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PERISTALTIC TRANSPORT OF BLOOD IN A HORIZONTAL CHANNEL

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Abstract : The present study is concerned with the peristaltic motion of blood through a horizontal channel. The blood is assumed to be conducting and non-Newtonian fluid of Rabinowitch type and a uniform magnetic field is applied along the transverse direction of the flow. The heat transfer in the liquid has also been taken into account. Using the assumption of long wavelength and low Reynolds number, the problem solved analytically. The effects of various parameters on velocity, pressure gradient and some other entities have been considered numerically and discussed through graphs.

Keywords: Conducting, Rabinowitch type, uniform magnetic field, heat transfer, Reynolds number.
2010 *Mathematics Subject Classification: 92B05*.

1. INTRODUCTION

Peristalsis, an innate property of many biological systems is found to occur in the movement of urine from the kidney to the bladder, vasomotion of small blood vessels, ovum transport in the fallopian tube, movement of chyme in the gastrointestinal tract and so on. Not only in physiological processes but it also gets a wide range of applications in engineering and industry also.

Several theoretical and experimental attempts have been made to understand the peristaltic motion under different normal and pathological conditions. The first theoretical investigation possibly was done by Latham (1966). Later Fung and Yih, (1968), Shapiro et al.(1969), Yin and Fung (1969), Gupta and Seshadri (1976), and Machireddy and Kattamreddy (2016) have also made significant contributions to understand such type of flow for Newtonian fluid. To get information's regarding the flow properties of physiological non-Newtonian fluids, Raju and Devanathan(1972) considered power law fluid of peristaltic motion in an axisymmetric tube arising by the proliferation of sinusoidal wave on the walls. Kaimal (1978) studied the peristaltic motion of arbitrary nature of wave shape for particle-fluid mixture in an axisymmetrical tube at low Reynolds number while Misra and Pandey (2002) studied the peristaltic transport of blood flowing through small blood vessels in which the core layer is Casson fluid while the outer layer is an incompressible Newtonian viscous fluid. Vajravelu et al. (2005) presented the peristaltic pumping of an incompressible Harschel Bulkley fluid model in a horizontal channel. Pandey and

Chaube (2011) investigated wall properties during the action of peristaltic motion of couple stress fluid and concluded that the mean velocity is reduce by raising the couple stress parameter but it increases with increasing wall tension. The peristaltic motion of Carreau fluids through an inclined channel in presence of a uniform transverse magnetic field has been studied by Reddy et al. (2011) by using the perturbation method. Akbar and Butt (2015) considered the heat transfer in peristaltic transport of Herschel-Bulkley fluid through a non-uniform inclined channel.

The study of heat transfer in association with peristalsis gets its importance as it plays a significant role in physiology. For instance, the thermodynamic features of blood are very useful in oxygenation and hemodialysis. In this connection, the work of Radhakrishnamachraya and Murty (1993) may be mentioned in which the heat transfer due to peristaltic transport in a channel of varying width has been analyzed for perturbed solutions for temperature and heat transfer coefficient. The problem of peristaltic pumping and heat transfer through an asymmetric channel was also studied bySrinivas and Kothandapani (2008) while Sinha et al. (2015) analysed the heat transfer of MHD peristaltic motion through an asymmetric channel with variable viscosity. Recently Bhatt et al. (2017) studied peristaltic transport and heat transfer through a channel of non-uniform geometry in which the walls were assumed to be permeable and concluded that the temperature decreases with an increase in Darcy's number. The study of heat and mass transfer in connection with the peristaltic motion of hyperbolic tangent fluid through a channel of varying width in presence of a uniform transverse magnetic field was due to Sarvana et al. (2016).

Rabinowitsch model is a well-established fluid model of non-Newtonian character. For such fluid, the shearing stress and shearing strain are connected by the relation :

$$\tau'_{YX} + \gamma {\tau'_{XY}}^{3} = \mu \frac{\partial U}{\partial Y} \tag{1}$$

where γ is the coefficient of pseudoplasticityon which the non-Newtonian nature of fluid depends, μ is the viscosity of the fluid, U is velocity, X and Y are axial and transverse coordinates respectively. This model exhibits dilatant, Newtonian and pseudoplastic fluids nature for $\gamma < 0$, $\gamma = 0$ and $\gamma > 0$ respectively. Wada and Hayashi (1971) analyzed this model experimentally to justify theoretical results. The Rabinowitsh fluid model has been utilized by Singh et al. (2011, 2012) and Singh (2013), to investigate the different types of hydrostatic, hydrodynamic and squeeze film bearing systems. Singh and Singh (2014) and Akbar and Nadeem (2014), Maraj and Nadeem (2015) also studied the Rabinowitsch fluid model for peristaltic motions through peristalsis in channels of various curvatures.

In the present investigation we proceed to analyse the effect of heat transfer for peristaltic transport of Rabinowitsch type fluid through a uniform horizontal channel. A uniform magnetic field is applied along the transverse direction of the flow. The present work seems to be helpful to understand the physiological nature of the fluid of pseudoplastic nature.

2. ANALYSIS

Let us consider the flow of Rabinowitsch fluid through a horizontal channel of uniform thickness. Sinusoidal wave is supposed to proliferate on the wall of the channel and moving with speed c. Taking (X, Y) as a rectangular coordinates in a fixed frame, the geometry of peristaltic flow is shown in Fig.1.

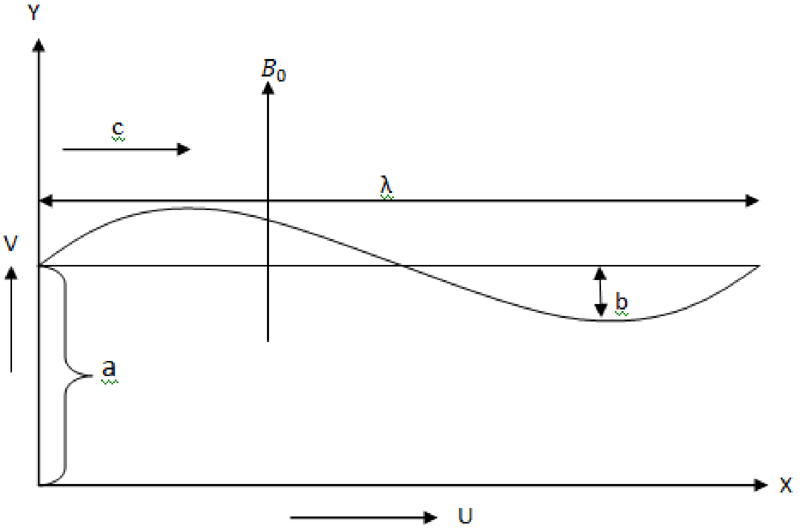

Fig 1. Geometry of the peristaltic flow

The geometry of wall surface is given as

$$H(X,t') = a + b\sin\left(\frac{2\pi(X-ct')}{\lambda}\right) \quad (2)$$

where$a$ is half channel width, b is the wave amplitude of the wave, t' is time andλ is the wavelength. Basic Equations are given by the following:

Continuity equation

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0, \quad (3)$$

Momentum equation

$$\rho\left(\frac{\partial U}{\partial t'} + U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y}\right) = -\frac{\partial p'}{\partial X} + \frac{\partial \tau'_{XX}}{\partial X} + \frac{\partial \tau'_{YX}}{\partial Y} - \sigma B_0^2 U, \quad (4)$$

$$\rho\left(\frac{\partial V}{\partial t'} + U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y}\right) = -\frac{\partial p'}{\partial Y} + \frac{\partial \tau'_{XX}}{\partial X} + \frac{\partial \tau'_{YX}}{\partial Y}, \quad (5)$$

Energy equation

$$\rho C_p\left(\frac{\partial T}{\partial t'} + U\frac{\partial T}{\partial X} + V\frac{\partial T}{\partial Y}\right) = \kappa\left(\frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial Y^2}\right) + \tau_{XX}\frac{\partial U}{\partial X} + \tau_{YY}\frac{\partial V}{\partial Y} + \tau_{YX}\left(\frac{\partial U}{\partial Y} + \frac{\partial V}{\partial X}\right),$$

(6)

where U and V are components of velocity along X and Y directions respectively in a fixed frame of reference, $C_p$is the specific heat at constant pressure, T is temperature, κ is thermal conductivity, p is pressure, ρ is density and $t'$is time, B_0 is the uniform transverse magnetic field.

The transformation between fixed and wave frames is given by

$$u' = U - c, v' = V, x' = X - ct', \; y' = Y, (7)$$

where$u', v', x', \; y'$ are axial velocity, transverse velocity, axial coordinate and transverse coordinate respectively in wave frame.

Introducing the following non-dimensional quantities

$$u = \frac{u'}{c}, v = \frac{v'}{c\delta}, x = \frac{x'}{\lambda}, y = \frac{y'}{a}, h = \frac{H}{a}, \delta = \frac{a}{\lambda}, p = \frac{p'a^2}{\mu c\lambda}, Re = \frac{\rho ac}{\mu}, \theta = \frac{T-T_0}{T_0},$$

$$t=\frac{ct'}{\lambda}, Pr=\frac{\mu c_p}{K}, Ec=\frac{c^2}{T_0 c_p}, \phi=\frac{b}{a}, \tau_{xy}=\frac{a\tau'_{XY}}{c\mu}, \tau_{xx}=\frac{a\tau'_{XX}}{c\mu}, \tau_{yy}=\frac{a\tau'_{YY}}{c\mu},$$

$\alpha=\frac{c^2\mu^2}{a^2}\gamma,\ M^2=\frac{\sigma B_0^2 a^2}{\mu}$(8)

and using transformationequations (1) to (6)with the assumption of long wavelength and low Reynolds number approximations, we get

$$\tau_{yx}+\alpha\tau_{xy}^3=\frac{\partial u}{\partial y}, \tag{9}$$

$$h=1+\phi\cos(2\pi x), \tag{10}$$

$$\frac{1}{\lambda}\frac{\partial u}{\partial x}+\frac{c}{a}\frac{\partial v}{\partial y}=0, \tag{11}$$

$$\frac{\partial \tau_{yx}}{\partial y}-M^2(u+1)=\frac{\partial p}{\partial x}, \tag{12}$$

$$\frac{\partial p}{\partial y}=0, \tag{13}$$

$$\frac{\partial^2\theta}{\partial y^2}=-Br\,\tau_{yx}\frac{\partial u}{\partial y}, \tag{14}$$

where the dimensionless quantities α, ϕ, Ec and Br are the parameters of pseudoplasticity, amplitude ratio, Eckert number and Prandlt number respectively.

The boundary conditions for equations (12-14) are as follows :

$u=-1 \quad at \quad y=h,$

$\frac{\partial u}{\partial y}=0 \quad at \quad y=0,$

$\frac{\partial \theta}{\partial y}=0 \quad at \quad y=0,$

$\theta=0 \quad at \quad y=h,$(15)

On solving equation (12) and equation (14) with boundary conditions equation (15) we have

$$u=\left(\frac{y^2-h^2}{2}\right)\left(\frac{dp}{dx}+M^2\right)+\alpha\left(\frac{dp}{dx}+M^2\right)^3\left(\frac{y^4-h^4}{4}\right)-1, \tag{16}$$

$$\theta=Br\left(\frac{dp}{dx}+M^2\right)^2\left[\frac{h^4-y^4}{12}+\alpha\frac{h^6-y^6}{30}\left(\frac{dp}{dx}+M^2\right)^2\right], \tag{17}$$

where the Brinkman Number (Br) = Ec . Pr.

The coefficient of heat transfer (Ω) at the wall is given by

$$\Omega=-2\pi\phi\sin(2\pi x)Br\left(\frac{dp}{dx}+M^2\right)^2\left[\frac{h^3}{3}+\alpha\frac{h^5}{5}\left(\frac{dp}{dx}+M^2\right)^2\right] \tag{18}$$

The corresponding stream function is obtained from the relations

$u=\frac{\partial\psi}{\partial y}, \qquad v=-\frac{\partial\psi}{\partial x}.$

Integrating equation (16) and using the condition $\psi=0\ at y=0$ the stream functionψ is obtained as

$$\psi=\left(\frac{y^3}{6}-\frac{yh^2}{2}\right)\left(\frac{dp}{dx}+M^2\right)+\alpha\left(\frac{dp}{dx}+M^2\right)^3\left(\frac{y^5}{20}-\frac{yh^4}{4}\right)-y \tag{19}$$

The volume flow rates in fixed frame (Q') and in wave frame (q') are given by

$$Q'=\int_0^H U\,dY \tag{20}$$

$$q'=\int_0^H u'\,dy' \tag{21}$$

Using equation (7), it follows from (20) and (21)

$$Q'=q'+cH \tag{22}$$

Also the average flow $\hat{Q} = \frac{1}{T}\int_0^T Q' \, dt'$ over the time $T = \frac{\lambda}{c}$, is

$$\hat{Q} = q' + ca. \quad (23)$$

This can be reduced in dimensionless form as

$$Q = q + 1. \quad (24)$$

where $= \frac{q'}{ac} = \int_0^h u \, dy \, ; Q = \frac{\hat{Q}}{ac}$.(25)

Using equation (16) in equation (25) we have

$$\left(\frac{dp}{dx} + M^2\right) + \frac{3}{5}\alpha h^2 \left(\frac{dp}{dx} + M^2\right)^3 + 3\left(\frac{q+h}{h^3}\right) = 0 \quad (26)$$

In the limiting casewhen $\alpha \to 0$, equation (26) reduces to

$$\frac{dp}{dx} + M^2 = -3\left(\frac{q+h}{h^3}\right). (27)$$

Since the equation (26) is a non-linear equation of first order, it is difficult to find an analytic solution for pressure; however, for small values of the pseudoplasticityparameter $(\alpha \ll 1)$, equation (26) can be perturbed as follows

$$p = p_0 + \alpha p_1 \quad (28)$$

so that

$$\frac{dp}{dx} + M^2 = -3\left(\frac{q+h}{h^3}\right) + \frac{81}{5}\alpha \frac{(q+h)^3}{h^7}. \quad (29)$$

Using equation (24) in equation (29), we have

$$\frac{dp}{dx} + M^2 = -3\left(\frac{Q-1+h}{h^3}\right) + \frac{81}{5}\alpha \frac{(Q-1+h)^3}{h^7}. \quad (30)$$

The pressure rise and friction force are given by

$$\Delta p = \int_0^1 \frac{dp}{dx} \mathrm{dx}\,, \quad (31)$$

$$\mathrm{F} = \int_0^1 h\left(-\frac{dp}{dx}\right)\mathrm{dx}\,. \quad (32)$$

3. NUMERICAL RESULTS AND DISCUSSIONS

Let us now analyze the effects of various parameters on pressure gradient, pressure rise, frictional force, fluid velocity and fluid temperature. In order to perform numerical computations, have been used the following values of the parameters:

Amplitude ratio : $0 < \varphi < 1$

The parameter of pseudoplasticity : $-0.1 < \alpha < 0.1$

Figures 2 (a-d) explain the behavior of pressure gradient in regard to the change of the rate of flow(Q), parameters of pseudoplasticity(α), amplitude ratio(φ) and Hartmann number (M), It can be observed that in the wider part of the channel for $x \in [0, 0.2]$, the pressure gradient is relatively small; where as, in the narrow part of the channel for $x \in [0.2, 0.7]$, a much higher pressure gradient is required to maintain the same flux.

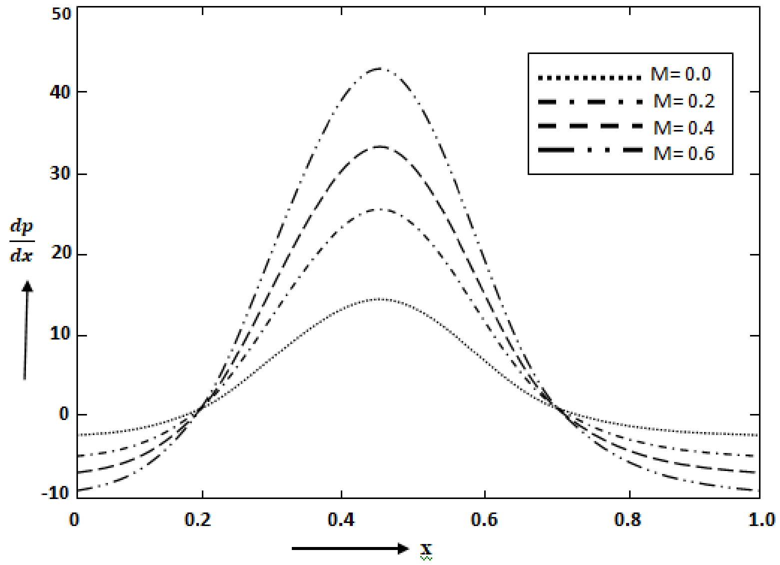

Fig. 2(a): Variation of the pressure gradient with x for different values of M when α = 0.1, Q = 0.2, φ = 0.4

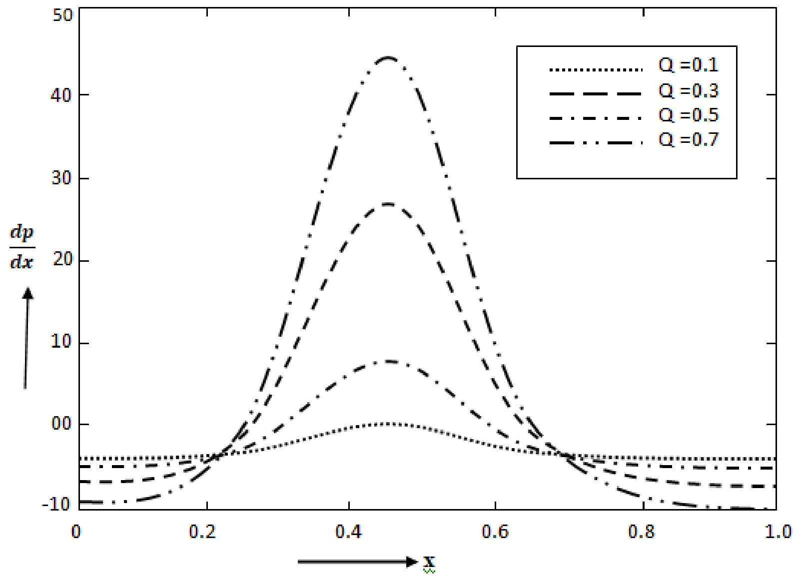

Fig. 2(b): Variation of the pressure gradient with x for different values of Q when α = 0.1, M = 0.4, φ = 0.4

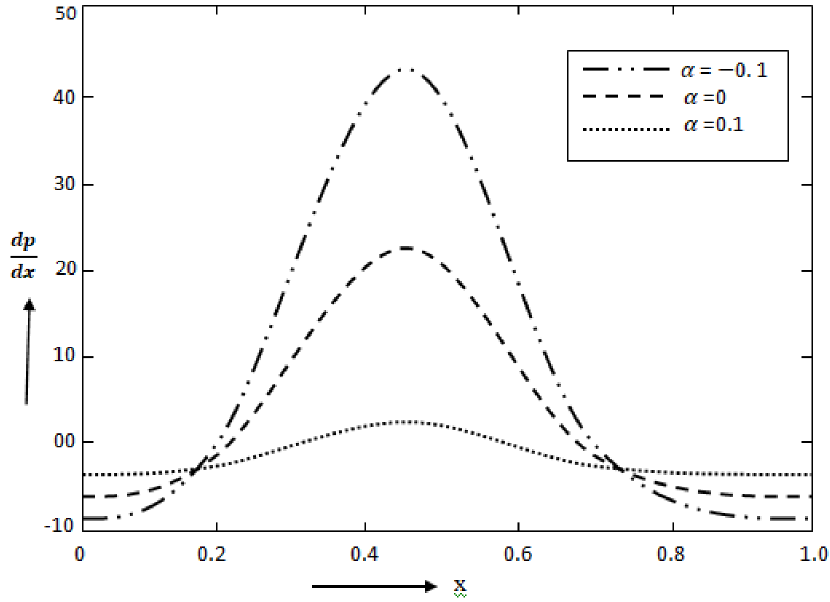

Fig. 2(c): Variation of the pressure gradient with x for different values of α when Q = 0.3, M = 0.4, φ = 0.4

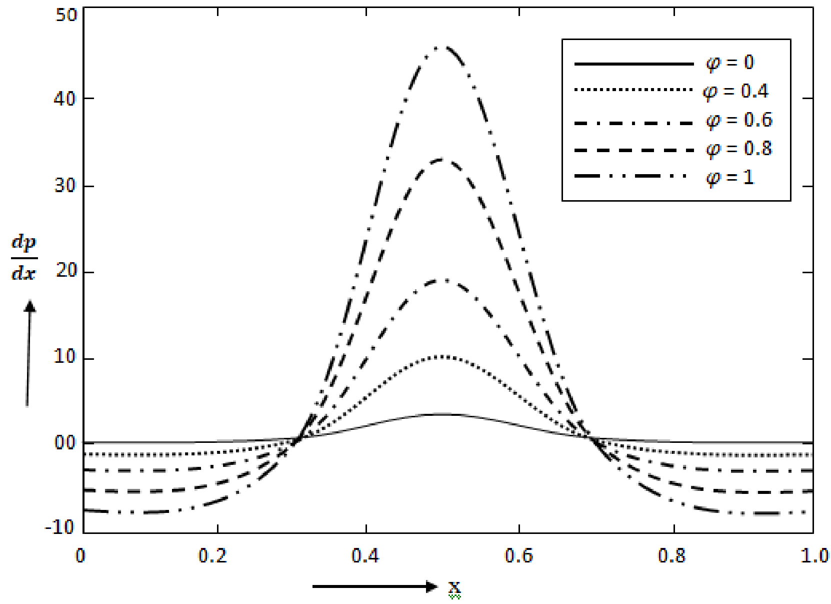

Fig. 2(d): Variation of the pressure gradient with x for different values of φ when Q = 0.3, M = 0.4, α = 0.1

Figures 3 (a-c) explain the behavior of pressure rise with the change in the rate of flow(Q), pseudoplasticity parameter (α), amplitude ratio(φ) and Hartmann number (M). The variation of pressure rise against the flow rate is shown in Figure 3(a) for different values of M, α = 0.1 and φ = 0.4. It is noted that the pressure rise is linearly connected to flow rate. The variation of pressure rise against the amplitude ratio is shown in Figure 3(b) for different values of Q, α= 0.1 and Hartmann number M=0.5,. In this caseon increasing flow rate the pressure rise decreases.Figure 3(c) depicts the change in pressure rise against the parameter of pseudoplasticity for different values of flow rates, taking φ = 0.4, M = 0.5.It is observed that on increasing flow rate the pressure rise also decreases.

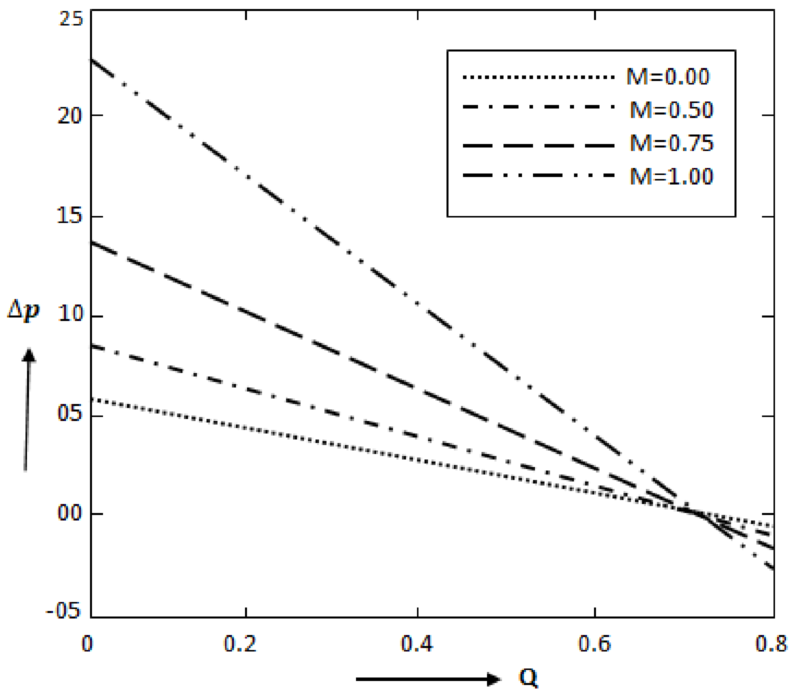

Fig. 3(a): Variation of the pressure rise with flow rate for different values of M when α = 0.1, φ = 0.4

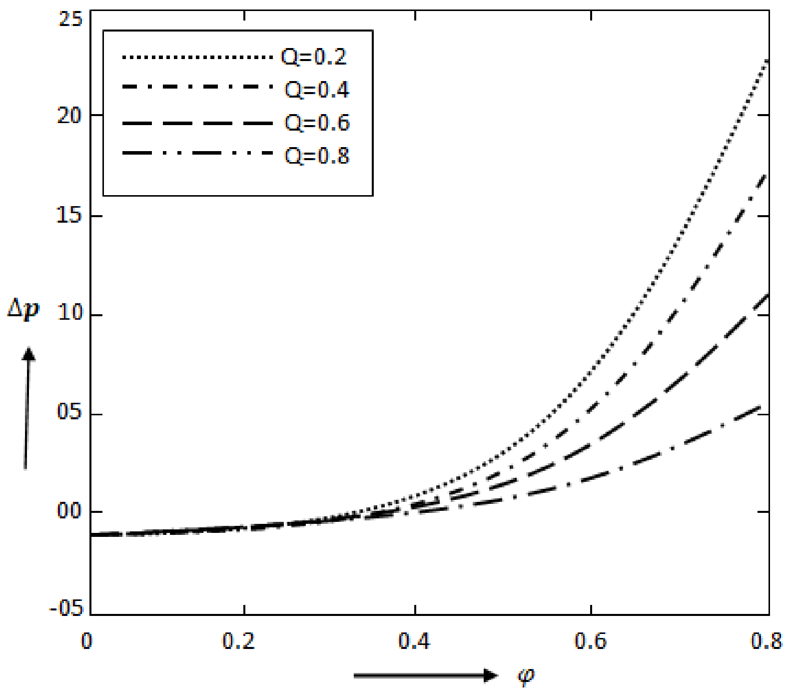

Fig. 3(b): Variation of the pressure rise with amplitude ratio for different values of Q when α = 0.1, M = 0.5,

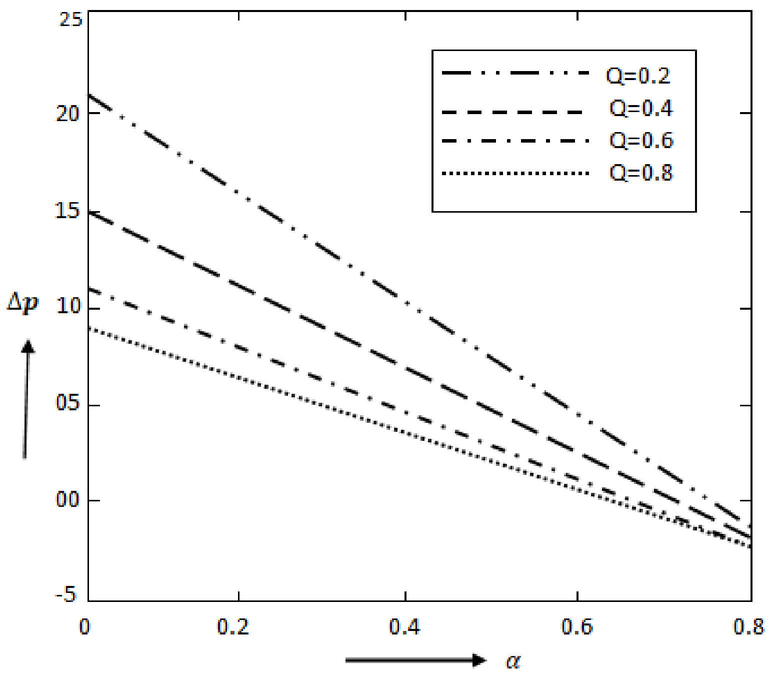

Fig. 3(c): Variation of the pressure rise with parameter of Pseudoplasticity(α) for different values of Q when φ = 0.4, M = 0.5, Figures 4(a-b) explain the behavior of frictional force with change in the rate of flow (Q), pseudoplasticity(α), amplitude ratio(φ) and Hartmann number (M). Fig. 4(a) shows the variation of friction force against the flow rate for different values of $\varphi$when α = 0.1, M = 0.5. It is obvious that the friction force is to increase with increase of amplitude ratio. Fig. 4(b) gives the information regarding the change in friction force against the amplitude ratio for different values of Qwhen α = 0.1, M = 0.5. It is noted that the effect of flow rate on friction force is in contrast to the effect of flow rate on pressure rise.

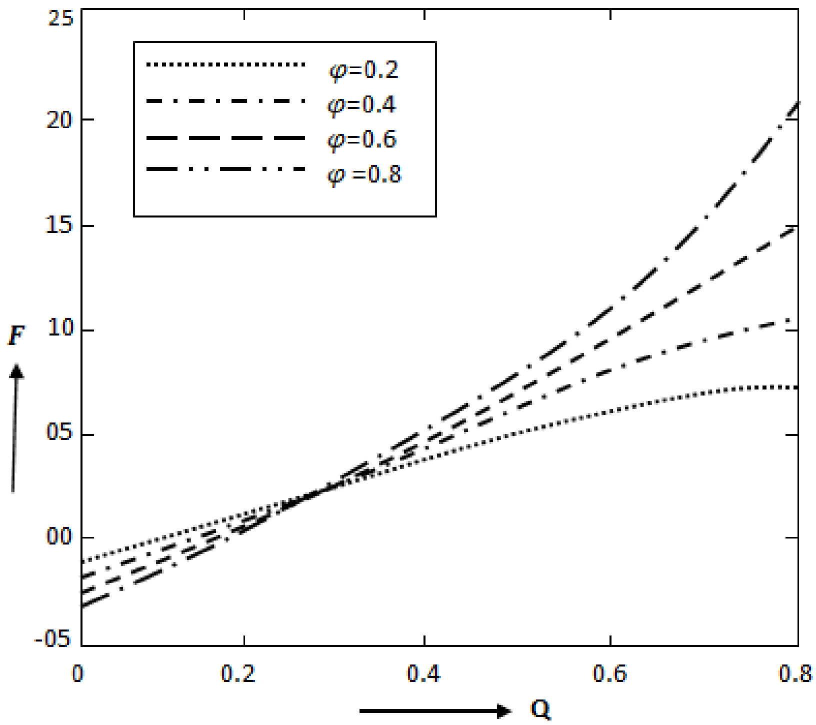

Fig. 4(a): Variation of the friction with flow rate for different values of φ when α = 0.1, M = 0.5

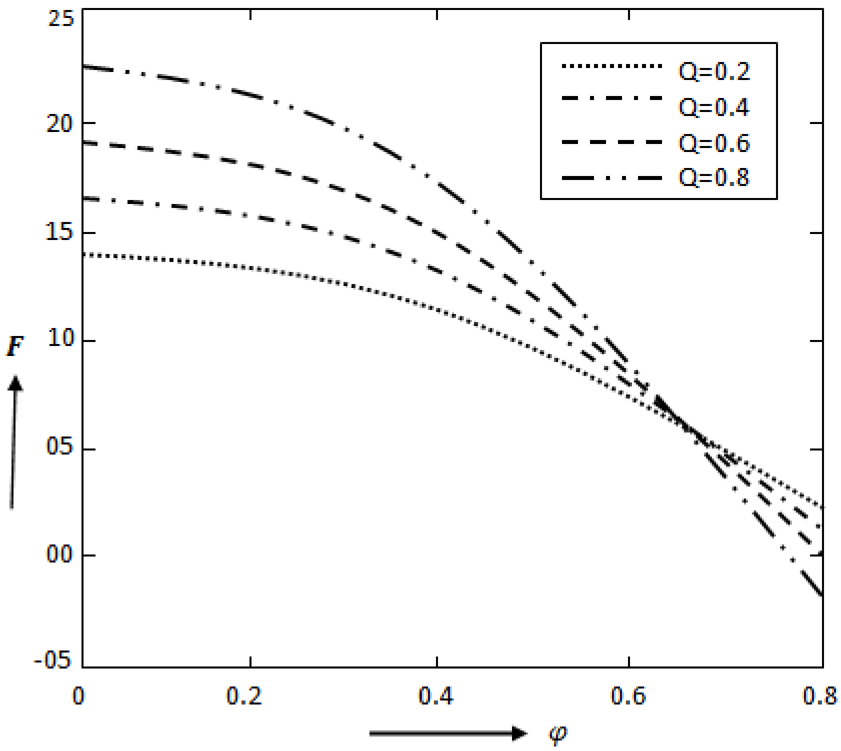

Fig. 4(b) Variation of the friction with amplitude ratio for different values of Q when α = 0.1, M = 0.5

Figures 5(a−d) discuss the behavior of temperature with the change in the rate of flow (Q), pseudoplasticity parameter (α), amplitude ratio (φ) and Hartmann number (M). The variation of temperature with y of the channelfor different values of M is shown in Fig. 5(a) for α= 0.1,φ = 0.4 Q = 0.3, Br = 0.3, x = 0.4.It was observed that the temperature decreases with increase of the magnetic fields. The variation of temperature with y of the channel different values of Br is shown in Fig. 5(b) for α= 0.1,φ = 0.4 Q = 0.3, M = 0.4, x = 0.4. It was noted that the temperature increases with increase of Br.The variation of temperature with y of the channelfor different values of φ is shown in Fig. 5(c) for α = 0.1,Br = 0.3, Q = 0.3, M = 0.4, x = 0.4. It was seen that the temperature increases with increaseof φ.The variation of temperature with y of the channel for different values of $Q$is shown in Fig. 5(d) for α = 0.1, Br = 0.3, φ= 0.4, M = 0.5, x = 0.4.In this case the temperature increases with increase of Q.

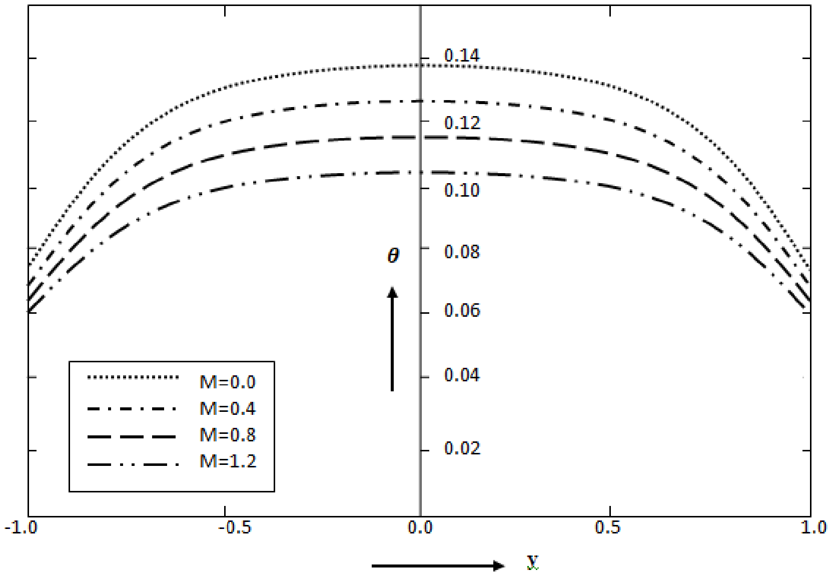

Fig. 5(a) Variation of temperature with y for different values of M, when $\alpha = 0.1$, $\varphi = 0.4$, Q = 0.3, Br = 0.3, x = 0.4

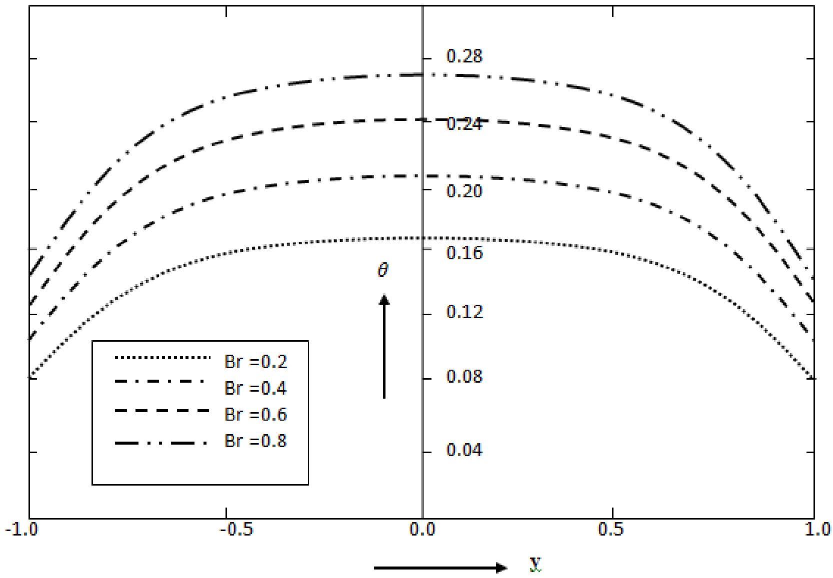

Fig. 5(b) Variation of temperature with y for different values of Br, when $\alpha = 0.1$, $\varphi = 0.4$, Q = 0.3, M = 0.4, x = 0.4

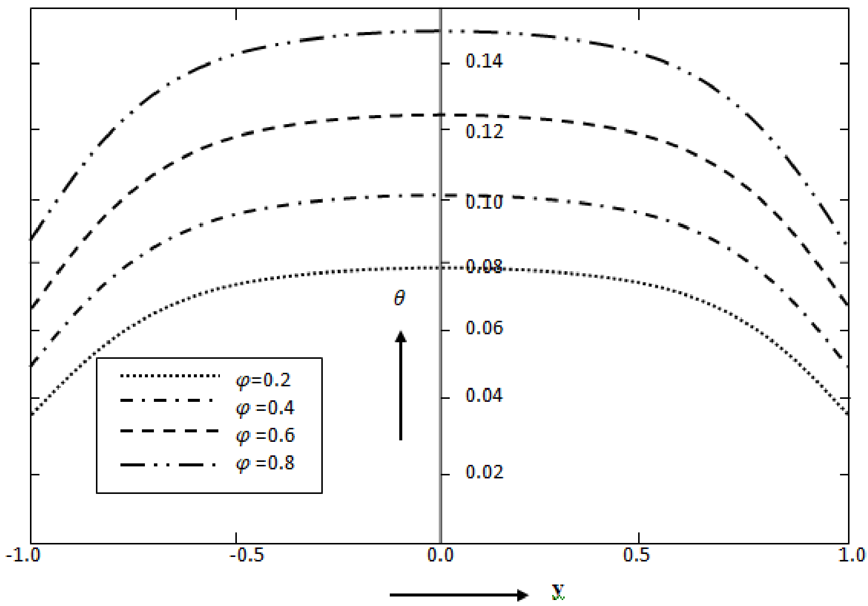

Fig. 5(c):Variation of temperature with y for different values of φ, when α = 0.1, Br = 0.3, Q = 0.3, M = 0.4, x = 0.4

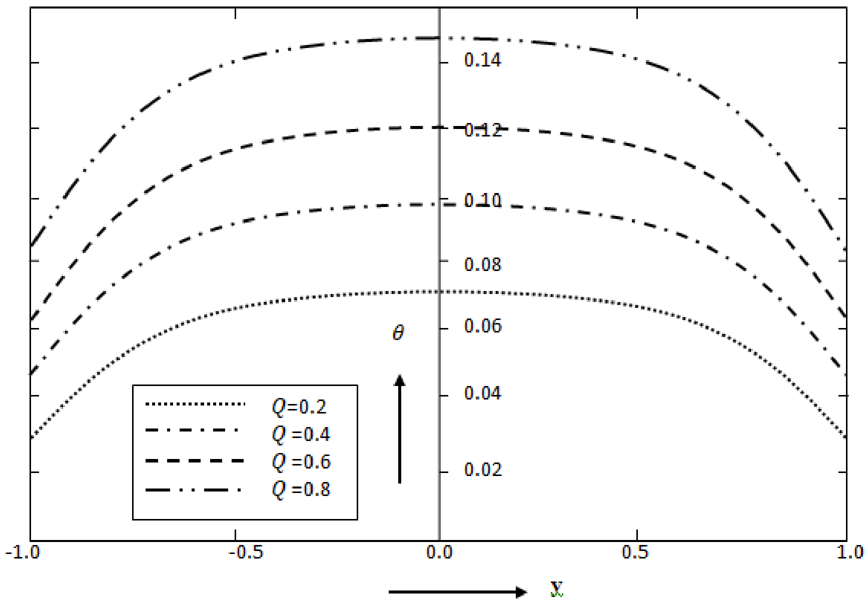

Fig. 5(d):Variation of temperature with y for different values of Q, when α = 0.1, Br = 0.3, φ= 0.4, M = 0.5, x = 0.4

Fig. 6(a–b) explain the behavior of heat transfer coefficient (Ω) along the axial direction with change of Hartmann number (M) and Brinkman number (Br).Fig. 6(a) shows the variation of heat transfer coefficient along the axial direction for different value of M, when α= 0.1, φ = 0.4, Q = 0.3, Br = 0.4. It is observed that the heat transfer coefficient decreases with increase of M.Fig. 6(b) shows the variation of heat transfer coefficient along the axial direction for different value of Br, when α =

0.1, $\varphi = 0.4$, Q = 0.3, M = 0.5. It is noted that the heat transfer coefficient increases with increase of Br.

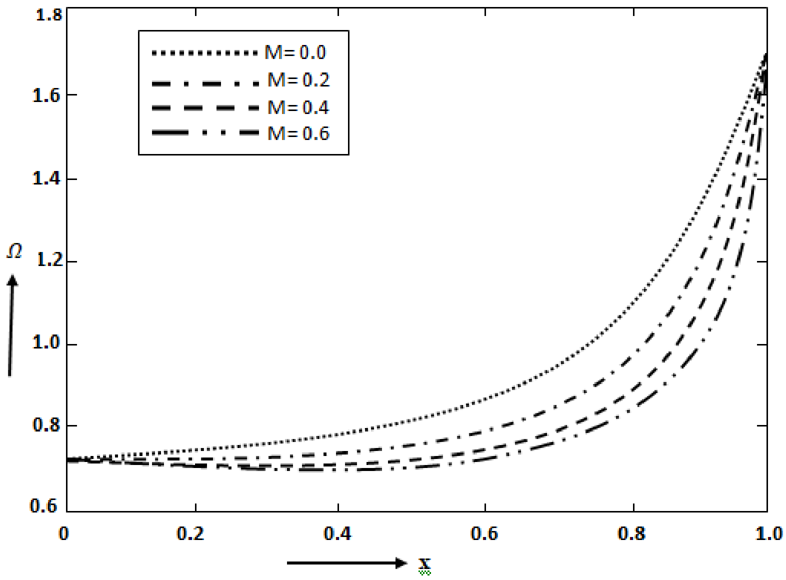

Fig. 6 (a): Effect of heat transfercoefficientwith x for different values of M, when α = 0.1, $\varphi = 0.4$, Q = 0.3, Br = 0.4.

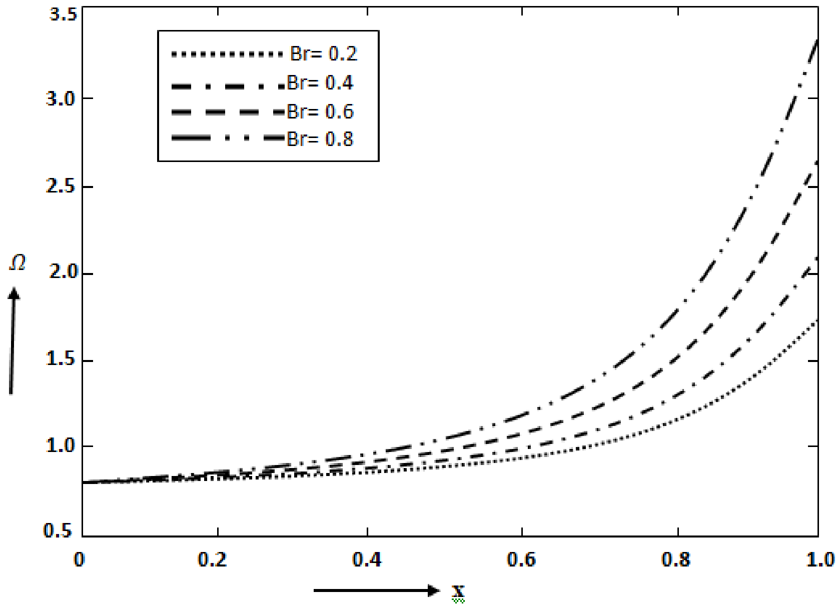

Fig. 6 (b): Effect of heat transfercoefficientwith x for differentvalues of Br, when α = 0.1, $\varphi = 0.4$, Q = 0.3, M = 0.5.

4. CONCLUDING REMARKS

Analyses of the above problem and its solutions give rise to the following effects on the peristaltic motion of blood through the channel:

i) Pressure gradient is relatively small in the wider part of the channel while it is higher in the narrow part.

ii) Pressure rise within the channel is linearly connected to the flow rate and increasing of flow rate reduces the pressure.
iii)The effect of flow rate on friction force is noticeable for the pressure rise.

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