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ORIGINAL ARTICLE

Heat and mass transfer on magnetohydrodynamic peristaltic flow in a porous medium with partial slip

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Compliant walls

Abstract The present study concerned with the impact of velocity slip on MHD peristaltic flow through a porous medium with heat and mass transfer is investigated. The relevant equations of flow with heat and mass transfer have been developed. Analytic solution is carried out under long-wavelength and small Reynolds number approximations. The expressions for the stream function, temperature and concentration and the heat transfer coefficient are obtained. Numerical results are graphically discussed for various values of physical parameters of interest. The velocity and temperature field increase with an increase in the velocity slip parameter and permeability parameter while it decreases with an increase in the Hartmann number.

1. Introduction

The transportation of many biological fluids is carried out with the help of naturally inherited mechanism inside the biological systems which is called peristalsis. It is nature's way of moving the content within hollow muscular structures by successive contraction of their muscular fibers. This principle is responsible for transport of biological fluids such as urine in the ureter, chime in the gastrointestinal tract, semen in the vas deferens, ovum in the fallopian tube, lymph transport in the lymphatic vessels, blood pumps in the heart lung machine etc. In plant physiology, the peristalsis is involved in phloem translocation by driving a sucrose solution along tubules by peristaltic contractions. The corrosive and noxious fluids can also be transported by peristalsis. Such flows in presence of heat transfer also have great value. This process is useful for the analysis of tissues, oxygenation and dialysis. Roller and finger pumps also work under the peristaltic mechanism. The seminal research on the peristaltic motion has been presented by Latham [1] and Jaffrin and Shapiro [2]. Since then the various experimental and theoretical studies have been presented in the viscous and non-Newtonian fluids [3–10]. In view of the importance of oxygenation and dialysis, the peristaltic flows with heat transfer have been also investigated [11–14]. Peristaltic transport of a Carreau fluid in a compliant rectangular duct was presented by Riaz et al. [15]. A mathematical study of non-newtonian micropolar fluid in arterial blood flow through composite stenosis was investigated by Ellahi et al. [16]. The influence of heat and mass transfer on MHD peristaltic flow through a porous space with compliant walls was investigated by Srinivas et al. [17]. Ellahi [18] have reported the effects of MHD and temperature dependent viscosity on the flow of non-Newtonian nanofluid in a pipe. Very recently, the influence of Joule heating on MHD peristaltic flow of a nanofluid with compliant walls was investigated by Gnaneswara Reddy and Venugopal Reddy [19].

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In several applications the flow pattern corresponds to a slip flow, and the fluid presents a loss of adhesion at the wetted wall making the fluid slide along the wall. When the molecular mean free path length of the fluid is comparable to the distance between the plates as in nanochannels or microchannels, the fluid exhibits non-continuum effects such as slip-flow as demonstrated experimentally by Derek et al. [20]. Investigations of the effects of slip on the peristaltic motion have been recently reported in [21–23].

The aim of the present paper is to discuss the velocity slip effects on the MHD peristaltic transport of non-Newtonian fluid in a porous space with heat and mass transfer. Such an analysis is of great interest in bio-medical research. The momentum, temperature equations and concentration equations have been linearized under long-wavelength and low-Reynolds number assumptions and exact solutions for the flow fluid dynamical variables have been derived. The contribution of several interesting parameters embedded in the flow system is examined by graphical representations.

2. Formulation of the problem

The motion of heat and mass transfer peristaltic flow of a Newtonian viscous fluid through a two-dimensional channel of uniform thickness filled with a porous medium is considered. The motion in a channel is induced by imposing moderate amplitude sinusoidal waves on the compliant walls of the channel as shown in Fig. 1 and thus the walls are defined by

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

where d is the mean half width of the channel, a is the amplitude, λ is the wavelength, t is the time and c is the phase speed of the wave respectively.

The magnetic Reynolds number and induced magnetic field are assumed to be small and neglected. Under these assumptions the governing equations of continuity, momentum, heat transfer and mass transfer are as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0. \tag{2}$$

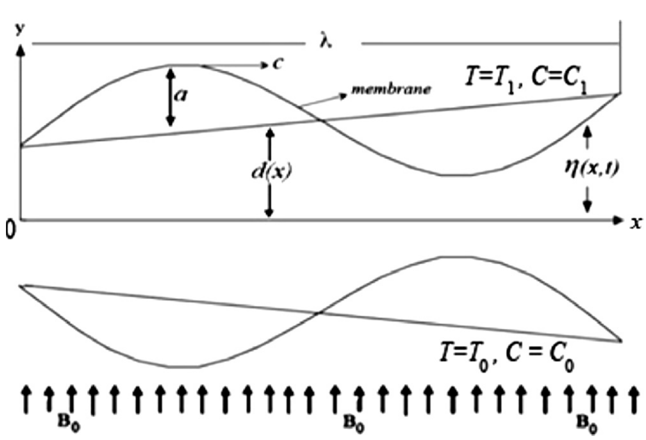

Figure 1 Schematic diagram of the problem.

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right] + \rho g\beta(T - T_0) + \rho g\beta^*(C - C_0) - \sigma B_0^2 u - \frac{\mu}{k}u. \tag{3}$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial p}{\partial y} + \mu\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right] - \frac{\mu}{\kappa}u. \tag{4}$$

$$\zeta\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = \frac{\kappa}{\rho}\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right] + v\left[\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + 2\left(\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2\right)\right] + \frac{\sigma B_0^2 u^2 \mu}{\rho}\left[2\left(\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2\right) + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2\right]. \tag{5}$$

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\left[\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\right] + \frac{DK_T}{T_m}\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right]. \tag{6}$$

where u, v are the components of velocity along x -and y directions, p is the pressure, μ is the coefficient of viscosity of the fluid, g is the gravitational acceleration, β is the coefficient of thermal expansion, β^* is the coefficient of concentration expansion, σ is the electrical conductivity of the fluid, k is the permeability parameter, B_0 is the applied magnetic field, α is the thermal diffusivity, v is the kinematic viscosity, ρ is the density of the fluid, ζ is the specific heat at constant pressure, k_1 is the chemical reaction of rate constant, T is the temperature, C is the concentration and D is the coefficient of mass diffusivity, K_T is the thermal-diffusion ratio, and T_m is the mean temperature.

The governing equation of motion of the flexible wall is expressed as

$$L^*(\eta) = p - p_0. \tag{7}$$

where L^* is an operator, which is used to represent the motion of stretching membrane with viscosity damping forces such that

$$L^* = -\tau\frac{\partial^2}{\partial x^2} + m\frac{\partial^2}{\partial t^2} + C'\frac{\partial}{\partial t} + B\frac{\partial^4}{\partial x^4} + H. \tag{8}$$

Here τ is the elastic tension in the membrane, m is the mass per unit area, C' is the coefficient of viscous damping forces, B is the flexural rigidity of the plate, H is the spring stiffness and p_0 is the pressure on the outside surface of the wall due to the tension in the muscles and assume that $p_0 = 0$.

The associated boundary conditions for the velocity slip, temperature and concentration at the wall interface are given by

$$u = \mp h\frac{\partial u}{\partial y},\ T = T_0 \text{ and } C = C_0 \text{ at } y = \pm\eta = \pm\left[d + a\sin\frac{2\pi}{\lambda}(x - t)\right]. \tag{9}$$

and the boundary conditions due to wall flexibility are

$$\frac{\partial}{\partial x}L^*(\eta) = \frac{\partial p}{\partial x} = \mu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right] - \rho\left[\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right] - \sigma B_0^2 u - \frac{\mu}{k}u \text{at } y = \pm\eta. \tag{10}$$