# RADIATION EFFECT ON MHD FREE CONVECTIVE HEAT ABSORBING NEWTONIAN FLUID WITH VARIABLE TEMPERATURE

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## Abstract

This paper presents a comprehensive analysis of the radiation effect on MHD free convective heat absorbing Newtonian fluid with the consideration of variable temperature. The governing equations related to the problem are solved for velocity and temperature by using perturbation method. The variations in velocity, temperature, local skin friction and rate of heat transfer under the effects of several parameters are studied and represented with the use of graphs.

**Keywords:** MHD, Heat Source/Sink, Porous Medium, Variable Temperature

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## INTRODUCTION

Free convection flow of magnetohydrodynamic fluid has attracted many researchers in view of its numerous applications in geophysics, astrophysics, meteorology, aerodynamics, magnetohydrodynamic power generators and pumps, boundary layer control energy generators, accelerators, aerodynamics heating, polymer technology, petroleum industry, purification of crude oil, and in material processing such as extrusion, metal forming, continuous casting wire, and glass fiber drawing. (Pohlhausen, 1921) has been invited Der Warmeaustrausch Zwischen fasten know and Flussigkeiten mit, (Chenna Kesavaiah et. al., 2022) studied the radiation and mass transfer effects on MHD mixed convective flow from a vertical surface with heat source and chemical reaction, (Ostrach, 1953) described an analysis of laminar free convection flow and heat transfer along a flat plate parallel to the direction of the generating body force, (Mallikarjuna Reddy et. al., 2019) explained the radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, (Ch Kesavaiah et. al., 2013) Effects of radiation and free convection currents on unsteady Couette flow between two vertical parallel plates with constant heat flux and heat source through porous medium, (Seigel, 1958) observed that the transient free convection from a vertical flat plate, (Karunakar Reddy et. al., 2013) illustrated the MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, International Journal of Innovative Research in Science, (Chenna Kesavaiah et. al., 2013) intended their ideas on natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, (Gebhart, 1961) motivated study on the transient natural convection from vertical elements, (Rami Reddy et. al., 2021) expressed the Hall Effect on MHD flow of a viscoelastic fluid through porous medium over an infinite vertical porous plate with heat source.

The role of thermal radiation is of major importance in some industrial applications such as glass production and furnace design and in space technology applications, such as cosmical flight aerodynamics rocket, propulsion systems, plasma physics and space craft re-entry aerothermodynamics which operate at high temperatures. When radiation is taken into account, the governing equations become quite complicated and hence many difficulties arise while solving such equations. Motivated studies of some authors by (Grif et. al., 1971) illustrated laminar convection of radiating gas in a vertical channel, (Chenna Kesavaiah et. al., 2022) described the radiation, radiation absorption, chemical reaction and hall effects on unsteady flow past an isothermal vertical plate in a rotating fluid with variable mass diffusion with heat source, (Hossain and Takhar, 1996) observed that the radiation effects on mixed convection along a vertical plate with uniform surface temperature, (Chenna Kesavaiah et. al. [14] explained in detailed information on MHD effect on boundary layer flow of an unsteady incompressible micropolar fluid over a stretching surface, (Chamkha et. al., 2003) expressed their ideas on thermal radiation effects on MHD forced convection flow adjacent to a non-isothermal wedge in the presence of heat source or sink, (Chamkha, 2002) worked out on thermal radiation and buoyancy effects on hydromagnetic flow over an accelerating permeable surface with heat source or sink, (Ganesan and Loganathan, 2002) reviewed on radiation and mass transfer effects on flow of an incompressible viscous fluid past a moving cylinder, (Chenna Kesavaiah et. al., 2022) measured on chemical reaction, heat and mass transfer effects on MHD peristaltic transport in a vertical channel through space porosity and wall properties, (Chenna Kesavaiah and Satyanarayana, 2013) intended their plains on MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, (Mallikarjuna Reddy et. al., 2018) motivated study on the effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates.

The research in MHD steam of electrically conductive liquid is really of incredible importance because of the magnetic field impacts on the regulation of boundary layer steam control as well as the adequacy of various frameworks utilizing electrically conductive fluids and their application in many engineering problems studied by (Chenna Kesavaiah et. al., 2022) observed on chemical reaction and MHD effects on free convection flow of a viscoelastic dusty gas through a semi infinite plate moving with radiative heat transfer, (Srinathuni Lavanya and Chenna Kesavaiah, 2017) explained in detailed information on heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, (Chenna Kesavaiah and Sudhakaraiah, 2014) studied the effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, (Ch Kesavaiah et. al., 2012) motivated study on radiation absorption, chemical reaction and magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux, (Ch Kesavaiah et. al., 2012) explained in detailed information on radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation, (Chenna Kesavaiah et. al., 2013) expressed on radiation and Thermo - Diffusion effects on mixed convective heat and mass transfer flow of a viscous dissipated fluid over a vertical surface in the presence of chemical reaction with heat source, (Chenna Kesavaiah and Venkateswarlu, 2020) described the chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, (Chenna Kesavaiah et. al., 2018) illustrated on MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium with effects of hall current, rotation and Dufour effects, (Chenna Kesavaiah et. al., 2021) observed that the radiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, (Chenna Kesavaiah et. al., 2017) measured on an analytical study on induced magnetic field with radiating fluid over a porous vertical plate with heat generation.

The aim of the present study is the radiation effect on MHD free convective heat absorbing Newtonian fluid with the consideration of variable temperature. The governing equations related to the problem are solved for velocity and temperature by using perturbation method. The variations in velocity, temperature, local skin friction and rate of heat transfer under the effects of several parameters are studied and represented with the use of graphs.

## 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 $t \le 0,$ 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:

$$\frac{\partial u^*}{\partial t^*} = \nu \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_T \left(T^* - T_\infty\right) - \frac{\sigma B_0^2}{\rho} u^* - \frac{\nu}{k} u^* \qquad (1)$$

$$\rho C_p \frac{\partial T^*}{\partial t^*} = k_T \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\partial q_r^*}{\partial y^*} - Q^*\left(T^* - T_\infty\right) \qquad (2)$$

The corresponding initial and boundary conditions governed are

$$\begin{aligned} & u^* = 0, T^* = T_\infty, \quad \textit{for all} \quad y^*,\ t^* \le 0 \\ & t^* > 0 : \left.\begin{aligned} & u^* = U_0 a^* t^*, \\ & T^* = T_\infty + \left(\frac{T_s^* - T_\infty}{1 + At^*}\right) \end{aligned}\right\} at \ \ y^* = 0 \qquad (3) \\ & u^* \to 0, T^* \to T_\infty \qquad as \ \ y^* \to \infty \end{aligned}$$

where $A = \frac{t^* U_0^2}{\nu}$ the non-dimensionless quantities are as follows

$$u = \frac{u^*}{U_0}, \quad y = \frac{y^* U_0}{\nu}, \quad t = \frac{t^* U_0^{\,2}}{\nu}$$

$$K = \frac{k U_0^{\,2}}{\nu^2}, \; a = \frac{\nu a^*}{U_0^{\,2}}, \; F = \frac{4 \nu I^*}{\rho C_p U_0^2}$$

$$Gr = \frac{\nu \beta_T g \left( T_s^* - T_\infty \right)}{U_0^{\,3}}, \quad \Pr = \frac{\nu \rho C_p}{k_T} \qquad (4)$$

$$\frac{\partial q_r^*}{\partial y^*} = 4\left( T^* - T_\infty \right) I^*, \; M = \frac{\sigma B_0^{\,2} \nu}{\rho U_0^{\,2}}$$

$$Q = \frac{\nu^2 Q^*}{k_T U_0^{\,2}}, \; \theta = \frac{T^* - T_\infty}{T_s^* - T_\infty}$$

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

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

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

The corresponding initial and boundary conditions are

$$\begin{aligned} & u = 0, \theta = 0, && \textit{for all} \quad y, t \le 0 \\ & t > 0 : u = a\,t, \theta = \frac{1}{1+t} && at \;\; y = 0 \qquad (7) \\ & u \to 0, \theta \to 0 && as \;\; y \to \infty \end{aligned}$$

## 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;

$$\begin{aligned} u &= u_0(y) + \varepsilon e^{at} u_1(y) \\ \theta &= \theta_0(y) + \varepsilon e^{at} \theta_1(y) \end{aligned} \qquad (8)$$

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

$$u_0'' - \beta_2 u_0 = -Gr\,\theta_0 \qquad (9)$$

$$u_1'' - \beta_3 u_1 = -Gr\,\theta_1 \qquad (10)$$

$$\theta_0'' - \beta_4 \theta_0 = 0 \qquad (11)$$

$$\theta_1'' - \beta_1 \theta_1 = 0 \qquad (12)$$

The corresponding boundary conditions can be written as

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

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

$$\theta_0 = L_1 e^{-\sqrt{\beta_4}\, y}; \theta_1 = 0$$

$$u_0 = L_1 e^{-\sqrt{\beta_4}\, y} + L_3 e^{-\sqrt{\beta_2}\, y}; u_1 = 0$$

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

$$u = L_1 e^{-\sqrt{\beta_4}\, y} + L_3 e^{-\sqrt{\beta_2}\, y}$$

$$\theta = L_1 e^{-\sqrt{\beta_4}\, y}$$

**Skin friction Coefficient:**

$$\tau = \left( \frac{\partial u}{\partial y} \right)_{y=0} = -\beta_4 L_1 - \beta_2 L_3$$

**Rate of heat transfer:**

$$\left( \frac{\partial \theta}{\partial y} \right)_{y=0} = -\beta_4 \, L_1$$

**Appendix**

$$L_1 = \left( \frac{1}{1+t} \right), L_2 = -\frac{Gr L_1}{\beta_4 - \beta_2}, L_3 = \left( at - L_1 \right)$$

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

$$\beta_3 = \left( \beta_2 + at \right); \beta_4 = \left( Q + F \Pr \right)$$

## RESULTS AND DISCUSSION

A representative set of numerical results is shown graphically in figures (1) – (13) to illustrate the influence of physical parameters viz., radiation parameter$(F)$, accelerating parameter$(a)$, porous parameter$(K)$, magnetic parameter$(M)$, Prandtl number$(\mathrm{Pr})$, heat source/absorption parameter$(Q)$, dimensionless time parameter$(t)$. In figure (1), the variation of velocity profiles in the presence of radiation parameter are indicated. The radiation$(F)$ direction denotes the radial coordinate and the $u$ direction the x-component of the velocity with $(F=1,2,3,4)$ the effect of radiation. The velocity profiles decrease with increasing radiation values. The variation of accelerating parameter $(a=0.5,0.6,0.7,0.8)$ in velocity profiles shown in figure (2), it is observed that an increasing accelerating parameter the velocity profiles as increases. Effects of the porous parameter $(K=0.1,0.2,0.3,0.4)$ on the velocity profiles depicted in figure (3). It is observed that the velocity decrease for increasing values of porous parameter. Furthermore, the momentum boundary layer thickness decreases as porous parameter increases. Figure (4) plotted for magnetic parameter$(M=2,4,6,8)$ on the velocity profiles. Here magnetic parameter increases as the velocity increases. Figure (5) shows the effect of Prandtl number $(\mathrm{Pr}=0.2,0.3,0.4,0.5)$ on velocity profiles; it is clear that the velocity decreases as Prandtl number increases. The velocity profiles for various values of heat source/absorbing parameter $(Q=0.5,1,1.5,2)$ shown in figure (6), it is clear that the velocity increases as heat source/absorbing parameter increases. The velocity profiles for different values of dimensionless parameter $(t=0.5,1,1.5,2)$ shown in figure (7); it is clear that the velocity increases with increases in dimension less parameter. There is a direct relationship between temperature and radiation parameter$(F=1,2,3,4)$. It can clearly be seen in figure (8). The temperature of the fluid decreases with increasing radiation parameter. The temperature distribution for different values of Prandtl number $(\mathrm{Pr}=0.71,1,7,100)$ shown in figure (9); it is observed that temperature distribution decreases as Prandtl number increases. This is in agreement with the physical fact that the thermal boundary layer thickness decreases with increasing Prandtl number. The effects of heat source/absorbing parameter $(Q=1,2,3,4)$ and dimensionless parameter$(t=1,2,3,4)$ are displayed in figure (10) and (11); the temperature decreases with increasing heat source/absorbing parameter and dimensionless parameter. The effect of radiation parameter $(F=0.5,0.6,0.7,0.8)$ on local skin friction is shown in figure (12). It is observed that the local skin friction decreases as radiation parameter increases. It is observed form figure (13) that an increases radiation parameter $(F=1,2,3,4)$ results in decreases the heat transfer (Nusselt number) profiles.

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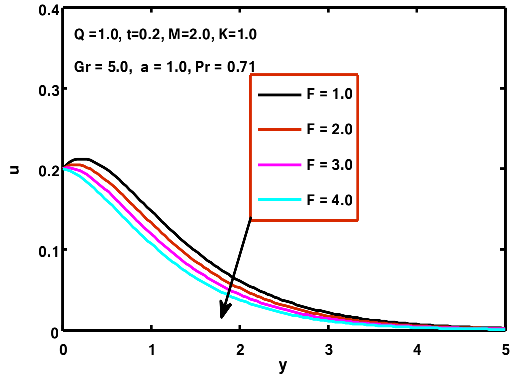

Fig. (1): Velocity profiles for different values of F

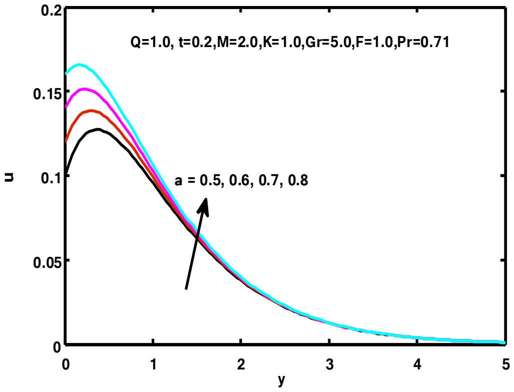

Fig (2): Velocity profiles for different values of a

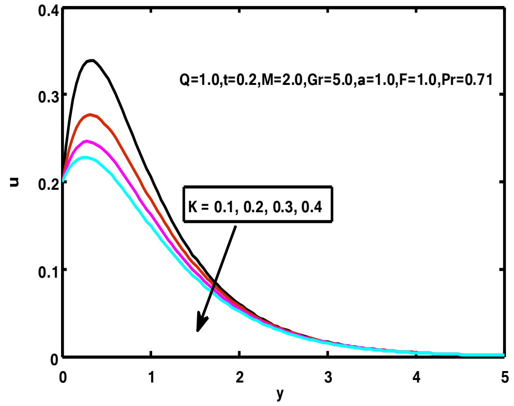

Fig. (3): Velocity profiles for different values of K

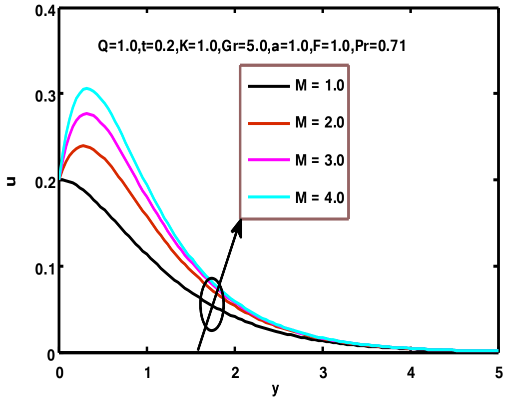

Fig. (4): Velocity profiles for different values of M

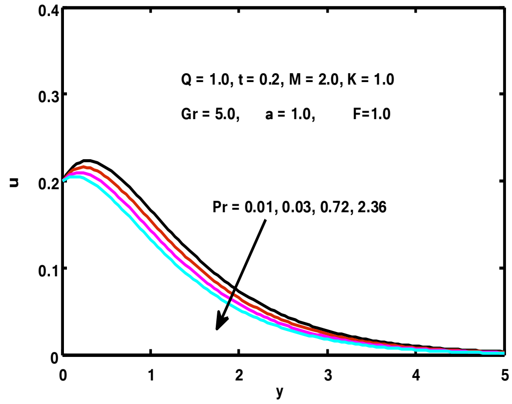

Fig. (5): Velocity profiles for different values of Pr

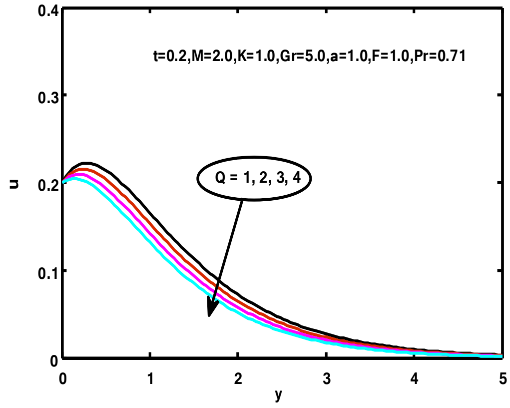

Fig. (6): Velocity profiles for different values of Q

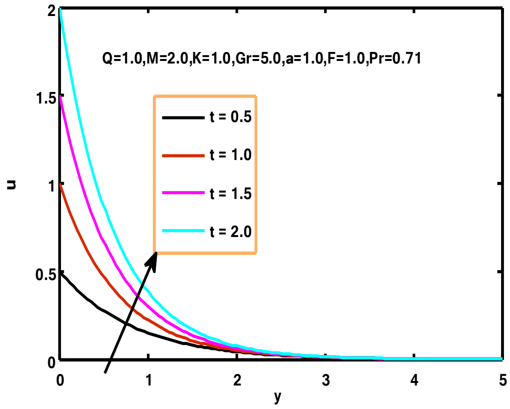

Fig. (7): Velocity profiles for different values of t

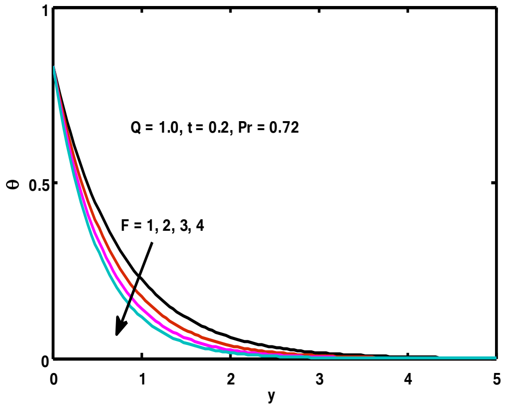

Fig. (8): Temperature profiles for different values of F

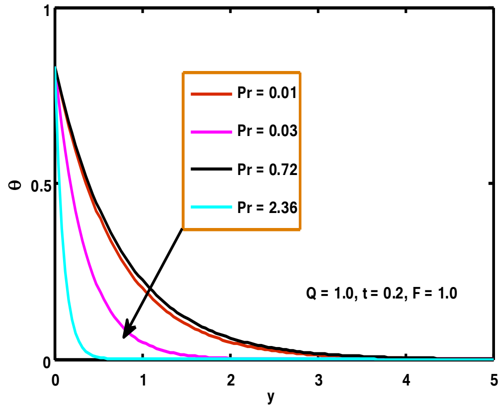

Fig. (9): Temperature profiles for different values of F

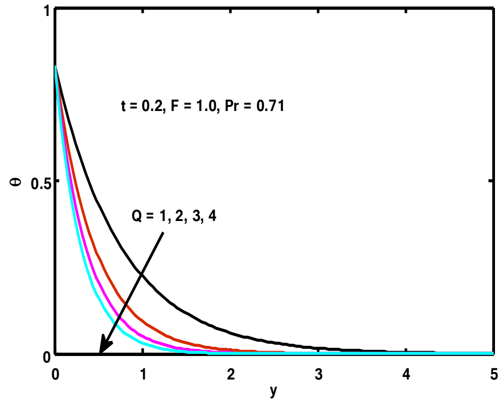

Fig. (10): Temperature profiles for different values of Q

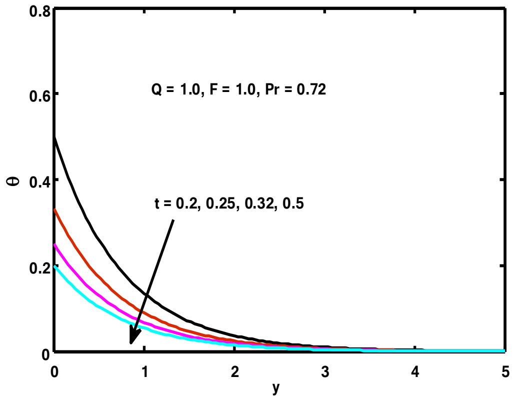

Fig. (11): Temperature profiles for different values of F

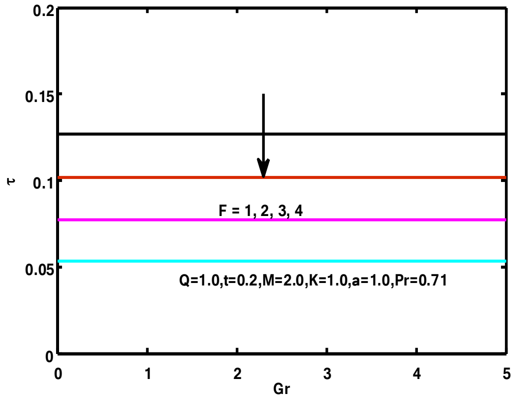

Fig. (12): Skin friction for different values of F

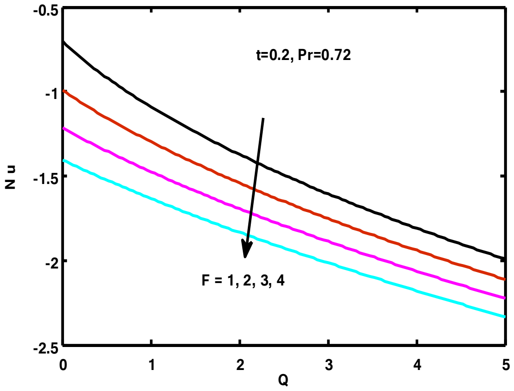

Fig. (13): Nusselt number for different values of F