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# Peristaltic transport of nanofluid in a compliant wall channel with convective conditions and thermal radiation

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ABSTRACT

Impact of thermal radiation on peristaltic transport of nanofluid in a channel satisfying wall properties and convective conditions is investigated. The considered model of nanofluid includes the effects of Brownian motion and thermophoresis. Long wavelength and low Reynolds number approach is followed in the mathematical modeling and development of solutions. Shooting technique is implemented for the numerical solutions of resulting nonlinear differential systems. The salient features of pertinent parameters like Brownian motion parameter, thermophoresis parameter, thermal radiation parameter, Prandtl number and Eckert number on the physical quantities of interest are discussed. It is found that the influence of thermal radiation parameter and the Biot number on the temperature and concentration are quite opposite. Further the heat transfer coefficient decreases when thermal radiation parameter is increased.

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## 1. Introduction

Peristalsis is an important mechanism of fluid transport when a progressive waves of area contraction or expansion propagates along the flexible walls of the channel or tube. Such flows frequently encountered in physiology and industrial applications like urine transport from kidney to bladder, swallowing food through esophagus, ovum movement in the female fallopian tube, vasomotion of small blood vessels, lymph transport in the lymphatic vessels, sanitary and corrosive fluids transport, blood pumps in heart lung machine and several others. Such mechanism in presence of heat transfer is regarded very useful in the hemodialysis and oxygenation process. Biomedical engineers have been attracted for the analysis of bio heat transfer in tissues for thermotherapy and thermoregulation system. It is also noted that several engineering process involve the simultaneous effects of heat and mass transfer. Particularly the mention may be made for chemical distillatory process, channel type solar energy collectors, design of heat exchangers, thermo-protection systems in this direction. Through such importance, various researches in the past have discussed the peristaltic flows through diverse aspects (see [1–10]). The existing literature on this topic however indicates that little attention is given to the interaction of peristalsis effects of heat and mass transfer. In fact Mitra and Prasad [11] explored compliant wall effects in the peristaltic motion of viscous fluid. Effects of wall properties on peristalsis in a non-uniform channel are described by Srinivasulu and Radhakrishnamacharya [12] Srinivasasacharya et al. [13] examined the wall properties characteristics in the peristaltic transport of dusty fluid. Radhakrishnamacharya and Srinivasulu [14] explained interaction of heat transfer and wall properties. Muthu et al. [15] revisited the study in ref. [11] for microploar fluid. Elnaby and Haroun [16] analyzed elastic properties of channel walls on the peristaltic transport of an incompressible viscous fluid. Heat transfer and magnetohydrodynamic (MHD) influences in a channel with elastic properties are described by Srinivas [17] and Srinivas and Kothadapani [18]. Peristaltic motion of Johnson-Segalman and Maxwell fluids in a flexible walls channel is examined by Hayat et al. [19,20] and Hayat and Hina [21] respectively. Peristaltic motion of viscous and third order fluids in a compliant wall curved channel is modeled by Hayat et al. [22,23]. Very recently, Mustafa et al. [24] examined the peristaltic transport of viscous nanofluid in a compliant wall channel.

All the aforementioned investigations witness that information for peristalsis of nanofluids in existing literature is scarce. No doubt the nanotechnology is hot topic of research at present. Keeping such facts in mind Shehzad et al. [25] performed a comparative study of peristaltic transport of water based nanofluid. Hayat et al. [26] investigated the magnetohydrodynamic three-dimensional flow of viscoelastic nanofluid subject to non-linear thermal radiation. Zhang et al. [27] studied the MHD radiative flow of nanofluids saturating porous media, variable surface heat flux and chemical reaction. Boundary layer flow of nanofluid over a convectively heated nonlinear stretching surface is reported by Mustafa et al. [28]. Sheikholeslami and Ellahi [29] investigated the three-dimensional flow of nanofluid in the presence of magnetic field and natural convection. Abbasi et al. [30] analyzed the

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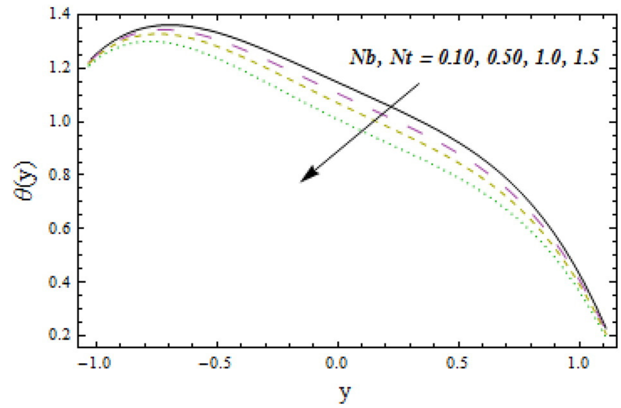


**Fig. 1.** Effects of $Nb$ and $Nt$ on temperature when $x=\varepsilon=0.2$, $t=0.1$, $E_1=0.02$, $E_2=0.03$, $E_3=0.02$, $\Pr=Ec=1$, $R_d=0.2$ and $Bi=10$.

hydromagnetic flow of Jeffrey nanofluid subject to heat and mass flux conditions. The non-Darcy natural convection flow of non-Newtonian nanofluid in presence of uniform heat and volume fraction fluxes is measured by Chamkha et al. [31]. Turkyilmazoglu [32] studied the effects of nanofluid flow due to rotating disk with heat transfer. Several recent researchers [33–44] are further engaged in advancements of flow models of nanofluids. The nanofluids are quite useful in modulators, optical switches, optical gratings, medicine, sink float separations, cancer therapy, drug delivery, magnetic cell separation and hyperthermia. On the other hand, the heat transfer in the literature has been dealt with either through the prescribed temperature or heat flux at the surface. Not much has been paid about the heat transfer mechanism via convective conditions. Thus the main objective of present attempt is to discuss the peristaltic flow of nanofluid in a compliant wall channel with convective boundary conditions. In addition, the thermal radiation effects are considered. Analysis has been examined for large wavelength and Small Reynolds number considerations. Shooting technique is used for the solution analysis. Impact of sundry variables on physical quantities of interest is pointed out.

## 2. Development of problem

Consider the peristaltic flow of an incompressible nanofluid in a channel of uniform thickness $2d_1$. The $x$-axis is taken along the channel walls while the $y$-axis is assumed normal to walls. Flow is generated due to propagation of peristaltic waves along the channel walls. The wall shapes of such peristaltic waves are put into the following forms:

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

where $c$ is the wave speed and $a$ and $\lambda$ are the amplitude and wavelength respectively. Here heat transfer analysis is carried out through convective conditions at the channel walls. Further the thermal radiation and viscous dissipation effects are present. The equations which can govern the present flow and heat transfer analysis are

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

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_f}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right), \tag{3}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho_f}\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right), \tag{4}$$

$$\begin{aligned}\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}&=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+\frac{\nu}{c_f}\left[4\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)^2\right]\\&-\frac{1}{\rho_f c_f}\frac{\partial q_r}{\partial y}+\tau\left[D_B\left(\frac{\partial C}{\partial x}\frac{\partial T}{\partial x}+\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}\right)+\frac{D_T}{T_m}\left\{\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2\right\}\right],\end{aligned} \tag{5}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)+\frac{D_T}{T_m}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right). \tag{6}$$

The subject boundary conditions can be put into the forms

$$u=0,\quad -k\frac{\partial T}{\partial y}=h\left\{\begin{matrix}T-T_0\\T_1-T\end{matrix}\right\},\quad C=\left\{\begin{matrix}C_1\\C_0\end{matrix}\right\}\quad \text{at } y=\pm\eta \tag{7}$$

$$\begin{aligned}&\left[-\tau_1\frac{\partial^3}{\partial x^3}+m_1\frac{\partial^3}{\partial x\partial t^2}+d\frac{\partial^2}{\partial t\partial x}\right]\eta=\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)\\&\quad-\rho_f\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)\quad \text{at } y=\pm\eta.\end{aligned} \tag{8}$$

In above equations $u$ and $v$ are the velocity components along the $x$ and $y$ directions respectively, $p$ the pressure, $\rho_f$ the density of the nanofluid, $\nu$ the kinematic viscosity, $\alpha$ the thermal diffusivity, $D_B$ the Brownian motion coefficient, $D_T$ the thermophoretic diffusion coefficient, $\tau$ $(=(\rho c)_p/(\rho c)_f)$ the ratio of effective heat capacity of the nanoparticle material to heat capacity of the fluid, $\tau_1$ the elastic tension, $m_1$ the mass per unit area, $d$ the coefficient of viscous damping, $k$ the thermal conductivity, $h$ the heat transfer coefficient, $T_m$ the mean temperature, $T_0$ and $T_1$ the respective temperatures at the upper and lower walls and $C_1$ and $C_0$ the concentration at the upper and lower walls respectively.

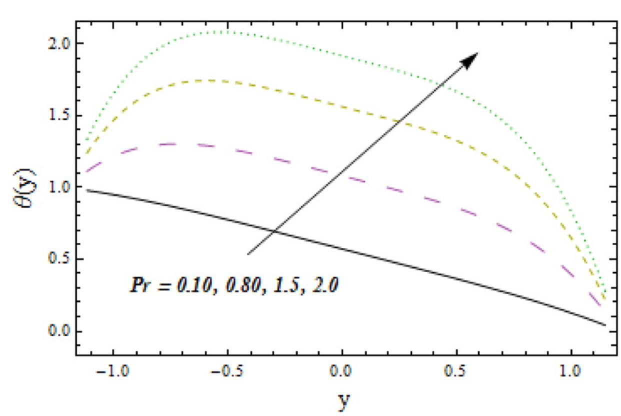


**Fig. 2.** Effect of Pr on temperature when $x=\varepsilon=0.2$, $t=0.1$, $E_1=0.02$, $E_2=0.03$, $E_3=0.02$, $Ec=1$, $R_d=0.2$, $Nb=Nt=0.10$ and $Bi=10$.

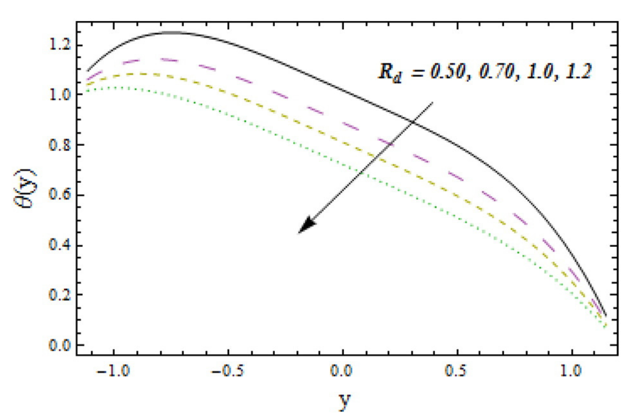


**Fig. 3.** Effect of $R_d$ on temperature when $x=\varepsilon=0.2$, $t=0.1$, $E_1=0.02$, $E_2=0.03$, $E_3=0.02$, $\Pr=Ec=1$, $Nb=Nt=0.10$ and $Bi=10$.

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