Thermal Effects on Peristaltic Transport in an Inclined Circular Elastic Tube

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Abstract

The present paper examines the constant of an incompressible flow of a Nanofluid in an elastic tube. Nonlinear linked equations of temperature profile and nanoparticle phenomena are explained using Homotopy Perturbation Method (HPM). The variation of flux is determined by Rubinow and Keller method and by the Mazumdar method. The effects of numerous pertinent parameters on a variation of flux with the radius of the tube for a Nanofluid in an elastic tube are calculated and represented through graphs. The conclusions obtained for the present flow characteristics reveal many unusual behaviors that allow further study of physiological fluids in an elastic tube.

Keywords: Peristalsis, Elastic tube, Nanofluid, Brownian Motion Parameter, Thermophoresis Parameter

Introduction

Peristalsis is a radially proportional contraction of muscles that develops in a wave down the muscular tube. In biomedical sciences, peristalsis is observed in the contraction of smooth muscles to impel contents through the digestive tract. The mechanism of peristaltic transport has been utilized for industrial applications like sanitary fluid transport, blood pumps in the heart-lung machine, transport of corrosive fluids. In view of its significance, many investigations have done on peristalsis [1,3,9,10,16,17,18,19,24,26,27].

Nanofluids are directed suspensions of nanometre-sized solid particles in a base fluid. Shelving small solid particles in the energy transmission fluids can increase their thermal conductivity and provides an adequate and innovative way to improve their heat transfer characteristics significantly. A nanoparticle is a small particle that varies between 1 to 100 nanometres in size. Undetectable by the human eye, nanoparticles can present significantly different physical and chemical properties to their larger material equivalents. Most nanoparticles are produced by only a few hundred atoms. Fist investigation on nanotechnology has done by SUS Choi in 1995. Many researches have contributed to this field [1, 4,8,13,14,20,21,22].

Most of the researchers were focused mainly on hard channels and tubes. But the flow geometries including an elastic structure are also acceptable in a mathematical simulation of biological systems related to rigid geometries because most physiological practices are elastic in composition. Thus, some major applications such as the bloodstream in a narrow blood artery, lymphatic artery, etc… are drawn by the non-Newtonian fluid flow within such complex geometries. To gain an insight into complicated physiological circumstances to understand the progress through the tubes that have an elastic structure following various conditions, a lot of different mathematical techniques have been developed. There are researches contributed in this area [2, 3, 5, 6, 7, 28].

The main objective of the existing work is to analyze the effect of peristaltic transport of a nanofluid in an elastic tube. The explanations for velocity and flux flow rate are determined. The variation of flux is determined by Rubinow and Keller and Mazumdar methods. The effects of various relevant parameters on the variation of flux along the tube radius for a nanofluid in an elastic tube are calculated and represented through graphs.

Mathematical Formulation

Consider the peristaltic motion of incompressible nanofluid in an elastic tube of the radius a^* with sinusoidal waves traveling along the tube with speed c^*, amplitude b^*, and wavelength λ^*. Further, suppose the tube is elastic at an angle $\emptyset$ with the horizontal axis as shown in Figure a.

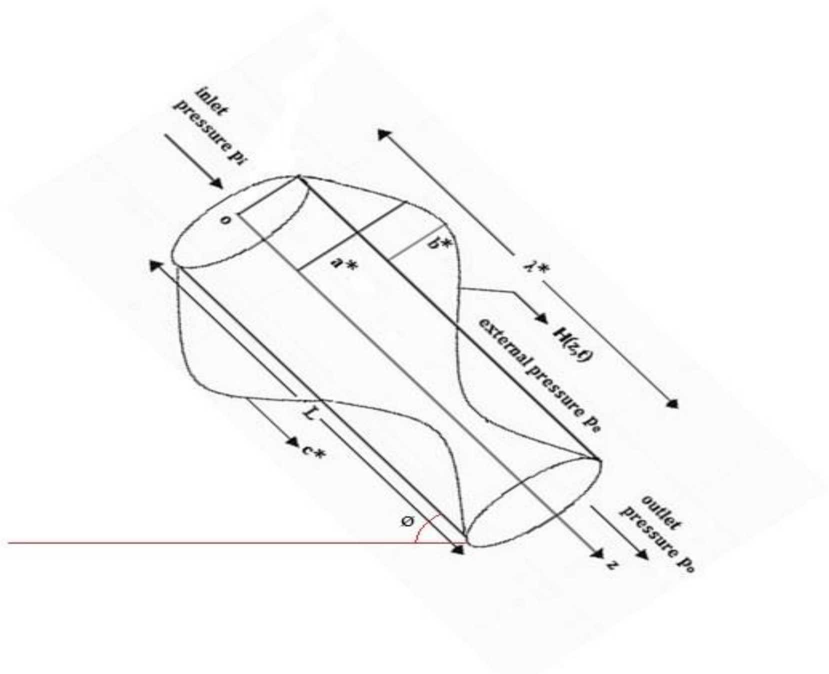

Figure a: Peristaltic Transport of Nanofluid in an Inclined Elastic Tube

The geometry of the wall surface is defined as

$$H(z,t) = a^*(\bar{Z}) + b^* \sin\frac{2\pi}{\lambda^*}(\bar{Z} - c^*\bar{t}), \qquad (1)$$

Where $a^*(\bar{Z}) = a^* + k\bar{Z}$, a^* is the radius of the inlet, k is the constant whose magnitude depends on the length of the tube and $\bar{t}$ is the time. Cylindrical-coordinate system $(\bar{R}, \bar{Z})$ is chosen, so that Z-axis coincides with the centerline of the tube and $\bar{R}$ is transverse to it. Further, the flow is assumed to be axisymmetric.

Using the transformations

$$\bar{z} = \bar{Z} - c^*\bar{t}\,, \qquad \bar{r} = \bar{R} \tag{2}$$

$$\bar{w} = \bar{W} - c^*, \qquad \bar{u} = \bar{U} \tag{3}$$

From a stationary to a moving frame of reference, where $\bar{U}$, $\bar{W}$, and $\bar{u}$, $\bar{w}$ are velocity components in the radial and axial directions in the fixed and moving frames respectively, the governing equations in a fixed frame for an incompressible nanofluid in an elastic tube are given by

$$\frac{1}{\bar{r}}\frac{\partial(\bar{r}\,\bar{u})}{\partial\bar{r}} + \frac{\partial\bar{w}}{\partial\bar{z}} = 0 \tag{4}$$

$$\rho\left[\bar{u}\frac{\partial\bar{u}}{\partial\bar{r}} + \bar{w}\frac{\partial\bar{u}}{\partial\bar{z}}\right] = -\frac{\partial\bar{P}}{\partial\bar{r}} + \mu\left[\frac{\partial^2\bar{u}}{\partial\bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial\bar{u}}{\partial\bar{r}} + \frac{\partial^2\bar{u}}{\partial\bar{z}^2} - \frac{\bar{u}}{\bar{r}^2}\right] - \frac{\sin\emptyset}{f} \tag{5}$$

$$\rho\left[\bar{u}\frac{\partial\bar{w}}{\partial\bar{r}} + \bar{w}\frac{\partial\bar{w}}{\partial\bar{z}}\right] = -\frac{\partial\bar{P}}{\partial\bar{z}} + \mu\left[\frac{\partial^2\bar{w}}{\partial\bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial\bar{w}}{\partial\bar{r}} + \frac{\partial^2\bar{w}}{\partial\bar{z}^2}\right] + \rho g\alpha(\bar{T} - \bar{T}_0) + \rho g\alpha(\bar{C} - \bar{C}_0) \tag{6}$$

$$\left[\bar{u}\frac{\partial\bar{T}}{\partial\bar{r}} + \bar{w}\frac{\partial\bar{T}}{\partial\bar{z}}\right] = \alpha\left[\frac{\partial^2\bar{T}}{\partial\bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial\bar{T}}{\partial\bar{r}} + \frac{\partial^2\bar{T}}{\partial\bar{z}^2}\right] + \tau\left\{D_B\left[\frac{\partial\bar{C}}{\partial\bar{r}}\frac{\partial\bar{T}}{\partial\bar{r}} + \frac{\partial\bar{C}}{\partial\bar{z}}\frac{\partial\bar{T}}{\partial\bar{z}}\right] + \frac{D_{\bar{T}}}{\bar{T}_0}\left[\left(\frac{\partial\bar{T}}{\partial\bar{r}}\right)^2 + \left(\frac{\partial\bar{T}}{\partial\bar{z}}\right)^2\right]\right\} \tag{7}$$

$$\left[\bar{u}\frac{\partial\bar{C}}{\partial\bar{r}} + \bar{w}\frac{\partial\bar{C}}{\partial\bar{z}}\right] = D_B\left[\frac{\partial^2\bar{C}}{\partial\bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial\bar{C}}{\partial\bar{r}} + \frac{\partial^2\bar{C}}{\partial\bar{z}^2}\right] + \frac{D_{\bar{T}}}{\bar{T}_0}\left[\frac{\partial^2\bar{T}}{\partial\bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial\bar{T}}{\partial\bar{r}} + \frac{\partial^2\bar{T}}{\partial\bar{z}^2}\right] \tag{8}$$

Where $\tau = \frac{(\rho C)_P}{(\rho C)_f}$ is the ratio between the effective heat capacity of the nanoparticle material and the heat capacity of the fluid.

The boundary conditions in the wave frame as follows

$$\frac{\partial\bar{w}}{\partial\bar{r}} = 0, \frac{\partial\bar{T}}{\partial\bar{r}} = 0, \frac{\partial\bar{C}}{\partial\bar{r}} = 0\ at\ \bar{r} = 0 \tag{9}$$

$$\bar{w} = 0, \bar{T} = \bar{T}_0, \bar{C} = \bar{C}_0\ at\ \bar{r} = \bar{h} = a^*(\bar{z}) + b^*\ sin\ \frac{2\pi}{\lambda^*}(\bar{z}) \tag{10}$$

The following are non-dimensional variables:

$$R = \frac{\bar{R}}{a^*}, r = \frac{\bar{r}}{a^*}, Z = \frac{\bar{Z}}{\lambda^*}, z = \frac{\bar{z}}{\lambda^*},$$

$$W = \frac{\bar{W}}{c^*}, w = \frac{\bar{w}}{c^*}, U = \frac{\lambda^*\bar{U}}{a^*c^*}, u = \frac{\lambda^*\bar{u}}{a^*c^*},$$

$$p = \frac{{a^*}^2\bar{p}}{c^*\lambda^*\mu}, \theta = \frac{\bar{T} - \overline{T_0}}{\overline{T_0}}, t = \frac{c^*\bar{t}}{\lambda^*},$$

$$\delta = \frac{a^*}{\lambda^*}, R_e = \frac{2\rho c^* a^*}{\mu}, \sigma = \frac{\bar{C} - \overline{C_0}}{\overline{C_0}},$$

$$h = \frac{\bar{h}}{a^*} = 1 + \frac{\lambda^* kz}{a_0} + \emptyset\ sin\ 2\pi z, \beta = \frac{k}{(\rho c)_f},$$

$$N_b = \frac{(\rho c)_p D_{\bar{B}}\overline{C_0}}{(\rho c)_f}, \quad N_t = \frac{(\rho c)_p D_{\bar{T}}\overline{T_0}}{(\rho c)_f \beta},$$

$$P_r = \frac{\gamma}{\beta}, G_r = \frac{g\beta {a^*}^3\bar{T}_0}{\gamma^2}, G_r = \frac{g\beta {a^*}^3\bar{C}_0}{\gamma^2} \tag{11}$$

In which N_b, N_t, G_r and B_r are the Brownian motion parameter, the thermophoresis parameter, local temperature Grashof number, and local nanoparticle Grashof number.

Introducing the non-dimensional variables into equations (4)-(10) under the assumption of long wavelength and low Reynolds number approximations, the equations (4)-(10) reduces to

$$\frac{\partial u}{\partial r} + \frac{u}{r} + \frac{\partial w}{\partial z} \tag{12}$$

$$\frac{\partial P}{\partial r} = -\frac{\sin\emptyset}{f} \tag{13}$$

$$\frac{\partial P}{\partial z}=\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial w}{\partial r}\right)+G_r\theta+B_r\sigma \tag{14}$$

$$0=\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \theta}{\partial r}\right)+N_b\frac{\partial \sigma}{\partial r}\frac{\partial \theta}{\partial r}+N_t\left(\frac{\partial \theta}{\partial r}\right)^2 \tag{15}$$

$$0=\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \sigma}{\partial r}\right)+\frac{N_t}{N_b}\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \theta}{\partial r}\right)\right) \tag{16}$$

The non-dimensional boundary conditions are

$$\frac{\partial w}{\partial r}=0,\frac{\partial \theta}{\partial r}=0,\frac{\partial \sigma}{\partial r}=0\ at\ r=0 \tag{17a}$$

$$w=0,\theta=0,\sigma=0\ at\ r=h=1+\frac{\lambda^* kz}{a_0}+\emptyset\ sin\ 2\pi z \tag{17b}$$

The Homotopy Perturbation Method (HPM) [11,12,13,14] for the equations (15) and (16) are as follows

$$H(q,\theta)=L(\theta)-L(\theta_{10})+qL(\theta_{10})+q\left[N_b\frac{\partial \sigma}{\partial r}\frac{\partial \theta}{\partial r}+N_t\left(\frac{\partial \theta}{\partial r}\right)^2\right] \tag{18}$$

$$H(q,\sigma)=L(\sigma)-L(\sigma_{10})+qL(\sigma_{10})+q\left[\frac{N_t}{N_b}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \theta}{\partial r}\right)\right] \tag{19}$$

For convenience, $L=\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right)$ is taken as linear operator.

$$\theta_{10}(r,z)=\left(\frac{r^2-h^2}{4}\right),\sigma_{10}(r,z)=-\left(\frac{r^2-h^2}{4}\right) \tag{20}$$

are defined as initial guesses which satisfy the boundary conditions.

Define

$$\theta(r,z)=\theta_0+q\theta_1+q^2\theta_2+.\ .\ . \tag{21}$$

$$\sigma(r,z)=\sigma_0+q\sigma_1+q^2\sigma_2+.\ .\ . \tag{22}$$

The series (21) and (22) are convergent for most of the cases. The convergent rate depends on the nonlinear part of the equation.

The solution for temperature and nanoparticle phenomena can be written for $q=1$ as

$$\theta(r,z)=N_b(N_b-N_t)\left(\frac{r^6-h^6}{1152}\right)-N_t(N_b-N_t)\left(\frac{r^6-h^6}{576}\right)-(N_b-2N_t)\left(\frac{r^4-h^4}{64}\right) \tag{23}$$

$$\sigma(r,z)=-\frac{N_t}{N_b}(N_b-N_t)\left(\frac{r^4-h^4}{64}\right) \tag{24}$$

Substituting the equations (23) and (24) in the equation (14) and applying boundary conditions, the closed form of analytical solution for velocity can be written as

$$w(r,z)=\left(\frac{r^2-h^2}{4}\right)\left(\frac{dp}{dz}-\frac{\sin\emptyset}{f}\right)-\frac{G_rN_b}{1152}(N_b-N_t)\left(\frac{r^8}{64}-\frac{r^2h^6}{4}+\frac{15h^8}{64}\right)+\frac{G_rN_t}{576}(N_b-N_t)\left(\frac{r^8}{64}-\frac{r^2h^6}{4}+\frac{15h^8}{64}\right)+\frac{G_r}{64}(N_b-2N_t)\left(\frac{r^6}{36}-\frac{r^2h^4}{4}+\frac{2h^6}{9}\right)+\frac{B_r}{64}\frac{N_t}{N_b}(N_b-N_t)\left(\frac{r^6}{36}-\frac{r^2h^4}{4}+\frac{2h^6}{9}\right) \tag{25}$$

Adopting the same procedure done by Shapiro et al., [25], the dimensionless flux Q in the moving frame is given by

$$Q=2\int_0^h rw\,dr \tag{26}$$

By substituting equation (25) in equation (26), the flux value will be

$$Q=P\frac{h^4}{8}-\frac{G_rN_b}{576}(N_b-N_t)(0.0563)h^{10}+\frac{G_rN_t}{288}(N_b-N_t)(0.0563)h^{10}+\frac{G_r}{32}(N_b-2N_t)(0.0521)h^8+\frac{B_r}{32}\frac{N_t}{N_b}(N_b-N_t)(0.0521)h^8+\frac{h^4}{8}\frac{\sin\emptyset}{f} \tag{27}$$

equation (27) can be written as

$$Q = P\frac{h^4}{8} + F \tag{28}$$

Where, $F = -\frac{G_r}{576}(N_b - N_t)(0.0563)h^{10}(N_b - 2N_t) + \frac{G_r}{32}(N_b - 2N_t)(0.0521)h^8$
$+\frac{B_r}{32}\frac{N_t}{N_b}(N_b - N_t)(0.0521)h^8 + \frac{h^4}{8}\frac{\sin\emptyset}{f}$ and $P = -\frac{dp}{dz}$

Theoretical Determination of Flux

To calculate the flux of nano-fluid through an elastic tube, we use the method of Rubinow and Keller [23]. Let p_1 and p_2 represent the pressure of the fluid at the entrance and exit respectively and p_0 is the external pressure. Here the inlet pressure p_1 is assumed to be greater than outlet pressure p_2. As a result of inside and outside pressure differences, the tube wall may expand or contract. The conductivity σ of the tube at z depends on the pressure difference. Therefore, the conductivity $\sigma = \sigma[p(z) - p_0]$ is a function of $(p(z) - p_0)$. Also, the flux Q and the pressure gradient are related by the expression

$$Q = \sigma(p - p_0)(P + F) \tag{29}$$

Where $\sigma(p - p_0) = \frac{h^4}{8}$ (30)

Integrating equation (29) with respect to z from $z = 0$ and using the inlet condition $p(0) = p_1$, we obtain

$$Q_z = \int_{p(z)-p_0}^{p_1-p_0} \sigma(p')\,dp' + \int_0^z \frac{h^4}{8}\,dz \tag{31}$$

Where $p' = p(z) - p_0$. Equation (31) determines $p(z)$ implicitly in terms of Q and z. To find Q, we set $z = 1$ and $p(1) = p_2$ in the equation (31), we get

$$Q_z = \int_{p(1)-p_0}^{p_1-p_0} \sigma(p')\,dp' + \int_0^1 \frac{h^4}{8}\,dz \tag{32}$$

In the present case, the radius h is a function of $p - p_0$, that is $h = h(p - p_0)$

Equation (32) can be written as

$$Q = \frac{1}{8}\left[\int_{p_2-p_0}^{p_1-p_0} h^4\,dp' + Fh^4\right] \tag{33}$$

If the stress or tension $T(h)$ in the tube wall is known as a function of h, then $h(p - p_0)$ is determined by the equilibrium condition

$$\frac{T(h)}{h} = p - p_0 \tag{34}$$

Method of Rubinow and Keller

Application to flow through an artery is determined by the static pressure-volume relation of 4cm long piece of the human external artery and converted into a tension versus length curve. Using the least-squares method, Rubinow and Keller [23] gave the following equation

$$T(h) = t_1(h - 1) + t_2(h - 1)^5 \tag{35}$$

Where $t_1 = 13$ and $t_2 = 300$, when substituting (35) in (34), on simplification we obtain

$$\mathrm{d}p' = \left[\frac{t_1}{h^2} + t_2\left(4h^3 - 15h^2 + 20h - 10 + \frac{1}{h^2}\right)\right] dh \tag{36}$$

using (36), (33) can be written as

$$Q = \frac{1}{8}\left[\int_{p_2-p_0}^{p_1-p_0} h^4\left[\frac{t_1}{h^2} + t_2\left(4h^3 - 15h^2 + 20h - 10 + \frac{1}{h^2}\right)\right] dh + F(h(p_2 - p_0)^4)\right] \tag{37}$$

On further simplification, flux is

$$Q = \frac{1}{8}\left[\left(g(h_1) - g(h_2)\right) + F h_2^4\right]$$
$$g(h) = t_1 \frac{h^3}{3} + t_2\left(4\frac{h^8}{8} - 15\frac{h^7}{7} + 20\frac{h^6}{6} - 10\frac{h^5}{5} + \frac{h^3}{3}\right)$$
where $h_1 = h(p_1 - p_0)$
$$h_2 = h(p_2 - p_0) \quad (38)$$

Method of Mazumdar

Following Mazumdar [15], the tension relation can be written as
$$T(h) = A(e^{kh} - e^{k}) \quad (39)$$
Where $A = 0.007435$ and $k = 5.2625$, substituting Eq. (39) in Eq. (34) , we get
$$p - p_0 = A\left[\frac{e^{Kh}}{h} - \frac{e^{K}}{h}\right] \quad (40)$$
$$dp' = A\left[e^{Kh}\left(\frac{K}{h} - \frac{1}{h^2}\right) + \frac{e^{K}}{h^2}\right] dh \quad (41)$$
Using Eq. (41) in Eq. (33), we get the flux as
$$Q = \frac{1}{8}\int_{p_2-p_0}^{p_1-p_0} h^4\left[A\left[e^{Kh}\left(\frac{K}{h} - \frac{1}{h^2}\right) + \frac{e^{K}}{h^2}\right]\right] dh + F(h(p_2 - p_0))^4$$
where $h = h(p - p_0)$ (42)
$$Q = \frac{1}{8}\left[\left(g(h_1) - g(h_2)\right) + F h_2^4\right] \quad (43)$$
Where $g(h) = \frac{e^{Kh}}{k^3}(h^3K^3 - 4h^2K^2 + 8Kh - 8) + \frac{e^{k}h^3}{3}$ (44)

Results and Discussions

In this present study effects of Peristaltic transport of a nano-fluid in an elastic tube are investigated. The flux is obtained by different methods namely Rubinow and Keller and Mazumdar. The influence of different pertinent parameters on flux variation along the elastic tube radius for nano-fluid is calculated and interpreted through the graphs.

The variation in flux along the radius of the tube using Rubinow and Keller method for different values of elastic parameters t_1 , t_2 , Brownian motion parameter N_b , the thermophoresis parameter N_t, local temperature Grashof number G_r, and local nanoparticle Grashof number B_r are represented through the Figures. 1 to 6.

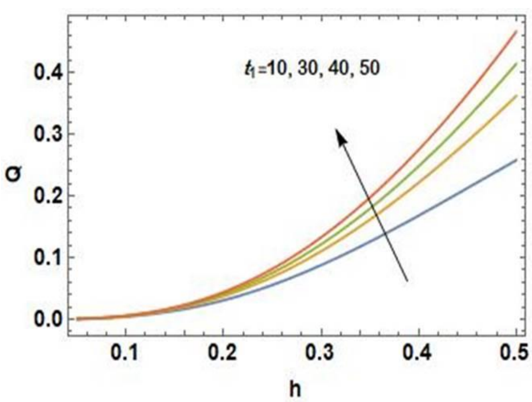

Figure 1. Variation of flux vs. radius for different values of elastic parameter t_1

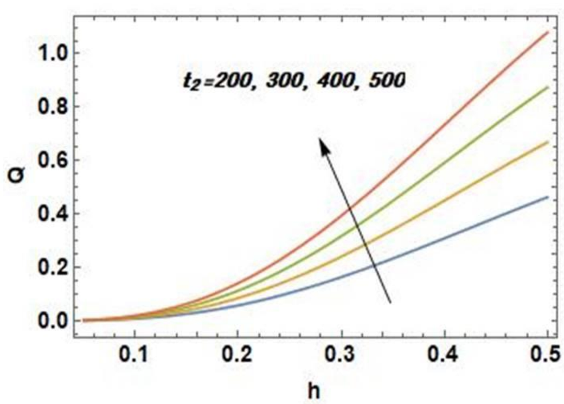

Figure 2. Variation of flux vs. radius for different values of elastic parameter t_2

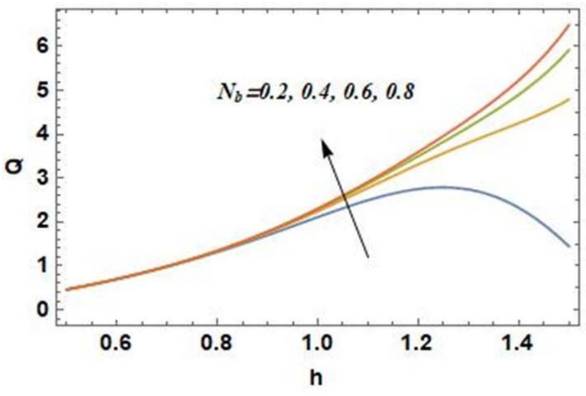

Figure 3. Variation of flux vs. radius for different values of Brownian motion parameter N_b

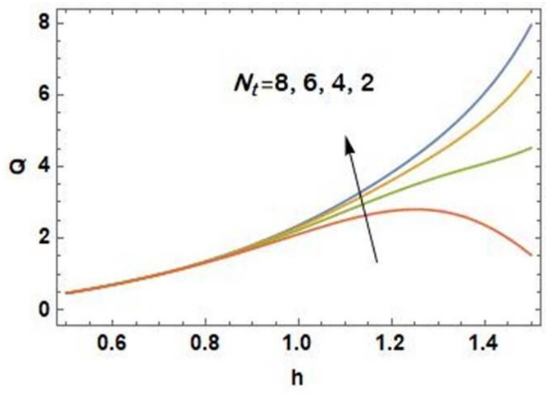

Figure 4. Variation of flux vs. radius for different values of thermophoresis parameter N_t

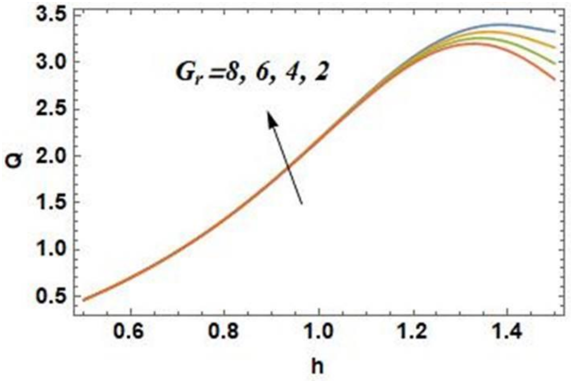

Figure 5. Variation of flux vs. radius for different values of Local temperature G_r

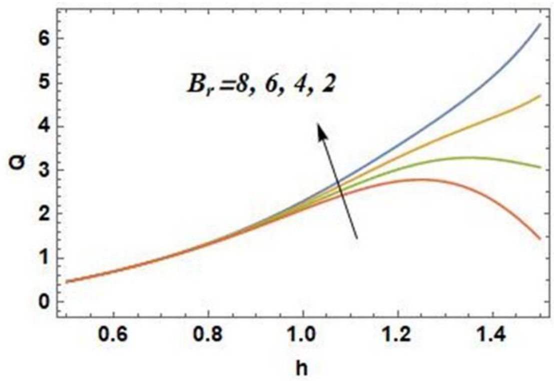

Figure 6. Variation of flux vs. radius for different values of Local nanoparticle Grashof number B_r

The variation in flux rate using the Mazumdar method for different values of elastic parameters t_1, t_2, Brownian motion parameter N_b, the thermophoresis parameter N_t, local temperature Grashof number G_r, and local nanoparticle Grashof number B_r are represented through Figures. 7 to 12.

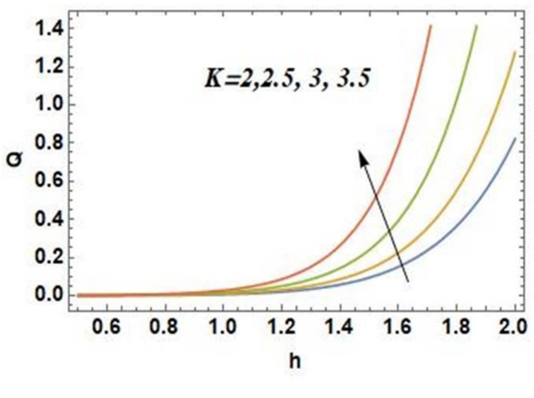

Figure 7. Variation of flux vs. radius for different values of elastic parameter k

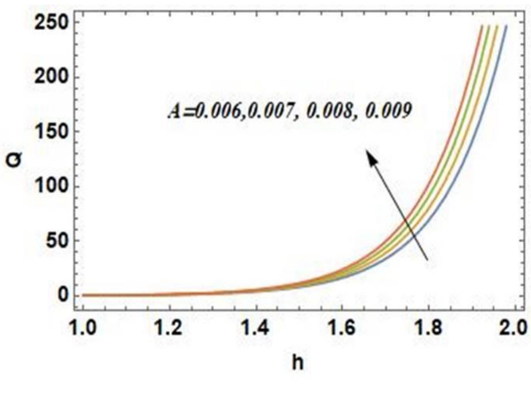

Figure 8. Variation of flux vs. radius for different values of elastic parameter *A*

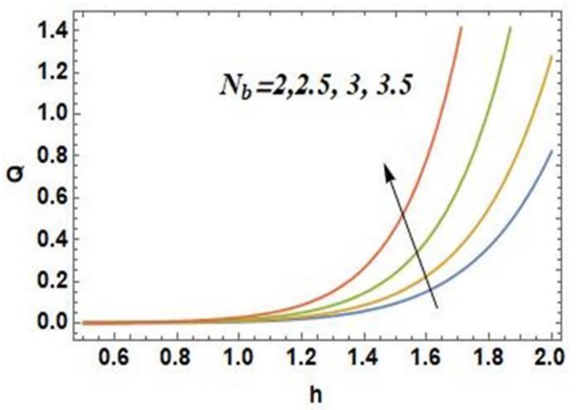

Figure 9. Variation of flux vs. radius for different values of Brownian motion parameter N_b

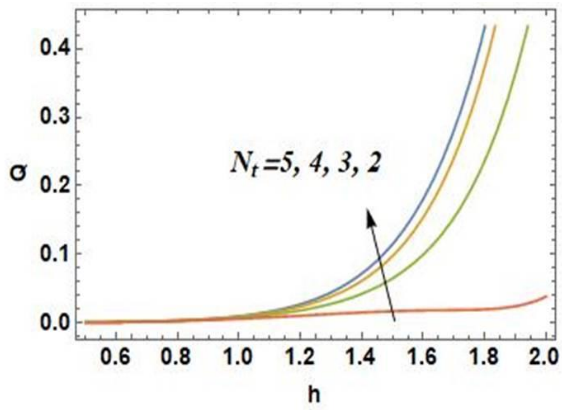

Figure 10. Variation of flux vs. radius for different values of thermophoresis parameter N_t

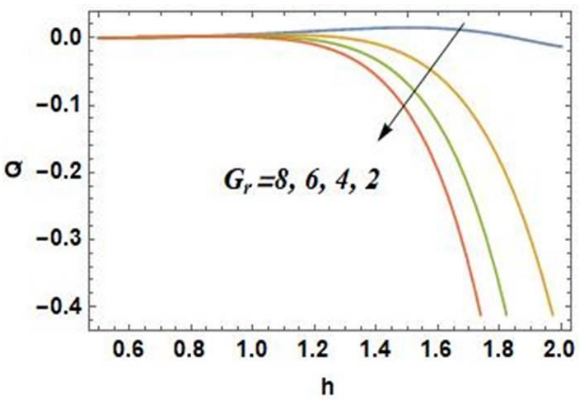

Figure 11. Variation of flux vs. radius for different values of Local temperature Grashof number G_r

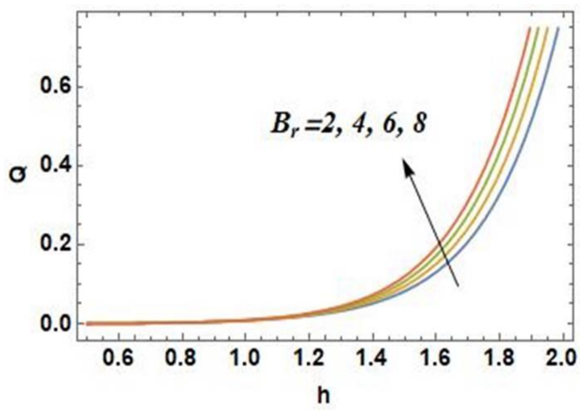

Figure 12. Variation of flux vs. radius for different values of Local nanoparticle Grashof number B_r

The flux increases with increasing values of elastic parameters t_1, t_2, and Brownian motion parameter N_b. The flux decreases with increasing values of thermophoresis parameter N_t, local temperature Grashof number G_r and local nanoparticle Grashof number B_r.

The variation in flux rate using Mazumdar method for different values of elastic parameters A, k Brownian motion parameter N_b, local nanoparticle Grashof number B_r. The flux decreases for increasing values of thermophoresis parameter N_t, local temperature Grashof number G_r.

The velocity profiles with the radius of the elastic tube for different values of N_b, N_t, G_r and B_r can be seen in Figs. 13 t0 16

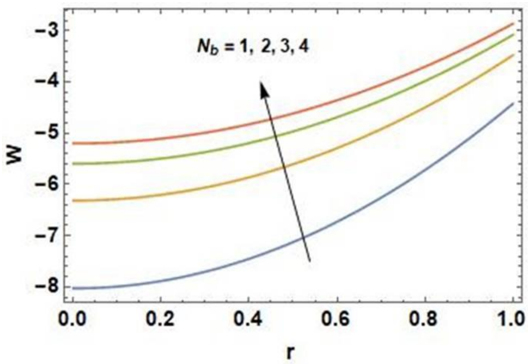

Figure 13. Velocity profile for different values of Brownian motion parameter N_b

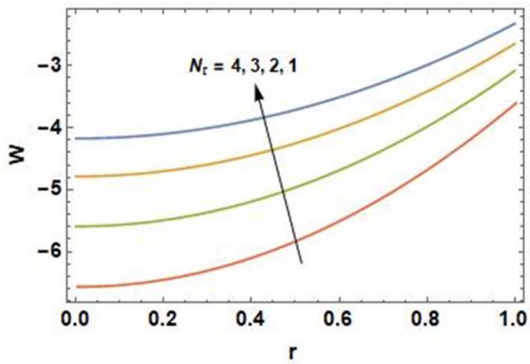

Figure 14. Velocity profile for different values of thermophoresis parameter N_t

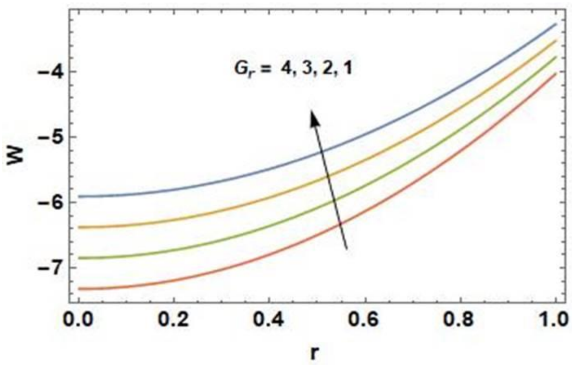

Figure 15. Velocity profile for different values of local temperature Grashof number G_r

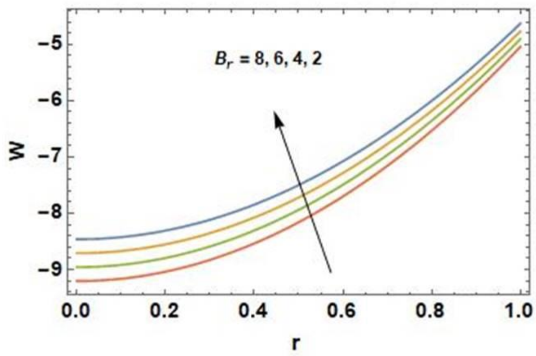

Figure 16. Velocity profile for different values of local nanoparticle Grashof number B_r

The Velocity increases with increasing values of Brownian motion parameter N_b and local nanoparticle Grashof number B_r. The Velocity decreases with increasing values of thermophoresis parameter N_t and local temperature Grashof number G_r.

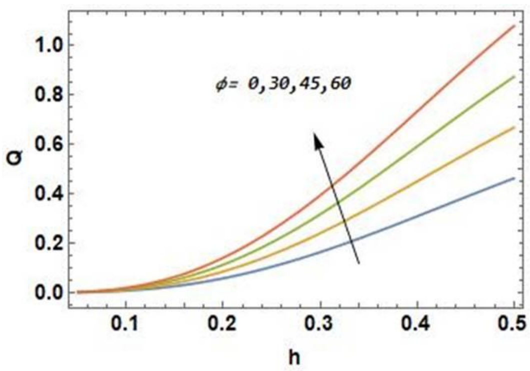

Figure 17. Variation of flux vs. radius for inclination ς (Rubinow and Keller)

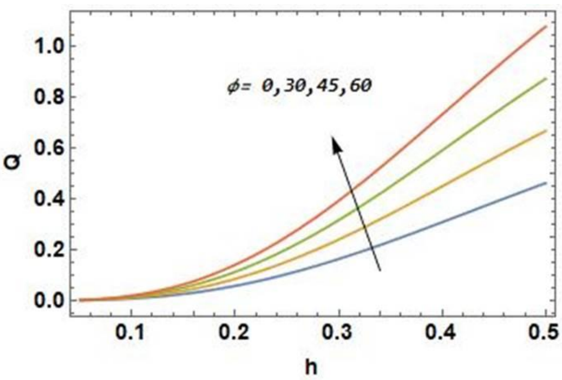

Figure 18. Variation of flux vs. radius for inclination ς (Mazumdar method)

The variation of flux Q along radius h with angle of inclination α shows that for Q increases with increasing in α from fig 18 and 19.

Conclusions

This study examines the effects of peristaltic transport of a nano-fluid passing through an elastic tube under the long wavelength and low Reynolds number assumptions. Temperature profile and nanoparticle phenomena have been calculated using the Homotopy perturbation technique. The variation of flux Q and radius h are analyzed for various physical parameters namely elastic parameters, Brownian motion parameter, thermophoresis parameter, local temperature Grashof number, and local nanoparticle Grashof number. The velocity profile with the radius of the elastic tube was calculated for different values of N_b, N_t, G_r and B_r.

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