International Journal of Heat and Mass Transfer 106 (2017) 18–24

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Studying peristaltic transport of shape nanosize silver–water nanomaterials in digestive system with heat generation effect

T. Hayat [a,b], Naseema Aslam [a], M. Rafiq [a,*], A. Alsaedi [b]

[a] Department of Mathematics, Quaid-I-Azam University 45320, Islamabad 44000, Pakistan
[b] Nonlinear and Applied Mathematics (NAAM) Research Group, Department of Mathematics, King Abdulaziz University, Jeddah 21589, Saudi Arabia

ARTICLE INFO

Article history:
Received 1 August 2016
Received in revised form 5 October 2016
Accepted 6 October 2016

Keywords:
Peristalsis
Nanofluid
Shape effect
Slip effect and wall properties

ABSTRACT

This communication addresses the peristaltic transport of silver–water nanofluid in the curved channel. Shape effects of nanosize particles are examined. Bricks, cylinder and platelets types nanoparticles are considered. Magnetic field is applied in the radial direction. Viscous dissipation and heat generation in the energy expression are included. Velocity and thermal slip conditions are invoked. Thermal conductivity model due to Hamilton-crosser is employed. A comparative study of velocity and the temperature for the considered nanoparticles is made. Outcome of sundry variables on velocity and temperature are graphically examined. It is noticed that both velocity and temperature are greater for brick type nanoparticles in comparison to cylinder and platelets. Moreover, the velocity is not symmetric about center of channel.

1. Introduction

Nanofluids with high rate of heat transfer have gained attention of researchers due to their vast applications in engineering and industrial processes. These fluids are prepared by suspension of nanometer (1–100 nm) size particle in traditional fluid. These particles include metals, oxides, carbides, carbon nanotubes etc. Nanofluid was initially coined by Choi [1]. The primary purpose of using nanofluids is to enhance heat transfer in heat exchangers and radiators but by the time these are also used in medical diagnosis and drug delivery systems. These materials are useful in the thermal therapy for the treatment of cancer diseases, in the automatic transmission of fluids, lubricants, coolants and engine oils. Out of all types of nanoparticles, silver nanoparticles (Ag NPs) seem to have attracted the most interests in terms of their potential applications. The availability of silver nanoparticles has ensured a rapid adoption in medical practice. Silver nanoparticles play an important role in the suppression and killing of various pathogenic micro-organisms. Silver nanoparticles are used in variety of applications such as anti-microbial processes (air and water purifications), optical (solar cell) and conductive (touch screen, LCDs) processes. Some recent researches in this direction can be seen through the studies [2–10].

Peristaltic transport plays an important role in physiology for the transport of fluids. It is used for conveying chyme, the movement of ovum, blood flow in cardiac chambers, transport of urine from kidney to bladder, venules and capillaries and ovum in the female fallopian tube. Hose and tube pumps through peristalsis are used to handle viscous chemicals and shear sensitive polymers. Besides these it is used in industry and biology as roller and finger pumps, food mixing processes and cilia transport. Further magnetohydrodynamic is significant in blood pump machines, radar systems, flow meters and power generation systems. In addition, hyperthermia, bleeding reduction during surgeries are also based upon the principles of MHD. The peristalsis with heat transfer has further importance in tissues, laser therapy, conduction and oxygenation. Many researchers have studied MHD peristaltic flow by using different fluids in channel/tubes. Representative attempts in this direction can be mentioned by Refs. [11–27]. Existing literature also witnesses that peristalsis subject to nanofluids is not given proper attention. For instance, Zhang et al. [28] study the nanofluids considering three type of nanoparticles (Cu, Al_2O_3, Ag) in porous media with radiative heat transfer and variable heat flux. They also observed the influence of first order chemical reaction in flow of nanofluids. The velocity and temperature distributions are affected greatly in the presence of nanoparticles. Effect of heat transfer on unsteady flow of pseudo-plastic nanofluid past a stretching sheet have been examined by Lin et al. [29]. Lin et al. [30] also discussed the Maragoni convective flow of nanofluid with variable thermal conductivity and radiation impacts. They perceived that TiO_2 have better improvement in comparison

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* Corresponding author.

E-mail addresses: tahaksag@yahoo.com (T. Hayat), anaseema907@gmail.com (N. Aslam), Maimona_88@hotmail.com (M. Rafiq), aalsaedi@kau.edu.sa (A. Alsaedi).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.10.019
0017-9310/

Al_2O_3, Cu and CuO with water based fluid. Nanofluid flow with velocity slip over a stretching sheet is analyzed by Zheng et al. [31]. The peristaltic flow of nanofluid considering various assumptions can be seen through the studies [32–34]. Peristaltic transport for water based nanofluid with mixed convection and Joule heating have been inspected by Hayat et al. [35]. Shehzad et al. [36] explored the peristaltic transport of nanofluids with heat transfer and mixed convection flow. They also interpreted the comparative study of the Maxwell's and Hamilton's crosser models. Hayat et al. [37] interpreted the peristaltic flow of nanofluid in a compliant wall channel with convective conditions. Peristaltic flow of carbon nanotubes in an inclined channel with second order slip is studied by Hayat et al. [38].

The present investigation discusses the peristaltic transport of silver–water nanofluid in curved channel. Shape effects of nanomaterials are particularly emphasized. Effects of mixed convection and viscous dissipation are analyzed. Heat generation/absorption is also considered. Uniform magnetic field is applied in the radial direction. Long wavelength and small Reynolds number are employed in the formulation. Results for influential variables on velocity and temperature are established.

2. Formulation

Let us consider the peristaltic transport of an incompressible nanofluid in a curved channel having thickness $2d$ (see Fig. 1). The channel is curved in a circle with radius R^* and center O. Curvilinear coordinates (r, x) are chosen for the considered problem. A radial magnetic field $\mathbf{B} = \left(\frac{B_0}{r+R^*}, 0, 0\right)$ is applied with strength of magnitude B_0. Induced magnetic field is neglected due to the consideration of low magnetic Reynolds number. Moreover, electric field is not taken into account. Channel walls are of complaint nature. The flow is induced by the propagation of sinusoidal wave of small amplitude a and wavelength λ along the channel walls. Let u and v be the velocity components in axial and radial directions respectively. The mathematical expression for the travelling waves are defined as:

$$r = \pm\eta(\mathrm{x}, \mathrm{t}) = \pm\left[\mathrm{d} + a\sin\left(\frac{2\pi}{\lambda}(\mathrm{x} - \mathrm{ct})\right)\right], \tag{1}$$

In the above expression c, t and $\pm\eta$ represent the wave speed, time and extreme positions of upper and lower walls respectively. Applied radial magnetic field with strength B_0 can be written in the form:

$$\mathbf{B} = \left(\frac{B_0}{r+R^*}, 0, 0\right). \tag{2}$$

Expression for the Lorentz force is:

$$\mathbf{F} = \left(0, \frac{\sigma_{nf} B_0^2 u}{(r+R^*)^2}, 0\right) \tag{3}$$

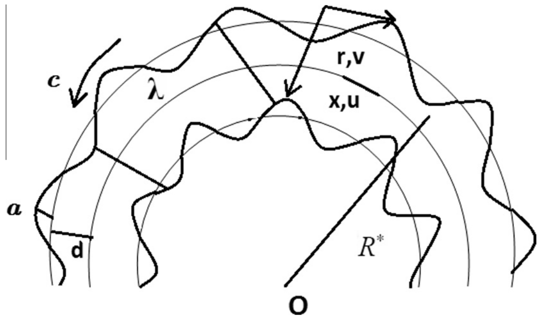

Fig. 1. Geometry of the problem.

where σ_{nf} shows the electrical conductivity of nanofluid and R^* the constant radius. Electrical conductivity expression satisfies [10] and [35]:

$$\sigma_{nf} = 1 + \frac{3\left(\frac{\sigma_p}{\sigma_f} - 1\right)\Phi}{\left(\frac{\sigma_p}{\sigma_f} + 1\right) - \left(\frac{\sigma_p}{\sigma_f} - 1\right)\Phi}.$$

Here ϕ, σ_p and σ_f denote the nanoparticle volume fraction and electric conductivities of nanoparticles and water respectively.

Equation of continuity for the flow analysis is

$$\frac{\partial[(r+R^*)v]}{\partial r} + R^* \frac{\partial u}{\partial x} = 0, \tag{4}$$

Velocity components in x and r direction are

$$\rho_{nf}\left(\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial r} + \frac{R^* u}{r+R^*}\frac{\partial v}{\partial x} - \frac{u^2}{r+R^*}\right) = -\frac{\partial p}{\partial r} + \frac{1}{r+R^*}\frac{\partial[(r+R^*)S_{rr}]}{\partial r} + \frac{R^*}{r+R^*}\frac{\partial S_{xr}}{\partial x} - \frac{S_{xx}}{r+R^*}, \tag{5}$$

$$\rho_{nf}\left(\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial r} + \frac{R^* u}{r+R^*}\frac{\partial u}{\partial x} + \frac{uv}{r+R^*}\right) = -\frac{R^* u}{r+R^*}\frac{\partial p}{\partial x} + \frac{1}{(r+R^*)^2}\frac{\partial[(r+R^*)^2 S_{rx}]}{\partial r} + \frac{R^*}{r+R^*}\frac{\partial S_{xx}}{\partial x} - \frac{\sigma_{nf} u B_0^2}{(r+R^*)^2} + (\rho\beta)_{nf} g(T - T_1). \tag{6}$$

Considering the effects of viscous dissipation and heat absorption, energy equation can be written as

$$(\rho C_p)_{nf}\left(\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial r} + \frac{R^* u}{r+R^*}\frac{\partial T}{\partial x}\right) = \kappa\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r+R^*}\frac{\partial T}{\partial r} - \left(\frac{R^*}{r+R^*}\right)^2\frac{\partial^2 T}{\partial x^2}\right) + (S_{rr} - S_{xx})\left(\frac{\partial v}{\partial r}\right) + S_{xr}\left(\frac{\partial u}{\partial r} + \frac{R^*}{r+R^*}\frac{\partial v}{\partial x} - \frac{u}{r+R^*}\right) + Q_0, \tag{7}$$

where ρ_{nf}, $(\rho C_p)_{nf}$, S_{ij} $(i, j = r, x)$, κ_{nf}, μ_{nf} and $(\rho\beta)_{nf}$ denote the effective density, heat capacitance, components of extra stress tensor, effective thermal conductivity, effective dynamic viscosity and thermal expansion coefficient of nanofluid respectively. Moreover, u and v denote the velocity components and T the temperature of fluid. We have [9]

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_{p,}(\rho C_p)_{nf} = (1-\phi)(\rho C_p)_f + \phi(\rho C_p)_p,$$

$$(\rho\beta)_{nf} = (1-\phi)(\rho\beta)_p + \phi(\rho\beta)_f, \quad \mu_{nf} = \frac{\mu_f}{(1-\phi)^{2.5}},$$

$$\alpha_{nf} = \frac{\kappa_{nf}}{(\rho C_p)_{nf}}.$$

The effective thermal conductivity for Hamilton-Crosser's model is defined as follows [10]:

$$\frac{\kappa_{nf}}{\kappa_f} = \frac{\kappa_p + (n-1)\kappa_f - (n-1)\phi(\kappa_f - \kappa_p)}{\kappa_p + (n-1)\kappa_f + \phi(\kappa_f - \kappa_p)}. \tag{8}$$

In above expressions ϕ, ρ_p, κ_p and β_p show the volume fraction, density, thermal conductivity and thermal expansion coefficient of nanoparticles respectively. Also ρ_f, κ_f, β_f and μ_f represent the density, thermal conductivity, thermal expansion coefficient and viscosity of base fluid respectively whereas n shows the shape factor.

Cauchy shear stress for an incompressible viscous nanomaterial is

$$\mathbf{T} = -\mathrm{p}\mathbf{I} + \mathbf{S}, \tag{9}$$

where $\mathbf{A}_1 = (\mathrm{grad}\mathbf{V}) + (\mathrm{grad}\mathbf{V})^*$ and $\mathbf{S} = \mu_{nf}\mathbf{A}_1$.