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Impact of Silver Nanoparticles Infused in Blood in a Stenosed Artery under the Effect of Magnetic Field Imp. of Silver Nano. Inf. in Blood in a Sten. Art. Under the Eff. of Mag. Field

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Abstract:- Nanotechnology and nanofluids offer promising avenues for enhancing our understanding and control of blood flow dynamics, providing novel solutions for addressing challenges in cardiovascular health and medical diagnostics. This paper investigates the impact of silver nanoparticles infused in blood within a stenosed artery under the influence of a magnetic field. The governing equations of continuity, mass, and heat transfer are non-dimensionalized to facilitate numerical solution. Utilizing the fourth-order Runge-Kutta method implemented in MATLAB, the non-dimensionalized equations are solved to analyze the effects of pertinent parameters on flow velocity and heat transfer in the presence of a magnetic field. The study reveals significant insights into the behavior of blood flow and heat transfer when silver nanoparticles are introduced into the bloodstream in the context of arterial stenosis and magnetic field exposure. The analysis provides valuable information on how the magnetic field and nanoparticle infusion affect flow characteristics and thermal dynamics within the stenosed artery. The rise in the volume fraction of nanoparticles slows down the nanofluid. The augmented values of magnetic parameter results in decrease in velocity but increase in temperature. The thickness of boundary layer at arterial wall decreases with enhancement in Prandtl number. The findings of this research hold promise for applications in biomedicine and medical science, offering potential strategies for enhancing therapeutic interventions in cardiovascular diseases. This study contributes to the advancement of biomedical engineering and offers avenues for the development of novel treatments and diagnostic techniques by elucidating the intricate interplay between nanoparticles, blood flow, and magnetic fields within stenosed arteries.

Keywords:- *Blood; Silver Nanoparticles; Nanofluid; Stenosed Artery; Magnetic Field.*

I. INTRODUCTION

In the realm of biomedical engineering, the integration of nanotechnology and magnetic fields has unveiled promising avenues for addressing vascular diseases, such as atherosclerosis [1]. A particularly innovative approach involves the utilization of silver nanoparticles within the bloodstream, coupled with the application of a magnetic field, to mitigate the effects of arterial stenosis. Arterial stenosis, characterized by the narrowing of blood vessels due to plaque buildup, poses a significant health risk worldwide, often leading to cardiovascular complications. The amalgamation of silver [2] nanoparticles and magnetic fields presents a novel strategy to combat this condition, potentially revolutionizing current treatment paradigms. Cardiovascular diseases (CVDs) [3] remain a leading cause of mortality worldwide, with arterial stenosis emerging as a critical contributor to this burden. Arterial stenosis, characterized by the narrowing of blood vessels due to the accumulation of plaque, significantly compromises blood flow and poses a substantial risk for myocardial infarction, stroke, and other adverse cardiovascular events. Conventional therapeutic approaches, including pharmacotherapy and invasive procedures such as angioplasty and stenting, although effective to some extent, are often associated with limitations such as systemic side effects, restenosis, and procedural complications. In light of these challenges, there is a pressing need for innovative strategies that offer targeted, efficacious, and minimally invasive interventions for the management of arterial stenosis [4]. The integration of silver nanoparticles infused in blood within a stenosed artery, under the influence of a magnetic field, represents a groundbreaking approach with far-reaching applications in cardiovascular medicine. This novel strategy holds immense promise in revolutionizing the current treatment paradigm for arterial stenosis by leveraging the unique properties of silver nanoparticles and magnetic fields [5]. Firstly, the targeted delivery of silver nanoparticles to the site of arterial stenosis, facilitated by the application of a magnetic field, offers a precise and localized therapeutic intervention, minimizing off-target

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effects and enhancing treatment efficacy. Moreover, the antimicrobial properties inherent to silver nanoparticles hold potential for combating infections commonly associated with arterial stenosis, thereby reducing the risk of secondary complications and improving patient outcomes. Additionally, the tunable nature of magnetic fields enables real-time adjustments, allowing for personalized and adaptable treatment regimens tailored to individual patient needs. Furthermore, the non-invasive nature of magnetic field-based interventions offers a promising alternative to traditional invasive procedures, potentially mitigating procedural risks and enhancing patient comfort and compliance [6-7].

Despite the considerable promise offered by the integration of silver nanoparticles and magnetic fields for the management of arterial stenosis, several critical research gaps persist, underscoring the need for further investigation in this burgeoning field. Firstly, while preclinical studies have demonstrated encouraging results regarding the efficacy of this approach in animal models, comprehensive understanding of its long-term safety profile in human subjects remains limited. Addressing this gap necessitates rigorous evaluation of potential cytotoxicity, immunogenicity, and biodistribution of silver nanoparticles within the human body to ensure their biocompatibility and minimize the risk of adverse reactions [8]. Moreover, elucidating the underlying mechanisms governing the interaction between silver nanoparticles, magnetic fields, and arterial plaque is paramount for optimizing treatment protocols and maximizing therapeutic outcomes [9]. Chakraborty et al. [10] explained the role of silver nanoparticles in treatment of cancer. Comprehensive studies elucidating the kinetics of nanoparticle accumulation, cellular uptake mechanisms, and potential interactions with biological constituents within the arterial microenvironment are imperative to inform the design of targeted and efficacious interventions. Furthermore, the translational feasibility of this approach from bench to bedside necessitates robust clinical trials to validate its safety, efficacy, and clinical utility across diverse patient populations. Large-scale, multicenter trials incorporating rigorous patient selection criteria, standardized treatment protocols, and comprehensive outcome assessments are essential to substantiate the clinical efficacy and establish the role of silver nanoparticle-based interventions in routine clinical practice [11]. Additionally, considerations regarding cost-effectiveness, scalability, and regulatory approval processes are crucial for facilitating the translation of these innovative therapies into widespread clinical adoption. By addressing these research gaps, this study aims to advance our understanding of the potential applications of silver nanoparticles infused in blood under the effect of a magnetic field for the management of arterial stenosis, thereby paving the way for the development of novel, targeted, and minimally invasive interventions with the potential to revolutionize cardiovascular care [12-14].

Our objective is to rigorously analyze the interplay of magnetic field and Prandtl number on blood flow behavior. This involves formulating and solving the relevant fluid dynamics equations, imposing appropriate boundary conditions, integrating the stenosis equation into the model, and ultimately interpreting the resultant flow characteristics. Through this investigation, we aim to deepen our understanding of how stenotic geometries impact blood flow parameters, with potential implications for diagnosing and treating vascular diseases.

II. MODELING OF PROBLEM

The current problem is modeled to stimulate comprehensive examination of blood flow dynamics within a stenotic artery, considering the blood as an incompressible, two-dimensional fluid. The stenotic artery is characterized by a length of $\frac{L_0}{2}$ and a diameter of $2R_0$. The fluid flow is directed along the x-axis, while the radial axis (r-axis) is perpendicular to this flow direction. Adding complexity to the geometric configuration, the artery houses a cosine-shaped stenosis, the profile of which is described by equation:

$$R(x)=\begin{pmatrix} R_0-\frac{\lambda}{2}\left(1+\mathrm{Cos}\left(\frac{4\pi x}{L_0}\right)\right), & -\frac{L_0}{4}<x<\frac{L_0}{4} \\ R_0, \mathrm{Otherwise} & \end{pmatrix}. \quad (1)$$

The equations that govern the steady boundary layer for the flow and heat transfer of a Newtonian nanofluid can be outlined as follows:

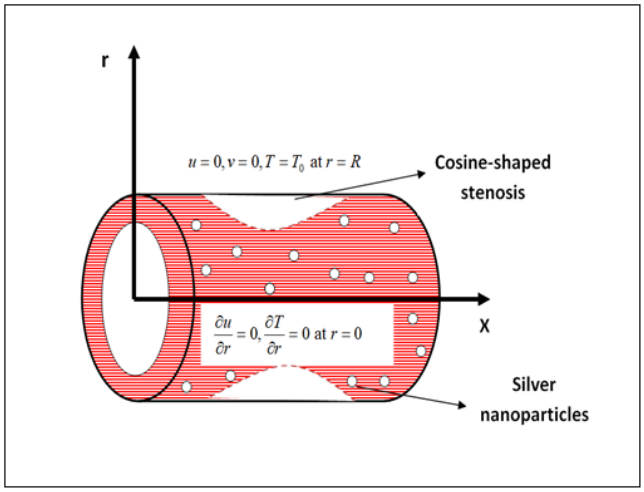

Fig 1: Geometry of Stenosed Artery with Silver Nanoparticles

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A. Continuity Equation

$$\frac{\partial(ru)}{\partial x}+\frac{\partial(rv)}{\partial r}=0, \tag{2}$$

B. Momentum Equation

$$\left(u\frac{\partial}{\partial x}+v\frac{\partial}{\partial r}\right)u=\frac{\mu_{nf}}{\rho_{nf}}\frac{\partial}{r\partial r}\left(ru_r\right)-\frac{\sigma B(x)^2}{\rho_{nf}} \tag{3}$$

C. Heat Equation

$$\left(u\frac{\partial}{\partial x}+v\frac{\partial}{\partial r}\right)T=\frac{k_{nf}}{\left(\rho C_p\right)_{nf}}\frac{\partial}{r\partial r}\left(rT_r\right), \tag{4}$$

With boundary conditions as follows:

$$\left.\begin{aligned} &u=0,v=0,T=T_0 \text{ at } r=R,\\ &\frac{\partial u}{\partial r}=0,\frac{\partial T}{\partial r}=0 \text{ at } r=0 \end{aligned}\right\}. \tag{5}$$

The continuity equation in (2) is trivially satisfied by considering the following relations involving the stream function ψ :

$$ur=\frac{\partial\psi}{\partial r},vr=-\frac{\partial\psi}{\partial x} \tag{6}$$

The expressions for density, dynamic viscosity, specific heat conductivity and thermal conductivity for blood-based nanolfuids are given by [16]

$$\left.\begin{aligned} \rho_{nf}&=\rho_f\left((1-\phi)+\phi\frac{\rho_s}{\rho_f}\right),\\ \mu_{nf}&=\frac{\mu_f}{(1-\phi)^{2.5}},\\ \left(\rho C_p\right)_{nf}&=\left(\rho C_p\right)_f\left((1-\phi)+\phi\frac{\left(\rho C_p\right)_s}{\left(\rho C_p\right)_f}\right),\\ \frac{k_{nf}}{k_f}&=\frac{k_s+2k_{bf}-2\phi\left(k_{bf}-k_s\right)}{k_c+2,k_{bf}+\phi\left(k_{bf}-k_s\right)}. \end{aligned}\right\}. \tag{7}$$

➢ *Defining the Following Non-Dimensional Variables [17]:*

$$\left.\begin{aligned} u=\frac{u_0x}{L_0}F'(\eta),v=-\frac{R}{r}\sqrt{\frac{u_0v_f}{L_0}}F(\eta),\eta=\frac{r^2-R^2}{2R}\sqrt{\frac{u_0}{v_fL_0}},\\ \theta(\eta)=\frac{T-T_0}{T_1-T_0},\psi=\sqrt{\frac{u_0x^2v_f}{L_0}}RF(\eta), \end{aligned}\right\}. \tag{8}$$

Utilizing the functions defined in equation (8) into the momentum and heat transfer equations (3) and (4), the following non-dimensional equations are obtained:

$$\left[(1+2\gamma\eta)F'''+2\gamma F''\right]+L_1L_2(FF''-F'^2-MF')=0, \tag{9}$$

$$\left[(1+2\gamma\eta)\theta''+2\gamma\theta'\right]+L_3L_4Pr(F\theta'-F'\theta)=0. \tag{10}$$

Where $\Pr=\frac{k_f}{\left(\mu C_p\right)_f}$ and $M=\frac{\sigma B_0^2}{c\rho_{nf}}$ are the Prandtl number and Magnetic parameter respectively.

For the sake of simplicity, the following functions are considered:

$$\left.\begin{aligned} (1-\phi)^{2.5}&=L_1,\\ (1-\phi)+\phi\frac{\rho_s}{\rho_f}&=L_2\\ (1-\phi)+\phi\frac{\left(\rho C_p\right)_s}{\left(\rho C_p\right)_f}&=L_3\\ \frac{k_s+2k_{bf}+\phi(k_{bf}-k_s)}{k_s+2k_{bf}-2\phi(k_{bf}-k_s)}&=L_4. \end{aligned}\right\}. \tag{11}$$

In view of equation (8), boundary conditions in equation (5) transforms to:

$$\left.\begin{aligned} F(0)=0,F'(0)=0,\theta(0)=1 \text{ at } \eta=0,\\ F''(\eta)=0,\theta'(\eta)=0 \text{ at } \eta=f. \end{aligned}\right\}. \tag{12}$$

III. METHOD OF SOLUTION

The non-dimensional differential equations obtained in equation (9) and (10) are first converted into a first order system of differential equations by considering:

$$F=p_1,F'=p_1'=p_2,F''=p_2'=p_3,$$
$$F'''=p_3',\theta=\mathrm{p}_4,\theta_4'=p_4'=p_5,\theta''=p_5'$$

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Where

$$F''' = \frac{-2\gamma F'' - L_1 L_2 (FF'' - F'^2 - MF')}{(1+2\gamma\eta)},$$

$$\theta'' = \frac{-2\gamma\theta' - L_3 L_4 Pr(F\theta' - F'\theta)}{(1+2\gamma\eta)}$$

The above system of first-order differential equations is then executed by Runge-Kutta numerical method of 4th order in computational tool MATLAB. The obtained results of velocity and temperature are presented in the form of graphs and discussed in detail.

IV. RESULTS AND DISCUSSION

A comprehensive analysis of blood-based silver nanoparticles in cosine-shaped stenosed artery is undertaken. The resulting partial differential equations are first non-dimensionalized and then transformed to non-linear ordinary differential equations. These equations are further converted into first order system of differential equations. This first order system is executed in MATLAB using Runge-Kutta 4th order method. To enable the numerical solution of the governing differential equations, the thermophysical properties of base fluid (blood) and silver nanoparticles are embedded in Table 1. Also, the numerical values of the pertinent parameters are taken as: $\phi = 0.01$, $\Pr = 6.0$, $M = 1.5$. The obtained results are encapsulated in the form of graphs as shown in Fig. 2-5.

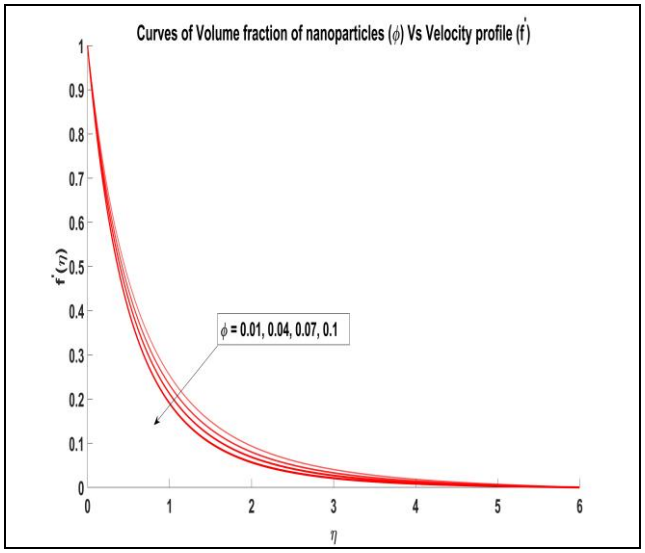

Fig 2: Impact Of Volume Fraction Of Nanoparticles on Velocity Profiles

Fig. 2-3 and 4-5 present comprehensive insights into the intricate dynamics of nanofluids, focusing on the interplay between key parameters and their effects on velocity and thermal properties.

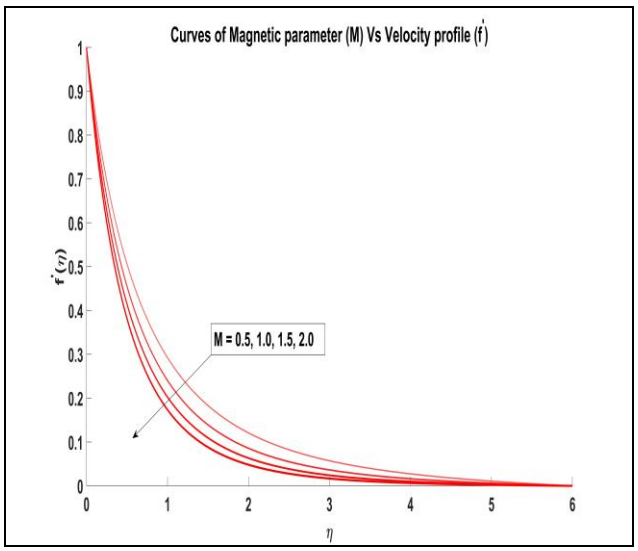

Fig 3: Impact of Magneic Parameter on Velocity Profiles

In Figure 2-3, the influence of the volume fraction of silver nanoparticles and magnetic parameter on nanofluid velocity is investigated. This analysis uncovers how changes in nanoparticle concentration and magnetic field strength alter fluid behavior, potentially revealing relationships between these parameters and velocity. On the other hand, Figure 4-5 delves into the impact of magnetic parameter and Prandtl number on the thermal behavior of silver-infused blood (nanofluid). These figures explain the understanding of variations in magnetic field intensity and thermal diffusivity affecting the nanofluid's ability to transfer heat.

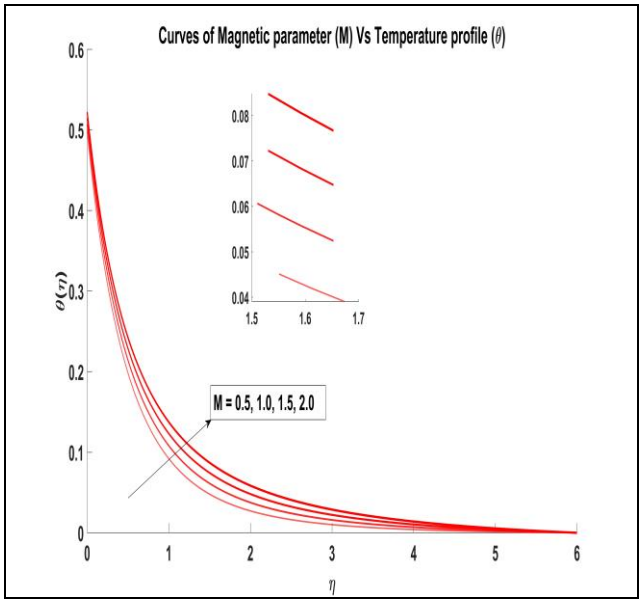

Fig 4: Impact of Magnetic Parameter on Temperature Profiles

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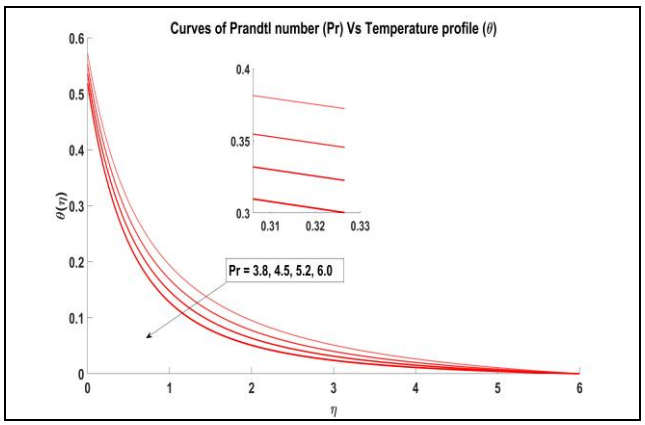

Fig 5: Impact of Prandtl Number on Temperature Profiles

In Figure 2, the observed decrease in nanofluid velocity with an increase in the volume fraction of silver nanoparticles suggests a nuanced interplay between nanoparticle concentration and fluid dynamics. This phenomenon can be elucidated through various physical considerations and implications. Firstly, as the volume fraction of nanoparticles rises, the overall density and viscosity of the nanofluid typically increase. This increase in density and viscosity could hinder the fluid's ability to flow freely, leading to a reduction in velocity.

Table 1: Thermo-Physical Properties of Blood and Silver Nanoparticles

Material	Thermo-Physical Properties of Blood and Silver Nanoparticles		
	Density (ρ)	Thermal Conductivity (k)	Specific Heat Capacity (c_p)
Blood	1063	0.492	3594
Silver nanoparticles	10500	429	235

Moreover, the presence of nanoparticles may disrupt the fluid's laminar flow characteristics, inducing more viscous or turbulent behavior, which in turn impedes the fluid's motion. Additionally, at higher nanoparticle concentrations, interactions between nanoparticles become more pronounced, potentially leading to aggregation or clustering, further complicating fluid flow. The significance of this observation lies in its relevance to practical applications, such as nanofluid-based heat transfer systems or biomedical applications where controlling fluid velocity is crucial. Figure 3 explores the impact of magnetic parameter on silver-infused fluid. As the magnetic parameter rises, a decrease in velocity of nanofluid is noted. This is because the stronger magnetic field induces various effects within the nanofluid, including the alignment or motion of suspended nanoparticles. The alignment or orientation of nanoparticles under the influence of the magnetic field alters the fluid's overall flow behavior, potentially leading to a decrease in velocity. Additionally, the magnetic field also induce magnetic forces between nanoparticles, causing them to aggregate or cluster, which further impedes the fluid motion.

Fig. 4 explains the influence of magnetic parameter on thermal profile of nanofluid. A rise in magnetic parameter leads to increase in temperature of nanofluid. This enhancement in thermal profile of Ag-blood nanofluid is due to the reason that that the magnetic field promotes better dispersion or alignment of nanoparticles within the fluid, facilitating more efficient heat transfer between the particles and the surrounding medium. The significance of this observation lies in its relevance to thermal management applications where precise control over temperature is crucial. Fig. 5 showcases the effect of Prandtl number on temperature profiles of nanofluid. On enhancing the Prandtl number, the decreased temperature profiles are obtained. The Prandtl number represents the ratio of momentum diffusivity to thermal diffusivity in a fluid. When the Prandtl number increases, it signifies a higher ratio of momentum to thermal diffusivity. In practical terms, this implies that the fluid's ability to transfer momentum is relatively higher compared to its ability to transfer heat. Consequently, as the Prandtl number increases, the fluid tends to exhibit enhanced momentum mixing or convection relative to thermal diffusion. Physically, this means that an increase in the Prandtl number leads to a reduced ability of the fluid to efficiently transfer heat. This could be due to a combination of factors, including reduced thermal boundary layer thickness and decreased convective heat transfer rates. In other words, a higher Prandtl number implies that the fluid has a tendency to retain more of its heat energy within its bulk rather than efficiently transferring it to its surroundings.

V. CONCLUSION

- The key outcomes of the detailed analysis of blood-based silver infused nanofluid in a cosine shaped stenotic artery are as follows:
- Fluid becomes more turbulent with the increase in volume fraction of silver nanoparticles thereby hindering its ability to flow freely.
- The rise in the values of magnetic parameter impedes the nanofluid motion due to clustering of magnetic nanoparticles.
- Thermal enhancement in the stenotic artery is noted with increasing values of magnetic parameter due to enhanced dispersion of nanoparticles ultimately enhancing thermal conductivity.
- Thickness of boundary layer decreases due to augmented values of Prandtl number leading to enhanced momentum diffusivity compared to thermal diffusivity.

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