International Journal of Thermal Sciences 109 (2016) 401–412

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

Slip examination on the wall of tapered stenosed artery with emerging application of nanoparticles

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ARTICLE INFO

Article history:
Received 25 January 2016
Received in revised form
15 March 2016
Accepted 6 June 2016
Available online 21 June 2016

Keywords:
Blood flow
Slip effects
Tapered tube
Copper and silver nanoparticles

ABSTRACT

In this analysis, slip effects on the wall of a tapered stenosed artery has been considered under the mild stenosis approximation. The theoretical analysis is carried out by considering blood as Newtonian fluid. An exact solution of temperature and velocity profile is obtained by solving the governing equations after using non dimensional parameters. Hemodynamic effects of stenosis are discussed through the graphs of resistance impedance to blood flow and wall shear stress. The examination shows that the addition of silver nanoparticles reduces the resistance impedance more effectively as comparing to the copper nanoparticles. The trapping pattern also shows that the impulsion of nanoparticles speed up blood flow in the stenotic region. This effect is noticeable and shows that this model could be helpful in some biomedical application.

1. Introduction

There is the number of theories available in the literature that predicts vascular fluid dynamics which plays a most important role in the development and progression of arterial diseases. These arterial diseases occur due to narrowing of arterial segments which are known as stenosis or atherosclerosis. The most serious significance of this arterial disease is increased in resistance to blood flow and related reduction of the blood to the particular vascular bed supplied by the artery [1,2]. The mathematical models are useful tools for supporting experiments and identifying a minor tapering phenomenon as well as the local features of stenosis which is not always clear by measurement. Different investigation on the flow of blood through arterial segments with obstruction has been carried out theoretically and experimentally by a number of investigators [3,4].

The facts that hemodynamic factors play an important role in the arterial diseases was first discussed by Mann et al. [5], after him a large number of researchers have presented this theory [6–8]. Liu et al. [9] investigated that the stenosis disturbs the flow field at the vicinity of the stenosis and easily leads to the formation of a flow separation region in the post-stenotic region. Mekheimer et al. [10] investigated the blood flow model through an elastic artery with overlapping stenosis to deliberate the influence of induced magnetic field on the blood flow through stenosis by considering nature of blood as viscous fluid. Chakraborty et al. [11] investigated flow of blood in an inclined artery with slip effects on stenotic wall. The procedure of catheters is important and has become a reliable tool for treatment and diagnosis in new medicine. The insertion of the catheter will change the hemodynamics conditions that occur in the blood vessel are discussed by many researchers as [13,14]. Mekheimer et al. [14] investigated the surgical technique for the injection of a catheter through tapered stenosed arteries. Srivastav et al. [15] investigated the blood flow through catheterized composite stenosed arteries and considered the effects of permeable walls. Dash et al. [16] investigated the blood flow pattern in tapered arteries and analyzed an increase in the friction due to catheterization.

The circulation of the blood through arteries with slip condition has been discussed by many investigators in which they assumed that the velocity of the fluid is linearly proportional to the shear stress [17,18]. The flow problems that exhibit boundaries slip conditions have important applications, such as in internal cavities and polishing valves of artificial hearts. Sinha et al. [19] investigated the influence of externally imposed periodic body acceleration on the blood flow through a stenosed arterial segment by taking velocity slip conditions into account. Ponalagusamy et al. [20] investigated the mathematical models for blood flow through stenosed arteries with velocity slip condition at the stenotic wall.

A nanoparticle with unique properties has gained much attention from investigators and numbers of investigations are available in literature on the benefits of nanotechnology such as [21–23]. Blood mediated nanoparticle distribution is a growing and new field

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http://dx.doi.org/10.1016/j.ijthermalsci.2016.06.017

in the development of diagnostics and therapeutics. Their unique size properties make these materials indispensable and superior in many biomedical applications especially silver and copper nanoparticles have been widely used for treatment, diagnosis, medical device coating and in drug delivery areas such as [24–28]. Nanofluids firstly in fluids introduced by Choi et al. [29] and specifies that it is the combination of nanoparticles and the considered base fluid. After him Nadeem et al. [30] examined that the effect of metallic nanoparticles minimize the significances of the hemodynamic effect of stenosis. Here they discussed time dependent overlapping stenosis. Gentile et al. [31] studied the longitudinal transport of nanoparticles in blood vessels. Akbar et al. [32] studied the ferromagnetic field effects for copper nanoparticles for blood flow through composite permeable stenosed arteries. In recent times, Nadeem et al. [33] investigated nanoparticles impulsion as a drug carrier on blood flow through bell shaped stenosed arteries under the inspiration of thermal and velocity slip effects.

The determination of the present considered examination is to deliberate the importance of nanoparticles injected into the blood serum in the presence of slip effects. The theoretical analysis is carried out by using appropriate exact method and some important conclusions have been obtained on the basis of the present considered analysis. The possessions of nanoparticle volume fraction, stenosis shape, stenosis height, velocity and thermal slip parameter are discussed through graphical illustration and trapping. The obtained results from present considered analysis contribute to the fundamental understanding of the nanoparticle influences as a drug carrier and provide a new vision of nanoparticles applications in the presence and absence of slip effects.

2. Formulation of the problem

We have considered the steady, laminar and incompressible blood flow in a tapered tube of a finite length L. The heat phenomenon is taken into account by giving temperature T_o to the inner wall of the catheter. The geometry of the stenosed artery is defined as [11,12] and given in (Fig. 1).

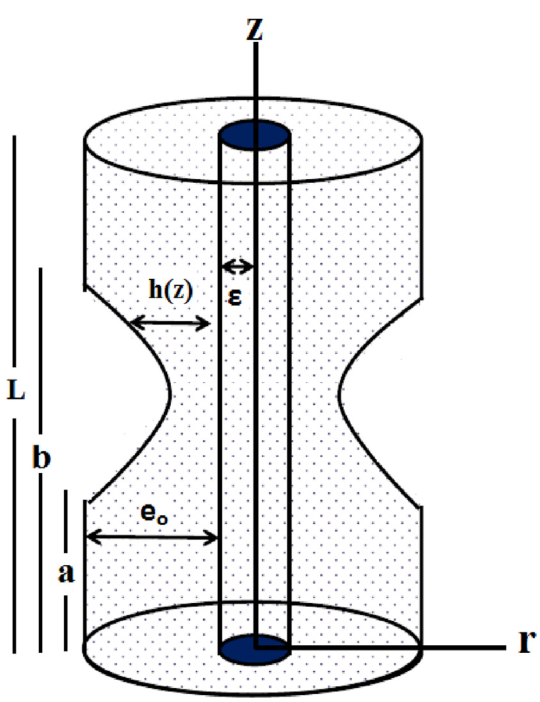

Fig. 1. Geometry of stenosed artery.

$$\bar{h}(z) = e_0\left[1 - \eta^*\left(b^{n-1}(\bar{z}-a) - (\bar{z}-a)^n\right)\right], \quad = e_0, \text{ or else } \quad a \le \bar{z} \le a+b, \tag{1}$$

here e_0 represents the radius of a non-stenotic arterial segment, b is the length of stenosis, a is the position of stenosis and $n \ge 2$ is the shape of stenosis. The parameter η^* is defined as

$$\eta^* = \frac{\delta^* n^{\frac{n}{n-1}}}{e_0 b^n (n-1)}, \tag{2}$$

where δ represents the maximum height of stenosis and located at

$$\bar{z} = a + \frac{b}{n^{\frac{1}{n-1}}}. \tag{3}$$

The corresponding boundary conditions are [23],

$$\bar{T} - T_w = -\gamma^* \frac{\partial \bar{T}}{\partial \bar{r}}, \text{ at } r = h, \quad \bar{T} = T_o \text{ at } r = \varepsilon, \quad \bar{w} - w_w = -\alpha^* \bar{S}_{rz}, \text{ at } r = h, \quad \bar{w} = 0 \text{ at } r = \varepsilon, \tag{4}$$

where in above equation $\bar{T}$ represents the temperature, T_w is the temperature at the wall ($T_w = T_1$), w is the velocity, w_w is the wall velocity ($w_w = 0$), γ^* is the dimensional thermal slip parameter and α^* is the dimensional velocity slip parameter.

The governing equations for nanofluid can be written as,

$$\frac{\partial \bar{u}}{\partial \bar{r}} + \frac{\bar{u}}{\bar{r}} + \frac{\partial \bar{w}}{\partial \bar{z}} = 0, \tag{5}$$

$$\rho_{nf}\left(\bar{u}\frac{\partial \bar{u}}{\partial \bar{r}} + \bar{w}\frac{\partial \bar{u}}{\partial \bar{z}}\right) = -\frac{\partial \bar{p}}{\partial \bar{r}} + \mu_{nf}\left(\frac{\partial^2 \bar{u}}{\partial \bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial \bar{u}}{\partial \bar{r}} + \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} - \frac{\bar{u}^2}{\bar{r}^2}\right) \tag{6}$$

$$\rho_{nf}\left(\bar{u}\frac{\partial \bar{w}}{\partial \bar{r}} + \bar{w}\frac{\partial \bar{w}}{\partial \bar{z}}\right) = -\frac{\partial \bar{p}}{\partial \bar{z}} + \mu_{nf}\left(\frac{\partial^2 \bar{w}}{\partial \bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial \bar{w}}{\partial \bar{r}} + \frac{\partial^2 \bar{w}}{\partial \bar{z}^2}\right) + g(\rho\gamma)_{nf}(\bar{T} - \bar{T}_1), \tag{7}$$

$$\left(\frac{\partial \bar{T}}{\partial \bar{t}} + \bar{u}\frac{\partial \bar{T}}{\partial \bar{r}} + \bar{w}\frac{\partial \bar{T}}{\partial \bar{z}}\right) = \frac{K_{nf}}{(\rho c_p)_{nf}}\left(\frac{\partial^2 \bar{T}}{\partial \bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial \bar{T}}{\partial \bar{r}} + \frac{\partial^2 \bar{T}}{\partial \bar{z}^2}\right) + \frac{Q_0}{(\rho c_p)_{nf}}. \tag{8}$$

in above equations $\bar{u}$ and $\bar{w}$ represents the components of velocity, $\bar{T}$ is the temperature of fluid, Q_0 is the constant heat absorption or heat generation [34]. For nanofluid model μ_{nf} represents the nanofluid viscosity, ρ_{nf} is the density, K_{nf} is the thermal conductivity, γ_{nf} is the thermal expansion coefficient and $(\rho c_p)_{nf}$ is the heat capacitance and the thermo physical properties are given as [23,33].

$$\frac{\mu_{nf}}{\mu_f} = \frac{1}{(1-\varphi)^{2.5}}, \rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s, \alpha_{nf} = \frac{K_{nf}}{(\rho c_p)_{nf}},$$
$$(\rho\gamma)_{nf} = (1-\varphi)(\rho\gamma)_f + \varphi(\rho\gamma)_s, (\rho c_p)_{nf} = (1-\varphi)(\rho c_p)_f + \varphi(\rho c_p)_s,$$
$$\frac{K_{nf}}{K_f} = \frac{(K_s + 2K_f) - 2\varphi(K_f - K_s)}{(K_s + 2K_f) + \varphi(K_f - K_s)}, \tag{9}$$

here ρ_f represents the density for the base fluid, $(\rho c_p)_f$ is the heat capacitance, μ_f is the constant fluid viscosity, γ_f is the thermal