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MHD CONVECTIVE MASS TRANSFER FLOW OF KUVSHINSKI FLUID PAST AN INFINITE MOVING PLATE EMBEDDED IN A POROUS MEDIUM WITH FIRST ORDER CHEMICAL REACTION AND VARIABLE SUCTION

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ABSTRACT

MHD convective mass transfer flow of Kuvshinski fluid past an infinite moving porous plate embedded in a porous medium in the presence of first order chemical reaction and variable suction velocity. The $x^* -$ axis is taken along the plate in the fluid flow direction and $y^* -$ axis normal to it. A uniform magnetic field of strength B_0 is applied. Governing equations of the flow are solved by using single perturbation technique and obtained the expression for velocity and species concentration distribution skinfriction coefficient and rate of mass transfer in terms of Sherwood number are also derived. The effects of various parameters on the above flow quantities have been presented and analyzed through graphs and tables.

KEYWORDS: Kuvshinski fluid, MHD, boundary layer, porous medium, chemical reaction, thermal diffusion.

INTRODUCTION

Free convection mass flow is often encountered in cooling of nuclear reactors. Along with the free convection flow the phenomenon of mass transfer is also very common in the theories of stellar structure. The convection porous medium has important applications in geothermal reservoirs and geothermal extractions. Chemical reactions are classified into two categories;

via homogeneous reaction and heterogeneous reaction, which involves two or more phases and occur at the interface between fluid and solid or between two fluids separated by an interface. The important applications of homogeneous reactions are the combination of common household gas and oxygen to produce a flame and the reactions between aqueous solutions of acids and bases. Effects of first order chemical reaction and variable suction an application in which the fluid is the working medium. The wide range of technological and industrial applications has stimulated considerable amount of interest in the study of chemical reaction in convection flows. The effects of a chemical reaction depend on whether the reaction is heterogeneous or homogeneous. This depends on whether they occur at an interface or as a single phase volume reaction. A reaction is said to be of first order, if the rate of reaction is directly proportional to concentration itself. Air or water contaminated with impurities like CO_2, NH_3,O_2,etc, or salt in water. The presence of such impurities is studied in the literature by considering it as a foreign mass. In many chemical engineering processes, there does occur the chemical reaction occurs between a foreign mass and the fluid in which the plate is moving. These processes take place in numerous industrial applications like polymer production, manufacturing of ceramics, or glassware and food processing etc.There are many interesting aspects of such flows, so in analytical solutions to such problems of flow have been presented by many authors. Gebhart and Pera[1] studied the effect of the presence of foreign mass on the free convection flow past a semi-infinite vertical plate. Soundalgekar et al.[2] observed the mass transfer effect on the flow past an impulsively started infinite vertical plate under several conditions. Hossain and Begum[3] studied the Effects of Mass transfer on the unsteady free convection flow past an accelerated vertical porous plate with variable suction. Cussler[4] studied that in most cases of chemical reaction, the reaction rate depends on the concentration of the species itself. Byon Bird et al.[5] studied the presence of a foreign mass in air or water causes some kind of chemical reaction, during a chemical reaction between two species, heat is also generated. Das et al.[6] studied effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction. Themelis[7] stated that the majority of chemical reactions encountered in applications are first order and heterogeneous reactions such as hydrolysis of methyl acetate in the presence of mineral acids and inversion of cane sugar in the presence of mieral acids. Shanker and Kishan[8] studied the effects of mass transfer on the MHD flow past an impulsively started infinite vertical plate with variable temperature or constant heat flux. Raptis[9] observed radiation and free convection flow through a porous medium. Muthukumaraswmay and Ganesan[10] studied Effects of Chemical reaction and injection on flow characteristics in an unsteady upward motion of an isothermal plate. Muthukumaraswamy[11] studied Effects of Chemical reaction on a moving isothermal vertical surface with suction. Hazem Ali Attia[12] studied effect of porosity on unsteady Poiseuille flow of a viscosity. Palani and Srikanth[13] observed MHD flow past a semi-infinite vertical plate with mass transfer. Hassan and El-Arabawy[14] studied exact solutions of mass transfer over a stretching surface with chemical reaction and Suction / Injection. Raju et al.[15] studied the radiation mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface. Arvind Kumar Sharma et al.[16] studied effect of Kuvshinski fluid on double-diffusive convection-radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effects. Midya[17] observed from their study that the first order chemical reaction is very important in chemical engineering where the chemical reactions take place between a foreign mass and working fluid. Bhuvaneswari et al.[18] used Lie group analysis to solvethe natural convection heat and mass transfer in an inclined surface with first order homogeneous chemical reaction. Battacharya and Layek[19] investigated the similarity solution of MHD boundary layer flow with diffusion and chemical reaction over a porous flat plate with suction blowing. They found that the concentration decreases on increasing the effect of chemical reaction. Reddy et al.[20] studied unsteady MHD radiative and chemically reactive free convection flow near a moving a vertical plate in porous medium. Chamkha et al.[21] studied unsteady MHD free convection flow past an exponentially accelerated vertical plate with mass transfer, chemical reaction and thermal radiation. Few other studies related to this area of research are worth mentioning done by the researchers.[22-30] Motivated by the above studies, in this made an attempt to investigate the effects of MHD convective mass transfer flow of Kuvshinski fluid past an infinite moving plate embedded in porous medium with first order chemical reaction and variable suction. We solved this problem through perturbation method and shown graphically.

MATHEMATICAL FORMULATION OF THE PROBLEM

Two dimensional unsteady flow of a laminar, conducting fluid past a semi-infinite vertical moving porous plate embedded in a uniform porous medium and subject to a uniform magnetic field in the presence of a pressure gradient has been considered with free convection, thermal diffusion, and chemical reaction. According to the coordinate system the x^*-axis is taken along the porous plate in the upward direction and y^*-axis normal to it. The fluid is assumed to be gray, absorbing-emitting but non-scattering medium. The radiative heat flux in the x^*-direction is considered negligible in comparison with that in the y^*- direction. It is assumed that there is no applied voltage of which implies the absence of an electric field. The transversely applied magnetic field and magnetic Reynolds number are very small and hence the induced magnetic field is negligible. Viscous and Darcy resistance terms are taken into account in the constant permeability porous medium. The MHD term is derived from the order of magnitude analysis of the full Navier-stokes equation. It is assumed here that the hole size of the porous plate is significantly larger than characteristics microscopic length scale of the porous medium. We regard the porous medium as an assemblage of small identical spherical particles fixed in space. A homogeneous first-order chemical reaction is between the fluid and the species concentration. The chemical reactions are taking place in the flow and all thermo physical properties are assumed to be constant of the linear momentum equation which is approximation. Due to the semi-infinite plane surface assumption furthermore, the flow variable are function of y* and t* only. The governing equation for this investigation is based on the balance of mass, linear momentum and concentration specie. Taking into consideration the assumption made above and followed by[29 & 30], these equations can be written in Cartesian frame of reference, as follows.

$$\frac{\partial v^*}{\partial y^*} = 0 \tag{1}$$

$$\rho\left\{\left(1+\lambda_1^*\frac{\partial}{\partial t^*}\right)\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*}\right\} = -\left(1+\lambda_1^*\frac{\partial}{\partial t^*}\right)\frac{\partial p^*}{\partial x^*} + \mu\frac{\partial^2 u^*}{\partial y^{*2}} - \rho g$$

$$-\left(\sigma B_o^2 + \frac{\mu}{K^*}\right)\left(1+\lambda_1^*\frac{\partial}{\partial t^*}\right)u^* \tag{2}$$

$$\frac{\partial C^*}{\partial t^*} + v^*\frac{\partial C^*}{\partial y^*} = D_M\frac{\partial^2 C^*}{\partial y^{*2}} - R^*(C^* - C_\infty^*) \tag{3}$$

The boundary conditions at the wall and in the free stream are:

$$u^* = u_p^*,\ C^* = C_w^* + \varepsilon A_c(C_w^* - C_\infty^*)e^{n^*t^*}\ at\quad y^* = 0 \tag{4}$$

$$u^* \to U_\infty^* = U_0(1+\varepsilon e^{n^*t^*}),\ C^* \to C_\infty^* \text{ as } y^* \to \infty \tag{5}$$

Where A_C a constant is takes the values 0 or 1

If plate is with Constant mass transfer (CMT) then $A_C = 0$

If plate is with Variable mass transfer (VMT) then $A_C = 1$

Where u^*, v^* -velocity components in X,Y directions respectively, g-Gravitational acceleration, t^* -Time, υ-Kinematic coefficient of viscosity, σ -Electrical conductivity, μ-The viscosity, ρ-Density of the fluid, λ_1^* -the coefficient of Kuvshinski fluid, k^*-Permeability parameter of the porous medium, D$_M$ -the coefficient of chemical molecular diffusivity, C^*- The dimensional concentration, C_w^*-The concentration at the wall, C_∞^*-The concentration in free stream, R^*- the reaction rate constant, Q_0- Source / skin constant, U_0 and n^*- constants. The magnetic and viscous dissipations are neglected in the study. It is assumed that the porous plate moves with a constant velocity, u_p^* in the direction of fluid flow, and the free stream velocity U_∞^* follows the exponentially increasing small perturbation law. In addition, it is assumed that the concentration at the wall as well as the suction velocity is exponentially varying with time.

It is clear from equation (1) that the suction velocity at the plate surface is a function of time only. Assuming that it takes the following exponential form:

$$v^* = -V_0\left(1 + \varepsilon A e^{n^* t^*}\right) \tag{6}$$

Where A is a real positive constant, ε and εA are small less than unity, and V_0 is a scale of suction velocity which has non-zero positive constant

In the free steam, from equation (2) we get

$$\rho \frac{dU_\infty^*}{dt^*} = -\frac{\partial p^*}{\partial x^*} - \rho_\infty g - \sigma B_0^2 U_\infty^* - \frac{\mu}{K^*} U_\infty^* \tag{7}$$

Eliminating $\dfrac{\partial P^*}{\partial x^*}$ between equation (2) and equation (8), we obtain

$$\rho\left\{\left(1+\lambda_1^* \frac{\partial}{\partial t^*}\right)\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*}\right\} = \rho\left(1+\lambda_1^* \frac{\partial}{\partial t^*}\right)\frac{dU_\infty^*}{dt^*} + \mu \frac{\partial^2 u^*}{\partial y^{*2}} + (\rho_\infty - \rho) g$$
$$+\left(\sigma B_0^2 + \frac{\mu}{K^*}\right)\left(1+\lambda_1^* \frac{\partial}{\partial t^*}\right)(U_\infty^* - u^*) \tag{8}$$

By making use the equation of state

$$(\rho_\infty - \rho) = \rho \beta^* \,(C - C_\infty^*) \tag{9}$$

Where β is the volumetric coefficient of thermal expansion, β* is the volumetric coefficient of expansion with concentration and ρ_∞ is the density of the fluid far away the surface. Then substituting from equation (10) into equation (9) we obtain

$$\left(1+\lambda_1^*\frac{\partial}{\partial t^*}\right)\frac{\partial u^*}{\partial t^*}+v^*\frac{\partial u^*}{\partial y^*}=\left(1+\lambda_1^*\frac{\partial}{\partial t^*}\right)\frac{dU_\infty^*}{dt^*}+\upsilon\frac{\partial^2 u^*}{\partial y^{*2}}+g\beta^*(C^*-C_\infty^*)$$

$$+\left(\frac{\sigma B_0^2}{\rho}+\frac{v}{K^*}\right)\left(1+\lambda_1^*\frac{\partial}{\partial t^*}\right)(U_\infty^*-u^*) \tag{10}$$

We now introduce the dimension less variables, as follows:

$$\left.\begin{aligned}&u=\frac{u^*}{U_0},\ v=\frac{v^*}{V_0},\ y=\frac{y^*V_0}{v},\ U_\infty^*=U_\infty U_0,\ u_p^*=U_pU_0\\&t=\frac{t^*V_0^2}{v},\ n=\frac{n^*v}{V_0^2},\ \ \phi=\frac{C^{*}-C_\infty^*}{C_w^*-C_\infty^*}\end{aligned}\right\} \tag{11}$$

Then substituting from equation (15) into equations (11),(14) and (4) and taking into account equation (7), we obtain

$$\left(1+\lambda_1\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial u}{\partial y}=\left(1+\lambda_1\frac{\partial}{\partial t}\right)\frac{dU_\infty}{dt}+\frac{\partial^2 u}{\partial y^2}$$

$$+G_{rC}\phi+N\left(1+\lambda_1\frac{\partial}{\partial t}\right)(U_\infty-u) \tag{12}$$

$$\frac{\partial\phi}{\partial t}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}-\delta\phi \tag{13}$$

Where

$G_C=\dfrac{\upsilon g\beta^*(C_w^*-C_\infty^*)}{V_0^2U_0}$ (SolutalGrashofnumber)

$M=\dfrac{\sigma B_0^2\upsilon}{\rho V_0^2}$ (Magnetic field parameter)

$K=\dfrac{K^*V_0^2}{\upsilon^2}$ (Permeability parameter)

$\delta=\dfrac{R^*\upsilon}{V_*^2}$ (Chemical reaction parameter)

$Sc=\dfrac{\upsilon}{D_M}$ (Schmidt number)

$\lambda_1=\dfrac{\lambda_1^*V_0^2}{\upsilon}$ (Visco-elastic parameter)

$$N = \left[M + \frac{1}{K} \right]$$

The corresponding boundary conditions are

$$u = U_p,\ \phi = 1 + \varepsilon A_C e^{nt} \ at\ y = 0 \tag{14}$$

$$u \to U_\infty = 1 + \varepsilon e^{nt},\ \phi \to 0\ ,\ \ as\ y \to \infty \tag{15}$$

ANALYTICAL APPROXIMATE SOLUTION

In order to reduce the above system of partial differential equations to a system of ordinary equations in dimension less form, we may represent the velocity and concentration as

$$u = u_0(y) + \varepsilon e^{nt} u_1(y) + O(\varepsilon^2) \tag{16}$$

$$\phi = \phi_0(y) + \varepsilon e^{nt} \phi_1(y) + O(\varepsilon^2) \tag{17}$$

By substituting the above equations (20) and (21) into equations (15) to (16) equating the harmonic and non-harmonic term and neglecting the higher – order terms of O $((\varepsilon^2)$, we obtain the following pairs of equations for $((u_o, \phi_0)$ and (u_1, ϕ_1)

$$u_o'' + u_o' - N u_o = -N - G_C \phi_o \tag{18}$$

$$u_1'' + u_1' - (N + n)(1 + n\lambda_1) u_1 = -(1 + n\lambda_1)(N + n) - A u_o' - G_C \phi_1 \tag{19}$$

$$\phi_o'' + Sc\phi_o' - \delta Sc\phi_o = 0 \tag{20}$$

$$\phi_1'' + Sc\phi_1' - (n + \delta) Sc\phi_1 = -ASc\phi_o' \tag{21}$$

Where, the primes denote differentiation with respect to y.

The corresponding boundary conditions are

$$u_o = U_p,\ u_1 = 0,\ \phi_o = 1,\ \phi_1 = A_C \quad at \quad y = 0 \tag{22}$$

$$u_o = 1,\ u_1 = 1,\ \phi_o \to 0,\ \phi_1 \to 0 \ \ as\ y \to \infty \tag{23}$$

The analytical solutions of equations (18) to (21) with satisfying boundary conditions (22) and (23) are given by

$$u_o = (U_p + E - 1) e^{-L_0 y} + 1 - E e^{-l_0 y} \tag{24}$$

$$u_1 = (I_3 + I_2 - I_1 - 1) e^{-L_1 y} + 1 + I_1 e^{-L_0 y} - I_2 e^{-l_0 y} - I_3 e^{-l_1 y} \tag{25}$$

$$\phi_0 = e^{-l_0 y} \tag{26}$$

$$\phi_1 = (A_C - D_0) e^{-l_1 y} + D_0 e^{-l_0 y} \tag{27}$$

Appendix

$$L_0=\frac{1+\sqrt{1+4N}}{2} \qquad F=Up+E-1 \qquad l_0=\frac{Sc+\sqrt{Sc^2+4\delta Sc}}{2}$$

$$L_1=\frac{1+\sqrt{1+4A_1}}{2} \qquad I_2=\frac{AE+G_C D_0}{l_0^2-l_0-A_1} \qquad l_1=\frac{Sc+\sqrt{Sc^2+4Sc(n+\delta)}}{2}$$

$$E=\frac{G_C}{l_0^2-l_0-N} \qquad I_3=\frac{G_C\left(A_C-D_0\right)}{l_1^2-l_1-A_1} \qquad D_0=\frac{AScl_0}{l_0^2-Scl_0-Sc(n+\delta)}$$

$$A_1=\left(N+n\right)\left(1+n\lambda_1\right)$$

In view of the above solution, the velocity and concentration distribution in the boundary layer become

$$u(y,t)=(u_p+E-1)e^{-L_0 y}+1-Ee^{-l_0 y}+\varepsilon[(I_2+I_3-I_1-1)e^{-L_1 y}+1+I_1e^{-l_0 y}-I_3e^{l_1 y}]e^{nt} \qquad (28)$$

$$\phi(y,t)=e^{-l_0 y}+\varepsilon[(A_C-D_0)e^{-l_1 y}+D_0e^{-l_0 y}]e^{nt} \qquad (29)$$

It is now important to calculate the physical quantities of primary interest, which are the local wall shear stress, the local surface mass flux. Given the velocity field in the boundary layer, we can now calculate the local wall shear stress (i.e., skin-friction) is given by

$$\tau_w^*=\mu\left(\frac{\partial u^*}{\partial y^*}\right)_{y^*=0} \qquad (30)$$

And in dimensionless form, we obtain

$$C_f=\frac{\tau_w^*}{\rho U_o V_o}=-\left(\frac{\partial u^*}{\partial y^*}\right)_{y^*=0}=L_0F-l_0E+\varepsilon e^{nt}[L_1(I_2+I_3-I_1-1)+L_0I_1-l_0I_2-l_1I_3] \qquad (31)$$

Similarly the mass transfer coefficient in terms of Sherwood number, as follows

$$Sh=\frac{J_w x}{D^*(C_w^*-C_\infty^*)} \quad where \quad J_w=\left[-D\frac{\partial C^*}{\partial y^*}\right]_{y^*=0}$$

$$Sh\ \mathrm{Re}_x^{-1}=\left(\frac{\partial\phi}{\partial y^*}\right)_{y^*=0}$$

$$Sh=-l_0+\varepsilon e^{nt}[(-l_1(A_C-D_0)+l_0D_0] \qquad (32)$$

RESULTS AND DISCUSSION

For physical insight in to the flow problem considered hear in. The numeral computation of the distribution of velocity u and concentration C is carried out for different values of Schmidt number S_c, SolutalGrashof number G_C, Permeability parameter K, Magnetic field parameter M, Chemical reaction parameter δ, Visco elastic paramerer λ_1 and U_p in two cases.

Case i):- Plate is with Variable Mass Transfer (VMT),i.e $A_C = 1$

The influence of Sc on the velocity is investigated. It is shown in fig. 1 that the increase value of Sc leads to a decrease in the velocity. From fig. 2 it is observed that an increase in Gc leads to rise in the value of velocity of the fluid. The effect of K on velocity profiles in the boundary layer is depicted in fig 3. From this figure it is seen that the value of K increase the velocity also increases. From fig. 4 it is observed that velocity decreases rapidly near the wall of the porous plate as M increases.

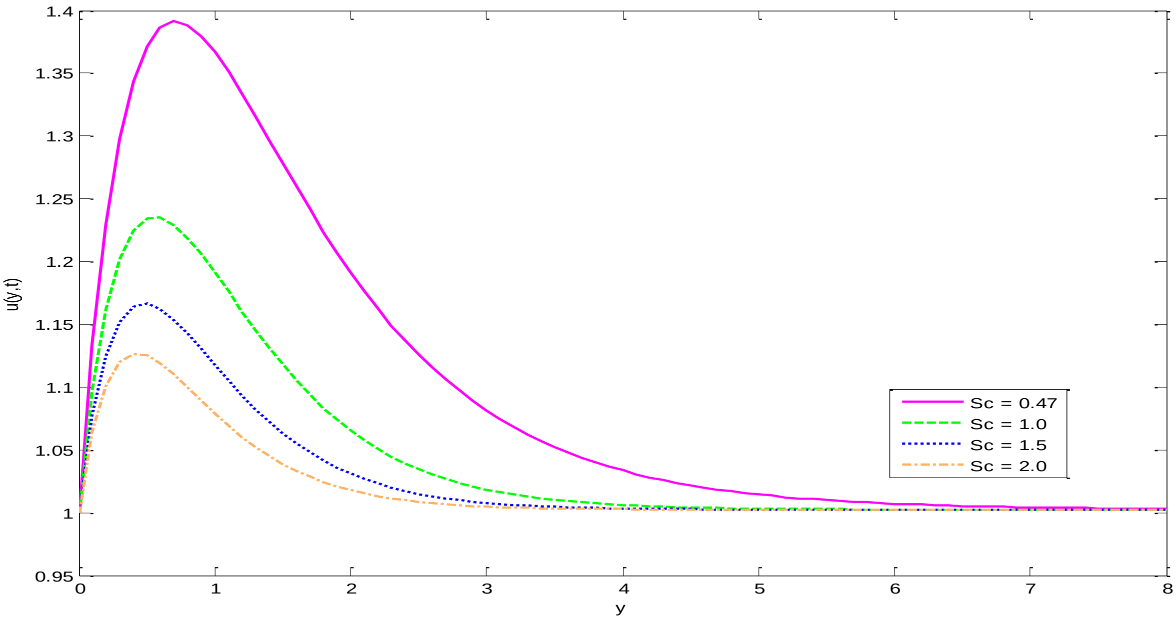

Fig 1: Velocity profile against y for different values of Sc at $A_C = 1$ $A = 1.0; Gc = 3.0; K = 1.0; M = 1.0; Up = 1.0; n = 0.2; \varepsilon = 0.002; \lambda_1 = 0.01; \delta = 1.0; t = 1.0$.

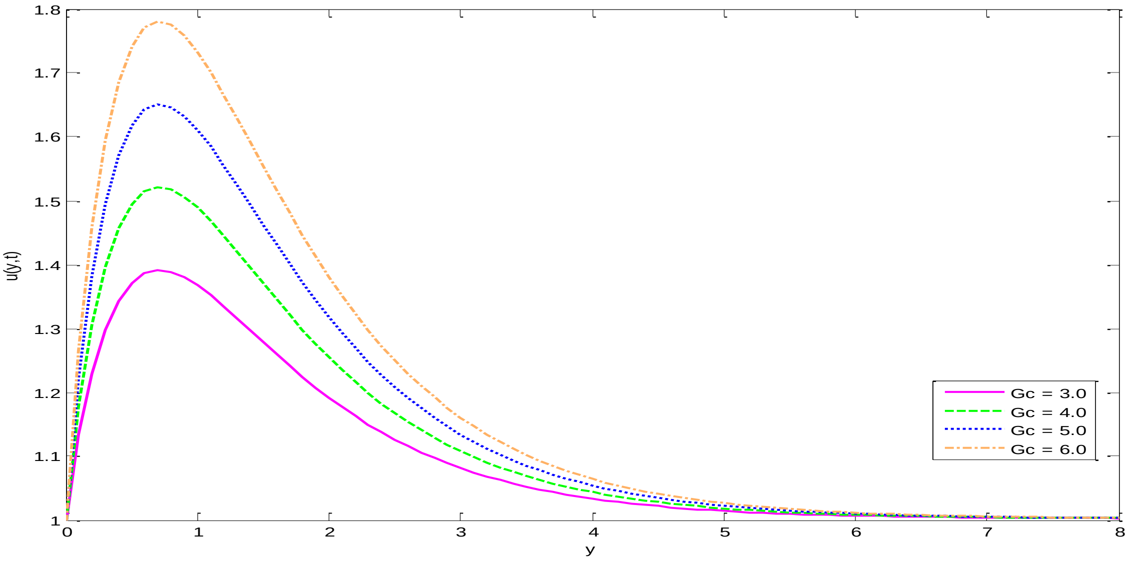

Fig 2: Velocity profile against y for different values of Gc at $A_C = 1$

$Sc = 0.47;\ A = 1.0;\ K = 1.0;\ M = 1.0;\ Up = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01;\ \delta = 1.0;\ t = 1.0$

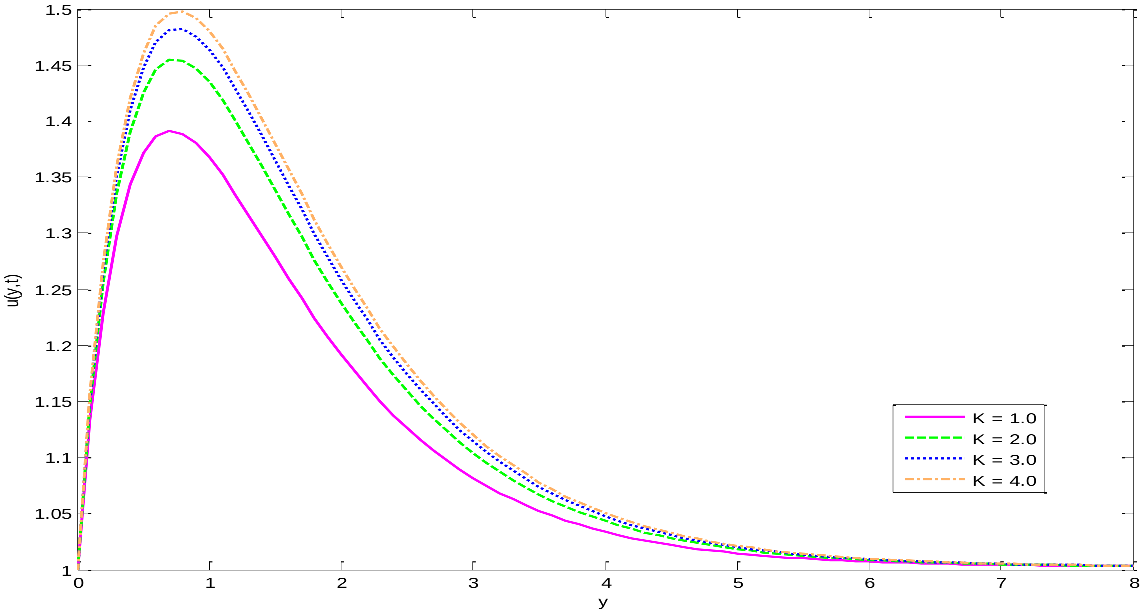

Fig 3: Velocity profile against y for different values of K at $A_C = 1$; $t = 1.0$

$Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ M = 1.0;\ Up = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01;\ \delta = 1.0;$

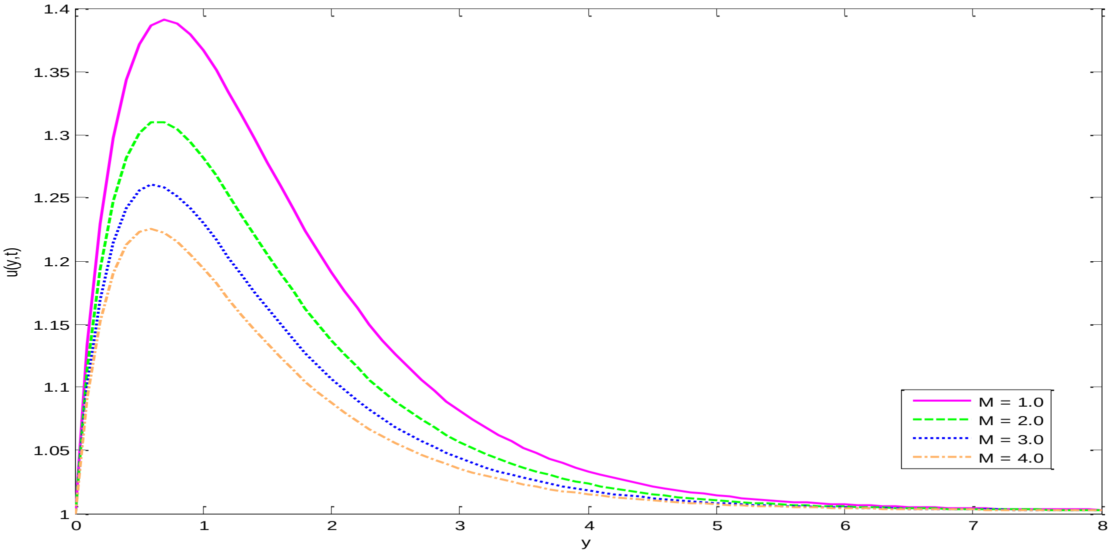

Fig 4: Velocity profile against y for different values of M at $A_C = 1$ $Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ K = 1.0;\ Up = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01;\ \delta = 1.0;\ t = 1.0$

Fig 5 illustrates the variation of velocity distribution across the boundary layer for several values of plate moving velocity in the direction of fluid flow. The velocity increases with the increase of U_p. Fig 6 illustrates the velocity profiles for different values of δ. Clearly as δ increases the peak values of the velocity decreases. From fig. 7 it is observed that the velocity slightly increases with increasing λ_1.

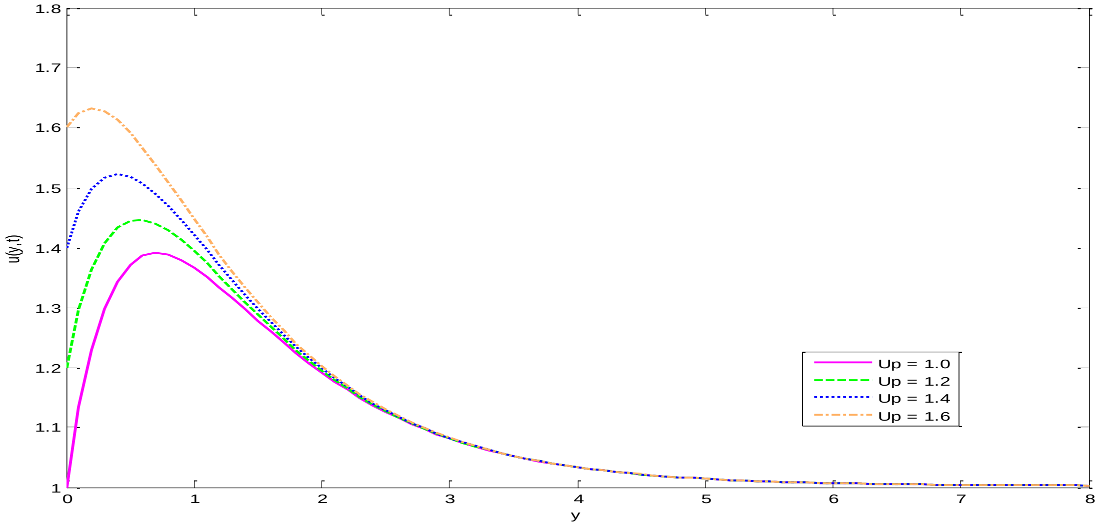

Fig 5: Velocity profile against y for different values of Up at $A_C = 1$ $Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ K = 1.0;\ M = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01;\ \delta = 1.0;\ t = 1.0$

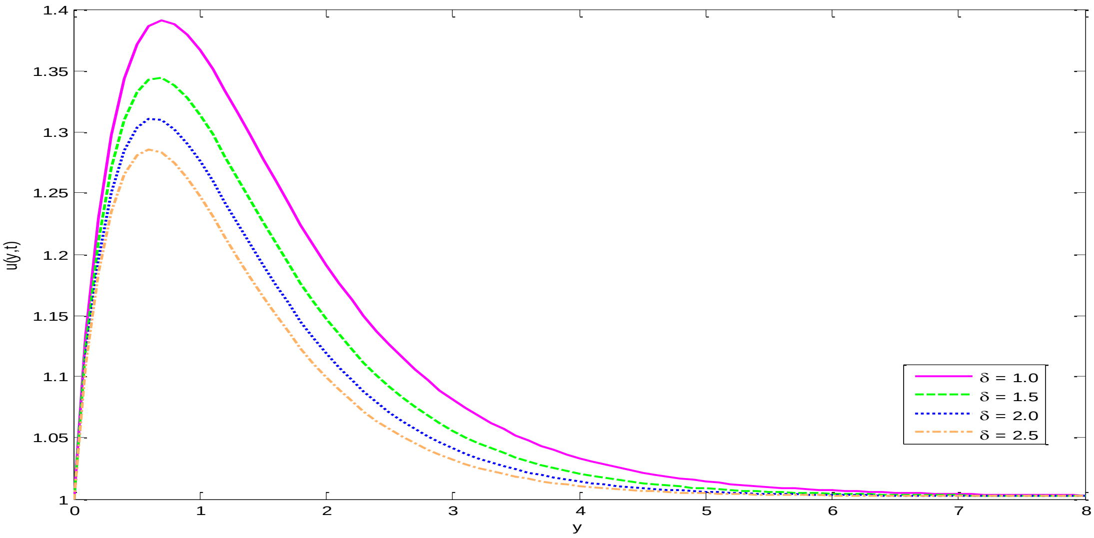

Fig 6: Velocity profile against y **for different values of** δ **at** $A_C = 1$ $Sc = 0.47;$ $A = 1.0;$ $Gc = 3.0;$ $K = 1.0;$ $M = 1.0;$ $Up = 1.0;$ $n = 0.2;$ $\varepsilon = 0.002;$ $\lambda_1 = 0.01$**;** $t = 1.0$

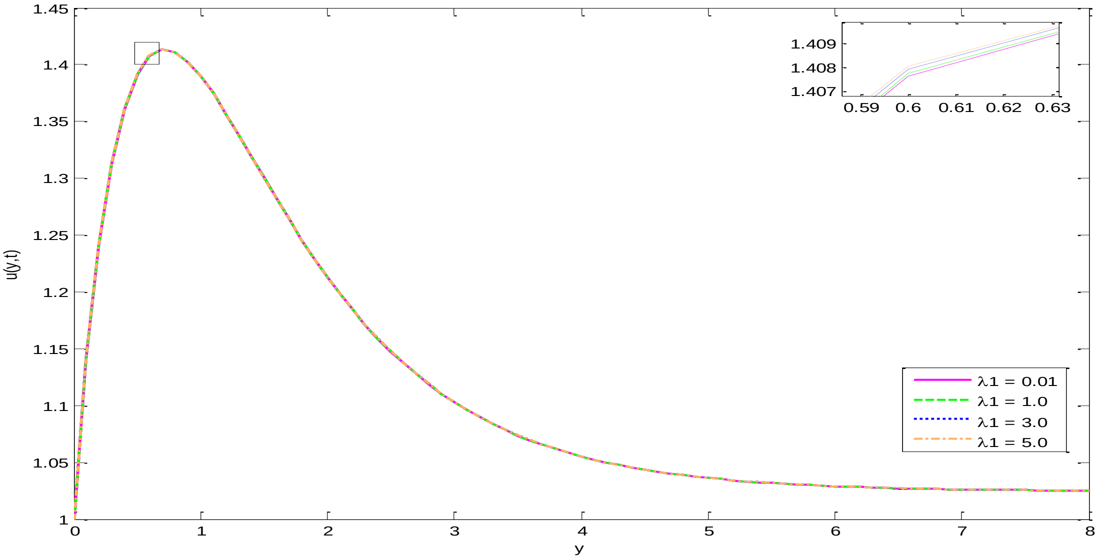

Fig 7: Velocity profile against y **for different values of** λ_1 **at** $A_C = 1$**;** $Sc = 0.47;$ $A = 1.0;$ $Gc = 3.0;$ $K = 1.0;$ $M = 1.0;$ $Up = 1.0;$ $n = 0.2;$ $\varepsilon = 0.002;$ $\delta = 1.0,$ **;** $t = 1.0$

The effect of Sc on concentration is shown in fig 8. It is clearly observed that the concentration decreases when Sc increases. The influence of δ on concentration is shown in fig 9. It is observed that the concentration profile decreases when δ increases.

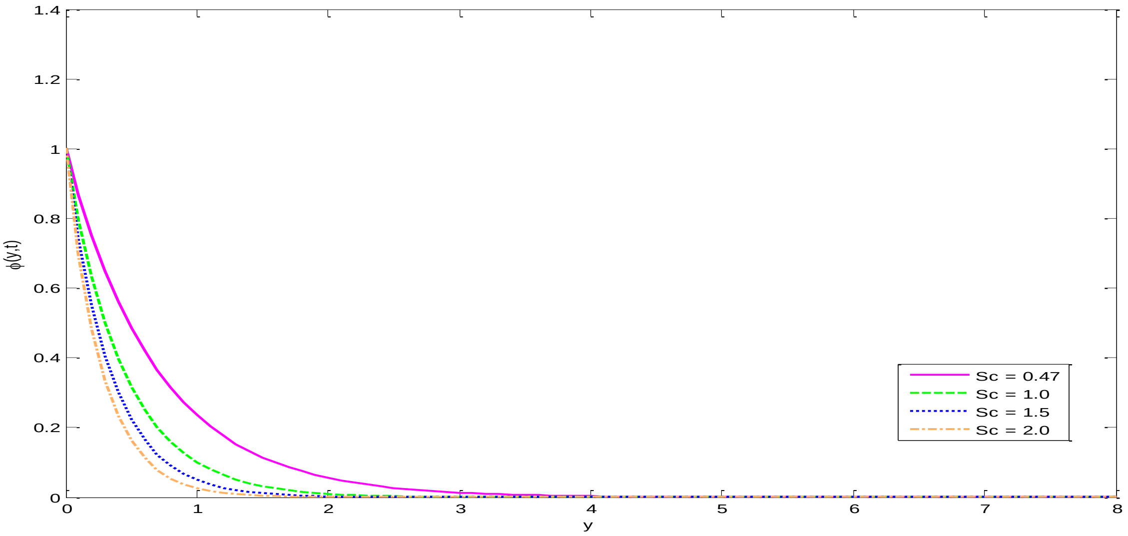

Fig 8: Concentration against y for different values of Sc at $Ac = 1.0$; $A = 1.0$; $Gc = 3.0$; $K = 1.0$; $M = 1.0$; $Up = 1.0$; $n = 0.2$; $\varepsilon = 0.002$; $\lambda_1 = 0.01$; $\delta = 3.0$; $t = 1.0$

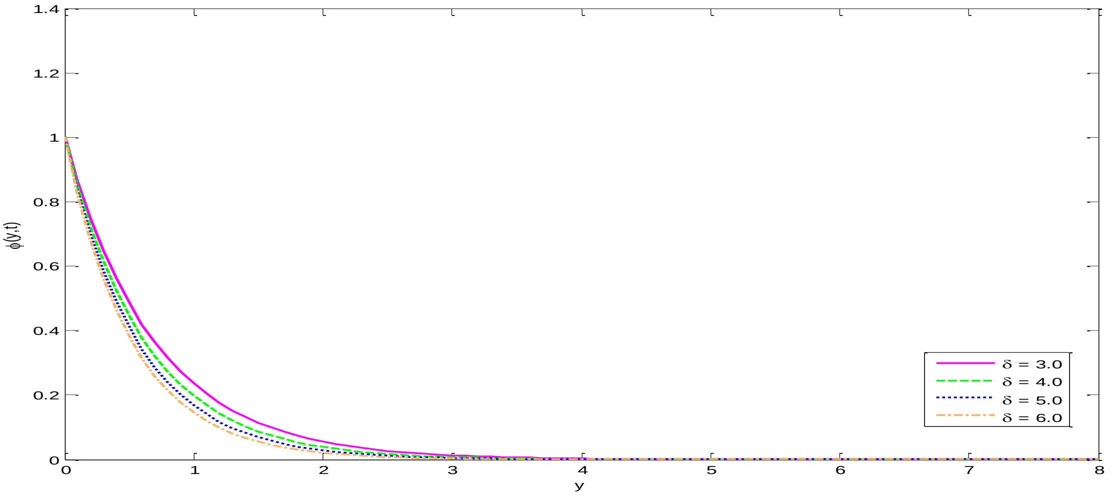

Fig 9: Concentration against y for different values of δ at $Ac = 1.0$; $A = 1.0$; $Gc = 3.0$; $K = 1.0$; $M = 1.0$; $Up = 1.0$; $n = 0.2$; $\varepsilon = 0.002$; $\lambda_1 = 0.01$; $t = 1.0$

Case ii):- Plate is with constant mass transfer (CMT),i.e $A_C = 0$

The effect of S_C on the velocity presented in fig 10. It is noticed that velocity decreases as S_C increases. Fig 11 shows the effect of G_C on velocity. As expected the numerical results shown that an increase in G_C results in an increase of velocity. From fig .12it is observedthat the velocity increases as K increases. For various value of M the velocity profiles are plotted in fig13.

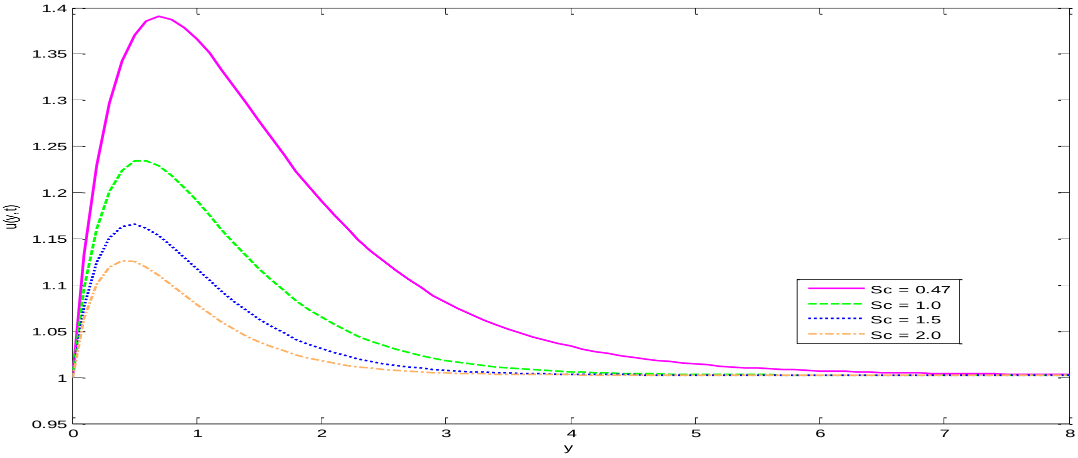

Fig 10: velocity profile against y **for different values of** Sc **at** $A_C = 0$**;** $Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ K = 1.0;\ M = 1.0;\ Up = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01;\ \delta = 1.0;\ t = 1.0$

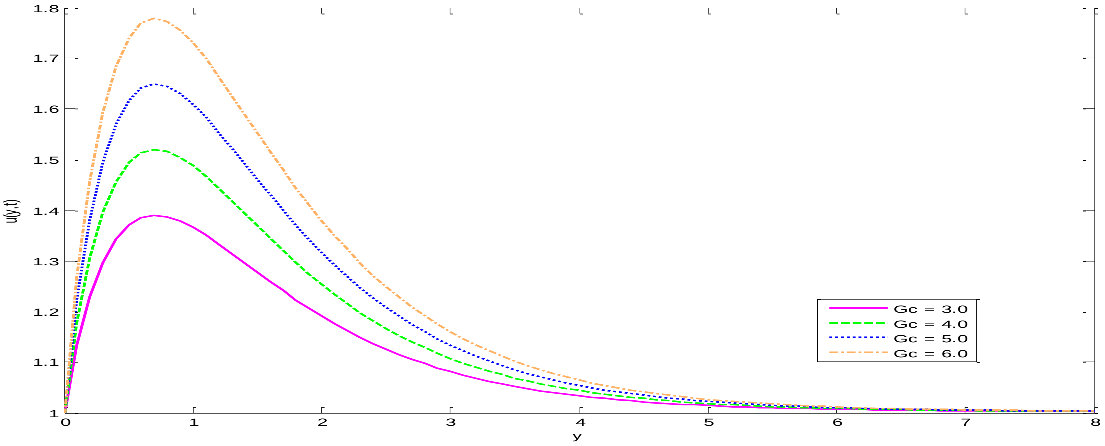

Fig 11: velocity profile against y **for different values of** Gc **at** $A_C = 0$**;** $Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ K = 1.0;\ M = 1.0;\ Up = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01;\ \delta = 1.0;\ t = 1.0$

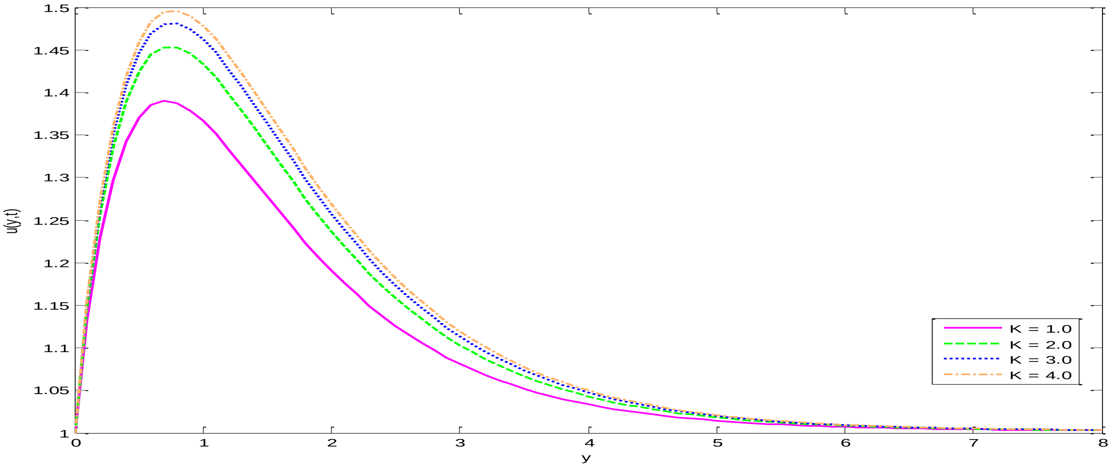

Fig 12: velocity profile against y **for different values of** K **at** $A_C = 0$**;** $Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ M = 1.0;\ Up = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01;\ \delta = 1.0;\ t = 1.0$

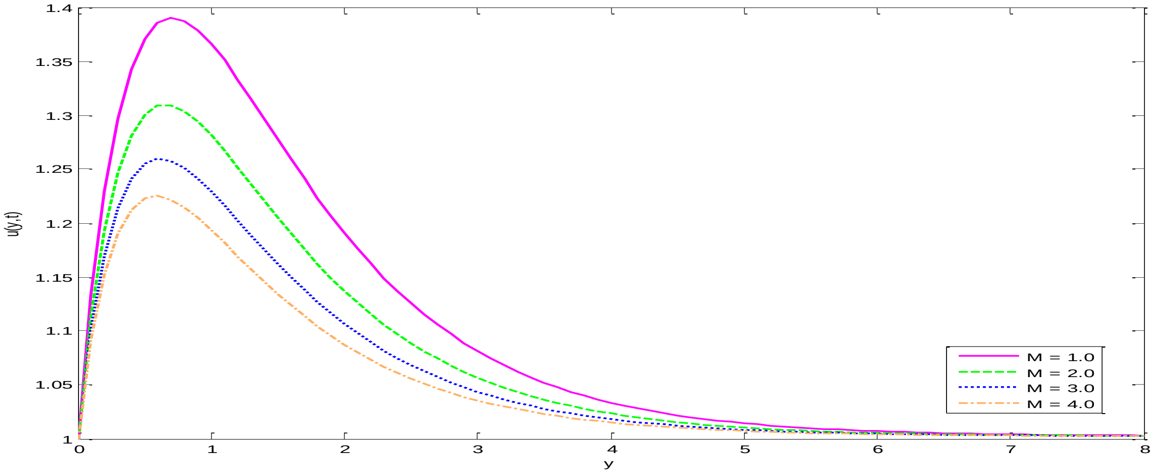

Fig 13: velocity profile against y **for different values of** M **at** $A_C = 0$**;** $Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ K = 1.0;\ Up = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01$**;** $\delta = 1.0;\ t = 1.0$

It is clear that M increases the velocity decreases. It is observed in fig .14 as expected that an increases in Up results in an increase of velocity with in the boundary layer. From fig 15 it is noticed that δ increases as velocity decreases. From fig.16 it is observed that the velocity slightly increases with increasing λ_1.

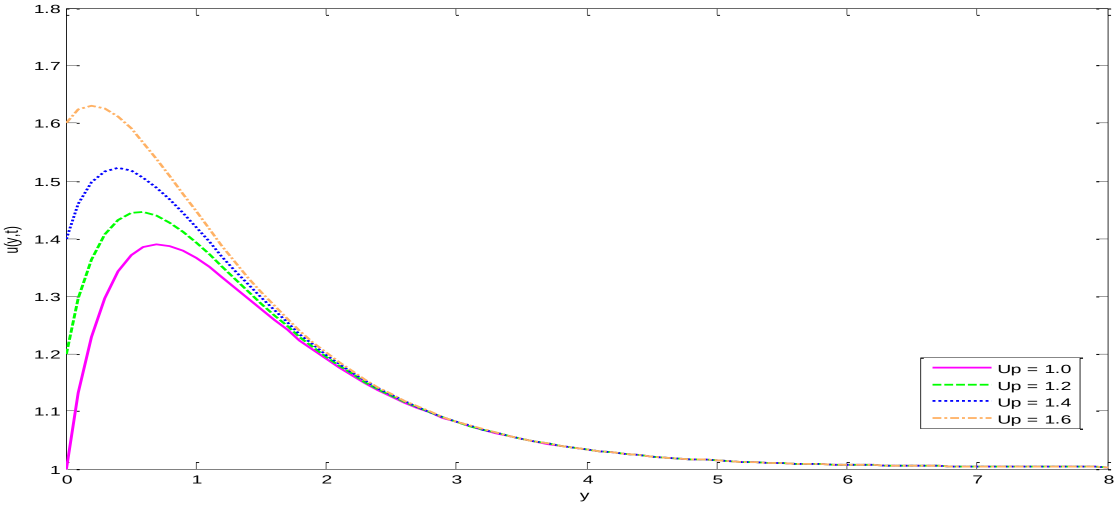

Fig 14: velocity profile against y **for different values of** Up **at** $A_C = 0$**;** $Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ K = 1.0;\ M = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01$**;** $\delta = 1.0;\ t = 1.0$

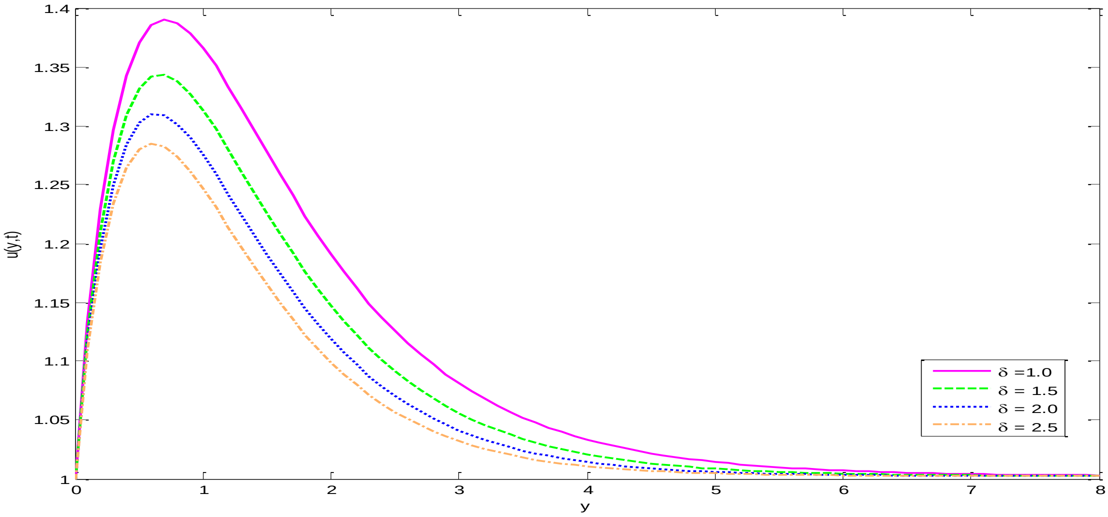

Fig 15: velocity profile against y for different values of δ at $A_C = 0$; $Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ K = 1.0;\ M = 1.0;\ Up = 1.0;\ n = 0.2;\ \varepsilon = 0.002;\ \lambda_1 = 0.01$; $t = 1.0$

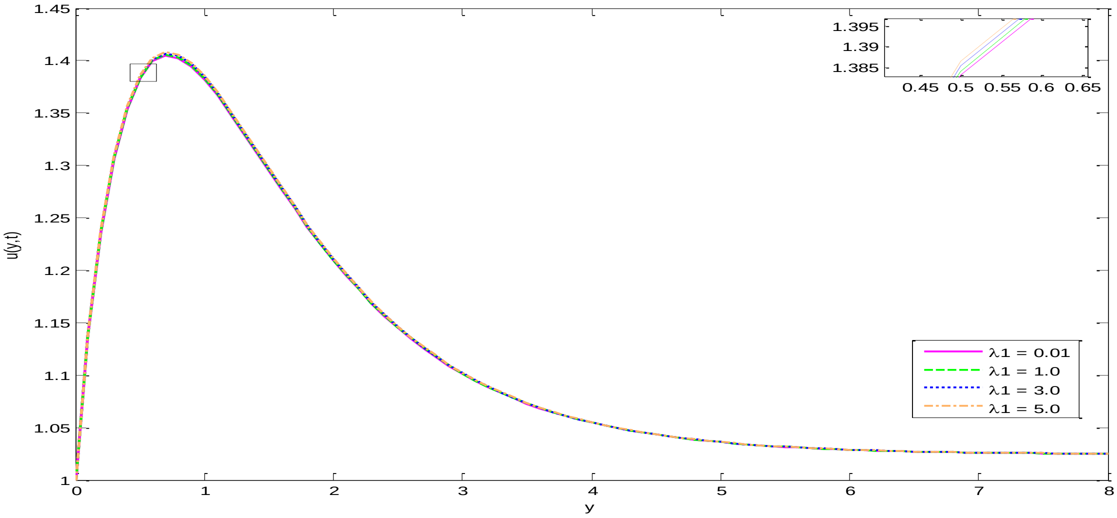

Fig 16: velocity profile against y for different values of λ_1 at $A_C = 0$; $Sc = 0.47;\ A = 1.0;\ Gc = 3.0;\ K = 1.0;\ M = 1.0;\ Up = 1.0;\ n = 0.2;\ \varepsilon = 0.002;$ $\delta = 1.0;$**;** $t = 1.0$

The concentration profiles for various values of S_C are shown in fig 17. Which shows that if S_C decreases then concentration decreases. The effect of δ on concentration field is shown in fig 18. It is noticed that concentration decrease with an increase of δ .

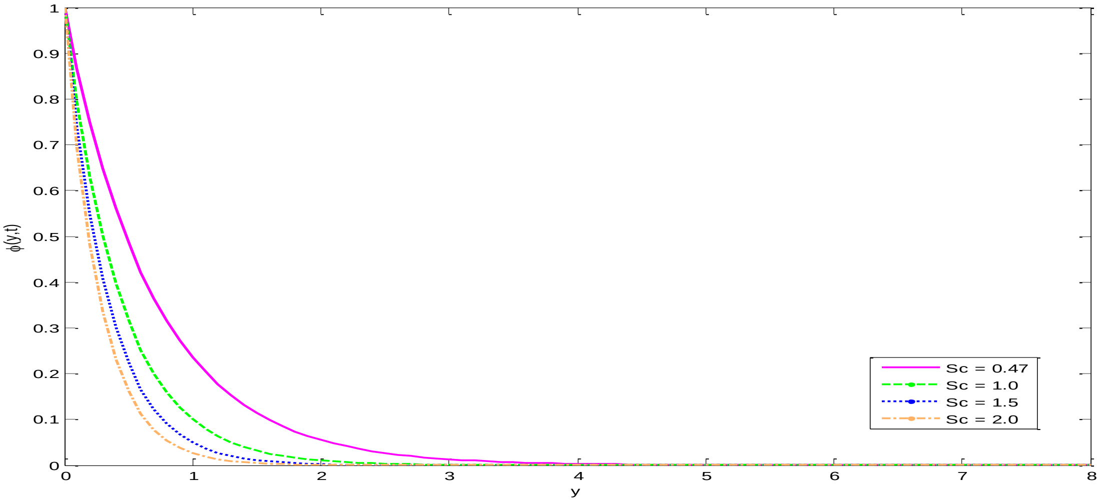

Fig 17: Concentration against y for different values of Sc *at* $A_C = 0$; $A = 1.0$; $n = 0.2$; $\varepsilon = 0.002$; $\lambda_1 = 0.01$; $\delta = 3.0$; $t = 1.0$

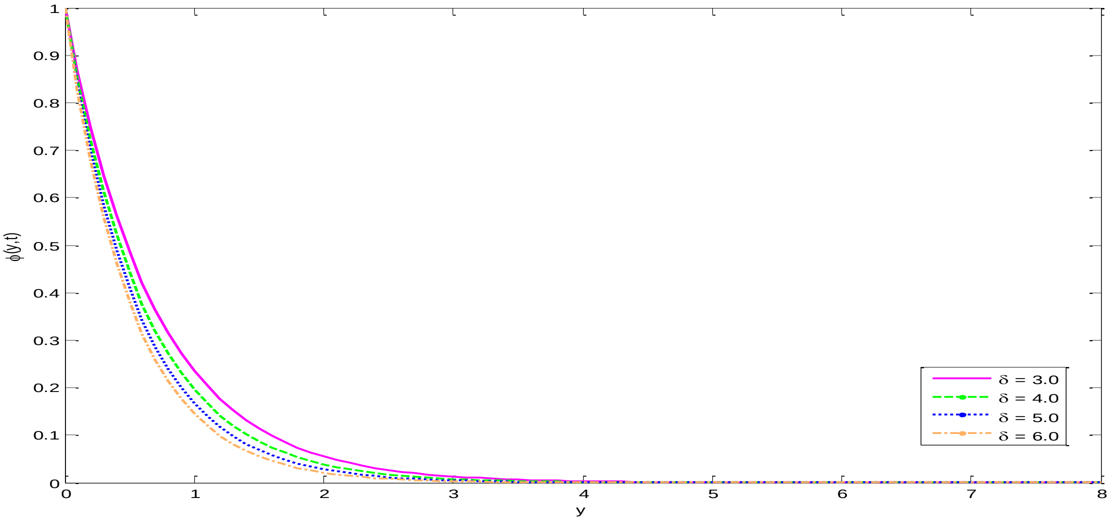

Fig 18: Concentration against y for different values of δ *at* $A_C = 0$ $S = 0.47$; $A = 1.0$; $n = 0.2$; $\varepsilon = 0.002$; $\lambda_1 = 0.01$; $t = 1.0$

We have also shown some tables of the skin-friction coefficient C_f and rate of mass transfer (Sherwood number) Sh by effect of $Sc, Gc, K, M, \lambda_1, \delta, \varepsilon, n$ and t. From the table the coefficient of Skin friction increases when $Sc / M / Up / \delta$ increases and the coefficient of Skin friction decreases when $Gc / K / \lambda_1$ increases in both cases variable mass transfer (VMT) and constant mass transfer (CMT). Also we observe that the rate of mass transfer (Sherwood number) Sh decreases as $Sc / n / t / \varepsilon / \delta$ increases in both cases at variable mass transfer(VMT) and constant mass transfer (CMT).

Table 1: Co-efficient of Skin friction at $A_C = 1$

Sc	G_C	K	M	Up	λ_1	δ	C_f
0.47	3.0	1.0	1.0	1.0	0.01	1.0	**-1.6169**
1.0	3.0	1.0	1.0	1.0	0.01	1.0	**-1.2365**
1.5	3.0	1.0	1.0	1.0	0.01	1.0	**-0.9639**
2.0	3.0	1.0	1.0	1.0	0.01	1.0	**-0.8551**
0.47	**4.0**	1.0	1.0	1.0	0.01	1.0	**-2.1391**
0.47	**5.0**	1.0	1.0	1.0	0.01	1.0	**-2.6612**
0.47	**6.0**	1.0	1.0	1.0	0.01	1.0	**-3.1834**
0.47	3.0	**2.0**	1.0	1.0	0.01	1.0	**-1.7676**
0.47	3.0	**3.0**	1.0	1.0	0.01	1.0	**-1.8304**
0.47	3.0	**4.0**	1.0	1.0	0.01	1.0	**-1.1864**
0.47	3.0	1.0	**2.0**	1.0	0.01	1.0	**-1.4152**
0.47	3.0	10	**3.0**	1.0	0.01	1.0	**-1.2823**
0.47	3.0	1.0	**4.0**	1.0	0.01	1.0	**-1.1863**
0.47	3.0	1.0	1.0	**1.2**	0.01	1.0	**-1.2138**
0.47	3.0	1.0	1.0	**1.4**	0.01	1.0	**-0.8106**
0.47	3.0	1.0	1.0	**1.6**	0.01	1.0	**-0.4074**
0.47	3.0	1.0	1.0	1.0	**1.0**	1.0	**-1.6188**
0.47	3.0	1.0	1.0	1.0	**3.0**	1.0	**-1.6224**
0.47	3.0	1.0	1.0	1.0	**5.0**	1.0	**-1.6259**
0.47	3.0	1.0	1.0	1.0	0.01	**2.0**	**-1.4309**
0.47	3.0	1.0	1.0	1.0	0.01	**3.0**	**-1.3166**
0.47	3.0	1.0	1.0	1.0	0.01	**4.0**	**-1.2380**

Table 2: Co-efficient of Skin friction at $A_C = 0$

Sc	G_C	K	M	Up	λ_1	δ	C_f
0.47	3.0	1.0	1.0	1.0	0.01	1.0	**-1.5359**
1.0	3.0	1.0	1.0	1.0	0.01	1.0	**-1.1523**
1.5	3.0	1.0	1.0	1.0	0.01	1.0	**-0.9416**
2.0	3.0	1.0	1.0	1.0	0.01	1.0	**-0.8071**
0.47	**4.0**	1.0	1.0	1.0	0.01	1.0	**-2.0462**
0.47	**5.0**	1.0	1.0	1.0	0.01	1.0	**-2.5565**
0.47	**6.0**	1.0	1.0	1.0	0.01	1.0	**-3.0668**
0.47	3.0	**2.0**	1.0	1.0	0.01	1.0	**-1.6876**
0.47	3.0	**3.0**	1.0	1.0	0.01	1.0	**-1.7507**
0.47	3.0	**4.0**	1.0	1.0	0.01	1.0	**-1.7854**
0.47	3.0	1.0	**2.0**	1.0	0.01	1.0	**-1.3318**
0.47	3.0	1.0	**3.0**	1.0	0.01	1.0	**-1.1963**
0.47	3.0	1.0	**4.0**	1.0	0.01	1.0	**-1.0975**
0.47	3.0	1.0	1.0	**1.2**	0.01	1.0	**-1.1356**
0.47	3.0	1.0	1.0	**1.4**	0.01	1.0	**-0.7353**
0.47	3.0	1.0	1.0	**1.6**	0.01	1.0	**-0.3350**
0.47	3.0	1.0	1.0	1.0	**1.0**	1.0	**-1.5858**
0.47	3.0	1.0	1.0	1.0	**3.0**	1.0	**-1.5927**
0.47	3.0	1.0	1.0	1.0	**5.0**	1.0	**-1.5985**

0.47	3.0	1.0	1.0	1.0	0.01	**2.0**	**-1.3996**
0.47	3.0	1.0	1.0	1.0	0.01	**3.0**	**-1.2878**
0.47	3.0	1.0	1.0	1.0	0.01	**4.0**	**-1.2111**

Table 3: Sherwood Number at $A_C = 1$

Sc	n	δ	t	ε	Sh
0.47	0.2	3.0	1.0	0.02	**-1.4885**
1.0	0.2	3.0	1.0	0.02	**-2.3752**
1.5	0.2	3.0	1.0	0.02	**-3.0990**
2.0	0.2	3.0	1.0	0.02	**-3.7698**
0.47	**1.0**	3.0	1.0	0.02	**-1.5481**
0.47	**2.0**	3.0	1.0	0.02	**-1.7457**
0.47	**3.0**	3.0	1.0	0.02	**-2.3149**
0.47	0.2	**4.0**	1.0	0.02	**-1.6733**
0.47	0.2	**5.0**	1.0	0.02	**-1.8368**
0.47	0.2	**6.0**	1.0	0.02	**-1.9850**
0.47	0.2	3.0	**10.0**	0.02	**-1.7056**
0.47	0.2	3.0	**15.0**	0.02	**-2.1525**
0.47	0.2	3.0	**20.0**	0.02	**-3.3673**
0.47	0.2	3.0	1.0	**0.04**	**-1.4590**
0.47	0.2	3.0	1.0	**0.06**	**-1.4657**
0.47	0.2	3.0	1.0	**0.08**	**-1.4725**

Table 4: Sherwood number at $A_C = 0$

Sc	n	δ	t	ε	Sh
0.47	0.2	3.0	1.0	0.02	**-1.4522**
1.0	0.2	3.0	1.0	0.02	**-2.3181**
1.5	0.2	3.0	1.0	0.02	**-3.0241**
2.0	0.2	3.0	1.0	0.02	**-3.6789**
0.47	**1.0**	3.0	1.0	0.02	**-1.4597**
0.47	**2.0**	3.0	1.0	0.02	**-1.4818**
0.47	**3.0**	3.0	1.0	0.02	**-1.5294**
0.47	0.2	**4.0**	1.0	0.02	**-1.6328**
0.47	0.2	**5.0**	1.0	0.02	**-1.7924**
0.47	0.2	**6.0**	1.0	0.02	**-1.9371**
0.47	0.2	3.0	**10.0**	0.02	**-1.4863**
0.47	0.2	3.0	**15.0**	0.02	**-1.5564**
0.47	0.2	3.0	**20.0**	0.02	**-1.7471**
0.47	0.2	3.0	1.0	**0.04**	**-1.4590**
0.47	0.2	3.0	1.0	**0.06**	**-1.4657**
0.47	0.2	3.0	1.0	**0.08**	**-1.4725**

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