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Entropy generation and energy conversion rate for the peristaltic flow in a tube with magnetic field

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ABSTRACT

Impact of entropy generation for the peristaltic flow in a tube is investigated. The entropy generation number due to heat transfer and fluid friction is formulated. The velocity and temperature distributions across the tube are presented along with pressure attributes. Exact analytical solution for velocity and temperature profile is obtained. Velocity, temperature, pressure gradient, pressure rise, Bejan number and streamlines are presented for radius of the tube a, Hartmann number M, amplitude ratio ε, Brinkman number B_r and flow Q presented graphically. It is found that the entropy generation number attains high values in the region close to the walls of the tube, while it gains low values near the center of the tube.

1. Introduction

Heat Transfer and fluid flow processes are inherently irreversible, which leads to an increase in entropy generation and thus, destruction of useful energy. The optimal second law design criteria depend on the minimization of entropy generation encountered in fluid flow and heat transfer processes. Bejan [1] showed that entropy generation in convective fluid flow is due to heat transfer and viscous shear stresses. Numerical studies on the entropy generation in convective heat transfer problems were carried out by different researchers. Drost and White [2] developed a numerical solution procedure for predicting local entropy generation for a fluid impinging on a heated wall. Further detail analysis on entropy is presented by Benedetti and Sciubba [3] they presented numerical calculation of the local rate of entropy generation in the flow around a heated finned tube. Abu-Hijleh et al. [4] studied numerical prediction of entropy generation due to natural convection from a horizontal cylinder. In another article numerical prediction of entropy generation in separated flows is discussed by Abu-Nada [5]. Slip law effects on heat transfer and entropy generation of pressure driven flow of a power law fluid in a microchannel under uniform heat flux boundary condition is presented by Anand [6]. Guelpa et al. [7] discussed entropy generation analysis for the design improvement of a latent heat storage system. They show that the improved system allows to reduce PCM solidification time and increase second law efficiency. Second law analysis of heat transfer in laminar flow for hexagonal cross-section duct was analyzed analytically Oztop et al. [8]. An analysis of entropy generation through circular duct with different shaped longitudinal fins of laminar flow is discussed by Dagtekin et al. [9]. Further analysis on entropy generation can be seen through Refs. [10–13].

Peristalsis is a radially symmetrical contraction and relaxation of muscles which propagates in a wave down a muscular tube, in an anterograde fashion. Peristalsis is often found in the contraction of smooth muscle tissue to propel food/chyme through a digestive tract, such as the human gastrointestinal tract, after the pioneer work done by Latham [14], this mechanism become an interesting topic for the researchers, A new numerical solution for the MHD peristaltic flow of a bio-fluid with variable viscosity in a circular cylindrical tube via Adomian decomposition method is presented by Ebaid [15]. Nadeem and Akbar [16] discussed influence of heat and chemical reactions on the peristaltic flow of a Johnson Segalman fluid in a vertical asymmetric channel with induced MHD. Akbar and Nadeem [17] discussed convective heat transfer of a Sutterby fluid in an inclined asymmetric channel with partial slip. Ellahi et al. [18]. studied series solutions of Magnetohydrodynamic peristaltic flow of a Jeffrey fluid in eccentric cylinders. Maraj et al. [19] analyze biological analysis of Jeffrey nano fluid in a curved channel with heat dissipation. Very recently Akbar [20] studied peristaltic flow of Tangent Hyperbolic fluid with convective

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Nomenclature

a	radius of the tube
b	amplitude of the sinusoidal wave
c	wave speed
λ	wavelength
u	velocity in the r direction
w	velocity in the z direction
ρ	density
μ	viscosity
c_p	specific heat
θ	temperature
k	thermal conductivity of the fluid
B_r	Brinkmann number
M	Hartmann number
P	pressure
ε	amplitude ratio
B_0	applied magnetic field
Pr	Prandtl number
Ec	Eckert number

boundary condition. Further recent literature related to the topic includes Refs. [17,21–29].

The entropy generation for the peristaltic flow is not discussed so far up to yet, to fill this gap entropy generation for the peristaltic flow in a tube is investigated in the present article. The entropy generation number due to heat transfer and fluid friction is formulated. The velocity and temperature distributions across the tube are presented along with pressure attributes. Exact analytical solution for velocity and temperature profile is obtained. It is found that the entropy generation number attains high values in the region close to the walls of the tube, while it gains low values near the center of the tube.

2. Problem formulation

Let us consider the peristaltic flow of an incompressible, natural convective peristaltic flow of in a horizontal uniform tube (walls of the tube are smooth i.e. radius of the tube is same in all section of the tube). Sinusoidal wave is propagating along the walls of the tube. We choose a cylindrical coordinate system $(\overline{R}, \overline{Z})$, where $\overline{Z}$-axis lies along the center line of the tubes and $\overline{R}-$ axis is normal to it. Wave is propagating with a velocity c along the wall of the tube. Keeping in view the analysis geometry of the wall surface is defined as

$$\overline{h}= a+b\sin\frac{2\pi}{\lambda}(\overline{Z}-c\overline{t}), \tag{1}$$

In the fixed coordinates system $(\overline{R}, \overline{Z})$, flow between the two tubes is unsteady. It becomes steady in a wave frame $(\overline{r}, \overline{z})$ moving with the same speed as the wave moves in the $\overline{Z}-$ direction. The transformations between the two frames are:

$$\overline{r}=\overline{R}, \overline{z}=\overline{Z}-c\overline{t}, \overline{v}=\overline{V}, \overline{w}=\overline{W}-c, \overline{p}(\overline{z},\overline{r},\overline{t})=\overline{p}(\overline{Z},\overline{R},\overline{t}) \tag{2}$$

The governing equations for the flow of an incompressible fluid can be written as:

$$\frac{1}{\overline{r}}\frac{\partial(\overline{r}\overline{u})}{\partial\overline{r}}+\frac{\partial\overline{w}}{\partial\overline{z}}=0, \tag{3}$$

$$\begin{aligned}\rho\left[\overline{u}\frac{\partial\overline{u}}{\partial\overline{r}}+\overline{w}\frac{\partial\overline{u}}{\partial\overline{r}}\right]&=-\frac{\partial\overline{p}}{\partial\overline{r}}+\mu\frac{\partial}{\partial\overline{r}}\left[2\frac{\partial\overline{u}}{\partial\overline{r}}\right]+\mu\frac{2}{\overline{r}}\left(\frac{\partial\overline{u}}{\partial\overline{r}}-\frac{\overline{u}}{\overline{r}}\right)\\&\quad+\mu\frac{\partial}{\partial\overline{z}}\left[\left(\frac{\partial\overline{u}}{\partial\overline{r}}+\frac{\partial\overline{w}}{\partial\overline{z}}\right)\right],\end{aligned} \tag{4}$$

$$\begin{aligned}\rho\left[\overline{u}\frac{\partial\overline{w}}{\partial\overline{r}}+\overline{w}\frac{\partial\overline{w}}{\partial\overline{z}}\right]&=-\frac{\partial\overline{p}}{\partial\overline{z}}+\mu\frac{\partial}{\partial\overline{z}}\left[2\frac{\partial\overline{w}}{\partial\overline{z}}\right]+\mu\frac{1}{\overline{r}}\frac{\partial}{\partial\overline{r}}\left[\overline{r}\left(\frac{\partial\overline{u}}{\partial\overline{z}}+\frac{\partial\overline{w}}{\partial\overline{r}}\right)\right]\\&\quad-\sigma B_0^2(\overline{w}+c),\end{aligned} \tag{5}$$

$$\begin{aligned}(\rho c_p)\left(v\frac{\partial\overline{T}}{\partial\overline{r}}+w\frac{\partial\overline{T}}{\partial\overline{z}}\right)&=k\left[\frac{\partial^2\overline{T}}{\partial\overline{r}^2}+\frac{1}{\overline{r}}\frac{\partial\overline{T}}{\partial\overline{r}}+\frac{\partial^2\overline{T}}{\partial\overline{z}^2}\right]\\&\quad+\mu\left(2\left(\left(\frac{\partial\overline{u}}{\partial\overline{z}}\right)^2+\left(\frac{\partial\overline{w}}{\partial\overline{r}}\right)^2\right)+\left(\frac{\partial\overline{u}}{\partial\overline{r}}+\frac{\partial\overline{w}}{\partial\overline{z}}\right)^2\right).\end{aligned} \tag{6}$$

where $\overline{r}$ and $\overline{z}$ are the coordinates. $\overline{z}$ is taken as the center line of the tube and $\overline{r}$ transverse to it, $\overline{u}$ and $\overline{w}$ are the velocity components in the $\overline{r}$ and $\overline{z}$ directions respectively, $\overline{T}$ is the local temperature of the fluid. Further, ρ is the effective density, μ is the effective dynamic viscosity, (ρc_p) is the heat capacitance and k is the effective thermal conductivity of the fluid (Fig. 1).

$$\begin{aligned}&r=\frac{\overline{r}}{a}, z=\frac{\overline{z}}{\lambda}, w=\frac{\overline{w}}{c}, u=\frac{\lambda\overline{u}}{ac}, p=\frac{a^2\overline{p}}{c\lambda\mu}, \delta=\frac{a}{\lambda}, \theta=\frac{(\overline{T}-\overline{T}_0)}{\overline{T}_0}, t=\frac{c\overline{t}}{\lambda},\\&M^2=\frac{\sigma B_0^2a^2}{\mu}, B_r=E_c\mathrm{Pr}, h=\frac{\overline{h}}{a}.\end{aligned} \tag{7}$$

with the help of Eq. (7), Eqs. (3)–(6) can be written as follows

$$\frac{dp}{dr}=0 \tag{8}$$

$$\frac{dp}{dz}=\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial w}{\partial r}\right)-M^2(w+1)\right], \tag{9}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\theta}{\partial r}\right)+B_r\left(\frac{\partial w}{\partial r}\right)^2=0, \tag{10}$$

The non-dimensionless boundary conditions are defined as follows

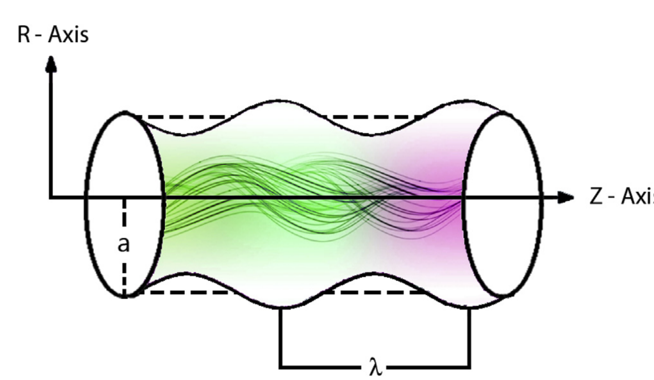

Fig. 1. Geometry of the problem.

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