ANALYTICAL SOLUTION FOR TRANSIENT FREE CONVECTION MHD FLOW THROUGH A POROUS MEDIUM BETWEEN TWO VERTICAL PLATES WITH HEAT SOURCE

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Abstract:
The main objective of this paper is to study the flow of a viscous incompressible and electrically conducting fluid through a porous medium whose effective viscosity is larger than the viscosity of the fluid and bounded by two long vertical parallel plates in the presence of a uniform magnetic field applied transversely to the plates with heat source. The governing partial differential equations are solved by using perturbation technique. Such material has a Darcy number and viscosity ration parameter or order 10, such analysis for a horizontal channel flow through high permeability porous medium taking into an account.

Keywords: Analytical solution, Transient free convection, MHD, Porous medium, Heat source

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Introduction

Transient free convection flows under the influence of a magnetic field have attracted the interest of many researchers in view of their applications in modern materials processing where magnetic fields are known to achieve excellent manipulation and control of electrically–conducting materials and these kind of problems are encountered to analyze the heat transfer form tube heating like air conducting systems, steam heated coils, electronic immersion heaters etc. Significant attention of many researchers is take place on the study of unsteady MHD free convection flow with mass transfer past a vertical porous plate due to its various applications viz. studied of plasma, extraction of geothermal energy, metallurgy, chemical, mineral and petroleum engineering etc. [1-15].

In recent years there has been a growing interest in studying the combined application of MHD flow and porous media. Since the use of magnetic field can influence the heat generation/absorption process in electrically conducting fluid flows, the rate of cooling in many metallurgical processes and consequently the desired properties of the end product can be controlled. Furthermore, the influence of magnetic field on boundary layer flows has brought about its application in geothermal energy recovery, oil extraction and thermal insulations [16-30].

During the past several decades, convective flow through porous media has been a subject of considerable research interest of a large number of scholars due to its diverse engineering applications. These applications include, but are not limited to, for example heat exchangers in high heat flux applications such as electronic equipment, insulation of the heated body, thermal energy storage and sensible heat storage beds, drying process (wood and food products), air conditioning and filtration process. During the last decades, several researchers studied free convection heat and mass transfer in a porous medium. [31-44].

The main objective of this paper is to study the flow of a viscous incompressible and electrically conducting fluid through a porous medium whose effective viscosity is larger than the viscosity of the fluid and bounded by two long vertical parallel plates in the presence of a uniform magnetic field applied transversely to the plates. Such material has a Darcy number and viscosity ration parameter or order 10, such analysis for a horizontal channel flow through high permeability porous medium, on taking into account.

1. Mathematical Formulation of the Problem

We consider here, the flow of the fluid through a porous medium whose effective viscosity μ_{eff} is far greater than the viscosity of the fluid flowing in the vertical upward direction through the channel, which is bounded by two long vertical parallel plates. The plates are maintained at same temperature. One plate is considered at $y=0$ along which $x'-$axis is taken and the other plate is at $y=h$ in the vertical upward direction. The axis is taken normal to the plate. Here $y'\varepsilon[0,h]$, B_0 acts in a direction normal to the flow. To write down the governing equations following assumption are made:

Under the above assumptions the governing equations are as follows:

- The plates are infinitely long, so flow variables are functions of y' and t' only
- Hall effects, polarization effect and induced magnetic field are neglected
- The external electric field is zero
- The pressure gradient term and gravity term are entirely expressed by buoyancy force term
- The viscous dissipative heat and the effects of the and longitudinal dispersion are neglected
- The flow motion is very slow and non-fully developed

$$\frac{\partial u'}{\partial t'} = g\beta\left(T'-T_h'\right)+\nu_{eff}\frac{\partial^2 u'}{\partial y'^2}-\nu\frac{u'}{k'}-\frac{\sigma B_0^2}{\rho}u';\ \nu=\frac{\mu}{\rho} \qquad (1)$$

$$\frac{\partial T'}{\partial t'}=\frac{1}{\rho C_p}\frac{\partial}{\partial y'}\left(\kappa\frac{\partial T'}{\partial y'}\right)-\frac{Q_0}{\rho C_p}\left(T'-T_h'\right) \qquad (2)$$

$$\begin{aligned} &u'=0,\ T'=T_h' \quad \forall \quad y'\le h, && t'\le 0\\ &u'=0, T'=T_w' \quad at \quad y'=0, && t'>0\\ &u\to 0, T\to T_h', y'=h, && y\to\infty, t'>0 \end{aligned} \qquad (3)$$

In order to write the governing equations, initial and the boundary conditions the following non-dimensional quantities are introduced:

$$y=\frac{y'}{h},\ u=\frac{u'\mu}{T_w{}'-T_h{}'},\ \ t=\frac{t'\mu}{\rho h^2},T=\frac{T'-T_h'}{T_w{}'-T_h'},M=B_0\sqrt{\frac{\sigma}{\mu}}$$
$$Da=\frac{K}{h^2},\quad Z=\frac{\nu_{eff}}{\nu},\quad \Pr=\frac{\mu C_p}{\rho k},\qquad Q=\frac{Q_0h^2}{\mu C_p} \tag{4}$$

In view of (4) the equations (1) and (2) are reduced to the following non-dimensional form

$$\frac{\partial u}{\partial t}=T+Z\frac{\partial^2 u}{\partial y^2}-\beta_1 u \tag{5}$$

$$\frac{\partial T}{\partial t}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2}-QT \tag{6}$$

$$\begin{aligned}&u=0,T=0\ \forall\ \ 0\le y\le 1, && t'\le 0\\ &u=0,T=1 && t>0,\quad at\ \ y=0\\ &u\to 0,\ T\to 0 && as\ \ y=1,t>0\end{aligned} \tag{7}$$

2. Method of Solution

Equation (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, temperature and concentration of the fluid in the neighbourhood of the fluid in the neighbourhood of the plate as

$$\begin{aligned}u(y,t)&=u_0(y)+u_1(y)e^{at}\\ T(y,t)&=T_0(y)+T_1(y)e^{at}\end{aligned} \tag{8}$$

Substitute equation (8) in to the equations (5) and (6) the set of ordinary differential equations are the following form

$$Zu_0''-\beta_1 u_0=-T_0 \tag{9}$$

$$Zu_1''-\beta_3 u_1=-T_1 \tag{10}$$

$$T_0''-Q\Pr T_0=0 \tag{11}$$

$$T_1''-\beta_2 T_1=0 \tag{12}$$

where

$$\beta_1=\left(\frac{1}{Da}+M\right);\beta_2=\left(Q+at\right)\Pr;$$
$$\beta_3=\left(\frac{1}{Da}+M+at\right);\beta_4=\left(\frac{\beta_1}{Z}\right)$$

$$\begin{aligned}&u=0,\quad T=0 && \forall\ \ 0\le y\le 1,\quad t'\le 0\\ &u_0=0,T_0=1,u_1=0,T_1=0, && t>0,at\ \ y=0\\ &u_0\to 0,T_0\to 0,u_1\to 0,T_1\to 0, && y=1,t>0\end{aligned} \tag{13}$$

The exact solution for the fluid velocity $u(y,t)$, fluid temperature $T(y,t)$ are obtained and expressed from equations from (9) - (12) under the equation (13) in the following form:

$$u(y,t)=A_3e^{m2y}+A_4e^{m1y}+A_8e^{-\sqrt{\beta_4}y}+A_{12}e^{\sqrt{\beta_4}y}$$
$$T(y,t)=A_1e^{m2y}+A_2e^{m1y}$$

Skin friction

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}=A_3m_2+m_1A_4-A_8\beta_4+A_{12}\beta_4$$

Nusselt number

$$Nu=\left(\frac{\partial T}{\partial y}\right)_{y=0}=m_2A_1+m_1A_2$$

3. Results and Discussion

We have computed numerical values of velocity and temperature and these are shown through figures (1) to (7). In figure (1) the velocity profiles are obtained for $(Da=0.1,0.2,0.3,0.4)$ and we see that it decreases for increasing values of Darcy number. In figure (2) the velocity profiles are shown for different values of heat source parameter $(Q=1,2,3,4)$ keeping other parameter are fixed respectively. In this figure we observed that as heat source parameter increases the fluid velocity decreases. Figure (3) is drawn different values of Prandtl number $(\Pr=2,5,7,9)$ at fixed other parameters to give the nature of the velocity distribution curve, it is clear that the velocity decreases in the increases of Prandtl number, also It is seen that Prandtl number remarkably influences the fluid velocity. Figure (4) is obtained for different values of Hartman number $(M=1,2,3,4)$ for fixed values of other parameters and we observed that an increases in Hartman number leads to an increases in the velocity. There is a curve in figure (4) which is free from magnetic field. If, we go through these two sets of curves, we have seen that there is the influence of magnetic field on velocity profiles. Figure (5) is drawn for variable viscosity ratio $(Z=0.1,0.2,0.3,0.4)$ at fixed other $(\Pr=0.71,0.9,7,100)$ and heat source parameter $(Q=1,2,3,4)$. From these figures we analyzed that the temperature profiles decreases with increasing values of Prandtl number and heat sources.

Table 1: Values for τ						
t	z	Da	M	$\frac{\tau}{\Pr}=0.71$	7	100
0.2	0.1	0.01	0.5	0.31456	0.33456	0.38456
0.2	0.1	0.01	0	0.32897	0.34897	0.38978
0.2	0.1	0.1	0.5	0.81245	1.05648	1.54268
0.2	0.1	2.0	1.0	1.84182	2.56914	3.84267
0.2	1.0	0.01	0.5	0.08524	0.19473	0.25891
0.2	1.0	0.1	1.0	0.22879	0.88440	1.62892
0.2	1.0	2.0	2.5	0.28579	-0.02583	-0.08651
0.2	5.0	0.01	0.5	0.04671	0.065812	0.054106
0.2	5.0	0.1	1	0.06235	0.014523	-0.01125
0.2	5.0	5.0	2	0.03604	0.039945	0.007108
0.2	10.0	0.01	0.5	0.03958	0.512454	1.051945
0.2	10.0	0.1	1	0.03943	0.012727	0.000148
0.2	10.1	5	2	0.04135	0.016253	0.005236

In table 1. a series of values of shear stress has been given for different values of magnetic field parameter, viscosity ratio parameter, Darcy number and the Prandtl number. It is observed that as the values of the Prandtl number increases, the skin friction also increases for fixed values of $z(=0.1)$ and for smaller values of Da and M. Here. For $M=0$, (when Da = .01) the values of skin friction increases. For increasing values of Prandtl number, we get the highest values of z for $z=0.1$. Da = 2, $M=1$. As Pr increases, we see the decreasing values of skin friction when magnetic Hartmann number is maximum (in table I) and $z=1$. Da = 2. When z takes the maximum value ($z=10$ in table 1), skin friction decreases for increasing values of Pr. The first two values of table I shows that as M increases from zero (at fixed values of % and Da) onwards, the values of skin friction decreases. Thus, it shows that the effects of increasing M decrease the skin friction. For standard combination of values of these four parameters, we can get an expected skin friction. On the other hand as the values of all these parameters increases the skin friction decreases. Hence, the porosity of the medium and magnetic field are the factors that can influence a great deal the flow field of fluid.

4. Conclusion

In this paper we have analyzed the effect of Darcy number, viscosity ratio parameter and the Prandtl number on free convection flow of viscous incompressible fluid through a porous medium bounded by two long vertical parallel plates whose effective viscosity is larger than the viscosity of the fluid. Series solutions are provided for velocity and temperature distributions in terms of the Darcy number, viscosity ratio parameter, the Prandtl number and the Hartmann number. Graphs drawn for velocity and temperature profiles show that these parameters have influence on these profiles. So, in order to predict accurately the flow behaviour of the electrically conducting fluid, all this parameters must be taken into consideration

5. Appendix

$$m_1 = \sqrt{Q\,\mathrm{Pr}},, m_2 = -\sqrt{Q\,\mathrm{Pr}}, A_1 = \frac{e^{m1}}{e^{m1} - e^{m2}}, A_2 = (1 - A_1)\, A_3 = \frac{A_1}{Zm_2^2 - \beta_1}, A_4 = \frac{A_2}{Zm_1^2 - \beta_1}$$

$$A_5 = A_3\left(e^{\sqrt{\beta_4}} - e^{m2}\right), A_6 = A_3\left(e^{\sqrt{\beta_4}} - e^{m1}\right), A_7 = -\left(A_5 + A_6\right), A_8 = \frac{A_7}{2\cosh\sqrt{\beta_4}}$$

$$A_9 = A_3\left(e^{-\sqrt{\beta_4}} - e^{m2}\right), A_{10} = A_3\left(e^{-\sqrt{\beta_4}} - e^{m1}\right), A_{11} = -\left(A_9 + A_{10}\right), A_{12} = \frac{A_{10}}{2\cosh\sqrt{\beta_4}}$$

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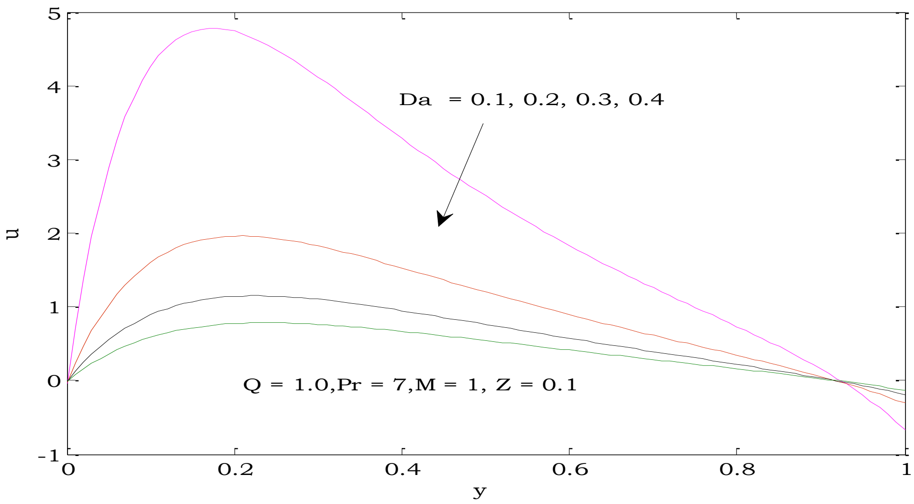

Figure (1): Velocity profiles for different values of Da

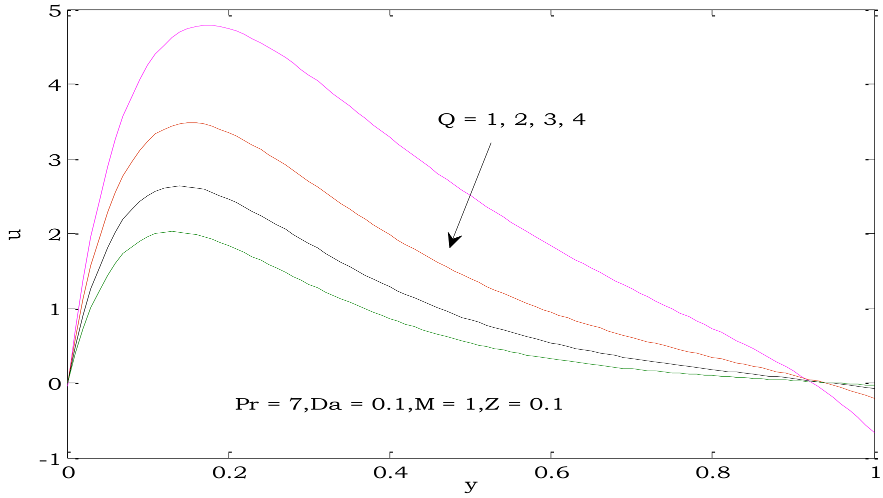

Figure (2): Velocity profiles for different values of Q

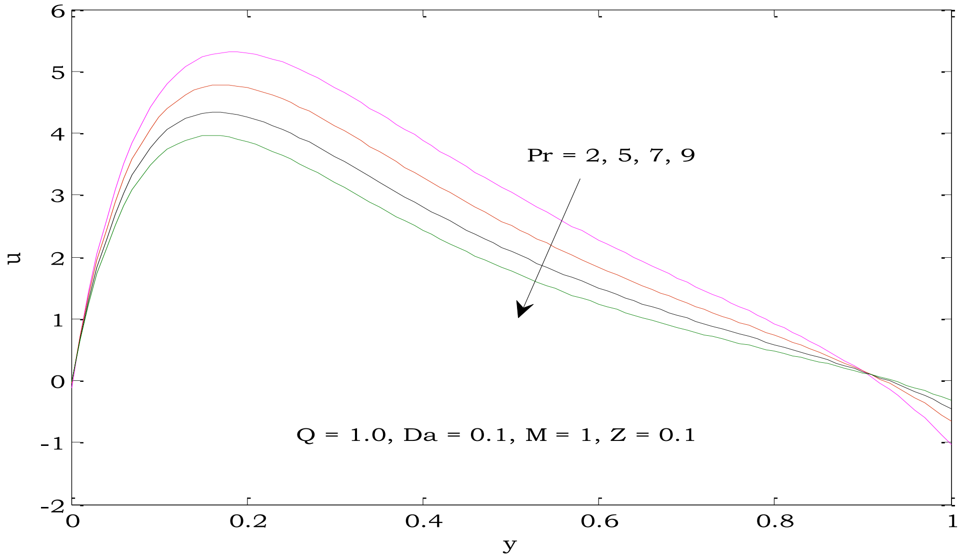

Figure (3): Velocity profiles for different values of Pr

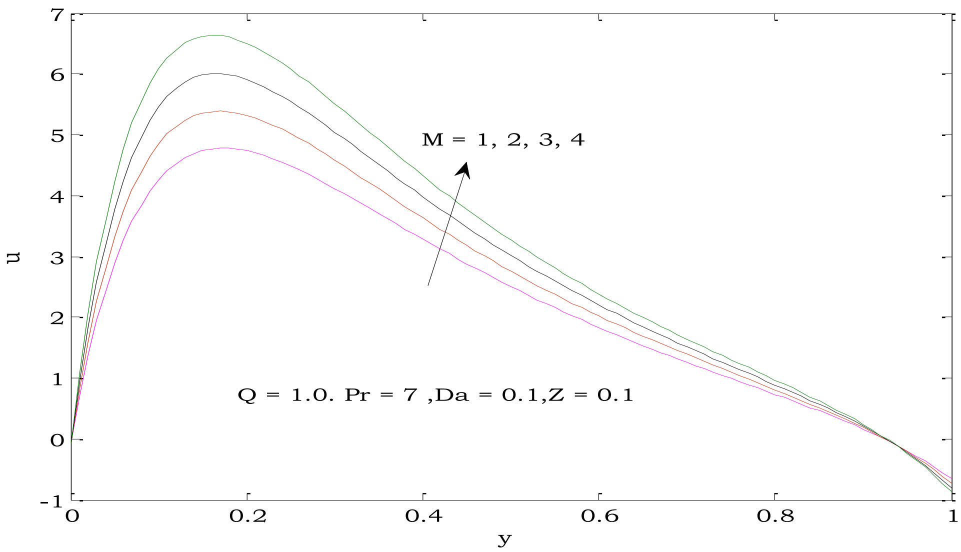

Figure (4): Velocity profiles for different values of M

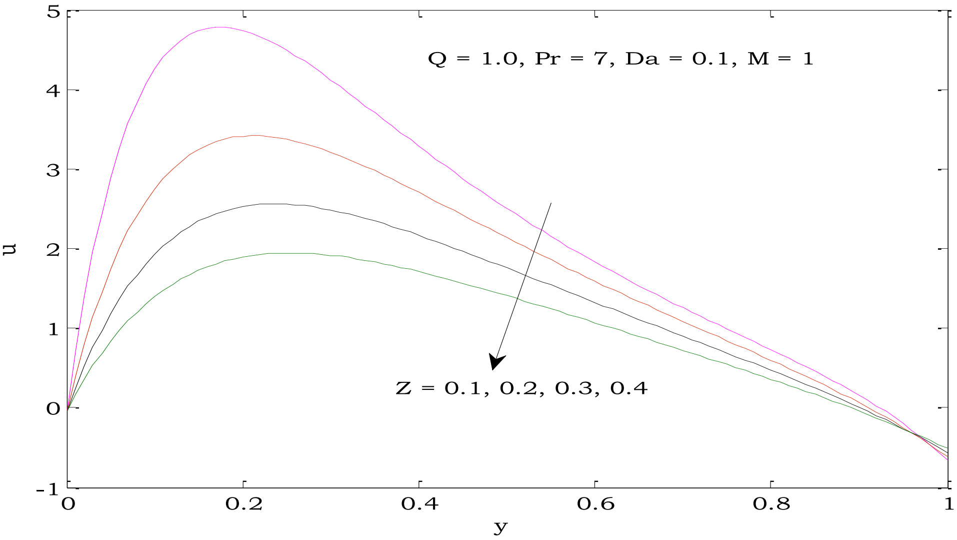

Figure (5): Velocity profiles for different values of Z

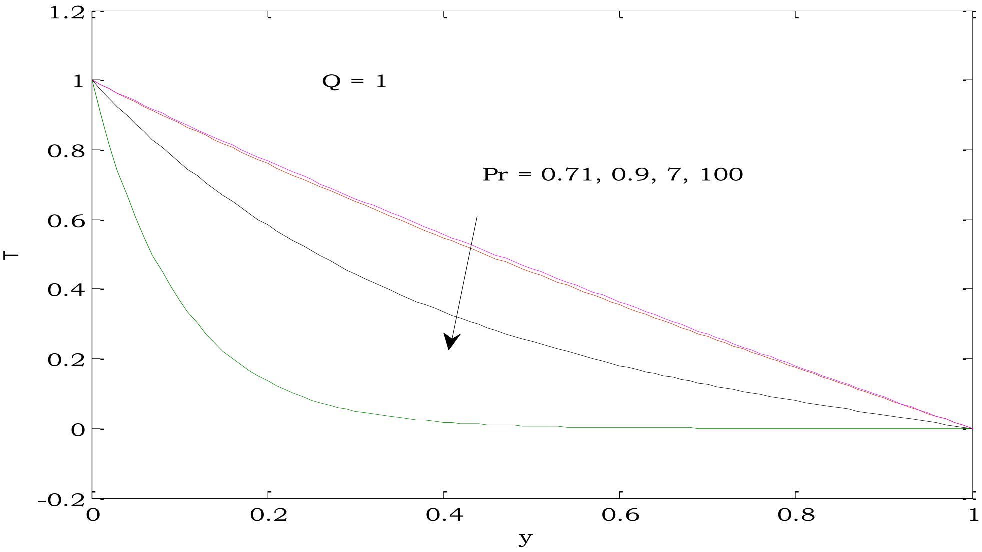

Figure (6): Temperature profiles for different values of Pr

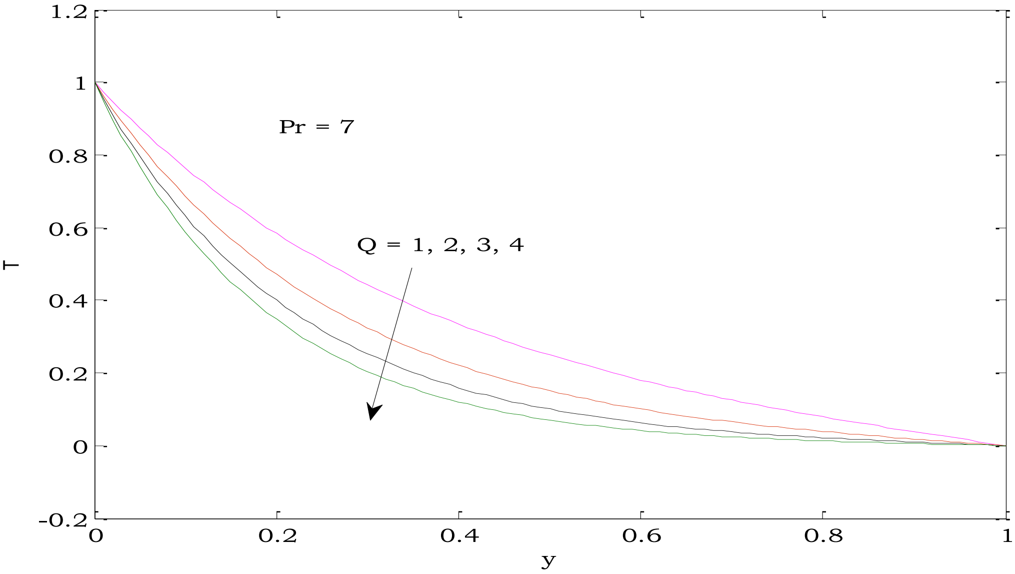

Figure (7): Temperature profiles for different values of Q