COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 131 (2016) 169–180

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Influences of slip and Cu-blood nanofluid in a physiological study of cilia

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ARTICLE INFO

Article history:
Received 8 January 2016
Received in revised form
14 March 2016
Accepted 7 April 2016

Keywords:
Cu-blood nanofluids
Cilia-induced flow
Curved channel
Slip conditions
Metachronal wave
Exact solution

ABSTRACT

Objective: The objective of this paper is to study the influences of slip and Cu-blood nanofluid in a physiological study of cilia.

Design/methodology/approach: The right wall and the left wall possess metachronal wave that is traveling along the outer boundary of the channel. The features of ciliary structures are determined by the dominance of viscous effects over inertial effects using the long wavelength approximation. The flow possessions for the viscous nano fluid are solved as a function of the cilia and metachronal wave velocity. Mathematica numerical simulation is used to calculate pressure rise. Exact solutions are calculated for the temperature and for the velocity profile.

Findings: Numerical integration has been implemented to get the expression of pressure rise. Graphical results have been offered for pressure rise, temperature and stream function for various physical parameters of interest. Symmetry of the curved channel is recovered for larger values of the curvature parameter. It is found from the graphs of the pressure rise that reflux case occurs for increasing values of curvature and velocity slip parameter. It is also found that temperature decreases for increasing values of nanoparticle volume fraction. Basically, higher thermal conductivity of the nanoparticles plays a key role for quick heat dissipation, and this justifies the use of the copper nanoparticles in different situations as a coolant.

Conclusions: Velocity graph near the right wall of the channel decreases when we add nanoparticles into our base fluid, whereas an opposite behavior is depicted near the left wall due to ciliated tips. Pressure gradient increases for increasing values of G_r (Grashof number), L (velocity slip parameter) ϕ (nanoparticle volume fraction) and k (curvature parameter). Pressure rise shows increasing behavior for the increasing values of ε, G_r and ϕ throughout the region. Shear stress graphs show the increasing behavior for increasing values of curvature parameter and volume fraction of the nanoparticle. Temperature profile decreases when we add nanoparticles into our base fluid. Temperature profile also increases with an increase in thermal slip parameter γ and heat absorption parameter. It is observed that the number of trapped bolus increases when we increase the value of the cilia length parameter.

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http://dx.doi.org/10.1016/j.cmpb.2016.04.008
0169-2607/

Nomenclature

$\tilde{U}, \tilde{V}$	Velocity components
T_1	Temperature of the left wall
a	Radius of the channel
ρ_{nf}	Nanofluid density
ρ_s	Solid particle density
μ_{nf}	Viscosity of the nanofluid
μ_f	Viscosity of the fluid
ϕ	Volume fraction of the nano particle
$(\rho c_p)_{nf}$	Heat capacity of nanofluid
$(\rho c_p)_s$	Heat capacity of solid
$\tilde{X}_0$	Reference position of the tip
G_r	Grashof number
R_e	Reynolds number
L	Dimensionless thermal slip parameter
T_0	Temperature of the right wall
λ	Wave length
$\tilde{P}$	Pressure
ρ_f	Fluid particle density
κ_{nf}	Thermal conductivity of the nanofluid
κ_f	Thermal conductivity of the fluid
κ_s	Thermal conductivity of the solid particle
Q_0	Constant of heat absorption
$(\rho c_p)_f$	Heat capacity of fluid
ε	Cilia length
α	Measure of the eccentricity
B	Heat source or sink parameter
c	Wave speed
γ	Dimensionless velocity slip parameter

1. Introduction

Cilia (singular cilium) are thin, hairlike structures extending outward from the cells. Usually, cilia have been characterized as either motile or immotile. They work separately and sometimes together. Because of their motility, they play an essential role in several functional processes such as circulation, locomotion, alimentation, respiration and reproduction [1,2].

Cilia function in periodic two-phase patterns of effective stroke and recovery stroke that generate a metachronal wave. Metachronal coordination among cilia is a position where cilia beat together with a constant phase difference between nearby neighbors and their tips practice a moving wave shape. Ciliated surfaces can have different patterns. When the wave propagates in the effective stroke direction, this type is known as Symplectic metachronism. When a wave propagates in an opposite direction to the effective stroke direction, this type of wave is known as Antiplectic metachronism. Diaplectic metachronism is the situation when the wave propagates in the perpendicular direction to the effective stroke direction [3].

At the present time, the study of interaction between cilia and their environment is a subject of great interest among researchers, who have been especially inspired by the possible use of cilia-based actuators as micro mixers, for flow controller in tiny bio sensors, or as micro pumps for drug-delivery systems. In humans, the flow produced by the deformation of cilia is involved in the transport of several biological fluids, including the removal of tracheobronchial mucus in the respiratory tract [4,5]. The hydrodynamics of protozoa that use cilia for locomotion was considered by Jahn and Bovee, and Blake [6,7]. Defective and dysfunctional functioning in motile and non-motile cilia disturbs multiple systems, and therefore, causing deafness, blindness, chronic respiratory infections, heart disease, kidney disease, obesity, infertility and diabetes. These symptoms have an important impact on those affected; some are devastating while most are dangerous [8]. More recent various studies are cited in References [9–11].

Recently, the development of nanofluid science has attracted the attention of many researchers. This is because such fluids enhance the thermal conductivity of the base fluid. Since the inventive work done by Choi and Eastman [12], various features of nanofluid are discussed by many researchers [13–28]. Nanofluids have vast uses in heat transfer, like microelectronics, fuel cells, pharmaceutical processes, hybrid-powered engines, grinding, domestic refrigerator, chiller, nuclear reactor coolant, space technology [29], deliver drugs by targeting rotten arteries that have developed as a noninvasive method to challenge heart disease, especially copper nanoparticles that improve abnormal heart enlargement or so-called hypertrophic cardiomyopathy [30]. Mroczek-Sosnowska et al. [31] determined that the use of copper nanoparticles increases the level of red blood cells (RBC), Hemoglobin (HGB), heterophils, monocytes and basophils. They also found that copper nanoparticles decrease the concentration of cholesterol and glucose. Akbar et al. [32] have explained the influence of induced magnetic field and heat flux with the suspension of carbon nanotubes for the peristaltic flow in a permeable channel. Akram and Nadeem [33] presented the combined effects of partial slip and nanofluid by considering different wave shapes in the peristaltic motion. Nadeem et al. [34] presented the analysis of Nanoparticles on Peristaltic flow of Prandtl Fluid model in an Endoscope. Akbar and Nadeem [35] have observed peristaltic non-Newtonian nanofluid in a small intestine.

The study of curved channel is important due to its physiological applications. Akbar et al. [36] discussed copper nanoparticles impinging on a curved channel with compliant walls and peristalsis. Ramanamurthy et al. [37] presented a generalized mathematical model describing the unsteady peristaltic flow of a viscous fluid in a two-dimensional curved channel. However, the study of ciliary motion in a curved channel with the combined effects of nanofluid and partial slip is still unexplored. Therefore, the main theme of this paper is to discuss the combined effects of copper blood nanofluid and slip conditions in a curved channel by the metachronal wave of cilia. Copper as nanoparticle with blood as its base fluid has been considered. Given equations are simplified by suppositions of low Reynolds number and long wave length. Later on, a valid solution is calculated for the resulting equation. At the end, the graphical results for pressure rise, pressure gradient, temperature profile and stream lines have been plotted for different values of the physical parameters.