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Natural Propulsion with Lorentz Force and Nanoparticles in a Bioinspired Lopsided Ciliated Channel

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Abstract

The transportation of biological and industrial nanofluids by natural propulsion like cilia movement and self-generated contraction-relaxation of flexible walls has tremendous applications in various fields. Inspired by multidisciplinary invention in this direction, a fluid mechanical model is proposed to study the Magneto-hydrodynamics (MHD) and heat transfer for nanofluids fabricated by the dispersion of nanoparticles in water as base fluid. The steady flow is induced by metachronal wave propulsion due to beating cilia. The flow regime is asymmetric channel. The flow is restricted under the low Reynolds number and long wavelength approximations. Cilia boundary conditions for velocity components are employed to find the exact solutions. The impacts of pertinent physical parameters on temperature profile, velocity profile, pressure, and stream lines are computed numerically. It is observed that velocity is inversely proportional to magnetic Reynolds number, Reynolds number, Strommer's number and velocity is directly proportional to flow rate. It is analyzed that temperature is inversely proportional to Strommer's number and magnetic Reynolds number and directly proportional to Brinkmann number and flow rate. The temperature is maximum at the center of the channel and it starts decreasing towards the boundary walls.

Keywords: copper water, nanoparticles, induced magnetic field, asymmetric ciliated channel

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1 Introduction

Suspensions of solid submicron- and nanometer-sized particles in various fluids (also called nanofluids) have been considered for applications as advanced heat transfer fluids for almost two decades. The use of nanofluids is to improve the heat-transfer performance of the working fluids because they primarily work as a coolant in heat transfer equipments. The cooling efficiency of a nanofluid is assessed in terms of its thermophysical properties. This idea was first conceived by Choi and Eastman[1]. Nanofluids have been found to possess enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of base fluids like oil or water[2–5]. Researchers have studied nanofluids and their numerous properties. Buongiorno[6] studied the effect of heat transfer on the transport of nanofluid. Akbar and Nadeem[7] studied the flow of Jeffrey nanofluid under the effect of magnetic field with mixed convection. Ebaid *et al*.[8,9] thoroughly discussed the boundary layer flow of nanofluids. Exact solutions are then obtained for the governing system at special cases of the physical parameters. Also an excellent accuracy is resulted on comparing them with those in the standard literature. Very recently Akbar[10–12] discussed the peristaltic flow in connection with the nanofluids for different geometries and analyzed that the velocity field for Cu-water is higher than for pure water. We have considered that the wall of the tube is ciliated with hairlike structures. The purpose of cilia is to the transport of the fluid. When a group of cilia operate together Metachronal waves are produced which apply a force on the fluid to move it in the direction of the effective stroke. Resistance is also faced by cilia during that particular effective stroke. The contact among cilia and their location has appealed physicians and engineers in the last few decades, who

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have been particularly interested by the potential use of cilia based actuators as micro liquidizers, for stream controller in tiny biosensors or as micro pumps for drug-delivery systems.

The asymmetric channel is generated by propagation of waves on the channel walls travelling with the same speed but different amplitudes and phases. Recently, Elshehawy *et al*.[13] studied the peristaltic transport in an asymmetric channel through a porous medium. Akbar *et al*.[14] examined the Interaction of nanoparticles for the peristaltic flow in an asymmetric channel with the induced magnetic field. Mekheimer and Abd elmaboud[15] discussed the influence of heat transfer and magnetic field on peristaltic transport of a Newtonian fluid in a vertical annulus. A study of ureteral peristalsis in cylindrical tube through porous medium is made by Rathod and Channakote[16]. Magneto-hydrodynamics (MHD) deals with the motion of highly conducting fluids in the presence of a magnetic field. Ebaid[15] discussed effects of magnetic field and wall slip conditions on the peristaltic transport of a Newtonian fluid in an asymmetric channel. The action of the magnetic field on these currents gives rise to mechanical forces which modify the flow of the fluid. The combined effect of heat and mass transfer is mostly useful in the chemical industry and in reservoir engineering in connection with thermal recovery process and may be found in salty springs in the sea. Further literatures can be viewed through Refs.[18–30].

In this paper the authors have discussed the flow of a nanofluid in ciliated asymmetric channel under the effect of induced magnetic field. We describe ciliary motion of the transport of fluids in human body based on the mathematical model of the copper nanofluid, with pure water as the base fluid. Basically the health benefits of copper include proper growth, utilization of iron, enzymatic reactions, connective tissues, hair, eyes, ageing and energy production. Apart from these, heart rhythm, thyroid glands, arthritis, wound healing, Red Blood Cells (RBC) formation and our cholesterol level are other health areas where role of copper is very important. The human body has complex homeostatic mechanism which attempts to ensure a constant supply of available copper, while eliminating excess copper whenever this occurs. Standards adopted by some nations recommend different copper intake levels for adults, women, infants, and children, corresponding to the varying needs for copper during different stages of life.

Inspired from multidisciplinary invention in this direction, a fluid mechanical model is proposed to study the MHD and heat transfer for nanofluids fabricated by the dispersion of nanoparticles in water as base fluid. The steady flow is induced by Metachronal wave propulsion due to beating cilia. The flow regime is asymmetric channel. The flow is restricted under the low Reynolds number and long wavelength approximations. Cilia boundary conditions for velocity components are employed to find the exact solutions. In the following sections we have discussed the formulation of the governing problem. The obtained expressions for velocity, temperature, pressure rise and pressure gradient are discussed graphically through variation in physical parameters. Streamlines are also drawn to discuss the trapping phenomenon in section **3**. Conclusion is presented in section **4**.

2 Mathematical modeling

We consider an incompressible nano fluid in an irregular channel under influence of inclined MHD with channel width d_1+d_2. Heat transfer is also taken into account. Sinusoidal wave propagate along the walls of the channel with constant speed c. The somatic model and harmonize system are shown in Fig. 1.

2.1 Flow equations

Irregularity in the channel flow is due to the following wall surfaces expressions that occurs due to the

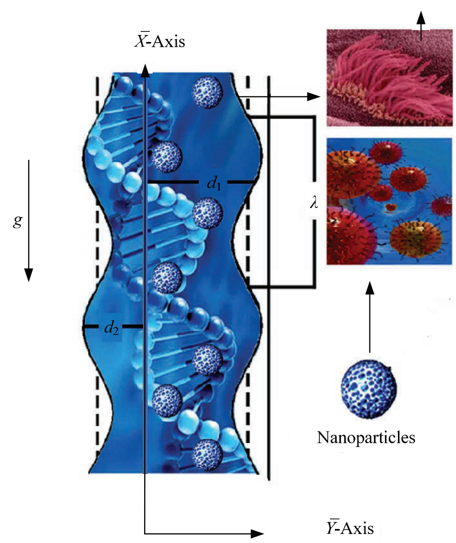

Fig. 1 Diagram of the projected model geometry.