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Impact of wall properties on the peristaltic flow of Cu-water nano fluid in a non-uniform inclined tube

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A B S T R A C T

The objective of this paper is to study the influence of wall properties and Cu-water nano fluid in a non-uniform inclined tube. In this analysis, two dimensional flow of a viscous nano fluid generated by peristaltic motion is observed, thermal and velocity slip effects are also taken into account. The features of peristaltic structures are determined by the dominance of viscous effects over inertial effects using the long wave length approximation. Exact solutions have been established for both velocity and temperature profiles, which include nanoparticle effects. Graphical results are also obtained for both velocity, temperature profile and trapping phenomena is also discussed. Temperature profile decreases by increasing values of nanoparticle volume fraction. This justifies the use of the nanoparticle in different type as a coolant.

1. Introduction

Peristaltic transport is the mechanism of fluid flow produced by a generation of wave trains along the channel/tube walls. This mechanism is useful where the pumping machinery is not available and generally this mechanism produced by, variation of pressure difference. Initially this mechanism was utilized by physiologist for fluid transport in many living organisms like blood flow in vessels, swallowing of food through esophagus, sperm pumping in ducts, lymph movement in lymphatic vessels, chyme movement in intestinal tract, transport of bile in bile ducts, etc. This principle was further adopted by biomedical engineers for many artificial appliances such as finger pumps, roller pumps, heart lung machine and dialysis machine. Intensive research was carried out by different research groups [1,2] to explicate the behavior of peristalsis in different conditions [3–11].

Heat transfer in peristaltic motion is also very important aspect and has wide-ranging applications in biomedical sciences, engineering and industry. Heat transfer is usually related to generation usage, transmission and exchange of thermal energy and heat among physical systems like oxygenation process, dilution technique in examining blood flow, heat conduction, heat generation and radiation, metabolism between surface and environment, hypothermic and cooling system of industrial equipment.

Shina et al. [12] studied peristaltic flow of Magneto hydrodynamics (MHD) and heat transfer in an asymmetric channel in the presence of variable viscosity and velocity- temperature slip conditions. Advancements in Nanotechnology has resulted in improved investigation processes by enhancement in properties such as thermal and physical properties of poor transmitting fluids like water, vinegar and kerosene oil etc. Conduction during heat transfer can also be boosted by adding nano- scaled metal particles. This can result in enhancement in behavior of heat transfer systems. Further utilizing nano fluids have also resulted in advancement in medical and engineering sciences. Previously few numerical models were developed by researchers to investigate the properties of nano particles and their impacts in various situations. The comprehension of nano scaled metal particles used for poor heat conductors as liquids/coolants was first presented by Maxwell [13]. After that, variety of hypothetical models were studied by Hamilton and Wasp [14–15]. Due to further developments and disclosure of many nanoparticles, research in the field of nano fluid got widespread attention. Nanoparticle suspension as a nano fluid was first presented by Choi et al. [16,17]. Buongiorno [18] simplified the mathematical formulation of nano fluids, where author stated that the fundamental mechanics principles contribute to Brownian diffusion, thermophoresis and thermal enhancement. Nano fluid flow and heat transfer models are usually categorized into two distinct models known as single and two phase models [19–27].

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Nomenclature

r, z	radial and axial direction in wave frame	σ	elastic tension in the membrane
c	wave speed	l_2	Radius of the non – uniform tube
λ	wave length	L^*	velocity slip parameter
C'	coefficient of viscous damping force	γ^*	thermal slip parameter
k	non-uniform parameter	m	mass per unit area
B	heat source/sink parameter	τ_{rz}	shear stress
ε	amplitude ratio	E_1	rigidity parameter
p	pressure	E_2	stiffness parameter
Re	Reynolds's number	E_3	viscous damping force parameter

The single phase and two phase model differ from each other on many fronts majorly actual properties of fluid are studied under single phase apart from nanoparticles and base fluid, whereas energy equations, momentum and continuity are studied by two phase model.

Kuznetsov and Nield [28] generalized this study of nanofluids into boundary layer model for free convective flows. Properties of heat transfer and nanofluid in revolving system using binary horizontal plates was observed by Sheikholeslami et al. [29]. Authors observed that the heat transfer rate usually rises in base fluid containing nanoparticles during suction and injection.

Raza et al. [30] investigated the effect of various branches of the solution containing copper- water nano fluid in a channel focusing on contraction and expansion of walls. Non-Newtonian copper-water nano fluid was studied by Domairry et al. [31] where authors observed natural convection, infinite parallel and binary vertical plates. This study revealed that boundary layer thickness is directly related to nanoparticles size and thermal boundary layer is inversely related to the size of nanoparticles. Raza et al. [32] investigated numerically stretching walls of copper water nanofluid in a channel and it was stated that if the values for solid volume fraction and suction are enhanced, heat transfer rate can be increased.

Sheikholeslami et al. [33–35] studied two-phase model where they studied the relationship between friction factor and convective heat transfer coefficients with the help of experimental results, whereas they also investigated nanofluid Simulation for two phase model in various fluid flow topologies.

Freidoonimehr et al. [36] observed unsteady MHD free convective flow past a permeable stretching vertical surface in a nanofluid. N. Akbar [37] also considered Cu-water nanofluids and discussed Mathematical model for ciliary-induced transport with magnetic induction in MHD flow. Another study of N. Akbar [38] Biomechanically driven unsteady non-uniform flow of Cu-water and silver water nanofluids through finite length channel. [39] Akbar et al. studied Analysis of Heat and mass transfer of Unsteady MHD Nano fluid flow through a channel with moving porous walls and medium. Garoosi et al. [40] investigated numerically Natural convection heat transfer of nanofluid in heat exchangers using a Buongiorno model, and it was observed by authors that size reduction of the nanoparticles contributes to increase in heat transfer rate.

Study of nano particle with temperature dependent viscosity and shape factor over heated tube with heat transfer also carefully investigated by Bint ul Hunda et al. [41]. Akbar et al. [42] studied Analysis of convective heat transfer of nanofluids (particle shape effects) through a flexible tube with buoyancy effects.

Effect of slip on solid boundaries was studied by many researchers [43–47] and observed that at low levels, slip has many applications in nano or macro-channels. Slip usually affects when boundaries are specially lubricated with a coating of thick mono-layer of hydrophobic octadecyl-thichorosilane or a thin layer of light oil is positioned on moving walls and many other engineering applications. Slip effect attained interest of many researchers [Yu and Ameel [43], Watannebe et al. [44], Jain and Sharma [45], Khaled and Vafai [46] and Akbar[47]]. Nonlinear equations can help to solve the problems arises during Cu-water nanofluid through a channel with stretching MHD flow and heat transfer associated to walls under the slip effects. Choi [48] studied mixed convection in an inclined channel with discrete heat source. K. Maruthi [49] analyzed the peristaltic transport of a nanofluid in an inclined tube. For a detail study of peristaltic flow of nano fluid with entropy generation we refer the reader to [50–51].

In the present study we investigated the influence of wall properties on peristaltic transport through a non-uniform inclined tube with nano particles and slip effects. Water as base fluid is used and copper nano particles are incorporated. The problem is first modeled and then exact solutions are obtained for velocity and temperature, Stream function also observed using velocity function. Results obtained and discussed for the flow over the geometry at different values of relevant parameters. Moreover, the trapping phenomenon is also investigated with the help of streamlines.

2. Mathematical formulation

We have carefully studied the peristaltic motion phenomenon for the two dimensional flow of an incompressible viscous nano fluid in a non-uniform inclined tube (shown in Fig. 1). The equations for conservation of mass, momentum and energy can be written as:

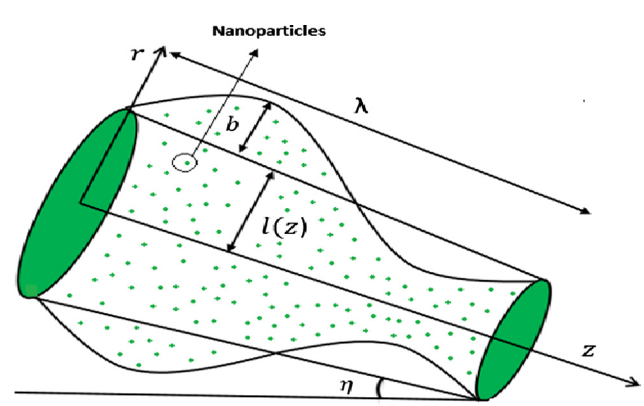

Fig. 1. Geometry of the problem. (a) k = 1.5, γ = 0.1, l_2 = 0.3, λ = 0.1, z = 0.1, ε = 0.2, t = 0.2 (b) ϕ = 0.1, k = 1.5, B = 0.1, λ = 0.1, l_2 = 0.3, z = 0.1, ε = 0.2, t = 0.2 (c) ϕ = 0.1, k = 1.5, B = 0.1, l_2 = 0.3, z = 0.1, ε = 0.2, t = 0.2.