A Review Report on a Two-Phase Peristaltic Flow of Newtonian and Non-Newtonian Fluids

K. Komala[1] M.Mohan Babu[2] and *C.K.Selvi[3]
[1,3]Department of Humanities and Sciences, Sri Venkateswara College of Engineering & Technology, R.V.S.Nagar, Chittoor- 517127, A.P. India.
[2] Department of Civil Engineering, Sri Venkateswara College of Engineering & Technology, R.V.S.Nagar, Chittoor- 517127, A.P. India.
Corresponding Author: *selvisailu@gmail.com

Article Info
Page Number: 1569 - 1576
Publication Issue:
Vol 70 No. 2 (2021)

Abstract

This report is a literature review representing a variety cases of peristaltic transport of two-layered flow patterns. The flows in multi phase models through the channel or tube are significant in modelling bio fluid flow applications. Two-layer flows direct to new instabilities and bifurcations related with deformation of the interface. Many researchers considered the two fluid models in different geometries with various Newtonian and non-Newtonian fluids. The subject of two or multi-phase flow has become more and more important in a broad variety of industrial systems for their optimum design and safe operations. The two phase models has many applications in organic systems such as Cardiovascular system; respiratory system; gastrointestinal tract; blood flow; bronchus flow and nasal cavity flow; capillary transport; body temperature control by perspiration, etc. This paper presents the report on various attempts has been made to understand two layered flow models.

Article History
Article Received*: 05 September 2021*
Revised*: 09 October 2021*
Accepted*: 22 November 2021*
Publication*: 26 December 2021*

Keywords: Two-layered flow, Peristaltic transport, Newtonian fluid, non-Newtonian fluid and Interface.

Definition and Motivation:

Peristalsis is a method of the fluid transport or flow of fluid from a lower pressure region to higher pressure region when a progressive wave of area contraction and expansion travels along the flexible wall of the tube. The force for the transport of the fluid is derived from the wave transmission in the surrounding wall. Some electro-chemical reactions are held responsible for this phenomenon. Fluid flow can be explained as a multi layer flow which one layer flows over another layer to form a different layer. The reason for this layer difference is temperature difference which implies different density. Bio fluid models are considered to discuss the two-phase peristaltic flows

Formation of the problem:

The two-fluid model is formed by considering two sets of equations that represents two regions (peripheral and core) governing the conservation of mass, momentum and energy. The two-fluid model is derived by taking into consideration of each phase separately. The peripheral region and Core region is separated by the interface. There are a various types of two-phase flows based on mixture of two phases as well as on interface structures. In this report we concentrate about the consideration of two Newtonian fluids in both peripheral region and core region. In some of the cases both Newtonian and non-Newtonian fluid models are considered in core and peripheral regions respectively. Peristaltic flow of two phase models has been modelled using long wave length and low Reynolds number approximations. For most two-phase flow problems, the formulation is based on the single-phase flow formulation with explicit moving interfaces encounters insurmountable mathematical and numerical difficulties, and therefore realistic or practical approach is quite difficult. This guide to the need of a macroscopic formulation based on proper averaging which gives a two-phase flow continuum formulation by effectively eliminating the interfacial discontinuities.

Classification of two-phase flows: The two-layer flows can be classified into majorly three types which are separated flows, mixed or transitional flows and dispersed flows. In separated flows we observe the film flow, annular flow and Jet flow. The typical regimes of mixed and transitional flows are turbulent flow, bubbly annular flow, droplet annular flow and bubbly annular droplet flow. Bubbly flow, droplet flow and particulate flow are observed in dispersed flows. In this report we contrite on separated flows in which both core and peripheral regions are separated by interface.

Introduction:

The two very important fluid dynamical phenomena inherent in peristalsis are trapping and reflux. The trapping occurrence was theoretically discovered by Shapiro (1969) that a streamline, under certain conditions splits to enclose a bolus of fluid particles is called tapping. In peristaltic motion the trapped bolus moves as a whole at the peristaltic wave speed as if trapped by the wave. The fluid particles contained the bolus move at a mean speed of advance. A convenient criterion for the presence of a trapped bolus is the existence of stagnation points in the wave frame. This physical phenomenon may be responsible for thrombus formation in blood and movement of food bolus in gastrointestinal tract. The second is reflux. There are two contradicting fundamental definitions from the beginning of the examination in peristaltic motion. There is a region of closed streamlines in the wave frame and thus some fluid is found trapped within a wave of propagation. The trapped fluid mass is found to move with the mean speed equal to that of the wave.

The human organs like ureters, intestine are coated with a fluids of diverse properties from those of the fluid pumped by them. The biofluid has to be treated as Newtonian or non-Newtonian or a combination of a Newtonian and non-Newtonian fluids based on the physiological situation. So extending the single fluid case to two-fluid case the first attempt was made by Shukla et al. (1980) by considering Newtonian fluid with Newtonian peripheral layer. The effects of peripheral - layer viscosity on peristaltic transport of a bio fluid was analyzed and it has been shown that for a given pressure drop, the flux gradually rises and frictional force decreases as the viscosity of the peripheral-layer fluid reduces. Also they have shown that for zero pressure drop, the flux does not depend upon this viscosity and the friction force decrease as it decreases. Shukla and Gupta (1982) deliberated the peristaltic transport of non-Newtonian Power-law fluid through tube by taking in to account the existence of peripheral layer. The effects of variable consistency on the peristaltic flow are discussed. It has been experiential that for non zero pressure drop, the flow rate increases and frictional force reduces as the consistency of peripheral layer fluid decreases.

Peristaltic transport of a two- layered model of physiological fluid was investigated by Srivastava and Srivastava (1982). They considered the peristaltic transport of two-fluid model in a non-uniform tube and channel. By treating the fluid as two-layered model (Peripheral fluid and core fluid), they compared these results with fluid flows without peripheral layer. It has been shown that the magnitude of pressure rise is small in the case of fluid flows with peripheral layer. The comparison of pressure rise in the case of non-uniform and uniform geometries are made.

The Peristaltic motion of blood: Casson model II was investigated by Srivastava and Srivastava (1984) by representing blood as two-layered model consisting the central layer of the suspension of all erythrocytes as a Casson fluid and plasma as a Newtonian fluid in the peripheral layer. They analyzed that the flow is independent of the presence of peripheral layer for zero pressure drop. The pressure rise decreases with the decrease in the viscosity of peripheral layer for given flow rate and the flow rate increases as the viscosity of peripheral layer decreases.

The influence of peripheral layer of diverse viscosity on pumping with Newtonian fluids was studied by Brasseur et al. (1987).The detailed analysis of the effect of the peripheral layer on the fluid motions, the pumping characteristics, and the phenomena of reflux and trapping are presented also shown that for prescribed wall motion, a peripheral layer is additional viscous than the inner fluid and the pumping performance is improved while a less-viscous outer layer degrades performance. The two important phenomenons of trapping and reflux also analysed by this group. The decreasing peripheral-layer viscosity results the overall decrease in trapping. The effects of volume flow rate and pressure head on reflux was discussed. A diminish in reflux with fixed flux and it increases with fixed pressure head.

The blood flow induced by the peristaltic waves in a uniform tube was investigated by Srivastava and Sxena (1995). In this work blood is treated as two fluid model which consists suspension of all erythrocytes as core region supposed to be Casson fluid and peripheral layer of plasma as Newtonian fluid. The equations for pressure drop and frictional force obtained and evaluated numerically. These results were compared with earlier results both analytically and numerically. Ramachandra Rao and Usha (1995) studied the Peristaltic motion of two immiscible viscous fluids in a circular tube with pumping and co pumping ranges. The consequence of peripheral layer viscosity on time averaged flux was analyzed. The important phenomenon of trapping for both core and peripheral layers are studied in detail. The influence of peripheral layer viscosity on the volume of bolus and reflux layer is observed. Also shown that the reflux occurs in entire pumping region for all viscosity ratios but it does not occur in entire co pumping region.

The peristaltic transport of two fluids in an elliptical tube is examined by Usha and Ramachandra Rao (1995). The elliptical cylindrical co ordinate system is used to study the significance of peripheral layer viscosity on the flux and frictional force. The two different amplitude ratios are defined due to the non uniformity of peristaltic wave. The time averaged flux and mechanical efficiency are studied for different eccentricities. It has been observed that for large eccentricity, the time averaged flux is not affected significantly by the pressure drop.

Usha and Ramachandra Rao (1997) given detail explanation of the Peristaltic motion of two layered Power-law fluids in an axisymmetric tube. Power-law fluid is taken due to independent choice of shear thinning or shear thickening. The interface between two- layer is determined. The variation of time mean flow with pressure rise or drop was discussed. It has been noticed that always sinusoidal wave yields the positive mean flow for power-law fluids. It is explained that the bolus volume decreases with higher shear thinning rate of core and peripheral layer fluids.

The analytic study of Peristaltic transport of non-Newtonian fluid with peripheral layer under long wavelength assumption was made by Mishra and Pandey(1999) The shape of interface between core layer and peripheral layer is obtained from the expression of stream function. It has been noticed that the flow rate of physiological Power-law fluids is less than that of Newtonian fluids under identical conditions. The viscosity of peripheral layer is responsible for increase flow rate. These results were analyzed and compared with those of Brasseur et al. (1987).

Mishra and Pandey (2002) studied the peristaltic transport of blood through small vessels by treating the blood as a two-layered model where core region is described by Casson model and peripheral region as a Newtonian viscous fluid. The influence of peripheral layer viscosity and yield stress on flow rate are discussed. It has been observed that the flux in case of a single layer is more when compared to two-layer case also flow rate increases with increasing viscosity of peripheral layer. The shape of interface is not affected when the viscosity of one of the two layers is varied with respect to other. These results are in contrast results obtained by Srivastava and Srivastava (1984). These results revealed that the flux is maximum when the two-layers have the same viscosity and the flow rate is enhanced in the absence of plug-flow region.

The study of Peristaltic flow in a two dimensional channel with a porus medium in the peripheral region and a Newtonian fluid in core region was made by Mishra and Ramachandra Rao (2005).the peristaltic transport in a two dimensional channel, with a porus medium in the peripheral layer and an incompressible Newtonian fluid in the core region. Flow quantities such as pumping, trapping, reflux and axial velocity are discussed for various parameters and these results were analyzed and compared with the results of Brasseur et al.(1987). It is observed that peristalsis works as a pump against greater pressure in two-layered model with a porus medium when compared with a viscous fluid in the peripheral layer.

Peristaltic flow of a Herschel-Bulkley fluid in contact with a Newtonian fluid in a channel is investigated by Vajravelu et al. (2006). Blood is considered as a Herschel – Bulkley fluid. The velocity, stream function and equation for interface is obtained. The results are analysed and compared with the results of Brasseur et al. (1987) when the yield stress is zero and index is one.

The flow of a Casson fluid in contact with Newtonian fluid in a circular pipe with permeable walls was investigated by Vajravelu et al. (2009). Casson and Newtonian fluids of different viscosities are considered in the core and peripheral regions respectively in a circular tube with permeable wall. The velocity field, stream function and pressure rise are discussed. The equation of interface is obtained and the effects yield stress and permeability parameter on the interface is analyzed. It is noticed that the smaller values of permeability parameter results the thinner peripheral layer in the dilated region. Peristaltic flow of a Bingham fluid in contact with Newtonian fluid is investigated by Narahari et al. (2010). The effects of yield stress and peripheral viscosity on time averaged flux are discussed. The shape of interface deduced and effects of yield stress viscosity ration on the interface are analyzed and compared the results with that of Brasseur et al. (1987).

Sreenadh et al. (2011) studied the flow of two immiscible Jeffrey fluids in an inclined circular tube. Two immiscible and incompressible Jeffrey fluids of different viscosities are and taken in core and peripheral layers in a circular tube. The effect of Jeffrey parameter on flow velocity and the shape of interface for different amplitude ratios are analyzed. These results were compared with that of Ramachandra Rao and Usha (1995).

Medhavi and Singh (2012) investigated the theoretical model to the flow of two-layered Newtonian fluid induced by peristaltic waves in catheterized tube. The various physical parameters of flow such as flow rate, pressure drop and the friction forces in the tube and catheter wall are derived. The significance of peripheral layer viscosity on the shape of interface is analyzed and compared the results with the results obtained by Mishra and Pandey (2002).It has been noticed that the pressure drop increases with catheter size and decreases with increasing peripheral layer thickness.

Arun kumar et al. (2013) examined the peristaltic pumping of two immiscible fluids with magnetic effect in a two dimensional channel. In this work Bingham fluid is taken in the core region and Newtonian fluid in the Peripheral region. The various flow quantities and the shape of interface of two fluids is obtained. The stream lines for different values of yield stress parameter are studied. It has been observed that the lower values of Hartmann number and yield stress results thicker peripheral layer. The peristaltic transport of two immiscible Power law fluids in a circular tube with permeable walls is investigated by Sreenadh et al. (2013). The influence of various parameters on velocity profiles and shape of interface of different amplitude ratios are discussed. The variations of velocity with radius for various values of Darcy numbers are observed and it increases with increasing power law index.

Peristaltic flow of a Bingham fluid in contact with a Newtonian fluid in an inclined channel with long wavelength approximation is studied by Prabakaran et. al. (2013).The variation of pumping characteristics due to the angle of inclination is discussed. The equation of interface is obtained and effect of yield stress on interface is analyzed. The peristaltic motion of a Herschel-Bulkley fluid in contact with a Newtonian fluid through circular tube is investigated by Narayana et al. (2014). The influence of various parameters on the velocity, interface and pressure rise are observed. It is noticed that the increase in viscosity ratio results increase in velocity also the influence of amplitude ratio is more on peripheral region. The shape of interface for different amplitude ratios are discussed and high amplitude ratio is responsible for thicker core layer.

Kavitha et al. (2015) studied the peristaltic flow of a Jeffrey fluid in contact with a Newtonian fluid in an inclined symmetric channel. The velocity field, stream function, pressure rise and frictional force for different values of parameters are discussed. The effect Jeffrey parameter on the shape of interface is discussed also it is observed that the increasing Jeffrey fluid parameter results the thinner peripheral region and thicker peripheral layer for low viscosity ratios.

Sreenadh et al. (2015) studied the peristaltic transport of a Power-law fluid in contact with a Jeffrey fluid in an inclined channel. Power-law fluid is considered in the core region and Jeffrey fluid in the peripheral region. The effects of permeability parameter on core layer and Jeffrey fluid parameter on pressure rise are discussed. The shape of interface between two fluids is obtained. These results are analysed and reduced to the case two immiscible Newtonian fluids in the absence of Jeffrey fluid parameter. It has been noticed that the increase in the permeability parameter increases the thickness of core layer.

Peristaltic Transport of two-layered blood flow Herschel-Bulkley Model is studied by Rajasekhar et al. (2018). Influence of heat and mass transfer on two-phase blood flow with joule heating and variable viscosity in the presence of variable magnetic field is presented by Tripathi and Sharma (2020). Theoretical analysis of two-layered electro-osmotic peristaltic flow of FENE-P fluid in an axisymmetric tube is explained by Ali et al. (2020). Flow of two immiscible non-Newtonian fluids in an elastic tube is discussed by Sreenadh et al. (2022). Recently Rusi kaesava and Srinivas (2022) studied Exploration of peristaltic pumping of Casson fluid flow through a porous peripheral layer in a channel.

Applications:

As we have many physiological applications for peristaltic transport, it is interesting to represent the peristaltic surge of bio fluids which are originating from inside the living bodies such as blood, urine, chyme, saliva, sweat, tears and bile etc. Most of the physiological fluids like intracellular fluids and extracellular fluids are the combination two or more fluids. The Multi-phase flow is also noticed in nature and technology like energy conversion, paper manufacturing, food manufacturing etc. Multi phase flow gives rise to very complex combinations and different flow structures. The simple case of multi phase flow is two phase flow. This can be classified in to transient flows or dispersed flows or separated flows. When modelling the two-layered flow the phenomenon, effects and flow structures are important. The very important phenomenon is the interface connecting the two-layered flows. The boundary between two fluids in case of dispersed flows is hard to track when compared to the separated flows. The study of the peristaltic transport of two layered fluids has its own importance in understanding the flow of the physiological fluids since the blood may be approximated through two-layered model as the suspension of all erythrocytes in the core region and plasma in the peripheral region.

In mathematical modeling of biological systems, the flow geometries plays key role. The mathematical modeling of such systems is the fundamental to design the various medical devices. This modeling definitely helpful in the design of artificial pumps, ventricular assists devices, artificial arteries, mechanical ventilators etc. The broad applicability of this two layer flows can lead to substantial benefits for a variety of industries and technologies. For instance, oil and nuclear energy companies will benefit from a better understanding of interfacial disturbances in two-phase pipe flows, leading to more efficient power plant and pipeline operations. Gas turbine and engine manufacturers will also benefit from more efficient simulations of liquid jets and the atomization process, eventually leading to better engine performance. Two immiscible fluids flows are also incorporated in Geophysics, Plasma physics and, petroleum industry. Two fluid flow is also present in other applications like steam generator, refrigeration, condenser, blood flow, spray casting air and mudflow.

Conclusions and future outlook:

The brief survey given in this paper reviews a variety of two-phase flow concepts, key parameters affecting peristaltic motion. The peristalsis concept was explained in depth. Various parameters that substantially impact the velocity, flux, pressure rise, and shape of interface were discussed. The characteristics of different non-Newtonian fluids were presented. The peripheral and core region classification are discussed. These reports on two-layered peristaltic flow characteristics reveal many interesting behaviours that warrant further study on the multi-phase flows of Newtonian non-Newtonian fluid phenomenon in different geometries.

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