



Impulsion of nanoparticles as a drug carrier for the theoretical investigation of stenosed arteries with induced magnetic effects

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ABSTRACT

In this paper hemodynamics of stenosis are discussed to predict effect of atherosclerosis by means of mathematical models in the presence of uniform transverse magnetic field. The analysis is carried out using silver and copper nanoparticles as a drug carrier. Exact solution for the fluid temperature, velocity, axial induced magnetic field and current density distribution are obtained under mild stenosis approximation. The results indicate that with an increase in the concentration of nanoparticle hemodynamics effects of stenosis reduces throughout the inclined composite stenosed arteries. The considered analysis also summarizes that the drug silver nanoparticles is more efficient to reduce hemodynamics of stenosis when compare to the drug copper nanoparticle. In future this model could be helpful to predict important properties in some biomedical applications.

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1. Introduction

The main objective of blood flow model in arteries is to evaluate hemodynamic effects which artery wall experiences due to different factors like the fluid flow geometry, the pulsatile blood flow and the blood rheology behavior (i.e., viscous or non-viscous properties of fluid). Further, it is important to discuss the correlation between abnormal biological events and flow pattern characteristics and arterial diseases like thrombosis, atherosclerosis and stenosis. One of the most serious significance of these arterial diseases is an increase in resistance to blood flow, which leads to the reduction of blood flow in the affected vascular bed. The hemodynamic effects play important roles in the access of arterial diseases and regulation of vascular biology is investigated by Mann et al. [1] and then investigated by a large number of researchers [2,3].

The mechanics of circulation of the blood through arteries with stenosis have been discussed theoretically and experimentally by many researchers [4–6]. Liu et al. [7] discussed the blood flow models through stenotic arteries. Here they deliberated that the stenosis disturbs the flow field at the throat of the stenosis. Liu et al. [8] discussed the stenosis severity and flow rate from numerical results. The procedure of catheters is important and has become a reliable tool for treatment and diagnosis in new medicine. A catheter is composed of medical grade polyvinyl chloride and polyester based thermoplastic polyurethane, etc. The insertion

of a catheter into blood arteries forms the new annular region between the arterial wall and the catheter wall that will change the hemodynamics conditions that occur in the blood vessel before catheterization [9,10]. Mekheimer et al. [11] investigated the surgical technique for the injection of catheter through tapered blood arteries. They studied the movement of blood between two eccentric tubes. Srivastav et al. [12] investigated the catheterized composite stenosis with permeable walls. They considered the effects on flow characteristics of a viscous fluid in inserted catheterized stenosed arteries.

Firstly, the idea of electromagnetic fields used in medical science was introduced by Kolin [13]. Mekheimer et al. [14] discussed model of blood flow through a multiple stenosed artery under the effects of magnetic field and porosity. Korchevskii et al. [15] discussed the possibility to regulate the blood movement in human system by applying magnetic field. Stud et al. [16] discussed the influence of moving magnetic effects that speed up the blood. Many researchers considered blood as viscous and non-viscous fluids in stenotic arteries with magnetic field effects [17,18] but very small amount of research is available on the effect of induced magnetic field on blood flow through stenosis. Mekheimer et al. [19] discussed the blood flow through an elastic artery with overlapping stenosis under the effect of induced magnetic field.

The blood mediated nanoparticle distribution is a growing and new field in the development of diagnostics and therapeutics. Nanoparticles with magnetic properties add a new dimension where they can be manipulated with the application of an external magnetic field. The magnetic nanoparticles as a drug agent have gained much attention based on their ease of preparation and ability to transport a drug directly to the centre of the disease. The

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concept of nanoparticles with magnetic field effects for drug delivery application is discussed by many researchers [20,21]. The innovative technique, which uses a mixture of base fluid and nanoparticles, was first introduced by Choi [22] in order to develop advanced heat transfer fluids and discussed by other researchers [23–25]. Nadeem et al. [26] discussed the examination of nanoparticles as a drug carrier on blood flow through bell shaped stenosed arteries under the influence of thermal and velocity slip effects. Akbar et al. [27] inspected the peristaltic flow containing metallic nanoparticles in an asymmetric channel. Recently, Nadeem et al. [28,29] discussed that the influence of metallic nanoparticles is imperative to reduce the significance of the hemodynamic effects of stenosis. The advantages of nanotechnology in biomedical applications and other fields have gained much attention from researchers and numerous studies such as [30–36].

The purpose of the present examination is to discuss the importance of nanoparticles injected into the blood flow in the presence of uniform transverse magnetic field. According to our knowledge this kind of study with blood flow is not reported so far. The effects of blood rheology, nanoparticle volume fraction, Strommers number and magnetic Reynolds number are discussed in the present analysis. Results obtained from this examination contribute to the fundamental understanding how the particulate nature of blood influences nanoparticle delivery and provide new visions of nanoparticles for drug delivery applications in the presence of uniform transverse magnetic field.

2. Formulation of the problem

Consider the laminar, steady and the incompressible blood flow in a tube of length L . Let us consider the velocity vector as $\mathbf{V} = (\bar{u}, 0, \bar{w})$, where $\bar{u}$ and $\bar{w}$ are defined as the velocity components in the r and z directions respectively. The system is stressed by an external magnetic field of strength $\frac{H_0 \bar{h}}{\bar{r}}$ and the total magnetic field will be $\mathbf{H}^+(\bar{H}_r(\bar{r}, \bar{z}) + \frac{H_0 \bar{h}}{\bar{r}}, 0, \bar{H}_z(\bar{r}, \bar{z}))$. Heat transfer phenomenon is taken into account by giving temperature T_1 to the wall of the catheter and T_0 to the upper wall of the inclined stenosed artery. The geometry of composite stenosis in dimensional form is given as [12]

$$\begin{aligned} \bar{h}(z) &= e_0 - \frac{2\delta}{L_0}(\bar{z} - d), \quad d \leq \bar{z} \leq d + \frac{L_0}{2}, \\ &= e_0 - \frac{\delta}{2} \left(1 + \cos \frac{2\pi}{L_0} \left(\bar{z} - d - \frac{L_0}{2} \right) \right), \quad d + \frac{L_0}{2} \leq \bar{z} \leq d + L_0, \\ &= e_0, \quad \text{otherwise,} \end{aligned} \quad (1)$$

where d represents the position, L_0 as the length, δ as the height, $h(z)$ as the radius of the stenotic segment, e_0 as the radius of the non stenotic segment (normal artery), $\bar{H}_r$ and $\bar{H}_z$ as the radial and axial components of total magnetic field, respectively. The steady governing equations are [19],

1. Maxwell equations are

$$\nabla \cdot \mathbf{H}^+ = 0, \quad \nabla \cdot \mathbf{E} = 0, \quad (2)$$

$$\nabla \times \mathbf{H}^+ = \mathbf{J}, \quad \text{where } \mathbf{J} = \sigma_{nf} \{ \mathbf{E} + \mu_{ef} (\mathbf{V} \times \mathbf{H}^+) \}, \quad (3)$$

$$\nabla \times \mathbf{E} = -\mu_{ef} \frac{\partial \mathbf{H}^+}{\partial t}, \quad (4)$$

2. Continuity and Navier Stokes equations are

$$\nabla \cdot \mathbf{V} = 0, \quad (5)$$

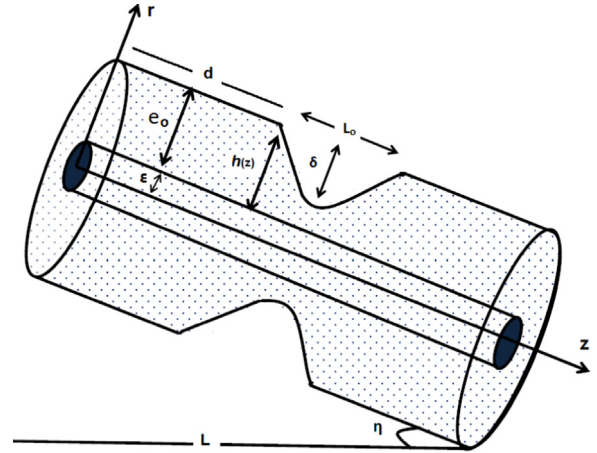


Fig. 1. Geometry of composite stenosed artery.

$$\rho_{nf} \left(\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V} \cdot \nabla \mathbf{V} \right) = -\nabla p + \mu_{nf} \nabla^2 \mathbf{V} + \rho_{nf} \mathbf{f} + \mu_{ef} (\mathbf{J} \times \mathbf{H}^+), \quad (6)$$

From Eqs. (2) to (4), we have

$$\frac{\partial \mathbf{H}^+}{\partial t} = \nabla \times \{ \mathbf{V} \times \mathbf{H}^+ \} + \frac{1}{\sigma_{nf} \mu_{ef}} \nabla^2 \mathbf{H}^+. \quad (7)$$

in which $\mathbf{E}$ is defined as the induced electric field, $\mathbf{J}$ as the electric current density, $\mathbf{V}$ as the velocity component, $\mathbf{f}$ as the body force and p as the pressure. For the proposed nanofluid model σ_{nf} represents the electrical conductivity, μ_{ef} is the magnetic permeability, ρ_{nf} is the density and μ_{nf} is the nanofluid viscosity.

In Fig. 1, ε is defined as the radius of catheter and η as the inclination angle. The governing flow equations for nanofluid in the presence of induced magnetic effects can be written as,

$$\frac{\partial \bar{u}}{\partial \bar{r}} + \frac{\bar{u}}{\bar{r}} + \frac{\partial \bar{w}}{\partial \bar{z}} = 0, \quad (8)$$

$$\frac{\partial \bar{H}_r}{\partial \bar{r}} + \frac{\bar{H}_r}{\bar{r}} = 0, \quad (9)$$

$$\begin{aligned} \rho_{nf} \left(\bar{u} \frac{\partial \bar{u}}{\partial \bar{r}} + \bar{w} \frac{\partial \bar{u}}{\partial \bar{z}} \right) &= -\frac{\partial \bar{p}}{\partial \bar{r}} + \mu_{nf} \left(\frac{\partial^2 \bar{u}}{\partial \bar{r}^2} + \frac{1}{\bar{r}} \frac{\partial \bar{u}}{\partial \bar{r}} + \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} - \frac{\bar{u}}{\bar{r}^2} \right) \\ &+ \mu_{ef} \left(-\frac{\partial \bar{H}_z}{\partial \bar{r}} \frac{\partial}{\partial \bar{z}} \left(\frac{H_0 \bar{h}}{\bar{r}} + \bar{H}_r \right) \right) \bar{H}_z \\ &- g(\rho \gamma)_{nf} (\bar{T} - \bar{T}_0) \cos \eta, \end{aligned} \quad (10)$$

$$\begin{aligned} \rho_{nf} \left(\bar{u} \frac{\partial \bar{w}}{\partial \bar{r}} + \bar{w} \frac{\partial \bar{w}}{\partial \bar{z}} \right) &= -\frac{\partial \bar{p}}{\partial \bar{z}} + \mu_{nf} \left(\frac{\partial^2 \bar{w}}{\partial \bar{r}^2} + \frac{1}{\bar{r}} \frac{\partial \bar{w}}{\partial \bar{r}} + \frac{\partial^2 \bar{w}}{\partial \bar{z}^2} \right) \\ &+ \mu_{ef} \left(\frac{H_0 \bar{h}}{\bar{r}} + \bar{H}_r \right) \left(\frac{\partial \bar{H}_z}{\partial \bar{r}} - \frac{\partial}{\partial \bar{z}} \left(\frac{H_0 \bar{h}}{\bar{r}} + \bar{H}_r \right) \right) \\ &+ g(\rho \gamma)_{nf} (\bar{T} - \bar{T}_0) \sin \eta, \end{aligned} \quad (11)$$

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