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Influence of magnetic field for metachoronical beating of cilia for nanofluid with Newtonian heating

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ABSTRACT

Influence of magnetic field for metachoronical beating of cilia for nanofluid with Newtonian heating in an asymmetric channel is considered. The governing coupled equations are constructed under long wavelength and low Reynold's number approximation. The Newtonian heating is controlled by a dimensionless conjugate parameter, which varies between walls of channel. Numerical solutions are evaluated for nanoparticle fraction, heat transfer, stream function and pressure gradient. The important findings in this study are the variation of the conjugate parameter for Newtonian heating γ, Hartmann number M, thermophoresis parameter N_t and Brownian motion parameter N_b on pressure rise, nanoparticle fraction, heat transfer phenomena, pressure gradient and streamlines. The velocity field increases due to increase in M near the channel walls while velocity field decreases at the centre of the channel.

1. Introduction

A tiny hairlike projection on the surface of some cells and microscopic organisms, especially protozoans. Cilia are capable of whipping motions and are used by some microorganisms, such as paramecia, for movement. Cilia lining the human respiratory tract act to remove foreign matter from air before it reaches the lungs. Cilia move digested food down the intestines [1–6].

Nanofluids are fluid deferments of nanometer-sized solid constituent part and filaments. These fluids have been anticipated as a route for unresolved the recital of heat transfer liquids currently available. Recent trials on nanofluids have designated noteworthy increases in thermal conductivity associated with liquids without nanoparticles or larger particles, strong temperature dependence of thermal conductivity and significant increases in critical heat flux in boiling heat transfer [7]. In recent years researchers and scientists have put their full attentions in the direction of the nanofluids with different flow geometries that can be defensible with the recent work done for nanofluids [8–12].

The process in which the internal resistance is assumed as negligible in comparison with its surface resistance is known as Newtonian heating or cooling process. The Newtonian heating conditions have been used only moderately by Lesnic et al. [13–15] and Pop et al. [16] to study the free convection boundary layer over vertical and horizontal surfaces as well as over a small inclined flat plate from the horizontal surface embedded in a porous medium. The steady Von Kármá n flow and heat transfer of an electrically conducting non-Newtonian fluid is discussed by Bikash Sahoo [17]. He extended to the case where the disk surface admits partial slip. Salleh et al. [18] gives the boundary layer flow and heat transfer over a stretching sheet with Newtonian heating. Some recent literature related to the topic is cited in Refs. [19–28].

Metachoronical beating of cilia for nanofluid with Newtonian heating in an asymmetric channel is considered. The governing coupled equations are constructed under long wavelength and low Reynold's number approximation. The Newtonian heating is controlled by a dimensionless conjugate parameter, which varies between walls of channel. Numerical solutions are evaluated for nanoparticle fraction, heat transfer, stream function and pressure gradient. The important findings in this study are the variation of the conjugate parameter for Newtonian heating γ, Hartmann number M, thermophoresis parameter N_t and Brownian motion parameter N_b on pressure rise, nanoparticle fraction, heat transfer phenomena, pressure gradient and streamlines. The velocity field

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Nomenclature

ϵ	ratio w.r.t cilia length
P	pressure
x	variable along the body
$\mathbf{B_r}$	local nanoparticle Grashof number
λ	wave length
β	wave number
y	variable horizontal to the body
γ	thermal slip parameter
P_r	Prandtl number
a, b, d	amplitude ratio
u, v	velocities
x	variable normal to the channel
μ	fluid viscosity
c	wave speed
N_t	thermophoresis parameter
α	measure of the eccentricity
N_b	Brownian motion parameter
G_r	local temperature Grashof number

increases due to increase in M near the channel walls while velocity field decreases at the centre of the channel.

2. Convective flow equations

Let us consider the flow of an incompressible nanofluid through an asymmetric human body. We choose the Cartesian coordinates (Y, X), where X-axis lies along the centre of the body and Y is transverse to it. Flow is generated due to the metachronal wave which is produced due to collective beating of the cilia with constant speed c along the walls of the body whose inner surface is ciliated. Temperature T_0, T_1 are given to the walls of the channel. The geometry of the wall surface are given by

$$Y = \bar{H}_1\left(\bar{X}, t\right) = d_1 + a_1 \cos\left[\frac{2\pi}{\lambda}\left(X - c_1 t\right)\right],$$
$$Y = \bar{H}_2\left(\bar{X}, t\right) = -d_2 - b_1 \cos\left[\frac{2\pi}{\lambda}\left(X - c_1 t\right) + \phi\right]. \tag{1}$$

The horizontal and vertical velocities of the cilia are given as [1,2]

$$U_0 = \frac{-\left(\frac{2\pi}{\lambda}\right) a\epsilon\alpha c_1 \cos\left(\frac{2\pi}{\lambda}\left(\bar{X} - c_1 t\right)\right)}{1 - \left(\frac{2\pi}{\lambda}\right) a\epsilon\alpha c_1 \cos\left(\frac{2\pi}{\lambda}\left(\bar{X} - c_1 t\right)\right)}, \tag{2}$$

$$V_0 = \frac{-\left(\frac{2\pi}{\lambda}\right) a\epsilon\alpha c_1 \sin\left(\frac{2\pi}{\lambda}\left(\bar{X} - c_1 t\right)\right)}{1 - \left(\frac{2\pi}{\lambda}\right) a\epsilon\alpha c_1 \sin\left(\frac{2\pi}{\lambda}\left(\bar{X} - c_1 t\right)\right)}. \tag{3}$$

The expression for fixed and wave frames is related by the following relations:

$$\bar{x} = \bar{X} - ct, \quad \bar{y} = \bar{Y}, \quad \bar{u} = \bar{U} - c, \quad \bar{v} = \bar{V}, \quad p(\bar{x}) = P(\bar{X}, t). \tag{4}$$

We introduce the following non-dimensional quantities:

$$x = \frac{2\pi\bar{x}}{\lambda}, y = \frac{\bar{y}}{d_1}, \quad u = \frac{\bar{u}}{c_1}, \quad v = \frac{\bar{v}}{c_1}, \quad t = \frac{2\pi\bar{t}}{\lambda}, \quad \beta = \frac{2\pi d_1}{\lambda}, \quad d = \frac{d_2}{d_1}, \quad P = \frac{2\pi d_1^2 P}{\mu c_1 \lambda}, h_1 = \frac{\bar{h}_1}{d_1}, \quad h_2 = \frac{\bar{h}_2}{d_2}, \quad \mathrm{Re} = \frac{\rho c_1 d_1}{\mu}, \quad a = \frac{a_1}{d_1}, \quad b = \frac{a_2}{d_1}, \quad d = \frac{d_2}{d_1}, \quad S = \frac{\bar{S} d_1}{\mu c_1}, \theta = \frac{\bar{T} - \bar{T}_0}{\bar{T}_1 - \bar{T}_0}, \quad \sigma = \frac{\bar{C} - \bar{C}_0}{\bar{C}_1 - \bar{C}_0}, \quad \alpha = \frac{k}{(\rho c)_f}, \quad N_b = \frac{(\rho c)_p D_B\left(\bar{C}_1 - \bar{C}_0\right)}{(\rho c)_f \alpha}, \quad P_r = \frac{\nu}{\alpha}, N_t = \frac{(\rho c)_p D_{\bar{T}}\left(\bar{T}_1 - \bar{T}_0\right)^2}{\bar{T}_0 (\rho c)_f \alpha}, \quad G_r = \frac{g\alpha d_1^2\left(\bar{T}_1 - \bar{T}_0\right)}{\nu c_1}, \quad B_r = \frac{g\alpha d_1^2\left(\bar{C}_1 - \bar{C}_0\right)}{\nu c_1}. \tag{5}$$

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