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MHD And Thermal Radiation Effects On Linearly Accelerated Isothermal Vertical Plate With Chemical Reaction Of First Order

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Abstract: Theoretical solution of thermal radiation and chemical reaction effecst on unstaedy flow past an uniformly accelerated infinite isothermal vertical plate with uniform mass diffusion, under the action of transversely applied magnetic field has been presented. The plate temperature is raised to T_ω and the concentration level near the plate is also raised to C'_ω. The dimensionless governing equations are solved using Laplace-transform technique. The velocity , temperature and concentration fields are studied for different physical parameters like magnetic field parameter, radiation parameter, chemical reaction papermeter, thermal Grashof number, mass Grashof number, Schmidt number, Prandtl number and time. It is observed that the velocity increases with increasing values of thermal Grashof number or mass Grashof number. But the trend is just reversed with respect to the chemical reaction parameter. It is also observed that the velocity increases with decreasing magnetic field parameter or radiation parameter.

Keywords: Accelerated, isothermal, radiation, vertical plate, heat and mass transfer, magnetic field, chemical reaction.

I.INTRODUCTION

MHD plays an important role in agriculture, petroleum industries, geophysics and in astrophysics. Important applications in the study of geological formations, in exploration and thermal recovery of oil,and in the assessment of aquifers,geothermal reservoirs and underground nuclear waste storage sites. MHD flow has application in metrology, solar physics and in motion of earths core. Also it has applications in the field of stellar and planetary magnetospheres, aeronautics, chemical engineering and electronics. In the field of power generation, MHD is receiving considerable attention due to the possibilities it offers for much higher thermal efficiencies in power plants.

Radiative heat and mass transfer play an important role in manufacturing industries for the design of fins, steel rolling, nuclear power plants, gas turbines and various propulsion device for aircraft, missiles, satellites and space vehicles are examples of such engineering applications. England and Emery[1] have studied the thermal radiation effects of a optically thin gray gas bounded by a stationary vertical plate. Radiation effect on mixed convection along a isothermal vertical plate were studied by Hossain and Takhar[2]. The governing equations were solved analytically. Das *et al*[3] have analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate.

Chemical reactions can be codified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. In well-mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be of first order, if the rate of reaction is directly proportional to the concentration itself. Chambre and Young [4] have analyzed a first order chemical reaction in the neighborhood of a horizontal plate. Das et al [5] have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. Again, mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction studied by Das et al [6]. The dimensionless governing equations were solved by the usual Laplace-transform technique.

Gupta *et al* [7] studied free convection on flow past an linearly accelerated vertical plate in the presence of viscous dissipative heat using perturbation method. Kafousias and Raptis[8] extended the above problem to include mass transfer effects subjected to variable suction or injection. Free convection effects on flow past an accelerated vertical plate with variable suction and uniform heat flux in the presence of magnetic field was studied by Raptis et al[9]. MHD effects on flow past an infinite vertical plate for both the classes of impulse as well as accelerated motion of the plate was studied by Raptis and Singh[10]. Mass transfer effects on flow past an uniformly accelerated vertical plate was studied by Soundalgekar[11]. Again, mass transfer effects on flow past an accelerated vertical plate with uniform heat flux was analyzed by Singh and Singh[12]. Basant Kumar Jha and Ravindra Prasad[13] analyzed mass transfer effects on the flow past an accelerated infinite vertical plate with heat sources.

Hence, it is proposed to study thermal radiation and hydromagnetic effects on unsteady flow past an uniformly accelerated infinite isothermal vertical plate with heat and mass transfer in the presence of chemical reaction of first order. The dimensionless governing equations are solved using the Laplace-transform technique. The solutions are in terms of exponential and complementary error function. Such a study found useful in chemical proceesing, magnetic control of molten iron flow in the steel industry, liquid metal cooling in nuclear reactors and magnetic suppression of molten semi-conducting materials.

II.MATHEMATICAL ANALYSIS

The magnetohydrodynamic flow of a viscous incompressible fluid past an uniformly accelerated isothermal vertical infinite plate in the presence of thermal radiation and chemical reaction of first order has been considered. Here the unsteady flow of a viscous incompressible fluid which is initially at rest and surrounds an infinite vertical plate with temperature T_∞ and concentration C'_∞. The *x*-axis is taken along the plate in the vertically upward direction and the *y*-axis is taken normal to the plate. At time $t' \leq 0$, the plate and fluid are at the same temperature T_∞. At time $t' > 0$, the plate is accelerated with a velocity $u = \frac{u_0^3}{\nu} t'$, in its own plane against gravitational field and the temperature from the plate is raised to T_w and the concentration levels near the plate are also raised to C'_w.It is assumed that the effect of viscous dissipation is negligible in the energy equation and there is a first order chemical reaction between the diffusing species and the fluid. A transverse magnetic field of uniform strength B_0 is assumed to be applied normal to the plate. The fluid considered here is a gray, absorbing-emitting radiation but a non-scattering medium. Then under usual Boussinesq's approximation the unsteady flow is governed by the following equations:

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

$$\rho C_p \frac{\partial T}{\partial t'} = k\frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} \quad (2)$$

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

With the following initial and boundary conditions:

$$\begin{array}{llllll} & u = 0, & T = T_\infty, & C' = C'_\infty & \text{for all} & y, t' \le 0 \\ t' > 0: & u = \dfrac{u_0^{\,3}}{\nu} t', & T = T_\omega, & C' = C'_\omega & \text{at} & y = 0 \\ & u \to 0 & T \to T_\infty, & C' \to C'_\infty & \text{as} & y \to \infty \end{array} \quad (4)$$

On introducing the following non-dimensional quantities:

$$U = \frac{u}{u_0}\ , \quad t = \frac{t' u_0^{\,2}}{\nu}, \quad Y = \frac{y u_0}{\nu},$$

$$\theta = \frac{T - T_\infty}{T_w - T_\infty},\ Gr = \frac{g\nu\beta(T_w - T_\infty)}{u_0^{\,3}},\ C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\ K = \frac{K_l \nu}{u_0^{\,2}}, Sc = \frac{\nu}{D}, \qquad (5)$$

$$R = \frac{16a^*\sigma T_\infty^{\,3}}{k}\left(\frac{\nu^2}{u_0^{\,2}}\right), Gc = \frac{g\nu\beta^*(C'_w - C'_\infty)}{u_0^{\,3}}\ , M = \frac{\sigma B_0^{\,2}\nu}{\rho u_0^{\,2}}, \Pr = \frac{\mu C_P}{k}.$$

The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y} = -4a^*\ \sigma\left(T_\infty^4 - T^4\right) \quad (6)$$

It is assume that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of the temperature. This is accomplished by expanding T^4 in a Taylor series about T_∞ and neglecting higher-order terms, thus

$$T^4 \cong 4T_\infty^3\, T - 3T_\infty^4 \quad (7)$$

By using equations (5) and (6), equation (2) reduces to

$$\rho\, C_p \frac{\partial T}{\partial t'} = k\frac{\partial^2 T}{\partial y^2} + 16a^*\sigma T_\infty^3\ (T_\infty - T) \quad (8)$$

in equations (1) to (4), leads to

$$\frac{\partial U}{\partial t} = Gr\theta + Gc\, C + \frac{\partial^2 U}{\partial Y^2} - M\ U \quad (9)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial Y^2} - \frac{R}{\Pr}\theta \quad (10)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial Y^2} - KC \quad (11)$$

The initial and boundary conditions in non-dimensional quantities are

$$\begin{array}{lllllll} & U = 0, & \theta = 0, & C = 0 & \textit{for all} & Y, t \le 0 & \\ t > 0: & U = t, & \theta = 1, & C = 1 & at & Y = 0 & \\ & U \to 0, & \theta \to 0, & C \to 0 & as & Y \to \infty & (12) \end{array}$$

III.SOLUTION PROCEDURE

The solutions are in terms of exponential and complementary error function. The relation connecting error function and its complementary error function is as follows:
erfc(x) =1- erfc(x)(13)
The dimensionless governing equations (9) to (11), subject to the initial and boundary conditions (12), are solved by the usual Laplace-transform technique and the solutions are derived as follows:

$$\theta = \frac{1}{2}\left[\exp(2\eta\sqrt{Rt})\ erfc\left(\eta\sqrt{\Pr} + \sqrt{at}\right) + \exp(-2\eta\sqrt{Rt})\ erfc\left(\eta\sqrt{\Pr} - \sqrt{at}\right)\right] \quad (14)$$

$$C = \frac{1}{2}\left[\exp(2\eta\sqrt{KtSc})\ erfc(\eta\sqrt{Sc} + \sqrt{Kt}) + \exp(-2\eta\sqrt{KtSc})\ erfc(\eta\sqrt{Sc} - \sqrt{Kt})\right] \quad (15)$$

$$
\begin{aligned}
U = & \left(\frac{t}{2}+d+e\right)\begin{bmatrix}\exp(2\eta\sqrt{Mt})erfc(\eta+\sqrt{Mt}) \\ +\exp(-2\eta\sqrt{Mt})erfc(\eta-\sqrt{Mt})\end{bmatrix} \\
& -\frac{\eta\sqrt{t}}{2\sqrt{M}}\left[\exp(-2\eta\sqrt{Mt})erfc(\eta-\sqrt{Mt})-\exp(2\eta\sqrt{Mt})erfc(\eta+\sqrt{Mt})\right] \\
& -e\exp(ct)\begin{bmatrix}\exp(2\eta\sqrt{(M+c)t})erfc(\eta+\sqrt{(M+c)t}) \\ +\exp(-2\eta\sqrt{(M+c)t})erfc(\eta-\sqrt{(M+c)t})\end{bmatrix} \\
& -d\exp(bt)\begin{bmatrix}\exp(2\eta\sqrt{(M+b)t})erfc(\eta+\sqrt{(M+b)t}) \\ +\exp(-2\eta\sqrt{(M+b)t})erfc(\eta-\sqrt{(M+b)t})\end{bmatrix} \\
& +d\exp(bt)\begin{bmatrix}\exp(2\eta\sqrt{\Pr(a+b)t})erfc(\eta\sqrt{\Pr}+\sqrt{(a+b)t}) \\ +\exp(-2\eta\sqrt{\Pr(a+b)t})erfc(\eta\sqrt{\Pr}-\sqrt{(a+b)t})\end{bmatrix} \\
& +e\exp(ct)\begin{bmatrix}\exp(2\eta\sqrt{Sc(K+c)t})erfc(\eta\sqrt{Sc}+\sqrt{(K+c)t}) \\ +\exp(-2\eta\sqrt{Sc(K+c)t})erfc(\eta\sqrt{Sc}-\sqrt{(K+c)t})\end{bmatrix} \\
& -e\left[\exp(2\eta\sqrt{KtSc})erfc(\eta\sqrt{Sc}+\sqrt{Kt})+\exp(-2\eta\sqrt{KtSc})erfc(\eta\sqrt{Sc}-\sqrt{Kt})\right] \\
& -d\ \left[\exp\left(2\eta\sqrt{Rt}\right)erfc\left(\eta\sqrt{\Pr}+\sqrt{at}\right)+\exp\left(-2\eta\sqrt{Rt}\right)erfc\left(\eta\sqrt{\Pr}-\sqrt{at}\right)\right]^{(16)}
\end{aligned}
$$

Where,

$$a=\frac{R}{\Pr},\ b=\frac{M-R}{\Pr-1},c=\frac{M-KSc}{Sc-1},d=\frac{Gr}{2b(1-\Pr)},\quad e=\frac{Gc}{2c(1-Sc)}\ \text{and}\ \eta=Y/2\sqrt{t}\,.$$

IV. RESULTS AND DISCUSSION

For physical understanding of the problem, numerical computations are carried out for different physical parameters Gr, Gc, Sc, K, R, M and t upon the nature of the flow and transport. The value of the Schmidt number Sc is taken to be 0.6 which corresponds to water-vapor. The value of Prandtl number Prischosen such that they represent air (Pr = 0.71).The numerical values of the velocity, temperature and concentration are computed for the above mentioned physical parameters.

The concentration profiles for different values of the chemical reaction parmeter (K=0.2, 2,5), Sc=0.6 and t=0.2 are shown in Fig. 1. The effect of chemical reaction parameter play an important role in concentration field. From Fig.1, It is observed that for the larger values of chemical reaction parameter (K = 5,2), the concentration profile rapidly decreases compare to the value of K=0.2.Fig.2 illustrates the effect of the concentration profiles for different values of the Schmidt number ($Sc = 0.16, 0.6, 2.01$), K=0.2 and $t = 0.2$ .The profiles have the common feature that the concentration decreases in a monotone fashion from the surface to a zero value far away in the free stream. It showed that the better improvement of the concentration profile for the smaller value of Schmidt number Sc = 0.16, which corresponds to water-vapor, compare to the larger value of Schmidt number (Sc = 0.6, Sc = 2.01).

The temperature profiles are calculated for different values of thermal radiation parameter($R = 0.2, 2, 5$) at time $t = 0.2$ and these are shown in Fig.3. The effect of thermal radiation parameter is important in temperature profiles. It is noticed that the temperature of the plate eradically increases for the smaller values of the thermal rediation parameter R = 0.2, R = 2 in the presence of air (Pr = 0.71) and it is better than the value of R = 5. This trend shows that there is a fall in plate temperature dur to higher thermal radiation.

The velocity profiles for different values of time $(t = 0.2, 0.4, 0.6)$, $K = 2, Gr = 2, Gc = 5, R = 5$ and $\mathrm{M} = 2$ are studied and presented in Fig.4. It is noticed that the trend shows that for higher values of time t = 0.6, t = 0.4 the velocity of the plate rapidly increases compare to the value of t = 0.2.Fig. 5. demonstrates the effects of the thermal radiation parameter on the velocity when ($R = 3,8,13$),M=2, K=5, Gr=2, Gc=5 and t=0.2 in the presence of thermal radiation. It is concluded that the velocity profile of the plate repidly decreasing for the larger values of thermal radiation parameter R = 13 and R = 8 compare to the value of thermal radiation parameter R = 3.

Fig. 6. demonstrates the effect on the velocity fields for different values of the chemical reaction parameter ($K = 2,5,10$), $Gr = 2, Gc = 5, R = 5$, $\mathrm{M} = 2$ and $t = 0.2$. It is demonstrated that for the larger value of the chemical reaction parameter K = 10 and K = 5, the velocity profile eradically decreasing while comparing to the smaller value of K = 2. Here this trend shows that there is a fall in velocity due to increasing values of the chemical reaction parameter.

Fig.7. illustrates the effects of the magnetic field parameter on the velocity when ($M = 2,4,5$), R=7, K=10, Gr=2, Gc=5 and $t = 0.2$. Here there is a better improvement for the smaller value of magnetic field parameter M = 2 in the velocity of the plate compare to the larger values of M = 4 and M = 5. This shows that the increase in the magnetic field parameter leads to a fall in the velocity. This agrees with the expectations, since the magnetic field exerts a retarding force on the free convective flow.

V.CONCLUSION

The theoretical solution of thermal radiation and hydromagnetic flow past an uniformly accelerated infinite isothermal vertical plate in the presence of chemical reaction of first order. The dimensionless governing equations are solved by the usual Laplace-transform technique. The effect of different parameters like thermal Grashof number, mass Grashof number, chemical reaction parameter, radiation parameter, magnetic field parameter and t are studied graphically. The conclusions of the study are as follows:

(i) The concentartion of the plate increases with decreasing values of the chemical reaction parameter or Schmidt number.
(ii) The plate temperature decreases with increasing values of the thermal radiation parameter.
(iii) The velocity increases with increasing values of the magnetic field parameter or chemical reaction parameter or thermal radiation parameter. But the trend is just reversed with respect to the time t.
(iv)

VI.NOMENCLATURE, GREEK SYMBOLS

C'	species concentration in the fluid
C	dimensionless concentration
C_w	wall concentration
C_∞	concentration far away from the plate
C_p	specific heat at constant pressure
D	mass diffusion coefficient
Gc	mass Grashof number
Gr	thermal Grashof number
g	accelerrated due to gravity

k	thermal conductivity
K	chemical reaction parameter
M	magnetic field parameter
Pr	Prandtl number
R	thermal radiation parameter
Sc	Schmidt number
T	temperature of the fluid near the plate
T_w	temperature of the plate
T_∞	temperature of the fluid far away from the plate
t'	time
t	dimensionless time
u	velocity of the fluid in the x-direction
u_0	velocity of the plate
U	dimensionless velocity
x	spatial coordinate along the plate
y'	coordinate axis normal to the plate
Y	dimensionless coordinate axis normal to the plate
β	volumetric coefficient of thermal expansion
β^*	volumetric coefficient of expansion with concentration
μ	cofficient of viscosity
υ	kinematic viscosity
ρ	density of the fluid
τ	dimensionless skin-friction kg.
θ	dimmensionless temperature
η	similarity parameter
erfc	complementary error function

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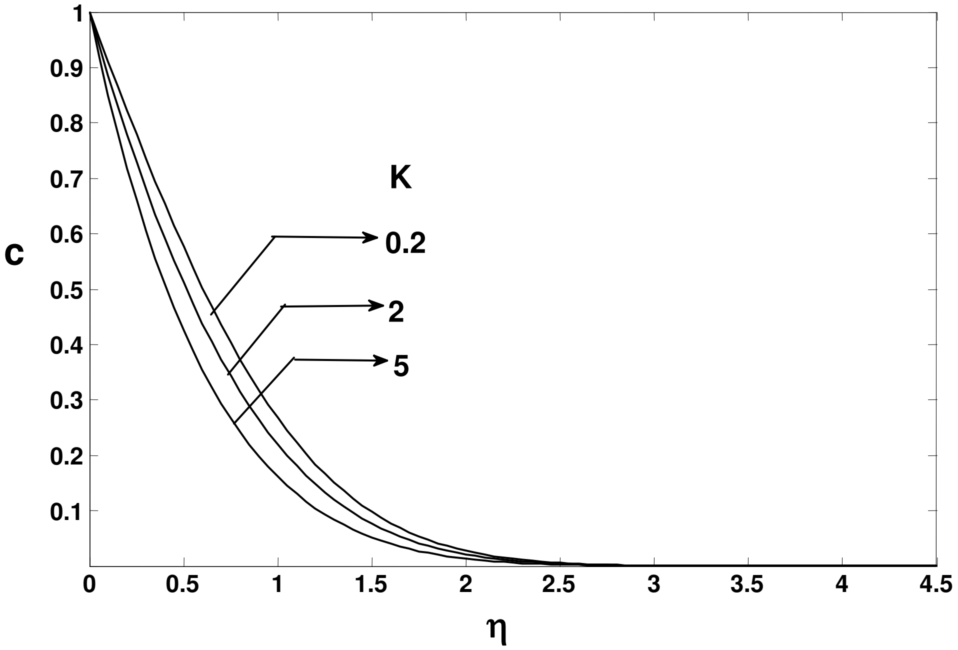

Fig. 1.Concentration profiles for different values of K

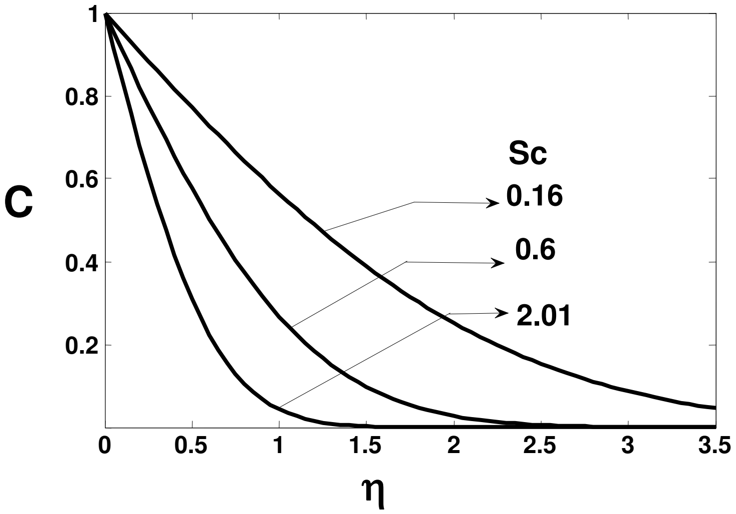

Fig.2.Concentration profiles for different values of Sc

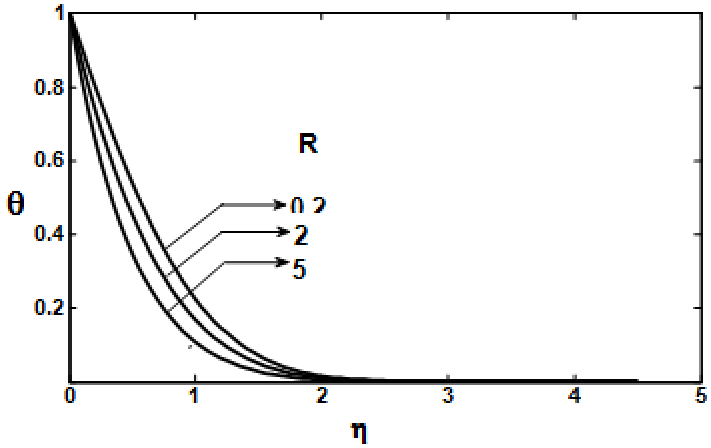

Fig. 3.Temperature profile for different values of R

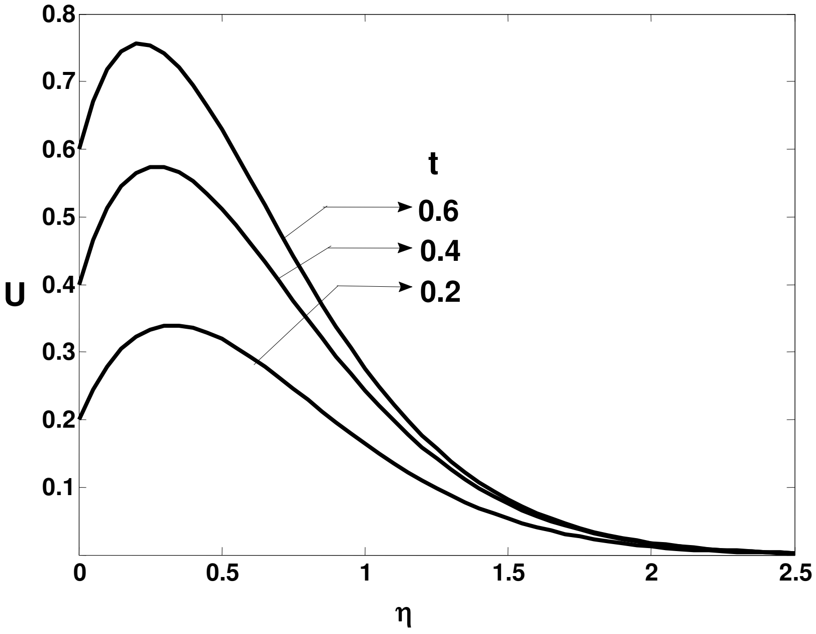

Fig. 4.velocity profiles for different values of t

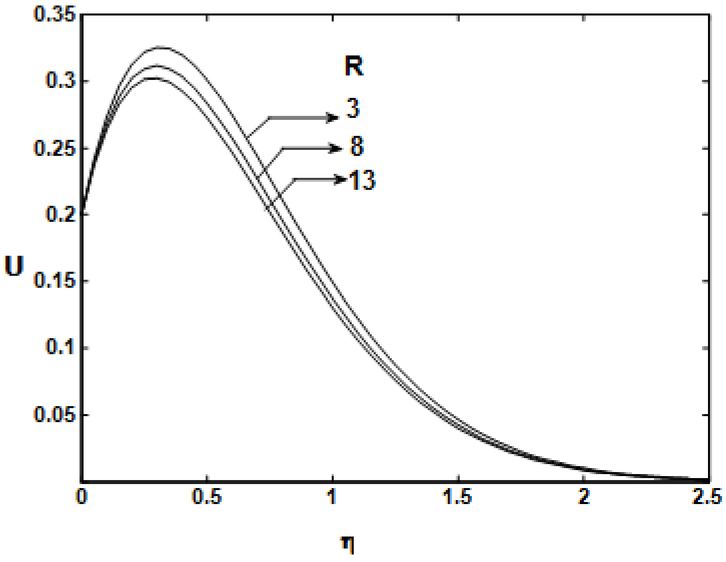

Fig. 5.Velocity profiles for different values of R

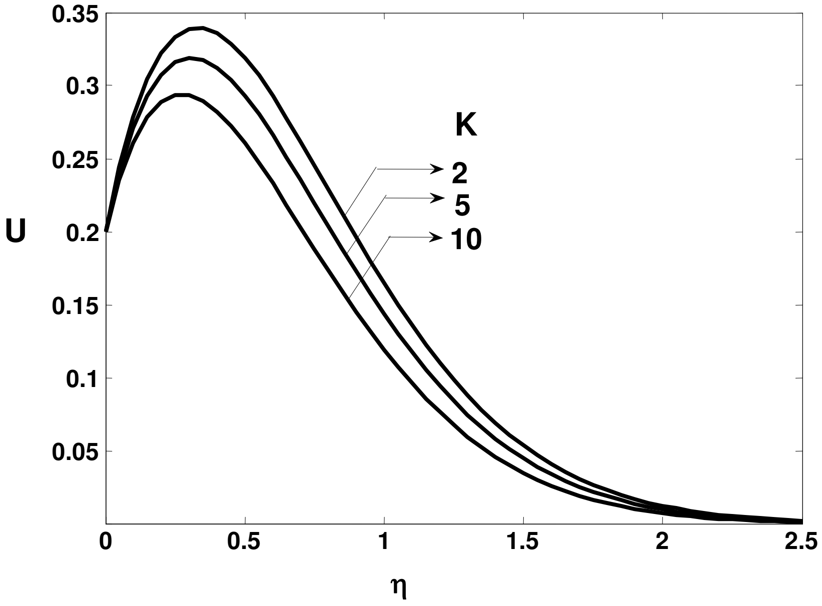

Fig. 6. Velocity profiles for different values of K