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Study of transient peristaltic heat flow through a finite porous channel

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ABSTRACT

Analytical and computational studies on transient peristaltic heat flow through a finite length porous channel are presented in this paper. Results for the temperature field, axial velocity, transverse velocity, pressure gradient, local wall shear stress, volume flow rate, averaged volume flow, mechanical efficiency, and stream function are obtained under the assumption of low Reynolds number (Re $\to$ 0) and long wavelength approximation ($a \ll \lambda \to \infty$). The current two-dimensional analysis is applicable in biofluid mechanics, industrial fluid mechanics, and some of the engineering fields. The impact of physical parameters such as permeability parameter, Grashof number and thermal conductivity on the velocity field, pressure distribution, local wall shear stress, mechanical efficiency of peristaltic pump, and two inherent phenomena (reflux and trapping) are depicted with the help of computational results. The main conclusions that can be drawn out of this study is that peristaltic heat flow resists more porous medium whereas the peristaltic heat flow improves with increasing magnitude of Grashof number, and thermal conductivity. The results of Tripathi (2012) [42] can be obtained by taking out the effects of porosity from this model.

1. Introduction

A variety of complex rheological fluids can easily be transported from one place to another place with a special type of pumping known as Peristaltic pumping. This pumping principle is called peristalsis. The mechanism includes involuntary periodic contraction followed by relaxation or expansion of the ducts the fluids move through. This leads to the rise of pressure gradient that eventually pushes the fluid forward. This type of pumping is first observed in physiology where the food moves in the digestive tract, urine transports from the kidney to the bladder through ureters, semen movement in the vas deferens, movement of lymphatic fluids in lymphatic vessels, bile flow from the gall bladder into the duodenum, spermatozoa in the ductus efferentes of the male reproductive tract and cervical canal, ovum moves in the fallopian tube, and blood circulation in small blood vessels. Historically, however, the engineering analysis of peristalsis was initiated much later than physiological studies. Applications in industrial fluid mechanics are like aggressive chemicals, high solids slurries, noxious fluid (nuclear industries) and other materials which are transported by peristaltic pumps. Roller pumps, hose pumps, tube pumps, finger pumps, heart-lung machines, blood pump machines, and dialysis machines are engineered on the basis of peristalsis. Owing to the importance of peristaltic flow, some significant investigations [1–14] on peristaltic flow have recently been reported. Takagi and Balmforth [1,2] discussed the peristaltic pumping with a rigid object and viscous fluids in an elastic tube. Chiu-On and Ye [3] introduced the Lagrangian approach for peristaltic pumping and Dudchenko and Guria [4] studied the self-sustained peristaltic waves. Beg and Tripathi [5] investigated the peristaltic flow of nanofluids with double-diffusive convection. Tripathi [6–10] reported the applications of fractional calculus in peristaltic pumping and Tripathi [11,12] studied the blood flow model with couple stress fluids through the porous medium with and without slip

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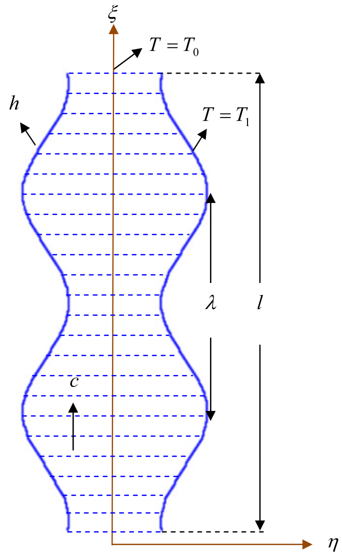

Fig. 1. Geometry of peristaltic flow pattern through finite porous channel.

effect. Tripathi [13] and Pandey et al. [14] presented the three layered peristaltic flow for viscous fluids and power law fluids respectively. They pointed out the effects of viscosities of core, intermediate and peripheral layers on peristaltic flow pattern.

Khaled and Vafai [15] presented an interesting review article *the role of porous media in modeling flow and heat transfer in biological tissues*. They concluded that models for convective transport through porous media are widely applicable in the production of the osteoinductive material, simulation of blood flow of tumors and muscles, and in modeling blood flow, when fatty plaques of cholesterol and artery-clogging clots are formed in the lumen, transport of drugs, and nutrients to brain cells. In the same line Narasimhan [16] wrote another review article on the role of porous medium in bio-thermo-fluids mechanics. He studied the two broad categories of bio-mass and bio-heat transport of human physiology and discussed the application in LDL transport in arteries, drug delivery, drug eluting stents, functions of organs modeled as porous medium, and porous medium modeling of microbial transport.

A porous medium (which contains a number of small holes distributed throughout the matter) plays a key role in the study of transport process in bio-fluid mechanics, industrial mechanics, and engineering fields. A good example of peristalsis in a porous medium is focused in intestinal fluid dynamics by Miyamoto et al. [17] and Jeffrey et al. [18]. Miyamoto et al. [17] studied the two-dimensional laminar flow in a circular porous tube and considered a small water absorption or secretion in the intestinal perfusion experiment whereas Jeffrey et al. [18] discussed the flow fields generated by peristaltic reflex in isolated guinea pig ileum. Elshehawey et al. [19] developed another model for peristaltic transport through an asymmetric porous channel and focused the application to intra uterine fluid motion in a sagittal cross-section of the uterus. Some authors [20–23] studied peristaltic flow of Newtonian fluid and non-Newtonian fluids such as power law fluid, magneto fluid and Maxwell fluid through the porous medium. They discussed the effect of permeability parameter on pressure and friction force across one wavelength through channel, asymmetric channel and tube.

The discipline of heat transfer is concerned with only two things: temperature, and the flow of heat. Temperature represents the amount of thermal energy available, whereas heat flow represents the movement of thermal energy from one place to another. A heat transfer mechanism can be grouped into three broad categories: conduction, convection, and radiation. In view of the wide range of applications of the heat transfer effect in peristaltic flow pattern, Vajravelu et al. [24] reported the peristaltic transport and heat transfer through vertical porous annulus. Srinivas and Kothandapani [25] studied the effect of heat transfer on peristaltic transport in an asymmetric channel. Hayat et al. [26] investigated the peristaltic flow with heat transfer in porous space. Nadeem et al. [27] incorporated the MHD fluids with variable viscosity and discussed the effect of heat transfer on peristaltic flow. Akbar and Nadeem [28] modeled for blood flow through a tapered artery with a stenosis by the heat transfer simulation of non-Newtonian fluids with the Reiner–Rivlin model. Tripathi and Beg [29] reported the influence of heat transfer on unsteady physiological magneto-fluid flow.

None of the above studies deals with the unsteady peristaltic flow through the finite length porous channel/tube. While from an application's point of view, it is needed to study the time dependent flow through the bounded geometries (length of the channel is finite) of a flow pattern. Considering these facts, Li and Brasseur [30] presented a model for unsteady peristaltic transport of incompressible Newtonian fluid through the finite length tube. They compared their results with experimental results (intrabolus pressure during oesophageal peristaltic transport by using a manometer) and found good agreement with manometric observations. Since the physical property of food bolus is not only of Newtonian character, this study does not cover non-Newtonian behavior of food bolus. Subsequently, Misra and Pandey [31], Tripathi et al. [32], Pandey and Tripathi [33–38] and Tripathi [39–41] have improved Li and Brasseur's model for non-Newtonian fluids such as