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Influence of heat transfer on peristaltic transport of a Newtonian fluid with wall properties in an asymmetric channel

T. Raghunath Rao

Department of Humanities and Sciences, Kamala Institute of Technology & Science, Singapur, Karimnagar, affiliated to JNT University, Hyderabad, Telangana, India

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ABSTRACT

The effect of heat transfer on the peristaltic transport of a Newtonian fluid with wall properties in a two dimensional flexible channel under long wave length approximation has been studied. A perturbation method of solution is obtained in terms of wall slope parameter and closed form of expressions has been derived for stream function, temperature and heat transfer coefficient. The effects of elastic parameters and pertinent parameters on temperature and the coefficient of heat transfer have been computed numerically. It is observed that temperature distribution increases with increase in elasticity parameters.

Keywords: Peristaltic transport, Heat transfer, Newtonian fluid and Temperature.

INTRODUCTION

The study of the mechanism of peristalsis, in both physiological and mechanical situations, has become the object scientific research. From fluid mechanical point of view peristaltic motion is defined as the flow of generated by a wave traveling along the walls of an elastic tube. In physiology it may be described as a progressive wave of area contraction or expansion along a length of a distensible tube containing fluid provided with transverse and muscular fibers. It consists in narrowing and transverse shortening of a portion of the tube which then relaxes while the lower portion becomes shortened and narrowed. The mechanism of peristalsis occur for urine transport from kidney to bladder through the ureter, movement of chime in the gastro-intestinal tract, the movement of spermatozoa in the ducts efferent's of the mail reproductive tract, movement of ovum in the fallopian tube, vasomotion in small blood vessels, the food mixing and motility in the intestines, blood flow in cardiac chambers etc. Also bio-medical instruments such as heart-lung machine use peristalsis to pump blood while mechanical devices like roller pumps use this mechanism to pump and other corrosive fluids.

The problem of the mechanism of peristalsis transport has attracted the attention of many investigators. Fung and Yih [1], Shapiro and Jaffrin et al. [2] have studied peristaltic pumping with long wavelength at low Reynolds number. Haroun [3], Ebaid [4], Mekheimer *et.al*. [5], Mishra & Rao [6] have studied peristalsis under different conditions. Mittra and Prasad [7] studied peristaltic transport in a two-dimensional channel considering the elasticity of the walls under the approximation of small amplitude ratio with dynamic boundary conditions. Muthu *et.al*.[8] have discussed On the Influence of wall Properties in the Peristaltic Motion of Micro polar Fluid. The interaction of peristalsis and heat transfer has become highly relevant and significant in several industrial processes also thermo dynamical aspects of blood become significant in process like haemodialysis and oxygenation when blood is drawn out of the body. Keeping these things in view, Victor and Shah [9] studied heat transfer to blood using the Casson model. Srinivas and Kothandapani [10] investigated the peristaltic transport of a Newtonian fluid with heat transfer in an asymmetric channel. Radhakrishnamacharya and Srinivasulu [11] investigated the influence of wall properties on peristaltic transport with heat transfer. Sankad *et.al*.[12] have studied the influence of wall properties on the Peristaltic Motion of a Hershel-Bulkley fluid in a channel. Sobh *et.al*.[13] studied heat Transfer in Peristaltic flow of Viscoelastic Fluid in an Asymmetric Channel. Raghunath Rao *et.al*.[14] investigated the effect of heat transfer on peristaltic transport of Viscoelastic fluid in a channel with wall properties and Raghunath Rao *et.al*.[15] also studied the influence of heat transfer on peristaltic transport of couple stress fluid through a porous medium.

The present research aimed is to investigate the interaction of peristalsis for the motion of a Newtonian fluid with wall properties in an asymmetric flexible channel under long wavelength approximation. A perturbation method of solution is obtained in terms of wall slope parameter and closed form of expressions has been derived for temperature distribution and heat transfer coefficient. The effects of elasticity parameters and pertinent parameters on temperature distribution and heat transfer coefficient have been computed numerically.

FORMULATION OF THE PROBLEM

We consider a peristaltic flow of a Newtonian fluid in an asymmetric channel of width $d_1 + d_2$, the walls of the channel are assumed to be flexible and are taken as a stretched membrane on which traveling sinusoidal waves of moderate amplitude are imposed.

The geometry of flexible walls are represented by

$$h_1(x,t) = d_1 + a_1 \operatorname{Cos} \frac{2\pi}{\lambda}(x - ct), \quad \text{upper wall} \tag{1}$$

$$h_2(x,t) = -d_2 - a_2 \operatorname{Cos}\left[\frac{2\pi}{\lambda}(x - ct) + \theta\right], \quad \text{lower wall} \tag{2}$$

Where a_1, a_2 are the amplitudes of the peristaltic waves, 'c' is the wave velocity, 'λ' is the wave length, t is the time and θ $(0 \le \theta \le \pi)$ is the phase difference. It should be noted that $\theta = 0$ corresponds to symmetric channel with waves out of phase, $\theta = \pi$ with waves in phase, and further a_1, a_2, d_1, d_2 and θ satisfy the following inequality Mishra and Rao[6]

$$a_1^2 + a_2^2 + 2a_1 a_2 \cos\theta \le (d_1 + d_2)^2 \tag{3}$$

The equation of continuity and the equations of motion are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{4}$$

$$\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \upsilon\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \tag{5}$$

$$\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \upsilon\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \tag{6}$$

Equation of energy

$$C_p\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = \frac{k}{\rho}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \upsilon\left[2\left(\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2\right) + \left(\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y}\right)^2\right] \tag{7}$$

Where u, v are the velocity components, 'p' is the fluid pressure, 'ρ' is the density of the fluid, 'υ' is the coefficient of kinematic viscosity, T is the temperature, 'C_p' is the specific heat at constant pressure and 'k' is the coefficient of thermal conductivity.

The governing equation of motion of the flexible wall may be expressed as

$$L\begin{Bmatrix} h_1 \\ h_2 \end{Bmatrix} = p - p_0 \tag{8}$$

Where 'L' is an operator, which is used to represent the motion of stretched membrane with damping forces such that

$$L \equiv -T^* \frac{\partial^2}{\partial x^2} + m\frac{\partial^2}{\partial t^2} + C\frac{\partial}{\partial t} \tag{9}$$

Here T^* is the elastic tension in the membrane, m is the mass per unit area and C is the coefficient of viscous damping forces, p_0 is the pressure on the outside surface of the wall due to tension in the muscles. For simplicity, we assume p_0 = 0. The horizontal displacement will be assumed zero. Hence the boundary conditions for the fluid are

$$u = 0 \quad \text{at} \quad \begin{cases} y = h_1 \\ y = h_2 \end{cases} \tag{10}$$

Continuity of stresses requires that at the interfaces of the walls and the fluid p must be same as that which acts on the fluid at $y = h_1$ & $y = h_2$. The use of '*x*' momentum equation the dynamic boundary conditions at flexible walls are

$$\frac{\partial}{\partial x} L \begin{Bmatrix} h_1 \\ h_2 \end{Bmatrix} = \frac{\partial p}{\partial x} = \rho\nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) \quad at \begin{cases} y = h_1 \\ y = h_2 \end{cases} \tag{11}$$

The conditions on temperature are

$$\left.\begin{aligned} T = T_0 \quad \text{on} \quad y = h_1 \\ T = T_1 \quad \text{on} \quad y = h_2 \end{aligned}\right\} \tag{12}$$

In view of the incompressibility of the fluid and two-dimensionality of the flow, we introduce the Stream function' ψ 'such that

$$u = \frac{\partial\psi}{\partial y} \quad and \quad v = -\frac{\partial\psi}{\partial x}$$

and introducing non-dimensional variables

$$x' = \frac{x}{\lambda},\ y' = \frac{y}{d},\ u' = \frac{u}{c},\ v' = \frac{v}{c\,\delta}, \psi' = \frac{\psi}{cd}, t' = \frac{ct}{\lambda},\ h_1' = \frac{h_1}{d_1},\ h_2' = \frac{h_2}{d_1},\ p' = \frac{p\,d^2}{\mu\, c\,\lambda}, \theta = \frac{T - T_0}{T_1 - T_0} \tag{13}$$

in equations of motion and the conditions (1) – (2), (3) – (6) & (8) – (10) and eliminating p , we finally get (after dropping primes)

$$h_1\,(\mathrm{x},t) = 1 + a\ \ \mathrm{Cos}\ 2\,\pi\,(\mathrm{x} - t) \tag{14}$$

$$h_2\,(\mathrm{x},t) = -d - b\,\mathrm{Cos}\left[2\,\pi\,(\mathrm{x} - t) + \theta\right] \tag{15}$$

$$R\delta\left(\left(\frac{\partial}{\partial t}\left(\nabla^2\psi\right)\right) + \frac{\partial\psi}{\partial y}\left(\frac{\partial}{\partial x}\left(\nabla^2\psi\right)\right) - \frac{\partial\psi}{\partial x}\left(\frac{\partial}{\partial y}\left(\nabla^2\psi\right)\right)\right) = \left(\frac{\partial^2}{\partial y^2}\left(\nabla^2\psi\right) + \delta^2\left(\frac{\partial^2}{\partial x^2}\left(\nabla^2\psi\right)\right)\right) \tag{16}$$

$$R\,\delta\left(\frac{\partial\theta}{\partial t} + \frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}\right) = \frac{1}{p_r}\left(\frac{\partial^2\theta}{\partial y^2} + \delta^2\frac{\partial^2\theta}{\partial x^2}\right) + E\left(4\,\delta^2\left(\frac{\partial^2\psi}{\partial x\,\partial y}\right)^2 + \left(\frac{\partial^2\psi}{\partial y^2} + \delta^2\frac{\partial^2\psi}{\partial x^2}\right)^2\right) \tag{17}$$

$$\frac{\partial\psi}{\partial y} = 0 \quad on \quad \begin{cases} y = h_1 \\ y = h_2 \end{cases} \tag{18}$$

$$\left(\frac{\partial^3\psi}{\partial y^3}+\delta^2\frac{\partial^3\psi}{\partial x^2\,\partial y}\right)-R\,\delta\left(\frac{\partial^2\psi}{\partial y\,\partial t}+\frac{\partial\psi}{\partial y}\frac{\partial^2\psi}{\partial x\,\partial y}-\frac{\partial\psi}{\partial x}\frac{\partial^2\psi}{\partial y^2}\right)$$
$$=\left(E_1\frac{\partial^3}{\partial x^3}+E_2\frac{\partial^3}{\partial x\,\partial t^2}+E_3\frac{\partial^2}{\partial x\,\partial t}\right)\begin{Bmatrix}h_1\\h_2\end{Bmatrix}\quad at\quad\begin{cases}y=h_1\\y=h_2\end{cases}\tag{19}$$

$$\left.\begin{aligned}\theta^*=0\quad on\quad y=h_1\\ \theta^*=1\quad on\quad y=h_2\end{aligned}\right\}\tag{20}$$

Where $\nabla^2=\frac{\partial^2}{\partial y^2}+\delta^2\frac{\partial^2}{\partial x^2}$

The non-dimensional parameters are

$R=\frac{c\,d}{\upsilon}$ (Reynolds number), $p_r=\frac{C_p\rho\,\upsilon}{k}$ (Prandtl number),

$E=\frac{c^2}{C_p\rho\,(T_1-T_0)}$ (Eckert number)

$a=\frac{a_1}{d_1}$, $b=\frac{a_2}{d_1}$, $d=\frac{d_2}{d_1}$ and $\delta=\frac{d}{\lambda}$ (geometric parameters)

$E_1=-\frac{T\,d^3}{\lambda^3\rho\,\upsilon\,c}$, $E_2=\frac{m\,c\,d^3}{\lambda^3\rho\,\nu}$, $E_3=\frac{C\,d^3}{\lambda^2\rho\,\nu}$ (elasticity parameters)

METHOD OF SOLUTION

We seek perturbation solution in terms of small parameter δ as follows:

$$\psi=\psi_0+\delta\,\psi_1+\delta^2\psi_2+.....\tag{21}$$
$$\theta^*=\theta_0^*+\delta\,\theta_0^*+\delta^2\theta_0^*+......\tag{22}$$

Substituting equations (21) – (22) in equations (16) – (20) and collecting the coefficients of various powers of δ
The zeroth order equations are

$$\frac{\partial^4\psi_0}{\partial y^4}=0\tag{23}$$

$$\frac{1}{P_r}\left(\frac{\partial^2\theta_0^*}{\partial y^2}\right)+E\left(\frac{\partial^2\psi_0}{\partial y^2}\right)^2=0\tag{24}$$

The corresponding boundary conditions are

$$\frac{\partial\,\psi_0}{\partial\,y}=0\quad on\quad\begin{cases}y=h_1\\y=h_2\end{cases}\tag{25}$$

$$\frac{\partial^3\psi_0}{\partial y^3}=\left(E_1\frac{\partial^3}{\partial x^3}+E_2\frac{\partial^3}{\partial x\,\partial t^2}+E_3\frac{\partial^2}{\partial x\,\partial t}\right)\begin{Bmatrix}h_1\\h_2\end{Bmatrix}\quad at\quad\begin{cases}y=h_1\\y=h_2\end{cases}\tag{26}$$

$$\left.\begin{aligned}\theta_0^*=0\quad on\quad y=h_1\\ \theta_0^*=1\quad on\quad y=h_2\end{aligned}\right\}\tag{27}$$

Zeroth-order problem
On solving the equations (23) & (24) subject to the conditions (25) to (27), we get

$$\psi_0 = A_1\frac{y^3}{6} + A_2\frac{y^2}{2} + A_3\, y \tag{28}$$

$$\theta_0^* = -a_1\left[A_1\frac{y^4}{12} + A_2\frac{y^3}{3} + A_3\frac{y^2}{2}\right] + G_8 y + G_9 \tag{29}$$

The first order equations are

$$R\left(\left(\frac{\partial}{\partial t}\left(\frac{\partial^2\psi_0}{\partial y^2}\right)\right) + \frac{\partial\psi_0}{\partial y}\left(\frac{\partial}{\partial x}\left(\frac{\partial^2\psi_0}{\partial y^2}\right)\right) - \frac{\partial\psi_0}{\partial x}\left(\frac{\partial}{\partial y}\left(\frac{\partial^2\psi_0}{\partial y^2}\right)\right)\right) = \frac{\partial^4\psi_1}{\partial y^4} \tag{30}$$

$$R\left(\frac{\partial\theta_0^*}{\partial t} + \frac{\partial\psi_0}{\partial y}\frac{\partial\theta_0^*}{\partial x} - \frac{\partial\psi_0}{\partial x}\frac{\partial\theta_0^*}{\partial y}\right) = \frac{1}{P_r}\left(\frac{\partial^2\theta_1^*}{\partial y^2}\right) + 2E\left(\frac{\partial^2\psi_0}{\partial y^2}\right)\left(\frac{\partial^2\psi_1}{\partial y^2}\right) \tag{31}$$

The corresponding boundary conditions are

$$\frac{\partial\psi_1}{\partial y} = 0 \quad on \quad \begin{cases} y = h_1 \\ y = h_2 \end{cases} \tag{32}$$

$$\frac{\partial^3\psi_1}{\partial y^3} - R\left(\frac{\partial^2\psi_0}{\partial y\,\partial t} + \frac{\partial\psi_0}{\partial y}\frac{\partial^2\psi_0}{\partial x\,\partial y} - \frac{\partial\psi_0}{\partial x}\frac{\partial^2\psi_0}{\partial y^2}\right) = 0 \quad at \quad \begin{cases} y = h_1 \\ y = h_2 \end{cases} \tag{33}$$

$$\left.\begin{aligned} \theta_1^* &= 0 \quad on \quad y = h_1 \\ \theta_1^* &= 0 \quad on \quad y = h_2 \end{aligned}\right\} \tag{34}$$

First-order problem

On solving the equation (30) & (31) subject to the conditions (32) to (34), we obtain

$$\begin{aligned}\psi_1 = R\Bigg[&\left(\frac{y^7}{2520} + \frac{y^6}{360}\right)B_1A_6 + \frac{y^5}{120}\left(A_4 + B_2A_7 + B_3A_6 + B_1A_8\right) + \frac{y^4}{24}\left(A_5 + B_3A_7\right)\Bigg] \\ &+ \frac{y^3}{6}B_4 + \frac{y^2}{2}B_5 + B_6 y\end{aligned} \tag{35}$$

$$\theta_1^* = \frac{y^8}{56}G_1 + \frac{y^7}{42}G_2 + \frac{y^6}{30}G_3 + \frac{y^5}{20}G_4 + \frac{y^4}{12}G_5 + \frac{y^3}{6}G_6 + \frac{y^2}{2}G_7 + G_{10}y + G_{11} \tag{36}$$

Substituting θ_0^* from (24) and θ_1^* from (36) into (22) for θ^*, we have temperature θ^* in the form

$$\begin{aligned}\theta^* = -a_1&\left(A_1\frac{y^4}{12} + A_2\frac{y^3}{3} + A_3\frac{y^2}{2}\right) + G_8 y + G_9 + \\ &\delta\left(\frac{y^8}{56}G_1 + \frac{y^7}{42}G_2 + \frac{y^6}{30}G_3 + \frac{y^5}{20}G_4 + \frac{y^4}{12}G_5 + \frac{y^3}{6}G_6 + \frac{y^2}{2}G_7 + G_{10}y + G_{11}\right)\end{aligned} \tag{37}$$

The heat transfer coefficient Z at the (upper) wall is given by

$$Z = \left(\frac{\partial h_1}{\partial x}\right)\left(\frac{\partial\theta^*}{\partial y}\right) \tag{38}$$

Substituting Eq. (14) & Eq. (37) in Eq. (38), we get

$$Z = \left(-2\,\pi a\ \ Sin\,2\,\pi\,(\mathrm{x}-t)\right)\left(-a_1\left(A_1\frac{y^3}{3}+A_2\,y^2+A_3\,y\right)+G_8\right)$$
$$+\left(\delta\left(\frac{y^7}{7}G_1+\frac{y^6}{6}G_2+\frac{y^5}{5}G_3+\frac{y^4}{4}G_4+\frac{y^3}{3}G_5+\frac{y^2}{2}G_6+G_7y+G_{10}\right)\right) \qquad (39)$$

Where

$$B_1 = 4\,\pi^3(E_1+E_2)(a\ Sin\ 2\pi(x-t)-b\ Sin\ 2\pi(x-t)+\theta)+$$
$$2E_3\pi^2(a\ Cos\ 2\pi(x-t)-b\ Cos\ 2\pi(x-t)+\theta)$$
$$B_2 = -\frac{B_1}{2}(h_1+h_2),\quad B_3 = B_1h_1h_2,\quad B_4 = R(A_9+B_3A_8)$$
$$B_5 = \frac{R}{h_1-h_2}[\frac{1}{24}(A_4+B_2A_7+B_3A_6-B_1A_8)(h_2{}^4-h_1{}^4)-\frac{1}{6}(A_5+B_3A_7)(h_1{}^3-h_2{}^3)$$
$$-\frac{1}{60}(B_2A_6)(h_1{}^5-h_2{}^5)+\frac{1}{360}(B_1A_7)(h_2{}^6-h_1{}^6)]+\frac{1}{2}(h_1+h_2)B_4$$
$$B_6 = R[-\frac{1}{12}(A_5+B_3A_7)(h_1{}^3+h_2{}^3)-\frac{1}{48}(A_4+B_2A_7+B_3A_6-B_1A_8)(h_1{}^4+h_2{}^4)$$
$$+\frac{1}{120}(B_2A_6)(h_2{}^5-h_1{}^5)-\frac{1}{720}(B_1A_6)(h_1{}^6+h_2{}^6)]-\frac{1}{4}B_4(h_1{}^2+h_2{}^2)-\frac{1}{2}B_5(h_1+h_2)$$
$$A_1 = B_1{}^2, A_2 = B_2{}^2, A_3 = B_1B_2, A_4 = B_{1t},\ A_5 = B_{2t},\ A_6 = B_{1x},\ A_7 = B_{2x},\ A_8 = B_{3x},\ A_9 = B_{3t},$$
$$G_{9t} = F_1,\ G_{10x} = F_2, G_{9x} = F_3, G_{10t} = F_4, a_1 = P_rE,\ a_2 = a_1R,\ a_3 = a_2P_r, a_4 = P_rR$$
$$G_1 = -(\frac{1}{36}a_3+\frac{1}{30}a_1)A_1A_6,\ G_2 = -(\frac{1}{6}a_3+\frac{1}{5}B_1a_1)B_2A_6,$$
$$G_3 = -[(\frac{1}{6}a_3+\frac{1}{3}a_2)B_1A_4+\frac{1}{6}(a_3+a_2)A_2A_6+\frac{1}{3}(a_3+a_2)B_1B_2A_7+$$
$$(\frac{1}{6}a_3+\frac{1}{3}a_2)B_1B_3A_6-\frac{1}{3}(a_3+a_2)A_1A_8]$$
$$G_4 = -[(\frac{1}{2}a_3+\frac{1}{3}a_2)A_2A_7+\frac{1}{3}(a_3+a_2)A_4B_2+\frac{1}{3}(a_3+a_2)A_6B_2B_3+(\frac{1}{3}a_3+a_2)B_1A_5$$
$$(a_2-\frac{1}{3}a_3)B_1B_3A_7-(a_3+\frac{1}{3}a_2)B_1B_2A_8-\frac{1}{2}a_4B_1F_3+\frac{1}{6}a_4A_6G_8]$$
$$G_5 = -[(a_3+a_1)B_2A_5+(a_3+a_2)B_2B_3A_7+2a_1B_1B_4-a_4B_2F_3-a_3A_2A_8$$
$$-\frac{1}{2}B_1F_2a_4+\frac{1}{2}a_4G_8A_7]$$
$$G_6 = -[2a_1(B_1B_5+B_2B_4)+a_4G_8A_8-F_1a_4-F_2B_2-a_4B_3F_3],\ G_7 = a_4F_4+F_2B_3-2a_1B_2B_5$$
$$G_8 = \frac{1}{h_2-h_1}+a_1[\frac{1}{12}A_1(h_2+h_1)(h_2{}^2+h_1{}^2)+\frac{1}{3}B_1B_2)(h_2{}^2+h_1{}^2+2h_2h_1)+\frac{1}{2}A_2(h_2+h_1)]$$
$$G_9 = \frac{1}{2}+a_1[\frac{1}{24}A_1(h_2{}^4+h_1{}^4)+\frac{1}{6}B_1B_2(h_2{}^3+h_1{}^3)+\frac{1}{2}A_2(h_2{}^3+h_1{}^3)-\frac{G_8}{2}(h_2+h_1)]$$

$$G_{10} = \frac{1}{h_2 - h_1}[G_1(h_2^8 - h_1^8) + G_2(h_2^7 - h_1^7) + G_3(h_2^6 - h_1^6) + G_4(h_2^5 - h_1^5) + G_5(h_2^4 - h_1^4) + G_6(h_2^3 - h_1^3) + G_7(h_2^2 - h_1^2)]$$

$$G_{11} = \frac{1}{-2}[G_1(h_2^8 + h_1^8) + G_2(h_2^7 + h_1^7) + G_3(h_2^6 + h_1^6) + G_4(h_2^5 + h_1^5) + G_5(h_2^4 + h_1^4) + G_6(h_2^3 + h_1^3) + G_7(h_2^2 + h_1^2) + G_{10}(h_2 + h_1)]$$

It is observed that, if we put $b = d = 1$ and $\theta = 1$ then the results of the problem coincide with the work of Radhakrishnamacharya G and Srinivasulu Ch [11].

RESULTS AND DISCUSSION

In this analysis we analyzed effect of temperature variation and the heat transfer coefficient on peristaltic motion of Newtonian fluid with wall properties in an asymmetric channel. The non-dimensional temperature distribution θ^*, heat transfer coefficient Z are depicted for different parametric values of R, the rigidity of the wall (E_1), the stiffness of the wall (E_2), the damping nature of the wall (E_3), the phase difference (θ), P_r, E, d. The temperature distribution θ is shown in figures (1)-(8). From (figure1), we noticed that there is no change in the temperature distribution θ^* with increase in R. The temperature distribution θ^* decreases in the region $0 \le y \le 0.28$ with increase in E_1, E_2, θ and further increases in the region $0.28 \le y \le 1$ and more significant at the boundary in (figures 2, 3 & 5), while the temperature distribution θ^* decreases in the region $0 \le y \le 0.28$ with increase in E_3, P_r, E and increases in the region $0.28 \le y \le 1$ and the enhancement is marginal at the boundary is shown in figures (4, 6 & 7). (figure8) represents the temperature distribution θ^* increases in the region $0 \le y \le 0.8$ with increase in d and further decreases in the region $0.8 \le y \le 1$.

The non-dimensional heat transfer coefficient Z are depicted for different parametric values of R, E_1, E_2, E_3, θ, P_r, E, d. The heat transfer coefficient is shown in figures (9-16). From figure(9), Z increases in the region $0 \le y \le 0.5$ and further decrease in the region $0.5 \le y \le 1$ with increase in R. Z increases in the region $0 \le y \le 0.8$ with increase in E_1, E_2, θ and further decrease in the region $0.8 \le y \le 1$ and significant change at centre y = 0 in (figures 10,11 &13). Z increases in the region $0 \le y \le 0.8$ with increase in E_3, P_r, E and further decrease in the region $0.8 \le y \le 1$ and no significant change at the centre and at the boundary in (figures12, 14 & 15). From (figure16) Z decreases rapidly for higher values of d and for smaller values Z is almost linear.

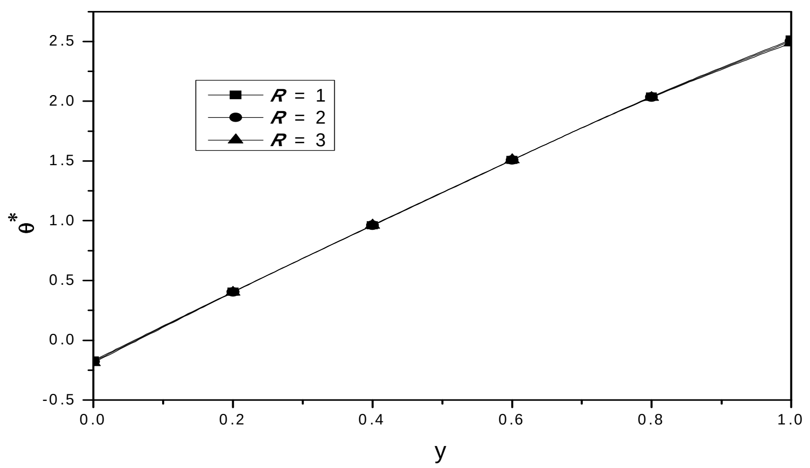

Figure 1-Effect of R on variation of θ^* for d = 0.1, b = 0.1, θ = π/3, a = 0.1, δ= 0.01, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, E=1, P_r = 0.7

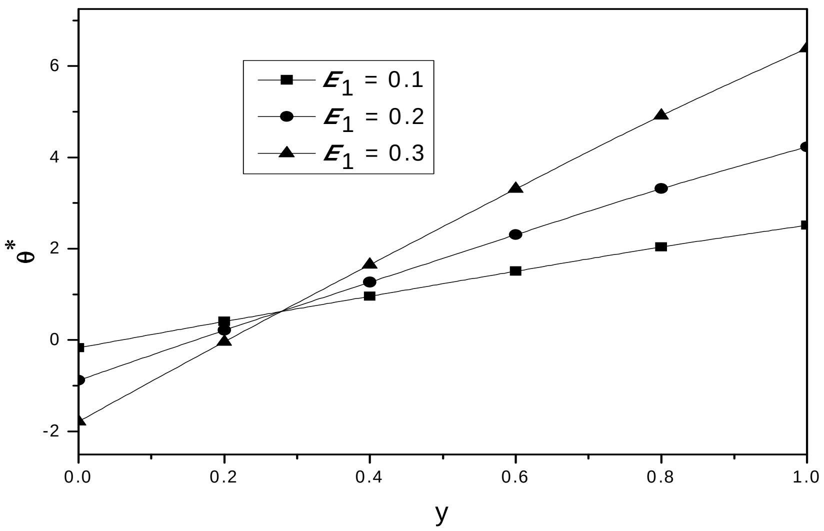

Figure 2-Effect of E_1 on variation of θ^* for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ = 0.01, R =1, E_2 = 0.2, E_3 = 0.3, E=1, P_r = 0.7

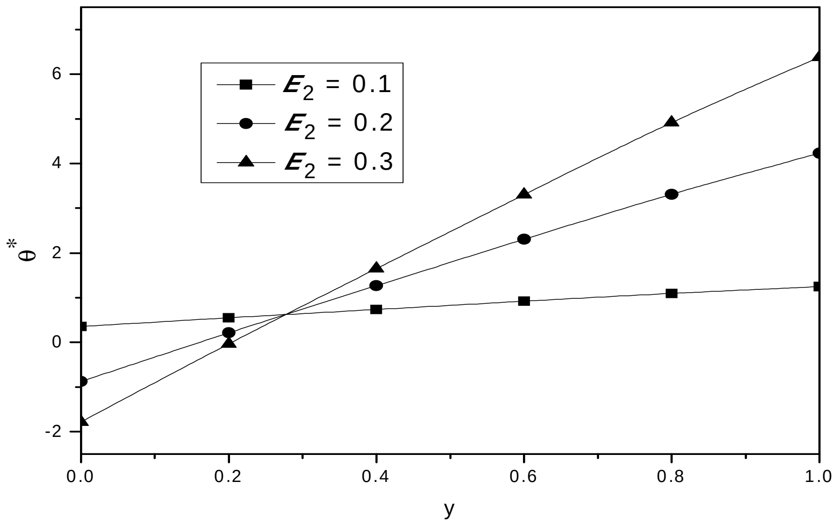

Figure 3- Effect of E_2 on variation of θ^* for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ = 0.01, R =1, E_1 = 0.1, E_3 = 0.3, E=1, P_r = 0.7

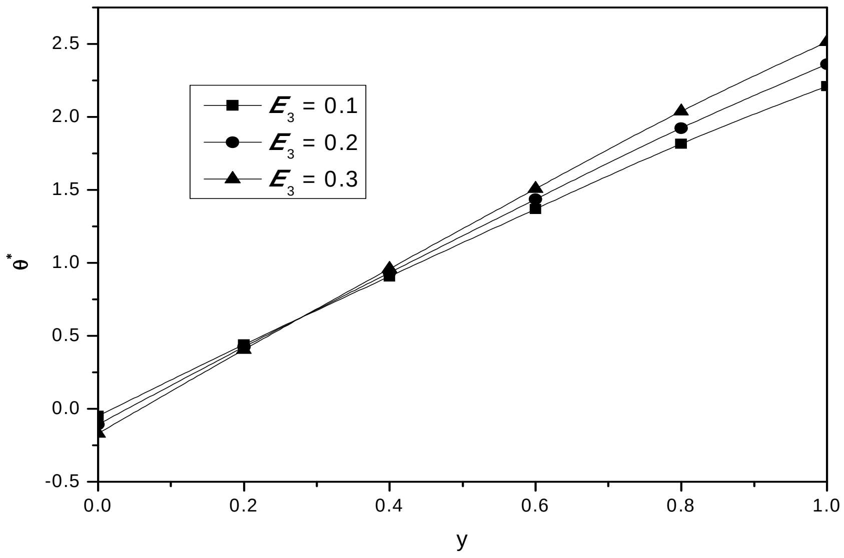

Figure 4- Effect of E_3 on variation of θ^* for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_1= 0.1, E_2 = 0.2, E=1, P_r = 0.7

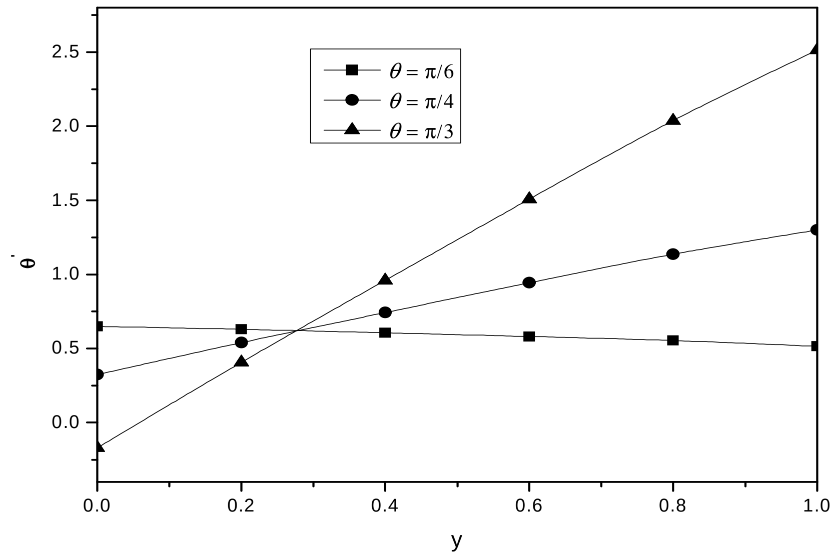

Figure 5- Effect of θ on variation of θ^* for d = 0.1, b = 0.1, a = 0.1, δ= 0.01, R =1, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, E=1, P_r = 0.7

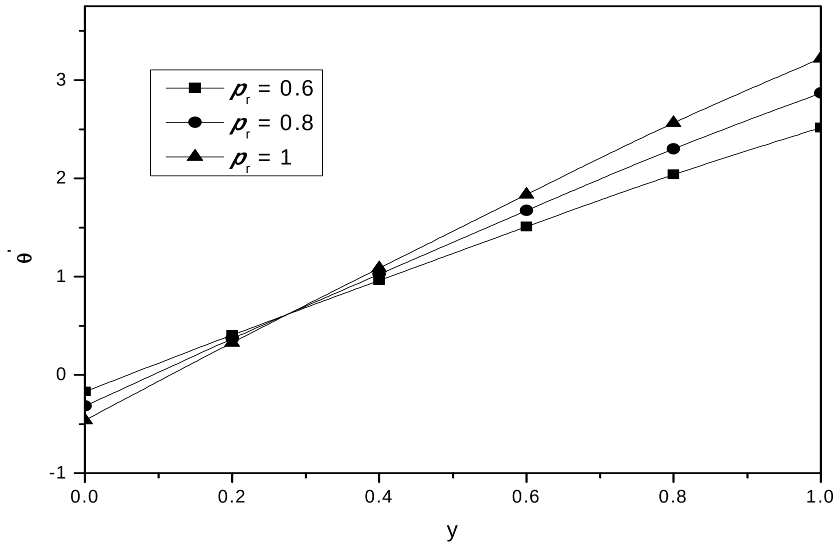

Figure 6-Effect of P_r on variation of θ^* for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, E=1

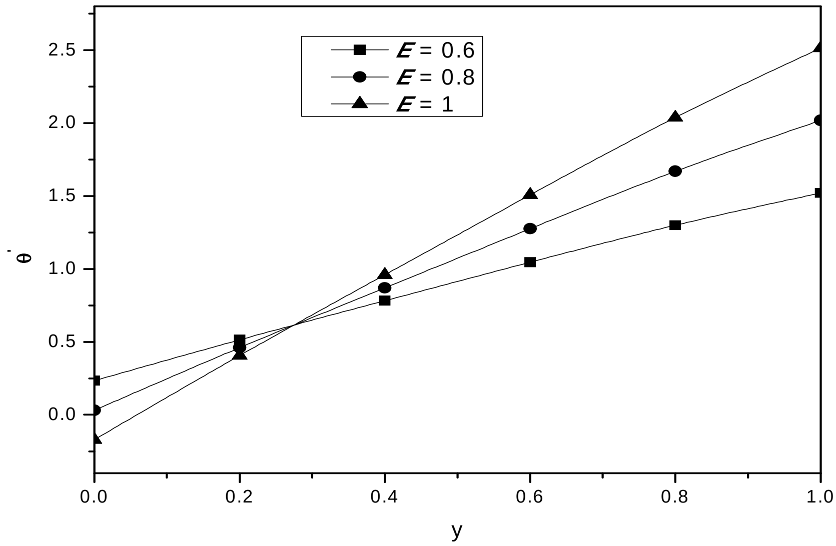

Figure 7-Effect of E on variation of θ^* for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, P_r = 0.7

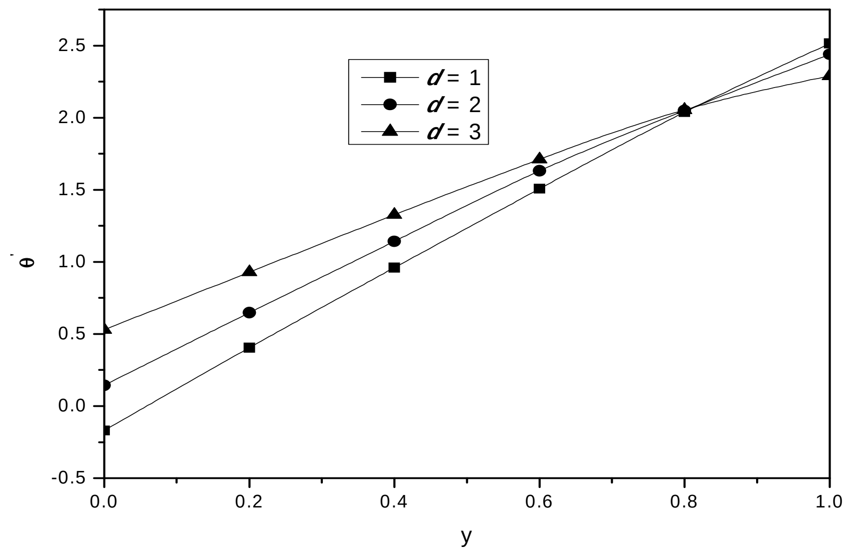

Figure 8-Effect of *d* on variation of θ^* for b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, E=1, P_r = 0.7

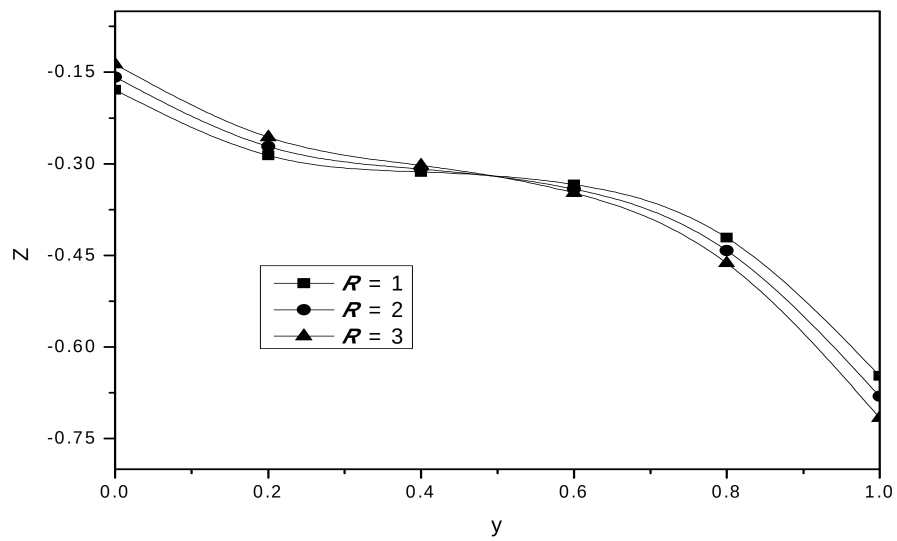

Figure 9- Effect of *R* on variation of *Z* for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, E=1, P_r = 0.7

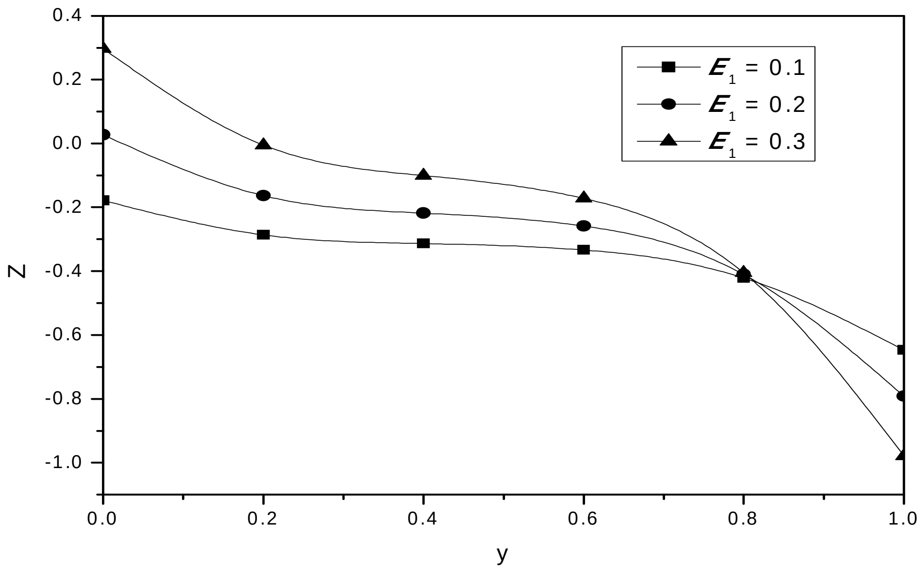

Figure 10- Effect of E_1 on variation of Z for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_2 = 0.2, E_3 = 0.3, E=1, P_r = 0.7

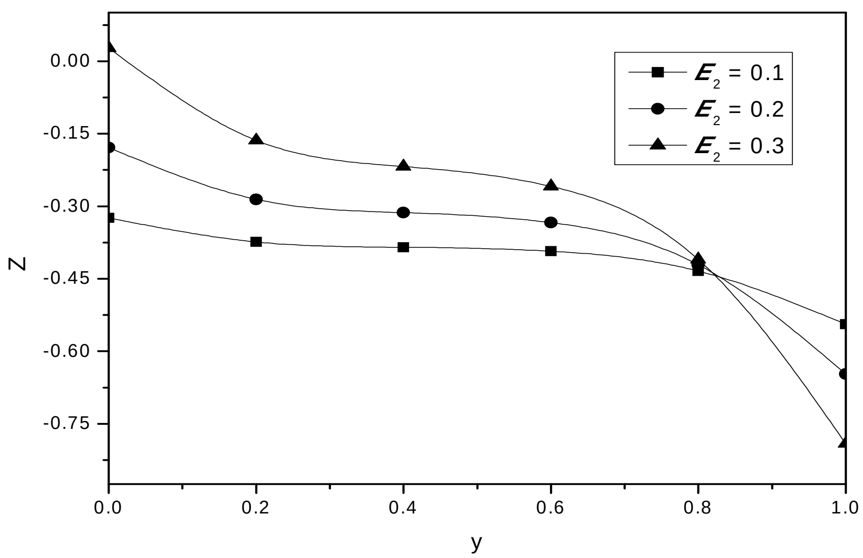

Figure 11- Effect of E_2 on variation of Z for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_1 = 0.1, E_3 = 0.3, E=1, P_r = 0.7

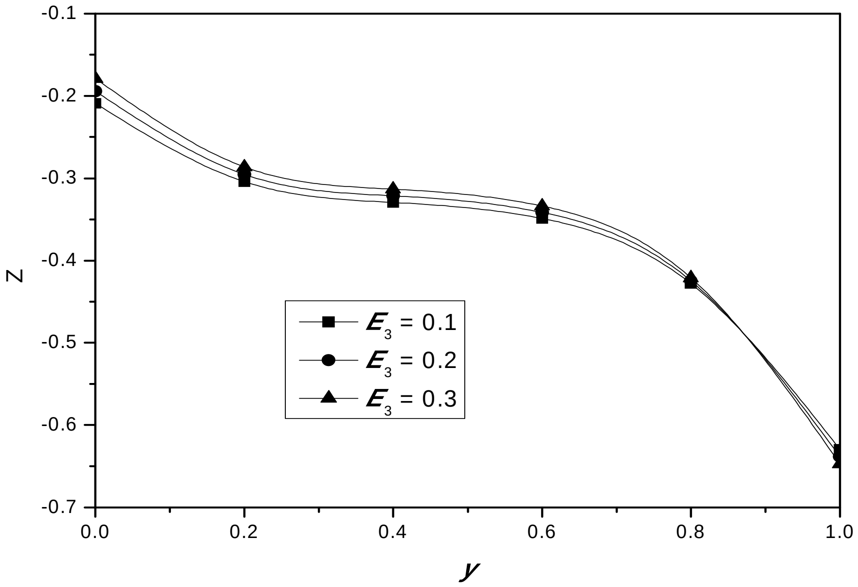

Figure 12- Effect of E_3 on variation of Z for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_1= 0.1, E_2 = 0.2, E=1, P_r = 0.7

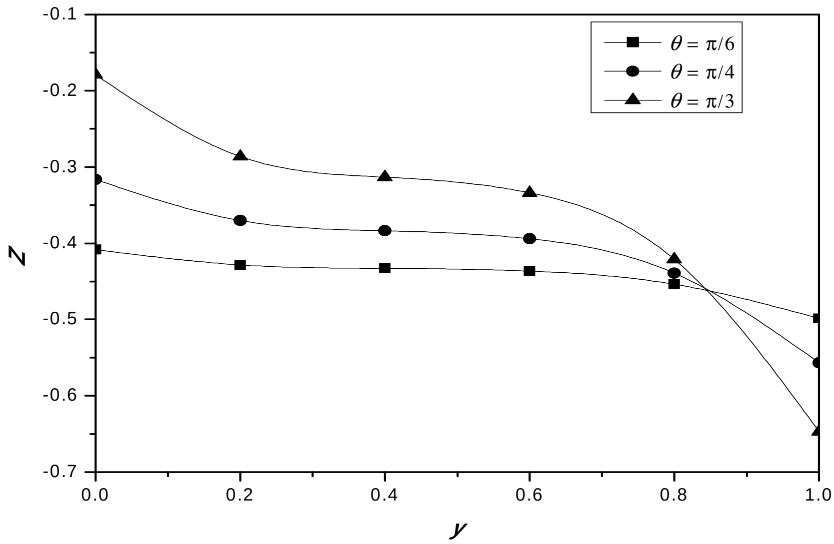

Figure 13- Effect of θ on variation of Z for d = 0.1, b = 0.1, a = 0.1, δ= 0.01, R =1, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, E=1, P_r = 0.7

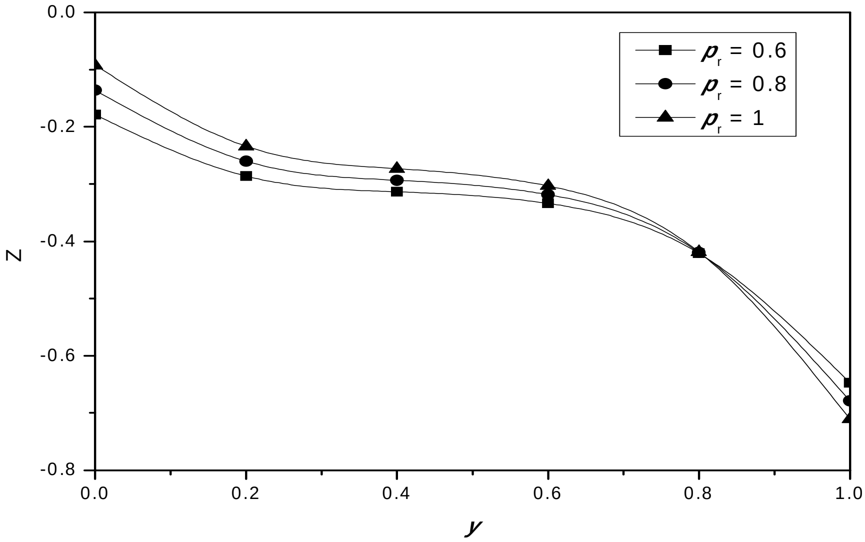

Figure 14- Effect of P_r on variation of Z for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, E=1

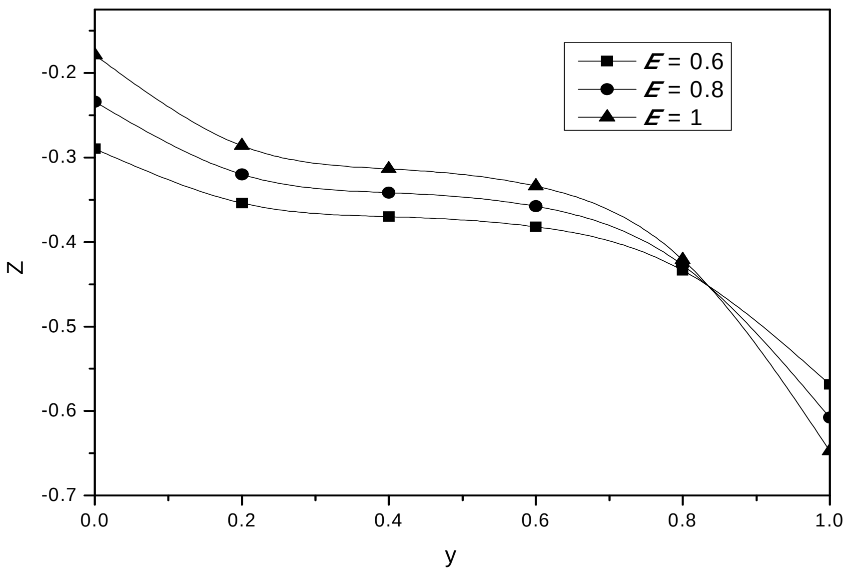

Figure 15-Effect of E on variation of Z for d = 0.1, b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, P_r = 0.7

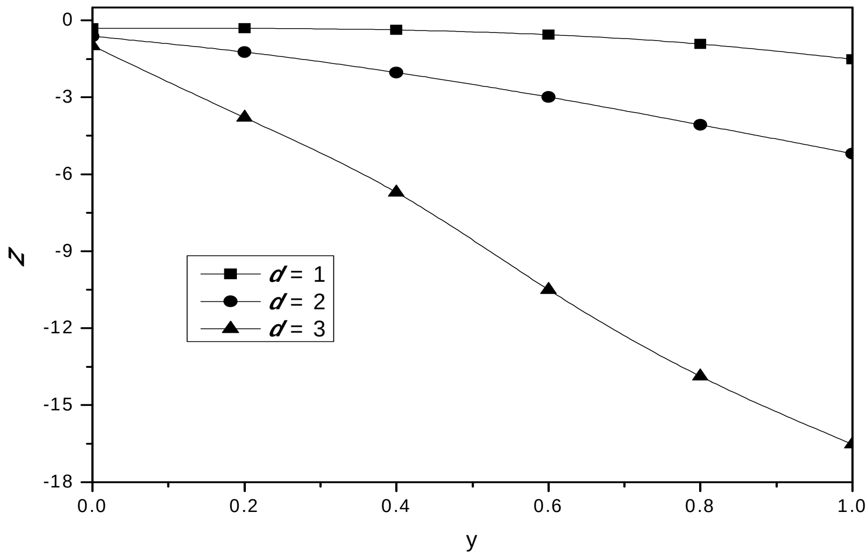

Figure16- Effect of d on variation of Z for b = 0.1, $\theta = \pi/3$, a = 0.1, δ= 0.01, R =1, E_1 = 0.1, E_2 = 0.2, E_3 = 0.3, E=1, P_r = 0.7

CONCLUSION

In this paper we have discussed the effect of heat transfer on peristaltic transport of a Newtonian fluid with wall properties in an asymmetric channel. The governing equations of motion are solved analytically using long wave length approximation. Furthermore, the effect of elastic parameters and pertinent parameters on temperature distribution and Heat transfer coefficient have been computed numerically and explained graphically. We conclude the following observations:

1. The temperature distribution θ^* increases in the region $0.28 \le y \le 1$ with increase in E_1, E_2, E_3, P_r, θ and E.

2. θ^* is more significant at the boundary with increase in E_1, E_2, θ and the enhancement is marginal at the boundary with increase in E_3, P_r, *and* E.
3. The temperature distribution increases in the region $0 \le y \le 0.8$ with increase in d.
4. Heat transfer coefficient Z increases in the region $0 \le y \le 0.8$ with increase in E_1, E_2, E_3, P_r, θ and E.
5. There is significant change in Z at centre y = 0 with increase in E_1, E_2, θ and no change at the centre and at the boundary with increase in E_3, P_r, *and* E.
6. Z decreases rapidly for higher values of d and for smaller values Z is almost linear.

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