THE PERISTALTIC FLOW AND THE INFLUENCE OF COMPLIANT WALL CHARACTERISTICS OF AN INCOMPRESSIBLE NEWTONIAN FLUID

Prabal Pratap Singh

Professor & Head, Department of Mathematics, J.S. University, Shikohabad, Uttar Pradesh, India

Guddu Kumar

Research Scholar, Department of Mathematics, J.S. University, Shikohabad, Uttar Pradesh, India

Seema Raghav

Department of Basic Education, Firozabad, Uttar Pradesh, India

Email id of corresponding Author: drppsingh0508@gmail.com

Abstract-

By considering the equations of the deformable barriers and the fluid, this study presents an analytical key for the peristaltic pumping of an incompressible Newtonian fluid through a uniform channel under the effect of compliant wall characteristics. Our focus is on the peristaltic motion of an incompressible Newtonian fluid and how it is affected by compliant wall features. The effects of sinusoidal waves on the channel walls are explored under the long wave length assumption. The necessary boundary value problem is solved by assuming small amplitudes. For different values of amplitude, wave speed, and wavelength as well as mass per unit area of membrane, several flow characteristics, including fluid velocity and mean velocity of interest, are illustrated and analyzed. All numerical work is performed in MATLAB 7.0.

Keywords- peristaltic motion, wall properties, wave speed, amplitude, wavelength

1. Introduction-

It is well-known that peristalsis is a major mechanism for fluid transfer in many different types of organisms. By passing periodic waves of area contraction and expansion over the flexible walls of a tube containing fluid, peristalsis serves as a mechanism for fluid transport. The Greek phrase for this action is peristalsis, which essentially means to clutch and compress. The upper part of the tube is compressed and shortened transversely, and then the tube relaxes, causing the lower part to undergo the same transformation. In physiology, systems are available in a wide assortment of circumstances, including the vehicle of pee from the kidney to the bladder by means of the ureter, the gulping of food through the throat, the development of chyme in the gastrointestinal lot, the vehicle of spermatozoa in the pipes of the male conceptive organ, the vehicle of ovum in the female fallopian tube, the vasomotion of little veins, the movement of spermatozoa in the Siphoning gadgets, for example, finger siphons and roller siphons use peristalsis to move blood, slurries, and burning substances.

The temperature dispersion inside a wavy, bending course was investigated by Ali et al. (2010). Versatile qualities of an adaptable conduit on a Maxwell liquid moving peristaltically were examined by Hina et al. (2012). Mekheimer et al. (2013) have presented the impact of medium porosity and attractive field on a compressible Maxwellian liquid streaming through a miniature channel. The peristaltic stream of non-Newtonian Rabinowitsch fuid across a bended channel was broke down by Maraj and Nadeem (2015). Bhatti et al. (2016) concentrated on the impacts of slip and endoscopic consequences for the peristaltic stream in a sporadic annulus of blood with suspended particles. **Ellahi et al. (2016)** investigated how the properties of the walls affected a pair stress fluid as it flowed peristaltically. Ellis fluid can move over a channel's flexible walls in a peristaltic fashion, as shown by **Abbas et al. (2017)**. The effect of sliding and relaxation time on compressible Maxwellian fluid moving peristaltically in a flexible duct was illustrated by **Eldesoky et al. (2019)**. In an asymmetric conduit with a permeable barrier, **Raza et al. (2020)** investigated the effects of magnetism on water-based nanofluids including nanoparticles of varying shapes. The impacts of peristaltic and electro osmotic powers on the progression of nanofluids in an unevenly little channel were concentrated by Abbasi et al. (2021). Involving the Jeffery liquid model within the sight of hall impacts and gooey dissemination, **Li et al. (2022)** examined the peristaltic movement of non-Newtonian nanofluid.

2. Setting out the Problem-

In our analysis of fluid flow, we have taken into account peristaltic pumping of an incompressible Newtonian fluid in a two-dimensional compliant-wall channel, with the x-axis passing through the centre of the fluid's motion. The channel wall-following flow is generated by a peristaltic wave moving at c. The propagating waves are depicted in Figure 1.

Here is an equation for the form of the wave:

$$y = k = d + b sin \frac{2\pi}{\lambda}(x - ct) \tag{1}$$

In this equation, c represents the wave speed, b the amplitude, λ the peristaltic wave's wavelength, and d the channel's half width.

In this case, the peristaltic motion of the two-dimensional flow of a Newtonian fluid via a uniform symmetric channel is described by the following equations:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2}$$

$$\rho\left[\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right] = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \tag{3}$$

$$\rho\left[\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right] = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \tag{4}$$

where ρ represents the density of the fluid,p is the pressure, μ represents the viscosity coefficient, u

represents the component of velocity in the x direction, and v represents the component of velocity in the y direction.
The equation that describes the stretchy wall motion in its entirety can be written as

$$L(h) = p - p_0 \tag{5}$$

where L is the damping-force-induced motion of a membrane in its inflated state, as determined by the following equation.

$$L = -T\frac{\partial^2}{\partial x^2} + m\frac{\partial^2}{\partial t^2} + C\frac{\partial}{\partial t} \tag{6}$$

m = mass per unit area, T = membrane tension, and C = viscous damping force coefficient.
Following the long-wavelength approximation solution of equations (2)-(4), we obtain

$$-\frac{\partial p}{\partial x} + \mu\frac{\partial^2 u}{\partial y^2} = 0 \tag{7}$$

and $-\frac{\partial p}{\partial y} = 0$ (8)

All that has to be in place on the peripheral to

$u = 0$ at $y = \pm k$ (9)

In this case, we assume that $p_0 = 0$ and the channel walls are inextensible, hence there will be no vertical wall displacement and only horizontal wall displacement, leading to the results in Equations (5) and (7).

$$L(k) = p - p_0 \Rightarrow L(k) = p$$

$\frac{\partial}{\partial x}L(k) = \frac{\partial p}{\partial x} = \mu\frac{\partial^2 u}{\partial y^2}$ at $y = \pm k$ (10)

Similarly, we can get the following from Eq. (7):

$$\frac{\partial}{\partial x}L(k) = \frac{\partial p}{\partial x} = -T\frac{\partial^3 k}{\partial x^3} + m\frac{\partial^3 k}{\partial x\,\partial t^2} + c\frac{\partial^2 k}{\partial x\,\partial t} \tag{11}$$

With (10) and (11) as constraints, we may solve for (8) and (9) to obtain

$$u(y) = \frac{1}{2\mu}\left(\frac{\partial p}{\partial x}\right)(y^2 - k^2) \tag{12}$$

The average speed is written as

$$\bar{u} = \frac{1}{2k}\int_{-k}^{k} u(y)dy \tag{13}$$

Our final result comes from combining Equations (12) and (13), which gives us

$$\bar{u} = -\frac{1}{\mu}\left(\frac{\partial p}{\partial x}\right)\frac{k^2}{3} \tag{14}$$

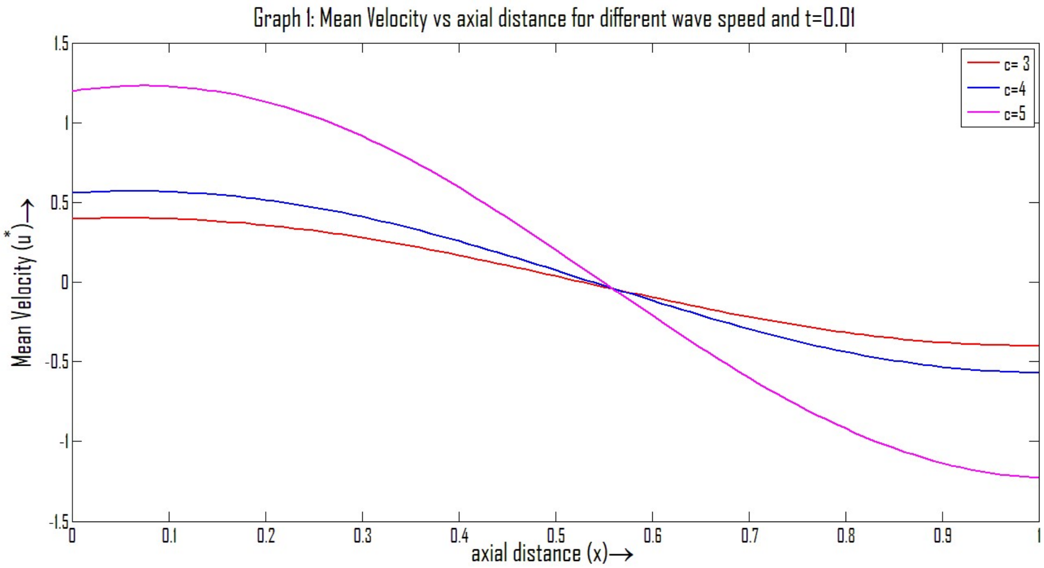
The following equation describes the velocity of a fluid relative to a plane flowing at the average speed of the flow if convection occurs over that plane.

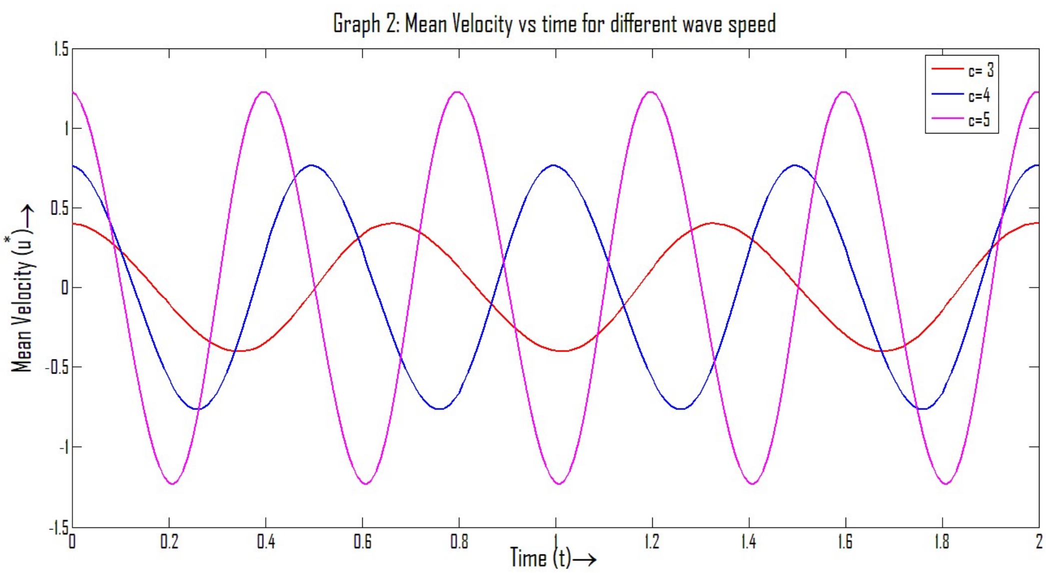
$$u_x = u - \bar{u} \tag{15}$$

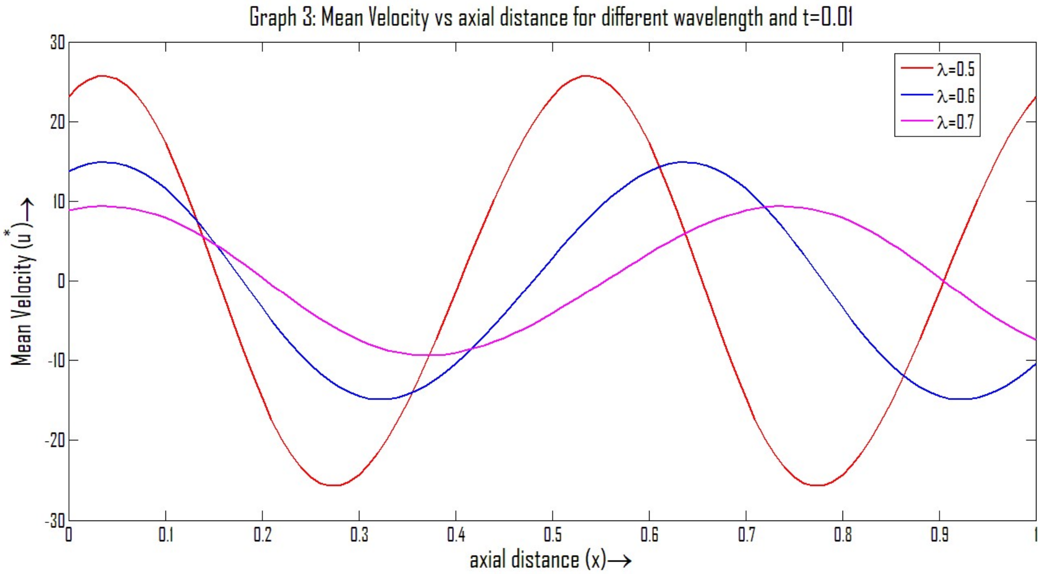
We get the following from Equations (12), (14), and (15)

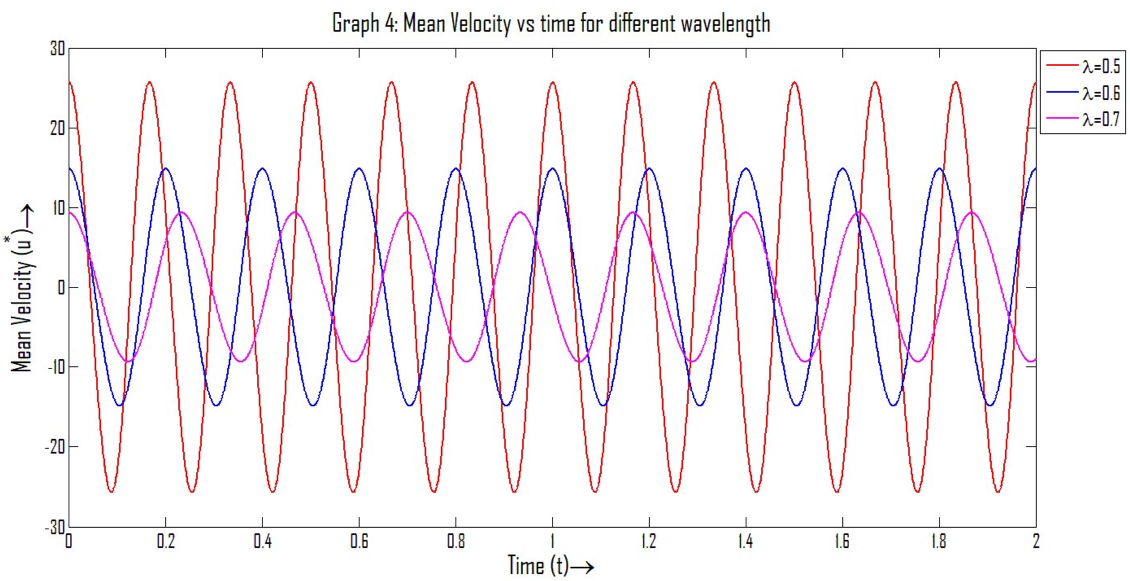
$$u_x = \frac{1}{2\mu}\left(\frac{\partial p}{\partial x}\right)\left(y^2 - \frac{k^2}{3}\right) \tag{16}$$

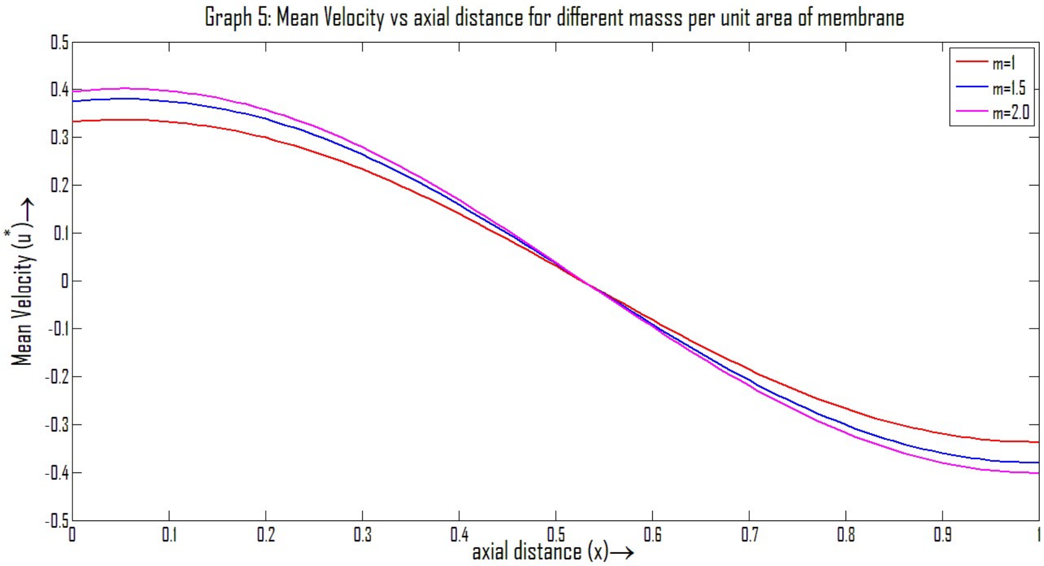
3. The findings and discussion-

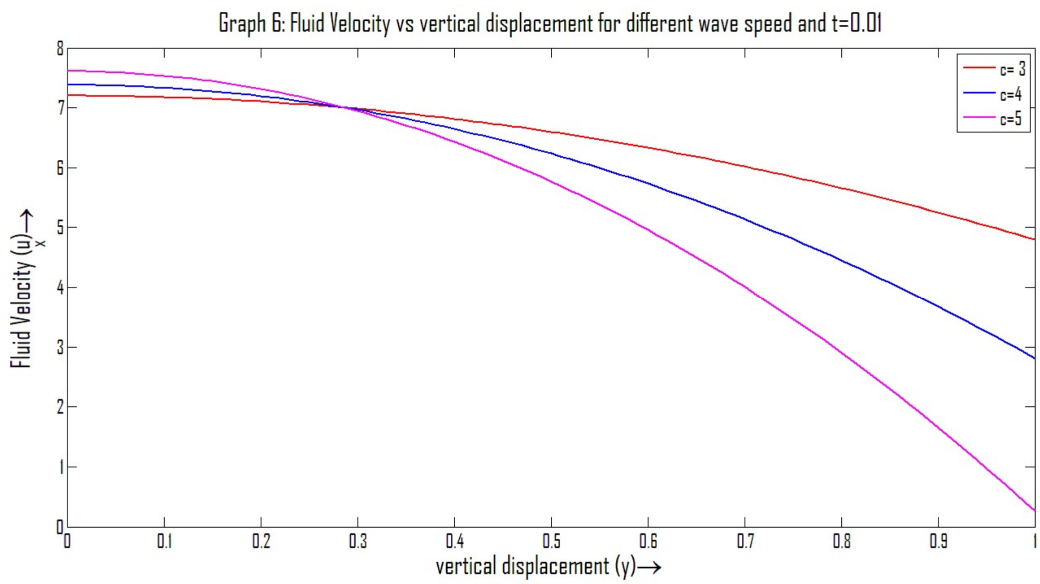


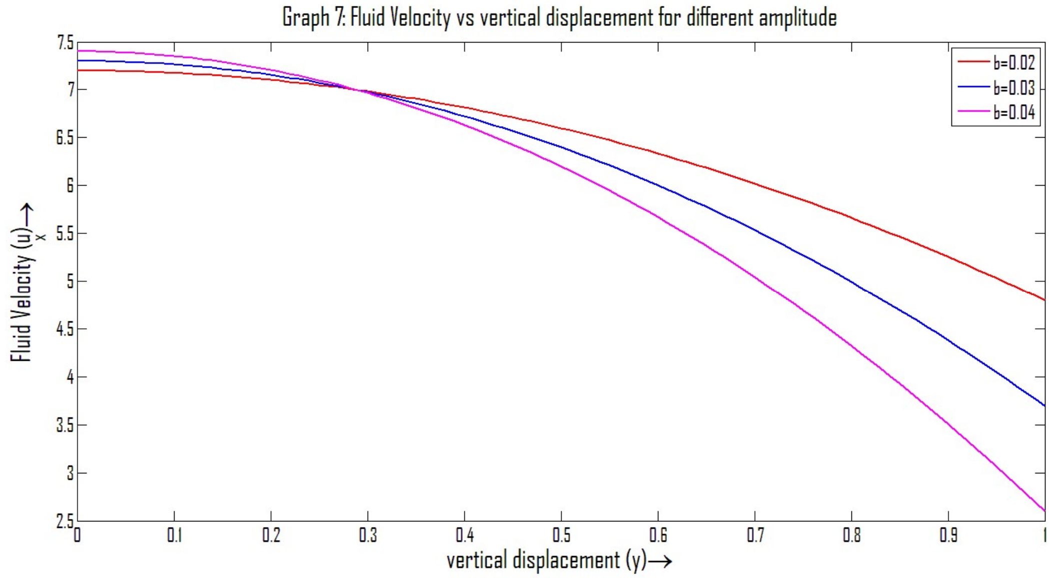


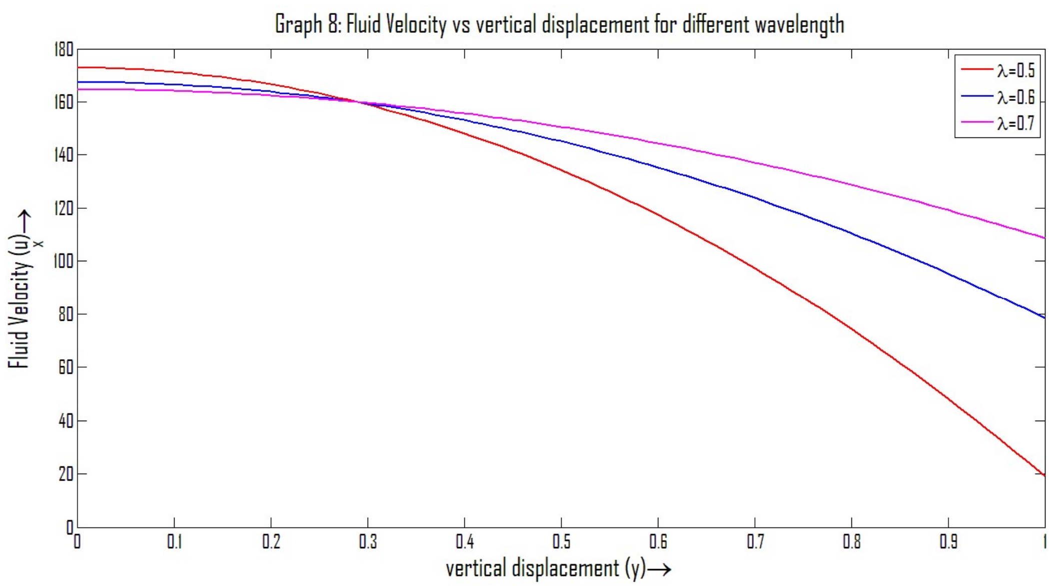

Graph 3: Mean Velocity vs axial distance for different wavelength and t=0.01
Mean Velocity (u*)→
axial distance (x)→
λ=0.5
λ=0.6
λ=0.7

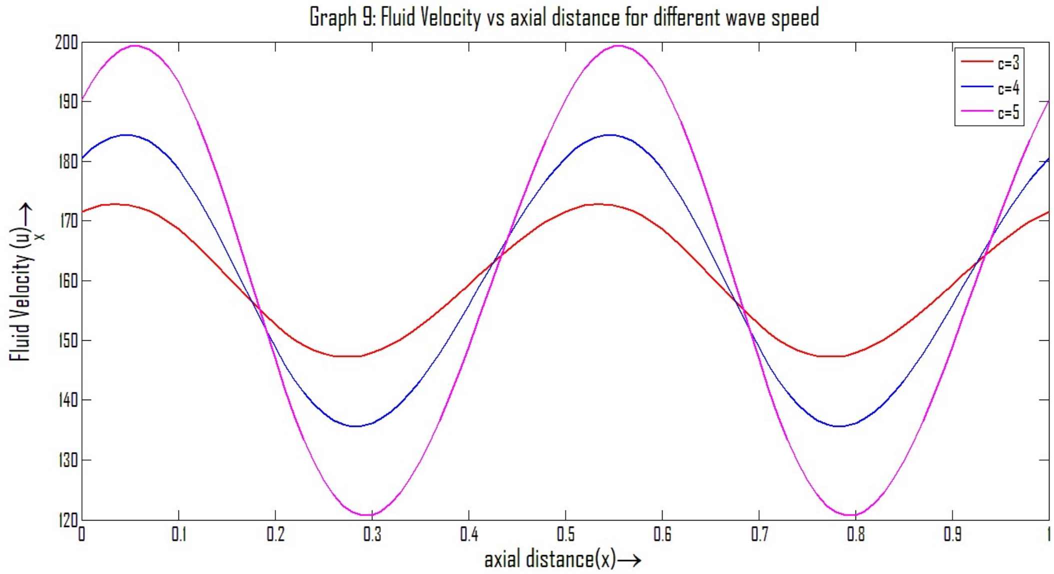

Graph 4: Mean Velocity vs time for different wavelength
Mean Velocity (u*)→
Time (t)→
λ=0.5
λ=0.6
λ=0.7

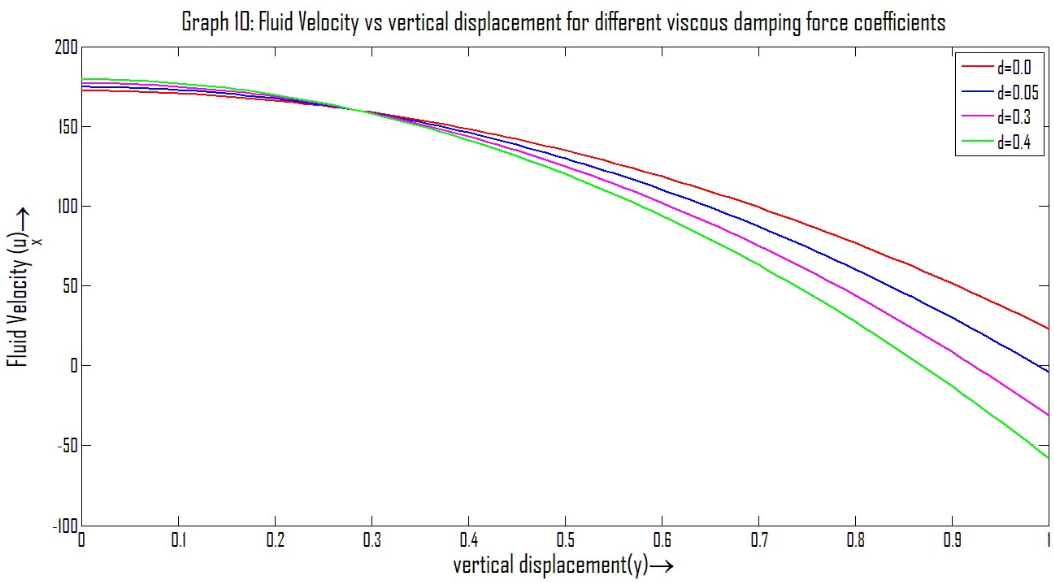

Graph 5: Mean Velocity vs axial distance for different masss per unit area of membrane
m=1
m=1.5
m=2.0
Mean Velocity (u*)→
axial distance (x)→

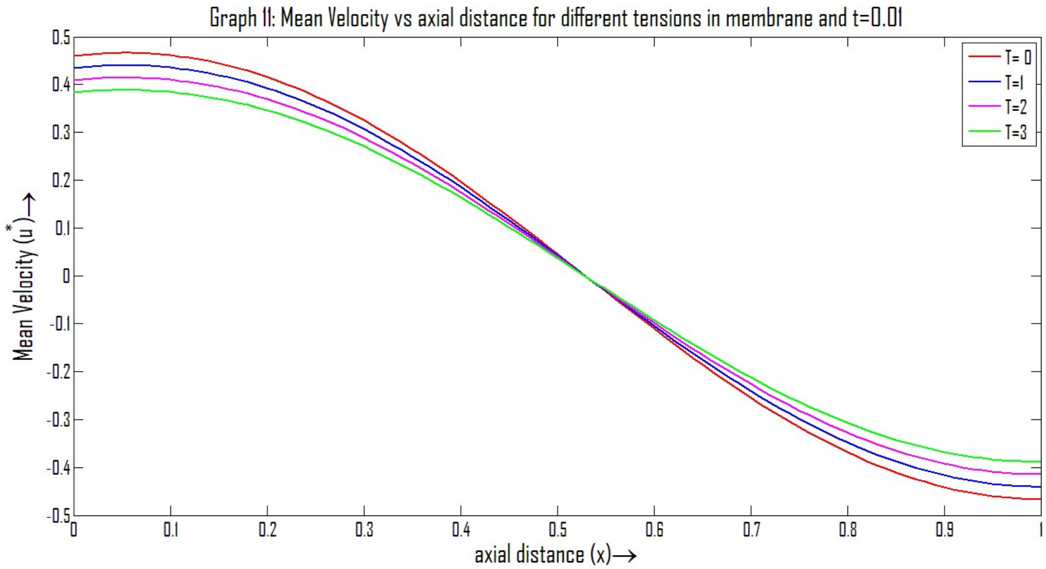

Graph 6: Fluid Velocity vs vertical displacement for different wave speed and t=0.01
c= 3
c=4
c=5
Fluid Velocity (u)x→
vertical displacement (y)→


Graph 7: Fluid Velocity vs vertical displacement for different amplitude
b=0.02
b=0.03
b=0.04
Fluid Velocity (u)x
vertical displacement (y)
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Graph 8: Fluid Velocity vs vertical displacement for different wavelength
λ=0.5
λ=0.6
λ=0.7
Fluid Velocity (u)x
vertical displacement (y)
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Graph 9: Fluid Velocity vs axial distance for different wave speed
c=3
c=4
c=5
Fluid Velocity $(u)_x$ →
axial distance(x) →


Graph 10: Fluid Velocity vs vertical displacement for different viscous damping force coefficients
d=0.0
d=0.05
d=0.3
d=0.4
Fluid Velocity $(u)_x$ →
vertical displacement(y) →



Analytical results produced in the previous section are visualized here. This analysis can be used to learn more about the effects of compliant wall characteristics on the peristaltic motion of an incompressible Newtonian fluid flowing through a uniform channel. The effect of various physical constraints on the flow velocity and average velocity of the fluid is discussed.

Graphs (1)-(5) show the influence of physical variables on the mean velocity of the fluid, including wave speed, wavelength, and membrane mass per unit area. Wave speed and wavelength are shown to be a function of the mean fluid velocity and the axial distance, respectively, in Graphs (1) and (3). By increasing the wave speed, we observe an increase in the average fluid velocity from $x = 0$ to $x = 0.6$ and a reduction from $x = 0.6$ to $x = 1$, while the wavelength decreases.

Graphs (2) and (4) show the average fluid velocity over time as the parameters wave speed and wavelength are scaled up. When the wave speed is increased, the mean velocity curves get taller and adopt a uniform parabolic path across the channel; when the wave speed is decreased; the mean velocity curves show the opposite behavior and likewise adopt a uniform parabolic path across the channel. In the graph (5),The average fluid velocity is seen to rise from $x = 0$ to $x = 0.5$ and fall from $x = 0.5$ to $x = 1$ as the membrane mass density is increased or decreased, respectively.

It can be seen in graphs (6) and (7) that the wave speed and amplitude of the wave both rise as they move from x=0 to x=0.3 and then decrease as they move from x=0.3 to x=1; however, the increase in wavelength exhibits the reverse effect in graph (8).

In the graph (9), It has been observed that the speed of the fluid varies directly with the speed of the waves. This means that if one were to increase the magnitude of the wave speed, the curves representing the speed of the fluid would attain a greater height and adopt a uniform parabolic path throughout the channel.

The coefficient of viscous damping force and membrane tension's influence on fluid and mean velocities at the channel's boundaries are depicted in Graphs (10) and (11), respectively. These plots illustrate that when membrane tension increases, the value of fluid velocity increases from x=0 to x=0.3 and drops from x=0.3 to x=1, whereas mean fluid velocities exhibit an opposite tendency.

4. Concluding Remarks-

This research aims to understand how wall compliance affects the peristaltic motion of a Newtonian fluid that cannot be compressed. We model the fundamental equations and offer the results for the free pumping case here. Previously, we discussed the peristaltic motion of a Newtonian fluid in a uniform channel with wall features. Analytical solution of the governing equations of motion is achieved by using a long wave length approximation. We have studied the impacts of wave speed, wavelength, amplitude of the wave, mass per unit area, tension in the membrane, and viscous damping force coefficient for peristaltic pumping through a uniform channel with compliant wall characteristics.

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