Applied Mathematics and Computation 213 (2009) 197–208

Contents lists available at ScienceDirect

Applied Mathematics and Computation

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

The influence of heat and mass transfer on MHD peristaltic flow through a porous space with compliant walls

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ARTICLE INFO

Keywords:
Peristalsis
Compliant walls
Porous medium
Heat and mass transfer
Schmidt number
Hartmann number

ABSTRACT

The present study investigates the effects of heat and mass transfer on peristaltic transport in a porous space with compliant walls. The fluid is electrically conducting in the presence of a uniform magnetic field. Analytic solution is carried out under long-wavelength and low-Reynolds number approximations. The expressions for stream function, temperature, concentration and heat transfer coefficient are obtained. Numerical results are graphically discussed for various values of physical parameters of interest.

1. Introduction

The transportation of fluid by a wave of contraction and expansion from a region of lower pressure to higher pressure is called peristaltic pumping. The study of peristaltic motion gained considerable interest because of its extensive applications. It is in inherent property of many biological systems. In living systems it is a distinctive pattern of smooth muscle contractions that propel the contents of the tube, as foodstuffs through esophagus and alimentary canal, urine from kidneys to bladder and other glandular ducts. The mechanism of peristaltic transport has been exploited for industrial applications like sanitary fluid transport, blood pumps in heart lung machine and transport of corrosive fluids where the contact of the fluid which the machinery parts is prohibited. Peristaltic transport of a toxic liquid is used in nuclear industry to avoid contamination of the outside environment. Extensive literature on the topic is now available and we can only mention a few recent interesting investigations in Refs. [1–25]. Abd Elnaby and Haroun [8] investigated the influence of compliant wall properties on peristaltic motion in two-dimensional channel, which is different from the model used by Mittra and Prasad [31] and Srivastava and Srivastava [34]. Muthu et al. [7] have analyzed the peristaltic motion of micropolar fluid in circular cylindrical tubes with elastic wall properties. Peristaltic flow of a Maxwell fluid in a channel with compliant walls has been investigated by Ali et al. [9]. Recently, Hayat et al. [10] have proposed a mathematical model to understand the MHD peristaltic motion of Johnson–Segalman fluid in a channel with compliant walls. Hayat et al. [23] have investigated the effects of compliant walls and porous space on the MHD peristaltic flow of a Jeffery fluid.

The interaction of peristalsis and heat transfer has also received some attention, as it might be relevant in processes like hemodialsysis and oxygenation. Victor and Shah [32] considered heat transfer to blood flowing in a tube assuming blood to be a Casson fluid. The interaction between peristalsis and heat transfer for the motion of a viscous incompressible fluid in a two-dimensional non-uniform channel has been studied by Radhakrishnamacharya and Radhakrishna Murthy [33]. Ogulu [35] studied heat and mass transport of blood in a single lymphatic blood vessel with uniform magnetic field. Vajravelu et al. [1] investigated peristaltic transport in a vertical porous annulus with heat transfer. Radhakrishnamacharya and Srinivasulu [3] have examined the influence of wall properties on peristaltic transport with heat transfer. Mekheimer and Abd elmaboud [11] analyzed the influence of heat transfer and magnetic field on peristaltic transport of a Newtonian fluid in a

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0096-3003/$ - see front matter
doi:10.1016/j.amc.2009.02.054

vertical annulus under a zero Reynolds number and long-wavelength approximations. Eldabe et al. [25] have studied the problem of peristaltic transport of a non-Newtonian fluid with variable viscosity in the presence of heat and mass transfer and mixed diffusion flow between a vertical wall that deforms in the shape of a traveling wave and a parallel flat wall. Srinivas and Kothandapani [12] have analyzed the magnetohydrodynamic (MHD) peristaltic flow of a viscous fluid in asymmetric channel with heat transfer. Recently, Kothandapani and Srinivas [13] have studied the influence of wall properties in the MHD peristaltic transport with heat transfer and porous medium. More recently, Hayat et al. [14] have examined the effect of heat transfer on the peristaltic flow of an electrically conducting fluid in a porous space.

When heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and the driving potentials are of more intricate nature. It has been found that an energy flux can be generated not only by temperature gradients but by composition gradients as well. The energy flux caused by a composition gradient is called the Dufour or diffusion-thermo effect. On the other hand, mass fluxes can also be created by temperature gradients and this is the Soret or thermal-diffusion effect. In general, the thermal-diffusion and diffusion-thermo effects are of a smaller order of magnitude than the effects described by Fourier's or Fick's law and are often neglected in heat and mass transfer processes. However, exceptions are observed therein. Due to the importance of Soret (thermal-diffusion) and Dufour (diffusion-thermo) effects for the fluids with very light molecular weight as well as medium molecular weight many investigators have studied and reported results for these flows of whom the names are Eckert and Drake [27], Dursunkaya and Worek [28], Postelnicu [29], Alam et al. [30] are worth mentioning.

To the best of our knowledge the influence of heat and mass transfer analysis on peristaltic flow of viscous fluid in a channel with compliant walls has not been studied before. We know that oxygen and other nutrients are transported in the blood vessels but need to diffuse into the tissue where they are needed for sustenance of life, hence the motivation for this investigation. Therefore the main goal here is to study the effect of heat and mass transfer on MHD peristaltic flow analysis of a Newtonian fluid in porous channel with compliant walls and thermal-diffusion. The momentum, energy equations and concentration equations have been linearized under long-wavelength and low-Reynolds number assumptions and analytical solutions for the flow variables have been derived. The obtained expressions are utilized to discuss the influence of various emerging parameters.

2. Mathematical formulation and solution

Consider the flow of a Newtonian viscous fluid through a two-dimensional channel of uniform thickness. The motion in a channel are induced by imposing moderate amplitude sinusoidal waves on the compliant walls of the channel 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.

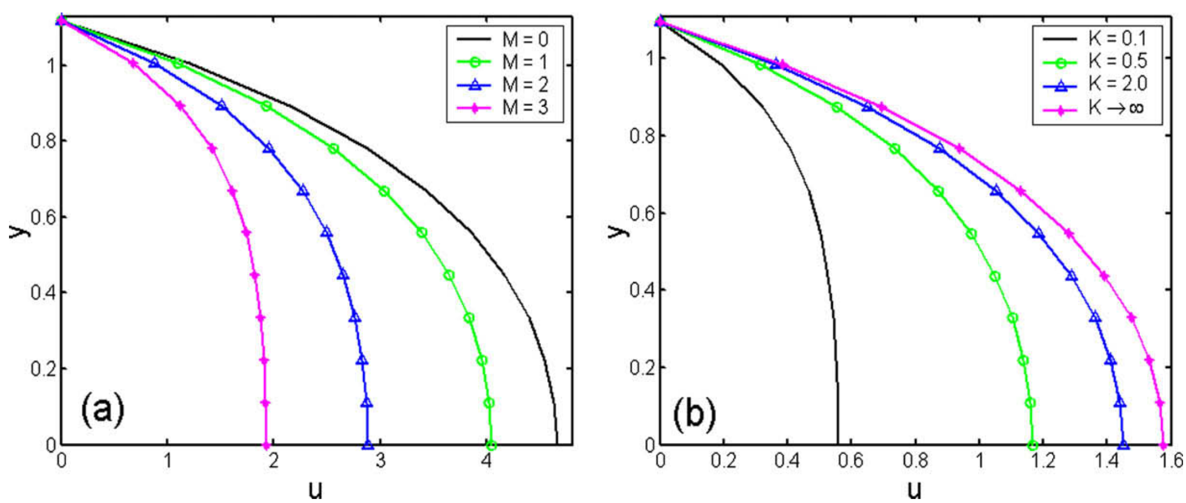

Fig. 1. The velocity distribution: (a) $E_1 = 1$, $E_2 = 1$, $E_3 = 0.3$, $E_4 = 0.02$, $E_5 = 0.3$, $\varepsilon = 0.1$, $M = 2$, $x = 0.3$, $t = 0.1$; (b) $E_1 = 1$, $E_2 = 0.5$, $E_3 = 0.1$, $E_4 = 0.02$, $E_5 = 0.2$, $\varepsilon = 0.2$, $K = 0.2$, $x = 0.2$, $t = 0.1$.