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Original Article

Convective thermal and concentration transfer effects in hydromagnetic peristaltic transport with Ohmic heating

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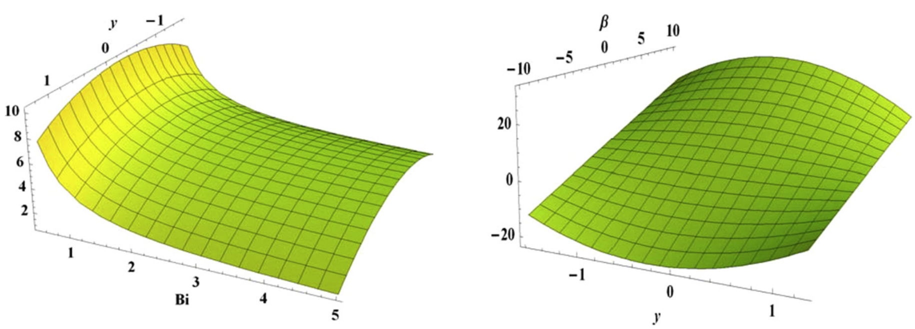
GRAPHICAL ABSTRACT



(a) (b)

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ABSTRACT

The primary theme of this communication is to employ convective condition of mass transfer in the theory of peristalsis. The magnetohydrodynamic (MHD) peristaltic transport of viscous liquid in an asymmetric channel was considered for this purpose. Effects of Ohmic heating and Soret and Dufour are presented. The governing mathematical model was expressed in terms of closed form solution expressions. Attention has been focused to the analysis of temperature and concentration distributions. The graphical results are presented to visualize the impact of sundry quantities on temperature and concentration. It is visualized that the liquid temperature was enhanced with the enhancing values of Soret-Dufour parameters. The liquid temperature was reduced when the values of Biot number were larger. It is also examined that mass transfer Biot number for one wall has no impact on transfer rate. Different mass transfer Biot numbers generate a non-uniform concentration profile throughout the channel cross section.

Introduction

It is well established fact that "peristalsis" is a mechanism of liquid transport produced by progressive wave of area expansion or contraction in length of a distensible tube containing fluid. At present, the physiologists considered it one of key mechanisms of liquid transport in various biological processes. Especially, it occurs in ovum movement of female fallopian tube, urine transport in the ureter, small blood vessels vasomotion, food swallowing via esophagus and many others. Mechanism of peristalsis has important applications in many appliances of modern biomedical engineering include heart-lung machine, dialysis machines and blood pumps. Apart from physiology and biomedical engineering, this type of mechanism is utilized in many engineering devices where

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the fluid is meant to be kept away from direct contact of machinery. Modern pumps are also designed through principle of peristalsis. Initial seminal works on the peristaltic motion was addressed by Latham [1] and Shapiro et al. [2]. Available literature on peristalsis through various aspects is quite extensive. Interested readers may be directed to some recent investigations on this topic [3–15].

Analysis of temperature and mass species transport is important for better understanding of any physical system. This is because of the fact that temperature and mass species transfer are not only vital in energy distribution of a system but also they greatly influence the mechanics of the systems. Clearly the relations between their driving potentials are more complicated when temperature and concentration phenomenon is occurred simultaneously in a system. Energy flux produced by concentration gradients is called Dufour effect while mass flux induced by energy gradient is known as Soret effect. No doubt, there is key importance of heat and mass transport in exchange of gases in lungs, blood purification in kidney, maintaining body temperature of warm blooded species, perspiration in hot weather, water and food transport from roots to all parts of plants, metal purification, controlled nuclear reaction etc. Also Soret-Dufour phenomenon has major importance in mixture of gases having medium and lighter molecular weights and in isotope separation. However, it is observed that almost all the previous contributions on peristalsis with heat transfer are presented via prescribed surface temperature or heat flux. The published studies about peristaltic flows subject to convective conditions of temperature are still scarce. From literature review, we stand out the following works by Hayat et al. [16] and Abbasi et al. [17].

Although peristaltic motion through heat and mass transport phenomenon is discussed but no information is yet available about peristaltic motion subject to convective condition for concentration. The aim here is to utilize such condition in the peristaltic flows. Therefore, the present attempt examines the MHD peristaltic flow of viscous fluid in an asymmetric channel with Joule heating and convective conditions for temperature and concentration distributions. Lubrication approach is used in the performed analysis. Temperature and concentration distributions are analyzed for various embedded parameters in the problem formulation. It is expected that presented analysis will provide a basis for several future investigations on the topic.

Mathematical formulation

We consider the peristaltic flow in an asymmetric channel with width $d_1 + d_2$. The considered liquid is electrically conducting through applied magnetic field B_0. A uniform magnetic field is applied in the $\overline{Y}-$ direction (see Fig. 1). An incompressible liquid is taken in channel. The flow is induced due to travelling waves along the channel walls. The wave shapes can be taken into the forms give below:

$$\overline{H}_1(\overline{X},\bar{t}) = \varepsilon_1 + d_1, \textit{Upperwall}; \overline{H}_2(\overline{X},\bar{t}) = -(\varepsilon_2 + d_2), \textit{Lowerwall}.$$

Here the disturbances generated due to propagation of peristaltic waves at the upper and lower walls are denoted by ε_1 and ε_2, respectively. The values of ε_1 and ε_2 are defined by

$$\varepsilon_1 = a\cos\left(\tfrac{2\pi}{\lambda}(\overline{X} - c\bar{t})\right),$$
$$\varepsilon_2 = b\cos\left(\tfrac{2\pi}{\lambda}(\overline{X} - c\bar{t}) + \alpha\right),$$

here a, b represent the amplitudes of waves, λ the wavelength and α the phase difference of waves. A schematic diagram of such an asymmetric channel has been provided through Fig.1a. The low magnetic Reynolds number assumption leads to ignorance of induced magnetic field. The upper and lower walls satisfy the convective conditions through temperature and concentration distributions. The basic laws which can govern the present flow analysis are

$$\overline{\nabla}.\overline{V} = 0,$$

$$\rho\frac{d\overline{V}}{dt} = -\overline{\nabla P} + \mu(\nabla^2\overline{V}) + \bar{J}\times\overline{B}.$$

In above equations $\overline{V} = [U(\overline{X},\overline{Y},\bar{t}), V(\overline{X},\overline{Y},\bar{t}), 0]$ is the velocity field, $\overline{P}$ is the pressure, μ is the dynamic viscosity, $\frac{d}{dt}$ is the material time derivative, $\bar{t}$ is the time, ρ is the fluid density, $\bar{J}$ is the current density and $\overline{B}$ is the applied magnetic field. Using the assigned values of velocity field, we have the following expressions:

$$\overline{U}_{\overline{X}} + \overline{V}_{\overline{Y}} = 0, \tag{1}$$

$$\overline{U}_{\bar{t}} + \overline{V}\overline{U}_{\overline{Y}} + \overline{U}\overline{U}_{\overline{X}} = -\frac{1}{\rho}\overline{P}_{\overline{X}} + \upsilon(\overline{U}_{\overline{XX}} + \overline{U}_{\overline{YY}}) - \frac{\sigma}{\rho}B_0^2\overline{U}, \tag{2}$$

$$\overline{V}_{\bar{t}} + \overline{V}\overline{V}_{\overline{Y}} + \overline{U}\overline{V}_{\overline{X}} = -\frac{1}{\rho}\overline{P}_{\overline{Y}} + \boldsymbol{\upsilon}[\overline{V}_{\overline{XX}} + \overline{V}_{\overline{YY}}], \tag{3}$$

The energy and concentration equations are

$$\begin{aligned} C_p(T_t + \overline{U}T_{\overline{X}} + \overline{V}T_{\overline{Y}}) &= \tfrac{K}{\rho}[T_{\overline{XX}} + T_{\overline{YY}}] \\ &+ \upsilon\left[2(\overline{U}_{\overline{X}}^2 + \overline{V}_{\overline{Y}}^2) + (\overline{U}_{\overline{Y}} + \overline{V}_{\overline{X}})^2\right] + \tfrac{DK_T}{\rho C_s}[C_{\overline{XX}} + C_{\overline{YY}}] + \tfrac{\sigma}{\rho}B_0^2\overline{U}^2 + \tfrac{\Phi}{\rho}, \end{aligned} \tag{4}$$

$$C_{\bar{t}} + \overline{U}C_{\overline{X}} + \overline{V}C_{\overline{Y}} = D[C_{\overline{XX}} + C_{\overline{YY}}] + \frac{DK_T}{T_m}[T_{\overline{XX}} + T_{\overline{YY}}], \tag{5}$$

where C_p the specific heat, T the temperature, $\boldsymbol{\upsilon}$ the kinematic viscosity, K the thermal conductivity, D the mass diffusivity, K_T the thermal diffusion ratio, C_s the concentration susceptibility, σ the electric conductivity, Φ the constant heat addition/absorption, C the concentration, T_m the fluid mean temperature, T_0, T_1, C_0, C_1 the temperature and concentration at the lower and upper walls respectively, and subscripts $(\overline{X}, \overline{Y}, \bar{t})$ are used for the partial derivatives.

The present phenomenon can be transfer from laboratory frame to wave frame via the following relations

$$\bar{x} = \overline{X} - c\bar{t}, \bar{y} = \overline{Y}, \bar{u} = \overline{U} - c, \bar{v} = \overline{V}, \bar{p}(\bar{x},\bar{y}) = \overline{P}(\overline{X},\overline{Y},\bar{t}), \tag{6}$$

where 'c' is the speed of propagation of wave. Implementation of above transformations gives the following expressions

$$\frac{\partial\bar{u}}{\partial\bar{x}} + \frac{\partial\bar{v}}{\partial\bar{y}} = 0, \tag{7}$$

$$\rho\left((\bar{u}+c)\frac{\partial}{\partial\bar{x}} + \bar{v}\frac{\partial}{\partial\bar{y}}\right)(\bar{u}+c) = -\frac{\partial\bar{p}}{\partial\bar{x}} + \mu\left(\frac{\partial^2\bar{u}}{\partial\bar{x}^2} + \frac{\partial^2\bar{u}}{\partial\bar{y}^2}\right) - \sigma B_0^2(\bar{u}+c), \tag{8}$$

$$\rho\left((\bar{u}+c)\frac{\partial}{\partial\bar{x}} + \bar{v}\frac{\partial}{\partial\bar{y}}\right)\bar{v} = -\frac{\partial\bar{p}}{\partial\bar{y}} + \mu\left(\frac{\partial^2\bar{v}}{\partial\bar{x}^2} + \frac{\partial^2\bar{v}}{\partial\bar{y}^2}\right), \tag{9}$$

$$\begin{aligned} \rho C_p\left((\bar{u}+c)\tfrac{\partial}{\partial\bar{x}} + \bar{v}\tfrac{\partial}{\partial\bar{y}}\right)T &= K\left(\tfrac{\partial^2T}{\partial\bar{x}^2} + \tfrac{\partial^2T}{\partial\bar{y}^2}\right) + \mu\left[2\left\{\left(\tfrac{\partial\bar{u}}{\partial\bar{x}}\right)^2 + \left(\tfrac{\partial\bar{v}}{\partial\bar{y}}\right)^2\right\} + \left(\tfrac{\partial\bar{v}}{\partial\bar{x}} + \tfrac{\partial\bar{u}}{\partial\bar{y}}\right)^2\right] \\ &+ \tfrac{DK_T}{C_s}\left(\tfrac{\partial^2C}{\partial\bar{x}^2} + \tfrac{\partial^2C}{\partial\bar{y}^2}\right) + \sigma B_0^2(\bar{u}+c) + \Phi, \end{aligned} \tag{10}$$

$$\left((\bar{u}+c)\frac{\partial}{\partial\bar{x}} + \bar{v}\frac{\partial}{\partial\bar{y}}\right)C = D\left(\frac{\partial^2C}{\partial\bar{x}^2} + \frac{\partial^2C}{\partial\bar{y}^2}\right) + \frac{DK_T}{T_m}\left(\frac{\partial^2T}{\partial\bar{x}^2} + \frac{\partial^2T}{\partial\bar{y}^2}\right). \tag{11}$$