ARTICLE IN PRESS
+ MODEL
Available online at www.sciencedirect.com
ScienceDirect
Karbala International Journal of Modern Science xx (2017) 1–15
http://www.journals.elsevier.com/karbala-international-journal-of-modern-science/

Peristaltically assisted nanofluid transport in an asymmetric channel

S. Noreen

Department of Mathematics, COMSATS Institute of Information Technology, Park Road, Chak Shehzad, Islamabad, akistan

Received 31 July 2017; revised 14 October 2017; accepted 17 October 2017

Abstract

This paper aims to study the diffusion-thermo analysis on the peristaltic flowing pseudoplastic nanofluid in an asymmetric channel. Mathematical formulation is based on basic laws and governing equations of pseudoplastic nanofluid under long wavelength approach. Solution is developed numerically with a focus towards the effects of thermophoretic diffusion and Brownian motion of nano particle. Diverse parameters approaching the problem are studied on velocity, stream function, concentration, pressure drop and temperature. Moreover, comparison between pseudoplastic and viscous nanofluid is also given in the present study.

Keywords: Mixed convection; Pseudo plastic-nano fluid; Asymmetric channel

1. Introduction

The word "peristalsis" comes from a Greek word "Peristaltikos" which means clasping and compressing. Peristaltic transport has become essential research area due to its applications in bio medical engineering and industry. The peristaltic flow is specifically involved in the flow of blood, urine, ovum, chyme etc. Roller pumps and sanitary transport name a few to diverse industrial applications. Preliminarily Latham [1] and Shapiro et al. [2] studied the peristaltic flow of viscous fluid. Since then, numerous attempts have been contributed to literature to explore further in this direction (see few recent studies [3–8]).

Physiologists argue that the intra-uterine fluid flow depicts peristaltic machinery. These myo-metrical contractions appear in symmetric and asymmetric channel [9]. In research articles [10–15], the peristaltic flow in asymmetric channels has given much to scientific community.

Cooling processes heat transfer is key area in industrial research. Traditional methods include fins for increasing flow rates. Such methods have limitations, which include super increase in heat system's size and pumping efficiency respectively. Thermal conductivity of fluids like ethylene, oil, glycol and water mixture are not enough. Today's industrial needs are different. To this end thermal conductivity of fluids is improved by dropping nano particles in ordinary liquids.

Choi defines a liquid of ultra-fine particles with dia less than 50 nm as "nano" [16]. The nanoparticles include carbide, metals, metal oxides and nitride. Literature on the flow of viscous nanofluid has been growing during the last few years (see Refs. [17–27] and many Refs. therein). To the best of my

E-mail address: laurel_lichen@yahoo.com.
Peer review under responsibility of University of Kerbala.

https://doi.org/10.1016/j.kijoms.2017.10.005

knowledge, Makinde et al. [28] studied the heat flow of nano fluid apast a shrinking sheet. Qasim et al. explained a part from that, heat flux and slip flow of Ferrofluid [29]. Makinde and Aziz [30] gave the results for flow of nanofluid with convective boundary conditions. In another investigation, Makinde et al. [31] explored the magneto hemodynamics of Nano fluid with heat and mass transfer in a slowly varying symmetrical channel. Reddy [32] discussed the hydro magnetic peristaltic motion of a reacting and radiating couple stress fluid in an inclined asymmetric channel filled with a porous medium. Few more, recent studies in the same regime are given in Refs. [33,34].

Motivated by above, current study aims to advance in realm of peristaltic transport for non-Newtonian fluids with nanoparticles. Here combined heat and mass effects on peristaltic transport of pseudoplastic nanofluid is examined in an asymmetric channel. Mathematical formulation is done considering Brownian motion and thermophoresis effects. We have also compared our results for the case for viscous nano fluid and for the case of symmetric channel along with a detailed presentation for all the results of present problem.

2. Mathematical formulation

Consider pseudoplastic nanofluid in a channel of thickness $d_1 + d_2$, which is asymmetric in nature. Let c be the speed of travelling sinusoidal waves along channel walls. Rectangular coordinates system $(\overline{X}, \overline{Y})$ is considered where $\overline{X}$ -axes is parallel and $\overline{Y}$ -axes is transverse to the direction of wave motion. Further T_0, C_0 and T_1 and C_1 are lower and higher wall temperature and nanoparticles concentration. The geometry of wall surfaces are

$$\overline{h}_1\left(\overline{X},\overline{t}\right) = \overline{d}_1 + \overline{a}_1 \cos\left(\frac{2\pi}{\lambda}\left(\overline{X} - c\overline{t}\right)\right) \quad \text{upper wall,} \tag{1}$$

$$\overline{h}_2\left(\overline{X},\overline{t}\right) = -\overline{d}_2 - \overline{a}_2 \cos\left(\frac{2\pi}{\lambda}\left(\overline{X} - c\overline{t}\right) + \phi\right) \quad \text{lower wall,} \tag{2}$$

where $\overline{a}_1, \overline{a}_2$ are the wave amplitudes and the phase difference ϕ varies in the range $0 \le \phi \le \pi$. The case $\phi = 0$ is subject to the symmetric channel with waves out of phase and the waves are in phase for $\phi = \pi$. Here λ is the wavelength, $\overline{t}$ the time and $\overline{a}_1, \overline{a}_2, \overline{d}_1, \overline{d}_2$ and ϕ satisfy $\overline{a}_1^2 + \overline{a}_2^2 + 2\overline{a}_1\overline{a}_2 \cos\phi \le \left(\overline{d}_1 + \overline{d}_2\right)^2$. Denoting the velocity components $\overline{U}$ and $\overline{V}$ along the $\overline{X}$ and $\overline{Y}-$ directions in the fixed frame, we have the velocity $\mathbf{V}$ as

$$\mathbf{V} = \left[\overline{U}\left(\overline{X},\overline{Y},\overline{t}\right), \overline{V}\left(\overline{X},\overline{Y},\overline{t}\right), 0\right]. \tag{3}$$

Extra stress tensor $\overline{\mathbf{S}}$ for pseudo plastic fluid model is given by Ref. [35]:

$$\overline{\mathbf{S}} + \overline{\lambda}_1 \overline{\mathbf{S}}^{\nabla} + \frac{1}{2}\left(\overline{\lambda}_1 - \overline{\mu}_1\right)\left(\overline{\mathbf{A}}_1\overline{\mathbf{S}} + \overline{\mathbf{S}}\,\overline{\mathbf{A}}_1\right) = \mu\overline{\mathbf{A}}_1, \tag{4}$$

$$\overline{\mathbf{S}}^{\nabla} = \frac{d\overline{\mathbf{S}}}{dt} - \overline{\mathbf{S}}\overline{\mathbf{L}}^T - \overline{\mathbf{L}}\overline{\mathbf{S}}, \tag{5}$$

$$\overline{\mathbf{A}_1} = \overline{\mathbf{L}} + \overline{\mathbf{L}}^T, \overline{\mathbf{L}} = grad\overline{\mathbf{V}}, \tag{6}$$

in which $\mu, \overline{\mathbf{S}}^{\nabla}, A_1, d/dt$ and $\overline{\mu}_1$ and $\overline{\lambda}_1$ respectively denote the dynamic viscosity, the upper-convected derivative, the first Rivlin-Ericksen tensor, the material derivative and the relaxation times.

The fundamental equations governing the flow of an incompressible fluid are

$$\frac{\partial\overline{U}}{\partial\overline{X}} + \frac{\partial\overline{V}}{\partial\overline{Y}} = 0, \tag{7}$$

$$\rho_f\left(\frac{\partial}{\partial\overline{t}} + U\frac{\partial}{\partial\overline{X}} + \overline{V}\frac{\partial}{\partial\overline{Y}}\right)\overline{U} = -\frac{\partial\overline{P}}{\partial\overline{X}} + \frac{\partial\overline{S}_{\overline{XX}}}{\partial\overline{X}} + \frac{\partial\overline{S}_{\overline{XY}}}{\partial\overline{Y}} + \rho_f g\kappa\left(\overline{T} - T_0\right) + \rho_f g\kappa'\left(\overline{C} - C_0\right), \tag{8}$$

$$\rho_f\left(\frac{\partial}{\partial\overline{t}} + U\frac{\partial}{\partial\overline{X}} + \overline{V}\frac{\partial}{\partial\overline{Y}}\right)\overline{V} = -\frac{\partial\overline{P}}{\partial\overline{Y}} + \frac{\partial\overline{S}_{\overline{XY}}}{\partial\overline{X}} + \frac{\partial\overline{S}_{\overline{YY}}}{\partial\overline{Y}}, \tag{9}$$

$$\left[\frac{\partial}{\partial\overline{t}} + \overline{U}\frac{\partial}{\partial\overline{X}} + \overline{V}\frac{\partial}{\partial\overline{Y}}\right]\overline{T} = \alpha\left[\frac{\partial^2\overline{T}}{\partial\overline{X}^2} + \frac{\partial^2\overline{T}}{\partial\overline{Y}^2}\right] + \tau\left[D_B\left(\frac{\partial\overline{C}}{\partial\overline{X}}\frac{\partial\overline{T}}{\partial\overline{X}} + \frac{\partial\overline{C}}{\partial\overline{Y}}\frac{\partial\overline{T}}{\partial\overline{Y}}\right) + \frac{D_T}{T_m}\left\{\left(\frac{\partial\overline{T}}{\partial\overline{X}}\right)^2 + \left(\frac{\partial\overline{T}}{\partial\overline{Y}}\right)^2\right\}\right], \tag{10}$$

$$\left[\frac{\partial}{\partial\overline{t}} + \overline{U}\frac{\partial}{\partial\overline{X}} + \overline{V}\frac{\partial}{\partial\overline{Y}}\right]\overline{C} = D_B\left[\frac{\partial^2\overline{C}}{\partial\overline{X}^2} + \frac{\partial^2\overline{C}}{\partial\overline{Y}^2}\right] + \frac{D_T}{T_m}\left[\frac{\partial^2\overline{T}}{\partial\overline{X}^2} + \frac{\partial^2\overline{T}}{\partial\overline{Y}^2}\right], \tag{11}$$

Where $\overline{P}$ is the pressure, D_T the thermophoretic diffusion coefficient, ρ the density of fluid, g acceleration due to gravity, κ the thermal conductivity, D_B the Brownian diffusion coefficient, α is thermal diffusivity, $\tau = (\rho c_p)_p/(\rho c_p)_f$ ratio of heat capacity of the nano particle material & fluid, κ the coefficient of thermal expansion, ρ_p particle density, κ' is coefficient of mass

Please cite this article in press as: S. Noreen, Peristaltically assisted nanofluid transport in an asymmetric channel, Karbala International Journal of Modern Science (2017), https://doi.org/10.1016/j.kijoms.2017.10.005