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Soret and Dufour effects on peristaltic transport in curved channel with radial magnetic field and convective conditions

T. Hayat [a,b], Quratulain [a], M. Rafiq [a,*], Fuad Alsaadi [b], M. Ayub [a]

[a] Department of Mathematics, Quaid-I-Azam University 45320, Islamabad 44000, Pakistan

[b] Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah 21589, Saudi Arabia

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ABSTRACT

This study addresses the impact of convective heat and mass conditions in the peristaltic transport of fluid in a complaint wall curved channel. Formulation for flow of third grade fluid is made. Soret and Dufour effects are considered. Fluid is conducting through applied magnetic field in radial direction. Lubrication approach is employed. Solutions for stream function, temperature and concentration fields are derived. The effects of pertinent parameters in the solutions are analyzed graphically. It is found that the velocity profile is not symmetric about the central line in curved channel. The velocity and temperature are reduced by increasing magnetic field strength. The number and size of streamlines are decreased in the presence of magnetic field effect.

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1. Introduction

Peristalsis is a well-known phenomenon that naturally occurs in many organisms and organs due to a travelling wave along the channel wall. This mechanism attracts the attention of mathematicians, physicists and biomedical engineers. It provides better understanding of many biological phenomena that occur in many organs inside human body like blood circulation in small vessels, urine transport from kidney to bladder through ureter, functioning of esophagus, swallowing of food, transport of lymph in lymphatic vessels, chyme transport in the gastrointestinal tract, etc. Peristalsis also provides base for inventions of mechanical finger and roller pumps, cell separators and heart–lung machine. This process of fluids flow also provides an efficient process for the drainage of toxic-liquid in nuclear industry. Mathematical analysis regarding a particular natural mechanism is acceptable only if obtained information agrees with actual experimental result. The precise mathematical study of flows in human body explains the main effects that influences many physiological flows of peristaltic nature. Latham [1] and Shapiro et al. [2] initially presented pioneering works about peristalsis of viscous fluids. Afterwards various attempts have been made for the peristaltic activity of both viscous and non-Newtonian fluids via diverse aspects (see few studies [3–10] and several studies therein). In biomedical engineering, the peristaltic activity has much interaction with magnetohydrodynamics. The process of blood purification, drug injection, blood pump machines, magnetic endoscopy, magnetic resonance imaging (MRI), constipation treatment, gastroenric pathology, hypertension, hyperthermia, cancer therapy, blood reduction during surgeries and arterial diseases can be mentioned in this direction. Having such view point, several authors are engaged in the discussion of peristaltic transport of viscous and non-Newtonian materials in the presence of magnetic field. For instance MHD peristalsis of fractional second grade material in a tube is studied by Hameed et al. [11]. Ramesh and Devakar [12] examined such flow for couple stress fluid in an inclined channel. This type of study for Jeffrey liquid has been presented by Abd-Alla and Abo-Dahab [13]. Kothandapani and Parkash [14] analyzed magnetic field effect in radiative peristaltic transport of viscous nanofluid in a tapered asymmetric channel. Akram et al. [15] explored induced magnetic field influence on peristalsis of Williamson fluid. MHD peristalsis of Jeffrey liquid in a rectangular duct has been addressed by Ellahi and Hussain [16]. MHD peristaltic flow of variable viscosity material is developed by Sinha et al. [17] . Impact of an induced magnetic field in peristalsis through annulus is pointed out by Abd elmaboud [18]. Pandey and Chaube [19] examined peristalsis of micropolar fluid via an applied magnetic field. Hayat et al. [20] highlighted an induced magnetic field effect in peristaltic flow of Carreau liquid.

Heat transfer has a great credence in biological tissues, blood flow examination, treatment of cancer tissues, etc. Heat transfer has also large applications in industry like paper and petroleum production, food processing and polymer engineering. Mass transfer combined with heat transfer can be observed in diffusion of nutrients from blood vessels to neighboring tissues in human

* Corresponding author.
E-mail address: maimona_88@hotmail.com (M. Rafiq).

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body. Simultaneous effects of heat and mass transfer effects in industrial applications include thermal recovery process, catalytic reactors and reservoir engineering. The transfer of radioactive nuclear waste material, filtration and separation processes in chemical engineering, transport processes in aquifers and transpiration cooling also worked through the principle of convective heat and mass transfer. Keeping such facts in mind, Ellahi et al. [21] discussed peristalsis in a non-uniform duct. Peristalsis of pseudoplastic liquid in the presence of heat and mass transfer is studied by Hina et al. [22]. Javed et al. [23] analyzed peristalsis of Burger's material in this direction. Saleem and Haider [23] studied peristaltic transport of bioviscosity fluid subject to heat and mass transfer. Shehzad et al. [24] discussed peristaltic transport of fluid in the presence of nanoparticles. Nadeem and Akbar [25] examined heat and mass transfer effects on peristalsis through an annulus. Hina et al. [26] explored chemical reaction effect in peristaltic transport of material through complaint wall channel. MHD peristalsis of Maxwell fluid in the presence of heat and mass transfer is studied by Hayat and Hina [27]. Vajravelu et al. [28] attempted such analysis for Carreau liquid. Peristaltic motion of viscous nanofluid filling porous space is developed by Abbasi et al. [29]. Tripathi and Beg [30] addressed peristalsis of nanomaterials with reference to drug delivery system. Inspite of all the above mentioned attempts, it has been noted that Soret and Dufour effects in peristalsis are given very little attention (see [31–34]). Also much attention in the past has been focused on the peristaltic transport through constant applied magnetic field and straight channels. No doubt the consideration of straight channels is not adequate in flows related to physiological and industrial applications. Thus some authors have considered the peristaltic transport in curved channels [35–37,37–40].

The purpose here is three fold. Firstly to examine the Soret and Dufour effects in the peristaltic transport of third grade fluid through curved complaint wall channel. To our knowledge such study is not made so far. Secondly to consider radial applied magnetic field. Thirdly to utilize the convective conditions through both heat and mass transfer. The relevant problems are first formulated and then solved successfully. Results of sundry parameters on the velocity, temperature, concentration and heat and mass transfer coefficients are analyzed. Streamlines are displayed and described.

2. Formulation

We investigate the peristaltic transport of third grade fluid in curved channel with radius R^* and uniform thickness $2d_1$, coiled in circle with centre O (see Fig. 1). Here r and x denote the radial and axial coordinates respectively. A radial magnetic field $\mathbf{B} = (Bo/r + R^*, 0, 0)$ is applied. Electric field effect is not taken into account. Induced magnetic field is neglected for small magnetic Reynolds number.

The sinusoidal wave shapes along the walls are selected in the form

$$r = \pm\eta(x, t) = \pm\left[d_1 + a\sin\frac{2\pi}{\lambda}(x - ct)\right], \tag{1}$$

in which a is the wave amplitude, λ represents the wavelength and c depicts the wave speed.

The present flow is governed by the following equations:

$$\frac{\partial v}{\partial r} + \frac{R^*}{r + R^*}\frac{\partial u}{\partial x} + \frac{v}{r + R^*} = 0, \tag{2}$$

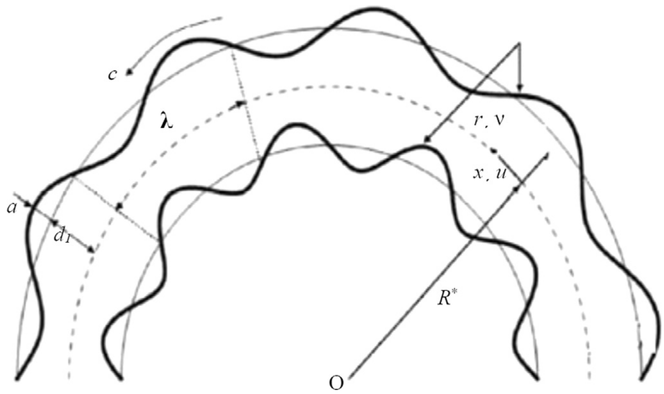

Fig. 1. Physical model.

$$\rho\left(\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial r} + \frac{R^* u}{r + R^*}\frac{\partial v}{\partial x} - \frac{u^2}{r + R^*}\right) = -\frac{\partial p}{\partial r} + \frac{1}{r + R^*}\frac{\partial}{\partial r}[(r + R^*)S_{rr}] + \frac{R^*}{r + R^*}\frac{\partial S_{xr}}{\partial x} - \frac{S_{xx}}{r + R^*}, \tag{3}$$

$$\rho\left(\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial r} + \frac{R^* u}{r + R^*}\frac{\partial u}{\partial x} + \frac{uv}{r + R^*}\right) = -\frac{R^*}{r + R^*}\frac{\partial p}{\partial x} + \frac{1}{(r + R^*)^2}\frac{\partial}{\partial r}[(r + R^*)^2 S_{rx}] + \frac{R^*}{r + R^*}\frac{\partial S_{xx}}{\partial x} - \frac{\sigma u Bo^2}{(r + R^*)^2}, \tag{4}$$

$$\rho C_p\left(\frac{\partial}{\partial t} + v\frac{\partial}{\partial r} + \frac{R^* u}{r + R^*}\frac{\partial}{\partial x}\right)T = \kappa\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r + R^*}\frac{\partial T}{\partial r} + \left(\frac{R^*}{r + R^*}\right)^2\frac{\partial^2 T}{\partial x^2}\right) + (S_{rr} - S_{xx})\frac{\partial v}{\partial r} + S_{xr}\left(\frac{\partial u}{\partial r} + \frac{R^*}{r + R^*}\frac{\partial v}{\partial x} - \frac{u}{r + R^*}\right) + \frac{DK_T}{C_s}\left(\frac{\partial}{\partial t} + v\frac{\partial}{\partial r} + \frac{R^* u}{r + R^*}\frac{\partial}{\partial x}\right)C, \tag{5}$$

$$\left(\frac{\partial}{\partial t} + v\frac{\partial}{\partial r} + \frac{R^* u}{r + R^*}\frac{\partial}{\partial x}\right)C = D\left(\frac{\partial^2 C}{\partial r^2} + \frac{1}{r + R^*}\frac{\partial C}{\partial r} + \left(\frac{R^*}{r + R^*}\right)^2\frac{\partial^2 C}{\partial x^2}\right) + \frac{DK_T}{T_m}\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r + R^*}\frac{\partial T}{\partial r} + \left(\frac{R^*}{r + R^*}\right)^2\frac{\partial^2 T}{\partial x^2}\right), \tag{6}$$

where p is pressure, σ the electrical conductivity of fluid, B_0 the strength of magnetic field, S_{ij} $(i, j = r, x)$ the components of extra stress tensor, C_p the specific heat at constant volume, ρ the density, κ the thermal conductivity, K_T the thermal diffusion ratio, D the mass diffusivity, C_s the concentration susceptibility and C and T the concentration and temperature of the fluid respectively.

Expression of an extra stress tensor $\mathbf{S}$ for the thermodynamically compatible third grade fluid is

$$\mathbf{S} = \mu\mathbf{A}_1 + \alpha_1\mathbf{A}_2 + \alpha_2\mathbf{A}_1^2 + \beta\,\mathrm{tr}(\mathbf{A}_1^2)\mathbf{A}_1, \tag{7}$$

$$\mathbf{A}_1 = (\mathrm{grad}\,\mathbf{V}) + (\mathrm{grad}\,\mathbf{V})^T, \tag{8}$$

$$\mathbf{A}_2 = \left(\frac{D\mathbf{A}_1}{Dt} + \left[\mathbf{A}_1\,\mathrm{grad}\,\mathbf{V} + \mathbf{A}_1(\mathrm{grad}\,\mathbf{V})^T\right]\right), \tag{9}$$

where $\mathbf{A}_1$ and $\mathbf{A}_2$ are the Rivilin Erickson tensors, D/Dt the material derivative, α_i $(i = 1, 2)$ and β the material constants respectively.

The boundary conditions have been taken in the form

$$u = 0 \text{ at } r = \pm\eta, \tag{10}$$

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