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ANALYSIS OF STENOSED ARTERIES INFLUENCED BY NANO PARTICLES WITH INDUCED MAGNETIC FIELD EFFECTS

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ABSTRACT

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.

Keywords: *Magnetic field effect, Copper and Silver Nanoparticles, Stenosis Hemodynamic Effects*

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 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.

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 $\mathbf{V}$ u, 0, w , where u and 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 $H_0 h$ and the total magnetic field will be $\mathbf{H}$ $H\ r,\ z\ H_0\ h,\ 0,\ H\ r,\ z$. Heat transfer phenomenon is taken into account by giving temperature T1 to the wall of the catheter and T0 to the upper wall of the inclined stenosed artery. The geometry of composite stenosis in dimensional form is given as [12]

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

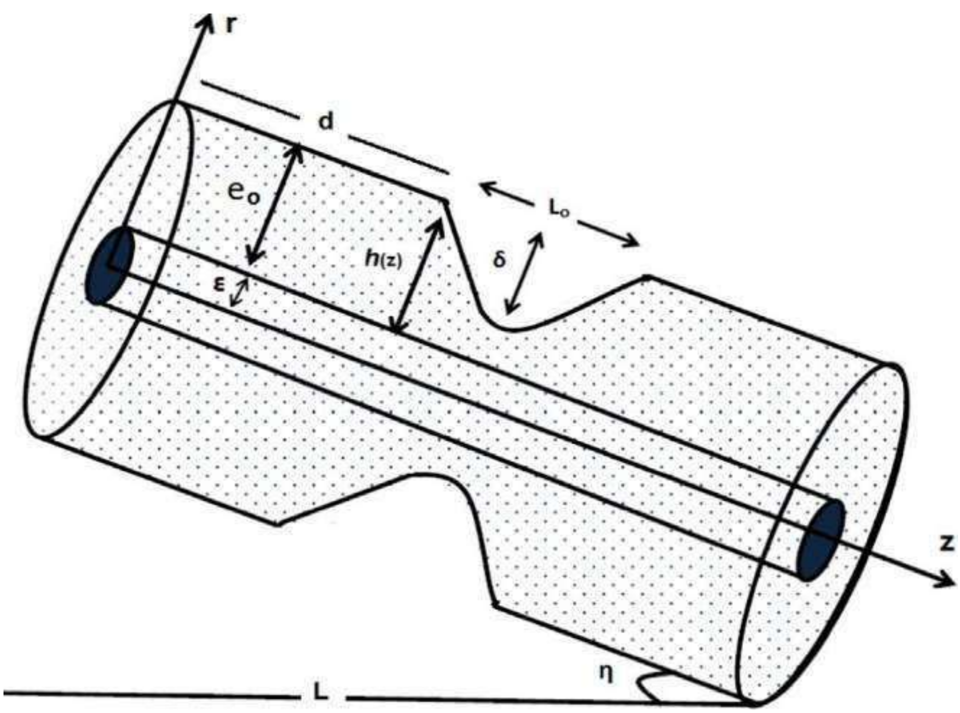


Fig. 1. Geometry of composite stenosed artery.

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

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 **E** is defined as the induced electric field, **J** as the electric current density, **V** as the velocity component, f as the body force and p as the pressure. For the proposed nanofluid model snf represents the electrical conductivity, μ ef is the magnetic permeability, ρnf is the density and μ nf is the nanofluid viscosity. In Fig. 1, ε is defined as the radius of cathered and η as the inclination angle. The governing flow equations for nanofluid in the presence of induced magnetic effects can be written as,

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

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

$$\rho\left(\bar{u}\frac{\partial \bar{u}}{\partial \bar{r}} + \bar{w}\frac{\partial \bar{u}}{\partial \bar{z}}\right) = -\frac{\partial \bar{p}}{\partial \bar{r}} + \mu\left(\frac{\partial^2 \bar{u}}{\partial \bar{r}^2} \quad \frac{\partial^2 \bar{u}}{\partial \bar{z}^2}\right)$$

$\left| \frac{u}{} \quad \frac{1}{} \frac{u}{} \quad \frac{u}{} \quad \frac{u}{} \right|$

where d represents the position, L0 as the length, δ as the height, h

$H \quad (H\,h \quad)) \; (\quad)(H\,h \quad) \quad \mu$

$nf \left(r \quad z \right) \quad r \quad nf \left(r^2 \quad r\,r \quad z^2 \quad r^2 \right)$

$\xi_{nf} \quad \left| \quad \bar{z} \quad \right| \quad o \; H_r \left|\right| \; u \quad w \; \left|\right| \frac{o}{} H_r \left| \right.$

$z \left(\quad r \; z \left(\; r \quad \right) \right) \left(r \quad z \right) \left(r \quad \right)$

$\left(\left(\frac{H_o \bar{h}}{H} \; \frac{u}{} \; H \frac{u}{} \right) \right.$

$\left|\right| \quad \left| \quad \right|,$

$\left(\left(\bar{r} \quad \right) r \quad z \right)$

$\xi_{nf} \left| 1 \quad \right| r \frac{H_z}{} \left| \quad \right| 1 \; \left|\right| \quad \frac{H_o h}{} H \left|\right|$

$\left(r\,r \quad r \quad z \left(r \quad r \right) \left(r \quad \right) \right)$

$u \quad w \quad H \quad \frac{H_o h}{} \; H \quad \frac{w}{} \; H \quad \frac{w}{},$

$\left(r \quad z \right) z \left(r \quad r \right) r \quad z$ 13

$$\left(T \quad T \quad T\right) - \frac{k_{nf}}{} \left(T \quad T T \quad T\right) \quad \frac{Q_0}{}$$

$$u \quad w \quad {}^2_2 \quad {}^2_2$$

$$t \quad r \quad z \quad \rho c_{p\,nf} \quad r \quad r\, r \quad z \quad \rho c_{p\,nf} \qquad 14 \qquad 2$$

where T is defined as the temperature of fluid, Q0 as the constant heat absorption or heat generation [37]. For the proposed nanofluid model knf is defined as thermal conductivity, γ nf as the thermal expansion coefficient and $\rho cp\ nf$ as the heat capacitance of nanofluid and the thermo physical properties are given in Table 1 and as [26 − 29],

$$\mu_{n\text{-}f} \quad \frac{1}{} \qquad \mu_{e\text{-}f} \quad \frac{1}{}$$

$$\mu_f \quad 1 \quad \phi^{2.5}, \qquad \mu_e \quad 1 \quad \phi^{2.5}, \qquad \rho_{nf} \quad 1 \quad \phi\rho_f \quad \phi\rho_s,$$

$$\rho\gamma_{nf} \quad 1 \quad \phi\rho\gamma_f \quad \phi\,\rho\gamma_s, \qquad \rho c_{p\,nf} \quad 1 \quad \phi\rho c_{pf} \quad \phi\,\rho c_{p\,s},$$

$$\frac{k_{nf}}{k_f} \quad \frac{k_s \quad 2k_f \quad 2\phi\, k_f \, k_s}{k_s \quad 2k_f \quad \phi\, k_f \quad k_s}, \quad \frac{\sigma_{nf}}{\sigma_f} \quad 1 \quad \frac{3\left(\frac{\sigma_s}{\sigma_f} \quad 1\right)\phi}{\left(\frac{\sigma_s}{\sigma_f}\right) \quad 2 \quad \left(\frac{\sigma_s}{\sigma_f} \quad 1\right)\phi}, \quad w \quad 0,$$

$$\alpha_{nf} \quad \frac{k_{nf}}{\rho c_{p\,nf}}, \quad \zeta_{nf} \quad \frac{1}{\sigma \quad \mu},$$

0, 18

$$p\,\mu \quad {}^2 w \quad 1\, w \quad h \quad H \quad \mu \quad \mu$$

$$f \qquad S^2 R \quad H \quad z \qquad f \quad ef$$

$$z\,\mu \qquad r\, r \qquad em \quad r \quad r \quad r \quad \mu \quad \mu$$

$$nf \quad r^2 \qquad nf \quad e$$

$$\frac{\mu_f}{\mu_{nf}} \frac{\rho\gamma_{nf}}{\rho\gamma_f} G \quad \theta \sin\eta, \qquad 19$$

$$\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial H}{\partial r}\right)\right) \quad R \left(h \frac{\partial H}{\partial z} \ldots \frac{\partial w}{\partial r}\right), \qquad (20)$$

$$\theta^2 \quad 1\,\bar{\theta} \quad k \quad {}^{t}\beta \; 0, \qquad (21)$$

$r \quad r \; r \quad k$

where $\chi = \frac{1}{\sigma_{nf}\,\mu_{ef}}\;\sigma_f\,\mu_e$. The boundary conditions and geometry of stenosis in the dimensionless form are defined as

$$h(z) = 1 - 2\delta(z - d), \quad d \le z \le d + \tfrac{1}{2},$$

$$1 - \frac{\delta}{2}\left(1 + \cos 2\pi\left(z - d - \tfrac{1}{2}\right)\right), \quad d + \tfrac{1}{2} \le z \le d + 1,$$

$$1, \quad \text{otherwise}. \qquad (22)$$

$$\theta = 0, \quad \text{and } H_z = H_r = 0 \text{ at } r = h(z), \qquad (23a)$$

$$w = 0, \quad \theta = 1, \quad \text{at } r = \varepsilon. \qquad (23b)$$

$nf \quad ef \qquad 15$

The solution of Eq. (17) shows that *Hr* 0, substituting into Eq. (20) we get here ρ f represents the density of the base fluid, μ f is the base fluid viscosity, μ e is the constant magnetic permeability, sf is the electrical conductivity, $\rho cp\, f$ is the heat capacitance, γ f is the thermal expansion coefficient and kf is the thermal conductivity, while ρ s

$$J \quad \frac{H_z}{r} - \frac{R_m}{\chi}\frac{hw}{r} \quad c. \quad 1$$
θ (24)

Since $J\theta$ 0 at r . h using in Eq. (24), which gives $c1$ 0, then denotes the density for solid nanoparticle, ss is the electrical

$$F_z \; {}^h \; rw \; dr. \qquad (27)$$

Using Eqs. (26) into Eq. (27), we get the expression for pressure gradient as follows:

$$\frac{dp}{dz} \quad \frac{F \; x_8 x_7 \left(1 \;\; \phi \;\; \phi \qquad \varrho \; z \right)}{1 \;\; \phi^{2.5} x_6 \qquad \varrho(z) }. \qquad (28)$$

The pressure drop (p p at z ¼.0 and p p at z . ¼L) through the stenosis that is calculated from above Eq. (28) can be defined as,

$$p \quad \int_0^L \left(\frac{dp}{dz} \right) dz. \qquad (29)$$

Using Eq. (29), the impedance resistance can be evaluated as

$$\lambda \;\; \frac{p}{F} \quad {}^d_0 \;\; \Omega z \qquad h1 \;\; dz \qquad {}^{d\,\frac{1}{2}}_{d} \; \Omega z dz \qquad {}^{d1}_{d\frac{1}{2}} \; \Omega z \; dz$$
L

$$\Omega \;\; h1$$
$d\;1$

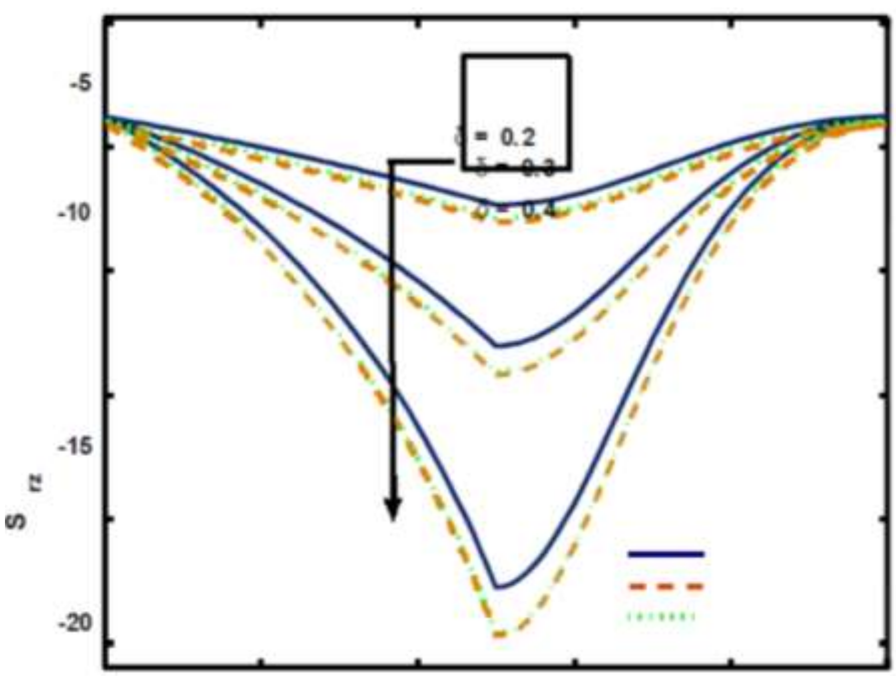
where $\quad z \qquad dz,$ (30)

$$\Omega z = \frac{1}{F}\left(\frac{F\, x_8 x_7 \left(1 - \phi + \phi \frac{\rho_s \gamma_s}{\rho_f \gamma_f}\right)}{1 - \phi^{2.5} x_6}\right). \qquad 31$$

Using Eqs. (31) into Eq. (30), we get

$$\lambda \quad \frac{p}{F} \quad L \;\; 1\Omega z \quad \int_{d}^{d1}{}^{2}{}_{h}\Omega z\, dz \quad \int_{d1_2}^{d1} \Omega z\, dz. \qquad -18 \quad 32$$

The expression for axial induced magnetic field *Hz* and the current density distribution $J\theta$ can be obtained using Eq. (26) into Eq. (24) and some straight forward calculation is done by using Mathematical software and the wall shear stress is obtained by using the following expression [17]:



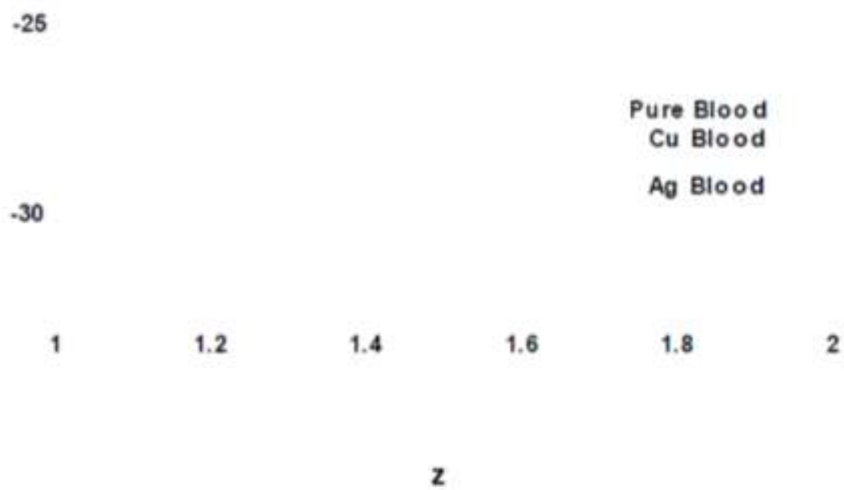


Fig. 2. Variation of wall shear stress for different values of the stenosis height δ .

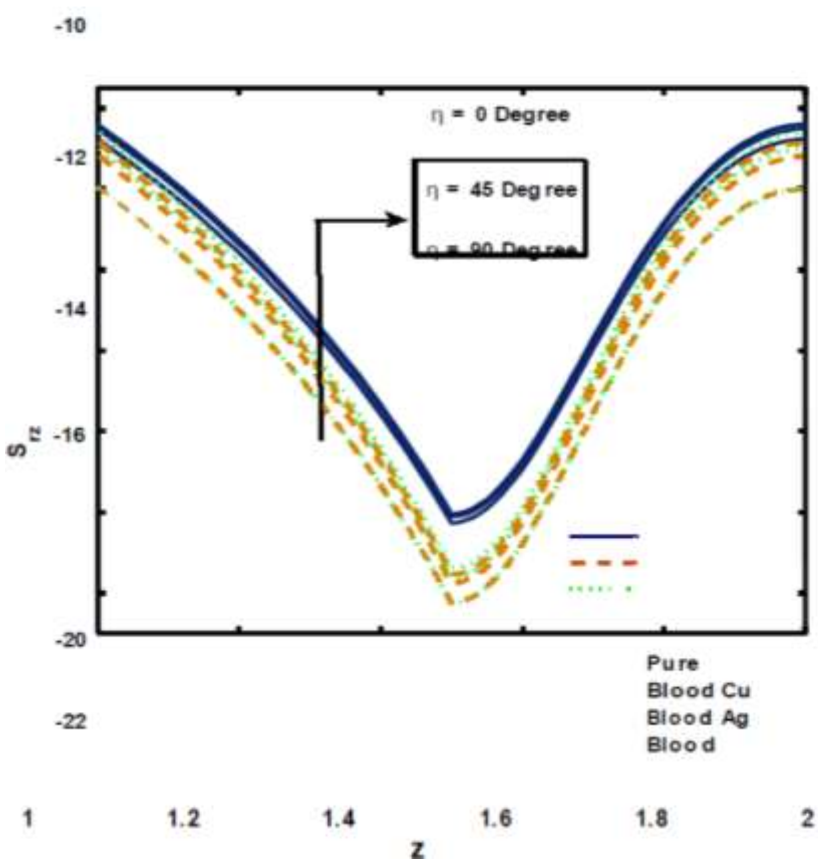


Fig. 3. Variation of wall shear stress for different values of the inclination angle η .

b in the rest of the region 0.59 *r h*.

Table 2: Variations of velocity profile for different values of the magnetic Reynolds *Rm*.

w 0.00	Pure blood ϕ			Copper Blood	Φ		Silver Blood		
r	R_m¼2.0	R_m 3	R_m 4	R_m¼2	R_m¼3	R_m¼4	R_m¼2	R_m¼3	R_m¼4
ε	0.00000	0.00000	0.0000	0.00000	0.00000	0.0000	0.00000	0.00000	0.00000
0.2	1.24305	1.10335	0.99375	1.21601	1.06477	0.94945	1.22545	1.07292	0.95659
0.3	1.98500	1.83106	1.70538	1.95791	1.78885	1.65396	1.96903	1.79872	1.66284
0.4	2.43504	2.32460	2.23025	2.41898	2.29567	2.19212	2.42795	2.30389	2.19973
0.5	2.61748	2.57151	2.52881	2.61400	2.56105	2.51236	2.61871	2.56557	2.51672
0.6	2.53407	2.55032	2.56046	2.54005	2.55644	2.56555	2.53984	2.55648	2.56578
0.7	2.18273	2.24235	2.29140	2.19310	2.25879	2.31163	2.18878	2.25494	2.30816
0.8	1.56110	1.63254	1.69404	1.57058	1.65054	1.71832	1.56447	1.64489	1.71306
h	0.00000	0.00000	0.0000 0	0.00000	0.00000	0.0000 0	0.00000	0.00000	0.00000

Table 3: Variations of velocity profile for different values of the Strommers number *S*2.

w 0.00	Pure blood ϕ			Copper Blood			Silver Blood		
r	S^2¼0.3	S^2 0.6	S^2¼0.9	S^2¼0.3	S^2¼0.6	S^2¼0.9	S^2¼0.3	S^2¼0.6	S^2¼0.9
ε	0.00000	0.00000	0.0000	0.00000	0.00000	0.0000	0.00000	0.00000	0.00000
0.2	1.61259	1.45012	1.24305	1.63931	1.44900	1.21601	1.65232	1.46041	1.22545
0.3	2.36817	2.20326	1.98500	2.39888	2.20537	1.95791	2.41331	2.21834	1.96903
0.4	2.69086	2.58365	2.43504	2.71508	2.58902	2.41898	2.72594	2.59907	2.42795
0.5	2.70909	2.67305	2.61748	2.72139	2.67883	2.61400	2.72648	2.68377	2.61871
0.6	2.48040	2.50542	2.53407	2.47936	2.50859	2.54005	2.47844	2.50799	2.53984
0.7	2.03639	2.09904	2.18273	2.02446	2.09802	2.19310	2.01889	2.09299	2.18878
0.8	1.39689	1.46557	1.56110	1.38046	1.46119	1.57058	1.37317	1.45442	1.56447
h	0.00000	0.00000	0.0000 0	0.00000	0.00000	0.0000 0	0.00000	0.00000	0.00000

Conclusion

A comprehensive mathematical analysis has been carried out in this paper for the description of blood flow in the presence of uniform transverse magnetic field. It is imperative to note that magnetic field can be used for magnetic drug targeting in useful circumstances. Some of the main observations of present analysis obtained by the graphical illustration are described as follows:

The contribution of copper and silver nanoparticles as drug carrier reveals that they are important to reduce hemodynamic of stenosis (i.e. wall shear stress and resistance impedance to blood flow).

The heat is dissipated throughout the considered inclined arter with an increase in the concentration of nanoparticle volume fraction.

The stresses on the wall of inclined arteries decrease with an

$$x_o \left(\frac{k_s 1 \ \phi k_f 2 \ \phi}{k_s 1 \ \ 2\phi \ \ 2k_f 1 \ \ \phi} \right) \quad \frac{\beta x_o}{\ } \quad x_1 \quad \frac{\ }{4},$$

$$x_2 \quad \frac{4 \ \beta x_o h \ \varepsilon h \ \ \varepsilon}{4 \ln h \ \ \ln \varepsilon},$$

$$x_3 \quad \frac{1}{4 \ln h \ \ \ln \varepsilon} \quad 4 \ \ln h \beta x_o \varepsilon^2 \ln h \ \ \beta x_o h^2 \ \ln \varepsilon,$$

$$x_4 \quad \frac{x_3 h}{4 \ K}^{2} \quad \frac{1}{16 \ K} \quad \frac{x h_2}{\ }^{4} \quad x^{2} \ \frac{h4 \ 4 \ K \ln h}{4 \ \ K^2},$$

$$x_5 \quad \frac{x_3 \varepsilon}{4 \ K} \quad \frac{x_1 \varepsilon}{16 \ K} \quad x^{2} \ \frac{\varepsilon \ 4 \ 4 \ K \ln h}{4 \ \ K^2}, \quad \sqrt{\ }$$

$$x \quad \frac{1}{\sqrt{\ }} \quad 1 \quad ^{2.5} \quad 16h^2 \ \sqrt{K} \ K^2 \ \sqrt{K}$$

References

[1] F.C. Mann, J.F. Herrick, H.E. Essex, E.J. Blades, Effects on blood flow of de- creasing the lumen of blood vessels, Surgery 4 (1938) 249 – 252.

[2] P.R.F.D. Young, F.Y. Tsai, Flow characteristics in model of arterial stenosis steady flow, J. Biomech. 6 (1973) 395 – 410.

[3] K.M. Channon, The endothelium and pathogenesis of atherosclerosis, Medi- cine 4 (2006) 173 – 177.

[4] S. Shaw, R.S.R. Gorla, P.V.S.N. Murthy, C.O. Ng, Pulsatile Casson fluid flow through a stenosed bifurcated artery, Int. J. Fluid Mech. Res. 36 (2009) 43 – 63.

[5] R. Ponalagusamy, The blood flow through an artery with mild stenosis: a two- layered model, different shapes of stenosis and slip velocity at the wall, J. Appl. Sci. 7 (2007) 1071 – 1077.

[6] S. Shaw, S.C. Pradhan, P. Murthy, A FSI model on the Casson fluid flow through an elastic stenosed artery, Int. J. Fluid Mech. Res. 39 (2012) 521 – 534.

[7] G.T. Liu, X.J. Wang, B.Q. Ai, L.G. Liu, Numerical study of pulsatile flow through a tapered artery with stenosis, Chin. J. Phys. 42 (2004) 401 – 409.

[8] B. Liu, D. Tang, A numerical simulation of viscous flows in collapsible tubes with stenosis, Appl. Numer. Math. 32 (2000) 87 – 101.

[9] Kh.S. Mekheimer, M.A. El Kot, Suspension model for blood flow through ar- terial catheterization, Chem. Eng. Commun. 197 (2010) 1195 – 1214.

[10] N.K. Vermaa, S. Mishrab, S.U. Siddiqui, R.S. Gupta, Study of blood flow through a catheterized artery, Adv. Appl. Sci. Res. 2 (2011) 114 – 122.

[11] Kh.S. Mekheimer, M.A. El Kot, Mathematical modeling of axial flow between two eccentric cylinders: application on the injection of eccentric catheter through stenotic arteries, Int. J. Non-Linear Mech. 47 (2012) 927 – 937.

[12] R.K. Srivastav, Mathematical model of blood flow through a composite ste- nosis in catheterized artery with permeable wall, Appl. Appl. Math. 99 (2014) 58 – 74.

[13] A. Kolin, An electromagnetic flow meter: principle of method and its appli- cation to blood flow acceleration, Exp. Biol. Med. 35 (1936) 53 – 56.

[14] Kh.S. Mekheimer, M.H. Haroun, M.A. El Kot, Effects of magnetic field, porosity, and wall properties for anisotropically elastic multi-stenosis arteries on blood flow characteristics, Appl. Math. Mech. 32 (2011) 1047 – 1064.