IMPACT OF MAGNETIC FIELD ON AN OSCILLATORY FLOW OF A NON-NEWTONIAN FLUID WITH RADIATION AND HEAT GENERATION

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Abstract

An anticipated outcome that is intended paper is to investigate impact of magnetic field on an oscillatory flow of a non-Newtonian fluid with thermal radiation and heat generation bounded by a vertical plane surface have been studied. Analytical solution for quasi-linear hyperbolic partial differential equations is obtained by using perturbation technique. Solution for mean velocity and mean temperature profiles for various combinations of parameters were discussed through graphically by using MATLAB code.

Keywords: *Thermal radiation, oscillatory flow, Heat transfer, Magnetic field*

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INTRODUCTION

When the fluid is electrically conducting and exposed to a magnetic field the Lorentz force is also active and interacts with the buoyancy force in governing the flow and temperature fields. Employment of an external magnetic field has increasing applications in material manufacturing industry as a control mechanism since the Lorentz force suppresses the convection currents by reducing the velocities. Study and thorough understanding of the momentum and heat transfer in such a process is important for the better control and quality of the manufactured products. Previous work on the MHD natural convection flow with mass and heat transfer in electrically conducting fluid had taken much attention in the literature because of their wide applications in the field of electrical power generation, meteorology, solar physics, chemical engineering, and geophysics. Under different boundary conditions, there are some exact solutions for such motion of viscous incompressible fluids over an infinite vertical plate.[1-11]

Non-Newtonian nanoliquid mass and heat transfer characteristics over curved geometries saturated in porous media has numerous industrial and scientific applications, such as, material processing, food storage, applied geophysics, production of heavy crude oil, oil reservoir engineering and many other areas where shear stress of the material flow cannot be determined by Newtonian relationships. Further, nanoliquids are emerged and which have higher rates of heat transfer compared to the common liquids. Many experimental theoretical studies suggested that there are many mechanisms which enhances the thermal conductivity of the general fluids, such as, shape of nanoparticle, thermophoresis, Magnus effect, surface area of nanoparticle, size of nanoparticle, Brownian motion, agglomeration, etc. Of which thermophoresis and Brownian motion are the most influencing parameters. These nanofluids are mostly utilized in nuclear reactors, manufacturing industry, vehicle cooling, food processing etc. Non-Newtonian fluids are well-known for their many classical features. With distinguished rheology and intricate nature, scientists are interested in exploring additional fascinating properties of such materials. The liquids of non-Newtonian provide significant contributions to a variety of making industries, chemical remediation and engineering.[12-22]

There are some characteristics of fluids that accept shape changes and flow’s ability. Those characteristics are usually caused by inability’s fluid function to hold a shear stress in static equilibrium. The consequence of this trait is Pascal's law which emphasizes the importance of pressure in characterizing fluid forms. Fluids can be characterized as Newtonian Fluids and Non-Newtonian Fluids. Newtonian fluid is a fluid whose behaviour is consistent with Newton's law, for example, water. Investigating the thermal behaviour and flow field within porous material is a relatively old topic in heat transfer and fluid mechanics. The porous media is used in industries such as thermal insulation technology, heat exchangers design, casting industries. The study of heat transfer near irregular surfaces is of fundamental importance; that is because it is often met in many practical applications and devices such as flat-plate solar collectors and flat-plate condensers in refrigerators. Real-world examples of non-Newtonian materials include molten, starch suspension, pharmaceuticals, blood, cosmetics, paints, etc., such materials characterization is often offered in three forms: differential and integral fluid types and types of rate. Several developed designing implementations have an investigation of the non-Newtonian fluids. This comprises polymer, clay digging for petroleum, food processing and biological gels. Furthermore, the flux of heat transport with non-Newtonian fluids has an important impact on paper manufacture, glass sheet blowing, and hot rolling.[23-36]

MATHEMATICAL FORMULATION

Consider a two-dimensional, unsteady free convective flow of a viscoelastic incompressible fluid which is bounded by a vertical infinite plane surface, embedded in a uniform porous medium with heat source under the action of uniform magnetic field applied normal to the direction of the flow. The effect of induced magnetic field is neglected. The magnetic Reynolds number is assumed to be small. The terms due to electrical dissipation is neglected in energy equation. We assume that the surface absorbs the fluid with a constant velocity and the velocity far away from the surface oscillates about a mean constant value with direction parallel to x' -axis. x' - axis is taken along the plane surface with direction opposite to the direction of the gravity and the y' -axis is taken to be normal to the plane surface. The heat due to viscous and joule dissipation are neglected for small velocities. All the fluid properties are assumed constant except that the influence of the density variation with temperature is considered only in the body force term. It is considered that the free stream velocity oscillates in magnitude but not in direction. Under the above stated assumptions and taking the usual Boussinesque approximation into account, the governing equations for the flow and temperature field in dimensionless form are given as under Walters.[37-38]

$$\frac{\partial u}{\partial t}-\frac{\partial u}{\partial \eta}=v\frac{\partial^2 u}{\partial \eta^2}+k_0\left(\frac{\partial^3 u}{\partial \eta^3}-\frac{\partial^3 u}{\partial \eta^2 \partial t}\right)-M\,u-\frac{1}{K}u+Gr\,T \quad (1)$$

$$\frac{\partial T}{\partial t}-\frac{\partial T}{\partial \eta}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial \eta^2}+\frac{\partial^2 T}{\partial t\,\partial \eta}-\frac{1}{\Pr}R\,T-\frac{1}{\Pr}\,Q\,T \quad (2)$$

Initial condition has been neglected as the problem is in semi-infinite region. The relevant boundary conditions in dimensionless form are

$$\begin{aligned} &u=-\left(1+\varepsilon e^{\text{int}}\right), T=\left(1+\varepsilon e^{\text{int}}\right)\ at \quad \eta=0 \\ &u\to 0, T\to 0 \qquad\qquad as \quad \eta\to\infty \end{aligned} \quad (3)$$

The dimensionless quantities introduced in the above equations are defined as u is the velocity along the x' -axis, is constant obtained after integration conservation of mass in pre-non dimensional form not mentioned, v is the velocity along x' -axis, is the kinematic viscosity, g is the acceleration due to gravity, T is the temperature of the fluid, is the coefficient of volume expansion, C_p is the specific heat at constant pressure, is a constant, σ is the Stefan-Boltzmann constant, λ is the mean absorption coefficient, T_w is the temperature of the surface, is the temperature far away from the surface, $\Pr$ is the Prandtl number, Gr is the Grashoff number, Q is Heat source parameter q_r is radiative heat flux in y direction, is the density, t is the time, k is the thermal conductivity of the fluid, n is the frequency of oscillation of the fluid and k_0 is the elastic parameter, B_0 is uniform magnetic field strength, M is the magnetic field parameter which is the ratio of magnetic force to the inertial force. It is a measure of the effect of flow on the magnetic field. Finally R is the radiation parameter. The effect of radiation parameter is to increase the rate of energy transport to the gas, thereby making the boundary layer becomes thicker and the fluid becomes warmer. Emissivity has been omitted in the expression of R, because for a black body the value of emissivity is unity. For Non non-Newtonian fluids like thick black paint the value of emissivity is 0.978.

SOLUTION OF THE PROBLEM

Equation (1) – (2) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (3). 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, temperature and concentration of the fluid in the neighbourhood of the fluid in the neighbourhood of the plate as

$$\begin{aligned} u &= u_0(\eta) + \varepsilon e^{it} u_1(\eta) \\ T &= T_0(\eta) + \varepsilon e^{it} T_1(\eta) \end{aligned} \tag{4}$$

Substituting (4) in Equation (1) – (2) and equating the harmonic and non – harmonic terms, and neglecting the higher order terms of $0(\varepsilon^2)$, we obtain

$$u_0'' + u_0' - \beta_1^2 u_0 = -Gr\,T_0 \tag{5}$$

$$(1 + ik_0) u_1'' + u_1' - \beta_2^2 u_1 = -Gr\,T_1 \tag{6}$$

$$T_0'' - \Pr\,T_0' - (R + Q)T_0 = 0 \tag{7}$$

$$T_1'' - \Pr(1+i)T_1' - (i\Pr + R + Q)T_1 = 0 \tag{8}$$

The corresponding boundary conditions can be written as

$$\begin{aligned} &u_0 = -1,\ \ T_0 = 1,\ \ T_1 = 1 \quad at\ \eta = 0 \\ &u_0 \to 0, T_0 \to 0, T_1 = 0 \quad as\ \eta \to \infty \end{aligned} \tag{9}$$

Solving these differential equations from (5) – (8) using boundary conditions (9) we obtain mean velocity and mean temperature as follows.

$$u_0(\eta, t) = Z_1 e^{\alpha_1 \eta} + Z_2 e^{\alpha_2 \eta}$$

$$T_0(\eta, t) = e^{\alpha_1 \eta}$$

APPENDIX

$$\alpha_1 = -\left(\frac{\Pr + \sqrt{\Pr^2 + 4(R+Q)}}{2} \right), \beta = (i\Pr + R + Q), \alpha_2 = -\left(\frac{1 + \sqrt{1 + 4\beta^2}}{2} \right)$$

$$\beta_1^2 = \left(M + \frac{1}{K} \right), \beta_2^2 = \left(i + M + \frac{1}{K} \right), Z_1 = -\frac{Gr}{\alpha_1^2 - \alpha_1 - \beta_1^2},\ Z_2 = -(1 + Z_1)$$

RESULTS AND DISCUSSION

In order to get clear insight into the problem, numerical computations are carried out for various parameters like $Gr, K, R, M, \Pr, Q$ are displayed .The numerical values of mean temperature has been obtained for different parameters like R, Q and $\Pr$ as taken in the governing equation (2) .

Similarly the numerical values of mean velocity have been obtained for different parameters like $Gr, K, R, Q, \Pr$ and M as taken in the governing equation (1). Plotting the temperature and velocity profiles pictorially has been showed from figures (2) - (10). It can be seen that the Prandtl number $\Pr = 0.71$ has been taken because this value corresponds to water which is known to be the Newtonian fluid. Free convection currents exist because of the temperature difference $\left(T_p - T_\infty\right)$ which may be positive, zero or negative. We know that the Grashof number is a common dimensionless group that is used when analyzing the potential effect of convection introduced by large temperature differences. So Grashof number will assume positive. From the physical point of view, $Gr < 0$ corresponds to an externally heated plate as free convection currents are carried towards the plate. $Gr > 0$ Corresponds to an externally cooled plate and $Gr = 0$ corresponds to the absence of free convection currents. The effect of cooling and heating on the velocity for the Grashoff number can be observed from figure (2) respectively, we observe from this figure that the mean velocity increase in cases of cooling for a visco - elastic fluid. Figure (3) and (4) illustrates the effects of porous medium shape factor parameter K and the radiation parameter R. It is observed from this figure that velocity goes on increasing with the increase of porous medium shape factor parameter $\left(K\right)$ as well as radiation parameter $\left(R\right)$. The influence of magnetic parameter $\left(M\right)$ is presented graphically in figure (5). 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. The influence of Prandtl number $\left(\Pr\right)$ on mean velocity profiles have been illustrated in figure (6). It is observed that an increase in $\Pr$ results also increases. Figure (7) shows the variation of mean velocity profiles for different values of heat source parameter $\left(Q\right)$. It is seen from this figure that mean velocity profiles decrease with an increasing of heat source parameter. The effect of thermal radiation parameter is important for temperature profiles. The mean temperature profiles for the case of the Newtonian fluid with thermal radiation are given in figure (7). It is observed that the mean temperature profiles decreases with increase of y. The mean temperature profiles for different parameters Prandtl number $\left(\Pr\right)$, radiation parameter $\left(R\right)$ heat source parameter $\left(Q\right)$ and are displayed in figure (8), (9) and (10). It is observed from this figure that the mean temperature decreases with the increase of Prandtl number, radiation parameter for the case of the Newtonian fluid. But the reverse effect observed in the heat source parameter.

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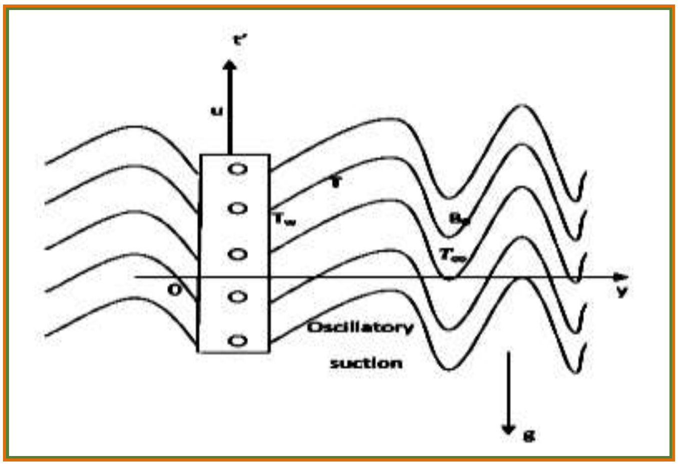

Fig. (1): Geometry of the problem

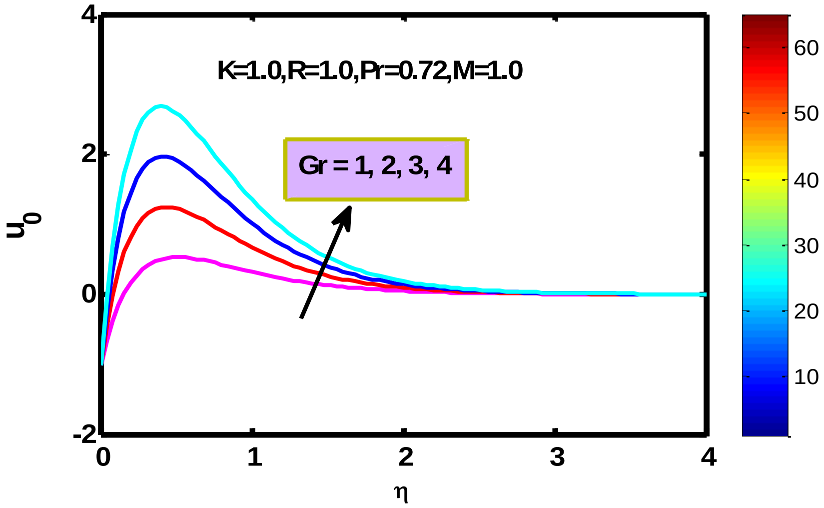

Fig. (2): Mean Velocity for Gr

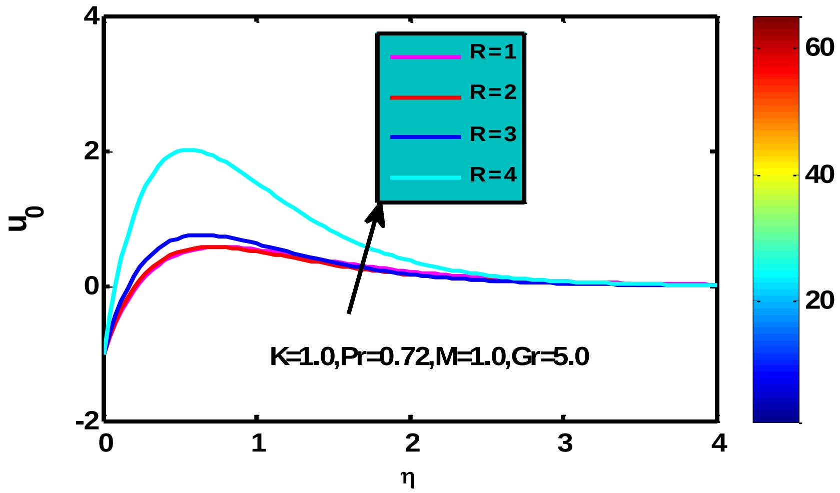

Fig. (4): Mean velocity for R

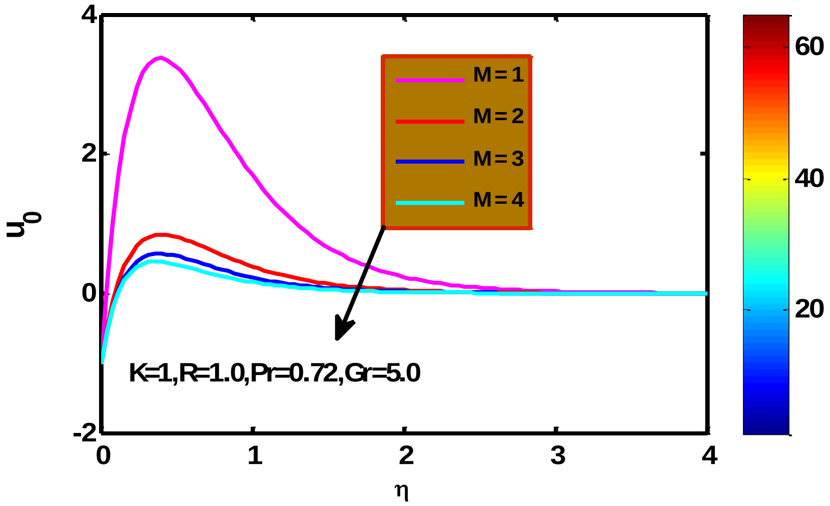

Fig. (5): Mean Velocity for M

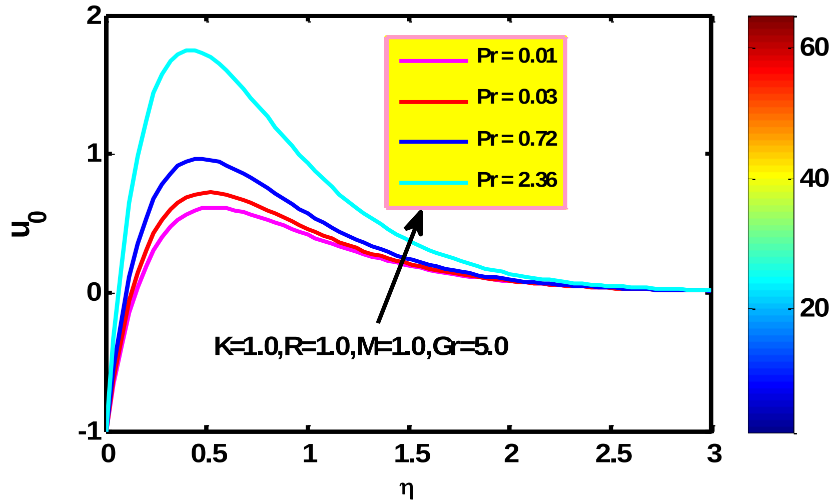

Fig. (6): Mean velocity for Pr

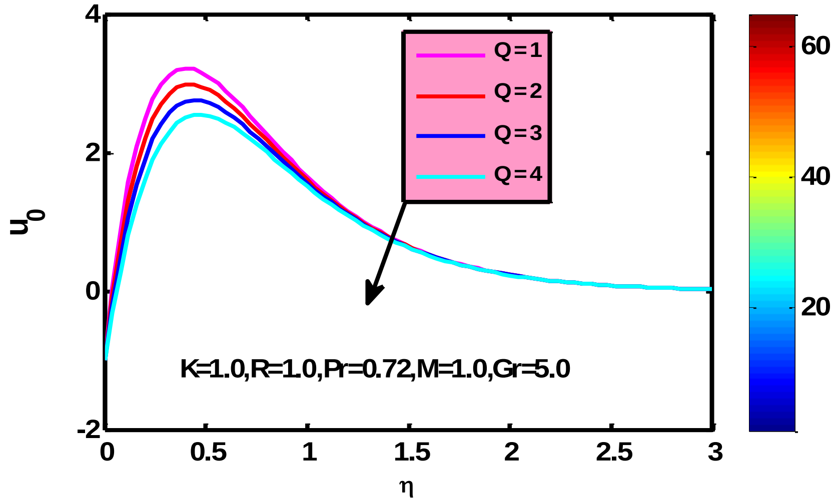

Fig. (7): Mean velocity for Q

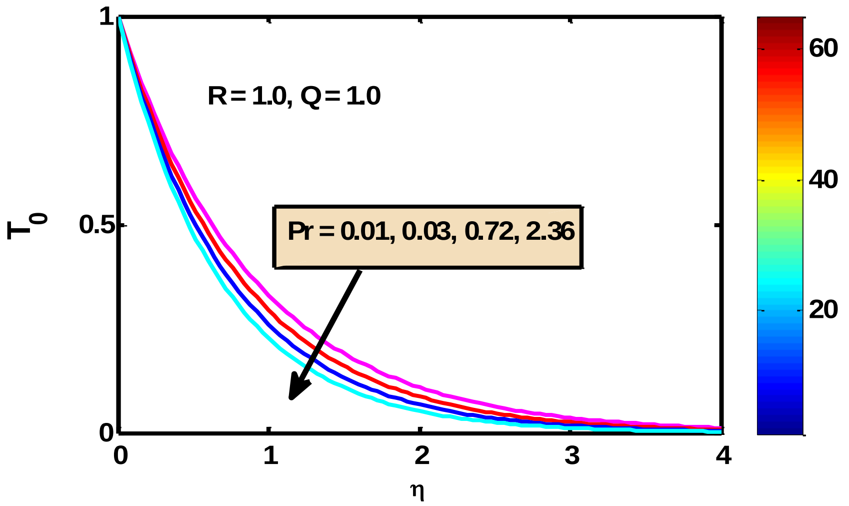

Fig. (8): Mean Temperature for Pr

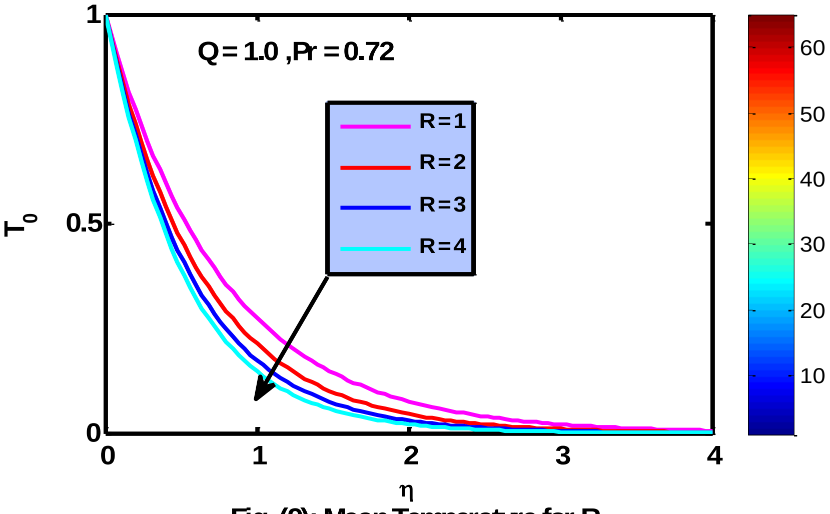

Fig. (9): Mean Temperature for R

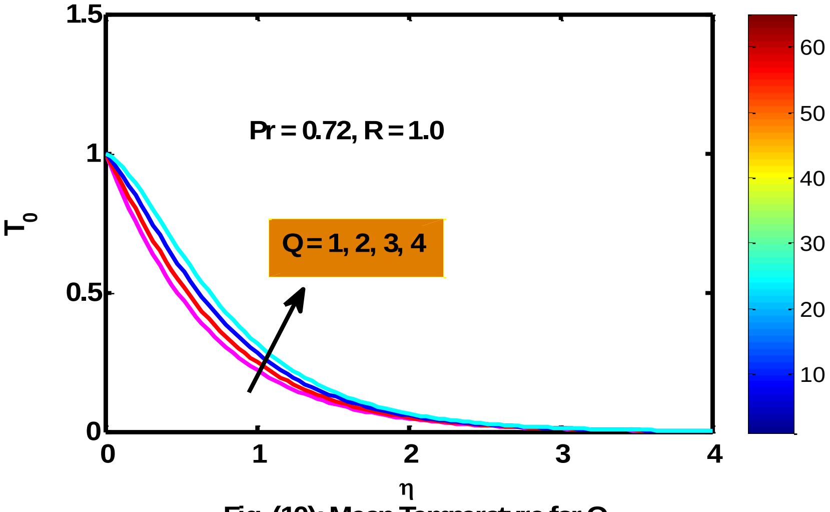

Fig. (10): Mean Temperature for Q