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Peristaltic flow with thermal conductivity of H_2O + Cu nanofluid and entropy generation

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ABSTRACT

In this article, it is opted to investigate the effects of entropy and induced magnetic field for the peristaltic flow of copper water fluid in the asymmetric horizontal channel , the mathematical formulation is presented, the resulting equations are solved exactly. The obtained expressions for pressure gradient , pressure rise, temperature, axial magnetic field, current density, velocity phenomenon entropy generation number and Bejan number are described through graphs for various pertinent parameters. The streamlines are drawn for some physical quantities to discuss the trapping phenomenon.

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Introduction

A recent research refer on flow of heat and nanoparticle concentration transfer phenomena in a channel/tube has increased considerably due to growths in the electronic industry, micro fabrication technologies, biomedical engineering and science, etc. Moreover, the interaction between peristalsis, heat and nanoparticle concentration transfer has been premeditated freshly. Heat transfer in biological tissues involves complicated processes such as heat conduction in tissues, heat convection due to blood flow through the pores of tissue, in addition to radiation heat transfer between a surface and its environment and there is also Nanoparticle concentration transfer in these processes. The first investigation on nanofluids was given by Choi [1] who verified that the suspension of solid nanoparticles with typical length scales of 1–50 nm with high thermal conductivity enhances the effective thermal conductivity and the convective heat transfer of the base fluid. An elaborated study of nanofluids was examined by Buongiorno [2].

The study of the peristaltic transport of a fluid in the presence of an external magnetic field and rotation is of great importance with regard to certain problems involving the movement of conductive physiological fluids, for example, blood and saline water. Pandey and Chaube [3] investigated an analytical study of the MHD flow of a micropolar fluid through a porous medium induced by sinusoidal peristaltic waves traveling down the channel wall. Akbar and Butt [4] studied the physiological transportation of Casson fluid in a plumb duct. They said that fluid is electrically conducting in the presence of a uniform magnetic field and developed analytical solution under long-wavelength and low-Reynolds number approximations. Ebaid [5,6], Haroun [7], Mekheimer [8] and Nadeem and Akbar [9,10] coated the peristaltic flow phenomena in different geometries for different fluid models.

In thermodynamics, entropy is a measure of the number of specific ways in which a thermodynamic system may be arranged, often taken to be a measure of disorder, or a measure of progressing towards thermodynamic equilibrium. Non-Newtonian .fluid flow in a pipe system with entropy generation is considered by Pakdemirli and Yilbas [11]: according to them entropy number increases with increasing Brinkman number. Souidi et al. [12] discussed entropy generation rate for a peristaltic pump. Entropy generation due to heat and fluid flow in backward facing step.ow with various expansion ratios is studied by Abu-Nada [13]. Further literature on the topic includes Refs. [14–32].

Therefore, in view of all above discussion the goal of this study was to analyze the entropy generation in heat conducting nanofluids in the presence of induced magnetic effect. While the analysis could be applied to any nanofluid, a copper–water nanofluid is used as the model due to the accessibility of its physical properties. We also consider thermal conductivity model with Brownian

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motion [14] for nanofluids, this gains the effects of particle size, particle volume fraction and temperature dependence. The analysis is performed under the well-established long wavelength and low Reynolds number approximations. The exact solution for the stream function, temperature and pressure gradient is given. All the physical features of the problems have been described with the help of graphs.

Mathematical formulation

Here we discussed an incompressible peristaltic flow of copper nano fluid in an irregular channel with channel width $d_1 + d_2$. Asymmetry in the flow is because of propagation of peristaltic waves of different amplitudes and phases on the channel walls. An external transverse uniform constant magnetic field H_0, induced magnetic field $H(h_X(X,Y,t), H_0 + h_Y(X,Y,t), 0)$ and the total magnetic field $H^{+}(h_X(X,Y,t), H_0 + h_Y(X,Y,t), 0)$ are taken into account. Finally the channel walls are considered to be nonconductive Sinusoidal wave propagating beside the walls of the channel with continuous hustle c_1. Disproportionate in the canal flow is reserved due to the subsequent hedge surfaces terminology:

$$Y = \overline{H}_1 = d_1 + a_1 \cos\left[\frac{2\pi}{\lambda}(\overline{X} - c_1\bar{t})\right],$$

$$Y = \overline{H}_2 = -d_2 - b_1 \cos\left[\frac{2\pi}{\lambda}(\overline{X} - c_1\bar{t}) + \omega\right]. \tag{1}$$

In the above equations a_1 and b_1 denote the waves amplitudes, λ is the wave length, $d_1 + d_2$ is the channel width, c_1 is the wave speed, $\bar{t}$ is the time, $\overline{X}$ is the direction of wave propagation and Y is perpendicular to $\overline{X}$.

Equations governing the flow and temperature in the presence of heat source or heat sink and the equation which governs the MHD flow are given as

(i) Maxwell's equations [8,15–17]

$$\nabla\cdot\mathbf{H} = 0, \quad \nabla\cdot\mathbf{E} = \mathbf{0}, \tag{2}$$

$$\nabla\wedge\mathbf{H} = \mathbf{J}, \quad \mathbf{J} = \sigma\{\mathbf{E} + \boldsymbol{\mu}_e(\mathbf{V}\wedge\mathbf{H})\}, \tag{3}$$

$$\nabla\wedge\mathbf{E} = -\boldsymbol{\mu}_e\frac{\partial\mathbf{H}}{\partial\mathbf{t}}, \tag{4}$$

(ii) The continuity equation

$$\nabla\cdot\mathbf{V} = \mathbf{0} \tag{5}$$

(iii) The equations of motion

$$\rho_{nf}\left(\frac{\partial\mathbf{V}}{\partial t} + \mathbf{V}\cdot\nabla\mathbf{V}\right) = -\nabla p + \mu_{nf}\,\mathrm{div}\,\mathbf{V} - \nabla\left(\frac{1}{2}\mu_e(H^{+})^2\right) - \mu_e(H^{+}.\nabla)H \tag{6}$$

(iv) The energy equation

$$(\rho c)_f\left(\frac{\partial\mathbf{T}}{\partial t} + \mathbf{V}\cdot\nabla\mathbf{T}\right) = \nabla\cdot k_{nf}\ \nabla T \tag{7}$$

Combining Eqs. (2)–(4), we obtain

$$\frac{\partial\mathbf{H}^{+}}{\partial t} = \nabla\wedge(\mathbf{V}\wedge\mathbf{H}^{+}) + \frac{1}{\xi}\nabla^2\mathbf{H}^{+}, \tag{8}$$

where $\zeta = \sigma\mu_e$ is the magnetic diffusivity, σ is the electrical conductivity, μ_e is magnetic permeability ρ_{nf} is the effective density of the incompressible nano fluid, $(\rho c)_{nf}$ is the heat capacity of the nano fluid, $(\rho c)_p$ gives effective heat capacity of the nano particle material, k_{nf} implies effective thermal conductivity of nano fluid, μ_{nf} is the effective viscosity of the fluid, d/dt gives the material time derivative, p is the pressure. The appearance of static and wave structures is connected by the subsequent associations

$$x = X - ct, y = Y, u = U - c, v = V. \tag{9}$$

The dimensionless parameters used in the problem are defined as follow

$$\bar{p} = \frac{a^2}{\mu_f c\lambda}p,\ \bar{v} = \frac{\lambda}{ac}v,\ \bar{u} = \frac{u}{c},\ \bar{x} = \frac{x}{\lambda},\ \bar{y} = \frac{y}{a},\ \bar{t} = \frac{c}{\lambda}t,\ \omega = \frac{b}{a},$$
$$\mathrm{Re} = \frac{\rho ca}{\mu_f},\ \delta = \frac{a}{\lambda},\ \bar{\theta} = \frac{T - T_0}{T_1 - T_0},\ Br = EcPr;\ \bar{\Phi} = \frac{\Phi}{H_0 a},\ \overline{\Psi} = \frac{\Psi}{ca},\ R_m = \sigma\boldsymbol{\mu}_e ac,$$
$$\overline{h_x} = \bar{\Phi}_{\bar{x}},\ \overline{h_y} = -\bar{\Phi}_{\bar{y}},\ S_1 = \frac{H_0}{c}\sqrt{\frac{\boldsymbol{\mu}_e}{\rho}},\ \alpha_{nf} = \frac{k}{(\rho c)_f},\ \tau = \frac{(\rho c)_p}{(\rho c)_f}. \tag{10}$$

After using the above non-dimensional parameters and transformation in Eq. (9) employing the assumptions of long wavelength $(\delta \to 0)$, the dimensionless governing equations $\left(\text{withoutusingbars}, u = \frac{\partial\Psi}{\partial y},\ v = -\frac{\partial\Psi}{\partial x}\right)$ for nanofluid in the wave frame take the final form as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{11}$$

$$\frac{dp}{dx} = A\times\frac{\partial^3\Psi}{\partial y^3} + \mathrm{Re}\ S_1^2\Phi_{yy}, \tag{12}$$

$$\frac{dp}{dy} = 0, \tag{13}$$

$$\Phi_{yy} = R_m\left(E - \frac{\partial\Psi}{\partial y}\right), \tag{14}$$

$$\frac{k_{nf}}{k_f}\frac{\partial^2\theta}{\partial y^2} + B_r A\times\left(\frac{\partial^2\Psi}{\partial y^2}\right)^2 = 0 \tag{15}$$

Putting Eqs. (14) into Eq. (12) we get

$$\frac{dp}{dx} = A\times\frac{\partial^3\Psi}{\partial y^3} + \mathrm{Re}\ S_1^2 R_m\left(E - \frac{\partial\Psi}{\partial y}\right), \tag{16}$$

Taking derivative of above equation with respect to y finally we get

$$A\times\frac{\partial^4\Psi}{\partial y^4} + \mathrm{Re}\ S_1^2 R_m\left(-\frac{\partial^2\Psi}{\partial y^2}\right) = 0, \tag{17}$$

The non-dimensional boundaries will take the form as

$$\Psi = \frac{F}{2},\ \frac{\partial\Psi}{\partial y} = -1,\ \text{at } y = h_1. \tag{18}$$

$$\Psi = -\frac{F}{2},\ \frac{\partial\Psi}{\partial y} = -1,\ \text{at } y = h_2. \tag{19}$$

$$\theta = 0 \text{ at } y = h_1,\quad \theta = 1 \text{ at } y = h_2, \tag{20}$$

$$\Phi = 0 \text{ at } y = h_1,\quad \Phi = 0 \text{ at } y = h_2, \tag{21}$$

The pressure rise Δp, axial induced magnetic h_x and current density J_z in non-dimensional form are defined as

Table 1
Thermal-physical properties of water and nanoparticles.

Physical properties	Water (H_2O)	Copper (Cu)
ρ (kg m^{-3})	997.1	8933
C_p	4179	385
$\beta\times10^5$ (K^{-1})	21	1.67
k, Wm^{-1} (K^{-1})	0.613	401

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