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Effects of variable permeability and heat absorption on MHD free convective Newtonian fluid

R. Srilatha[1], G. Bhaskar Reddy[2], Lavanya Srinathuni[3], G. Rami Reddy[4*]

[1]Department of Mathematics, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad - 500090, Telangana, India, Email: bsrilatha82@gmail.com

[2]Department of Science and Humanities, A. M. Reddy Memorial College of Engineering and Technology, Narasaraopeta, Andhra Pradesh, India, Email: drgbhaskarreddy@gmail.com

[3]Department of H & BS, Visvesvaraya College of Engineering and Technology, M. P. Patelguda, Ibrahimpatnam, R. R. Dist, Telangana, India, Email: lavanyaram83@gmail.com

[4]Department of Mathematics, Malla Reddy Engineering College (Autonomous), Maisammaguda, Kompally (Mandal), Medchal Malkajgiri (Dist)-500100, Telangana, India, Email: dr.g.ramireddy76@gmail.com

[*]***Corresponding author: G. Rami Reddy,*** *Department of Mathematics, Malla Reddy Engineering College (Autonomous), Maisammaguda, Kompally (Mandal), Medchal Malkajgiri (Dist)-500100, Telangana, India, Email: dr.g.ramireddy76@gmail.com*

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Abstract

An analysis is performed to study theoretically effects of variable permeability and radiation absorption on MHD free convective Newtonian fluid has been carried out. The governing equations related to the problem are solved for velocity and temperature by using perturbation technique. The variations in velocity, temperature under the effects of several parameters are studied and represented with the use of graphs.

Keywords: MHD, Heat absorption, Porous medium, Variable permeability

1. Introduction

The change of shear stress versus strain rate inside a fluid which depends on viscosity can be classified as a linear, nonlinear or plastic response. When the shear stress is linearly proportional to the strain rate it is known as Newtonian fluid, the constant of proportionality being the coefficient of dynamic viscosity. In case of non-Newtonian fluid the shear stress is nonlinear to strain rate, can even be time dependent and hence a constant coefficient of dynamic viscosity can't be defined. In non-Newtonian fluid flow the property is treated by rheology, the science is related to the deformation and flow of a substance. If viscosity decreases as the shear stress or strain rate remains constant i.e. depends on time such fluids which possess this property are Thixotropic. When shear stress is independent of strain rate the material possesses plastic deformation. Recently, many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes imperative for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles, satellites, and space vehicles are examples of such engineering areas. The effects of suction on boundary layer flow also have greater influence over the engineering application and have been widely investigated by numerous researchers. Various authors have studied the effects of viscous dissipation and constant suction in difference surface geometries [1-20].

MHD free convection fluid flows frequently occur in natural world. Fluid passes through porous medium are of great interest nowadays and many researchers attract towards the applications in the fields of science and technology namely in the area of agriculture engineering to know about the ground water resources, in fuel technology to study the moment of natural gas, oil, and water through the oil reservoirs. Magnetohydrodynamic (MHD) investigation of heat transfer and the boundary layer viscous fluid flow upon a flat plate are momentous in numerous manufacturing processes for example glass-fiber, hot rolling, metal extrusion, drawing of copper wires, MHD pumps, polymer extrusion, artificial fibers, MHD bearings, continuous stretching of plastic films, MHD generator, metal spinning, and wire drawing. In the present theoretical study we have effects of variable permeability and radiation absorption on MHD free convective Newtonian fluid has been carried out. The governing equations related to the problem are solved for velocity and temperature by using perturbation technique. The variations in velocity, temperature under the effects of several parameters are studied and represented with the use of graphs. Also we have recorded the numerical values for local skin friction, rate of heat transfer and discussed their characteristics [21-41].

2. Formulation of the problem

We considered MHD free convective heat absorbing/generating Newtonian fluid with variable temperature. A magnetic field of consistent strength is applied vertical to the plate. Let $x'-$ axis is taken along the plate in the vertically upward direction and the $y'-$axis is taken perpendicular to the plate. At $t \leq 0,$ time the plate is maintained at the temperature higher than ambient temperature and the fluid is at rest. At $t > 0,$ time the plate is linearly accelerated with increasing time in its own plane and the temperature decreases with temperature$\left(\frac{1}{1+at}\right)$. Similarly the species concentration decreases with time t. It is assumed that the effect of viscous dissipation is negligible and by usual Boussineq's and boundary layer approximation. Based on the above considerations the flow is governed by the following equations;

$$\frac{\partial u'}{\partial t'} = \nu \frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_0^2}{\rho} u' - \frac{\nu}{k} u' + g\beta_T \left(T' - T_\infty{}'\right) \tag{1}$$

$$\rho C_p \frac{\partial T'}{\partial t'} = k_T \frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} - Q'\left(T' - T_\infty{}'\right) \tag{2}$$

The corresponding initial and boundary conditions governed are

$$\begin{array}{lll} u' = 0, T' = T_\infty{}', & \text{for all} & y', t' \le 0 \\ u' = U_0 a' t',\ T' = T_\infty + \left(\dfrac{T_s' - T_\infty{}'}{1 + At'}\right) & \text{at } y' = 0 & \multirow{2}{*}{$\Big\}\, t' > 0$} \\ u' \to 0, T' \to T_\infty{}' & \text{as } y' \to \infty & \end{array} \tag{3}$$

where $A = \frac{t' U_0^2}{\nu}$ the non-dimensionless quantities are as follows

$$u = \frac{u'}{U_0}, y = \frac{y' U_0}{\nu}, t = \frac{t' U_0{}^2}{\nu}, \theta = \frac{T' - T_\infty{}'}{T_s' - T_\infty{}'}, K = \frac{k U_0{}^2}{\nu^2}, a = \frac{\nu a'}{U_0{}^2}$$

$$Gr = \frac{\nu \beta_T g \left(T_s{}' - T_\infty{}'\right)}{U_0{}^3},\ \Pr = \frac{\nu \rho C_p}{k_T},\ Q = \frac{\nu^2 Q'}{k_T U_0{}^2},\ M = \frac{\sigma B_0{}^2 \nu}{\rho U_0{}^2} \tag{4}$$

$$R = \frac{16 a^* \nu^2 \sigma T_\infty^3}{k u_0^2}$$

The non – dimensional parameters applied to the equations (1) – (3) and they reduces to following form

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} - Mu - \frac{1}{K} u + Gr\theta \tag{5}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr} \frac{\partial^2 T\theta}{\partial y^2} - \frac{1}{\Pr}\left(R + Q\right)\theta \tag{6}$$

The corresponding initial and boundary conditions are

$$\left.\begin{array}{lll} u=0,\theta=0, & \text{for all} & y,t\le 0 \\ u=a\,t, \quad \theta=\dfrac{1}{1+t} & \text{at} \quad y=0 & \\ u\to 0,\theta\to 0 & \text{as} \quad y\to\infty & \end{array}\right\} \; t>0 \tag{7}$$

3. Solution of the problem

The linear partial differential equations (5) – (6) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (7). However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. This can be done by representing the velocity and temperature of the fluid in the neighbourhood of the fluid in the neighbourhood of the plate as;

$$\begin{aligned} u &= u_0(y)+\varepsilon e^{a\,t}u_1(y)+\,.... \\ \theta &= \theta_0(y)+\varepsilon e^{a\,t}\theta_1(y)+.... \end{aligned} \tag{8}$$

Substituting (8) in Equation (5) – (6) and equating the harmonic and non – harmonic terms, we obtain

$$u_0''-\beta_2 u_0=-Gr\,\theta_0 \tag{9}$$

$$u_1''-\beta_3 u_1=-Gr\,\theta_1 \tag{10}$$

$$\theta_0''-\left(Q+R\right)\theta_0=0 \tag{11}$$

$$\theta_1''-\beta_1\theta_1=0 \tag{12}$$

The corresponding boundary conditions can be written as

$$\begin{aligned} & u_0=at,\, u_1=0,\theta_0=\frac{1}{1+t},\, \theta_1=0 \qquad at\;\; y=0 \\ & u_0\to 0,u_1\to 0,\theta_0\to 0,\theta_1=0 \qquad as\;\; y\to\infty \end{aligned} \tag{13}$$

Solving equations (9) – (12) under the initial and boundary conditions; we get the solution as:

$$\theta_0=L_1\,e^{-\sqrt{Q}\,y}; \qquad \theta_1=0$$

$$u_0=L_1\,e^{-\sqrt{Q}\,y}+L_3\,e^{-\sqrt{\beta_2}\,y}; \quad u_1=0$$

In view of the above equation (8) can be written as:

$$u=L_1\,e^{-\sqrt{Q}\,y}+L_3\,e^{-\sqrt{\beta_2}\,y}$$

$$\theta=L_1\,e^{-\sqrt{Q}\,y}$$

Skin friction coefficient:

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}=-QL_1-\beta_2 L_3$$

Rate of heat transfer:

$$\left(\frac{\partial \theta}{\partial y}\right)_{y=0}=-Q\,L_1$$

Appendix

$$\beta_1=\left(R+Q+\Pr at\right);\beta_2=\left(M+\frac{1}{K}\right);\beta_3=\left(\beta_2+at\right)$$

$$L_1=\left(\frac{1}{1+t}\right),L_2=-\frac{GrL_1}{Q-\beta_2},L_3=\left(at-L_1\right)$$

4. Results and discussion

This segment is devoted to investigates the significance of fluid parameters on fluid motion, thermal distribution profiles as demonstrated for various parameters included in the problem, viz., M,Q,a,t,K are plotting the velocity profiles, temperature profiles, skin friction and Nusselt number are pictorially has been showed from figures (1) - (9). In this paper we considered the radiation parameter $R=0$ for justification. The influence of magnetic parameter $\left(M\right)$ is presented graphically in figure (1). As expected, the mean velocity decreases with increasing magnetic parameter. The effect of the transverse magnetic field leads to a resistive type of force similar to drag force, which tends to resist the retarding flow of viscoelastic fluid flow. Figure (2) depicts the effect of heat absorption $\left(Q\right)$ on velocity profiles, it is clear that the velocity decreases with increasing values of heat absorption. This is expected since the presence of a heat sink in the boundary layer absorbs energy. Which in turn cause the temperature of the fluid to decrease. This decrease in temperature produces a decrease in the flow field due to the buoyancy effect which couples the flow and thermal field. The variation of velocity profiles with dimensionless permeability parameter $\left(K\right)$ is presented in figure (3). This figure clearly indicates that the value of velocity profiles decreases with increasing the dimensionless permeability parameter. Figure (4) represents the velocity profiles for different values of accelerating parameter $\left(a\right)$. From the figure the velocity is found to increase with an increase in accelerating parameter. It is also found that the fluid velocity due to the impulsive start of the plate (accelerating parameter is equal to zero) is less than due to the exponentially accelerated start (accelerating parameter is not equal to zero). Figure (5) illustrates the effects of the dimensionless time parameter $\left(t\right)$. It is observed from this figure that velocity goes on increasing with the increase of dimensionless time parameter. Figure (6) shows the variation of temperature profiles for different values of heat absorption parameter $\left(Q\right)$. It is seen from this figure that temperature profiles decrease with an increasing of heat absorption parameter in the kinematic energy as well as thermal energy of the fluid. Typical variation of the temperature profiles are shown in figure (7) for different values of dimensionless time parameter (t). The results show that an increase of dimensionless time parameter results in a decreases. Hence the momentum and thermal boundary layers get thinner in case of heat absorbing fluids. Figure (8) depicts the variations in skin friction. The skin friction decreases with increases in heat source parameter (Q). Figure (9) displays the effect of dimensionless time parameter (t) on Nusselt number. It is clear that the Nusselt number increases with the increasing values of dimensionless time parameter.

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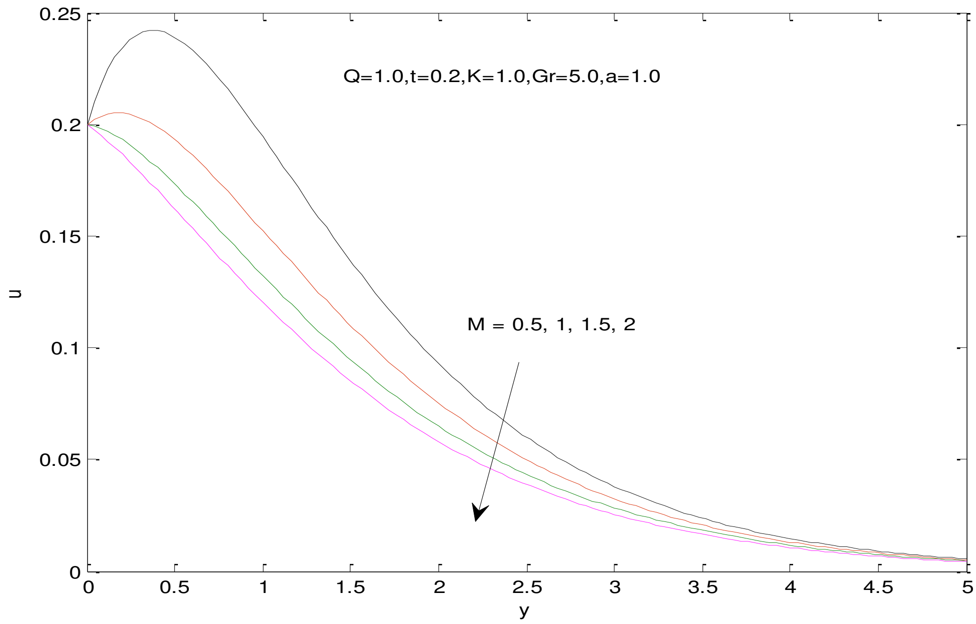

Figure (1): Velocity profiles for different values of M

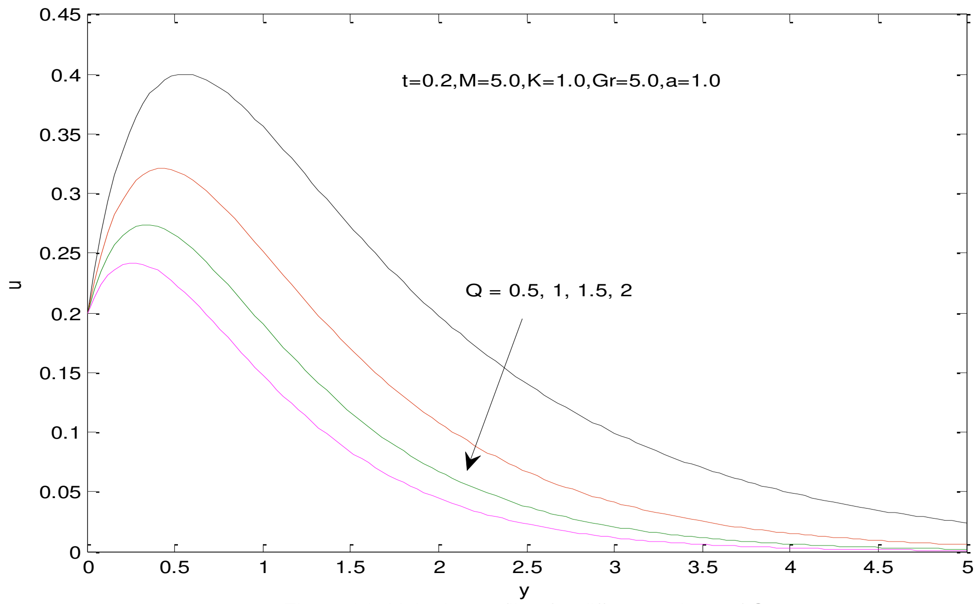

Figure (2): Velocity profiles for different values of Q

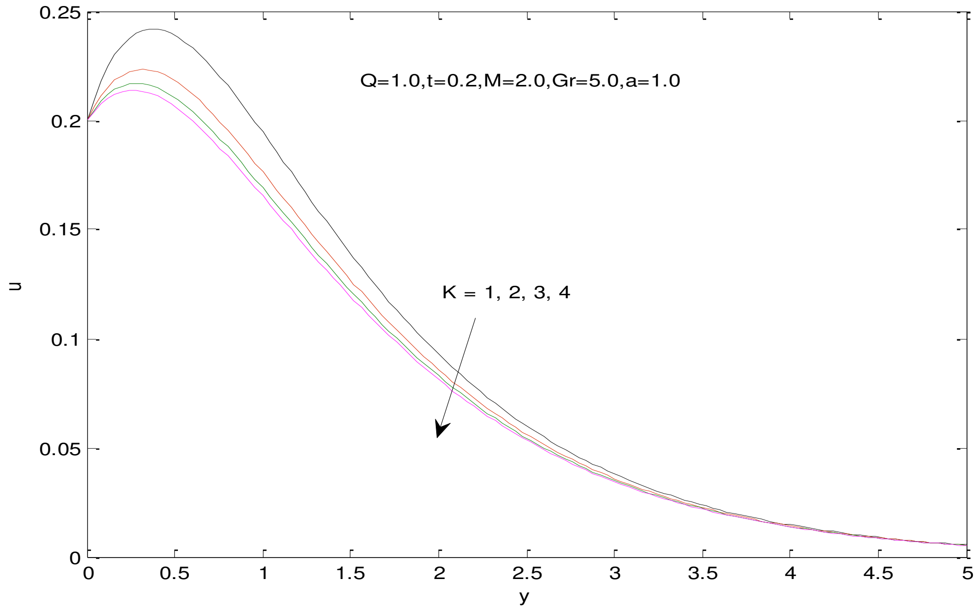

Figure (3): Velocity profiles for different values of K

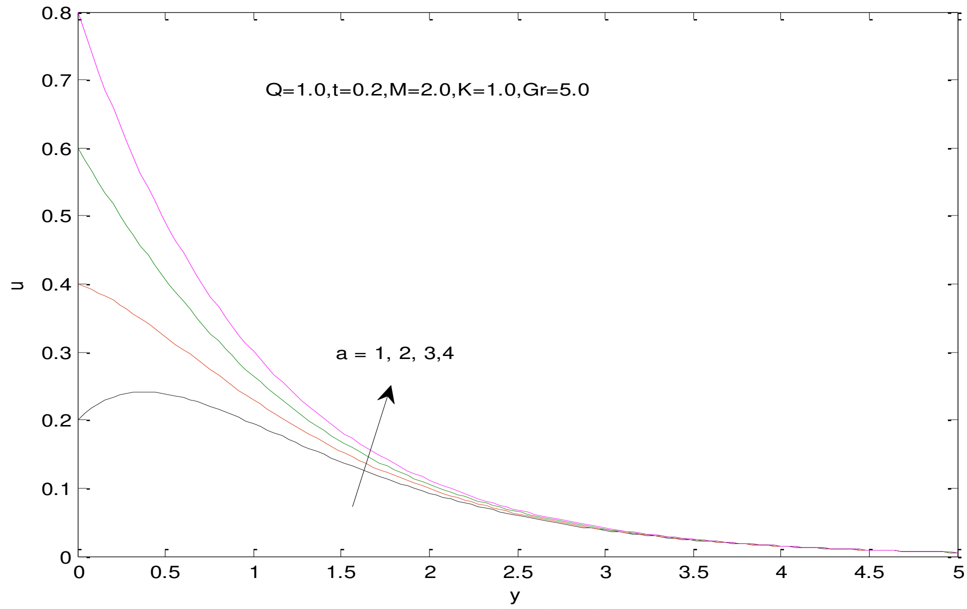

Figure (4): Velocity profiles for different values of a

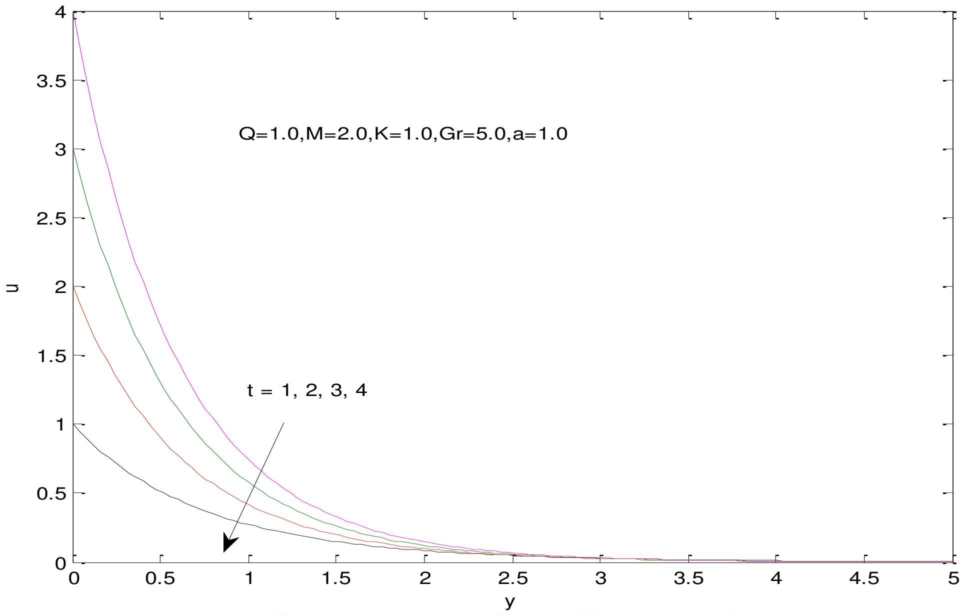

Figure (5): Velocity profiles for different values of t

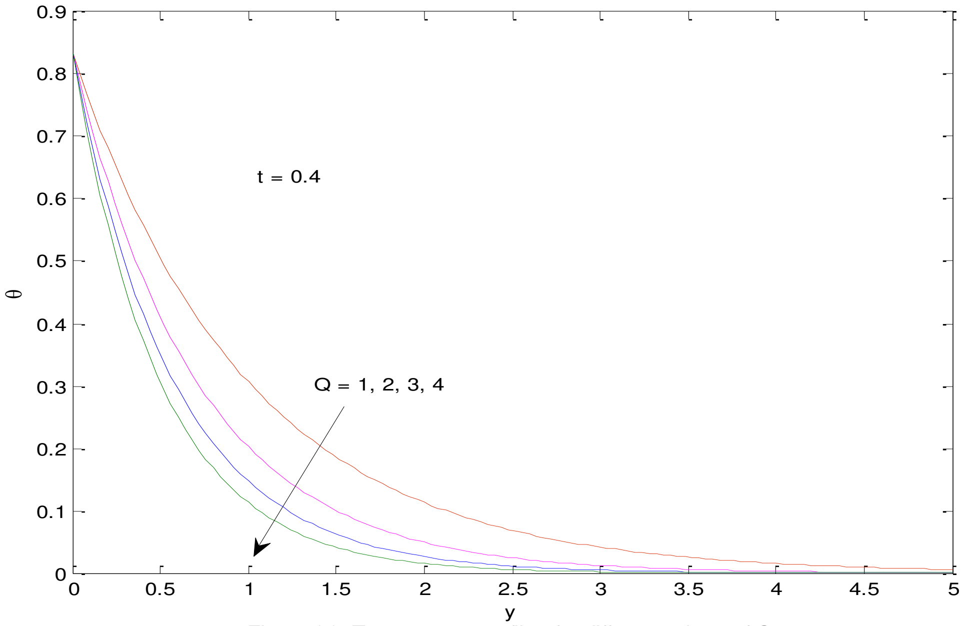

Figure (6): Temperature profiles for different values of Q

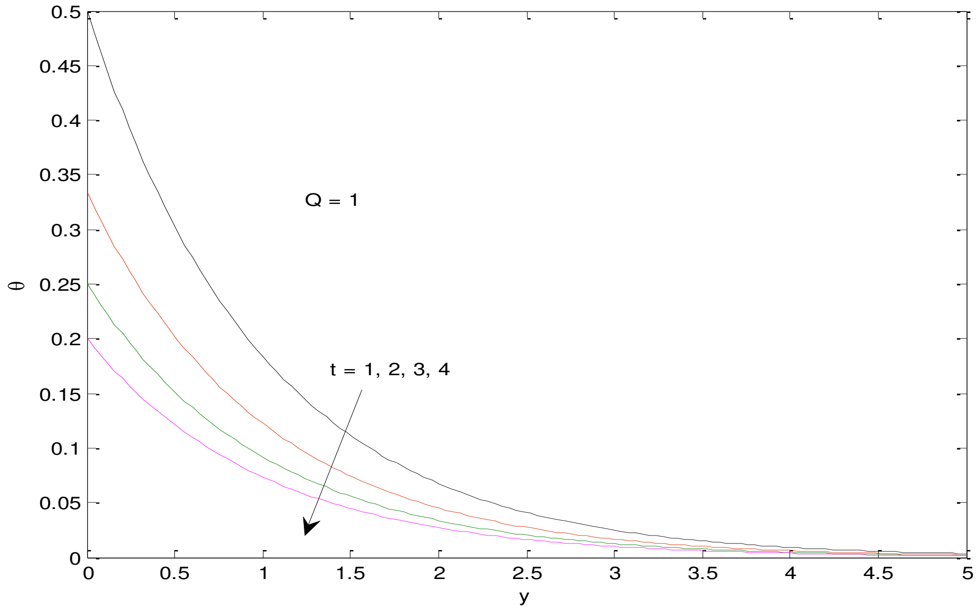

Figure (7): Temperautre profiles for different values of t

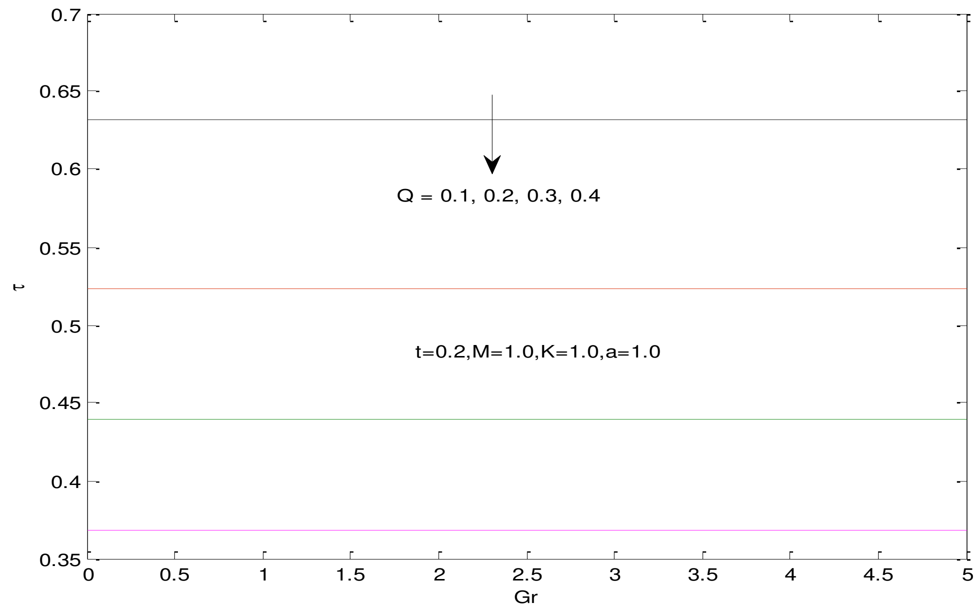

Figure (8): Skin friction for different values of Q

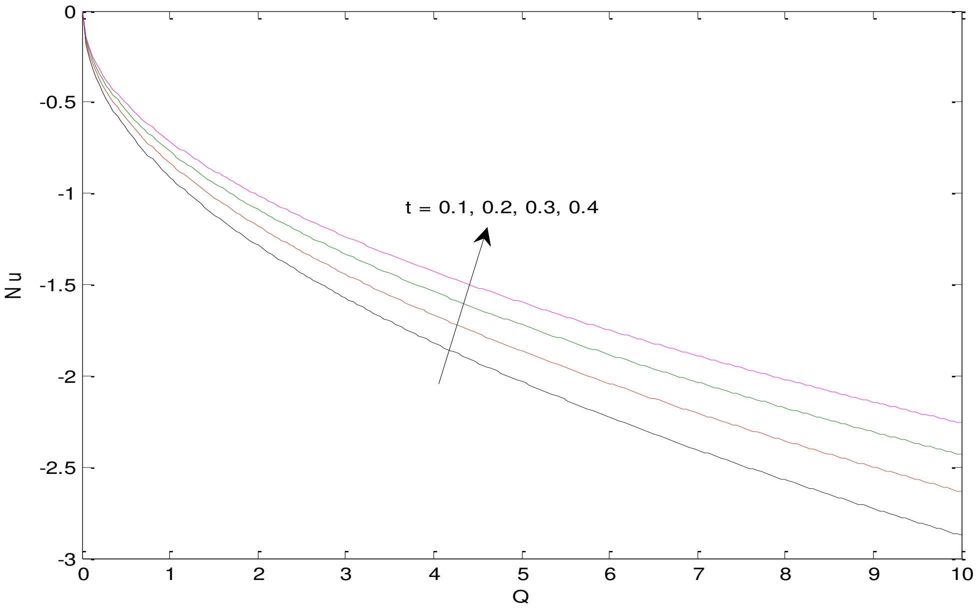

Figure (9): Nusselt number for differet values of t