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Effect of Magnetic and Perturbation Parameters on Blood Flow Distribution through an Artery

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Abstract

The motion of the blood inside an artery is investigated under the transverse magnetic field. The velocity and temperature variation of the blood flow motion are solved by perturbation technique. We considered the magnetic field is constant and viscosity of the fluid distribution depends on temperature. We derived flow rate and wall shear stress during the flow of blood through the human artery. We analyzed the effect of temperature profiles, flow rate and wall shear stress during the propagation of blood. It is observed that the human will die with respect to the increase temperature in the blood flow distribution.

Keywords: Flow of blood through an artery; Poiseuille-flow; Magnetic field; Flow rate; Wall shear stress; Electrical conductivity; Variable Viscosity

MSC 2010 No.: 76Z05, 74G10

Nomenclature

H	Magnetic field strength
μ_e	Magnetic permeability

B_o	Magnetic field induction ($B_o = \mu_e H$)
C_p	Specific heat at constant pressure
k	Thermal conductivity
M	Magnetic parameter
μ^*	Viscosity of fluid
μ	Dimensionless viscosity
T^*	Temperature of fluid
T_o	Temperature of fluid at the center of the tube
μ_o	Coefficient of viscosity at temperature $T^* = T_o$
P_r	Prandtl number
E_c	Eckert number
β	Measure of variation of viscosity with temperature
N	Perturbation parameter ($N = \beta P_r E_c$)
z	Axis of the tube through the center
P	Pressure gradient ($P = -\frac{dp}{dz}$)
Q	Flow rate
r^*	Radial direction
R	Radius of tube
σ	Electrical conductivity
T	Dimensionless temperature
T_w	Wall temperature
τ^*	Shear stress at r = R
τ_o	Shear stress at the center of the tube
τ	Dimensionless shear stress
θ	Azimuthal angle
u_r^*	Velocity component along the radial direction
u_θ^*	Velocity component along the tangential direction
u_z^*	Velocity component along the axial direction
u	Dimensionless velocity component

1. Introduction

Blood flow is a study of measuring the blood pressure in an artery. This study is important for human health. Several researchers studied the blood flow motion in the arteries and veins. The motivation of the study is to understand about the nature of blood flow distribution in an artery. Heart problem is a major cause of death in several countries. Heart problem occurs when the coronary arteries become narrowed Pablo et al. (2014).

Mishra et al. (2010) studied the flow of a bio-magnetic viscoelastic fluid and estimated the blood flow in arteries during electromagnetic hyperthermia. They have constructed therapeutic procedure for cancer treatment. Malota et al. (2018) obtained the impact of flow rate, heart rate, vessel geometry and degree of stenosis on coronary hemodynamic indices by using numerical methods.

Cardiovascular system is the blood distribution network in the body. The cardiovascular system in the body consists of three components: blood, heart and blood vessels. When blood flows through the vessels, pressure is detected on the wall which is termed as the blood pressure. Blood pressure depends mainly on flow rate and size of the vessels and on the pressure gradient. There are three major types of blood vessels: arteries, capillaries and veins. Arteries are large blood vessels that carry blood away from the heart to all regions of the body. The arterioles further divide into smaller vessels called capillaries. Capillaries are the anatomic units that connect the arterial and venous circulatory system.

Many researchers investigated transportation of blood flow through arteries. Bansal (1976) observed external magnetic field plays an important role for various biological systems of the body. The applied magnetic field on the human bodies provides an effective kind of medical treatment. Earlier in Japan, the magnetic belt, cap, pillow and bed were used for the treatment of hypertension and neurasthenia patient. It is observed magnetic treatment cure the hypertension, coronary thrombosis, angina pectoris and high blood-lipoid.

Chongwen and Wangyi (1993) studied the thrombus and other blood rheological properties with an applied magnetic field. They measured the effect of the magnetic field with blood viscosity at different shear rates. They pointed out in a short period of time; the constant magnetic field obstructs the blood circulation. They also found magnetic field is more effective for the small vessels. Desikachar & Rao (1985) analyzed the influence of magnetic field on the blood flow during oxygenation process. Haldar and Ghosh (1994) investigated the effect of magnetic field on blood flow through an indented tube in the presence of erythrocytes. Sud and Shekhon (1989) numerically studied the effect of magnetic field on blood flow through the human arterial system. Heat transfer plays an important role in the living system. Wang (2008) studied the problem of convective heat transfer through a small tube. Mazumdar et al. (1996) used numerical method to study the effects of magnetic field considering Newtonian fluid in circular tube. They observed fluid viscosity is always constant and it vary with temperature and pressure. Chaturani & Saxena Bharatiya (2001) represented two layered magneto-hydrodynamic (MHD) flow through parallel plates. Tzirtzilakis and Loukopoulos (2005) constructed mathematical model for blood flow by using magnetic field. Verma & Singh (1998) presented the generalized Poiseuille flow between two parallel plates with temperature dependent viscosity. Victor and Shah (1976) investigated the steady state heat transfer of the blood flow in the entrance region of a tube. Chato (1980) analyzed the heat transfer on blood vessels. Hooman and Ranjbar-Kani (2004) used perturbation-based analysis to investigate forced convection in a porous saturated tube. Gupta (2012) analyzed the blood flow in small vessel with the help of magnetic field. Sharma and Katiyar (2015) studied the effect of magnetic field on the blood flow by using cylindrical tube. Tripathi & Sharma (2018) demonstrated the effect of variable viscosity on MHD inclined arterial blood flow with chemical reaction. Ahmad and Ahmad (2012) studied the effect of blood flow through renal tube. They obtained the solutions of periodic blood fluid distribution with radial velocity component.

2. Mathematical model

In this paper, we have considered, Hagen-Poiseuille type of flow in a circular tube and studied the effect of magnetic field as well as perturbation parameters during the motion of the blood. Considered a steady viscous incompressible laminar and Newtonian fluid problem through a horizontal tube with radius R, under the effect of external magnetic field. Further we considered variable viscosity depends on temperature. Here the magnetic Reynold's number of the fluid flow is taken to be small enough, so that the induced magnetic field can be neglected. The cylindrical coordinate system is introduced in figure 1. The variable magnetic field slow down the motion of the blood flow distribution, Mishra et al. (2010). A constant magnetic field B_o is originally imposed perpendicular to the axis of the tube. The z-axis lies along the center of the tube with radius R. The fluid is assumed to be flowing parallel to the axis of the tube with velocity u^* under the influence of a constant pressure gradient and the Lorenz force. The velocity components $u_r^*,\ u_\theta^*$ and $u_z^* = u_z^*(r)$ are along the r, θ and z directions, respectively.

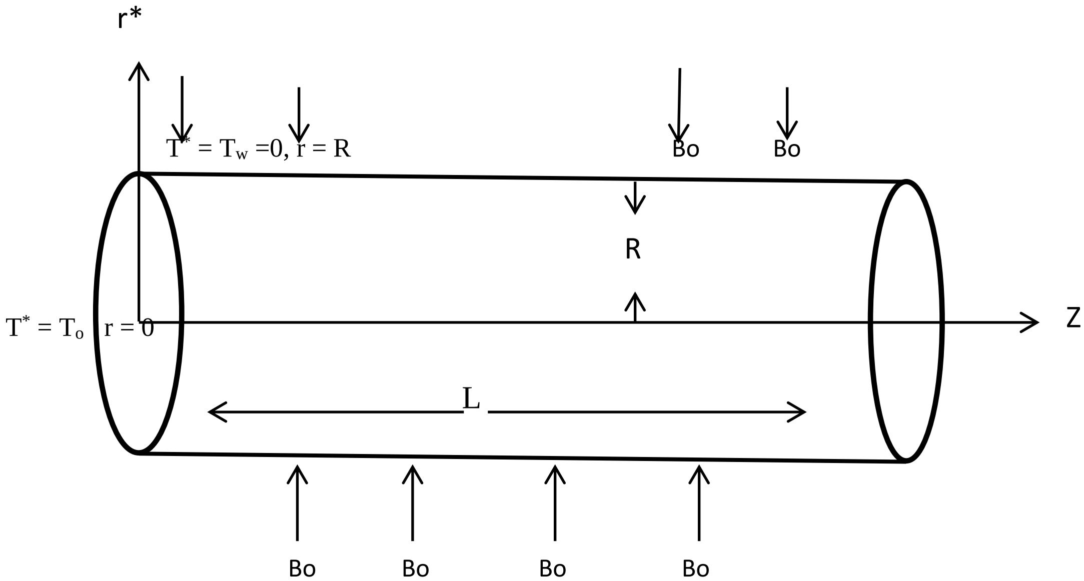

Figure 1. Schematic diagram of the blood flow through a tube

Flow assumptions for the governing model are mentioned as below:

(i) Flow is steady which implies $\frac{\partial}{\partial t} = 0$,

(ii) Flow is unidirectional where $u_r^* = u_\theta^* = 0$ and $u_z^* = u_z^*(r)$,

(iii)Flow is incompressible which yield $\frac{\partial \rho}{\partial t} = 0$,

(iv) Flow is axisymmetric shows $\frac{\partial}{\partial \theta} = 0$,

(v) Fully developed system provides $\frac{\partial}{\partial z} = 0 = \frac{\partial^2}{\partial z^2}$,

(vi) Pressure gradient is constant yield $P = -\frac{\partial p}{\partial z} = -\frac{dp}{dz}$, and

(vii) Wall of the tube is kept at a constant temperature leads to $\frac{\partial T}{\partial z} = 0 = \frac{\partial^2 T}{\partial z^2}$.

The energy momentum equation is given as below:

$$-\frac{dp^{\star}}{dz}+\frac{1}{r^{*}}\frac{d}{dr^{*}}\left(\mu^{*}\, r^{*}\,\frac{du^{*}}{dr^{*}}\right)-\sigma B_0^2 u^{*}=0, \tag{1}$$

$$\frac{k}{r^{*}}\frac{d}{dr^{*}}\left(r^{*}\frac{dT^{*}}{dr^{*}}\right)+\mu^{*}\left(\frac{du^{*}}{dr^{*}}\right)^2=0\,, \tag{2}$$

where $\frac{dp^{*}}{\partial z}$ is the pressure gradient, σ *is* the electrical conductivity, k is the coefficient of thermal conductivity, T^{*} is the fluid temperature, $\mu^{*}$is the viscosity and r^{*} is the radial direction. Boundary conditions are given as below.

(i) $u^{*}=0\,,\quad T^{*}=T_w=0\;$ at $\;r^{*}=R,$

(ii) $\frac{du^{*}}{dr^{*}}=\frac{dT^{*}}{dr^{*}}=0,\;$ at $\;r^{*}=0,$

(iii) u^{*} is finite and $T^{*}=T_0$ at $r^{*}=0.$

Using the following non-dimensional quantities

$$u=\frac{u^{*}}{u_m},\quad \eta=\frac{r^{*}}{R},\;\; \mu=\frac{\mu^{*}}{\mu_0},\;\; T=\frac{T^{*}-T_0}{T_w-T_0}=\frac{T_0-T^{*}}{T_0}\,,\qquad P_r=\frac{\mu_0 C_p}{k},$$

$$E_c=\frac{u_m^2}{C_p T_0},\qquad M=B_0 R\sqrt{\frac{\sigma}{\mu_0}},$$

$$\tau=\frac{\tau^{*}}{\tau_0},\;\text{ where }\; u_m=-\frac{R^2}{\mu_0}\frac{dp^{*}}{dz}\;\text{ and }\;\tau_m=\frac{\mu_0\, u_m}{R}.$$

The equations (1) and (2) are reduced to:

$$\frac{1}{\eta}\frac{d}{d\eta}\left(\mu\,\eta\,\frac{du}{d\eta}\right)-M^2u=-1, \tag{3}$$

$$\frac{1}{\eta}\frac{d}{d\eta}\left(\eta\,\frac{dT}{d\eta}\right)-\mu\,P_r E_c\left(\frac{du}{d\eta}\right)^2=0. \tag{4}$$

The corresponding boundary conditions for equations (3) and (4) are given as below

$$\left.\begin{aligned} &u=T=0\;\text{ at }\;\eta=1,\\ &\frac{du}{d\eta}=\frac{dT}{d\eta}=0\;\text{ at }\;\eta=0,\\ &u\text{ and }\theta\text{ are finite at }\eta=0.\end{aligned}\right\} \tag{5}$$

In order to solve the equations (3) and (4), we considered an empirical relation between viscosity and temperature as $\frac{T_0-T^*}{T_0} \ll 1$, Nahme (1940).

The dimensionless relation is considered as below;

$$T = \frac{\theta}{\beta}, \qquad \text{and} \quad \mu = e^{-\theta}. \tag{6}$$

where β is a dimensionless parameter which depend on the nature of the fluid. Using Maclaurin series expansion, equation (6) can be written as

$$\mu = 1 - \beta\theta + O(\theta^2). \tag{7}$$

$$\frac{d\mu}{d\eta} = -\beta\frac{d\theta}{d\eta}. \tag{8}$$

Substituting equations (6-8) in equations (3-5), we obtain

$$\frac{d^2u}{d\eta^2} - \theta\frac{d^2u}{d\eta^2} + \frac{1}{\eta}\frac{du}{d\eta} - \frac{\theta}{\eta}\frac{du}{d\eta} - \frac{du}{d\eta}\frac{d\theta}{d\eta} + \theta\frac{du}{d\eta}\frac{d\theta}{d\eta} - M^2u = -1, \tag{9}$$

$$\frac{d^2\theta}{d\eta^2} + \frac{1}{\eta}\frac{d\theta}{d\eta} - N(1-\theta)\left(\frac{du}{d\eta}\right)^2 = 0, \tag{10}$$

where $N = \beta P_r E_c = 0.00125 \ll 1$, is the perturbation parameter.

3. Solution

To obtain the analytical solutions of equations (9) and (10) easily, we considered asymptotic method by using perturbation technique. Here we assumed the perturbation N as a small parameter, which is given as below:

$$u \sim u_0 + N\,u_1 + O(N^2), \tag{11}$$

$$\theta \sim N\theta_0 + N^2\theta_1 + O(N^3). \tag{12}$$

In view of equations (11) and (12), equations (9) and (10), yield

$$O(1): \frac{d^2u_0}{d\eta^2} + \frac{1}{\eta}\frac{du_0}{d\eta} - M^2u_0 = -1, \tag{13}$$

$$O(N): \frac{d^2u_1}{d\eta^2} + \frac{1}{\eta}\frac{du_1}{d\eta} - M^2u_1 = \theta_0\frac{d^2u_0}{d\eta^2} + \theta_0\frac{du_0}{d\eta} + \frac{du_0}{d\eta}\frac{d\theta_0}{d\eta}, \quad (14)$$

$$U(N): \frac{d^2\theta_0}{d\eta^2} + \frac{1}{\eta}\frac{d\theta_0}{d\eta} - \left(\frac{du_0}{d\eta}\right)^2 = 0, \quad (15)$$

$$O(n^2): \frac{d^2\theta_1}{d\eta^2} + \frac{1}{\eta}\frac{d\theta_1}{d\eta} - 2\frac{du_0}{d\eta}\frac{du_1}{d\eta} + \theta_0\left(\frac{du_0}{d\eta}\right)^2 = 0, \quad (16)$$

Reducible boundary conditions are given by

$$\left.\begin{aligned} u_0(1) = u_1(1) = 0, \\ \theta_0(1) = \theta_1(1) = 0, \\ u_0'(0) = u_1'(0) = 0, \\ \theta_0'(0) = \theta_1'(0) = 0. \end{aligned}\right\} \quad (17)$$

Equations (13), (16) and (17), yield;

$$u_0 = \frac{(1-\eta^2)}{4+M^2}, \quad (18)$$

$$\theta_0 = \frac{(\eta^4-1)}{4(4+M^2)^2}, \quad (19)$$

$$u_1 = \frac{1}{(4+M^2)^3}\left(\frac{\eta^2}{8} + \frac{\eta^3}{18} + \frac{M^2\eta^4}{128} + \frac{M^2\eta^5}{450}\right) - \frac{(4+M^2\eta^2)}{(4+M^2)^4}\left(\frac{13}{72} + \frac{289M^2}{28800}\right), \quad (20)$$

$$\theta_1 = \left[\begin{array}{c} \frac{4}{(4+M^2)^4}\left\{\begin{array}{c} 0.02229 + M^2(0.00109 - 0.000868\eta^6 - 0.000227\eta^7) \\ -0.0156\eta^4 - 0.00667\eta^5 + \frac{0.08M^2}{(4+M^2)^4}(1+\eta^5) \end{array}\right\} \\ -\frac{1}{(4+M^2)^4}\{0.04688 + 0.0156(\eta^8 - 4\eta^4)\}. \end{array}\right]. \quad (21)$$

Substituting equations (18) and (21) in equations (11) and (12), we obtain

$$u = \left[\frac{(1-\eta^2)}{4+M^2}\right] + \left[0.00125\left\{\frac{1}{(4+M^2)^3}\left(\frac{\eta^2}{8} + \frac{\eta^3}{18} + \frac{M^2\eta^4}{128} + \frac{M^2\eta^5}{450}\right) - \frac{(4+M^2\eta^2)}{(4+M^2)^4}\left(\frac{13}{72} + \frac{289M^2}{28800}\right)\right\}\right]. \quad (22)$$

$$\theta = \left[\frac{0.00125(\eta^4 - 1)}{4(4 + M^2)^2}\right] + \frac{0.00000625}{(4 + M^2)^4}\left[\begin{array}{c} 0.02229 + M^2(0.00109 - 0.000868\eta^6 - 0.000227\eta^7) \\ -0.0156\eta^4 - 0.00667\eta^5 + \dfrac{0.08M^2}{(4 + M^2)^4}(1 + \eta^5) \end{array}\right] - \left(\frac{0.00000625}{(4+M^2)^4}\right)[0.04688 + 0.0156(\eta^8 - 4\eta^4)] \tag{23}$$

Here, we discussed the flow rate of the fluid distribution. The flow rate is the total volume of the fluid crossing any section per unit time is given by:

$$Q = 2\pi R^2 \int_0^1 u\, \eta d\eta. \tag{24}$$

In view of equations (22) and (24), we get

$$Q = 2\pi R^2 \left[\begin{array}{c} \dfrac{0.25}{4 + M^2} + \dfrac{0.00125}{(4 + M^2)^3}(0.04236 + 0.00162M^2) \\ -\dfrac{0.00125(8 + M^2)}{4(4 + M^2)^4}(0.1806 + 0.0101M^2) \end{array}\right]. \tag{25}$$

The dimensionless form of wall shear stress is defined as

$$\tau = (1 - \theta)\left(\frac{du}{d\eta}\right)_{\eta=1}, \tag{26}$$

where

$$(1 - \theta) = 1 - \left[\begin{array}{c} \dfrac{0.00125(\eta^4-1)}{4(4+M^2)^2} + \\ \dfrac{0.00000625}{(4+M^2)^4}\left\{\begin{array}{c} 0.0223 + M^2\left(\begin{array}{c} 0.0011 - 0.0009\eta^6 \\ -0.0003\eta^7 \end{array}\right) \\ -0.0156\eta^4 - 0.0067\eta^5 + \dfrac{0.08M^2}{(4+M^2)^4}(1 + \eta^5) \end{array}\right\} \end{array}\right], \tag{27}$$

$$\left(\frac{du}{d\eta}\right)_{\eta=1} = \left[\begin{array}{c} \dfrac{-2}{4+M^2} + \dfrac{0.00125}{(4+M^2)^3}(0.25 + 0.167 + 0.1424M^2) \\ -\dfrac{0.00125}{(4+M^2)^4}(0.362M^2 + 0.0201M^4) \end{array}\right]. \tag{28}$$

Substituting equations (27) and (28) in equation (26), we get

$$\tau = 1 - \left[\frac{0.00125(\eta^4 - 1)}{4(4+M^2)^2} + \frac{0.00000625}{(4+M^2)^4}\left\{\begin{matrix} 0.0223 + M^2(0.0011 - 0.0009\eta^6 - 0.0003\eta^7) \\ -0.0156\eta^4 - 0.0067\eta^5 + \frac{0.08M^2}{(4+M^2)^4}(1+\eta^5) \end{matrix}\right\}\right]$$
$$\left[\frac{-2}{4+M^2} + \frac{0.00125}{(4+M^2)^3}(0.25 + 0.167 + 0.0424M^2) - \frac{0.00125}{(4+M^2)^4}(0.362M^2 + 0.0201M^4)\right]. \quad (29)$$

In order to obtain numerical solutions, here we considered human blood at 37℃. Chato (1980), Sud and Sekhon (1989) and Chaturani and Saxena Bharatiya (2001), has been taken physiological data as follows

$$\rho = 1050kgm^{-3}, \quad \sigma = 1.4\, mho.m^{-1}, \quad \mu = 3.2 \times 10^{-3}m^{-1}s^{-1},$$

$$C_p = 14.65Jkg^{-1}K^{-1}, \quad k = 2.2 \times 1^{-3}jm^{-1}s^{-1}K,$$

$$\mu_0 = 1.2 \times 10^{-3}m^{-1}s^{-1},\ u_m = 90 \times 10^{-2}ms^{-1},\ R = 0.4 \times 10^{-2}\, m,$$

$$\beta = 0.021℃^{-1},\ T_0 = 310\, K\ ,\ B_0 = 8T(\text{Tesla}).$$

Using the above physiological values for blood flow, we obtained the approximate values of Prandtl number, Eckert number, magnetic parameter and perturbation parameter which are given as below:

$$P_r = \frac{\mu_0 C_p}{k} \approx 8.79 \approx 9,\ E_c = \frac{u_m^2}{C_p T_0} \approx 1.79 \times 10^{-4},\ M = B_0 R\sqrt{\frac{\sigma}{\mu_0}} \approx 1.1, \text{ and}$$
$$N = 0.00125 \ll 1.$$

4. Results and Discussion

The solutions of equations (9) and (10) are represented in equations (22) and (23). Numerical results are mentioned in Figures (2) and (6). Figure (2) shows the velocity distribution for different values of magnetic parameter *M*. Further from Figure (2), we observed that blood velocity decreases with the increase of magnetic field strength. Figures (3) and (4) illustrate the effect of perturbation parameter and magnetics parameter on the flow rate. Also, Figures (5) and (6) depict the effect of perturbation parameter (*N*) and magnetics parameter (*M*) on temperature distribution and shear rate, respectively. We found flow rate of the blood flow rate decrease with respect to magnetic field and perturbation parameters. From Figures (5) and (6), it is observed that temperature and shear rate of the blood increases with the increasing the values of magnetic and perturbation parameters.

5. Conclusion

We analyzed the effect of magnetic parameter, flow rate, temperature of the blood flow motion and wall shear stress in an artery. The results obtained here yield significant role in fluid dynamics as well as in the field of medical science. Further the results are more useful to study the problems involving the control of blood flow through artery and veins with external magnetic field. The obtained results are very useful for hypertension patients. But the temperature and shear stress of the blood increases with respect to perturbation and magnetic parameters. This situation is dangerous for the human being, as the increase of blood temperature will damage blood oxygenation in hemodialysis. Also, wall shear stress increases with the increase of strength of magnetic field. At the higher value of magnetic field, the label of viscosity increases so significantly that it may cause the paralysis or sudden death.

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APPENDIX

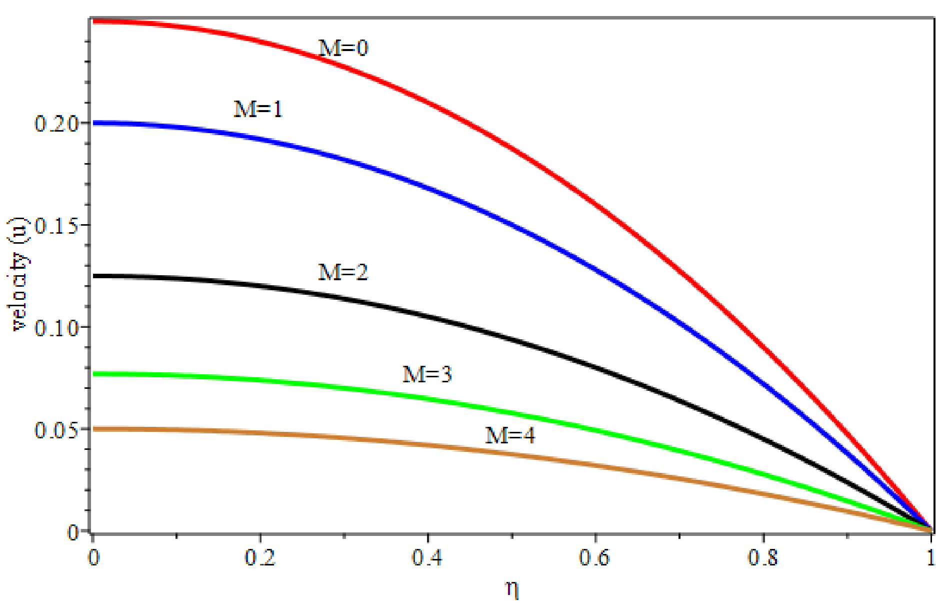

Figure2. Effect of different values of magnetic parameter M on axial velocity

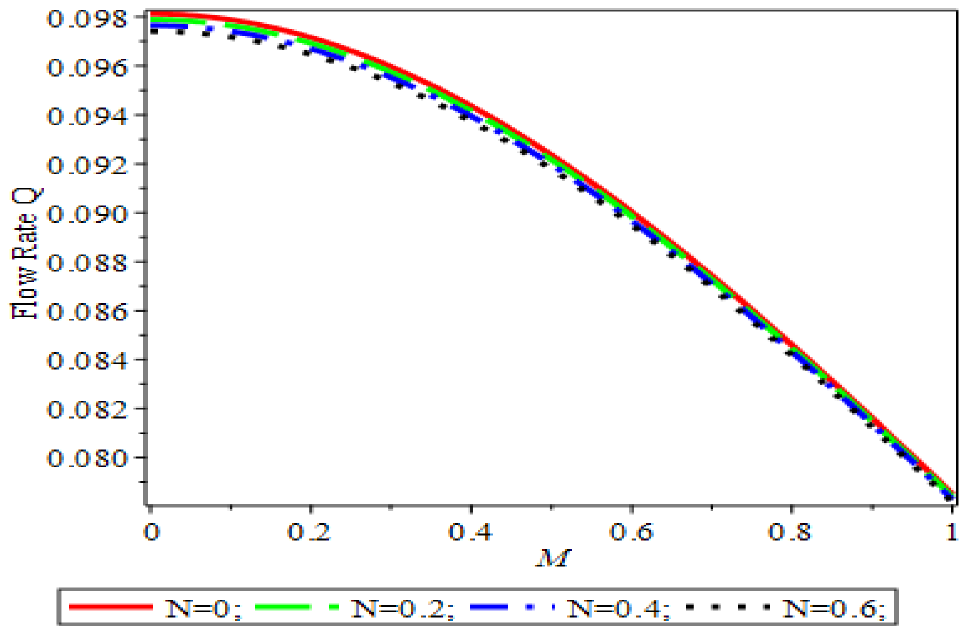

Figure 3. Effect of different values of perturbation parameter N on flow rate

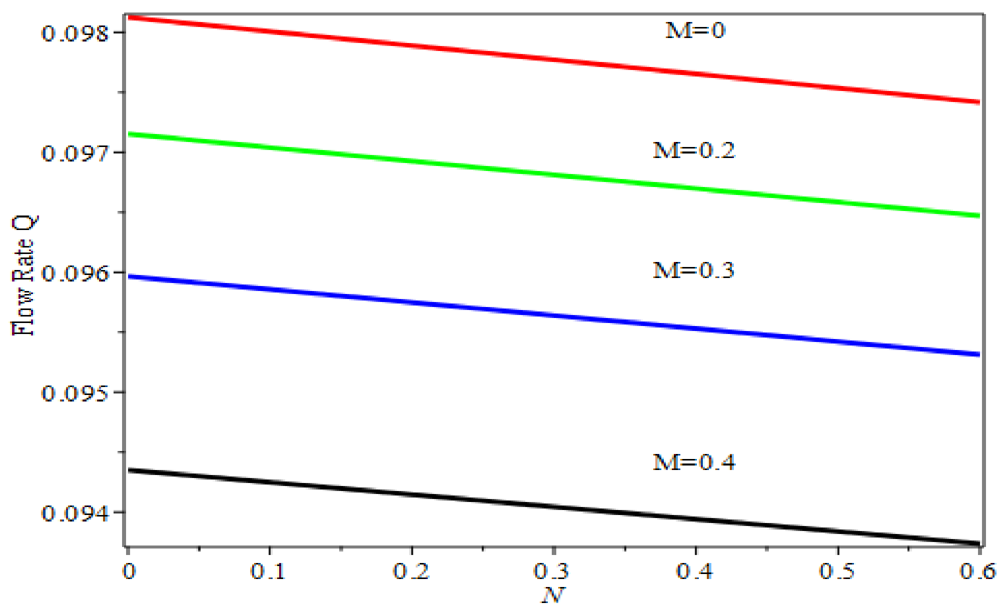

Figure 4. Effect of different values of magnetic parameter M on flow rate

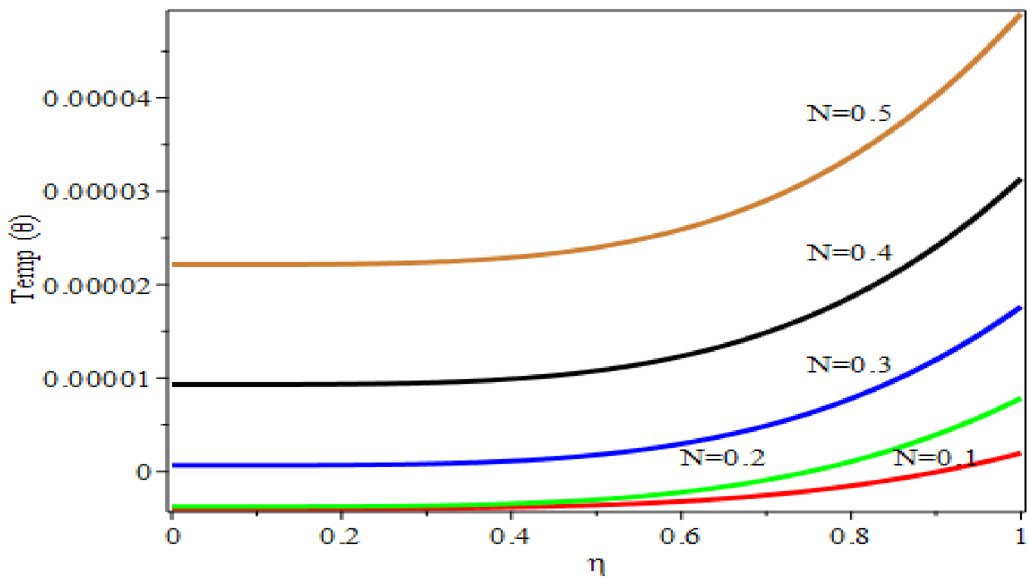

Figure 5. Effect of different values of perturbation parameter N on temperature at *M*=1

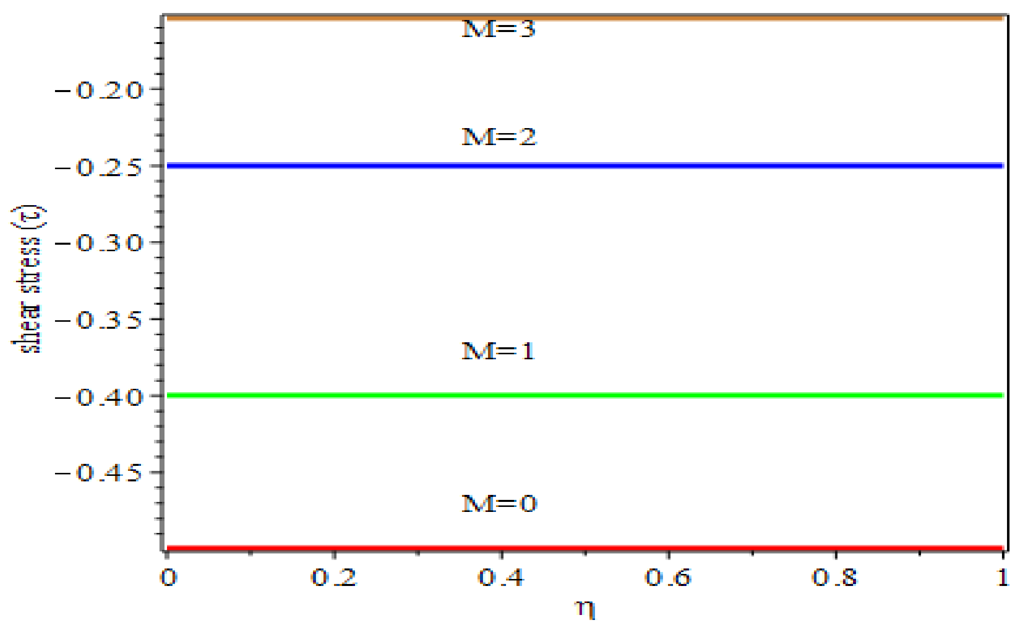

Figure 6. Effect of different values of magnetic parameter M on shear stress at *N*=0.1