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Peristaltic flow of Powell-Eyring fluid in curved channel with heat transfer: A useful application in biomedicine

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ABSTRACT

Background and objective: In this work, we explore the heat transfer characteristics in the peristaltic transport of Powell-Eyring fluid inside a curved channel with complaint walls. The study has motivation toward the understanding of blood flow in microcirculatory system.
Method: Formulation is developed in the existence of velocity slip and temperature jump conditions. Perturbation approach has been utilized to present series expressions of axial velocity and temperature distributions. Streamlines are prepared to analyze the interesting phenomenon of trapping. Moreover, the plots of heat transfer coefficient for a broad range of embedded parameters are presented and discussed.
Results: The results indicate that slip effects substantially influence the velocity and temperature distributions. Axial flow accelerates when slip parameter is incremented. Temperature rises and wall heat flux grows when viscous dissipation effect is strengthened. In contrast to the planar channels, here velocity and temperature functions do not exhibit symmetry with respect to the central line. In addition, bolus size and its shape are different in upper and lower portions of the channel.
Conclusions: Heat transfer coefficient enlarges when the curvature effects are reduced. The behaviors of wall tension and wall mass parameters on the profiles are qualitatively similar.

1. Introduction

The process in which physiological fluid is transported by means of periodic progressive waves advancing axially across the length of distensible tube is termed as peristalsis. The phenomenon of peristalsis is widely recognized by physiologists because it is one of the key mechanisms for fluid transport in biological systems such as passage of urine from kidneys to the bladder through ureter, transport of spermatozoa in the ductus efferentus of male reproductive tract and in the cervical canal, transport of lymph in the lymphatic vessels, movement of ovum in fallopian tube, swallowing of food bolus through esophagus and embryo transport in non-pregnant uterus. Apart from this, peristalsis is also involved in the design of mechanical components like heart–lung machine, roller and finger pumps and cell separators. It is important to note that the fluid involved in the aforementioned applications is usually non-Newtonian. Due to this reason, the researchers paid special attention to the peristalsis of non-Newtonian fluids. For example,

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Nomenclature

t	time
x,r	space coordinates
u,v	velocity components
a	wave amplitude
c	wave speed
Br	Brinkman number
T	local fluid temperature
d_1	half width of the channel
c_1	material fluid parameter
p	pressure
E_1,E_2,E_3	complaint wall parameters
A,B	non-dimensional material fluid parameters
Re	Reynolds number
k	curvature parameter
C_p	specific heat
R^*	radius of the channel
m	mass per unit area
d	viscous damping coefficient
Pr	Prandtl number
Ec	Eckert number

Greek symbols

β_1,β_2	velocity and thermal slip parameters
$\tau_{rx},\tau_{rr},\tau_{xx}$	components of the extra stress tensor
δ	wave number
θ	dimensionless temperature
κ	thermal conductivity
ρ	fluid density
μ	dynamic viscosity

peristalsis of viscoelastic fluid filling a porous space was addressed by Abd elmaboud and Mekheimer [1]. Transient peristaltic motion of biofluids with an application in digestive transport was discussed by Tripathi and Beg [2]. Hayat et al. [3] provided numerical approximations for peristaltically induced flow of Carreau–Yasuda fluid through a curved passage. Mustafa et al. [4] used implicit finite difference method to study the mixed convection flow of fourth-grade fluid with peristalsis. Kothandapani et al. [5] examined the MHD peristaltic flow of Carreau fluid in a tapered channel. Influence of nanoparticles on the peristaltic flow of Willamson fluid with thermal radiation was reported by Kothandapani and Prakash [6]. Recently, numerical solution for peristaltic motion of Bingham fluid at large Reynolds number was presented by Khabazi et al. [7]. Application of differential transform method (DTM) for solving non-linear problem arising in the peristaltic motion of viscoelastic fluid was discussed by Tripathi et al. [8]. Abd-Alla et al. [9] examined the consequences of radially varying magnetic field strength on peristaltic transport of Jeffrey fluid with an endoscope. Hall effects on peristaltically induced flow of Willamson fluid filling a porous space were addressed by Eldabe et al. [10]. Peristalsis of Ellis fluid through a planar channel was numerically addressed by Ali et al. [11]. Exact solutions for peristaltic flow of Jeffery fluid filled with nanoparticles were provided by Ebaid et al. [12]. In this work, some serious shortcomings of homotopy perturbation method (HPM) for peristaltic flows were highlighted. Ramesh and Devakar [13] studied the consequences of couple stresses on peristaltic transport in an inclined channel with magnetic field. Analytical solutions for peristaltic/blood flow containing nanoparticles were obtained by Ghasemi et al. [14]. In another study, Ghasemi et al. [15] presented analytical and numerical simulations for peristaltic motion of nanofluid. Ghasemi et al. [16] also discussed the pulsatile flow of blood in femoral and coronary arteries through an efficient differential quadrature method.

No-slip condition is not practically applicable for the non-Newtonian fluids because these possess macroscopic wall slip effects. Slip conditions are also appropriate for rough surfaces and in micro-electro-mechanical-components (MEMS). The slip condition in the fluid flow is of special value when the boundary is composed of foams, emulsions, suspensions and polymer solutions. Particularly, the slip condition has importance in industrial applications such as polishing of artificial heart valves, rarefied fluid problems in polymer industry and flow on multiple interfaces. Chu and Fung [17] first discussed the peristaltic mechanism in the presence of slip effects using conventional assumptions of negligible inertial effects and long wavelength of channel wall. Later, Ali et al. [18] developed numerical solutions for peristalsis in circular cylindrical tube considering third grade fluid. Chaube et al. [19] examined the slip flow of micropolar fluid with peristalsis. Peristalsis of Williamson fluid with velocity slip and temperature jump conditions was addressed by Hayat and Hina [20]. Some recent attempts involving peristaltic flow problem with slip conditions can be found in refs [21–25].

Peristalsis with curved channel is practically important since most of the arteries and blood vessels in human body are curved. First of all Sato et al. [26] explored the peristaltic flow problem for a curved channel. Then peristalsis of non-Newtonian fluids inside curved channel was addressed by some researchers (see Ali et al. [27], Hina et al. [28,29], Ramanamurthy et al. [30], Kalantari et al. [31] etc.). Heat transfer analysis for peristaltic transport in curved channel was initially discussed by Ali et al. [32]. Recent attempts in this direction are presented by Hina et al. [33], Narla et al. [34] and Hina et al. [35]. Main objective here is to venture further in this regime. Therefore, we study the behaviors of velocity and thermal slip conditions on the peristaltic motion of Powell-Eyring fluid in a curved channel with complaint walls. Energy balance equation is formulated with heat dissipation effects. Analytical solutions of velocity and temperature distributions are obtained by means of perturbation method. Graphical illustrations are used to emphasize the role of pertinent parameters on the solutions.

2. Mathematical modeling

We consider the peristaltic flow of Powell-Eyring fluid in a curved channel wall slip effects. Heat transfer due to viscous dissipation is also considered. Curved channel having width $2d_1$ is coiled in a circle of center C and radius R^*. Flow is induced by the sinusoidal waves advancing axially across the channel walls (see Fig. 1). The channel walls are flexible and possess neuromuscular properties of any tubular smooth muscle. Before the initiation of peristaltic activity, the channel walls support the hydrostatic pressure p. This has been catered by introducing