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Peristaltic Transport of Hyperbolic Tangent Fluid in a Tapered Asymmetric Channel

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Abstract

Objectives: The study intends to investigate the problem of peristalsis transport of hyperbolic tangent fluid in a tapered asymmetric channel. **Methods**: The two-dimensional equations of a hyperbolic tangent fluid have been simplified under the suspicions of low Reynolds number and long wavelength approximations. The reduced equations are solved by using standard perturbation technique. The numerical results obtained are presented in the graphical form for various values of physical parameters and are discussed. **Findings**: It is showing that for the larger values of non-uniform parameter, pressure rise diminishes and the axial velocity diminishes at the core part of the channel and increases at the right and left side of the channel for the increasing values of non-uniform parameter. **Applications**: Hyperbolic tangent fluid model anticipate the shear thinning phenomenon very accurately and are being used mostly in laboratory experiments and industries.

Keywords: Reynolds number; Hyperbolic tangent fluid; peristaltic transport; tapered asymmetric channel

1 Introduction

The system of peristaltic transport has been coined by Latham. Now a day's many researchers are fascinated towards tapered asymmetric channel of non-Newtonian fluid with peristalsis because of its widespread applications in medical, physiological and industrial processes. Peristalsis can be found in many physiological processes such as in the chyme movement in gastrointestinal tract, blood circulation in small blood vessels and also in food digestion. In biomedical field the dialysis and heart lung machines worked on the peristaltic principle.

Nadeem and Akram [(1)] have analyzed the hyperbolic tangent fluid under long wavelength and low Reynolds number approximations in an asymmetric channel with peristalsis via regular perturbation method. Also they have extended their work for the same fluid under the influence of MHD with heat transfer in a vertical asymmetric channel [(2)]. Many experiments [(3–10)] have been made for hyperbolic tangent fluid for different types of channels.

Kothandapani et al. [(11)] have studied the peristaltic transport in the presence of tapered asymmetric channel for Johnson–Segalman fluid. From their study it is revealed that as the values of amplitude increases the pressure rise increases also in the increment of non-dimensionless parameter and Weissenberg number the pressure rise decreases. Hayat et al.[12] have scrutinized the effect of magnetic field and nonlinear radiation of peristaltic motion of Sisko fluid in an inclined tapered asymmetric channel. Kothandapani and Prakash[13] have analyses the peristaltic transport of Williamson nanofluids under the influence of magnetic field and thermal radiation parameter in a tapered asymmetric channel. Prakash et al.[14] have studied the peristaltic motion in a tapered asymmetric channel for a third grade fluid. From their study it is noticed that as the non-uniform parameter (m) increases the pressure rise decreases and axial velocity enhances at the boundaries by increasing in non-uniform parameter (m). The peristaltic phenomena in the presence of tapered asymmetric channel has discussed in the literatures[15–19]. Kothandapani et al.[20] have observed the peristaltic flow of an incompressible non-Newtonian fourth grade fluid with the influence of uniform magnetic field in a tapered asymmetric channel. Further similar studies can be found in relevant literature[21–30].

To the best of our knowledge, no attempt has been made to analyses the peristaltic transport of the hyperbolic tangent fluid in a tapered asymmetric channel. The governing equations are simplified under the assumptions of long wavelength and low Reynolds number approximations. The stream function and pressure gradient have calculated by adopting regular perturbation method. The effect of various physical parameters on pressure rise and axial velocity are discussed and explained graphically.

2 Mathematical Modelling and Methods

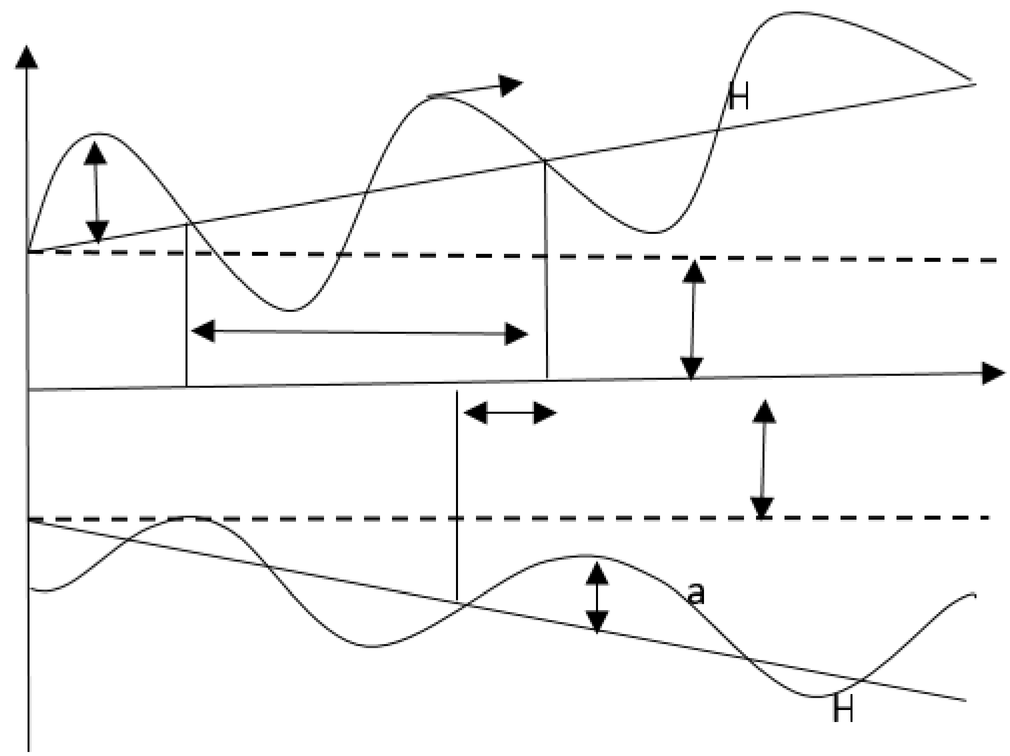

Fig 1. Schematic diagram of a tapered asymmetric

Let us consider the peristalsis of two-dimensional hyperbolic tangent fluid through the channel of width 2d. Here the medium is considered to the tangent hyperbolic fluid flow is produced by the propagation of sinusoidal wave trains with constant speed c along the walls of the tapered asymmetric channel, such that

$$H_2\left(\bar{X},\bar{t}\right) = d + m'\bar{X} + a_2 sin\left[\frac{2\pi}{\lambda}\left(\bar{X} - c\bar{t}\right)\right] \qquad \text{(Upper wall 1(a))}$$

$$H_1\left(\bar{X},\bar{t}\right) = -d - m'\bar{X} - a_1 sin\left[\frac{2\pi}{\lambda}\left(\bar{X} - c\bar{t}\right) + \varnothing\right] \qquad \text{(Lower wall 1(b))}$$

Where,a_1 and a_2 are the amplitudes of the wave, λ is the wave length, width of the channel is 2d, phase speed of the wave is depicted with c, $\bar{t}$ be the time, and $\bar{X}$ is the sinusoidal wave propagation direction, the non uniform parameter is denoted by $m'\left(m' \ll 1\right)$. The phase difference $\phi \in [0, \quad \pi]$ and the quantity $\phi = 0$ imply the symmetric channel with waves out of phase i.e. both walls move towards the outward or inward simultaneously. And the physical variables $a_1,\ a_2,\ d\ and\ \phi$ obey the following required relation.

$$a_1^2 + a_2^2 + 2a_1a_2cos\varnothing \ \leq\ (2d)^2 \tag{2}$$

Thus, based on the above considered geometry and assumptions, in the fixed frame of reference the governing equations for unsteady two-dimensional tangent hyperbolic fluid[1,2,4] are as follows:

$$\frac{\partial \bar{U}}{\partial \bar{X}} + \frac{\partial \bar{V}}{\partial \bar{Y}} = 0 \tag{3}$$

$$\rho\left(\frac{\partial \bar{U}}{\partial \bar{t}} + \bar{U}\frac{\partial \bar{U}}{\partial \bar{X}} + \bar{V}\frac{\partial \bar{U}}{\partial \bar{Y}}\right) = -\frac{\partial \bar{P}}{\partial \bar{X}} - \frac{\partial \bar{\tau}_{\bar{X}\bar{X}}}{\partial \bar{X}} - \frac{\partial \bar{\tau}_{\bar{X}\bar{Y}}}{\partial \bar{Y}} \tag{4}$$

$$\rho\left(\frac{\partial \bar{V}}{\partial \bar{t}} + \bar{U}\frac{\partial \bar{V}}{\partial \bar{X}} + \bar{V}\frac{\partial \bar{V}}{\partial \bar{Y}}\right) = -\frac{\partial \bar{P}}{\partial \bar{Y}} - \frac{\partial \bar{\tau}_{\bar{X}\bar{Y}}}{\partial \bar{X}} - \frac{\partial \bar{\tau}_{\bar{Y}\bar{Y}}}{\partial \bar{Y}} \tag{5}$$

Following transformations indicate the moment of a considered wave frame $\left(\bar{x}, \bar{y}\right)$ travelling with velocity c away from the immovable frame $\left(\bar{X}, \bar{Y}\right)$ as follows.

$$\bar{x} = \bar{X} - c\bar{t}\ ,\quad \bar{y} = \bar{Y}\ ,\ \bar{u} = \bar{U} - c\ ,\bar{v} = \bar{V},\ \ and\ \bar{p}(x) = \bar{P}(X,t) \tag{6}$$

The dimensionless variables for the purpose of non-dimensionalization are

$$\left.\begin{array}{c} x = \frac{\bar{x}}{\lambda}, y = \frac{\bar{y}}{\bar{d}_1}, u = \frac{\bar{u}}{c}, t = \frac{c}{\lambda}\bar{t}, v = \frac{\bar{v}}{c\delta}, h_1 = \frac{\bar{h}_1}{\bar{d}_1}, h_2 = \frac{\bar{h}_2}{\bar{d}_1}, \tau_{xx} = \frac{\lambda}{\eta_0 c}\bar{\tau}_{\bar{x}\bar{x}} \\ \tau_{xy} = \frac{\bar{d}_1}{\eta_0 c}\bar{\tau}_{\bar{x}\bar{y}}, \quad \tau_{yy} = \frac{\bar{d}_1}{\eta_0 c}\bar{\tau}_{\bar{y}\bar{y}}, \delta = \frac{\bar{d}_1}{\lambda}, \mathrm{Re} = \frac{\rho c \bar{d}_1}{\eta_0}, W\ e = \frac{\Gamma c}{\bar{d}_1}, P = \frac{\bar{d}_1{}^2}{c\lambda\eta_0}\bar{p}, \dot{\gamma} = \frac{\dot{\gamma}\bar{d}_1}{c} \\ m = \frac{m'\lambda}{d} \end{array}\right\} \tag{7}$$

By utilizing the above non-dimensional parameters in the Eqs (1-7) and in view of stream function $\psi\left(u = \frac{\partial\psi}{\partial y}, v = -\delta\frac{\partial\psi}{\partial x}\right)$, the resultant equations are as follows:

$$\delta Re\left[\left(\frac{\partial\psi}{\partial y}\frac{\partial}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial}{\partial y}\right)\frac{\partial\psi}{\partial y}\right] = -\frac{\partial P}{\partial x} - \delta^2\frac{\partial\tau_{xx}}{\partial x} - \frac{\partial\tau_{xy}}{\partial y} \tag{8}$$

$$\delta^3 Re\left[\left(\frac{\partial\psi}{\partial y}\frac{\partial}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial}{\partial y}\right)\right]\frac{\partial\psi}{\partial x} = -\frac{\partial P}{\partial y} - \delta^2\frac{\partial\tau_{xy}}{\partial x} - \delta\frac{\partial\tau_{yy}}{\partial y} \tag{9}$$

$$\tau_{xx} = -2\left[1 + n\left(We\ \dot{\gamma} - 1\ \right)\right]\frac{\partial^2\psi}{\partial x\partial y}$$

$$\tau_{xy} = -\left[1 + n\left(We\,\dot{\gamma} - 1\right)\right]\left(\frac{\partial^2\psi}{\partial y^2} - \delta^2\frac{\partial^2\psi}{\partial x^2}\right)$$

$$\tau_{yy} = 2\delta\left[1 + n\left(We\,\dot{\gamma} - 1\right)\right]\frac{\partial^2\psi}{\partial x\partial y}$$

$$\dot{\gamma} = \left[2\delta^2\left(\frac{\partial^2\psi}{\partial x\partial y}\right)^2 + \left(\frac{\partial^2\psi}{\partial y^2} - \delta^2\frac{\partial^2\psi}{\partial x^2}\right)^2 + 2\delta^2\left(\frac{\partial^2\psi}{\partial x\partial y}\right)^2\right]^{1/2}$$

In above equations of τ_{xx}, τ_{xy} and τ_{yy}, δ is wave number, Re is Reynolds number and We be the Weissenberg number respectively. According to the assumptions of low Reynolds number and long wave length approximation $(\delta \ll 1)$, as well as ignoring the terms of higher order δ, we can reduce the Eqs. (8) and (9) to the following form.

$$\frac{\partial P}{\partial x} = \frac{\partial}{\partial y}\left[1 + n\left(We\,\frac{\partial^2\psi}{\partial y^2} - 1\right)\right]\frac{\partial^2\psi}{\partial y^2} \tag{10}$$

$$\frac{\partial P}{\partial y} = 0 \tag{11}$$

After removal of pressure gradient from Eqs. (10-11)

$$\frac{\partial^2}{\partial y^2}\left[1 + n\left(We\,\frac{\partial^2\psi}{\partial y^2} - 1\right)\right]\frac{\partial^2\psi}{\partial y^2} = 0 \tag{12}$$

The boundary conditions are

$$\left.\begin{array}{llll} \psi = -\dfrac{F}{2}, & \dfrac{\partial\psi}{\partial y} = 0 & \text{for} & y = h_1(x) \\ \psi = \dfrac{F}{2}, & \dfrac{\partial\psi}{\partial y} = 0 & \text{for} & y = h_2(x) \end{array}\right\} \tag{13}$$

Where

$$h_2(x) = 1 + mx + bsin\left(2\pi\ (x - t)\right)$$

$$h_1(x) = -1 - mx - asin\left(2\pi\ (x - t) + \varnothing\right)$$

Also, the quantities a, b, ϕ and d satisfy the following inequality:

$$a^2 + b^2 + 2ab\cos\phi \leq 4$$

2.1 Method of Solution

Here the flow quantities ψ, F and P are expanded in terms of power series as follows to get the simplified form of Eqn (12) by utilising boundary conditions :

$$\psi = \psi_0 + We\,\psi_1 + O(We^2) \tag{14}$$

$$F = F_0 + We\,F_1 + O(We^2) \tag{15}$$

$$P = P_0 + We\,P_1 + O(We^2) \tag{16}$$

Replacing Eqs. (14)-(16) in the above Eqs. (10), (12) and (13) and rearranging the coefficients of powers of We gives the following system of equations.

2.2 System of order We^0

$$\frac{\partial^4 \psi_0}{\partial y^4} = 0 \tag{17}$$

$$\frac{\partial P_0}{\partial x} = (1-n)\frac{\partial^3 \psi_0}{\partial y^3} \tag{18}$$

$$\psi_0 = \frac{F_0}{2}, \quad \frac{\partial \psi_0}{\partial y} = 0 \quad for \quad y = h_2(x) \tag{19}$$

$$\psi_0 = -\frac{F_0}{2}, \quad \frac{\partial \psi_0}{\partial y} = 0 \quad for \quad y = h_1(x) \tag{20}$$

2.3 System of order We^1

$$\frac{\partial^4 \psi_1}{\partial y^4} = \frac{n}{n-1}\frac{\partial^2}{\partial y^2}\left(\frac{\partial^2 \psi_0}{\partial y^2}\right)^2 \tag{21}$$

$$\frac{\partial P_1}{\partial x} = (1-n)\frac{\partial^3 \psi_1}{\partial y^3} + n\frac{\partial}{\partial y}\left(\frac{\partial^2 \psi_0}{\partial y^2}\right)^2 \tag{22}$$

$$\psi_1 = \frac{F_1}{2}, \quad \frac{\partial \psi_1}{\partial y} = 0 \quad for \quad y = h_2(x) \tag{23}$$

$$\psi_1 = -\frac{F_1}{2}, \quad \frac{\partial \psi_1}{\partial y} = 0 \quad for \quad y = h_1(x) \tag{24}$$

2.4 Solution for Zeroth order (We^0)

Solution of the Eq. (17) satisfying the required boundary conditions defined in Eqs. (19-20) are written as

$$\psi_0 = C_1 + C_2 y + C_3 y^2 + C_4 y^3 \tag{25}$$

$$\frac{\partial P_0}{\partial x} = -6\, C_4\, (-1+n) \tag{26}$$

2.5 Solution for First order (We^1)

Substituting Eq. (25) and satisfying the boundary conditions (23-24) into the Eq. (21), we get the solution of first order as follows

$$\psi_1 = C_5 + C_6 y + C_7\, y^2 + C_8\, y^3 + 72\, {C_4}^2\, y^4 \tag{27}$$

$$\frac{\partial p_1}{\partial x} = -6\, C_8\, (-1+n) + 24\, C_4 (C_3\, n + 3\, C_4 (24 - 23\, n) y) \tag{28}$$

$$C_1 = \frac{1}{2}F_0\left(1+\frac{2h_2^2(-3h_1+h_2)}{(h_1-h_2)^3}\right)$$

$$C_2 = \frac{6F_0h_1h_2}{(h_1-h_2)^3}$$

$$C_3 = -\frac{3F_0\,(h_1+h_2)}{(h_1-h_2)^3}$$

$$C_4 = \frac{2F_0}{(h_1-h_2)^3}$$

$$C_5 = 72{C_4}^2h_1^2h_2^2 + \frac{F_1(h_1+h_2)(h_1^2-4h_1h_2+h_2^2)}{2(h_1-h_2)^3}$$

$$C_6 = \frac{6h_1h_2(F_1-24{C_4}^2(h_1-h_2)^3(h_1+h_2))}{(h_1-h_2)^3}$$

$$C_7 = -\frac{3(F_1(h_1+h_2)-24\,{C_4}^2(h_1-h_2)^3(h_1^2+4h_1h_2+h_2^2))}{(h_1-h_2)^3}$$

$$C_8 = 2\left(\frac{F_1}{(h_1-h_2)^3}-72\,{C_4}^2(h_1+h_2)\right)$$

By invoking

$$F = F_0 + We\,F_1 \tag{29}$$

By gathering all perturbation solutions of the considered problem for small parameter We, up to ψ, $\frac{dP}{dx}$ and $\triangle p$ as

$$\psi = \psi_0 + We\,\psi_1 \tag{30}$$

$$\frac{dP}{dx} = \frac{dP_0}{dx} + We\,\frac{dP_1}{dx} \tag{31}$$

$$\triangle p = \triangle p_0 + We\,\triangle p_1 \tag{32}$$

Utilizing$F_0 = F - We\,F_1$ and then ignoring the terms higher than $O(We)$the results given by Eq. (30-32) can be explicitly calculated.

The axial velocity obtained from the equation $u = \frac{\partial\psi}{\partial y}$.

The non-dimensional term for the average rise in pressure $\triangle p$ is over one period of wavelength is given as follows

$$\triangle p = \int_0^1\int_0^1\left(\frac{\partial p}{\partial x}\right)_{y=0} dxdt \tag{33}$$

3 Results and discussion

This category of the paper is to illustrate the outcomes of our problem graphically. MATHEMATICA software has been utilized to calculate pressure rise. The influences of various physical parameters like wave amplitude parameters a and b, width of the channel d, non uniform parameter m, Weissenberg number We, phase difference ϕ and power law index n for hyperbolic tangent fluid in a tapered asymmetric channel are discussed. Figures 2, 3, 4, 5, 6, 7 and 8 shows the average rise in pressure $\triangle P$ against time average flux Q. Figure 2. reveals that the pressure rise for the values of wave amplitude a. It is noticed that, pressure rise increases in pumping section and co-pumping section. Figure 3. elucidate that behavior of wave amplitude b in pressure rise. It is interesting to note down that an increase in b values results the increment in pressure rise. From Figure 4. it is observed that pressure rise enhances as channel width increases. From Figure 5. it is interesting to note that as the non uniform parameter m, increases the pressure rise decreases in the pumping section and opposite behavior occurred in co-pumping region. Figure 6. shows that pressure rise decreases for the larger values of power law index in pumping region and increases in co-pumping region. Similar behavior exposed in Figure 7. for the values of phase difference ϕ. It is noticed that from Figure 8. that as the Weissenberg number increases (We) the pressure rise increases.

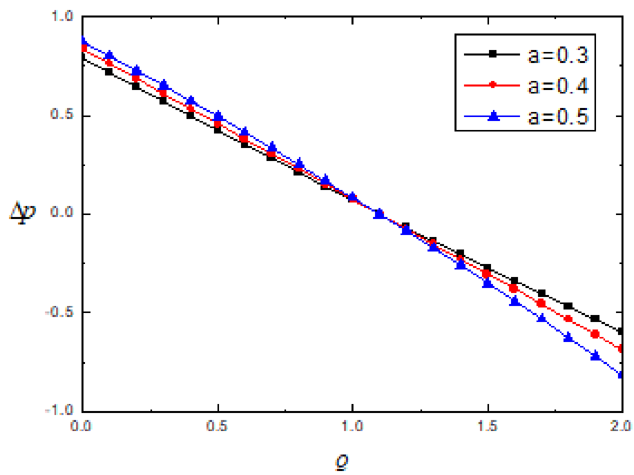

Fig 2. Variation of Δp versus Q for different values of a $n = 0.5, d = 0.1, \phi = 2\pi, we = 0.01, b = 0.4$ and $m = 0.3$

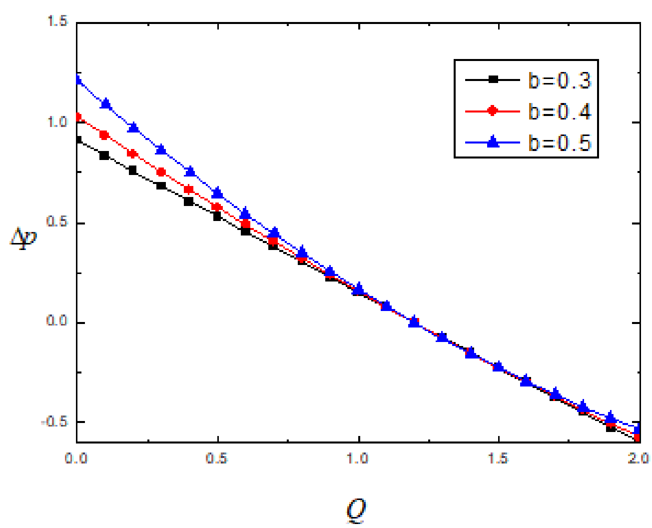

Fig 3. Variation of Δp versus Q for different values of b $n = 0.3, d = 0.2, \phi = \frac{2\pi}{3}, we = 0.03, a = 0.3$ and $m = 0.3$

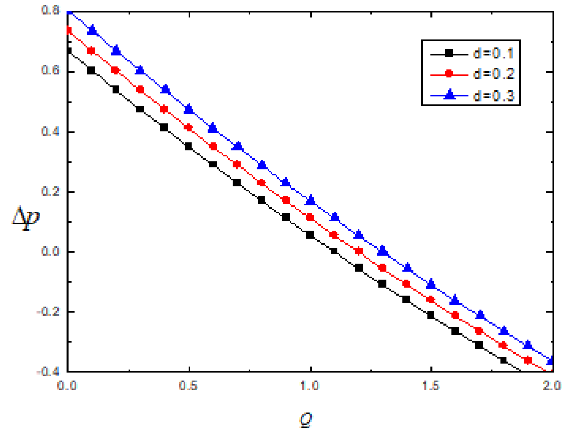

Fig 4. Variation of Δp versus Q for different values of d $n = 0.3, b = 0.4, \phi = \frac{2\pi}{3}, we = 0.03, a = 0.2$ and $m = 0.3$

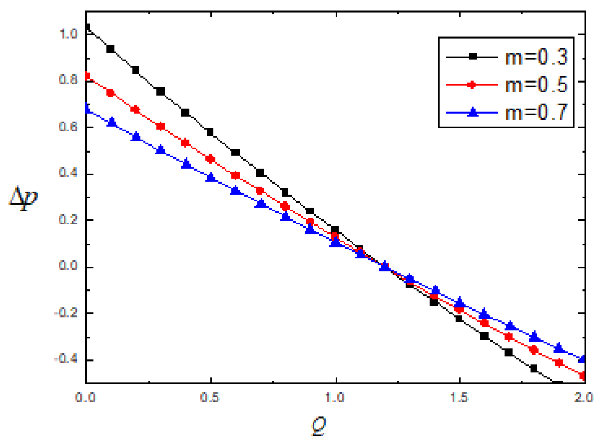

Fig 5. Variation of Δp versus Q for different values of $mn = 0.3, b = 0.4, \phi = \frac{2\pi}{3}, we = 0.03, a = 0.3$ and $d = 0.2$

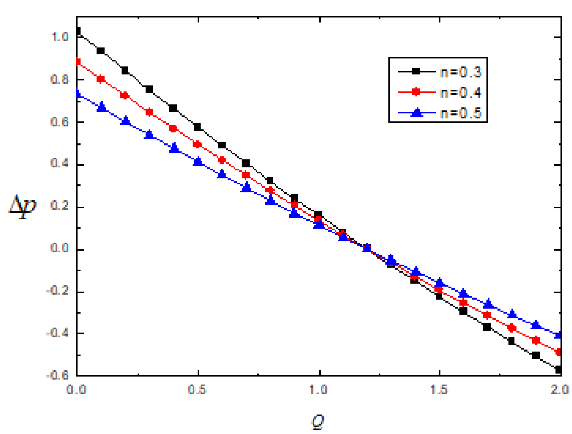

Fig 6. Variation of Δp versus Q for different values of $nm = 0.3, b = 0.4, \phi = \frac{2\pi}{3}, we = 0.03, a = 0.3$ and $d = 0.2$

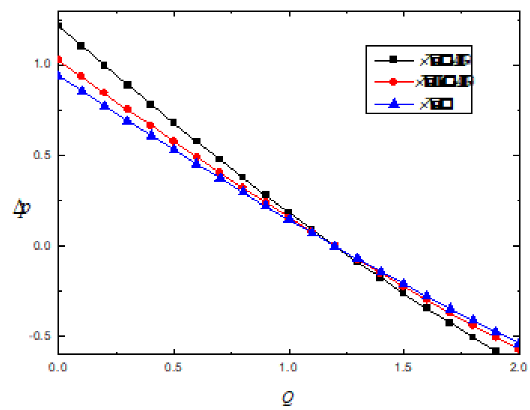

Fig 7. Variation of Δp versus Q for different values of $\phi m = 0.3, b = 0.4, n = 0.3, we = 0.03, a = 0.3$ and $d = 0.2$

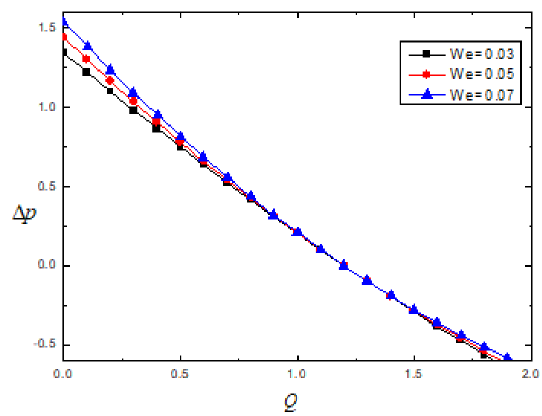

Fig 8. Variation of Δp versus Q for different values of we $m = 0.3, b = 0.4, n = 0.2, \phi = \frac{2\pi}{3}, a = 0.3$ and $d = 0.2$

Figures 9, 10, 11 and 12 illustrate distribution of axial velocity (u) is plotted against y. Figure 9 shows that axial velocity decreases right and left side of the channel for the escalating values of wave amplitude a and situation revered in the core part of the channel. It is clear from the Figure 10.

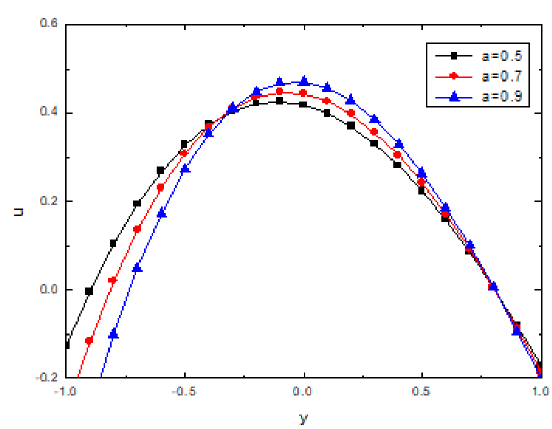

Fig 9. Axial velocity for different values of $am = 0.5, b = 0.4, n = 0.2, \phi = \frac{2\pi}{3}, d = 0.02, t = 0.6, we = 0.01$

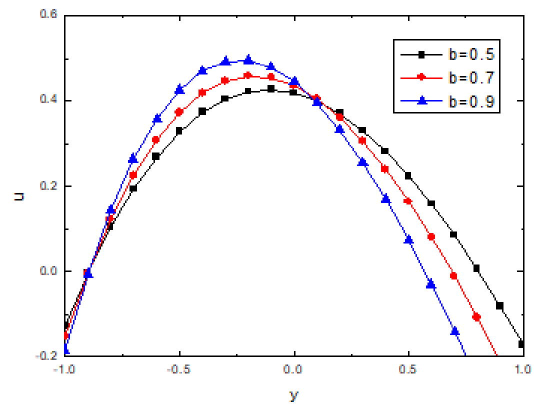

Fig 10. Axial velocity for different values of $bm = 0.5, n = 0.2, \phi = \frac{2\pi}{3}, a = 0.5, d = 0.02, t = 0.6, we = 0.01$

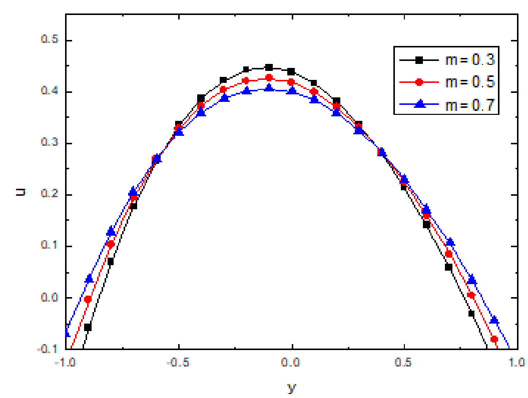

Fig 11. Axial velocity for different values of $mb = 0.4, n = 0.2, \phi = \frac{2\pi}{3}, a = 0.5, d = 0.02, t = 0.6, we = 0.01$

That axial velocity increases in the region (-0.875, 0.125) for the increasing values of wave amplitude b and the opposite behavior is observed in the region (0.125, 1). It is interesting to note that from Figure 11. An increase in non-uniform parameter m the axial velocity increases at the right and left side of the channel and at the core part of the channel of u gets decreased. In Figure 12. The impact of Weissenberg number on axial velocity is observed. It increases in the region (-0.75, 0) with an enhance in Weissenberg number and converse in behaviour is noticed in the region (0, 0.75) of the channel.

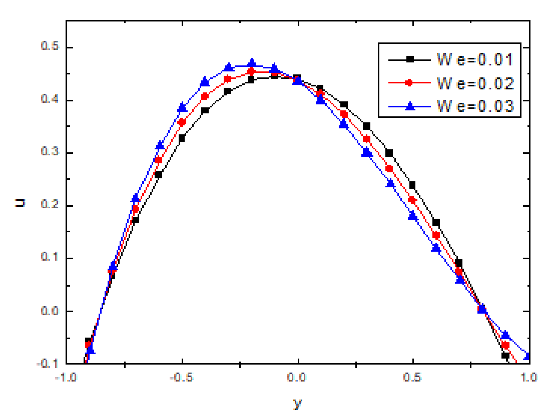

Fig 12. Axial velocity for different values of $web = 0.5, n = 0.6, \phi = \frac{2\pi}{3}, a = 0.6, d = 0.01, t = 0.6, m = 0.5$

4 Conclusion

In this study, we have considered the peristaltic motion of hyperbolic tangent fluid in the presence of tapered asymmetric channel. This representation is one of the most important fluid models in the group of non-Newtonian fluids. From laboratory experiments, it is found that this model anticipates the shear thinning phenomenon very accurately and are being used mostly in laboratory experiments and industries. The exact solutions of governing equations are difficult due to highly non-linear system of partial differential equations. A standard perturbation method is used to produce semi analytic results. The impact of different physical parameters like wave amplitude parameters a and b, width of the channel d, non-uniform parameter m, Weissenberg number We, phase difference ϕ and power law index n are discussed. The following observations have been made. The average rise in pressure increases with the increase in Weissenberg number and amplitude parameter a and b. For the larger values of non-uniform parameter (m) pressure rise diminishes. The axial velocity decreases at the central part of the channel and increases at the right and left side of the channel for the increasing values of non-uniform parameter (m).

Nomenclature

$a_1 a_2$ Amplitudes of the wave
λ Wave length
2d Width of the channel
τ_{xx}, τ_{xy} and τ_{yy} Components of extra stress tensor
δ Wave number
Re Reynolds number
We Weissenberg number
m Non uniform parameter
ϕ Phase difference
n Power law index

References

1) Nadeem S, Akram S. Peristaltic Transport of a Hyperbolic Tangent Fluid Model in an Asymmetric Channel. *Zeitschrift für Naturforschung A*. 2009;64(9-10):559–567. Available from: https://dx.doi.org/10.1515/zna-2009-9-1004.
2) Nadeem S, Akram S. Magnetohydrodynamic peristaltic flow of a hyperbolic tangent fluid in a vertical asymmetric channel with heat transfer. *Acta Mechanica Sinica*. 2011;27(2):237–250. Available from: https://dx.doi.org/10.1007/s10409-011-0423-2.
3) Abbas MA, Bai YQ, Bhatti MM, Rashidi MM. Three dimensional peristaltic flow of hyperbolic tangent fluid in non-uniform channel having flexible walls. *Alexandria Engineering Journal*. 2016;55(1):653–662. Available from: https://dx.doi.org/10.1016/j.aej.2015.10.012.
4) Akram S, Nadeem S. Effects of partial slip on the peristaltic transport of a hyperbolic tangent fluid model in an asymmetric channel. *Computational Mathematics and Mathematical Physics*. 2015;55(11):1899–1912. Available from: https://dx.doi.org/10.1134/s0965542515110147.
5) Akbar NS, Hayat T, Nadeem S, Obaidat S. Peristaltic flow of a Tangent hyperbolic fluid in an inclined asymmetric channel with slip and heat transfer. *Progress in Computational Fluid Dynamics, An International Journal*. 2012;12(5):363–363. Available from: https://dx.doi.org/10.1504/pcfd.2012.049100.
6) Reddy SN, Reddy GV, Reddy S. Peristaltic flow of a hyperbolic tangent fluid through a porous medium in a planar channel. *International Journal of Mathematical Archive*. 2013;4(8):28–38. Available from: http://www.ijma.info/index.php/ijma/article/view/2264.
7) Jyothi B, Rao K. Influence of magnetic field on hyperbolic tangent fluid through a porous medium in a planar channel with peristalsis. *International Journal of Mathematical Archive*. 2013;4(8):171–182. Available from: http://www.ijma.info/index.php/ijma/article/view/2281.
8) Reddy BJ, Reddy MVS. Peristaltic flow of a Hyperbolic tangent fluid through a porous medium in a vertical channel. *International Journal of Engineering and Technical Research*. 2016;4(2):93–97. Available from: http://www.erpublication.org/published_paper/IJETR041258.pdf.
9) Jyothi S, Reddy MVS, Gangavathi P. Hyperbolic Tangent Fluid Flow Through A Porous Medium in an Inclined Channel with Peristalsis. *International Journal of Advanced Scientific Research and Management*. 2016;1(4):113–121. Available from: http://ijasrm.com/wp-content/uploads/2016/04/IJASRM_V1S4_035_113_121.
10) Malik MY, Salahuddin T, Hussain A, Bilal S. MHD flow of tangent hyperbolic fluid over a stretching cylinder: Using Keller box method. *Journal of Magnetism and Magnetic Materials*. 2015;395:271–276. Available from: https://dx.doi.org/10.1016/j.jmmm.2015.07.097.
11) Kothandapani M, Prakash J, Pushparaj V. Nonlinear peristaltic motion of a Johnson–Segalman fluid in a tapered asymmetric channel. *Alexandria Engineering Journal*. 2016;55(2):1607–1618. Available from: https://dx.doi.org/10.1016/j.aej.2016.02.002.
12) Hayat T, Akram J, Zahir H, Alsaedi A. Peristaltic motion of Sisko fluid in an inclined asymmetric tapered channel with nonlinear radiation. *Journal of Thermal Analysis and Calorimetry*. 2019;138(1):545–558. Available from: https://dx.doi.org/10.1007/s10973-019-08088-w.
13) Kothandapani M, Prakash J. Effects of thermal radiation parameter and magnetic field on the peristaltic motion of Williamson nanofluids in a tapered asymmetric channel. *International Journal of Heat and Mass Transfer*. 2015;81:234–245. Available from: https://dx.doi.org/10.1016/j.ijheatmasstransfer.2014.09.062.
14) Prakash J, Siva EP, Balaji N, Kothandapani M. Effect of peristaltic flow of a third grade fluid in a tapered asymmetric channel. *Journal of Physics: Conf Series*. 2018;1000(012165). Available from: https://doi.org/10.1088/1742-6596/1000/1/012165.
15) Hasona WM. Temperature-Dependent Electrical Conductivity and Thermal Radiation Effects on MHD Peristaltic Motion of Williamson Nanofluids in a Tapered Asymmetric Channel. *Journal of Mechanics*. 2020;36(1):103–118. Available from: https://dx.doi.org/10.1017/jmech.2019.23.

16) Ali MK, Abdulhadi AM. Influence of an Inclined Magnetic Field on Peristaltic Transport of Pseudoplastic Nanofluid Through a Porous Space in an Inclined Tapered Asymmetric Channel with Convective Conditions. *American Journal of Mechanics and Applications*. 2016;3(5):42–55. Available from: 10.11648/j.ajma.20150305.12.
17) Prakash J, Balaji N, Siva EP, Kothandapani M, Govindarajan A. Effects of Magnetic field on Peristalsis transport of a Carreau Fluid in a tapered asymmetric channel. *Journal of Physics: Conf Series*. 2018;1000(012166). Available from: https://iopscience.iop.org/article/10.1088/1742-6596/1000/1/012166.
18) Abdulhadi AM, Ahmed TS. Effect of magnetic field on peristaltic flow of Walters B fluid through a porous medium in a tapered asymmetric channel. *Journal of Advances in Mathematics*. 2017;12(12):6889–6893. Available from: https://dx.doi.org/10.24297/jam.v12i12.4440.
19) Hayat T, Iqbal R, Tanveer A, Alsaedi A. Mixed convective peristaltic transport of Carreau-Yasuda nanofluid in a tapered asymmetric channel. *Journal of Molecular Liquids*. 2016;223:1100–1113. Available from: https://dx.doi.org/10.1016/j.molliq.2016.08.003.
20) Kothandapani M, Pushparaj V, Prakash J. Effect of magnetic field on peristaltic flow of a fourth grade fluid in a tapered asymmetric channel. *Journal of King Saud University - Engineering Sciences*. 2016;30(1):86–95. Available from: https://doi.org/10.1016/j.jksues.2015.12.009.
21) Tanveer A, Mahmood S, Hayat T, Alsaedi A. On electroosmosis in peristaltic activity of MHD non-Newtonian fluid. *Alexandria Engineering Journal*. 2021;60(3):3369–3377. Available from: https://dx.doi.org/10.1016/j.aej.2020.12.051.
22) Iqbal N, Yasmin H, Bibi A, Attiya AA. Peristaltic motion of Maxwell fluid subject to convective heat and mass conditions. *Ain Shams Engineering Journal*. 2021. Available from: https://dx.doi.org/10.1016/j.asej.2021.01.015.
23) Hussain Z, Muhammad T. Simultaneous Influence of Hall and Wall Characteristics in Peristaltic Convective Carbon–Water Flow Subject to Soret and Dufour Effects. *Arabian Journal for Science and Engineering*. 2021;46(3):2033–2046. Available from: https://dx.doi.org/10.1007/s13369-020-05017-0.
24) Devindrappa L, Naduvinamani NB, Shit GC. Peristaltically Induced Electroosmotic Flow of Jeffrey Fluid with Zeta Potential and Navier-Slip at the Wall. *International journal of Innovative Technology and Exploring Engineering*. 2019;8(10):1324–1329. Available from: https://www.ijitee.org/wp-content/uploads/papers/v8i10/I8254078919.pdf.
25) Devindrappa L, Naduvinamani N. Electro kinetic flow of peristalitic transport of Jeffery fluid in a porous channel. *Journal of Information and Computational Science*. 2019;9(9):679–690. Available from: http://www.joics.org/gallery/ics-1285.pdf.
26) Devindrappa L, Naduvinamani NB. Transfer of heat and hall current effects on peristaltic flow of a bingham fluid in a channel by Adomian decomposition method. *International Journal of Emerging Trends in Engineering Research*. 2021;9(3):250–259. Available from: https://doi.org/10.30534/ijeter/2021/17932021.
27) Vaidya H, Rajashekhar C, Divya BB, Manjunatha G, Prasad KV, Animasaun I. Influence of transport properties on the peristaltic MHD Jeffrey fluid flow through a porous asymmetric tapered channel. *Results in Physics*. 2020;28(103295). Available from: https://doi.org/10.1016/j.rinp.2020.103295.
28) Manjunatha G, Rajashekhar C, Vaidya H, Prasad KV. Heat Transfer Analysis on Peristaltic Transport of a Jeffery Fluid in an Inclined Elastic Tube with Porous Walls. *International Journal of Thermofluid Science and Technology*. 2020;7(1):1–17. Available from: https://dx.doi.org/10.36963/ijtst.20070101.
29) Manjunatha G, Rajashekhar C, Vaidya H, Prasad KV, Makinde OD, Viharika JU. Impact of Variable Transport Properties and Slip Effects on MHD Jeffrey Fluid Flow Through Channel. *Arabian Journal for Science and Engineering*. 2020;45(1):417–428. Available from: https://dx.doi.org/10.1007/s13369-019-04266-y.
30) Manjunatha G, Basavarajappa KS, Thippeswamy G, Vaidya H. Peristaltic Transport of Three Layered Viscous Incompressible Fluid. *International Journal of Mechanical and Materials Engineering*. 2013;9(2):93–107. Available from: https://www.researchgate.net/profile/Manjunatha-Gudekote/publication/281269598_Peristaltic_Transport_of_Three_Layered_Viscous_Incompressible_Fluid/links/55dd958508ae83e420ee83e2/Peristaltic-Transport-of-Three-Layered-Viscous-Incompressible-Fluid.pdf.