Physica E 70 (2015) 146–156

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

Study on blood flow containing nanoparticles through porous arteries in presence of magnetic field using analytical methods

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HIGHLIGHTS

- Flow analysis for a third grade non-Newtonian blood with nanoparticles in porous arteries in presence of magnetic field is simulated analytically and numerically.
- Collocation Method (CM) and Optimal Homotopy Asymptotic Method (OHAM) are used to solve the Partial Differential Equation (PDE) governing equation.
- Increasing the thermophoresis parameter (N_t) caused an increase in temperature values in whole domain and an increase in nanoparticles concentration near the inner wall.

ARTICLE INFO

Article history:
Received 5 November 2014
Received in revised form
1 March 2015
Accepted 3 March 2015
Available online 5 March 2015

Keywords:
Blood flow
Porous artery
Nanoparticle
Optimal Homotopy Asymptotic Method (OHAM)
Collocation Method (CM)

ABSTRACT

In this paper, flow analysis for a third grade non-Newtonian blood in porous arteries in presence of magnetic field is simulated analytically and numerically. Blood is considered as the third grade non-Newtonian fluid containing nanoparticles. Collocation Method (CM) and Optimal Homotopy Asymptotic Method (OHAM) are used to solve the Partial Differential Equation (PDE) governing equation which a good agreement between them was observed in the results. The influences of the some physical parameters such as Brownian motion parameter, pressure gradient and thermophoresis parameter, etc. on temperature, velocity and nanoparticles concentration profiles are considered. For instance, increasing the thermophoresis parameter (N_t) caused an increase in temperature values in whole domain and an increase in nanoparticles concentration near the inner wall.

1. Introduction

Blood can be considered as a non-Newtonian fluid which its physical properties are presented by Abdel Baieth [1]. Blood which is composed of plasma, red and white blood cells, platelets, etc. can be considered as one of the most important multi-component mixtures occurring in nature. Ogulu and Amos [2] modeled the pulsatile blood flow in the cardiovascular system employing the Navier–Stokes equation and found an increase in the wall shear stress when the porosity of the medium was increased. In an experimental study Praveen Kumar et al. [3] investigated the effect of gold nanoparticles in blood from bio-medically view point which can be used in drug delivery applications. Recently, Hatami et al. [4] studied the third grade non-Newtonian blood conveying gold nanoparticles in a porous and hollow vessel by two analytical methods called Least Square Method (LSM) and Galerkin Method (GM). They considered temperature dependency for blood by Vogel's model and investigated the effect of Brownian motion and magneto-hydrodynamic on nanoparticles in blood flow. Moyers-Gonzalez et al. [5] on the modeling of oscillatory blood flow in a tube, observed that as the frequency of the (constant amplitude) pressure gradient oscillations increases, the peak values of the velocity field and shear stress decreases. The characteristics of flow and heat transfer of the second-grade viscoelastic electrically

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http://dx.doi.org/10.1016/j.physe.2015.03.002
1386-9477/

Nomenclature

A, B	constants in viscosity function
B_r	Brownian diffusion constant
c	pressure gradient
c_1, c_2, c_3, c_4, c_5, c_6	unknown constants for CM
C_{11},C_{12},C_{21},C_{22},C_{31},C_{32}	unknown constants for OHAM
D_b	Brownian diffusion coefficient
D_T	thermophoretic diffusion coefficient
E	electric field
g	gravitational vector
G_r	Grashof number
$H(p)$	auxiliary function for OHAM
J	electric current density
J_1, J_2, J_3	functionals of OHAM
k	permeability
M	MHD parameter
N_b	Brownian motion parameter
N_t	thermophoresis parameter
p	embedding parameter for OHAM
P	porosity parameter
r_1	inner radius
r_2	outer radius
R_1, R_2, R_3	residuals
T	stress in a third-grade fluid
V	velocity vector
v_0	reference velocity

Greek symbols

α, β	material modules
β_T	volumetric expansion coefficient
Λ	third-grade parameter
λ_r	retardation time
μ	Vogel Viscosity
μ_0	reference viscosity
ϕ	nanoparticles mass concentration
θ	temperature
θ_w	pipe temperature
θ_m	fluid temperature
ρ_f	density of the base fluid
ρ_p	density of the nanoparticles
φ	porosity
ϕ_m	mass concentration
σ	electrical conductivity

conducting blood in a channel with oscillatory stretching walls in the presence of an externally applied magnetic field are investigated by Misra et al. [6]. Massoudi and Phuoc [7] modeled blood as a modified second-grade fluid where the viscosity and the normal stress coefficients depend on the shear rate. They considered Fahraeus–Lindqvist effect which assumes that the blood near the wall behaves as a Newtonian fluid, and in the core as a non-Newtonian fluid. In a pioneer study, Majhi and Nair [8] mathematically modeled pulsatile blood flow subjected to externally-imposed periodic body acceleration by considering blood as a third grade fluid using numerical Crank Nicholson Method.

As mentioned before, blood can be assumed as non-Newtonian fluid, so many studies are focused on second and third grade non-Newtonian fluids which some of them are presented in this section. Modeling and solution of the unsteady flow of an incompressible third grade fluid over a porous plate within a porous medium is investigated by Aziz et al. [9]. They considered that the fluid is electrically conducting in the presence of a uniform magnetic field applied transversely to the flow. The magneto-hydrodynamic (MHD) flow due to non-coaxial rotation of a porous disk moving with uniform acceleration in its own plane is examined by Asghar et al. [10]. Keimanesha et al. [11] solved the problem of a third grade non-Newtonian fluid flow between two parallel plates by Multi-step Differential Transformation Method (Ms-DTM). The influence of third grade, partial slip and other thermophysical parameters on the steady flow, heat and mass transfer of viscoelastic third grade fluid past an infinite vertical insulated plate subject to suction across the boundary layer has been investigated by Baoku et al. [12]. Furthermore, Hayat et al. [13–16] completely discussed about the treatment of third grade non-Newtonian fluids in different applications and Ellahi et al. [17,18] discussed on the third grade non-Newtonian nanofluid in porous media between two cylinders as Hatami and Ganji [19] presented it analytically for SA-TiO_2 nanofluids. Also, many biomedical problems have been studied by using numerical, mathematical and computational methods by researchers in this field [20–23].

The main aim of this paper is to simulate the problem of blood flow in porous arteries by efficient analytical methods called CM and OHAM and compare the results obtained by fourth order Runge–Kutta numerical method. Also the effects of some parameters such as Brownian motion parameter, pressure gradient and thermophoresis parameter, etc. on temperature, velocity and nanoparticles concentration profiles are examined.

2. Statement of the problem

Consider a porous artery which contains steady, incompressible, non-Newtonian nanofluid in presence of magnetic field. A schematic of the physic of the problem and coordinates is shown in Fig.1. The nanofluid's density, ρ should be defined as [24]

$$\rho = \phi\rho_p + (1-\phi)\rho_{f0} \cong \phi\rho_p + (1-\phi)\left\{\rho_f\left(1-\beta_T(\theta-\theta_w)\right)\right\} \tag{1}$$

where ρ_{f0}, is the base fluid's density, θ_w, is a reference temperature, ρ_f is the base fluid's density at the reference temperature, β_T is the volumetric coefficient of expansion. Taking the density of base fluid as that of the nanofluid, density ρ in Eq. (1), thus becomes [25]:

$$\rho \cong \phi\rho_p + (1-\phi)\left[\rho_f\left(1-\beta_T(\theta-\theta_w)\right)\right] \tag{2}$$

ρ_f is the nanofluid's density at the reference temperature [25]. Clearly a viscous fluid is governed by continuity and Navier–Stokes

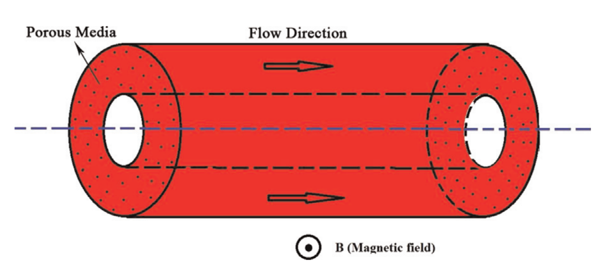

Fig. 1. Schematic of blood flow through a porous artery in presence of magnetic field.