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Peristaltic transport in an asymmetric channel with heat transfer — A note☆

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Abstract

The problem of heat transfer for the motion of a viscous incompressible fluid induced by travelling sinusoidal waves has been analytically investigated for a two-dimensional asymmetrical channel. The channel asymmetry is produced by choosing the peristaltic wave train on the walls to have different amplitudes and phase. The flow is investigated in a wave frame of reference moving with the velocity of the wave. The momentum and energy equations have been linearized under long-wavelength and low-Reynolds number assumptions and closed form expressions for temperature and coefficient of heat transfer have been derived. The effect of Hartmann number, Eckert number, width of the channel and phase angle on temperature and coefficient of heat transfer are discussed numerically and explained graphically.

Keywords: Peristaltic transport; Asymmetric channel; Hartmann number; Heat transfer coefficient

1. Introduction

The word peristalsis stems from the Greek work peristalikos, which means clasping and compressing. It is used to describe a progressive wave of contraction along a channel or tube whose cross-sectional area consequently varies. In physiology, it has been found to be involved in many biological organs, e.g., in transport of spermatozoa in the ductus efferentes of the male reproductive tracts and in the cervical canal, in the movement of ovum in the fallopian tubes and in the vasomotion of small blood vessels as well as blood flow in arteries. Some worms use peristalsis as a means of locomotion. Roller and finger pumps using viscous fluids also operate on this principle. The mechanism of peristaltic transport has been exploited for industrial applications like sanitary fluid transport, blood pumps in heart lung machine and transport of corrosive fluids where the contact of the fluid with the machinery parts is prohibited. Since the first investigation of Latham [1], a number of analytical, numerical and experimental [2–15] studies of peristaltic flows of different fluids have been reported under different conditions with reference to physiological and mechanical situations. Eytan and Elad [10] have presented a mathematical model of wall-induced peristaltic fluid flow in a two-dimensional channel with wave trains having a phase difference moving independently on the upper and lower walls to simulate intra-uterine fluid motion in a

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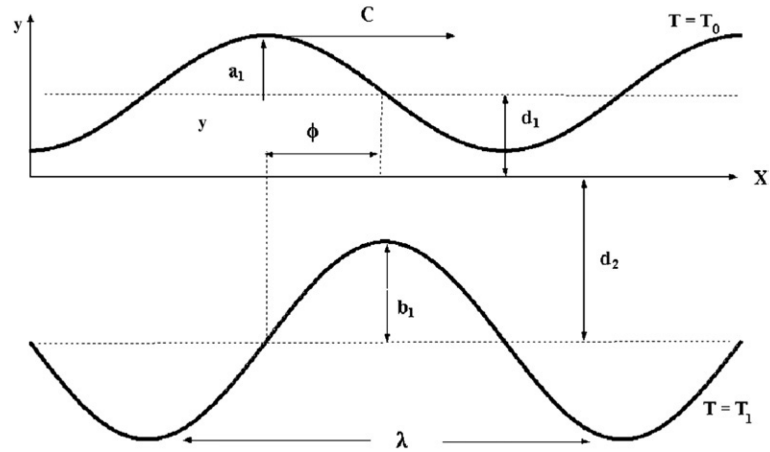

Fig. 1. Flow geometry.

sagittal cross-section of the uterus. They have obtained a time dependent flow solution in a fixed frame by using lubrication approach. Recently, Haroun [12] studied the effect of wall compliance on peristaltic transport of a Newtonian fluid in an asymmetric channel. Srinivas and Pushparaj [16] have investigated the peristaltic pumping of MHD gravity flow of a viscous incompressible fluid in a two-dimensional asymmetric inclined channel. The literature on the peristaltic transport is now quite extensive and several investigations have already been reported on peristaltic flow, which involve Newtonian and non-Newtonian fluids. However, the interaction between peristalsis and heat transfer has not received much attention. Thermodynamic aspects of blood become significant in processes like oxygenation and hemodialysis [14,15].

In the present note, a mathematical model is presented to understand the interaction between peristalsis and heat transfer for the motion of a viscous incompressible fluid in a two-dimensional asymmetric channel. The momentum and energy equations have been linearized under long-wavelength and low-Reynolds number assumptions and analytical solutions for the flow variables have been obtained.

2. Mathematical formulation and solution

We consider the motion of an incompressible viscous fluid in a two-dimensional channel (see Fig. 1) induced by sinusoidal wave trains propagating with constant speed c along the channel walls

$$Y = H_1 = d_1 + a_1 \cos \frac{2\pi}{\lambda}(X - ct) \qquad \ldots \text{ upper wall,}$$

$$Y = H_2 = -d_2 - b_1 \cos\left(\frac{2\pi}{\lambda}(X - ct) + \phi\right) \qquad \ldots \text{ lower wall,} \tag{1}$$

where a_1,b_1 are the amplitudes of the waves, λ is the wave length, d_1+d_2 is the width of the channel, the phase difference ϕ varies in the range $0 \le \phi \le \pi$, $\phi=0$ corresponds to symmetric channel with waves out of phase and $\phi=\pi$ the waves are in phase, and further a_1, b_1, d_1, d_2 and ϕ satisfies the condition

$$a_1^2 + b_1^2 + 2a_1 b_1 \cos\phi \le (d_1 + d_2)^2. \tag{2}$$

Upper wall is maintained at temperature T_0 and Lower wall at T_1.

3. Equations of motion

$$\rho\left[\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y}\right] = -\frac{\partial p}{\partial X} + \mu\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right) - \sigma B_0^2 U \tag{3}$$

$$\rho\left[\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y}\right] = -\frac{\partial p}{\partial Y} + \mu\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) \tag{4}$$