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# Chemically Reactive Boundary Layer Flow Past an Accelerated Plate with Radiation and Newtonian heating

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**ABSTRACT.** An analysis is performed to study the effect of heat and mass transfer chemically reactive flow past an accelerated vertical plate with Newtonian heating in the presence of radiation. Closed form analytic solutions are obtained for temperature, concentration, velocity by Laplace Transform technique and presented graphically for different values of physical parameters. Expressions of skin friction, Nusselt number, and Sherwood number are obtained and presented in graphical forms. The effects of various parameters on flow variables are illustrated graphically and the physical aspects of the problem are discussed.

**KEY WORDS**: Free convection, mass transfer, chemical reaction, Newtonian heating, radiation, accelerated plate.

## INTRODUCTION:

Free convection flow over a vertical surface are very much interested to study due to their potential applications in soil physics, geo–hydrology, biological system etc. The unsteady flow has its importance in space science technology and in aerodynamics. In nature many transport processes exist in which the simultaneous heat and mass transfer occur as a result of combined buoyancy effects of thermal diffusion and diffusion of chemical species. The phenomenon of combined heat and mass transfer frequently occurs in chemically processed industries, distribution of temperature and moisture over agricultural fields, dispersion of fog and environmental pollution and polymer production. A number of investigations have already been carried out with combined heat and mass transfer under the assumption of different physical situations. The illustrative examples of mass transfer can be found in the book of Cussler [1].Combined heat and mass transfer flow past a surface is analyzed by Chaudhary et. al. [2] , Muthucumaraswamy et. al. [3] and Rajput et. al. [4] under different physical conditions. Chaudhary et. al. [5] pioneered unsteady heat and mass transfer flow past a surface by Laplace Transform method. An unsteady flow past an exponentially accelerated plate with variable mass transfer is analyzed by Asogwa et. al.[6].

Mass transfer with chemical reaction is one of the most commonly encountered circumstances in chemical industry as well as in physical and biological sciences. It is found that in many chemical engineering processes, chemical reaction takes place between foreign masses (present in the form of ingredients) and the fluid. This type of chemical reaction may change the temperature and the heat content of the fluid and may affect the free convection process. However, if the presence of such foreign mass is very low then we can assume the first order chemical reaction so that heat generation due to chemical reaction can be considered to be very negligible. Here only first order chemical reaction is considered. A reaction is said to be of the first order if the rate of reaction is directly proportional to the concentration. Flow past a vertical plate with chemical reaction is analyzed by Fayez[7] and Sarada et. al. [8] under different physical situations. Bhaben et. al. [9] analyzed chemical reaction effects on flow past a vertical plate with variable temperature.

Generally, the problems of free convection flows are usually modeled under the assumption of constant surface temperature, ramped wall temperature, or constant surface heat flux. However, in many practical situations where the heat transfer from the surface is taken to be proportional to the local surface temperature, the above assumptions fail to work. Such types of flows are termed as conjugate convective flows, and the proportionally condition of the heat transfer to the local surface temperature is termed as Newtonian heating. Recently, Newtonian heating conditions have been used by researchers in view of their practical applications in several engineering devices, for instance in a heat exchanger where the conduction in solid tube wall is greatly influenced by convection in the fluid flowing over it. Unsteady boundary layer flow past a vertical plate with Newtonian heating is elucidated by Chaudhary et.al.[10]. Chemical reaction and mass transfer effects on flow past a surface with Newtonian heating is analyzed by Rajesh [11]. Combined buoyancy effect on unsteady flow past an impulsively started plate with Newtonian heating is analyzed by Raju [12 ].

In the above mentioned studies, the effects of radiation on flow has not been considered. The radiation effect on convective flow and heat transfer flow has become more important industrially. In the context of space technology and the process involving high temperatures the effects of radiation are of vital importance.Recent development in hypersonic flight, missile reentry, rocket combustion chambers, power plants for interplanetary flights have focused attention on thermal radiation and emphasize the need for improved understanding of radiation heat transfer in these processes. Natural convective flow past a plate in the presence of radiation is studied by Chaudhary et. al. [13]. Thermal radiation effect on an impulsively started vertical plate with mass transfer using finite difference scheme is elucidated by Prasad et.al. [14].Rajput et. al. [15] analyzed the radiation effect on an impulsively started infinite vertical plate with variable mass transfer by Laplace transform technique. Radiation and Newtonian heating effects on flow past an impulsively started vertical plate under different physical conditions are analyzed by Narahari et. al. [16] and Das et. al. [17]. Recently, Jain [18, 19] pioneered effects of radiation and chemical reaction on flow past a vertical surface using Laplace Transform technique. Very recently chemically reactive double diffusive convective flow is analyzed by Jain [20]

The aim of the present work is to provide an exact solution for the problem of chemically reactive fluid flow over a moving vertical plate in presence of radiation with Newtonian heating. The solutions are obtained numerically for various parameters entering into the problem and discussed them from the physical point of view.

**MATHEMATICAL ANALYSIS:** Consider unsteady two-dimensional flow of an incompressible and electrically conducting viscous fluid along an infinite vertical plate. The x'-axis is taken on the infinite plate and parallel to the free stream velocity and y'-axis normal to it. Initially, the plate and the fluid are at same temperature $T'_\infty$ with concentration level $C'_\infty$ at all points. At time t' > 0, It accelerates with a velocity $U_R$ in its own plane. At the same time, the heat transfer from plate to the fluid is directly proportional to the local surface temperature $T'$ and the plate concentration is raised linearly with respect to time. It is assumed that there exist a homogeneous chemical reaction of first order with constant rate $K_l$ between the diffusing species and the fluid. Since the plate is infinite in extent therefore the flow variables are the functions of y' and t' only. The fluid is considered to be gray absorbing-emitting radiation but non scattering medium . The radiative heat flux in the x'-direction is considered negligible in comparison that of y'-direction. Then neglecting viscous dissipation and assuming variation of density in the body force term (Boussinesq's approximation), the problem can be governed by the following set of equations:

$$\frac{\partial T'}{\partial t'} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y'} \qquad \ldots(1)$$

$$\frac{\partial C'}{\partial t'} = D\,\frac{\partial^2 C'}{\partial y'^2} - k_1 C' \qquad \ldots(2)$$

$$\frac{\partial u'}{\partial t'} = \nu\frac{\partial^2 u'}{\partial y'^2} + g\,\beta\,(T' - T'_\infty) + g\,\beta_c\,(C' - C'_\infty{}') \qquad \ldots(3)$$

with following initial and boundary conditions

$$u' = 0,\ T' = T'_\infty,\ C' = C'_\infty \text{ for all } y', t' \leq 0 \qquad \ldots(4)$$

$$u' = U_R,\ \frac{\partial T'}{\partial y'} = -h_s T',\ C' = C'_\infty + \left(C'_w - C'_\infty\right)\frac{u_R^2 t'}{\nu} \qquad \text{at } y' = 0,\ t' > 0$$

$$u' \to 0,\ T' \to T'_\infty,\ C' \to C'_\infty \qquad \text{as } y' \to \infty, t' > 0$$

The radiation heat flux term, by using the Rosseland's approximation is given by

$$q_r = -\frac{4\sigma'}{3\kappa^*}\frac{\partial T'^4}{\partial y'} \qquad \ldots(5)$$

where $U_R$ is reference velocity, g is gravitational acceleration, $C_p$ is specific heat at constant pressure, D is mass diffusivity, $\beta$ is thermal expansion coefficient, $\beta_C$ is concentration expansion coefficient, $\rho$ is density, $\kappa$ is thermal conductivity of fluid, $\kappa^*$ is mean absorption coefficient, $\nu$ is kinematic viscosity and , $q_r$ is radiative heat flux, $\sigma'$ is Stefan-Boltzmann Constant.

We assume that the temperature differences within the flow are such that $T'^4$ may be expressed as a linear function of the temperature T'. This is accomplished by expanding $T'^4$ in a Taylor series about $T'_\infty$ and neglecting higher-order terms

$$T'^4 \simeq 4T'^3_\infty T' - 3T'^4_\infty \qquad \ldots(6)$$

By using equations (5) and (6), equation (1) gives

$$\rho C_p \frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial y'^2} + \frac{16\sigma' T'^3_\infty}{3\kappa^*} \frac{\partial^2 T'}{\partial y'^2} \quad \ldots(7)$$

Introducing the following dimensionless quantities

$$t = \frac{t'}{t_R},\ y = \frac{y'}{L_R},\ u = \frac{u'}{U_R},\ k = \frac{U_R^2 k_l}{\nu^2},$$

$$Pr = \frac{\mu C_p}{\kappa},\ Sc = \frac{\nu}{D},\ \theta = \frac{T' - T'_\infty}{T'_\infty}, G = \frac{g\beta_T T'_\infty \nu}{U_R{}^3}$$

$$C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\ Gm = \frac{\nu g\,\beta_C (C'_w - C'_\infty)}{U_R^3}, k = \frac{\nu k_l}{U_R^2},\ R = \frac{\kappa^* \kappa}{4\sigma' T'^3_\infty}$$

$$\Delta T = T'_w - T'_\infty, U_R = (\nu g\beta\Delta t)^{1/3},$$

$$L_R = \left(\frac{g\beta\Delta T}{\nu^2}\right)^{-1/3}, t_R = (g\beta\Delta T)^{-2/3}\nu^{1/3} \quad \ldots(8)$$

where $L_R$ is reference length, $t_R$ is reference time, Gm is modified Grashof number, Pr is Prandtl number, Sc is Schmidt number and u is dimensionless velocity component, $\theta$ is dimensionless temperature, C is dimensionless concentration, $\mu$ is viscosity of fluid, t is time in dimensionless coordinate, R is radiation parameter and k is chemical reaction parameter.

The governing equations (1) to (3) reduce to the following non-dimensional form

$$Pr \frac{\partial \theta}{\partial t} = (1 + \frac{4}{3R})\frac{\partial^2 \theta}{\partial y^2} \quad \ldots(9)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - kC \quad \ldots(10)$$

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + G\theta + Gm\,C \quad \ldots(11)$$

with the following initial and boundary conditions

$$u = 0,\ \theta = 0,\ C = 0 \qquad \text{for all } y, t \le 0 \quad \ldots(12)$$

$$u=1,\ \frac{\partial\theta}{\partial y}=-\gamma(1+\theta),\ C=t \qquad \text{at } y=0, t>0 \qquad \ldots(13)$$
$$u\to 0, \theta\to 0, C\to 0 \qquad \text{as } y\to\infty,\ t>0$$

On taking Laplace-transform of equations (9) to (11) and boundary conditions

(12, 13), we get

$$\left(\mathbf{1}+\frac{\mathbf{4}}{\mathbf{3R}}\right)\frac{d^2\bar{\theta}}{dy^2}-p\Pr\bar{\theta}=0 \qquad \ldots(14)$$

$$\frac{d^2\bar{C}}{dy^2}-(k+pSc)\bar{C}=0 \qquad \ldots(15)$$

$$\frac{d^2\bar{u}}{dy^2}-p\,\bar{u}=-G\bar{\theta}\,(y,p)\ \text{-}Gm\bar{C} \qquad \ldots(16)$$

$$\bar{u}=\frac{1}{p},\ \frac{d\bar{\theta}}{dy}=-\gamma\left(\frac{1}{p}+\bar{\theta}\right),\ \bar{C}=\frac{1}{p^2} \quad \text{at } y=0, t>0 \qquad \ldots(17)$$
$$\bar{u}\to 0,\ \bar{\theta}\to 0,\ \bar{C}\to 0 \qquad \text{as } y\to\infty,\ t>0$$

Where p is the Laplace -transform parameter and $\gamma=\frac{h_s\nu}{U_R}$ is Newtonian heating Parameter. Equation (13) gives θ=0 when ϒ=0 which physically means that no heating from the plate exists.

Solving equations (14) to (16) with the help of boundary condition (17), we get

$$\bar{\theta}\,(y,p) = \frac{b\exp(-y\sqrt{pa})}{p(\sqrt{p}-b)} \qquad \ldots(18)$$

$$\bar{C}(y,p) = \frac{\exp(-y\sqrt{(kSc+p\,Sc)})}{p^2} \qquad \ldots(19)$$

$$\bar{u}(y,p)=\frac{\exp(-y\sqrt{p})}{p}$$

$$+\frac{Gb\exp(-y\sqrt{p})}{p^2(a-1)(\sqrt{p}-b)}-\frac{Gm\exp(-y\sqrt{p})}{p^2(1-Sc)(p-d)}$$

$$-\frac{G\,b}{p^2\ (a-1)\left(\sqrt{p}-b\right)}\left\{\exp\left(-y\sqrt{pa}\right)\right\}$$

$$+\frac{Gm\exp\left(-y\sqrt{(p+k)Sc}\right)}{p^2(p-d)\left(\mathbf{1}-Sc\right)} \qquad \ldots(20)$$

On taking inverse Laplace-transform of equations (18) to (20), we get

$$\theta=\exp(-\mathbf{2}\gamma\eta\sqrt{t}+b^2t)\,\mathrm{erfc}\,(\eta\sqrt{a}\text{-}b\sqrt{t})-\mathrm{erfc}\left(\eta\sqrt{a}\right) \qquad \ldots(21)$$

$$C=\frac{t}{2}\{\exp(2\eta\sqrt{kSc\,t})\mathrm{erfc}\,(\eta\sqrt{Sc}+\sqrt{kt})+\exp(-2\eta\sqrt{kSc\,t})\mathrm{erfc}\,(\eta\sqrt{Sc}-\sqrt{kt})\}$$
$$+\frac{\eta\sqrt{Sct}}{2\sqrt{k}}\{\exp(2\eta\sqrt{kSc\,t})\mathrm{erfc}\,(\eta\sqrt{Sc}+\sqrt{kt})-\exp(-2\eta\sqrt{kSc\,t})\mathrm{erfc}\,(\eta\sqrt{Sc}-\sqrt{kt})\}$$

$$\ldots(22)$$

For $Sc \neq 1$

$$u=\mathrm{erfc}(\eta)$$

$$+\frac{Gb}{a-1}\left\{\frac{1}{4\sqrt{\pi t}}\exp(\text{-}\eta^2)+b\exp(b^2t-2b\eta\sqrt{t})\mathrm{erfc}(\eta-b\sqrt{t})\right\}$$

$$-\frac{Gb}{a-1}\left\{\frac{1}{4\sqrt{\pi t}}\exp(\text{-}\eta^2a)+b\exp(b^2t-2\gamma\eta\sqrt{t})\mathrm{erfc}(\eta\sqrt{a}-b\sqrt{t})\right\}$$

$$+\frac{Gm}{k\,Sc}\left\{t\left(\mathbf{1}+\mathbf{2}\eta^2\right)\mathrm{erfc}(\eta)-\frac{\mathbf{2}\eta e^{-\eta^2}}{\sqrt{\pi}}\right\}+\frac{Gm(\mathbf{1}-Sc)}{k^2Sc^2}\mathrm{erfc}(\eta)$$

$$-\frac{Gm(1-Sc)}{2k^2Sc^2}\{\exp(\frac{kSc\,t}{1-Sc})((\exp(2\eta\sqrt{\frac{kSc\,t}{1-Sc}})\mathrm{erfc}(\eta+\sqrt{\frac{kSc\,t}{1-Sc}})+\exp(-2\eta\sqrt{\frac{kSc\,t}{1-Sc}})\mathrm{erfc}(\eta-\sqrt{\frac{kSc\,t}{1-Sc}})$$

$$+\frac{Gm(1-Sc)}{2k^2Sc^2}\exp(\frac{kSc\,t}{1-Sc})(\exp(2\eta\sqrt{\frac{kSct}{1-Sc}})\mathrm{erfc}(\eta\sqrt{Sc}+\sqrt{\frac{k\,t}{1-Sc}})+\exp(-2\eta\sqrt{\frac{kSct}{1-Sc}})\mathrm{erfc}(\eta\sqrt{Sc}-\sqrt{\frac{k\,t}{1-Sc}})$$

$$-\frac{Gm\,t}{2k\,Sc}\left(\exp(2\eta\sqrt{k\,Sct}\right)\mathrm{erfc}(\eta\sqrt{Sc}+\sqrt{k\,t})+\left(\exp(-2\eta\sqrt{k\,Sct}\right)\mathrm{erfc}(\eta\sqrt{Sc}-\sqrt{k\,t})$$

$$-\frac{Gm\eta}{2kSc}\sqrt{\frac{tSc}{k}}\left(\exp(2\eta\sqrt{kSct}\right)\operatorname{erfc}(\eta\sqrt{Sc}+\sqrt{kt})+\left(\exp(-2\eta\sqrt{kSct}\right)\operatorname{erfc}(\eta\sqrt{Sc}-\sqrt{kt})$$

$$-\frac{Gm(1-Sc)}{2k^2Sc^2}\left(\exp(2\eta\sqrt{kSct}\right)\operatorname{erfc}(\eta\sqrt{Sc}+\sqrt{kt})+\left(\exp(-2\eta\sqrt{kSct}\right)\operatorname{erfc}(\eta\sqrt{Sc}-\sqrt{kt})$$

…(23)

Where $b=\frac{\gamma}{\sqrt{a}}$, $a=\frac{Pr}{1+R}$, $\eta=\frac{y}{2\sqrt{t}}$ $d=\frac{kSc}{1-Sc}$

In expressions, erfc($x_1$+i $y_1$) is complementary error function of complex argument which can be calculated in terms of tabulated functions in Abramowitz et al. [21].The tables given in Abramowitz et al. [21] do not give erfc ($x_1$ + i $y_1$) directly but an auxiliary function $W_1(x_1 + iy_1)$ which is defined as

$$\operatorname{erfc}(x_1+iy_1)=W_1(-y_1+ix_1)\exp\{-(x_1+iy_1)^2\}$$

Some properties of $W_1$ ($x_1$ + i$y_1$) are

$$W_1(-x_1+iy_1)=W_2(x_1+iy_1)$$

$$W_1(x_1-iy_1)=2\exp\{-(x_1-iy_1)^2\}-W_2(x_1+iy_1)$$

where $W_2(x_1+iy_1)$ is complex conjugate of $W_1(x_1+iy_1)$.

## SKIN-FRICTION:

From velocity field , skin-friction at the plate in non dimensional form is expressed as:

$$\tau=-\left(\frac{\partial u}{\partial y}\right)_{y=0}$$

For $Sc\neq 1$

$$=\frac{1}{\sqrt{\pi t}}+\frac{2Gm}{kSc}\sqrt{\frac{t}{\pi}}+\frac{Gb}{a-1}\left\{\frac{b}{\sqrt{\pi t}}+b^2\exp(b^2t)\operatorname{erfc}(-b\sqrt{t})\right\}$$

$$+\frac{Gm(1-Sc)}{k^2Sc^2}\left(\exp(\frac{kSct}{1-Sc})\right)\sqrt{\frac{kSc}{1-Sc}}\left\{\operatorname{erf}(\sqrt{\frac{kSct}{1-Sc}})+\operatorname{erf}(\sqrt{\frac{kt}{1-Sc}})\right\}$$

$$+\frac{2Gm(1-Sc)}{k^{2}Sc^{2}\sqrt{\pi t}}-\frac{Gb^{3}\sqrt{a}}{(a-1)}e^{b^{2}t}erfc(-b\sqrt{t})-\frac{Gb^{2}}{(a-1)}e^{b^{2}t}\sqrt{\frac{a}{\pi t}}$$

$$-\frac{Gm\,t}{k\,Sc}\left\{\sqrt{kSc}\,erf\left(\sqrt{kt}\right)+\sqrt{\frac{Sc}{\pi t}}\,e^{-kt}\right\}$$

$$-\frac{Gm(1-Sc)}{k^{2}Sc^{2}}\left\{\sqrt{kSc}\,erf\left(\sqrt{kt}\right)\right\}+\frac{Gm}{2k^{3/2}\sqrt{Sc}} \qquad \ldots(24)$$

## NUSSELT NUMBER

From temperature field, the rate of heat transfer in non-dimensional form is expressed as

$$Nu = -\frac{\nu}{U_R(T'-T'_\infty)}\frac{\partial T'}{\partial y'}\bigg|_{y'=0}$$

$$=\frac{\mathbf{1}}{\theta(\mathbf{0},t)}+\mathbf{1} \qquad \ldots.(25)$$

$$b\sqrt{a}\left\{\mathbf{1}+\frac{\mathbf{1}}{e^{b^{2}t}(\mathbf{1}+erf\,(b\sqrt{t})-\mathbf{1}}\right\}$$

## SHERWOOD NUMBER

From the concentration field, the rate of concentration transfer, which when expressed in non-dimensional form, is given by

$$Sh = -\frac{\partial\varphi}{\partial y}\bigg|_{y=0}$$

$$=t\left\{\sqrt{\frac{k\,Sc}{2}}\left(2+\sqrt{\frac{Sc}{\pi t}}\,exp(-kt)\right)\right\}+\frac{1}{2}\sqrt{\frac{Sc}{k}}\,erf\,\sqrt{(kt)} \qquad \ldots(26)$$

**DISCUSSION**: In order to determine the effects of various parameters such as R, K, Sc on flow characteristics the numerical values of temperature field, velocity field, skin-friction, Nusselt number are computed and shown in the figures. Further,

In order to get physical insight into the problem, the values of Schmidt number are chosen to represent the presence of species by hydrogen (0.22) and water vapor (0.60) at $25^{0}$C temperature and 1 atmospheric pressure, the values of Pr are chosen 0.71 and 7 which represent air and water respectively at $20^{0}$C temperature and 1 atmospheric pressure. The values of other parameters are chosen arbitrary.

The effect of radiation parameter R on temperature profile against y (distance from the plate) is revealed in Figure 1. It is evident from the figure that the magnitude of temperature is maximum at the plate and then decays to zero away from the plate. The increase in temperature is very less far away from the plate in comparison to near the plate. Moreover, it is noticed that an increase in radiation parameter increases the temperature due to increase in thermal boundary layer thickness of fluid. Figure 2 elucidates the effect of time on temperature and it is found that it increases with an increase in time in the whole flow field. The magnitude of temperature is maximum at the plate and then decays to zero asymptotically. Figure shows that fall in the temperature is more near the plate than away from the plate and this fall in temperature is more for higher values of time. The effects of Pr and $\Upsilon$ on temperature profile is elucidated in Figure 3 & 4 respectively. It is observed that temperature is maximum at the plate then tends to zero asymptotically. Moreover, thickness of thermal boundary layer decreases as Pr increases. The reason is that the thermal conductivity of fluid decreases with increasing Pr, resulting a decrease in thermal boundary layer thickness. It is obvious from figure that it decreases sharply for Pr = 7 than that of Pr = 0.71. On the other hand, the thermal boundary layer thickness increases with an increase in Newtonian heating parameter $\Upsilon$ as a result the surface temperature of the plate increases.

Figure 5 exhibits the species concentration profiles verses $\eta$. It is clear from figure that the concentration at the plate is equal to time then increases to maximum value after that tends to zero as $\eta \to \infty$. Moreover, an increase in the value of Sc leads to a decrease in concentration boundary layer thickness in the whole field. It is due to the fact that since increase of Sc means decrease of molecular diffusivity which results in decrease of concentration boundary layer. Hence, the concentration of species is higher for small values of Sc. It is also observed that concentration increases with an increase in time whereas it falls with an increase in chemical reaction parameter k. It is noteworthy that since increase in k gives rise to increase in Sc so the same effect is observed as that in the case of increase of Sc.

Figure 6 illustrates the influences of Sc, t on the velocity against $\eta$ for Pr=0.71 and 7. It is noticed that at the plate, fluid velocity is equal to one then it increases and attains maximum velocity in the vicinity of the plate($\eta$<1) after that it decreases and vanishes far away from the plate for Pr=0.71 whereas for Pr=7 same phenomenon is observed in opposite direction. Further, magnitude of velocity for Pr=0.71 is higher than that of Pr=7. Physically, it is possible because fluids with high Prandtl number have high viscosity and hence move slowly. In addition, magnitude of velocity decreases with an increase in time at each point in the flow field for both Pr=7 and Pr=0.71 when hydrogen gas is present in the flow. The change in velocity is more near the plate than away from the plate due to increase in parameters Sc, t. On the other hand the magnitude of velocity decreases with an increase in Sc for water. It is justified since increase in the value of Sc increases the viscosity of fluid which reduces the velocity of fluid whereas velocity increases with an increase in the value of Sc for Pr=0.71.

Figure 7 indicates the effects of G, Gm on velocity profile for Pr=7 and 0.71. It is noticed that the magnitude of velocity increases with $\eta$ then attains its maximum value then decreases far away from the plate for Pr=0.71 and for Pr=7 same shape of velocity profile is observed in reverse direction. For Pr=7 boundary layer separation occurs for all values of parameters. Moreover with an increase in Gm the magnitude of velocity decreases for air whereas increases for water. Moreover with an increase in value of G the magnitude of velocity increases for air but decreases for water.

The effects of $k, \Upsilon$ on velocity profile for Pr=7 and Pr=0.71 is indicated in Figure 8. It is clear from figure that the magnitude of velocity is equal to one at the plate then increases to maximum value after that it decreases to zero value for Pr=0.71 but for Pr=7 the same shape of profile is found in reverse direction. On the other hand it is observed that fluid velocity increases with an increase in the value of chemical reaction parameter k for air but it decreases with an increase in value of k for water. It is due to the fact that increase in chemical reaction parameter k gives rise to an increase in viscosity of fluid which means velocity boundary layer thickness decreases. It is also concluded from figure that fluid velocity increases with an increase in value of $\Upsilon$ for Pr=0.71 whereas for water the magnitude of velocity decreases with an increase in value of Newtonian heating parameter. The change in thickness of velocity profile due to variation in the values of $\Upsilon$ and k is more near the plate than away from the plate.

Figure 9 depicts the skin- friction against time t for different parameters. It is clear from figure that for smaller values of t the maximum value of skin friction occurs and then it decreases rapidly with an increase in t ($t \leq 0.5$) and after this value of t the value of skin friction falls slowly. The magnitude of skin friction decreases sharply with an increase in t for higher values of Gm and k. Moreover, the Figure depicts that the value of skin-friction increases with an increase of Gm. It is observed from figure that magnitude of skin friction is lower for hydrogen gas (Sc=0.22) in comparison to water vapor (Sc=0.60). Physically, it is correct since an increase in Sc serves to increase momentum boundary layer thickness. Moreover, magnitude of skin friction increases with an increase in the value of chemical reaction parameter k.

Figure 10 exhibits the Nusselt number against time. It is observed that Nusselt number decreases as time passes and it decreases sharply for $t \leq \mathbf{0.4}$. It is also concluded from the figure that there is a decrease in it with an increase in the value of radiation parameter R and Newtonian heating parameter $\Upsilon$. Further, the value of Nusselt number increases with an increase in Pr. It is consistent with the fact that smaller values of Pr are equivalent to increasing thermal conductivities and therefore heat is able to diffuse away from the plate more rapidly than higher values of Pr, hence the rate of heat transfer is reduced.

Figure 11 depicts the effect of chemical reaction parameter k and Schmidt number Sc on Sherwood number. It is found that Sherwood number increases with an increase in k and Sc. Since increase in Sc means decrease in molecular diffusivity which in turn gives rise to increase in Sherwood number as Sherwood number is the ratio of convective and diffusive mass transfer coefficient. Chemical reaction parameter increases the interfacial mass transfer so Sherwood number increases with an increase in k.

**CONCLUSION:** This paper presents an exact solutions of natural convection flow of chemically reactive incompressible fluid past a vertical plate with Newtonian heating and variable mass diffusion in the presence of radiation. The Laplace transform technique is used for solving the problem. Numerical evaluations of closed form solutions were performed and some graphical results were obtained to illustrate the details of flow, heat and mass transfer characteristics and their dependence on some physical parameters. From the present study we can make the following conclusions:

1. Increasing radiation parameter and Prandtl number the temperature decreases whereas it increases with increasing time.

2. Concentration profile decreases with an increase in Sc and k whereas it increases with an increase in time.

3. Fluid velocity decreases with an increase in Sc, k, G and $\Upsilon$ for water whereas velocity increases with an increase in the value of Sc, G, k, $\Upsilon$ for air. On the other hand it is observed that fluid velocity decreases with an increase in the value of time for both Pr=7 and Pr=0.71. It is also found that velocity of fluid decreases with an increase in value of Gm for air but it increases for water. Further, velocity also decreases with an increase in value of Pr.

4. There is a rise in the value of skin friction with an increase in Schmidt number, chemical reaction parameter and modified Grashof number. The rate of heat transfer increases with an increase in the value of Prandtl number but decreases with increase in $\Upsilon$ and radiation parameter. Sherwood number increases with an increase in chemical reaction parameter and Schmidt number.

## REFERENCES:

[1] Cussler E. L.,“ Diffusion Mass Transfer in Fluid Systems”, Cambridge University Press, Cambridge, 1998.

[2] Chaudhary, R .C. and Jain , Arpita, **“**Combined heat and mass transfer effect on MHD free convection flow past an oscillating plate embedded in porous Medium”, Rom. Journ. Phys., 52 , 505-524, 2007.

[3] Muthucumaraswamy R, Raj M Sundar and Subramanian V. S. A., “Unsteady flow past an accelerated infinite vertical plate with variable temperature and uniform mass diffusion”, Int. J. of Appl. Math and Mech. 5, 51 – 56, 2009 .

[4] Rajput U. S. and Surendra Kumar, “MHD flow past an impulsively started vertical plate with variable temperature and mass diffusion”,Applied Mathematical Sciences, 5, 149 –157, 2011.

[5] Chaudhary,R. C. and Jain Arpita, “An exact solution of magnetohydrodynamic convection flow past an accelerated surface embedded in porous medium”, International Journal of Heat and Mass Transfer, 53, 1609-1611, 2010.

[6] Asogwa et al. “Flow past an exponentially accelerated infinite vertical plate and temperature with variable mass diffusion”, International Journal of Computer Applications., 45, 2012.

[7] Fayza Mohammed Nasser El-Fayez, “Effects of chemical reaction on the unsteady free convection flow past an infinite vertical permeable moving plate with variable temperature”, JSEMAT, 2, 100-109, 2012.

[8] Sarada, K. and B. Shanker, “The effect of chemical reaction on an unsteady MHD free convection flow past an infinite vertical porous plate with variable suction”, International Journal of Engineering Modern Research, 3, 725 – 735, 2013.

[9] Bhaben Ch. Neog,. Das Rudra Kr, “Unsteady Free Convection MHD Flow past a vertical plate with variable temperature and chemical reaction”, International Journal of Engineering Research & Technology, 1, 1-5, 2012.

[10] Chaudhary, R. C. and Jain, P., “Unsteady free convection boundary layer flow past an impulsively started vertical surface with Newtonian heating and chemical reaction”, Romanian Journal of Physics, 51, 911– 925, 2006.

[11]. Rajesh, V., “Effects of mass transfer on flow past an impulsively started infinite vertical plate with Newtonian heating and chemical reaction”, Journal of Engineering Physics and Thermophysics, 85, 221–228, 2012.

[12] Raju, M. C., “Heat and Mass transfer effects on unsteady free convection boundary layer flow past an impulsive started vertical surface with Newtonian heating”, international Journal of Scientific Research, 2, 263-265, 2013.

[13] Chaudhary, R. C. and Jain, Arpita, “ Unsteady free convection flow past an oscillating plate with constant mass flux in the presence of radiation”, Acta Technica CSAV, 52, 93-108, 2007.

[14] Prasad V. R., Reddy N. B. and Muthucumaraswamy R., “Radiation and mass transfer effects on two dimensional flow past an impulsively started infinite vertical plate”, Int. J. Thermal Sci.,46, 1251-1258,2007.

[15] Rajput U. S. and Kumar S., "Radiation Effects on MHD flow past an impulsively started vertical plate with variable heat and mass transfer", Int. J. of Appl. Math. and Mech. 8, 66-85, 2012.

[16] Narahari M. and Yunus Nayan M., "Free convection flow past an impulsively started infinite vertical plate with Newtonian heating in the presence of thermal radiation and mass diffusion", Turkish Journal of Engineering and Environmental Sciences, vol. 35, 187–198, 2011

[17] Das S., Mandal C., and Jana R. N., "Radiation effects on unsteady free convection flow past a vertical plate with Newtonian heating", International Journal of Computer Applications, 41, 36–41, 2012.

[18] Jain Arpita, "Radiation and chemical reaction effects on unsteady double diffusive convective flow past an oscillating surface with constant heat flux", ISRN Chemical Engineering, http://dx.doi.org/10.1155/2013/846826, 2013.

[19] Jain Arpita, "Heat and mass transfer effect of chemically reactive fluid on flow over an accelerated vertical surface in presence of radiation with constant heat flux", International Journal of Advancement in Research &Technology, 2, 133- 156, 2013.

[20] Jain Arpita, "Radiative and chemically reactive double diffusive convective flow past a vertical surface with constant heat flux", Acta Technica, In Press.

[21] Abramowitz B. M. and Stegun I. A., "Handbook of Mathematical Functions", Dover Publications, New York, 1970.

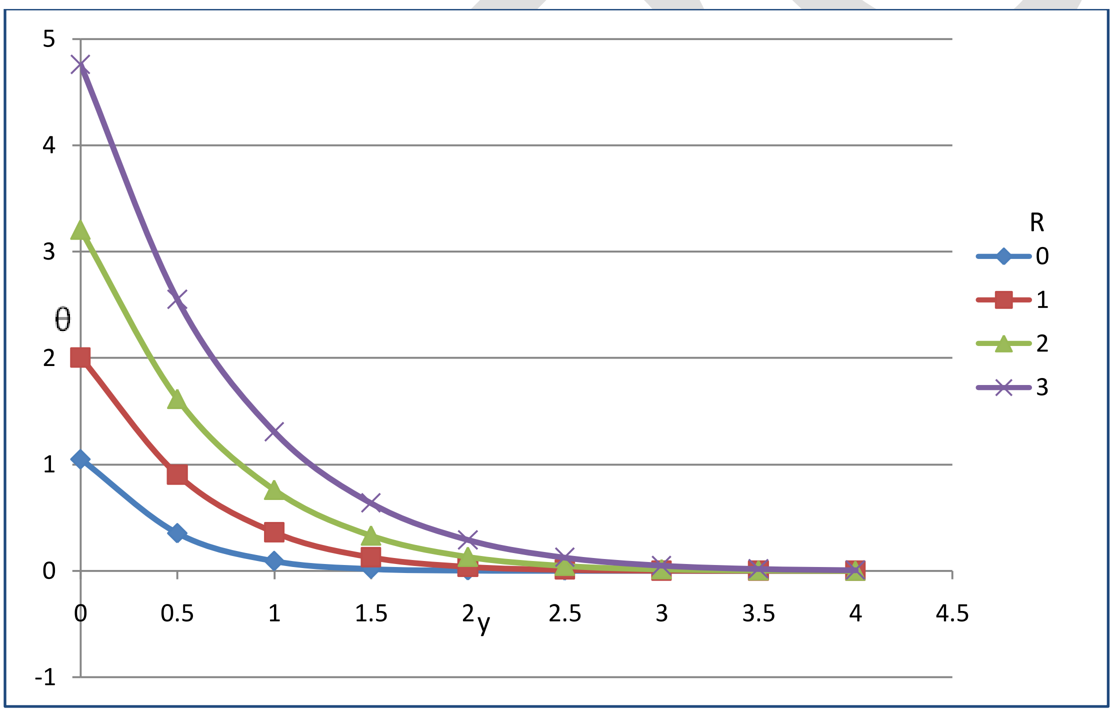


**Figure 1: Temperature profile ϒ=1, Pr=0.71, t=0.2**

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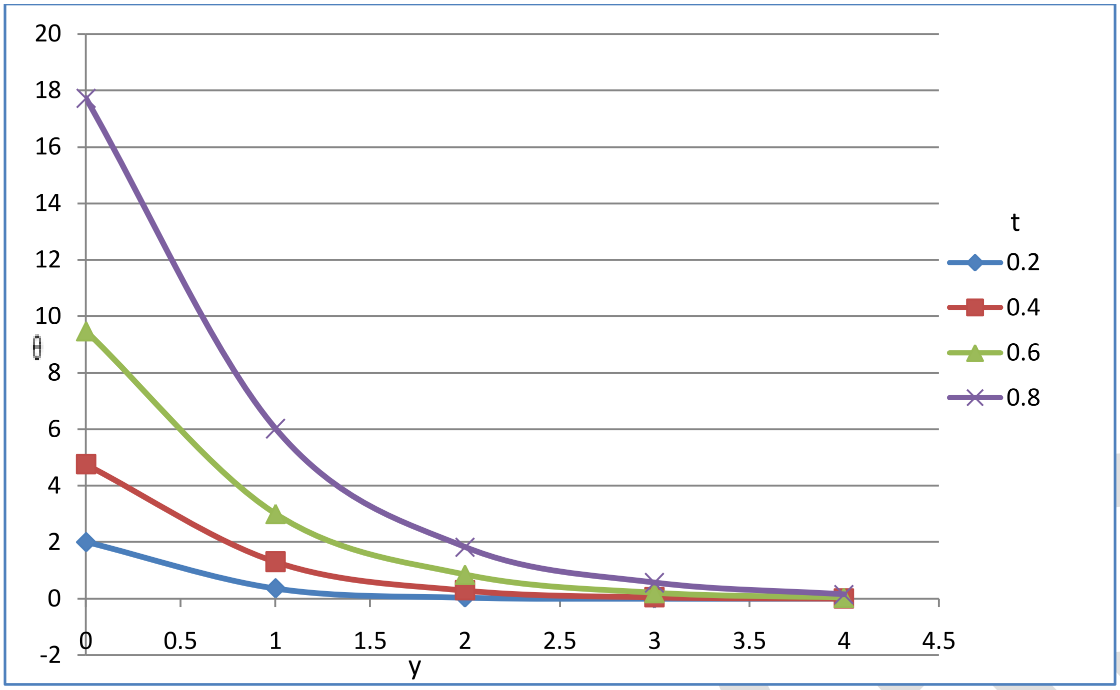
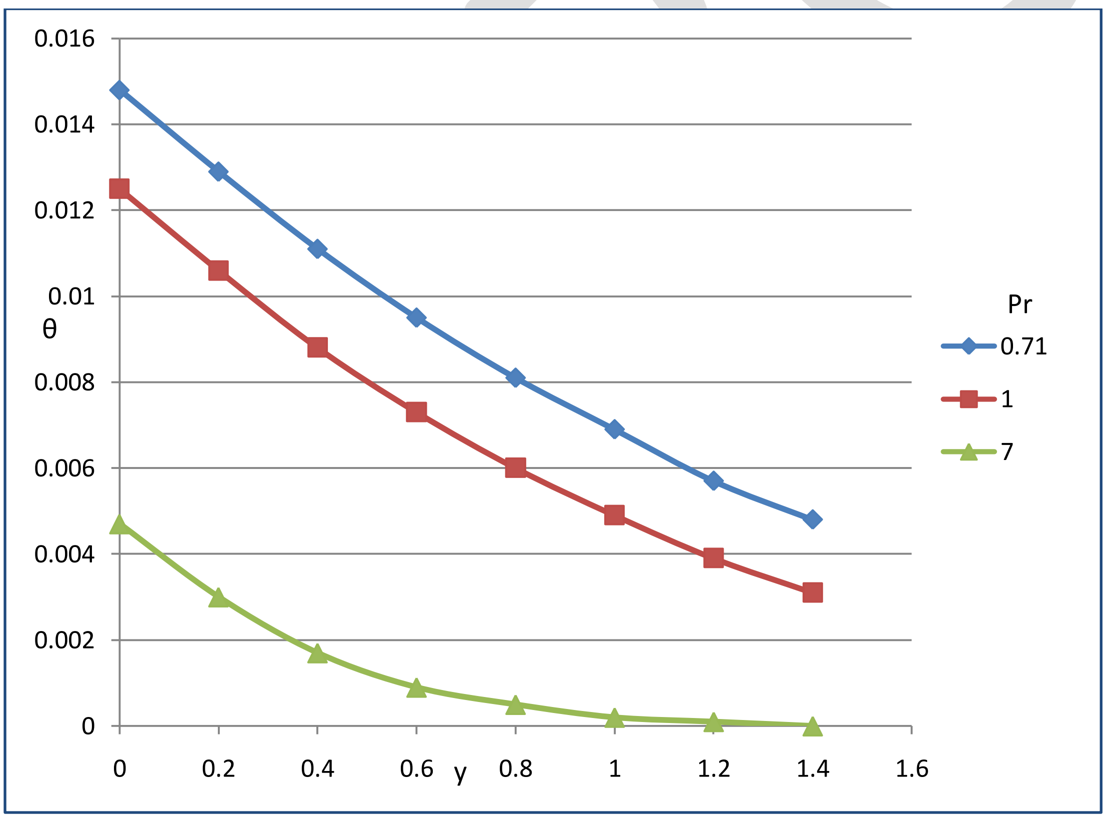



**Figure 2: Temperature profile ϒ=1, Pr=0.71, R=1**




**.Figure 3: Temperature profile ϒ=0.01, R=5, t=0.2**

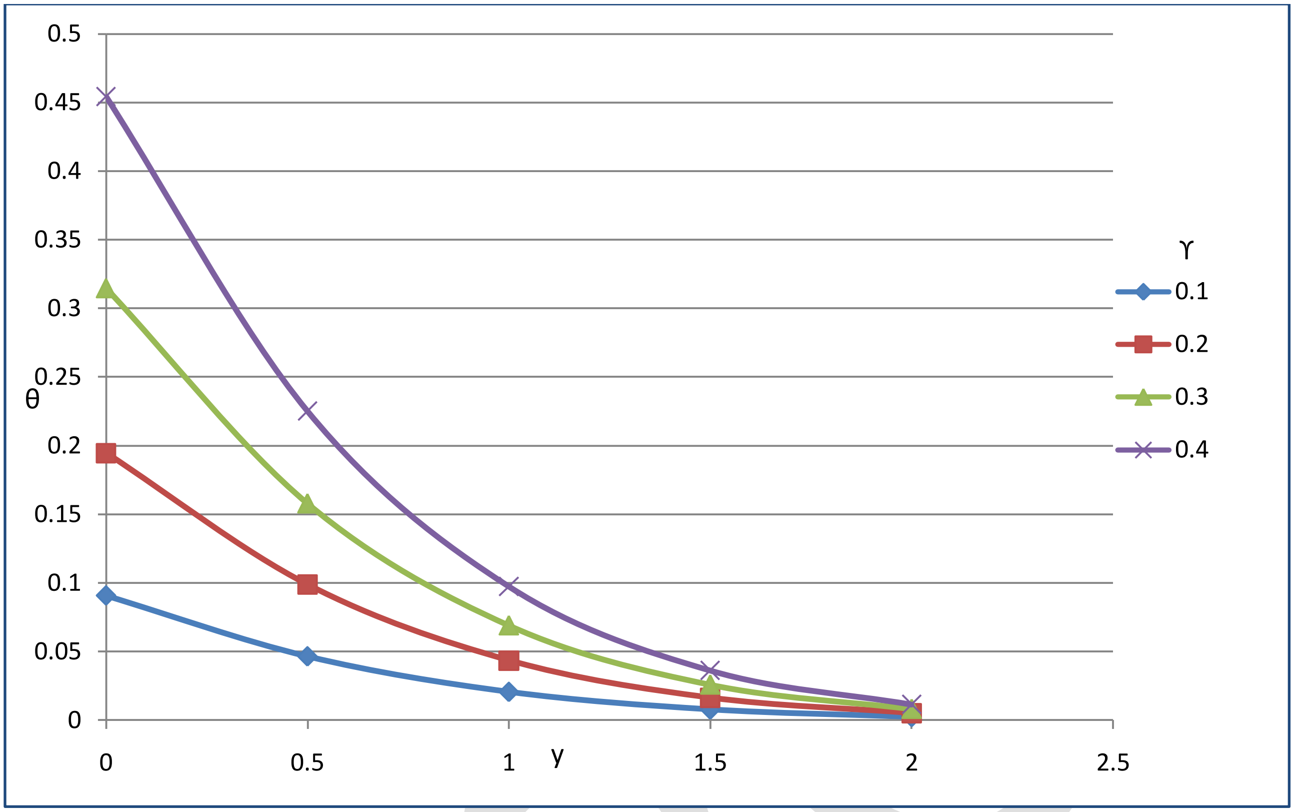



**Figure 4: Temperature profile t=0.2, Pr=0.71, R=1**

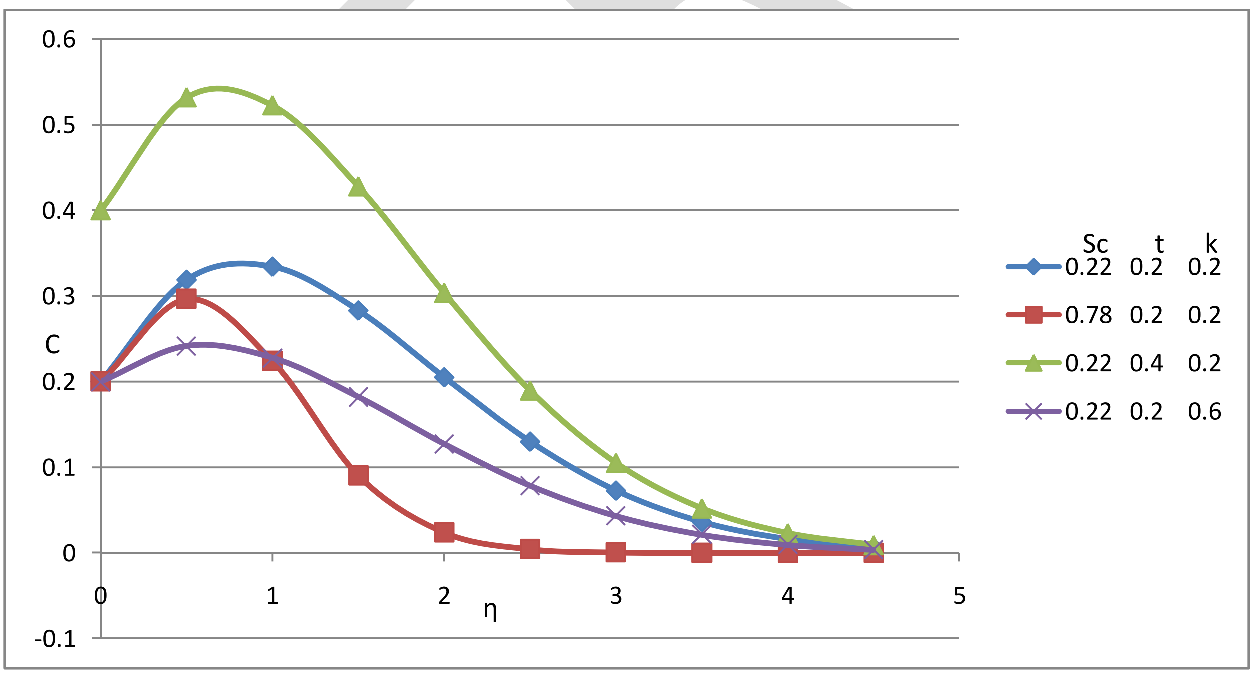



**Figure 5: Concentration profile**

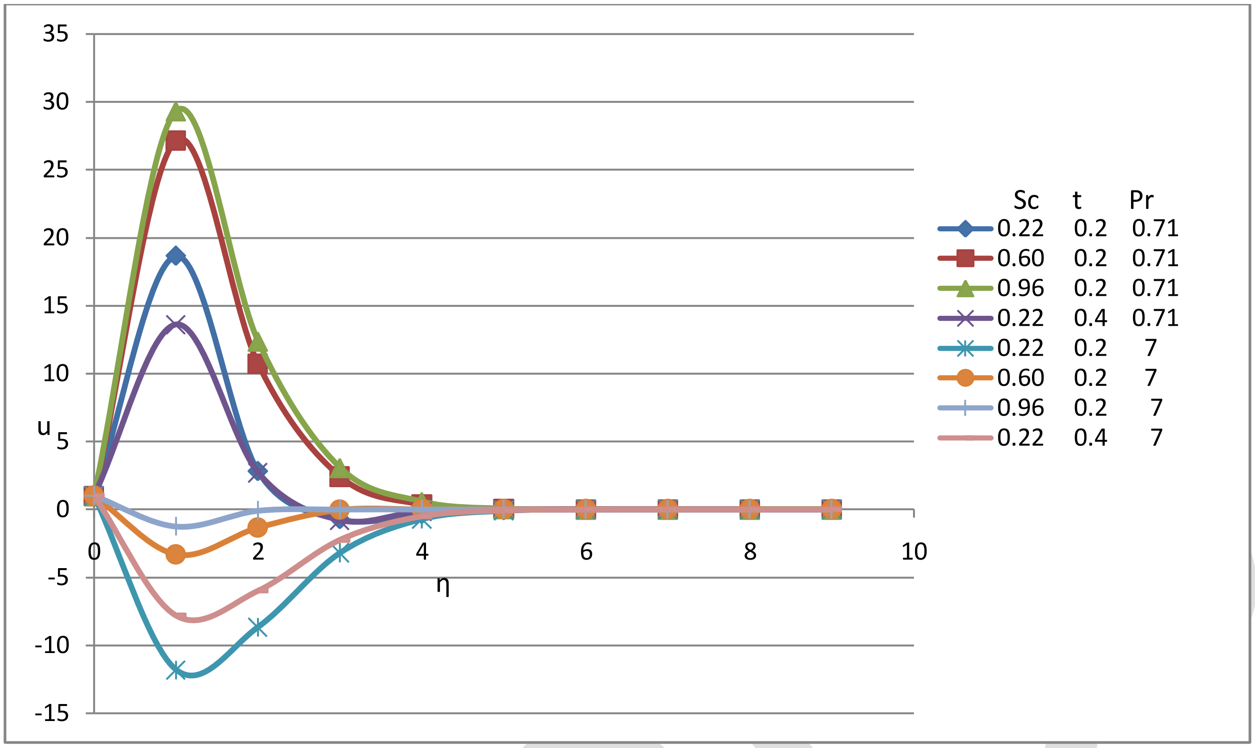



**Figure 6 : Velocity profile for R=2, k=0.2, G=5, ϒ=1, Gm=2**

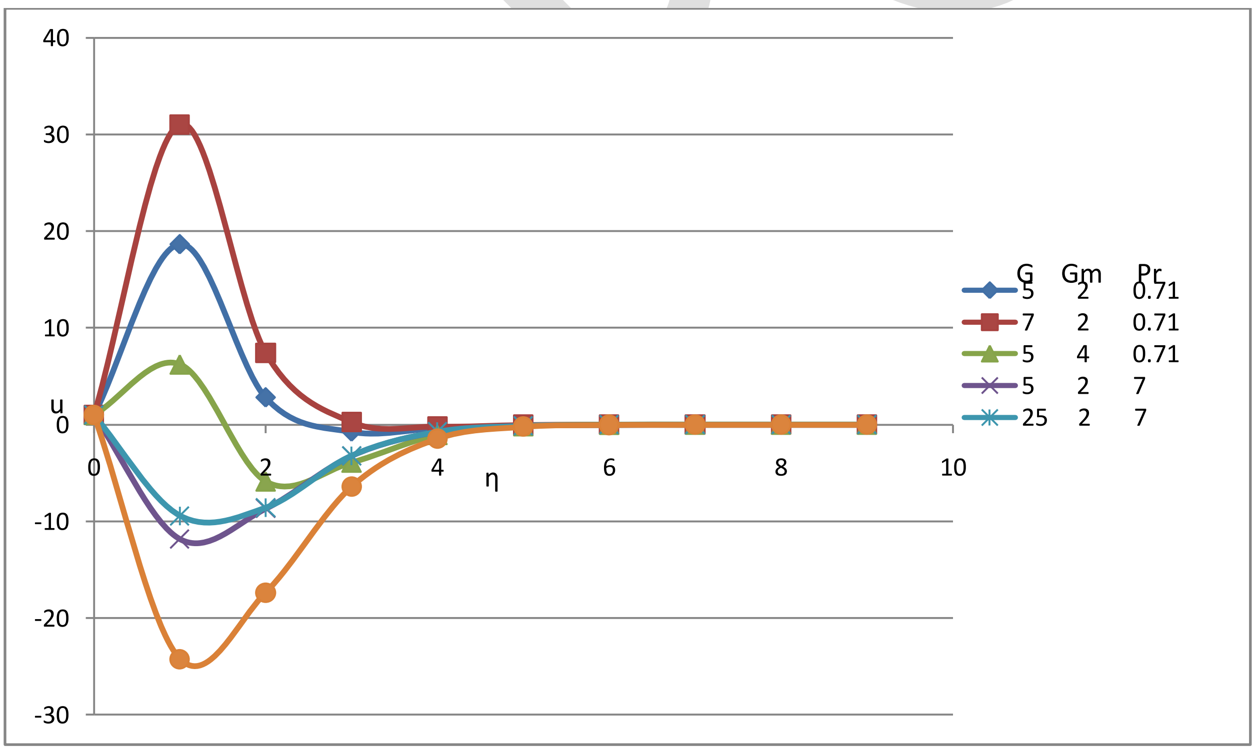



**Figure 7: Velocity profile Sc=0.22, t=0.2, ϒ=1, k=0.2, r=2**

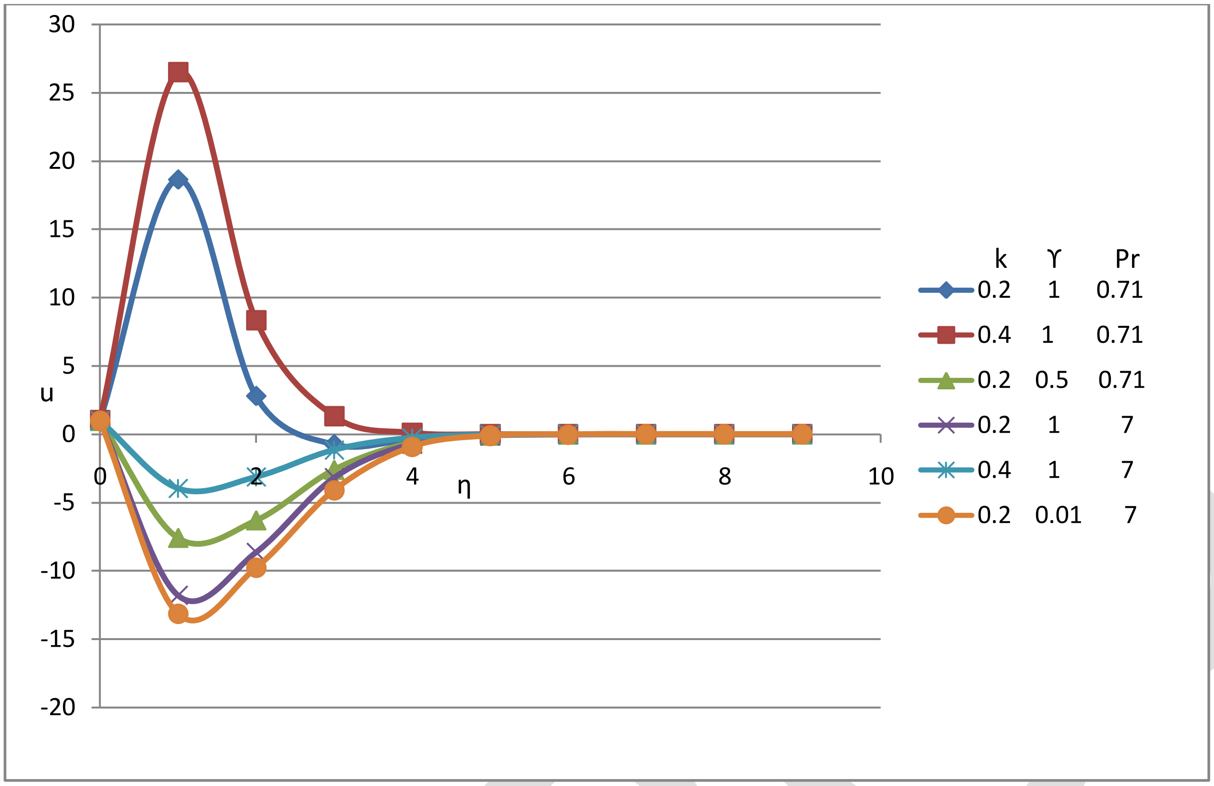



**Figure 8: Velocity profile R=1, t=0.2, Sc=0.22, G=5, Gm=2**

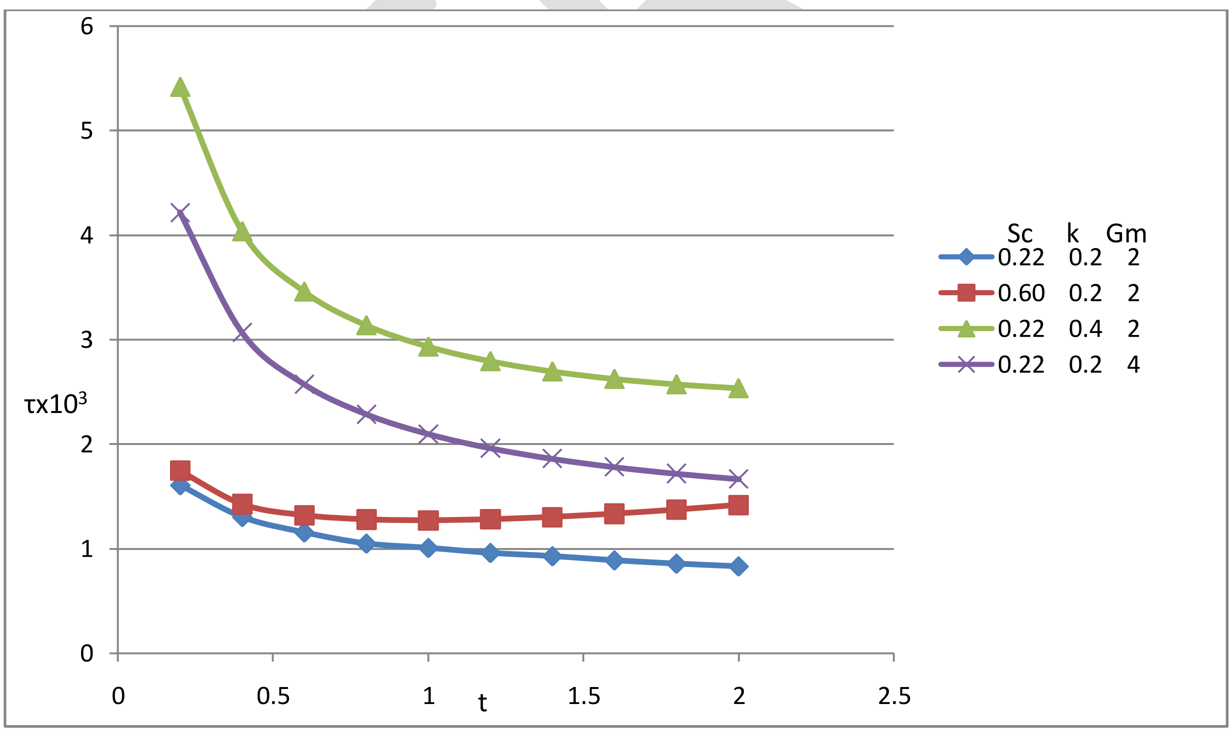



**Figure 9: Skin-friction for R=3, G=5, Pr=7, ϒ=0.2**

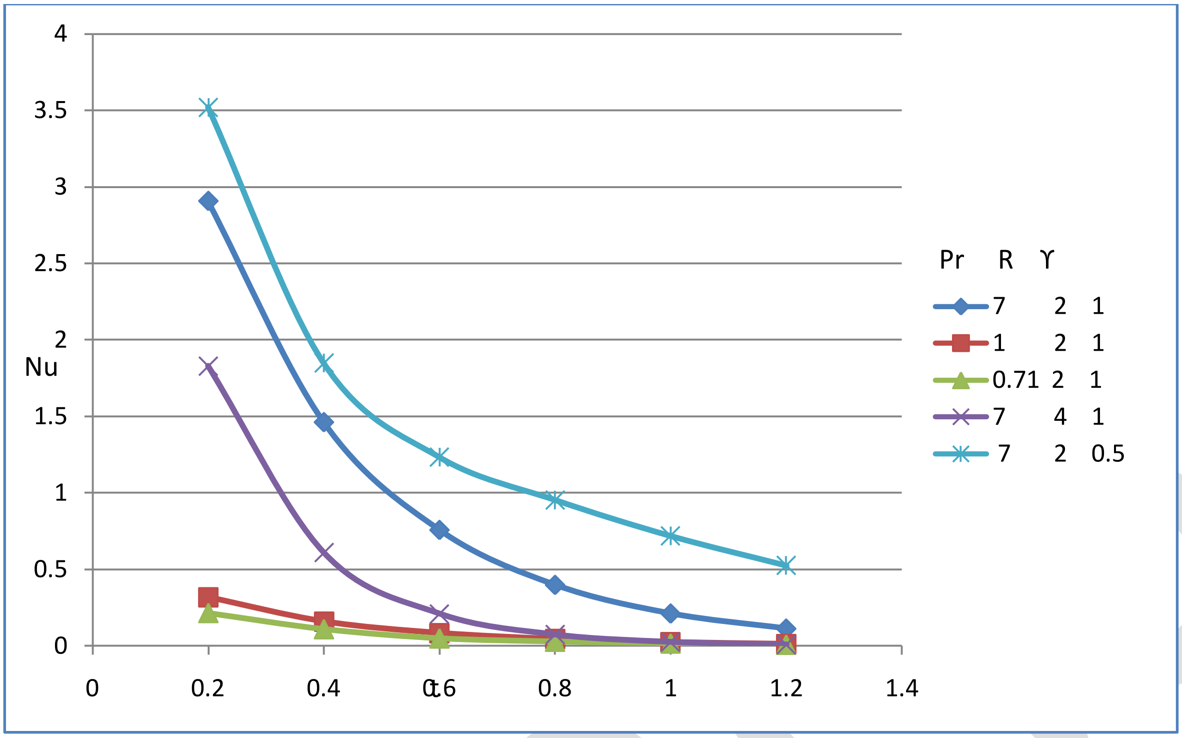



**Figure 10: Nusselt number**

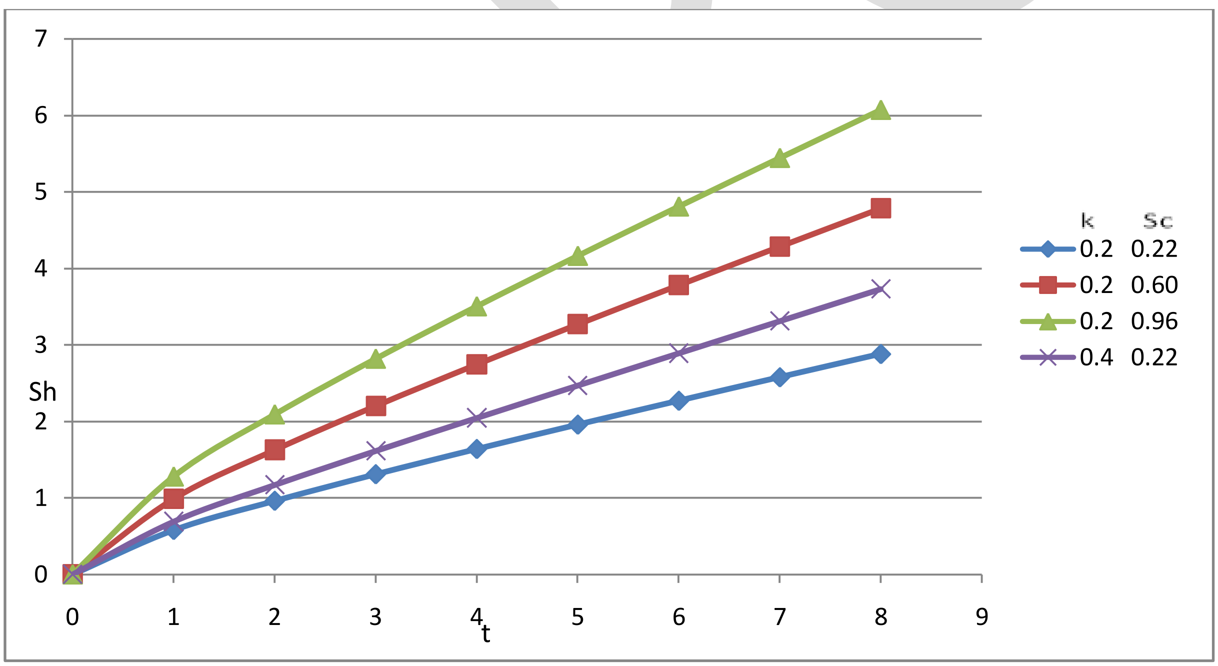



**Figure 11 : Sherwood number**