Computational role of Blood-based Casson fluid flow through a Stenotic Artery: An application to cardiovascular issues

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Abstract

The living muscular system's blood circulation structure includes veins with nanoparticles. Flowing blood is non-Newtonian throughout vessel section. The stenosed artery interior is taken into account. Iron (III) oxide and silver nanoparticles have several biological uses because they oxidize quicker when compared to other nanoparticles throughout the blood and purify blood within the stenosed artery. Atherosclerosis channels decrease cardiovascular function. It may restrict blood flow to your heart and brain. Based on the motivation, the present framework's primary goal is to investigate the significance of Fe_2O_3 and Silver nano particles in red blood cells in the existence of magnetohydrodynamic within a stenotic artery. The flow problem is highly non-linear coupled partial differential equation, which are transformed into ordinary differential equations with the help of similarity variables. These are solved numerically using the BVP5c method in MATLAB Software. In order to facilitate the presentation of the theoretical outcomes of this drug delivery mechanism. The use of iron and silver nanoparticles used in medical delivery agent. For instance, as expected, a decrease in blood circulation occurred when the parameter for magnetic fields was increased in an effort to enhance the magnetic characteristics of the living organisms composing the bloodstream. Increasing the flow parameter values enhanced the temperature profile. The findings of this study have important implications for the fields of healthcare engineering. Heat treatment, targeted drug delivery, and ultrasound imaging among all areas that might benefit from its use in the medical field.

Keywords: Bvp5c technique, MHD, Stenotic artery, Casson fluid model, Fe_2O_3 and Silver nanoparticles.

1. Introduction

Nanoparticle characteristics including size, chemical composition, and structure may be enhanced to improve their performance in biomedical industry. A significant development of nanoparticles has occurred for several biomedical uses, particularly a few nanoparticles demonstrating significant promise in the therapy and monitoring of illnesses. Scientists are constantly investigating new techniques to employ the characteristics of iron oxide nanoparticles for diagnosis and treatment therapy, contributing towards continuing advancements in their biomedical applications. It is crucial to emphasize that the protection, biological compatibility, and for long-time effects of these nanoparticles require to be extensively examined before they can be used in medical applications. Magnesium oxide (Fe_2O_3) and ferric oxide (Fe_3O_4) solids are used as MRI antagonists. Nanoparticles of iron oxide and Fe_3O_4 have magnetic features that enhance difference in MRI images, allowing for better visualization of abnormal organs, tissues, and individuals. The use of Fe_2O_3 and tiny particles of iron oxide as drug carriers is a promising area of research. Therapeutic compounds may be attached to the surface of iron oxide fragments by the integration approach. Using magnetic forces, it is possible to guide the tiny particles to certain sites, allowing for more precise medication delivery from outside[1][2][3][4][5].

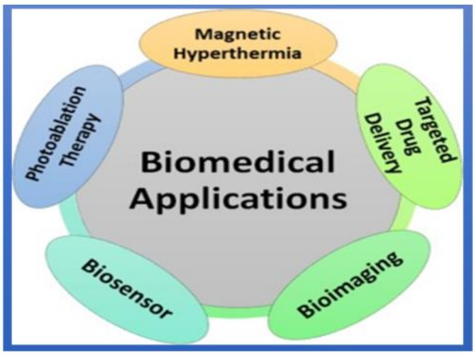
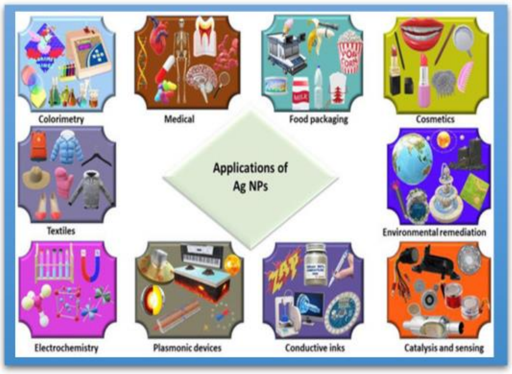
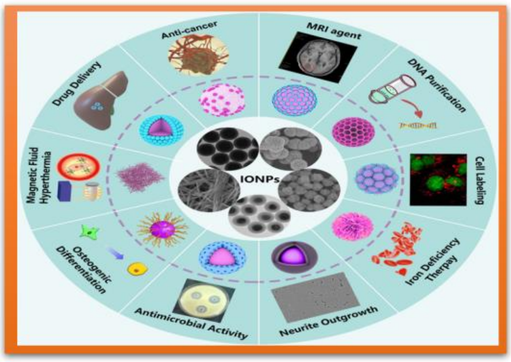


Fig 1. Illustration showing the biological applications of nanoparticles.

In biomedicine, focused drug delivery is crucial for delivering chemotherapy drugs into tumor sites without harming nearby cells that are alive. At this time, particles made of ferrous oxide are the primary source of magnetic compounds that have been utilized for delivering chemotherapy drugs to locations that are specifically targeted. Magnetic thermal therapy is a significant biological use of small particles. During hyperthermia using magnets therapy, tumors are heated over 42°C to eliminate tumor cells that are malignant. One advantage of this method over treatment with chemotherapy involves the fact that it focuses the tumor without harming adjacent healthy tissue, which is shown in Fig 1.



(a)



(b)

Fig 2 (a and b). Figure showing the biological applications of Fe_2O_3 and Silver nanoparticles.

The blood stream transports anticancer medications to tumors during radiotherapy. Adverse

reactions of this medication include insufficient specificity and harmful effects, which may harm normal cells and tissues. Consequently, tailored medication delivery has been explored as a substitute to radiotherapy. Focused medication delivery aims to increase medicine delivery to the tumor location while minimizing negative effects. Focused medication delivery uses magnets to place the medicament precisely. Coating magnets with suitable coatings like precious metals or polymer compounds allows for drug conjugation or encapsulation, as demonstrated in Fig 2 (a and b) [6][7][8].

This condition, which is more frequently referred to as cardiovascular stenosis, is rather prevalent throughout the human circulatory artery network. Blocks or narrowings are also fairly prevalent. A disruption occurs in the normal course of circulation via the vessel as a result of the narrowing. The scientific field of nanostructures encompasses a wide range of topics. Recent developments in nanotechnology for delivering of medications are focused on the development of artificial nanometer-sized delivery mechanisms that are specifically adapted to the administration of pharmaceutical medications. Liposomes, tiny capsules, tiny emulsion, small particles, as well as other service-delivered medication delivery systems demonstrate a broad variety of advantageous characteristics. They provide various benefits to the user. Moreover, they have multiple disadvantages. Therefore, every mechanism was developed as a make-up for the deficiencies of the framework that came before it and Experimental and computational efforts have been considered by various researchers are acknowledge the mechanics of Casson model through blood flow and heat transfer analysis [9-16]. This research aims to assess the value of iron oxide and tiny silver particles introduced entering the circulation through stenosed vessels. Various elements, such as the MHD and Casson fluid model are examined in this portion of the study. The findings are provided in the form of graphs and tables. Initially, the governing mathematical flow equations are solved and then a computational solution is achieved by utilizing the MATLAB program. Secondly, the graphs have been plotted in order to provide a description of the physical amounts of the various parameters. At the very conclusion, some concluding observations are presented. The present research is important in a variety of uses within the field of biomedicine.

2. Mathematical formulation of the problem

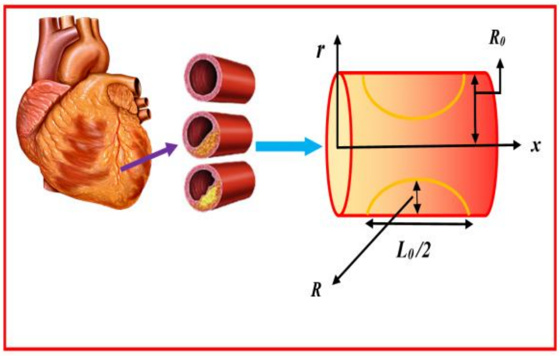


Fig 3. The artery's physical structure.

- The present model assumed in this scenario that circulatory blood circulates via a length-restricted artery ($L_0/2$) constriction such as incompressible steady liquid.

- The circulation of blood is considered across the *x*-direction and perpendicular towards the *r*-direction according to the chosen coordinate framework is presented in Fig 3 and thermo physical properties of nano particles are presented in Table 1.

- In artery's figure of the flow model, circulation of flow via artery outline for the stenosed region is considered as

$$R(x) = R_0 - \frac{\chi}{2}\left(1 + \mathrm{Cos}\left(\frac{4\pi x}{L_0}\right)\right), \quad -\frac{L_0}{4} < x < \frac{L_0}{4} = R_0 \quad Otherwise, \tag{1}$$

Considering each of these circumstances, the formulae that follow may be formulated to control the circulation and thermal transmission in non-Newtonian nanofluids.

The mathematical flow equations are [17-20]

$$\frac{\partial(r\bar{u})}{\partial x}+\frac{\partial(r\bar{v})}{\partial r}=0, \tag{2}$$

$$\rho_{nf}\left(\bar{u}\frac{\partial\bar{u}}{\partial x}+\bar{v}\frac{\partial\bar{u}}{\partial r}\right)=\mu_{nf}\left(1+\frac{1}{\beta}\right)\frac{\partial}{r\partial r}\left(r\frac{\partial\bar{u}}{\partial r}\right)-\sigma_{nf}B^2\bar{u}, \tag{3}$$

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

$$\bar{u}\frac{\partial\bar{C}}{\partial x}+\bar{v}\frac{\partial\bar{C}}{\partial r}=D_B\frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial\bar{C}}{\partial r}+\frac{D_T}{T_\infty}\frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial\bar{T}}{\partial r}. \tag{5}$$

Along with the boundary conditions are [17-20]

$$\left.\begin{array}{ll}\bar{u}=u_0,\bar{v}=0,\bar{T}=T_w,C=C_w & at\ \ r=R,\\ \bar{u}\to 0,\bar{T}\to T_\infty,C\to C_\infty & as\ r\to\infty.\end{array}\right\} \tag{6}$$

Thermophysical properties of nanofluid are

$$A_1=\frac{\mu_{nf}}{\mu_f},\ A_2=\frac{\rho_{nf}}{\rho_f},\ A_3=\frac{\sigma_{nf}}{\sigma_f},\ A_4=\frac{(\rho c_p)_{nf}}{(\rho c_p)_f},\ A_5=\frac{k_{nf}}{k_f} \tag{7}$$

The continuity eq. (1) can be satisfied by introducing stream function ψ for u and v such that.

$$\bar{u}=\frac{1}{r}\frac{\partial\psi}{\partial r},\bar{v}=-\frac{1}{r}\frac{\partial\psi}{\partial x} \tag{8}$$

The similarity variables are:

$$\left.\begin{array}{l}u=\frac{u_0x}{L_0}f'(\eta),\ v=-\frac{R}{r}\sqrt{\frac{u_0\upsilon_f}{L_0}}f(\eta),\ \theta(\eta)=\frac{T-T_0}{T_1-T_0}\\ \eta=\frac{r^2-R^2}{2R}\sqrt{\frac{u_0}{\upsilon_fL_0}}.\end{array}\right\} \tag{10}$$

After applying suitable self-similarity transformation, the Eqs. $(8-9)$ finally takes the following form:

$$\frac{1}{A_1A_2}\left[(1+2\gamma\eta)\left(1+\frac{1}{\beta}\right)f'''+2\gamma f''\right]+ff''-f'^2-\frac{A_3}{A_2}Mf'=0 \tag{11}$$

$$\frac{A_5}{A_4}\frac{1}{Pr}\left[(1+2\gamma\eta)\theta''+2\gamma\theta'\right]+f\theta'-f'\theta=0 \tag{12}$$

The non-dimensional equations are:

$$\left|\begin{array}{l}f(0)=0,\ f'(0)=1,\theta(0)=1,\\ f'(\eta)\to 0,\theta(\eta)\to 0\ \ as\ \eta\to\infty.\end{array}\right. \tag{13}$$

Where $Pr = \frac{k_f}{(\mu C_p)_f}$ is the Prandtl number, $\gamma = \sqrt{\frac{\upsilon_f L_0}{u_0 R^2}}$ is flow parameter, $M = \frac{\sigma_f B^2 L_0}{u_0 \rho_f}$ is the Magnetic parameter.

Some significant physical parameters related to the C_f, and Nu, and the heat transfer features of the transport are defined in dimensional form by

$$C_f = \left(1 + \frac{1}{\beta}\right)\frac{2\tau_w}{\rho_f U_w^2} \tag{14}$$

Where shear stress τ_w is

$$\tau_w = \mu_{nf} \left.\frac{\partial u}{\partial r}\right|_{r=R}$$

$$Nu = \frac{x q_w}{k_f (T_w - T_\infty)} \tag{15}$$

Where heat flux q_w is

$$q_w = -k_{nf} \left.\frac{\partial T}{\partial r}\right|_{r=R}$$

The dimensionless equations are

$$Re_r^{1/2} C_f = A_1 \left(1 + \frac{1}{\beta}\right) f''(0), \tag{16}$$

$$Re_r^{-1/2} Nu_r = -\frac{k_{nf}}{k_f}\theta'(0). \tag{17}$$

Where Re_r local Reynolds number.

Table 1. The thermophysical properties of Fe_2O_3/silver-Blood [21][22].

Property	**Blood**	**Fe_2O_3**	**Silver**
Density ρ (kgm^{-3})	1050	5180	10,500
Specific heat C_p ($Jkg^{-1}K^{-1}$)	3617	670	235
Heat conductivity k_f ($Wm^{-1}K^{-1}$)	0.52	9.7	429
Electrical conductivity σ $(\Omega m)^{-1}$	0.8	25000	63×10^{-6}
Pr	21		

3. Solution methodology

The ODE system (11–12) with BCs (13) is characterized by highly nonlinear behavior. The numerical strategy called the Bvp5c technique to handle these equations. The management problem-solving may be resolved by employing the software program MATLAB solver. The normal operating process for the model approach is outlined below. The results of the present code were compared to those obtained by Waqas et al. for the case of various values of γ, ϕ_1, as shown in Table 2 and the full details about the working procedure of the method is presented in Fig 4. The study discovered a significant level of convergence between the current findings. In this case, the step size in the technique is $(h = 0.001)$, and the operation is frequent until the desired level $\left(1\times10^{-8}\right)$ of accuracy is reached. As a result, the current code is justified.

The phases of the shooting strategy are listed below:

$$f=\xi_1, f'=\xi_2, f''=\xi_3, f'''=\xi_3', \theta=\xi_4, \theta'=\xi_5, \theta''=\xi_5'$$

The approach known as substitution is used in order to generate first-order nonlinear ordinary differential equations. In order to construct a mathematical setting that is similar, the technique that follows should be followed.

$$\xi_1' = \xi_2$$

$$\xi_2' = \xi_3$$

$$\xi_3' = -\left[-\frac{\dfrac{1}{A_1A_2}2\gamma\xi_3+\xi_1\xi_3-(\xi_2)^2-\dfrac{A_3}{A_2}M\xi_2}{(1+2\gamma\eta)\left(1+\dfrac{1}{\beta}\right)\dfrac{1}{A_1A_2}} \right]$$

$$\xi_4' = \xi_5$$

$$\xi_5' = -\left[-\frac{\dfrac{A_5}{A_4}\dfrac{1}{Pr}2\gamma\xi_5+\xi_1\xi_5-\xi_2\xi_4}{\dfrac{A_5}{A_4}\dfrac{1}{Pr}(1+2\gamma\eta)} \right]$$

As well as the boundary conditions are

$$\left.\begin{array}{l}\xi_1(\eta)=0, \xi_2(\eta)=1, \xi_4(\eta)=1, at\ \eta=0\\ \xi_2(\eta)\to0, \xi_4(\eta)\to0\ \ as\ \eta\to\infty.\end{array}\right\}$$

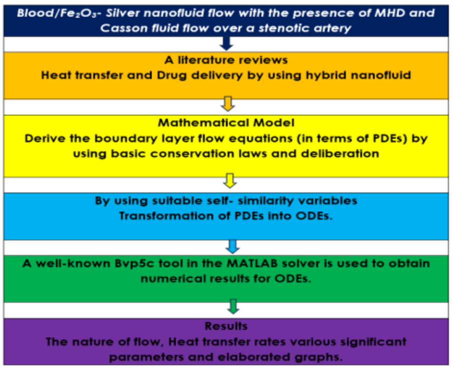


Fig 4. Flow chart of the present investigation problem.

4. Results and discussion

The Casson nanofluid movement across a stenotic arterial was described using the bvp5c procedure in the MATLAB solver throughout the present study and also the ranges of all parameters $0.2<M<0.6, 0.1<\gamma<0.3, 0.5<\beta<1.5, 1.0<\gamma<3.0, 0.01<Silver, Fe_2O_3<0.03.$ Velocity and temperature graphs reveal various key characteristics. Fig. 5 influence the impact of M on the velocity profile. It is exposed that the declined trend on the velocity outline for the increasing values of the M parameter. From a physical standpoint when M grows, it produces a Lorentz pressure that restricts the movement of fluids. Whenever the Lorentz effect resists fluid motion, its speed decreases due to the extra resistance, leading to a drop in the field of acceleration. The impact of γ parameter on velocity outline is shown in Fig 6. The velocity graph is enhanced as the value of γ values are increased. And also, same trend noticed on energy graph, which is demonstrated in Fig 8. It is important to remember how the non-Newtonian nature of the Casson fluid, which is also called viscoelastic liquid, depends on an amount of Casson fluid. The fluid behaves like a fluid that obeys Newton's laws and its movement rate rises as Casson fluid parameter grows because the stress caused by shear is greater than the stress due to yield. The graphic shows that when the Casson fluid value increases, fluid flexibility increases, velocity and barrier layer width decreases, which is shown in Fig 7. Figs. 9 and 10 demonstrates the effect of the Silver and Fe_2O_3 nanoparticles. When the Silver and Fe_2O_3 values are increases, the energy profile increased. Boosting the amount of silver and iron oxide nanoparticles across narrowed arteries requires greater energy on a physical level in order to overcome metabolic obstacles, promote their natural relationships, and produce the therapeutic effects that are needed. This causes the energy profile to rise, which stands for the fact that more energy is required to accomplish the same goals at increasing concentrations of nanoparticles.

The effect of Casson fluid and Magnetic field parameters on Skin friction profile is demonstrated in Fig 11. For the higher values of the Casson fluid parameter on the Skin friction profile decreased, due to the physical phenomenon of as a consequence that are a heat diffusion goes down, which makes temperature transfer worse. Which is leads to in the creation of a greater amount of power through movement. while the opposite trend noticed on Nusselt number outline is presented in Fig 12. Streamlines, the investigation of liquid behavior and the portrayal of flow, in particular, include a range of qualities that, when taken into account together, allow them to be excellent tools for analyzing and conducting research on the movements of fluids. This is particularly true when used to the investigation of fluid circulation. Figs. 13, 14, 15 magnetic parameters demonstrate effects on streamline graphs over a range of values. The intensity of the M parameter attracts electrically conducting particles to the primary flow, and Figure 16 shows the speed contour as well.

Table 2: Comparision results for $C_f Re_r^{1/2}$ for various values of γ *and* ϕ_1 [18].

Waqas et al. [18]		Present outcomes (bvp5c)
γ, ϕ_1	$C_f Re_r^{1/2}$	$C_f Re_r^{1/2}$
0.1, 0.01	0.939968	0.939962
0.12, 0.01	0.924794	0.924786
0.14, 0.01	0.911311	0.911301
0.1, 0.05	1.329552	1.329548
0.1, 0.1	1.175985	1.175964

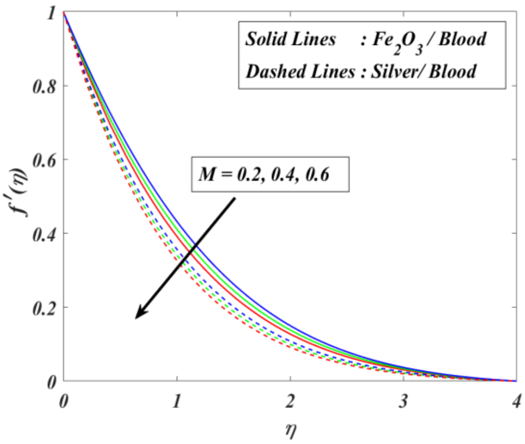


Fig 5. Variation due to M on $f'(\eta)$.

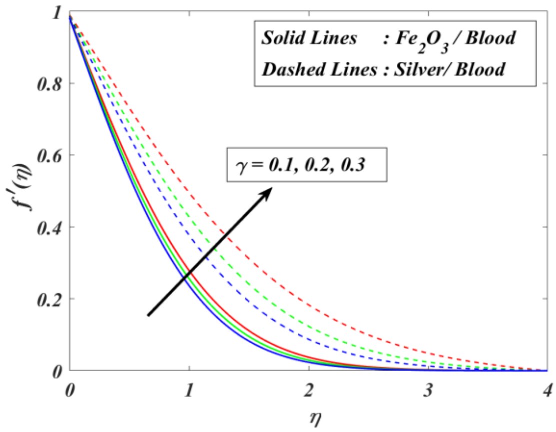


Fig 6. Variation due to γ on $f'(\eta)$.

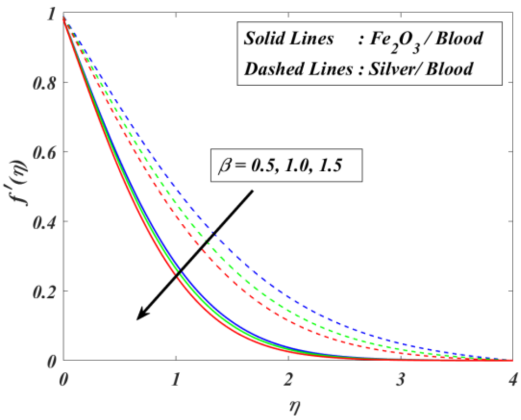


Fig 7. Variation due to β on $f'(\eta)$.

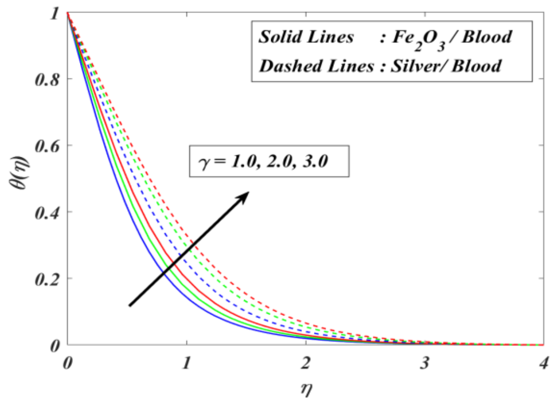


Fig 8. Variation due to γ on $\theta(\eta)$.

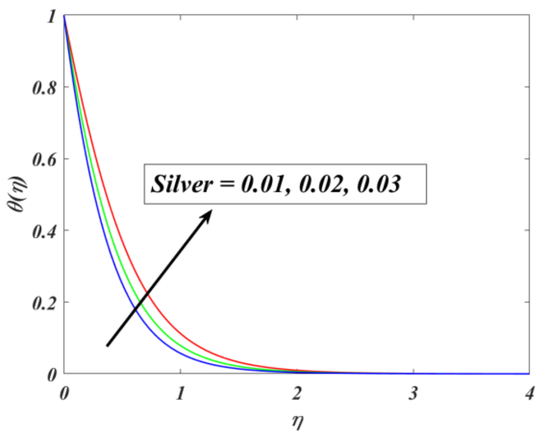


Fig 9. Variation due to *Silver* on $\theta(\eta)$.

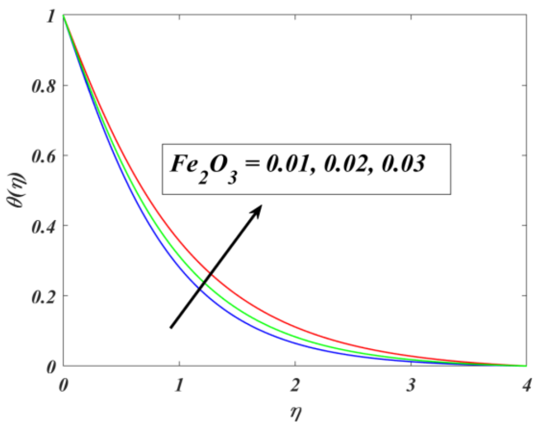


Fig 10. Variation due to Fe_2O_3 on $\theta(\eta)$.

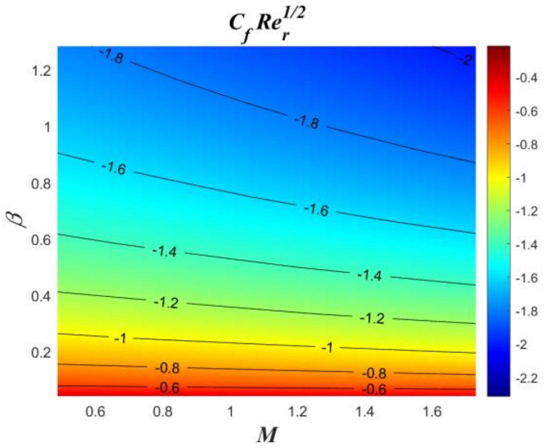


Fig 11. Impact of β and M for $C_f Re_r^{1/2}$.

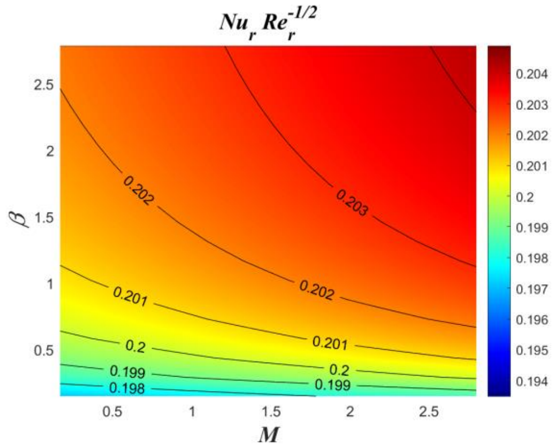


Fig 12. Impact of β and M for $C_f Re_r^{1/2}$.

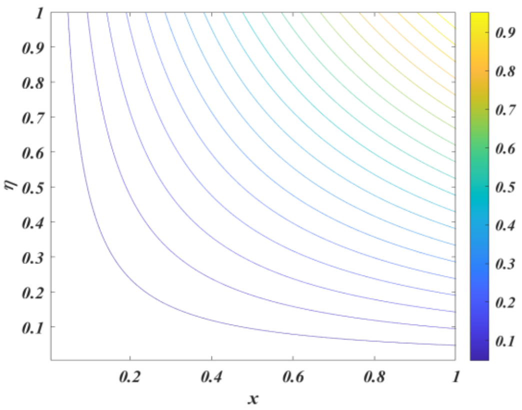


Fig 13. Streamline effects for $M = 0.5$.

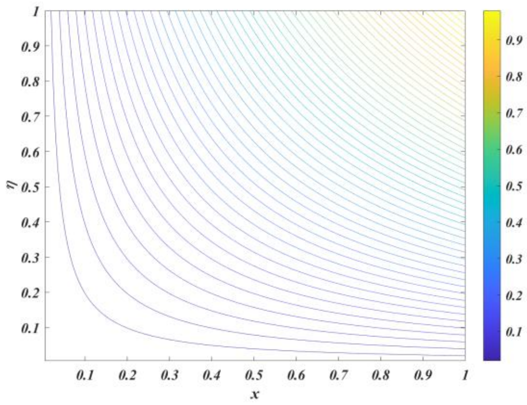


Fig 14. Streamline effects for $M = 1.0$.

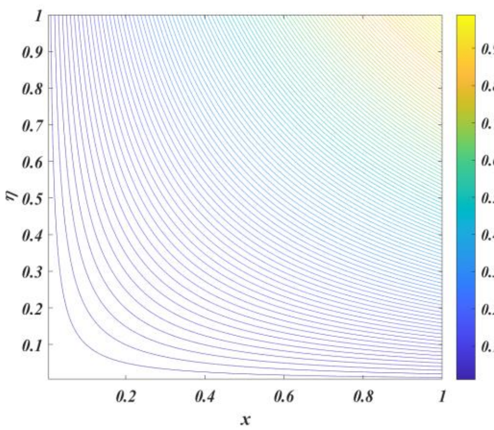


Fig 15. Streamline effects for $M = 2.0$.

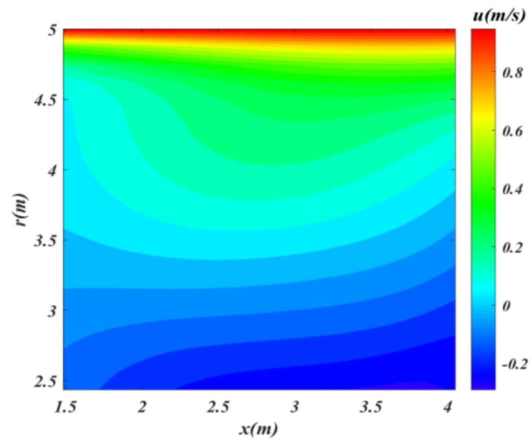


Fig 16. Velocity contours for the velocity along *x*-direction.

5. Conclusion

The present investigation analysed a mathematical simulation of blood conveying Fe_2O_3 and Silver nano particles embedded through a Stenotic artery with the presence of magnetohydrodynamic. The theoretical system of partial differential equations are translated into corresponding ordinary differential equations by using the similarity variables and the outcome is computationally drawn utilizing the bvp5c approach in MATLAB solver.

The key results are:

- The velocity profile decreased when increasing the Casson fluid parameter values.
- Increasing the magnetic field parameter values, results in declined nature of the velocity profiles.
- By enhancing the values of flow parameter and the size of nanoparticle the flow of blood and the temperature increases.
- The energy profile improved, increasing the nanoparticles volume fractions values, Boosting the amount of silver and iron oxide nanoparticles across narrowed arteries requires greater energy on a physical level in order to overcome metabolic obstacles, promote their natural relationships, and produce the therapeutic effects that are needed.
- The Skin friction and Nusselt number profiles are increased at higher values of the magnetic field parameter.
- Through the use of the magnetic field parameter, streamline patterns are revealed.

Feature directions or Potential Improvements

- The present model for Fe_2O_3-silver/Blood hybrid nanofluid can be examined for the cooling process for various biomedical applications and better enhancement purpose may analyse various set of combinations.
- Expand the research to two or three-dimensional movement to get a deeper understanding of hybrid/ternary/tetra nanofluids for practical significance.
- Examine the impact of various kinds and forms of tiny particles on movement and temperature characteristics.
- Consider the different impacts of additional factors like Williamson and Carreau fluids, and non-uniform magnetic fields for various engineering applications.
- Employ the mathematical framework to practical technical scenarios to verify and optimize theoretical results.
- This particular area of research offers a lot of promise for practical use in circumstances where good heat transmission is critical, as well as becoming intellectually stimulating.
- For model accuracy purpose the present study is going to study various numerical, analytical, and semi analytical techniques.
- The computational framework might be solved by expending a technology known as Machine learning.

Nomenclature

(x, r) Coordinates (m)	T, θ Dimensional and dimensionless temperature (C^0)
R Radius of artery (m)	ϕ Nanoparticles volume fraction
L_0 Length (m)	ψ Stream function
R_0 Width of unblocked region (m)	v_f Kinematics viscosity of fluid (m^2/s)
χ Maximum height of stenosis	ρ_f Density of fluid (kg/m^3)
T_0 Temperature of fluid (C^0)	η Similarity index
(u, v) Velocity components (m/s)	Pr Prandtl number
γ flow parameter,	M Magnetic parameter.

f' Non-dimensional velocity of the fluid	D_B Coefficient of the Brownian diffusion
D_T Thermophoretic diffusion coefficient	B Magnetic field strength $kgs^{-2}A^{-1}$
' Differentiation of η	f, nf Base fluid, Nanofluid

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability

No data was used for the research described in the article.

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