frac{t\,\mathrm{P_r}}{\pi}}e^{-\frac{F_1}{\mathrm{P_r}}t}\right]
\end{aligned} \tag{5.25}$$

APPENDIX

$$a_1 = \frac{S_0 S_C \Pr}{\Pr - S_C} \qquad a_2 = \frac{F_1 - S_C K_c}{\Pr - S_C} \qquad a_3 = \frac{S_0 S_C F_1}{\Pr - S_C}$$

$$b_1 = -\frac{a_1}{a_2} \qquad b_2 = \frac{a_1}{a_2} \qquad b_3 = -\frac{a_3}{a_2{}^2}$$

$$b_4 = \frac{a_3}{a_2{}^2} \qquad b_5 = \frac{a_3}{a_2} \qquad w_1 = \frac{z_1}{z_2}$$

$$w_2 = -\frac{z_1}{z_2} \qquad z_3 = \frac{-Gm(b_1 + b_3)}{S_c - 1} \qquad z_4 = \frac{z_3}{\left(z_2 - a_2\right)}$$

$$z_5 = -\frac{z_3}{\left(z_2 - a_2\right)} \qquad z_6 = \frac{-Gm(b_5)}{S_c - 1} \qquad z_7 = \frac{-z_6}{z_2^2}$$

$$z_8 = \frac{z_6}{z_2} \qquad z_9 = \frac{z_6}{z_2^2} \qquad z_{10} = w_1 + z_7$$

$$z_{11} = w_2 + z_5 + z_9 \qquad z_{12} = \frac{-Gm(b_2 + b_4)}{\Pr - 1} \qquad z_{13} = \frac{(F_1 - M_1)}{\Pr - 1}$$

$$z_{14} = \frac{z_{12}}{z_{13}} \qquad z_{17} = \frac{-z_{16}}{z_{13} - a_2} \qquad z_{18} = \frac{z_{16}}{z_{13} - a_2}$$

$$z_{18.a} = \frac{-Gm(b_5)}{\Pr - 1} \qquad z_{19} = \frac{-z_{18.a}}{z_{13}^2} \qquad z_{20} = \frac{z_{18.a}}{z_{13}}$$

$$z_{21} = \frac{z_{18.a}}{z_{13}^2} \qquad z_{22} = \frac{-Gr}{\Pr - 1} \qquad z_{23} = \frac{-z_{22}}{z_{13}^2}$$

$$z_{24} = \frac{z_{22}}{z_{13}} \qquad z_{25} = \frac{z_{22}}{z_{13}^2} \qquad z_{28} = z_{15} + z_{17} + z_{21} + z_{25}$$

$$z_{29} = z_{10} + z_{26}$$

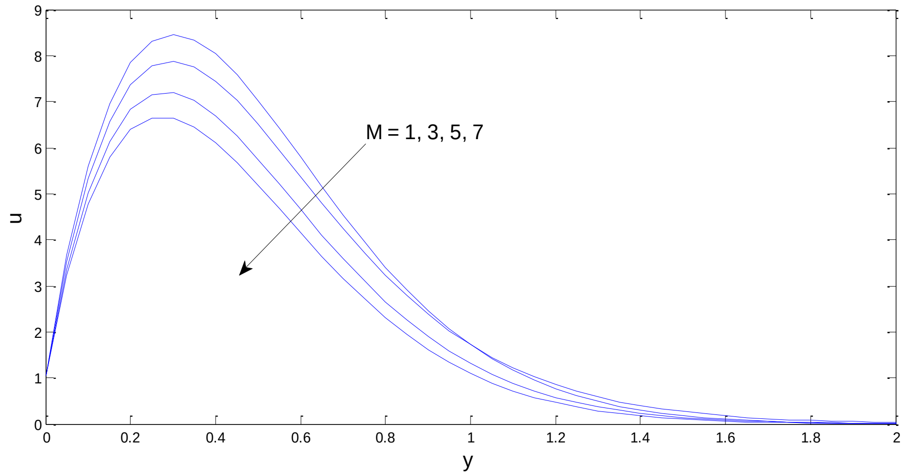

Fig.1. Velocity profiles with the variations in magnetic parameter M and for fixed values of

$G_r = 5$, $G_m = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $S_c = 2.01$, $F = 1$, $t = 0.2$, $S_0 = 2$, $H = 2$, $a = 0.2$

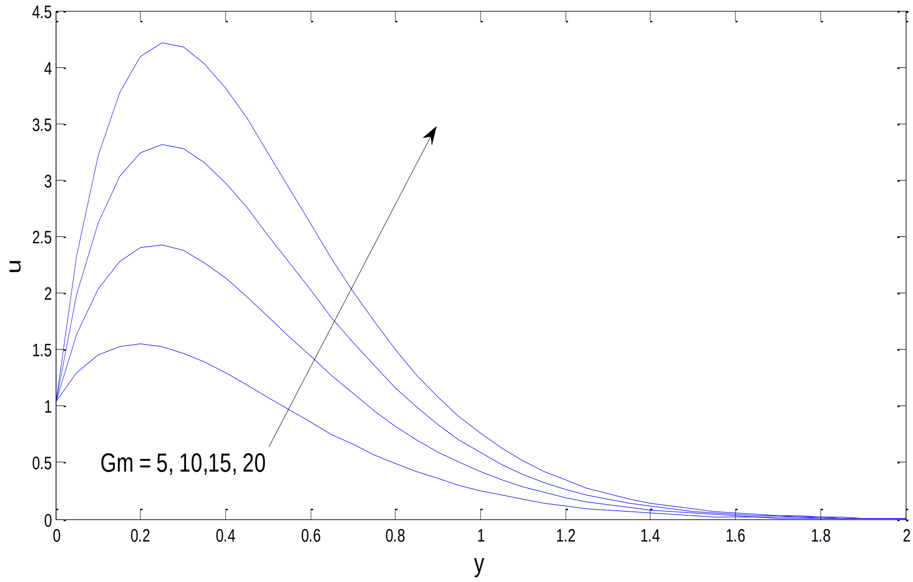

Fig.2. Velocity profiles with the variations in modified Grashof number G_m and for fixed values of

$G_r = 5$, $M = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $S_c = 2.01$, $F = 1$, $t = 0.2$, $S_0 = 2$, $H = 2$, $a = 0.2$

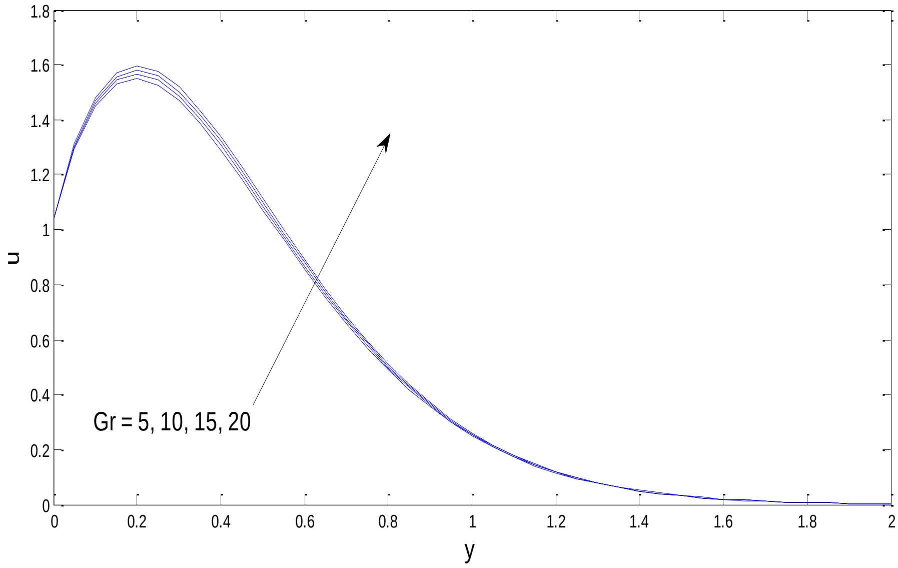

Fig.3. Velocity profiles with the variations in Grashof number G_r and for fixed values Of $G_m = 5$, $M = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $S_c = 2.01$, $F = 1$, $t = 0.2$, $S_0 = 2$, $H = 2$, $a = 0.2$

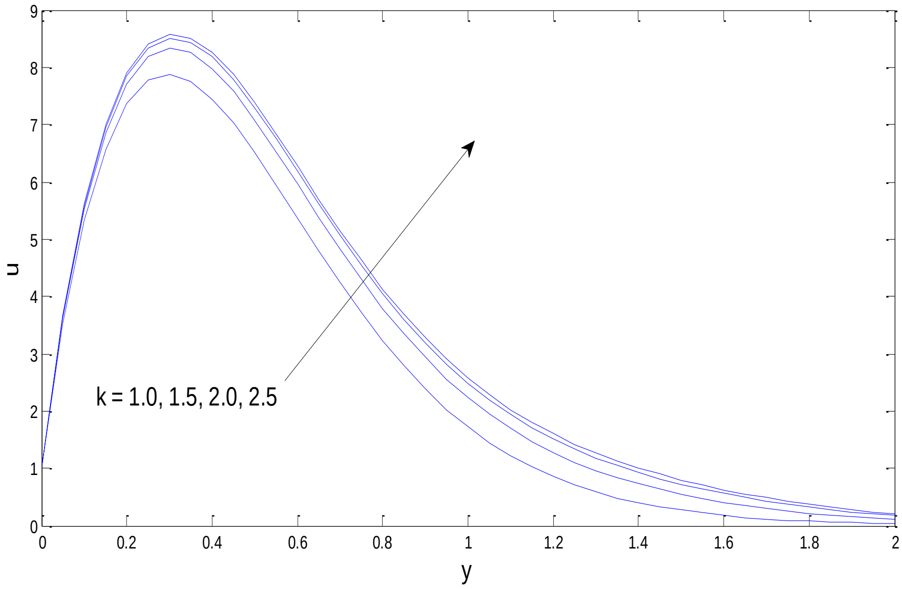

Fig.4. Velocity profiles with the variations in Grashof number G_r and for fixed values Of $G_m = 5$, $M = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $S_c = 2.01$, $F = 1$, $t = 0.2$, $S_0 = 2$, $H = 2$, $a = 0.2$

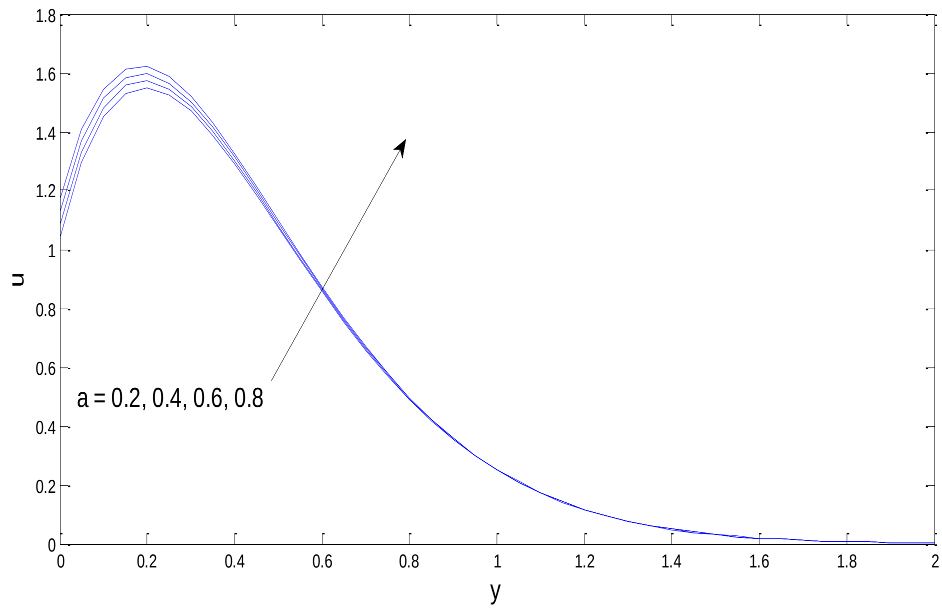

Fig.5. Velocity profiles with the variations in absorption coefficient ‘a’ and for fixed values of

$G_m = 5$, $G_r = 5$, $M = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $S_c = 2.01$, $F = 1$, $t = 0.2$, $H = 2$, $S_0 = 2$.

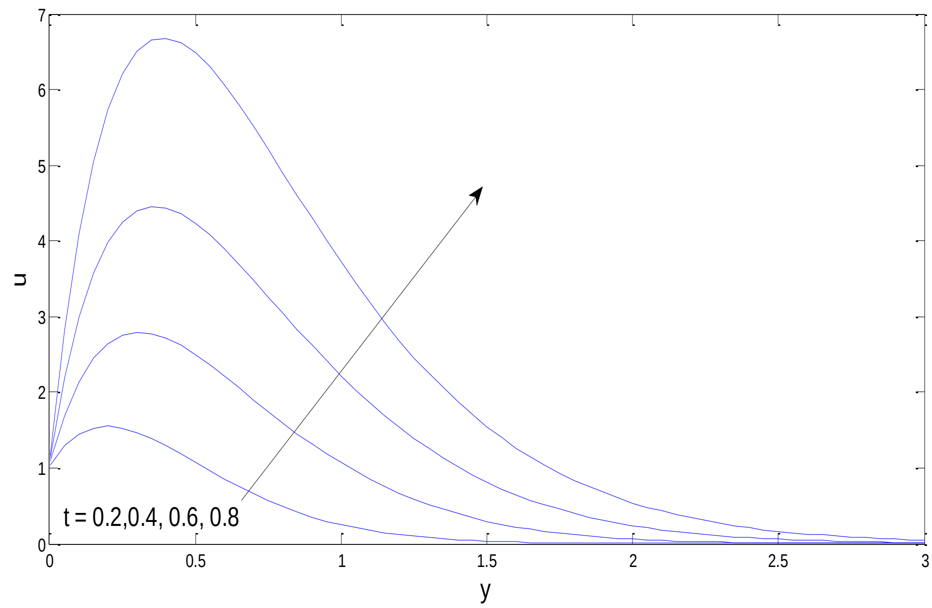

Fig.6. Velocity profiles with the variations in time ‘t’ and for fixed values of

$G_m = 5$, $G_r = 5$, $M = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $S_c = 2.01$, $F = 1$, $H = 2$, $a = 0.2$, $S_0 = 2$.

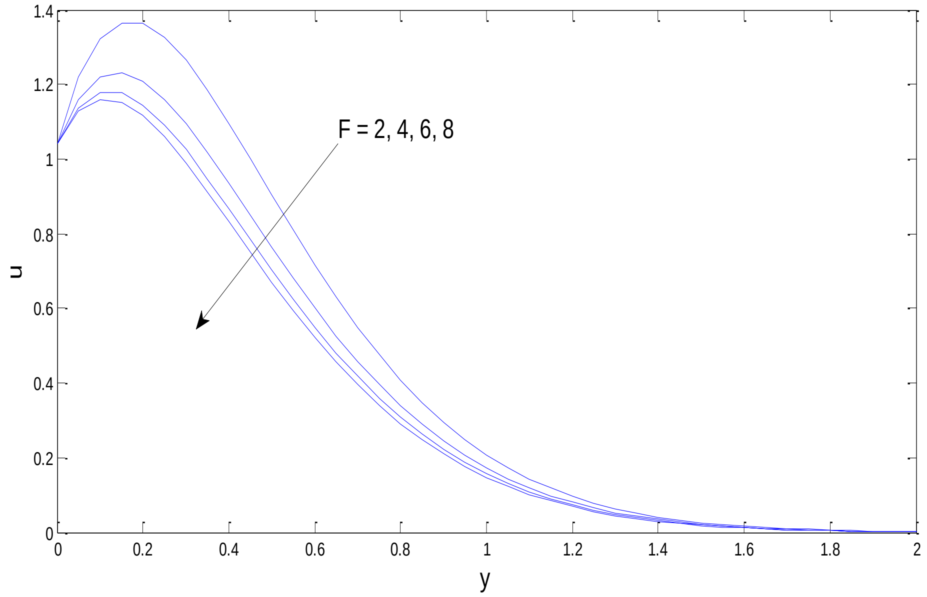

Fig.7. Velocity profiles with the variations Radiation parameter 'F' and for fixed values of

$G_m = 5$, $G_r = 5$, $M = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $S_c = 2.01$, $a = 0.2$, $H = 2$, $t = 0.2$, $S_0 = 2$.

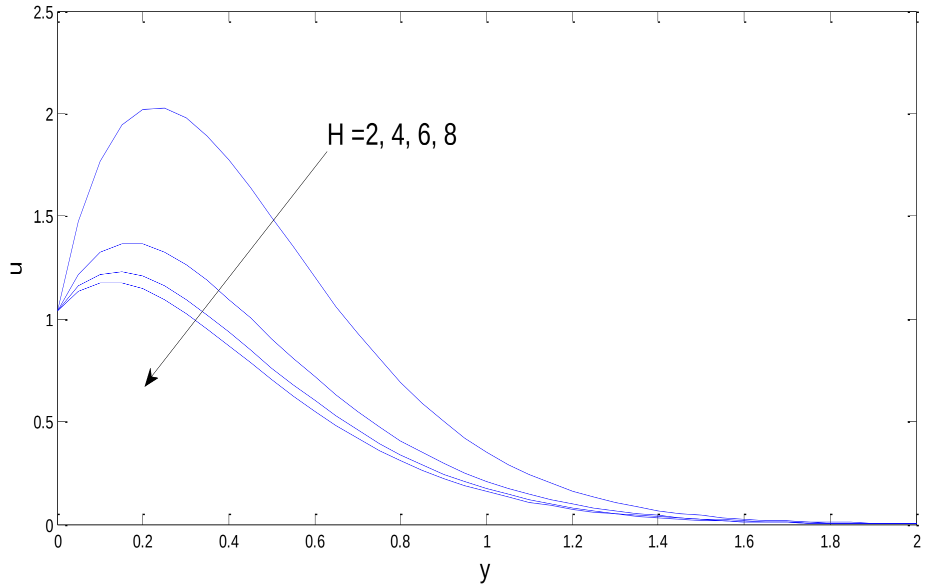

Fig.8. Velocity profiles with the variations Heat absorption parameter 'H' and for fixed values of

$G_m = 5$, $G_r = 5$, $M = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $S_c = 2.01$, $F = 1$, $t = 0.2$, $S_0 = 2$.

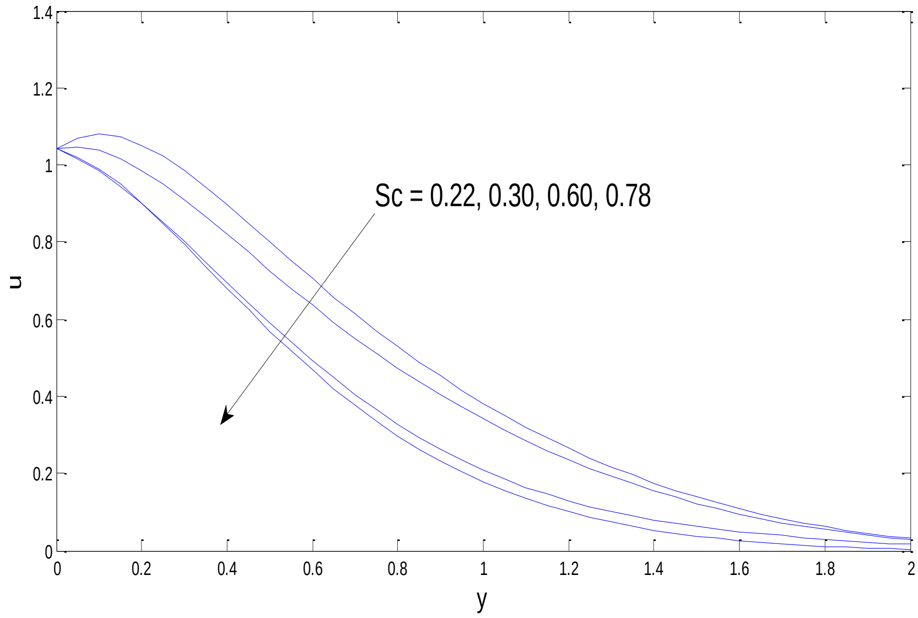

Fig.9. Velocity profiles with the variations Schmidt number 'S_c' and for fixed values of

$G_m = 5$, $G_r = 5$, $M = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $H = 2$, $F = 1$, $t = 0.2$, $S_0 = 2$.

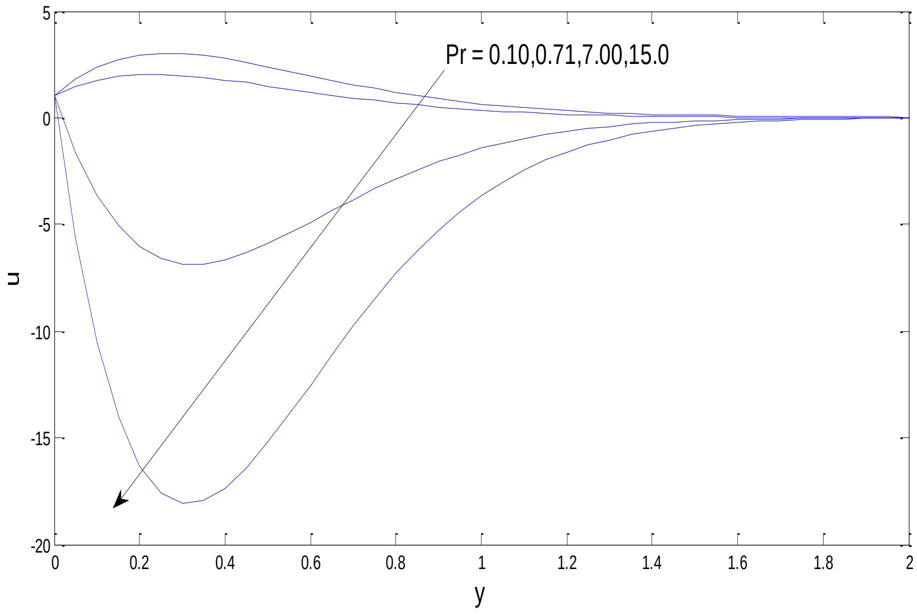

Fig.10. Velocity profiles with the variations Prandtl number 'P_r' and for fixed values of

$G_m = 5$, $G_r = 5$, $M = 2$, $K_c = 1$, $k = 1$, $P_r = 0.71$, $H = 2$, $F = 1$, $t = 0.2$, $S_0 = 2$.

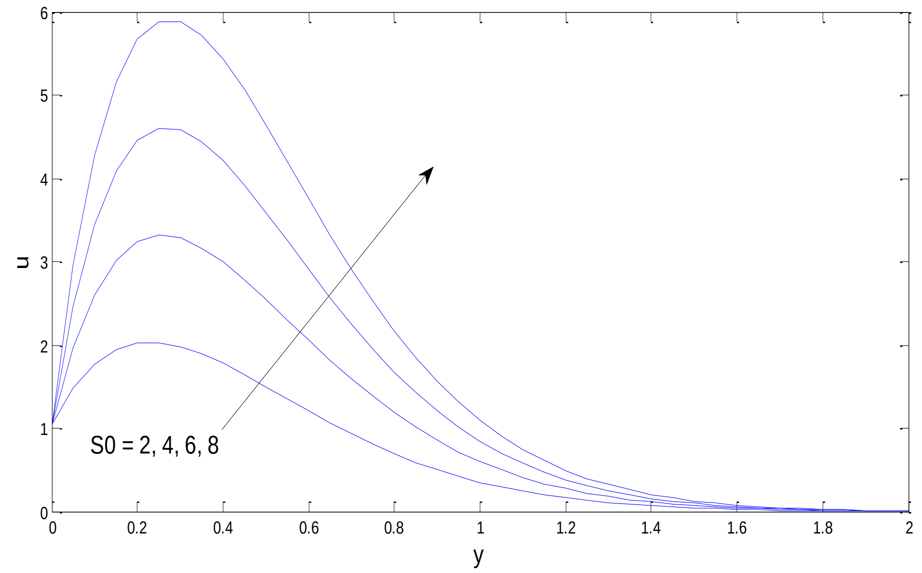

Fig.11. Velocity profiles with the variations Soret number 'S_0' and for fixed values of Gr = 5, Gm = 5, M = 2, kc=1, k=1, Sc = 2.01, F =1, t = 0.2, t = 0.2, $S_0 = 2$.

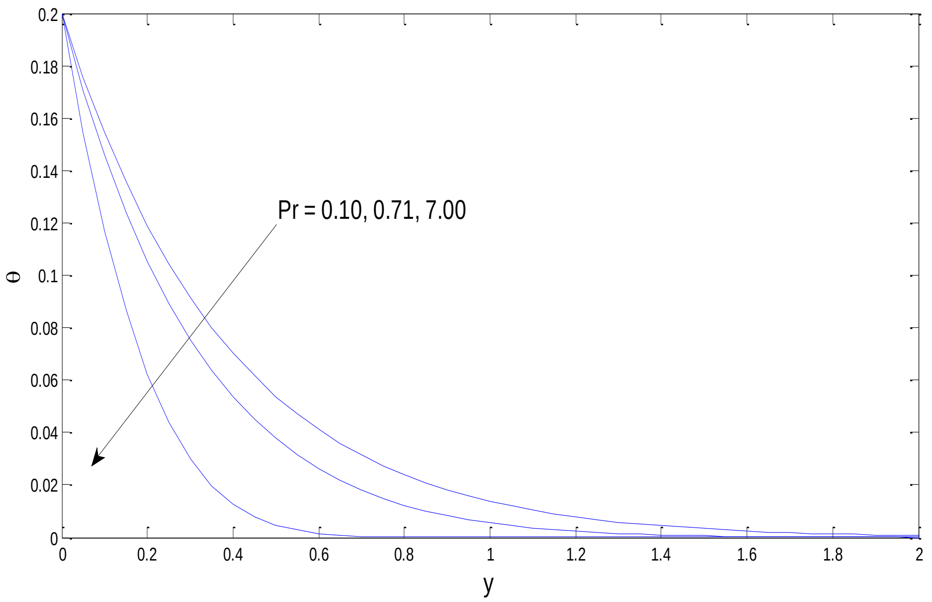

Fig.12. Temperature profiles with the variations Soret number 'S_0' and for fixed values of

$S_c = 2.01$, F =1, t = 0.2, H = 4.

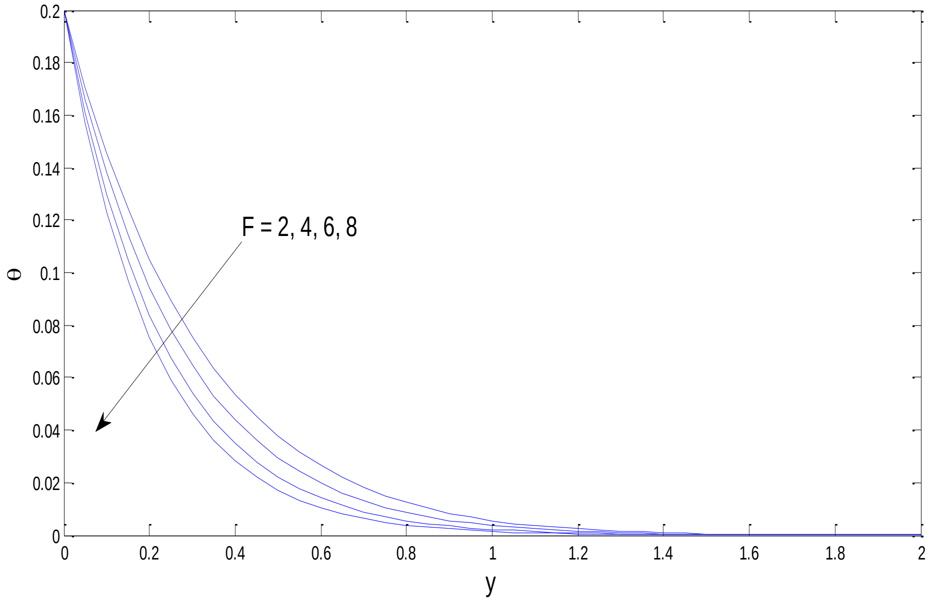

Fig.13. Temperature profiles with the variations Radiation parameter ‘F’ and for fixed values of

$S_c = 2.01$, $P_r = 0.71$, $t = 0.2$, $H = 4$.

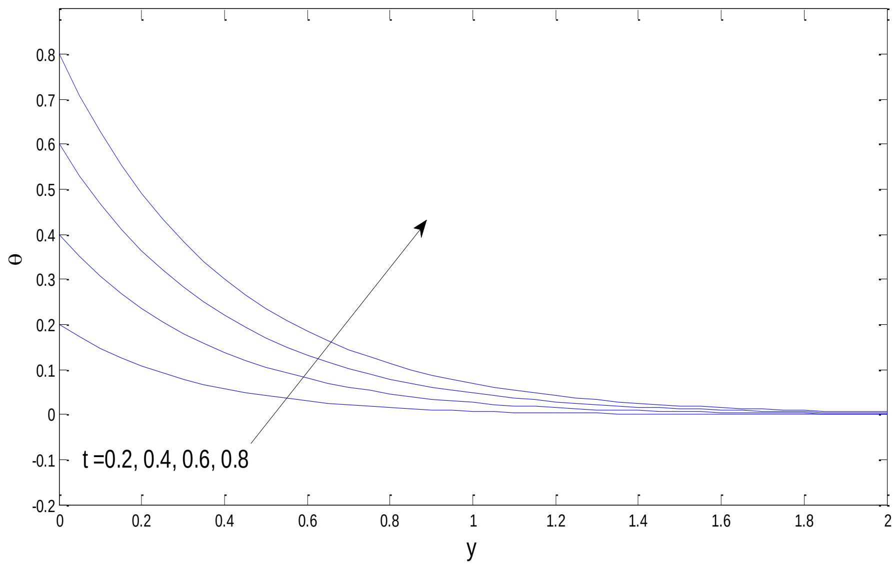

Fig.14. Temperature profiles with the variations time‘t’ and for fixed values of

$S_c = 2.01$, $P_r = 0.71$, $F = 1$, $H = 4$.

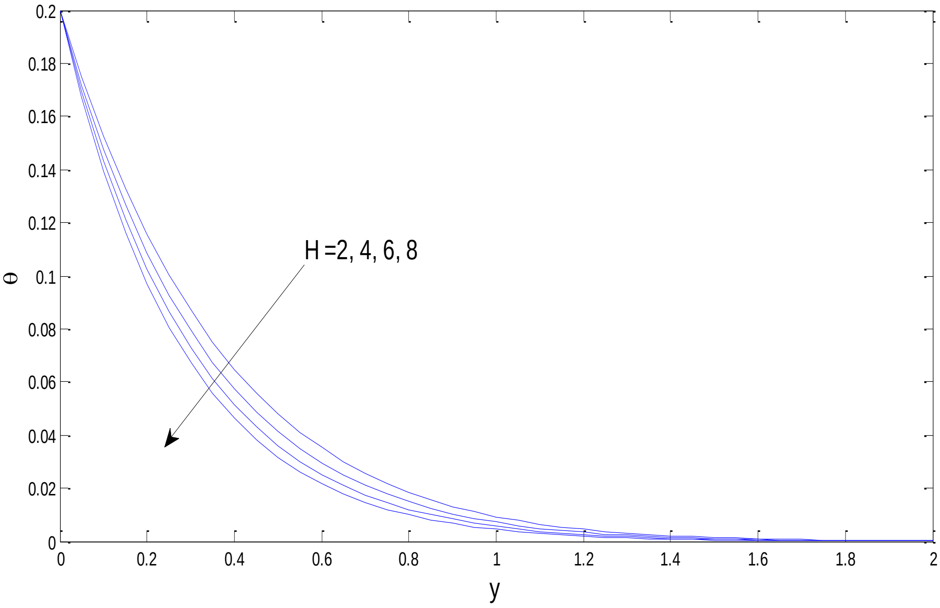

Fig.15. Temperature profiles with the variations absorption coefficient ‘H’ and for fixed values S_c = 2.01, P_r = 0.71, F = 1, t = 0.2.

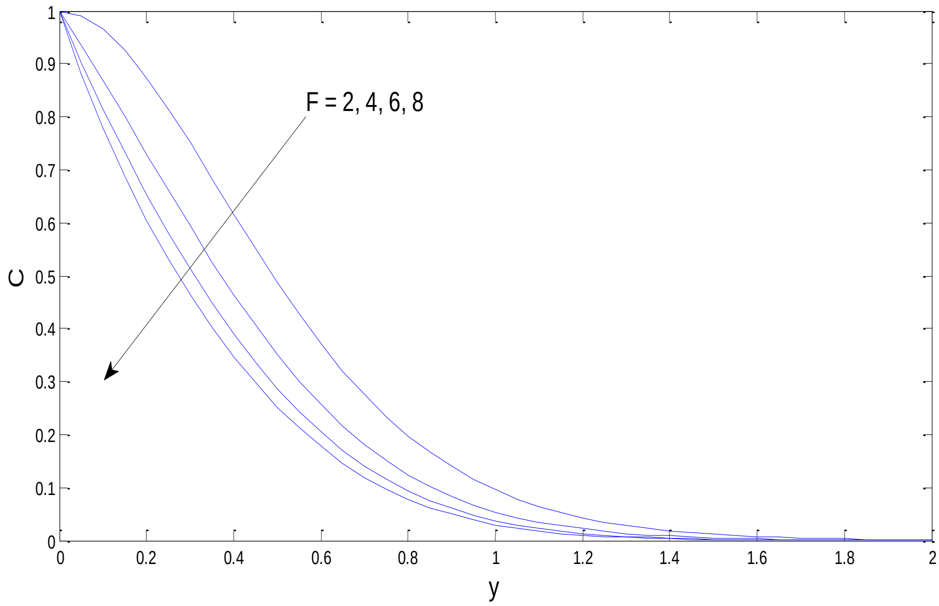

Fig.16. Concentration profiles with the variations in Radiation Parameter F and for fixed values K_c = 1, P_r = 0.71, k = 1, Sc = 2.01, t = 0.2, S_0 = 2, H = 4.

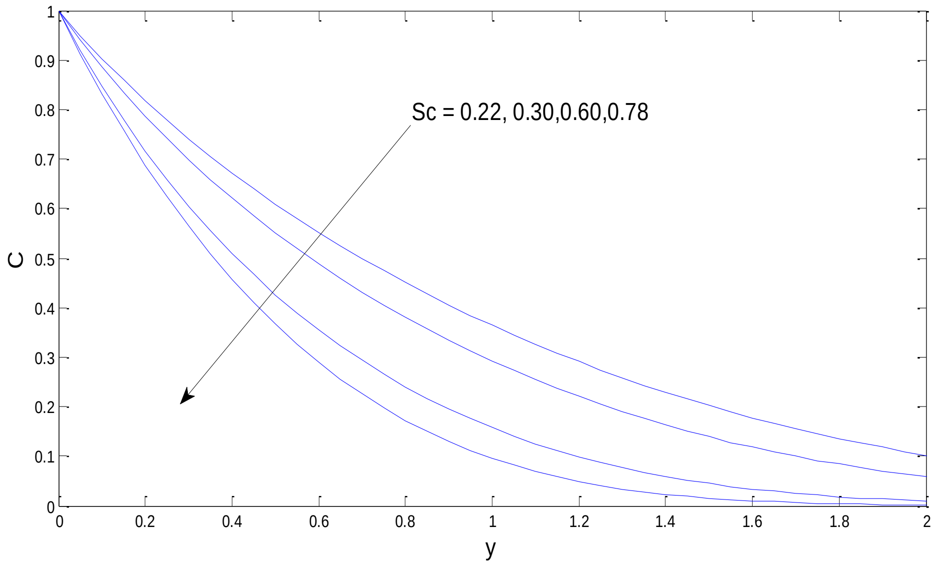

Fig.17. Concentration profiles with the variations in Schmidt number 'S_c' and for fixed values of $K_c = 1$, $P_r = 0.71$, $k = 1$, $F = 1$, $t = 0.2$, $S_0 = 2$, $H = 4$.

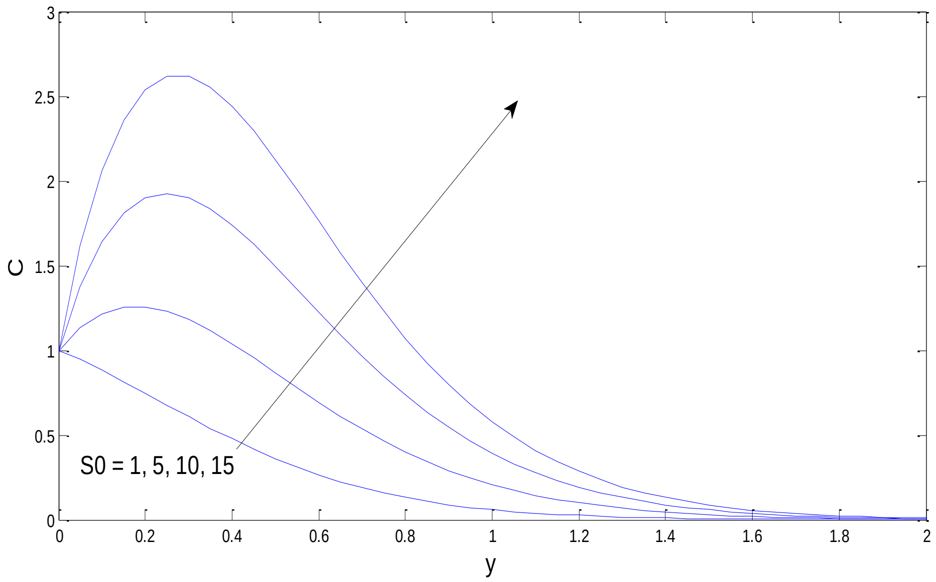

Fig.18. Concentration profiles with the variations in Soret number 'S_0' and for fixed values of

$K_c = 1$, $P_r = 0.71$, $k = 1$, $F = 1$, $t = 0.2$, $S_c = 2.01$, $H = 4$.

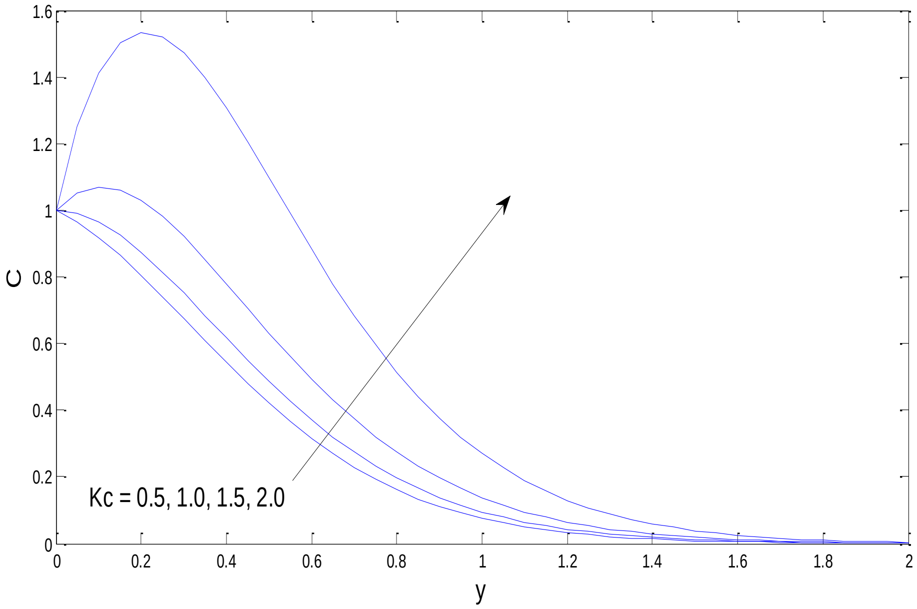

Fig.19. Concentration profiles with the variations in Chemical reaction parameter 'K_c' and for

fixed values of Kc=1, Pr=0.71, k=1, F= 1, t = 0.2, S_c = 2.01, H=4.

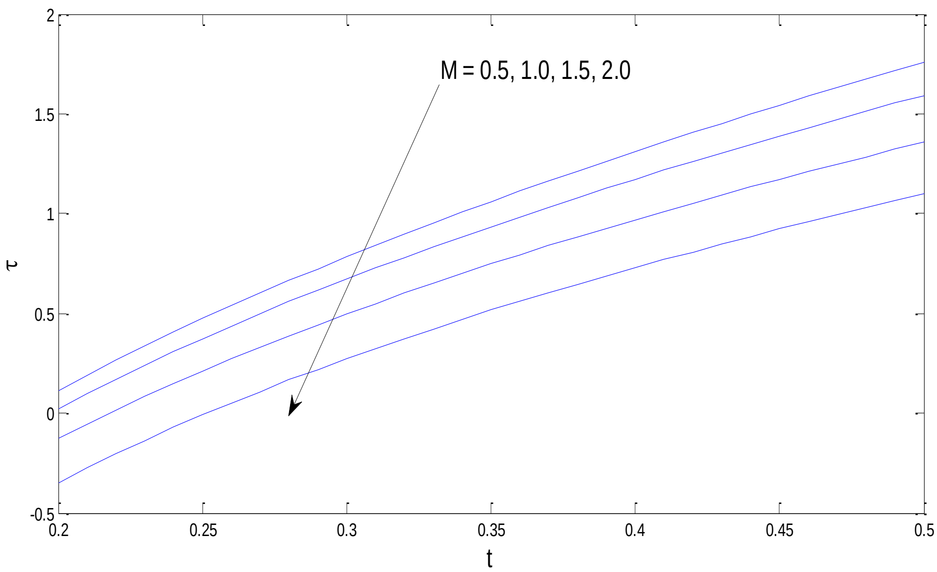

Fig.20. Skin friction profiles with the variations in Magnetic Parameter M and for fixed values

Of G_m = 5, G_r = 5, K_c = 1, k = 1, P_r = 0.71, S_c = 0.22, F = 1, S_0 = 2, H = 2, a = 0.2

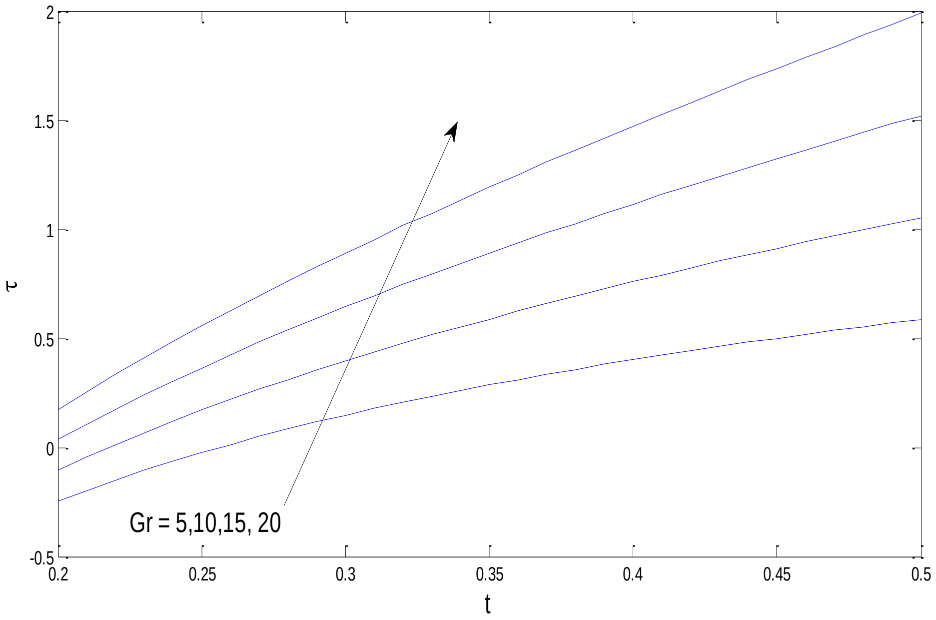

Fig.21. Skin friction profiles with the variations in Grashof number G_r and for fixed values

Of G_m = 5, M = 2, K_c = 1, k = 1, P_r = 0.71, S_c = 0.22, F = 1, S_0 = 2, H = 2, a = 0.2

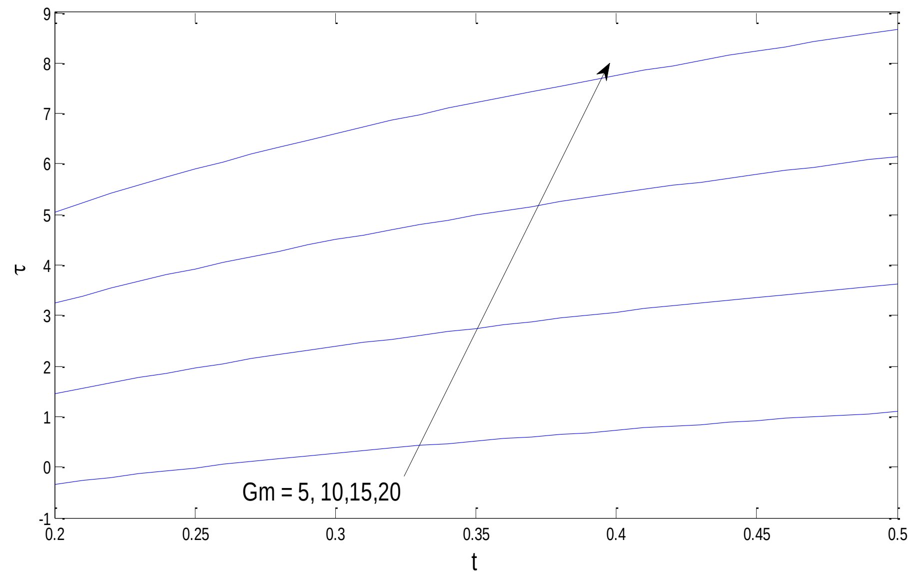

Fig.22. Skin friction profiles with the variations in modified Grashof number G_m and for fixed Values of G_r = 5, M = 2, K_c = 1, k = 1, P_r = 0.71, S_c = 0.22, F = 1, S_0 = 2, H = 2, a = 0.2

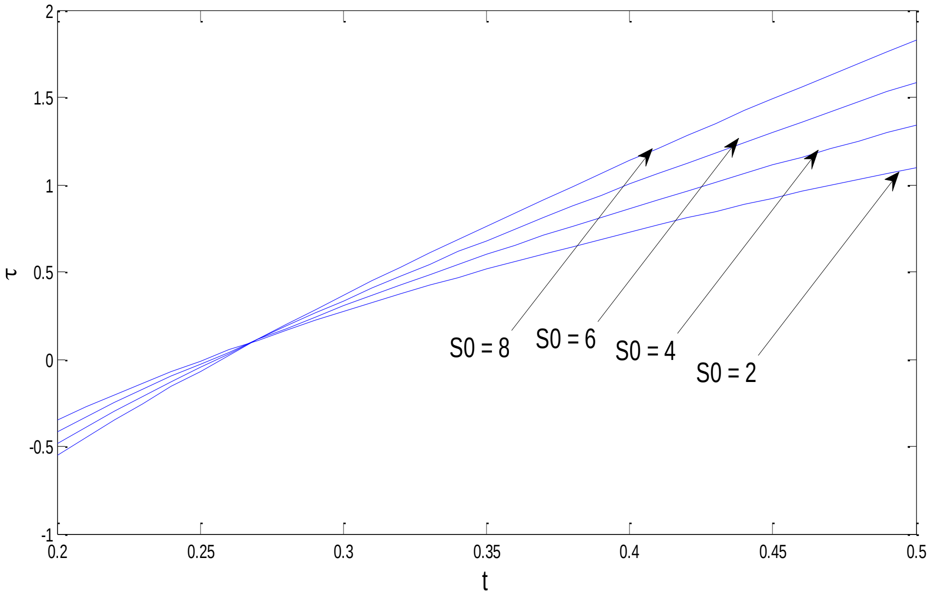

Fig.23. Skin friction profiles with the variations in Soret number S_0 and for fixed Values of G_r = 5, G_m = 5, M = 2, K_c = 1, k = 1, P_r = 0.71, S_c = 0.22, F = 1, H = 2, a = 0.2

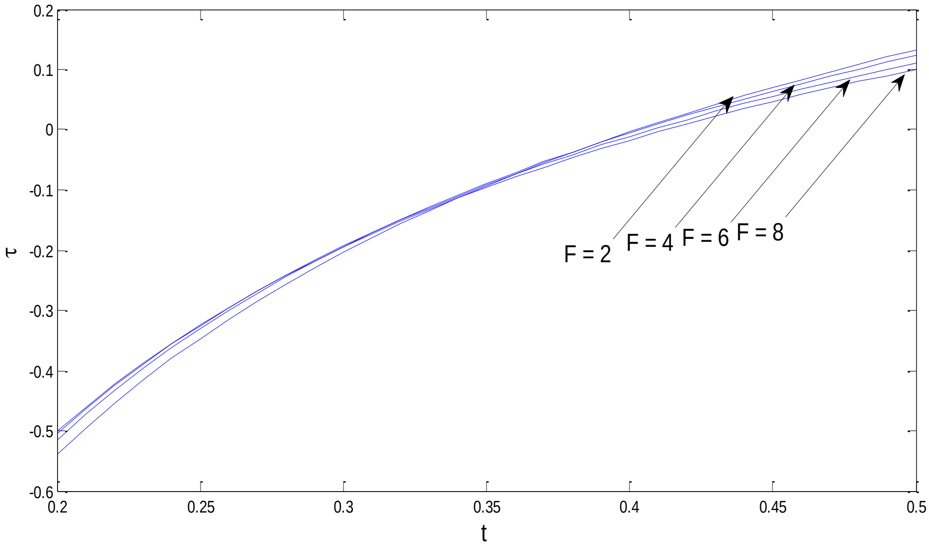

Fig.24. Skin friction profiles with the variations in radiation Parameter F and for fixed Values of G_r = 5, G_m = 5, S_0= 2, K_c = 1, k = 1, P_r = 0.71, S_c = 0.22, M = 2, H = 2, a = 0.2

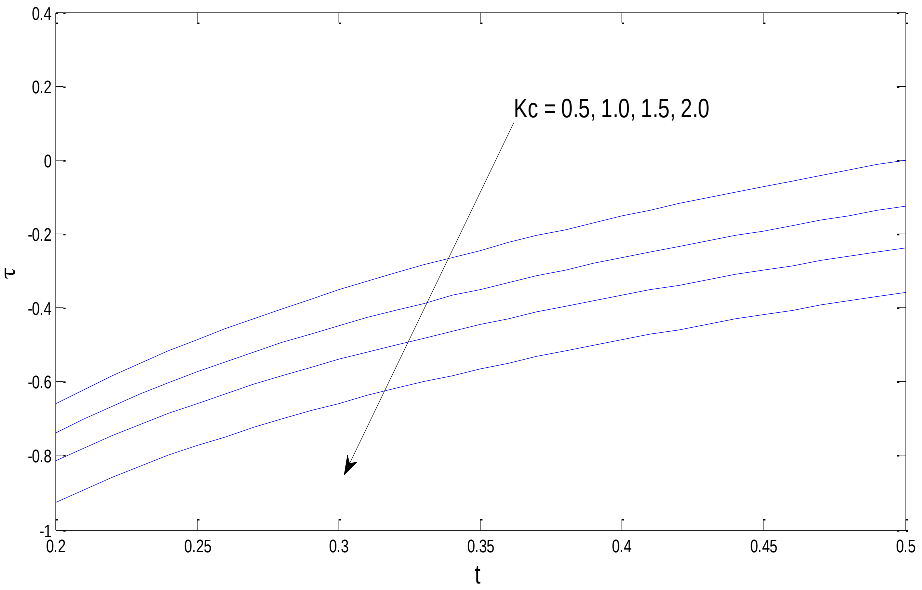

Fig.25. Skin friction profiles with the variations in chemical reaction Parameter K_c and for fixed

Values of G_r = 5, G_m = 5, M = 2, F= 1, k = 1, P_r = 0.71, S_c = 0.22, H = 2, a = 0.2

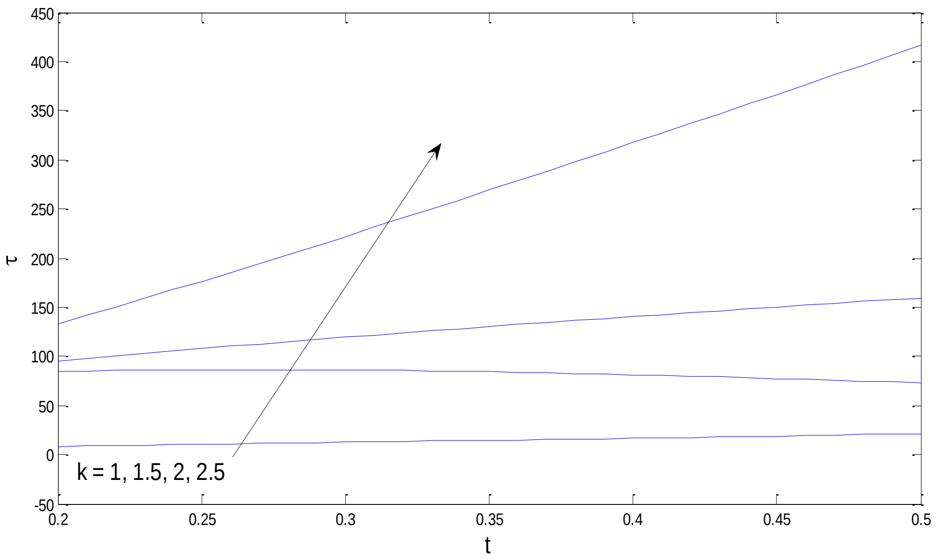

Fig.26. Skin friction profiles with the variations in permeability Parameter k and for fixed

Values of G_r = 5, G_m = 5, M = 2, F= 1, k = 1, P_r = 0.71, S_c = 0.22, H = 2, a = 0.2

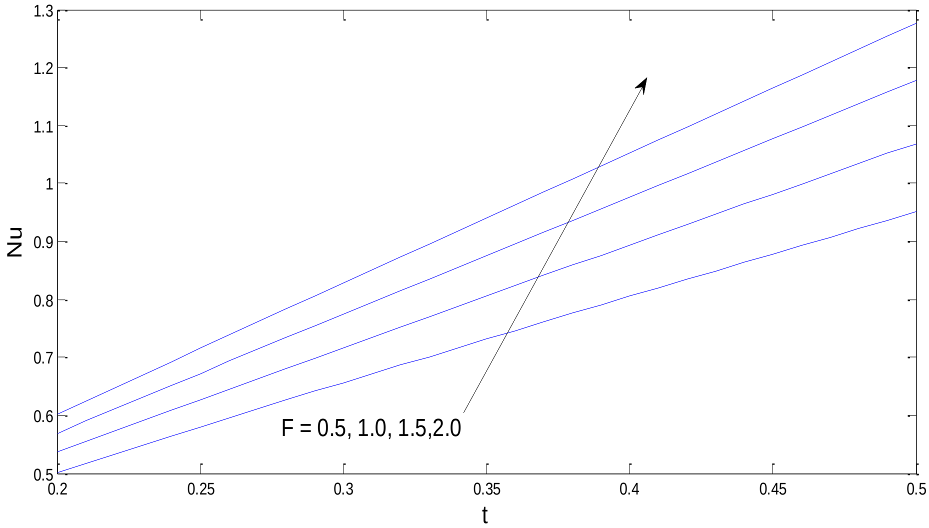

Fig.27. Nusselt number profiles with the variations Radiation parameter F and for fixed values of

P_r = 0.71, H = 2.

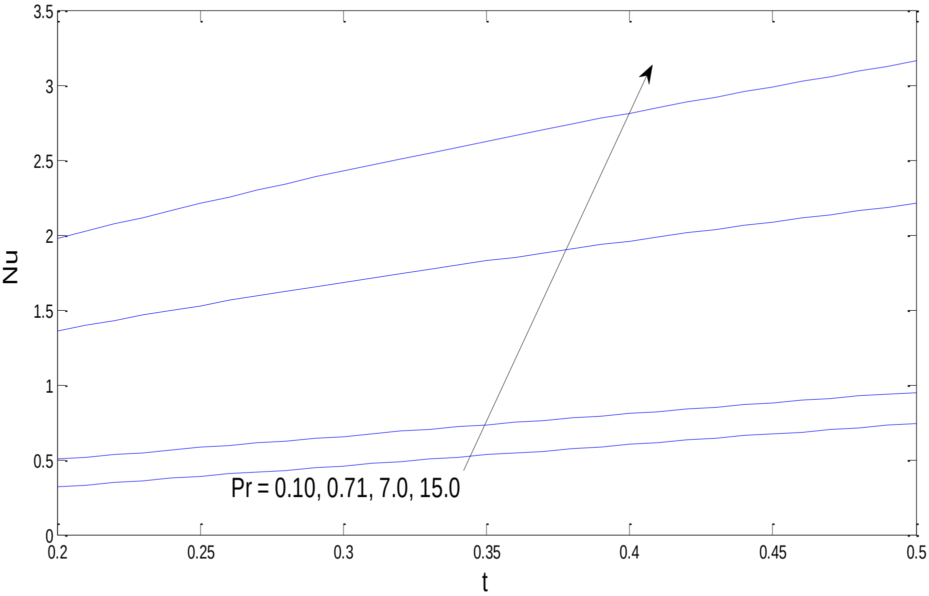

Fig.28. Nusselt number profiles with the variations Prandtl number 'P_r' and for fixed values of

F =1, H=2.

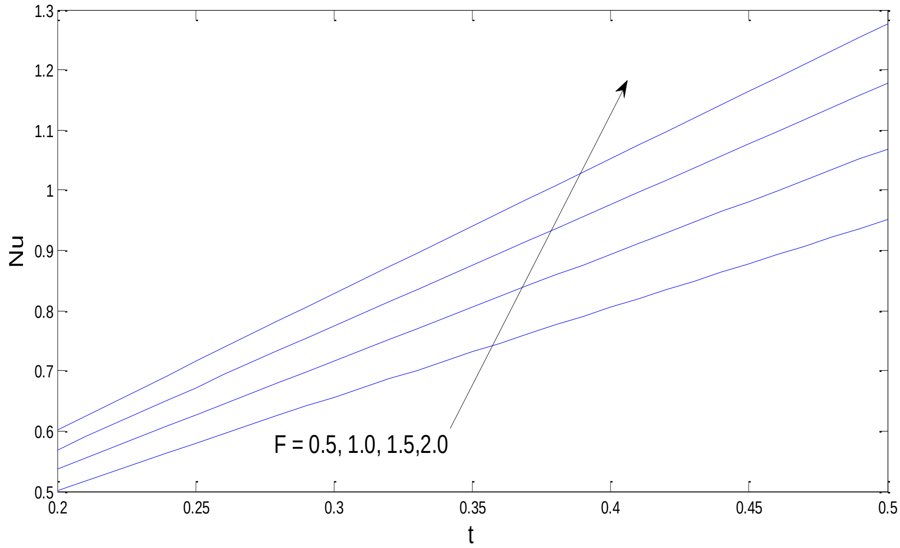

Fig.29. Nusselt number profiles with the variations heat source parameter H and for fixed values of

F =1, P_r = 0.71.

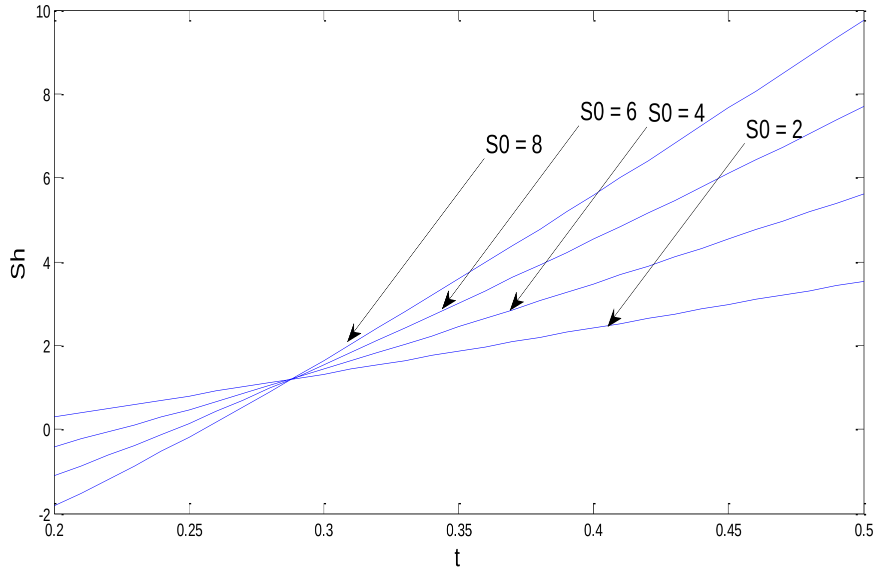

Fig.30. Sherwood number profiles with the variations in Soret number 'S_0' and for fixed values Values of K_c = 1, P_r = 0.71, k = 1, F = 1, S_c = 2.01, H = 4

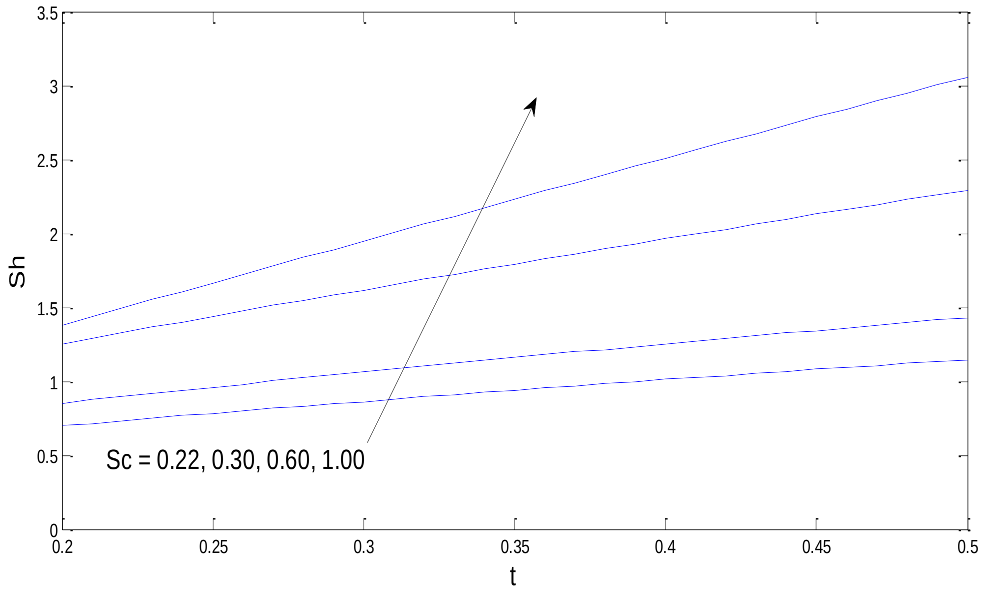

Fig.31. Sherwood number profiles with the variations in Schmidt number 'S_c' and for fixed Values $K_c = 1$, $P_r = 0.71$, $k = 1$, $F = 1$, $S_0 = 2$, $H = 4$

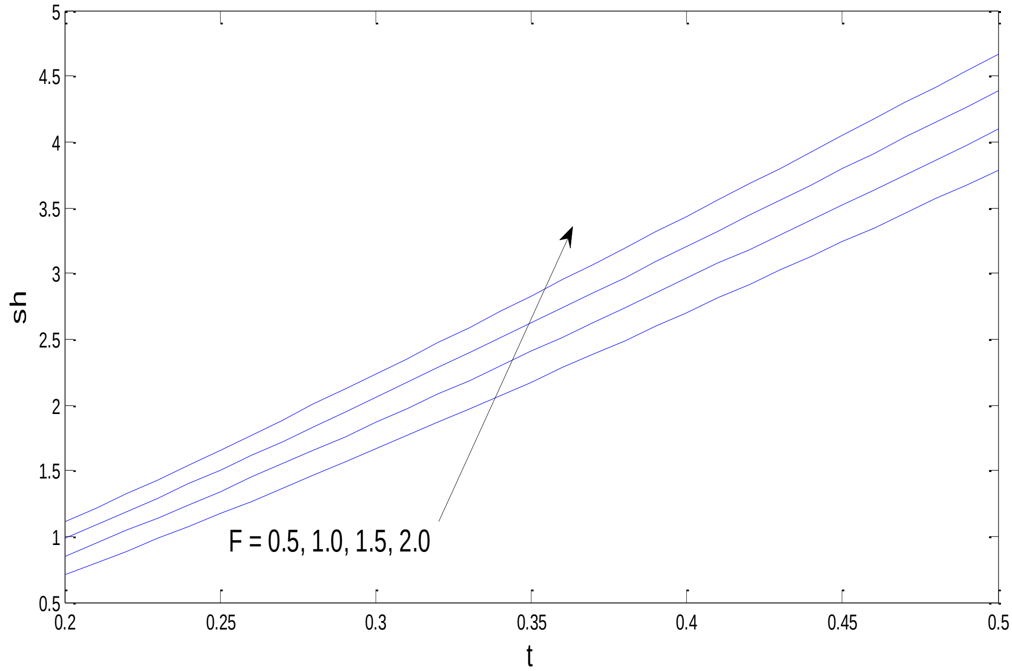

Fig.32. Sherwood number profiles with the variations in Radiation Parameter F and for fixed Values of $K_c = 1$, $P_r = 0.71$, $k = 1$, $S_c = 2.01$, $S_0 = 2$, $H = 4$

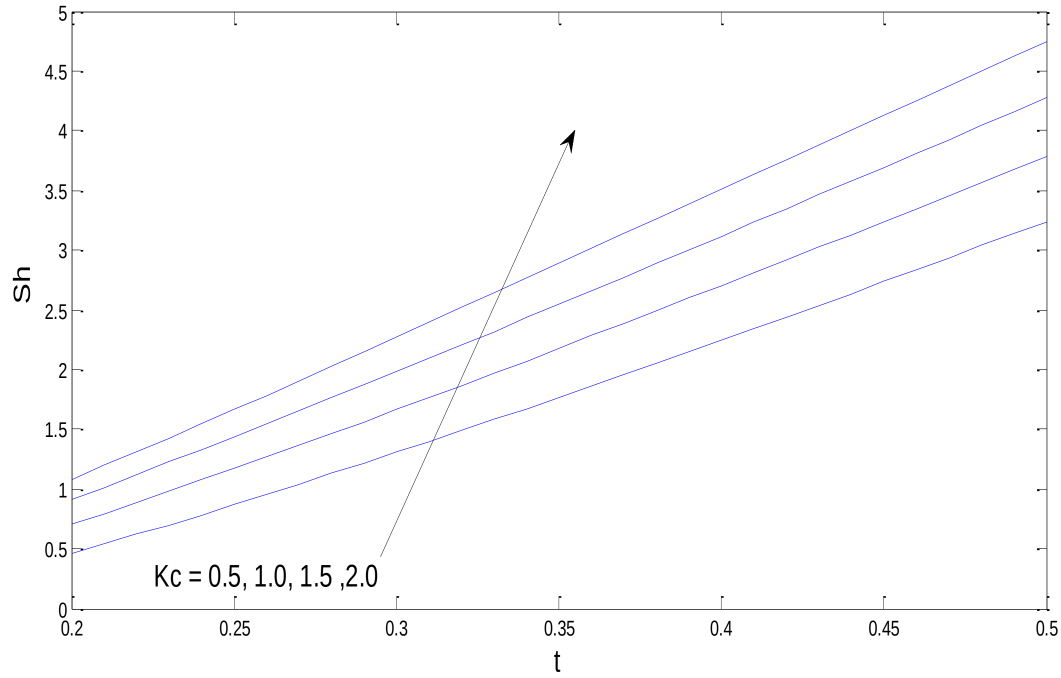

Fig.33. Sherwood number profiles with the variations in Chemical reaction parameter 'K_c' and Values of F = 1, P_r = 0.71, k = 1, S_c = 2.01, S_0 = 2, H = 4

6.5 RESULTS AND DISCUSSIONS:

Numerical evaluation of the analytical results reported in the previous section was performed and a representative a set of results is reported graphically in figures 1-18.these results are obtained to illustrate the influence of the magnetic parameter M, the Grashof number Gr, the modified Grashof number Gm, the absorption coefficient a, the time t, the radiation parameter F, the heat absorption H, the Schmidt number Sc, the Prandtl number Pr, the soret number S0, and the chemical reaction parameter Kc. The values of the Prandtl number are chosen Pr = 7 (water) and Pr = 0.71 (air). The values of Schmidt number are chosen to represent the presence of species by hydrogen (0.22), water vapour (0.60), ammonia (0.78), Ethyl benzene (2.01) and Carbondioxide (0.96). In the present study the boundary condition for $y \to \infty$ is replaced by where y_{max} is a sufficiently large value of y where the velocity profile appearances the relevant free stream velocity. A span wise step distance Δy of 0.01 is used with y_{max} = 2. In order to assess the accuracy of our method, we have compared our results with accepted data sets for the velocity and skin friction profiles for an exponentially accelerated vertical plate corresponding to the case computed by Rajesh and Varma [16]. The results of this comparison are found to be very good agreement.

Figure 1 presents typical velocity profiles in boundary layer for different values of magnetic parameter M while all other parameters are kept at some fixed values. The velocity distribution attains a distinctive maximum value in the vicinity of the plate surface and then decreases properly to approach the free stream value zero. It was found that an increase in the value of M leads to a decrease in the velocity distribution across the boundary layer. It is because of the application of transverse magnetic field which results a Lorentz force similar to drag force that tends to resists fluid flow and thus reduces its velocity. In figures 2 - 5 we have shown the effects of Gm, Gr, a, and t respectively. From these figures this evident that velocity distribution increases with an increase in each of these parameters. Figures 6 - 10 illustrate the influence of F, H, Sc, Pr and S_0 on the velocity respectively. It is observed that an increase in F, H, Sc, and Pr leads to decay the values of velocity and it shows reverse effect in case of soret number S0. Figure 11 shows the temperature profiles for different values of Prandtl number Pr. Clearly as Pr increase the temperature decreases. Figure 12 depicts the temperature profiles with span wise co-ordinate y for various F. The numerical results show that the effect of increasing values of F results in decreasing thermal boundary layer thickness and more uniform temperature distribution across the boundary layer. Whereas it shows reverse effect in case of t, figure 13. Figure 14 displays the influence of heat absorption parameter H on the temperature profiles. Physically speaking, the presence of heat absorption (thermal sink) effects has the tendency to reduce the fluid temperature (see Ref. [2]). Concentration profiles are displayed in figures 15-18. It is noticed that concentration decreases with an increase in F and Sc whereas it shows reverse effect in presence S0 and Kc. Figures 19-23 illustrate the effects of Grashof number, soret number, modified Grashof number, Magnetic parameter, and radiation parameter on the skin friction coefficient respectively. The coefficient of skin friction increases with an increase in Gr, Gm, So and F and it shows opposite reaction in case of M. Effects of F, Pr and H on Nusselt number are studied through graphs 24-26. Nusselt number increases with the increase in F, Pr and H. The rate of mass transfer increases with an increase in S0, Sc, F and Kc. These behaviors are clearly shown in figures 27-30

CONCLUSIONS

1. Velocity decreases with the increase in the magnetic parameter M or the radiation parameter F, the coefficient of heat absorption H, the Schmidt number Sc or Prandtl number Pr.
2. Velocity increases with the increase in Grashof number G_r or modified Grashof number G_m or acceleration coefficient a or soret number S_0.
3. The skin friction coefficient increased due to increase in the concentration buoyancy effects while it decreases due to increase the magnetic parameter M.
4. The Nusselt number and Sherwood number increases with increasing values of radiation parameter F or heat absorption parameter H or chemical reaction parameter K_c.

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