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Effects of Radiation on Magnetohydrodynamic Convection Flow past an Impulsively Started Vertical Plate Submersed in a Porous Medium with Suction

Dahake S.P.[1*] and Dubewar A.V.[2]

[1*] Faculty of Science, Pacific Academy of Higher Education and Research University, Udaipur, India
[2] Department of Mathematics, Datta Meghe College of Engineering, Airoli, Navi Mumbai, India

[*]*Corresponding Author: dahakesp@gmail.com*

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***Abstract*— The thermal effects of the suction velocity, in conjunction with other flow parameters, on an unsteady free convective viscous incompressible flow past an infinite vertical flat plate submersed in a saturated porous medium is investigated. The effect of various flow parameters like chemical reaction parameter Kr, Schimdt number Sc, radiation absorption coefficient Q_1, heat absorption coefficient φ radiation parameter N, Magnetic parameter M, Permeability parameter K, and time t on the velocity, temperature and concentration as well as the skin friction, rates of heat and mass transfer are obtained numerically and discussed. The results obtained are presented with the help of graphs.**

***Keywords*- Magnetohydrodynamic; Porous media; Radiation; Suction velocity;Schimidt number;Nusselt number**

I. INTRODUCTION

Study of MHD flow with heat and mass transfer plays an important role in chemical, mechanical and biological Sciences. Some important applications are cooling of nuclear reactors, liquid metals fluid, power generation system and aerodynamics. In addition, flow through a porous medium have numerous engineering and geophysical applications, for example, in chemical engineering for filtration and purification process; in agriculture engineering to study the underground water resources; in petroleum technology to study the movement of natural gas, oil and water through the oil reservoirs. In view of these applications, many researchers have studied MHD free convective heat and mass transfer flow in a porous medium. Free convection effects on the oscillating flow past an infinite vertical porous plate with constant suction was studied by Soundalgekar [1]. A.V.Dubewar and V.M.Soundalgekar [2] obtain the exact solution of Mass transfer effects on transient flow past an infinite plate with periodic heat flux and extended their study to Mass transfer effects on free convection flow past an infinite vertical porous plate [3]. V.Ambethkar [4] obtained the numerical solutions of heat and mass transfer effects of an unsteady MHD free convective flow past an infinite vertical plate with constant suction. Unsteady oscillatory free convection flow plays an important role in chemical engineering, turbo machines, and aerospace technology. Such flows arise due to unusual motion of boundary or boundary temperature. Recently Singh et al. [5] have investigated the effect of oscillatory suction velocity on free convection and mass transfer flow of a viscous fluid past an infinite vertical porous plate.

Sahoo et al. [6] have analysed MHD unsteady free convective flow past an infinite vertical plate with constant suction and heat sink. Extension to this problem has been done by Muthucumaraswamy and Kumar [7]. Acharya et al. [8] have studied free convection and mass transfer flow through a porous medium bounded by vertical infinite surface with constant suction and heat flux. In this study, we have extended the flow problem for the case of radiative heat transfer in porous media but restricted to the case to semi-infinite moving plate.

II. MATHEMATICAL FORMULATION

An unsteady laminar free MHD convective flow of a electrically conducting and radiating, viscous incompressible fluid past an infinite vertical porous flat plate in slip-flow regime, with periodic temperature and concentration when variable suction velocity distribution $v^* = -V_0(1+\varepsilon e^{\omega t})$ is considered whereV_0 is the mean suction velocity and ε is a small quantity less than unity. The negative sign indicates that the suction velocity is directed towards the plate. A co-ordinate system is employed with wall lying vertically in x^*y^* -plane. The x^* - axis is taken in vertically upward direction along the vertical porous plate and y^* -axis is taken normal to the plate. Since the plate is considered infinite in the x^* direction, hence all physical quantities will be independent of x∗. Under this assumption, the physical variables are purely

the functions of y∗ and t∗ only. In the fitness of the realistic situation by neglecting viscous dissipation and then assuming variation of density in the body force term under Boussinesq's approximation the flow is governed by the following set of equations:

$$\frac{\partial u^*}{\partial t^*} - V_0(1+\varepsilon e^{\omega t})\frac{\partial u^*}{\partial y^*} = \nu\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T^* - T_\infty) + g\beta(C^* - C^*_\infty) - \frac{\sigma B_o^2}{\rho}u^* - \frac{\nu}{\kappa^*}u^* \quad (1)$$

$$\frac{\partial T^*}{\partial t^*} - V_0(1+\varepsilon e^{\omega t})\frac{\partial T^*}{\partial y^*} = \frac{K}{C_p\rho}\frac{\partial^2 T^*}{\partial y^{*2}} + \frac{Q_0}{C_p\rho}(T^* - T_\infty) + Q_1^*(C^* - C^*_\infty) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^*} \quad (2)$$

$$\frac{\partial C^*}{\partial t^*} - V_0(1+\varepsilon e^{\omega t})\frac{\partial C^*}{\partial y^*} = K^1(C^* - C^*_\infty) + D\frac{\partial^2 C^*}{\partial y^{*2}} \quad (3)$$

Where $T^*, C^*, K^*, u_t^*, T_\infty, C_\infty, \beta^*, Q_1^*, Q_0, \rho, \sigma, \beta, \kappa^*, B_0$, C_p, q_r, ν, K^1, D are dimensional temperature, dimensional concentration, permeability parameter, wall dimensional velocity, free stream temperature, free stream concentration, coefficient of concentration expansion, radiation absorption parameter, heat absorption coefficient, density of the fluid, electric conductivity of the fluid, the coefficient of thermal expansion, thermal conductivity, magnetic induction, the specific heat at constant pressure, the radiative heat flux, kinematic viscosity, chemical reaction parameter, the mass diffusivity coefficient respectively.

The Rosseland diffusion flux is used and defined following

$$q_r = -\frac{4\sigma^*}{3Ke}\frac{\partial T^4}{\partial y} \quad (4)$$

where σ^* is the Stephen Boltzmann constant and K_e is the mean absorption coefficient. It should be noted that by using the Rosseland approximation, the present analysis is limited to optically thick fluids. If the temperature differences within the flow are sufficiently small, then equation (4) can be linearized by expanding T^4 into the Taylor series about $T\infty$, which after neglecting higher order terms takes the form

$$T^4 \cong 4T^{*3}_\infty T^* - 3T^{*4}_\infty \quad (5)$$

Using equation (5), the energy equation (2) becomes

$$\frac{\partial T^*}{\partial t^*} - V_0(1+\varepsilon e^{\omega t})\frac{\partial T^*}{\partial y^*} = \frac{K}{C_p\rho}\frac{\partial^2 T^*}{\partial y^{*2}} + \frac{Q_0}{C_p\rho}(T^* - T_\infty) + Q_1^*(C^* - C^*_\infty) + \frac{16\sigma^* T^3_\infty}{\rho C_p Ke}\frac{\partial^2 T}{\partial y^2} \quad (6)$$

The corresponding initial and boundary conditions are

$$\left.\begin{array}{l} for\ \ y^* = 0, u^* = u_w^*,\ T^* = T_w,\ C^* = C_w \\ for\ \ y^* \to \infty, u^* = U(t),\ \ T^* = T_\infty,\ C^* = C_\infty \end{array}\right\} \quad (7)$$

In order to write the governing equations and the boundary conditions in dimensionless form, the following non-dimensional quantities are introduced

$$\left.\begin{array}{l} u = \dfrac{u^*}{V_0},\quad y = \dfrac{V_0 u^*}{V_0} \\ U(t) = \dfrac{U^*}{V_0}, \nu = \dfrac{\nu^*}{V_0} \\ t = \dfrac{V_0^{*2} t^*}{\nu},\ u_w = \dfrac{u_w^*}{V_0} \\ Q_1 = \dfrac{Q_1^*(T_w - T_\infty)\nu}{V_0^2(C_w - C_\infty)} \\ \theta = \dfrac{(T^* - T_\infty)}{(T_w - T_\infty)}, \gamma = \dfrac{K_1\nu}{V_0^2} \\ C = \dfrac{(C^* - C_\infty)}{(C^*_w - C_\infty)} \end{array}\right\}$$

$$\left.\begin{array}{l} \Pr = \dfrac{\mu Cp}{\kappa},\ K = \dfrac{V_0^2 K^*}{\nu} \\ Gr = \dfrac{g\beta\nu(T_w - T_\infty)}{\overline{u}_0^3} \\ Gc = \dfrac{g\nu\beta(c_w - C_\infty)}{V_0^3}, \\ \phi = \dfrac{\nu Q_0}{V_0^2}, N = \dfrac{Kek}{4\sigma^*\overline{T}_\infty^3} \\ M = \dfrac{\sigma B_0^2\nu}{\rho V_0^2},\ S_c = \dfrac{\nu}{D} \end{array}\right\} \quad (8)$$

Using the above non-dimensional quantities the governing equations (1), (3) and (6) becomes

$$\frac{\partial u}{\partial t} - (1+\varepsilon e^{\omega t})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{K}\right)u + GcC + G_r\theta \quad (9)$$

$$\frac{\partial \theta}{\partial t} - (1+\varepsilon e^{\omega t})\frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\left(1 + \frac{4}{3N}\right)\frac{\partial^2 \theta}{\partial y^2} + Q_1 C - \phi\theta \quad (10)$$

$$\frac{\partial C}{\partial t} - (1+\varepsilon e^{\omega t})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - \gamma C \quad (11)$$

The corresponding initial and boundary conditions are

$$\left.\begin{array}{l} for\ \ y = 0, u = u_w,\ \theta = 1, C = 1 \\ for\ \ y \to \infty, u = U(t),\ \ \theta = 0, C \to 0 \end{array}\right\} \quad (12)$$

III. SOLUTION OF THE PROBLEM

In order to solve the dimensionless governing equations (9) to (11) subject to boundary conditions (12) we apply the regular perturbation method due to their non-linearity. However, the fact that perturbation parameter is small in most practical problems. This can be done by representing the velocity, temperature and concentration of the fluid in terms of perturbation parameter, with U (t) $=1+\varepsilon e^{\omega t}$, which is as follows:

$$u(y,t) = u_0(y)+\varepsilon e^{\omega t} u_1(y),\ \theta(y,t) = \theta_0(y) + \varepsilon e^{\omega t}\ \theta_1(y),\ C(y,t)= C(y)+\varepsilon e^{\omega t} C(y) \tag{13}$$

Zeroth Order

$$\frac{d^2u_0}{dy^2} + \frac{du_0}{dy} - a_3u_0 + Gr\ \theta_0 + GcC_0 = 0 \tag{14}$$

$$\frac{1}{\Pr}\left(1+\frac{4}{3N}\right)\frac{d^2\theta_0}{dy^2} + \frac{d\theta_0}{dy} - a_4\theta_0 + \phi\theta_0 + Q_1C_0 = 0 \tag{15}$$

$$\frac{1}{Sc}\frac{d^2C_0}{dy^2} + \frac{dC_0}{dy} - \gamma C_0 = 0 \tag{16}$$

With the boundary conditions

$$\left.\begin{array}{l} for\ \ y=0, u_0=u_w,\ \theta_0=1,\ C_0=1 \\ for\ \ y\to\infty, u_0=1,\ \ \theta_0\to 0,\ C_0\to 0 \end{array}\right\} \tag{17}$$

Solving (14) – (16) subject to (17) the solution of zero th order is obtained as

$$u_0(y) =1+B_{10}e^{-m_1y} +B_9e^{-m_1y} +B_8e^{-m_3y} +B_{11}e^{-m_5y} \tag{18}$$

$$\theta_0(y) =B_2e^{-m_1y} -B_2\ e^{-m_3y} + e^{-m_3y} \tag{19}$$

$$C_0(y) = e^{-m_1y} \tag{20}$$

First order

$$\frac{d^2u_1}{dy^2} + \frac{du_1}{dy} - a_4u_1 + Gr\ \theta_0 + GcC_0 = 0 \tag{21}$$

$$\frac{1}{\Pr}\left(1+\frac{4}{3N}\right)\frac{d^2\theta_0}{dy^2} + \frac{d\theta_0}{dy} - a_4\theta_0 + \phi\theta_0 + Q_1C_0 = 0 \tag{22}$$

$$\frac{1}{Sc}\frac{d^2C_0}{dy^2} + \frac{dC_0}{dy} - \gamma C_0 = 0 \tag{23}$$

The boundary conditions are

$$\left.\begin{array}{l} for\ \ y=0, u_1=0,\ \theta_1=0,\ C_1=0 \\ for\ \ y\to\infty, u_1=1,\ \ \theta_1\to 0,\ C_1\to 0 \end{array}\right\} \tag{24}$$

Solving (21) – (23) subject to (24) the solution of first order is obtained as

$$U_1(y) =1+A_1e^{-m_5y} + A_2e^{-m_1y} + A_3e^{-m_3y} +A_4e^{-m_1y} +A_5e^{-m_4y} +A_6e^{-m_3y} +A_7e^{-m_1y} +A_8e^{-m_1y} +A_9e^{-m_2y} +A_{10}e^{-m_1y} +A_{11}e^{-m_6y} \tag{25}$$

$$\Theta_1(y) =B_3e^{-m_3y} + B_4\ e^{-m_1y} + B_5e^{-m_1y} +B_6e^{-m_2y} + +B_7e^{-m_4y} \tag{26}$$

$$C_1(y) = B_1\ e^{-m_1y} +B_1e^{-m_2y} \tag{27}$$

Where

m_1= (Sc +$\sqrt{Sc^2+4\gamma Sc}$)/2,
m_2= (Sc +$\sqrt{Sc^2+4a_1Sc}$)/2,
m_3= (Pr +$\sqrt{Pr^2+4Pr\phi}$)/2,
m_4= (Pr +$\sqrt{Pr^2+a_2Pr}$)/2,
m_5= (1 +$\sqrt{1+4a_3}$)/2,
m_6= (1 +$\sqrt{1+4a_4}$)/2,
$a_2=\omega+\phi, a_3=M+\frac{1}{K}, a_4=a_3+\omega$
$B_1=m_1Sc/(m_1^2-m_1Sc-a_1Sc)$,$B_2=-Q_1\Gamma(\Gamma Pr)/(m_1^2-m_1\Gamma Pr-\phi\Gamma Pr)$,$B_3$ = -$m_3(1-B_2)\Gamma(\Gamma Pr)/(m_3^2-m_3\Gamma Pr-a_2\Gamma Pr)$,$B_4 = m_1(\Gamma Pr)/(m_1^2-m_1\Gamma Pr-a_2\Gamma Pr)$,$B_5 = -A_1Q_1(\Gamma Pr)/(m_1^2-m_1\Gamma Pr-\Gamma Pr)$,$B_6 = Q_1(\Gamma Pr)/(m_2^2-m_2\Gamma Pr-a_2\Gamma Pr)$,$B_7=-(B_6+B_5+B_4+B_3)$,$B_8=(G_rB_2-G_r)/(m_3^2-m_3-a_3)$,$B_9=-G_rB_2/(m_1^2-m_1-a_3)$,

$$B_{10}=-G_c/(m_1^2-m_1-a_3B_{11}=u_W-(B_{10}+B_9+B_8+1)$$

$A_1=(M_5B_{11})/(m_5^2-m_5-a_4)$, $A_2=(m_3B_8)/(m_3^2-m_3-a_4)$, $A_3=(m_1B_9)/(m_1^2-m_1-a_4)$, $A_4=(m_1B_{10})/(m_1^2-m_1-a_1)$, $A_5=(G_rB_7)/(m_4^2-m_4-a_4)$, $A_6=-(G_3B_3)/(m_3^2-m_3-a_4)$, $A_7=-G_rB_4/(m_1^2-m_1-a_4)$, $A_8=-G_rB_5/(m_1^2-m_1-a_4)$, $A_9=-G_rB_6/(m_2^2-m_2-a_4)$, $A_{10}=-G_cB_1/(m_1^2-m_1-a_4)$, $A_{11}=-G_cB_1/(m_2^2-m_2-a_4)$

Now it is important to calculate the physical quantities of primary interest, which are the skin friction, surface heat flux and Sherwood number.

Dimensionless surface heat flux or Nusselt number is obtained as

$$Nu = -\left(\frac{\partial\theta}{\partial y}\right)_{y=0} = \frac{-\delta q_w}{\kappa(T_w-T_\infty)} \tag{28}$$

Dimensionless local wall shear stress or skin-friction is obtained as,

$$\tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0} = \frac{\tau}{U_0\rho V_0} \tag{29}$$

Dimensionless mass transfer coefficient or the Sherwood number is obtained as,

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = \frac{-\delta M}{D(C_w-C_\infty)} \tag{30}$$

IV. RESULTS AND DISCUSSION

In order to illustrate the influence of various physical parameters viz., thermal radiation, magnetic parameter, chemical reaction parameter and permeability parameter on the velocity, temperature, concentration, skin-friction, Nusselt number and Sherwood number, the numerical calculations are carried out and results are presented graphically with figures. Throughout the calculations, the parametric values are taken as, Gr = 4, Gc = 2, Q1 = 2, K = 2, M = 2, ε=0.2, ω=0.1 u_t=0.5, Pr =0.71, t =1, ϕ = 2, γ = 0.2 and Sc = 0.2 unless otherwise stated specifically.

In **Fig.1.** it is seen that the temperature decreases as the radiation parameter N increases. This result qualitatively agrees with expectation since the effect of radiation is to decrease the rate of energy transport to the fluid, thereby decreasing the temperature of the fluid.

In **Fig.2.** It is observed that an increase in the radiation parameter leads to an increase in the temperature.

In **Fig.3**. It is noticed that there is decrease of the boundary layer thickness due to the increasing value of Prandtl number Pr.

In **Fig.4**. It is observed that rise in the heat absorption parameter leads to a decrease in the temperature.

Fig.5. shows the effect of permeability parameter K on the velocity distribution. It is observed that the velocity rises due to rise in K this agrees with the fact that increase in K will decrease the resistance of the porous medium resulting in increase in velocity.

Fig.6. shows the effect of magnetic parameter M on velocity it is seen that increase in the value of M results the decrease in velocity. It is true as magnetic force retards the flow velocity.

Fig.7 and 8. shows the effect of velocity for different values of Gr, the thermal bouncy force and Gc, the species bouncy force from these it is noticed that velocity increases with the increase in values of Gm and Gc.

The effects of Sc, the Schmidt number on velocity and concentration profile are plotted in **Fig.9-10.** respectively. It is found that an increase in Sc leads to a decrease in both the values of velocity and concentration.

Fig.11. shows the effect of concentration on chemical reaction parameter γ.It is noticed that chemical reaction γ increases the concentration decreases.

The effects of K, M, γ and Sc on C_f , the skin-friction coefficient are plotted in **Fig.12-15.** It is noticed that as K or γ or Sc increases the skin-friction coefficient increases whereas the skin-friction decreases as M increases.

Fig.16 -19. depicts the effects of γ, Pr, ϕ, Q_1 on the Nusselt number. It is observed that the Nusselt number increases as the radiation parameter or Prandtl number, Pr or heat absorption parameter, ϕ increases, whereas it decreases as the radiation absorption parameter, Q_1 increases.

Fig.20- 21. delineates the effects of chemical reaction parameter γ and Schmidt number Sc on the Sherwood number Sh. It is noticed that the Sherwood number increases as chemical reaction parameter or Schmidt number increases.

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Authors Profile

Mr. Sadashiv P. Dahake pursued Bachelor of Science from Nagpur University and Master of Science from Amaravati University of Amaravati, Maharashtra, India in year 1985. He is currently pursuing Ph.D. in *Faculty of Science, Pacific Academy of Higher Education and Research University, Udaipur, Rajasthan, India*. He is currently working in Department of Mathematics, *Shah and Anchor Kutchhi Engineering College, Chembur, Mumbai, Maharashtra, India.* He is a life member of ISTE.

Mr A.V.Dubewar pursued Bachelor of Science, Master of Science and Doctorate from Marathwada University of Aurangabad, Maharashtra,India. in year 2003. He is currently working in Department of Mathematics, *Datta Meghe College of Engineering, Airoli,NaviMumbai, Maharashtra, India.* He has published more than 14 research papers in reputed international and national journals. He is a life member of ISTE

FIGURES

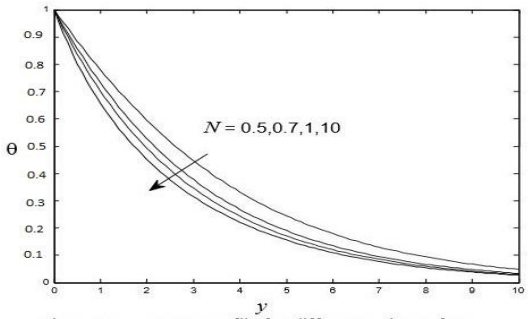

Fig.1. Temperature profile for different values of N

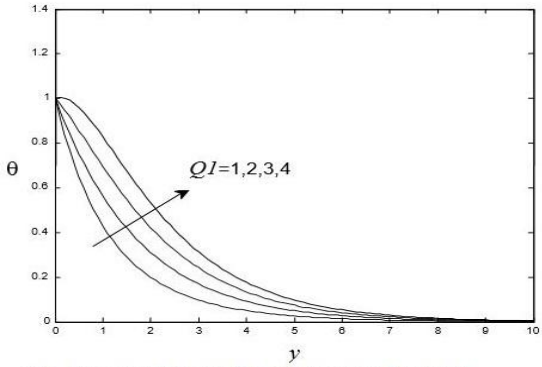

Fig.2. Temperature profile for different values of Q1

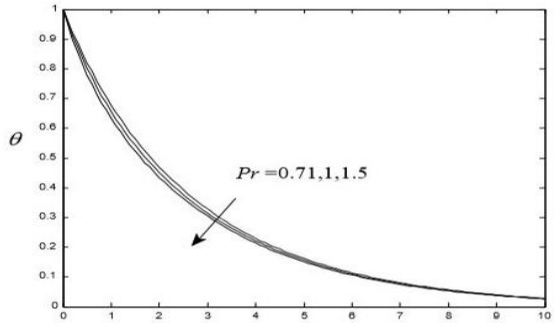

Fig.3. Temperature profile for different values of Pr

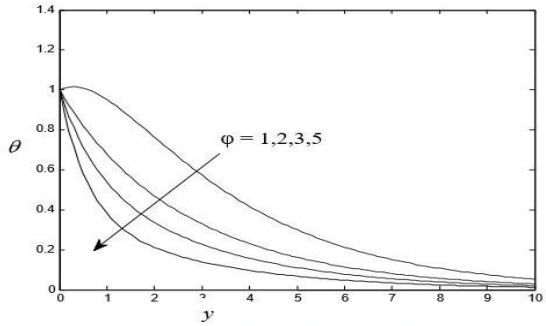

Fig.4. Temperature profile for different values of φ

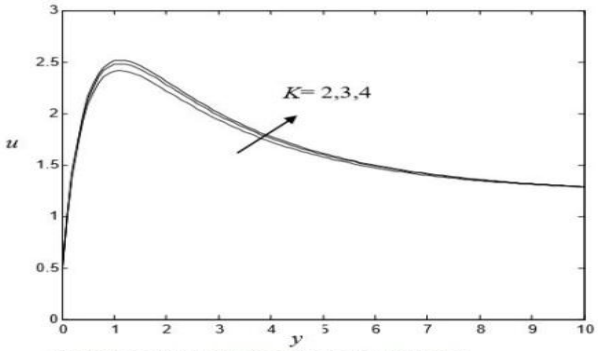

Fig.5. Velocity profile for different values of K

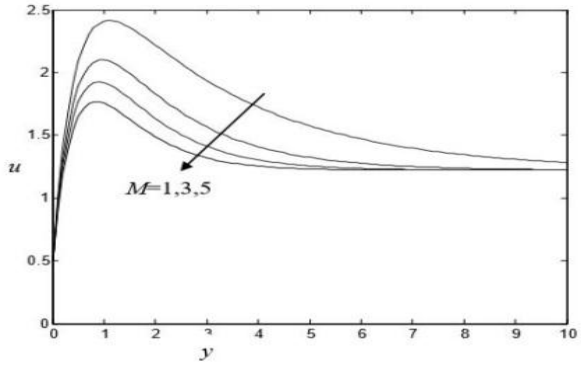

Fig.6. Velocity profile for different values of M

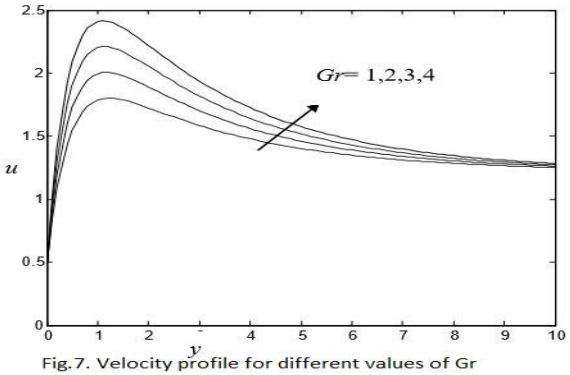

Fig.7. Velocity profile for different values of Gr

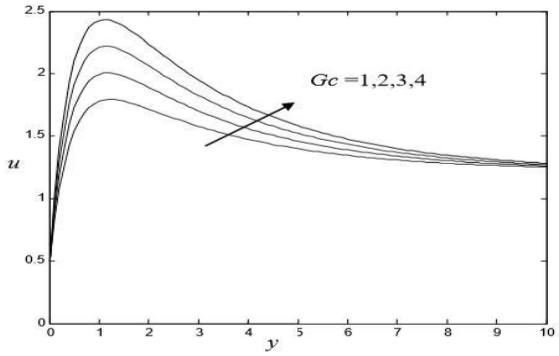

Fig.8. Velocity profile for different values of Gc

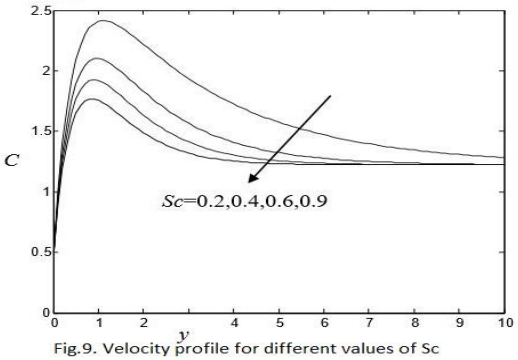

Fig.9. Velocity profile for different values of Sc

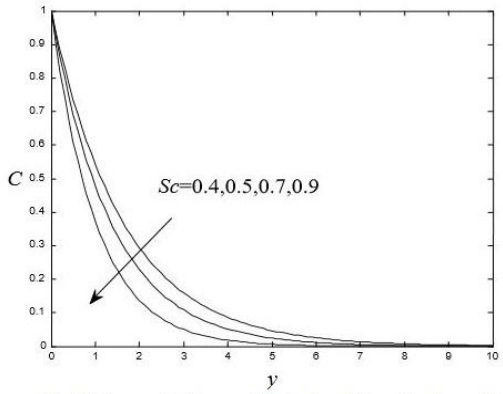

Fig.10. Concentration profile for for different values of Sc

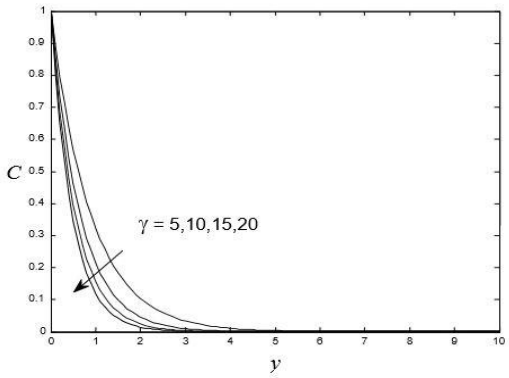

Fig.11. Concentration profile for different values of γ

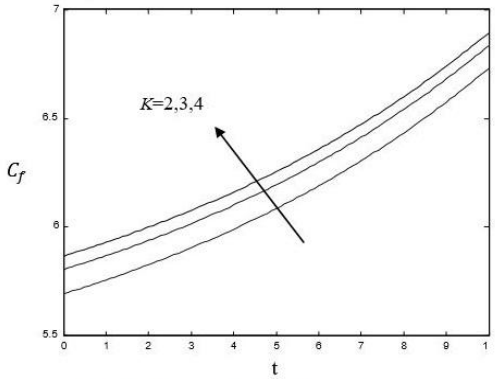

Fig.12. Effects of K on skinfriction coefficient

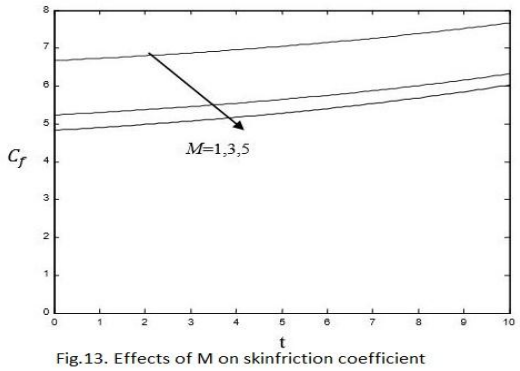

Fig.13. Effects of M on skinfriction coefficient

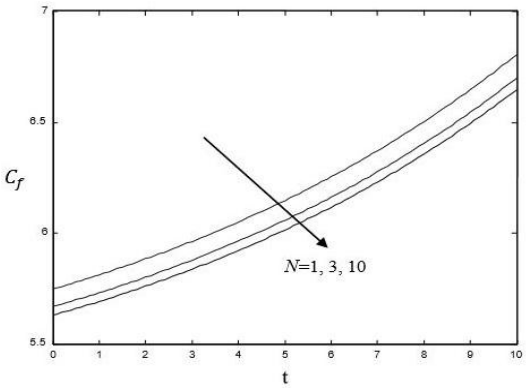

Fig.14. Effect of N on skinfriction coefficient Cf

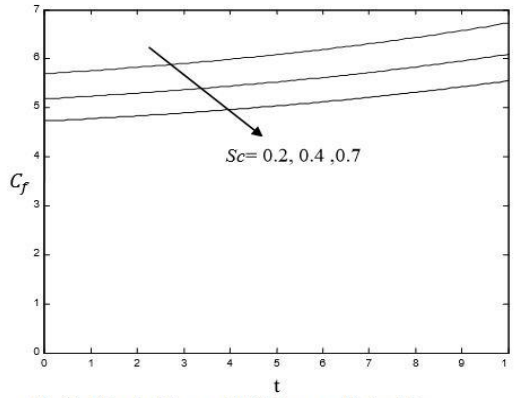

Fig.15. Effect of Sc on skinfriction coefficient Cf

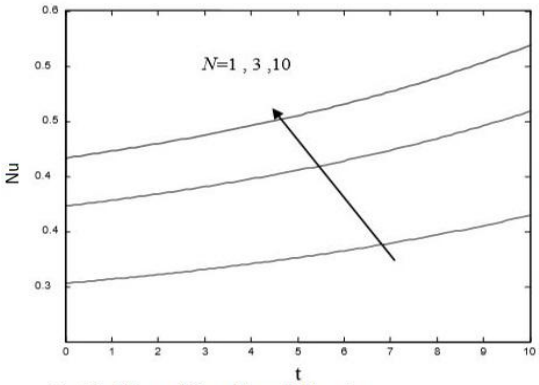

Fig.16. Effect of N on Nusselt Number

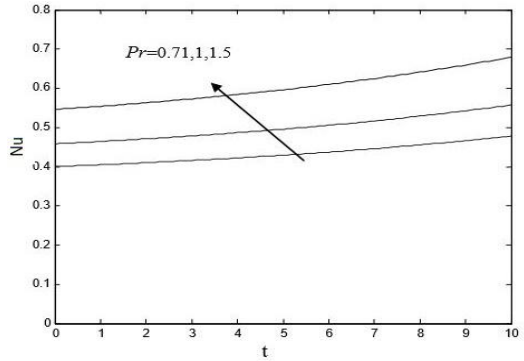

Fig.17. Effect of Pr on Nusselt number

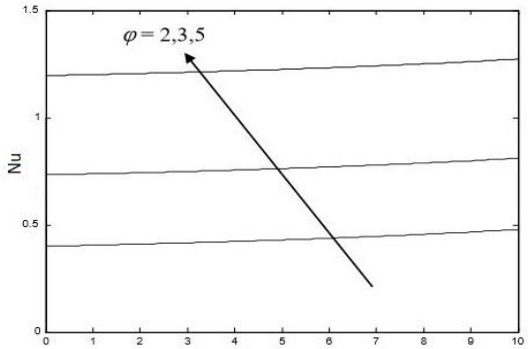

Fig.18. Effect of φ on heat transfer coefficient

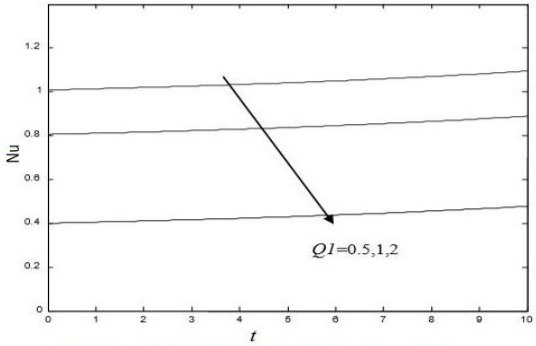

Fig.19. Effect of parameter Q_1 on Nusselt number

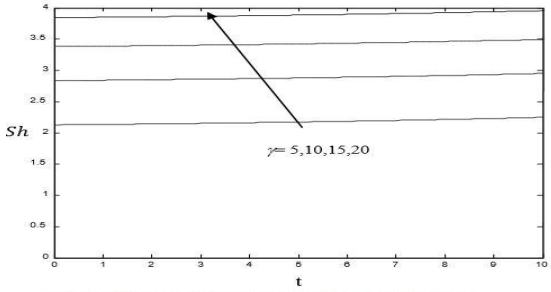

Fig.20. Effect of parameter γ on Sherwood number

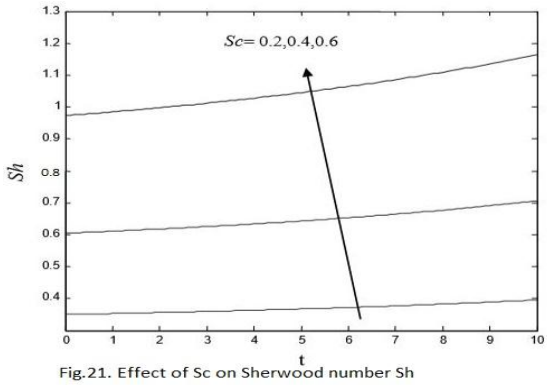

Fig.21. Effect of Sc on Sherwood number Sh

