SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Semarak International Journal of Mechanical Precision and Engineering

Journal homepage:
https://semarakilmu.my/index.php/sijmpe/index
ISSN: 3083-9546

# Influence of Stenosis Geometry on Magnetohydrodynamic Hybrid Nanofluid Blood Flow and Heat Transfer in Bifurcated Artery

Siti Nor Asimah Hamid[1], Kannigah Thirunanasambantham[1], Zuhaila Ismail[1,*], Lim Yeou Jiann Hamid[1], Amnani Shamjuddin[2], Yahaya Daniel Shagaiya[3]

[1] Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia
[2] Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310, Malaysia
[3] Department of Mathematical Sciences, Tafawa Balewa Way, Kabala Coastain, 800283, Kaduna, Nigeria

**ARTICLE INFO**

***Article history:***
Received 19 July 2025
Received in revised form 29 August 2025
Accepted 10 September 2025
Available online 30 December 2025

***Keywords:***
Stenosis; magnetohydrodynamic; hybrid nanofluid; heat transfer; bifurcated artery

**ABSTRACT**

Atherosclerosis, caused by plaque-induced arterial stenosis, restricts blood flow and reduces oxygen delivery to tissues. This study investigates magnetohydrodynamic (MHD) hybrid nanofluid blood flow in bifurcated arteries with different types of stenoses under a uniform magnetic field. A mathematical model is developed for incompressible, laminar, Newtonian flow, with silver (Ag) and gold (Au) nanoparticles dispersed in blood to form the hybrid nanofluid. Simulations are performed using COMSOL Multiphysics and validated against existing literature. Velocity fields and streamline patterns are analyzed to evaluate the effects of stenosis geometry and location on hemodynamics. Results show that incorporating gold and silver nanoparticles improves flow uniformity, while an external magnetic field further enhances performance. The findings indicate that MHD-assisted hybrid nanofluids, combined with optimized stenosis management, present a promising approach for biomedical applications in mitigating the adverse effects of arterial stenosis.

## 1. Introduction

Cardiovascular diseases particularly arterial stenosis, remain one of the leading causes of morbidity and mortality worldwide. Zaman *et al.,* [1] defines coronary artery disease as atherosclerosis produced by stenosis, which is caused by build of fatty substances, cholesterol, cellular waste products and smooth muscle cells in the arterial wall. According to Khan *et al.,* [2], a stenosed region affects blood flow distribution and speed, reducing oxygen and nutrient level available to tissues and potentially leading to coronary heart disease. Arterial inflammation can drastically block blood flow and nutrient. This could result in insufficient blood and oxygen increasing the risk of a heart attack, failure or even worse stroke. Since the primary role of the circulatory system is delivered oxygenated blood efficiently to all tissues, any obstruction can have life-threatening consequences according to Shankar *et al.,* [3]. Bifurcated arteries provide a more realistic

* *Corresponding author.*
*E-mail address: zuhaila@utm.my*

https://doi.org/10.37934/sijmpe.4.1.4251

physiological model than straight arterial segments because plaque deposition and stenosis formation are common at bifurcation points.

The effect of stenosis severity and geometry on blood flow has been thoroughly investigated in earlier research. The flow pattern in different shapes of stenosed arteries (50-90% cross section area reduction) is shown by Roy *et al.,* [4]. According to results, 90% blockage in an artery can be extremely dangerous because of flow become transient and turbulent flow. Similar to Kumar *et al.* [5] study the evaluates blood flow patterns in symmetrical, elliptical, trapezoidal, triangular, cosine-shaped and bell-shaped stenosed arteries with heat transfer. The generalized power law for the non-Newtonian model is numerically simulated by Abd Aziz *et al.,* [6] using three angles of a bifurcated artery. As a result, as the severity of angle of degree grows, pressure increases, potentially causing changes in blood flow pressure in the human artery.

With the advancement of nanotechnology, the stenosed can be cure by the ability to go through cells, tissues and organs. According to Waqas *et al.,* [7], nanofluids are a process of heat transfer fluid that contains designed suspension nanostructure (1-100 nm) that are disseminated in the fluid. By adding nanoparticles, researcher is looking to change and improve the properties of the blood flow so that it can be used to treat diseases by Jalili *et al.,* [8]. Further progress in nanotechnology has led to the emergence of hybrid nanofluid which are a type of nanofluid that made up of two or more distinct forms of nanoparticles fused together in a base liquid by Saeed *et al.* [9]. The transportation of blood through stenosed artery with permeable wall with the aid of nanoparticles was explicated by Nadeem and Ijaz [10]. Gold (Au) and copper (Cu) hybrid nanoparticles are distributed in the study by Imoro *et al.,* [11] through a stenosed artery with thermal radiation effect. Shahzad *et al.* [12] also employing the silver (Ag) and gold (Au) and blood as a base fluid along a cylindrical duct to know understanding blood behaviour. The purpose of employing hybrid nanofluid (HNF) is to increase the base fluid's thermal conductivity.

Furthermore, the presence of an external magnetic field introduces magnetohydrodynamic (MHD) effect which can significantly influence blood flow behaviour due to the electrically conducting nature of blood. Alsaedi *et al.,* [13] said it consists of three words magneto, hydro and dynamics which mean magnetic effects, water and movement. Sharma *et al.,* [14] reported that MHD can be controlling parameter for blood velocity. The MHD hybrid nanofluid flow in a rotating system with an inclined magnetic field and thermal radiation was investigated by Arshad [15]. Vaida *et al.,* [16] utilized the perturbation method to analyse the complex rheological behaviour of MHD blood flow through stenosed arteries. Zain *et al.,* [17] study the evaluates blood flow patterns in symmetrical, elliptical, trapezoidal, triangular, cosine-shaped and bell-shaped stenosed arteries with heat transfer. This study aims to analyse the simultaneous effects of stenosis geometry, magnetic field and hybrid nanofluids on blood flow and thermal transport in a bifurcated artery with emphasis on velocity distribution, heat flux and nanoparticle transport under the realistic physiological conditions. By integrating the critical factors into a single framework, this study provides deeper insights into hemodynamic regulation in diseased arteries and contributes to the advancement of nanotechnology.

## 2. Mathematical Formulation

Fig. 1 illustrates a two-dimensional blood flow situation in different type of stenosis. The Newtonian fluid is assumed to be incompressible, laminar and unsteady in a Cartesian coordinates system. The hybrid nanofluid, NPs employed in this problem are Ag and Au, and blood is the base fluid.

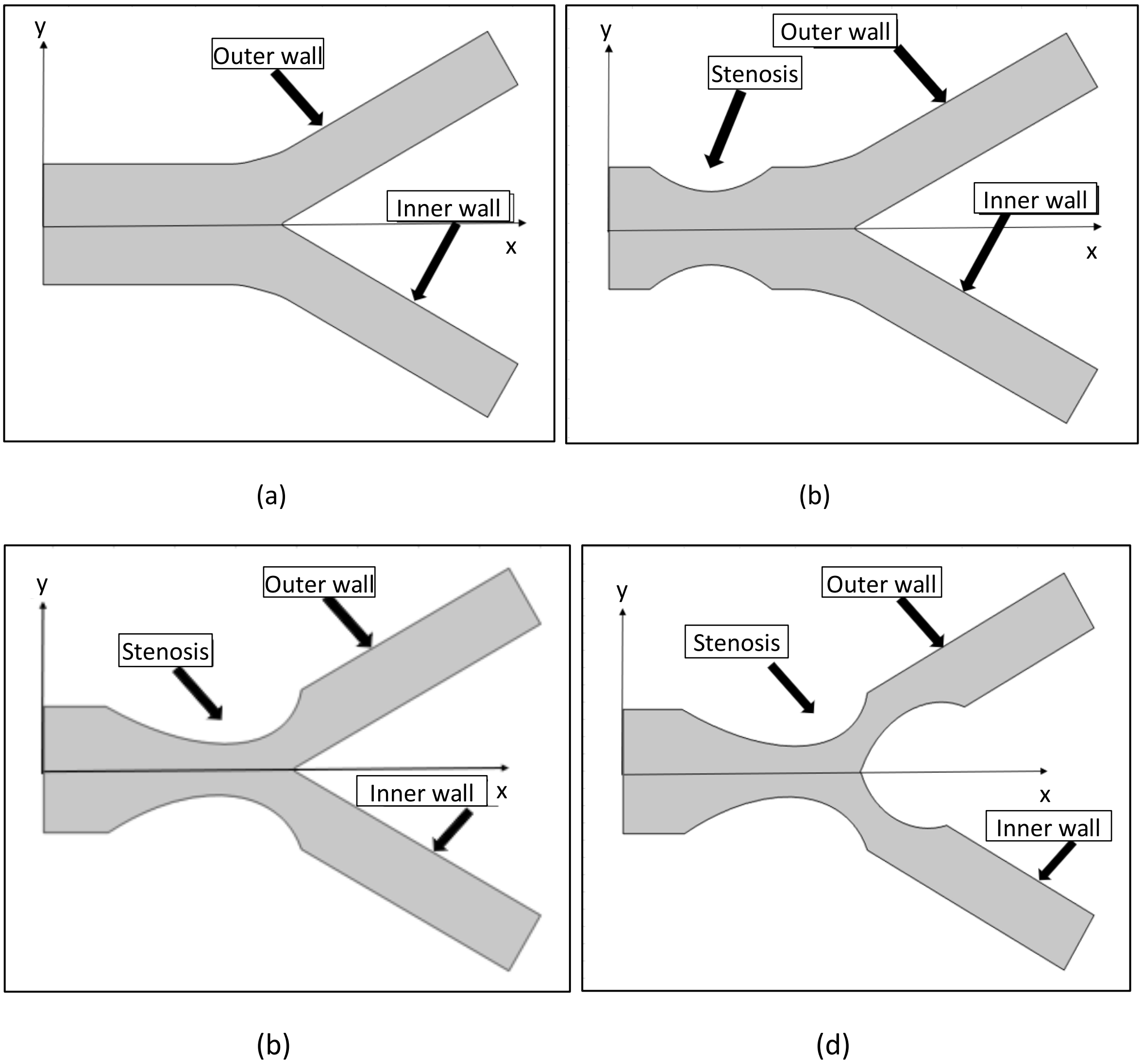



**Fig. 1.** Different type of stenosis (a) TYPE I (b) TYPE II (c) TYPE III (d) TYPE IV

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \tag{1}$$

$$\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\frac{1}{\mathrm{Re}}\frac{\mu_{hnf}}{\mu_f}\frac{\rho_f}{\rho_{hnf}}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{\sigma_{hnf}}{\sigma_f}Mu, \tag{2}$$

$$\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\frac{1}{\mathrm{Re}}\frac{\mu_{hnf}}{\mu_f}\frac{\rho_f}{\rho_{hnf}}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right), \tag{3}$$

$$\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\frac{\sigma_{hnf}}{\sigma_f}\frac{1}{\mathrm{Pr}\bullet\mathrm{Re}}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right), \tag{4}$$

Where $\mathrm{Re}=\frac{\rho_f D u_0}{\mu_f}, M=\left(\frac{\sigma_f D B_0^2}{\rho_f u_0}\right)^{\frac{1}{2}}$ and $\mathrm{Pr}=\frac{\left(\rho C_p\right)_f D}{k_f}$ (5)

*u* and *v* are constituent parts of velocity in the x and y directions, respectively. *Re* is the Reynolds number, *M* is the Hartmann number and *Pr* is the Prandtl number [11]. The dimensionless boundary condition is given as [11].

Inflow velocity: $u(x,y,t)=u_{\max}\left(1-\left(\frac{y^2}{a^2}\right)\right)$ and $v(x,y,t)=0$ at $t=0$ and $-a\leq y\leq a$, (6)

Outflow: $\left(-\rho I+\tau\right)\bullet n=0,$ (7)

Upper and lower wall: $u(x,y,t)=0,\ v(x,y,t)=0,$ (8)

Temperature at the artery wall: $T(x,y,t)=T_0$ at $x=0,$ (9)

Where **n** is a unit outward normal vector with the pressure point constraint, *p=0* [11] is implemented at x=0 and y= - 0.5, and **I** is the unit tensor. Tables 2 and 3 show the HNF thermophysical properties and parameters where blood is denoted as *(f)*, nanofluid *(nf)*, and $\phi_1$ and $\phi_2$ are the volume fractions, subscripts $s_1$ and $s_2$ represent *Au* and *Ag*, respectively.

**Table 2**
Thermophysical characteristics of the base fluid and nanoparticles [13]

| Property | $\rho[Kg/m^3]$ | $\mu\left[Pa/s\right]$ | $k\left[W/mK\right]$ | $\sigma\left[Wm^{-1}K^{-1}\right]$ | $C_p[J/kgK]$ |
|---|---|---|---|---|---|
| Blood | 1063 | 0.003 | 0.52 | 1090 | 3746 |
| Copper | 19300 | 0.00464 | 310 | $5.96 \times 10^7$ | 129 |
| Silver | 10500 | 0.005 | 429 | $4.10 \times 10^6$ | 235 |

**Table 3**
The thermophysical properties of the HNF [13]

| Property | Equations |
|---|---|
| Viscosity, $\mu$ | $\mu_{hnf}=\dfrac{\mu_f}{\left(1-\phi_1\right)^{2.5}\left(1-\phi_2\right)^{2.5}}$ |
| Density, ρ | $\rho_{hnf}=\left(1-\phi_2\right)\left[\left(1-\phi_1\right)\rho_f+\phi_1\rho_{s_1}\right]+\phi_2\rho_{s_2}$ |
| Electrical conductivity, $\sigma$ | $\sigma_{hnf}=\sigma_{nf}\left[\dfrac{\sigma_{s_2}+2\sigma_{nf}-2\phi_1\left(\sigma_{nf}-\sigma_{s_2}\right)}{\sigma_{s_2}+2\sigma_{nf}+\phi_2(\sigma_{nf}-\sigma_{s_2})}\right]$ |
| Thermal conductivity, *k* | $k_{hnf}=k_f\left[\dfrac{k_{s_1}+2k_f-2\phi_1\left(k_f-k_{s_1}\right)}{k_{s_1}+2k_f+\phi_1\left(k_f-k_{s_1}\right)}\times\dfrac{k_{s_2}+2k_f-2\phi_2(k_f-k_{s_2})}{k_{s_2}+2k_f+\phi_2\left(k_f-k_{s_2}\right)}\right]$ |
| Heat Capacity, $\rho C_p$ | $(\rho C_p)_{hnf}=(1-\phi_2)\left[\left(\rho C_p\right)_f+\phi_1\left(\rho C_p\right)_{s_1}\right]+\left(\rho C_p\right)_{s_2}\phi_2$ |

## 3. Validation

Validation was performed using the geometric problem studied by Hussain *et al.*,[18], which involved a 2D artery with stenosis. The same parameters values were applied in COMSOL Multiphysics to determine the maximum velocity in the stenosed region [18]. The magnitude surface velocity from both results was compared, with the maximum value showing a slight difference at the stenosis curve (refer to Figure 2). Therefore, the surface velocity is deemed sufficient to provide a good solution for the model.

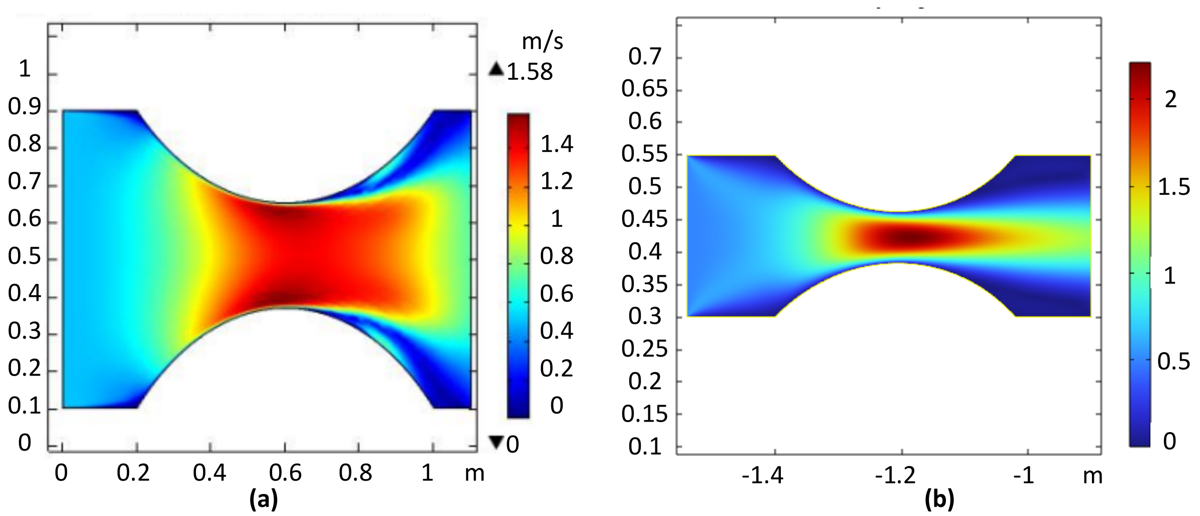



**Fig. 2.** Surface velocity magnitude at 0.2 s (a) Hussain et al., [18] (b) present study

## 4. Result and Discussion

The volume fraction, φ of Ag and Au is set at 0.005 and M=0, 36.6 in order to analyse the efficiency of NPs. Figure 3 Illustrates the blood flow with the presence of MHD under Hartmann number, M=0 in a bifurcated artery under different types of stenosis: TYPE I (normal, healthy), TYPE II (mild stenosis), TYPE III (moderate stenosis) and TYPE IV (severe stenosis). Figure 3 show for the Hartmann number under M=0 in different type of stenosed artery. In the healthy case, Figure 3(a) show distributed smoothly and symmetric. As stenosis gets worse: Figure 3(b), 3(c) and 3(d), the flow speeds up significantly with greatest velocities reaching up from 0.571933m/s to 0.845725m/s and recirculation areas from downstream of the stenotic throat. The distributed and asymmetric velocity profile in Figure 3(c) and Figure 3(d) illustrate the unstable impact of severe stenosis in the absence of magnetic influence. Figure 4. show the blood flow with the presence of MHD under Hartmann number, M=36.6. When the magnetic field is applied at highest, a clear stabilizing effect is observed. For the Figure 4(a), the maximum velocity slightly decreased compared to M=0, indicating a that flow acceleration is reduced. The maximum velocities in the stenosed cases, especially in Figure 4(b) until Figure 4(d), are significantly lower than M=0. The size of the recirculation zones downstream of the stenosis is also reduced and the velocity contours become smoother. This illustrates how the magnetic field improves flow uniformly by minimizing excessive velocity gradients and irregular flow.

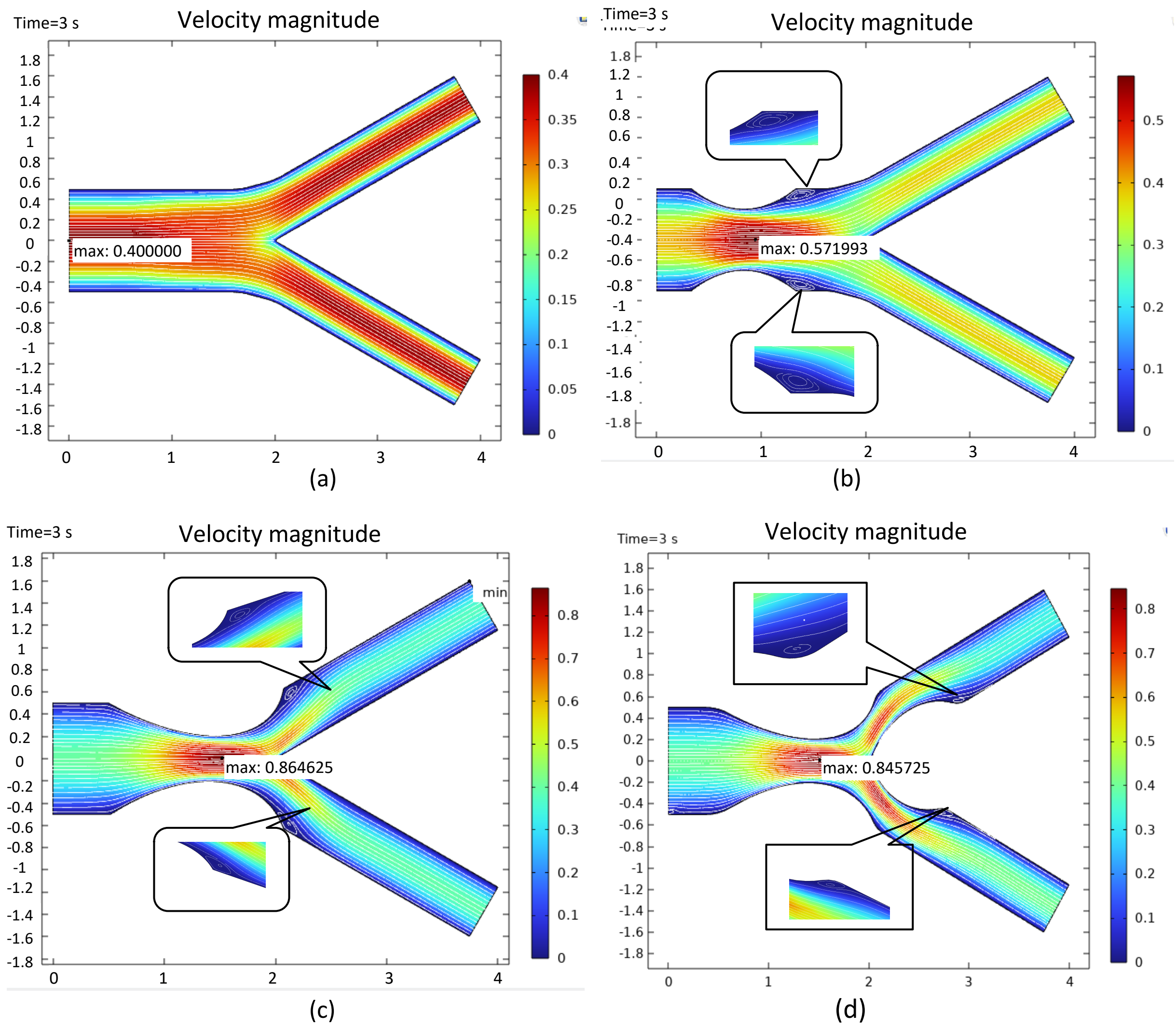
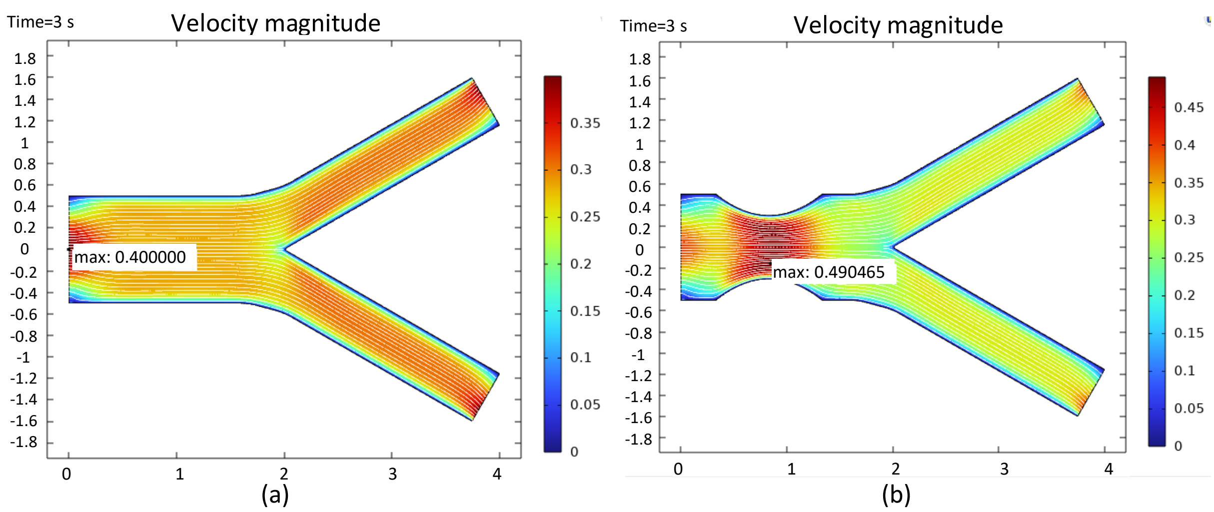



**Fig. 3.** Hartmann number, M=0 (a) TYPE I (b) TYPE II (c) TYPE III (d) TYPE IV



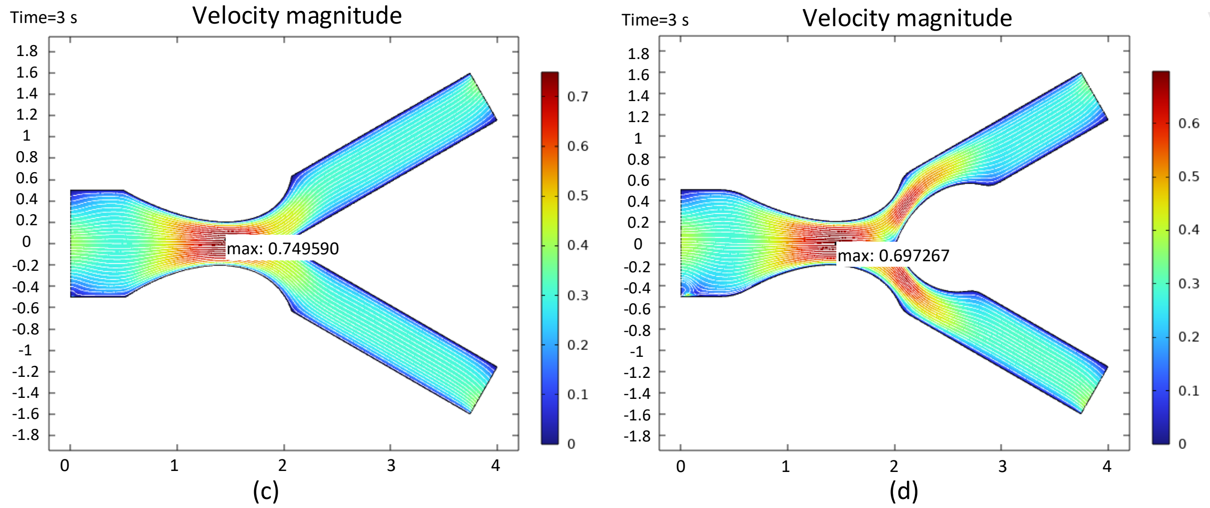



**Fig. 4**. Hartmann number, M = 36.6 (a) TYPE I (b) TYPE II (c) TYPE III (d) TYPE IV

In the Figure 5 demonstrates the distribution of heat flux at the center stenosis for different types stenosis geometry using pure blood, Au-blood nanofluid and Ag-blood nanofluid as the blood models. Every single case, the heat flux shows a parabolic profile, with the core region showing the highest values and the arterial walls showing the lowest values. In the Figure 5(a) show the cases of nanofluid indicate a marginally higher heat flux than pure blood. Because of increased flow and increased shear stress at the narrowed throat region, the maximum heat flux increases as the severity of stenosis: Figure 5(b) until Figure 5(c) increase. Pure blood exhibits the lowest values of heat flux, while Au-blood consistently exhibits the highest, followed by Ag-blood. This is explained by the higher thermal conductivity of gold nanoparticles which improves the fluid's overall heat transfer capabilities. The difference between pure blood and nanofluids is more notable in severe stenosis Figure 5(d), highlighting the potential of hybrid nanofluids to enhance thermal regulation in pathological flow conditions.

For the Figure 6 highlights the influence of nanoparticles by showing the volume fraction magnitude of Au and Ag nanofluids under 0.005 for Figure 6(a) TYPE I and Figure 6(b) TYPE IV. With little difference between Au and Ag, the volume fraction distribution in the healthy artery stays comparatively symmetrical and smooth. However, because of the accelerated flow and velocity gradients, the distribution becomes extremely non-uniform in severe stenosis with larger accumulation in the throat region. This implied that stenosis has a direct impact on the distribution and transport of nanoparticles, which in turn affects the efficiency of heat transfer. These results show that adding nanoparticles will improves heat transfer when compared to pure blood and the effects gets more significant as the severity of the stenosis increases.

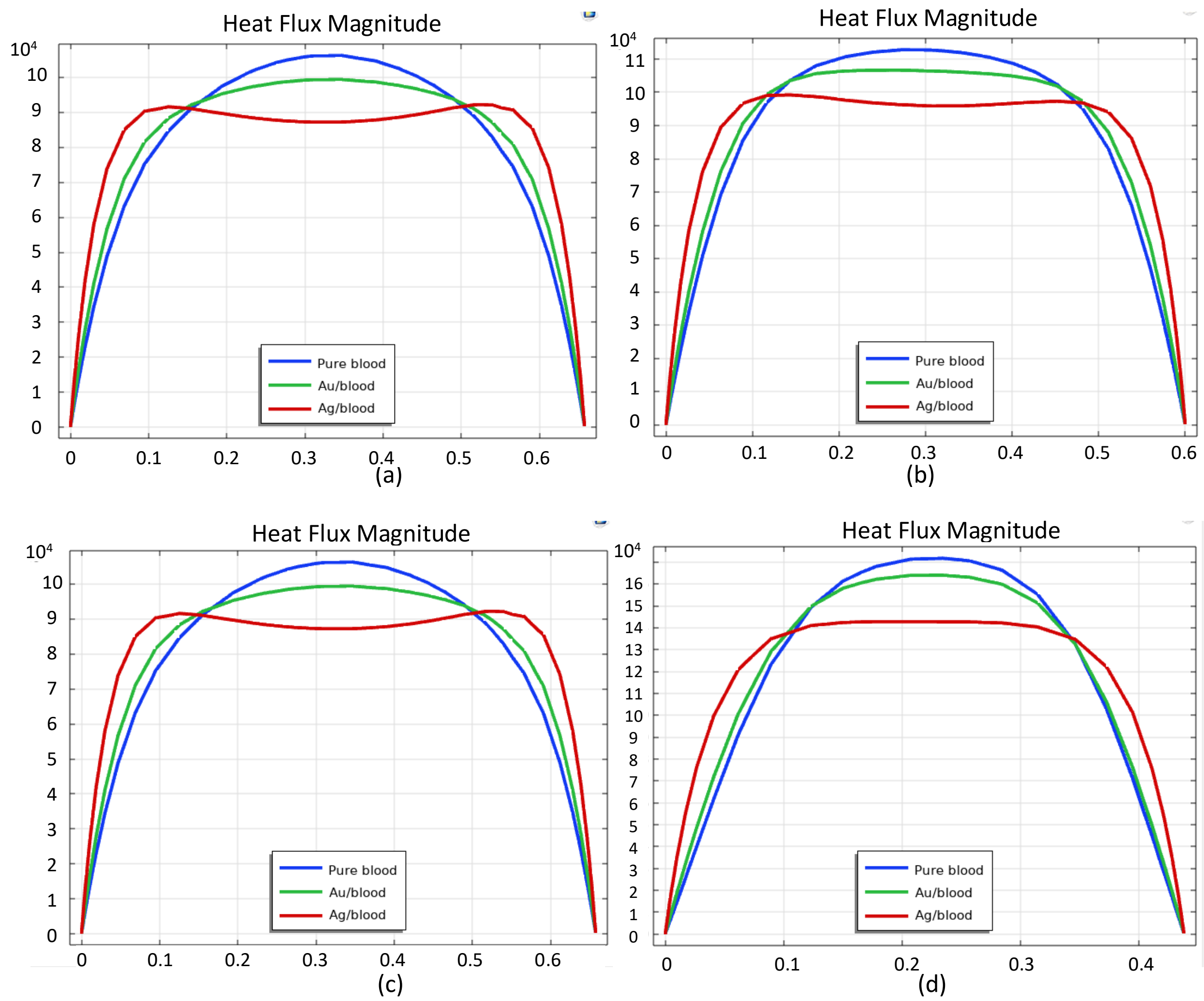



**Fig. 5.** Heat flux at center of stenosis (a) TYPE I (b) TYPE II (c) TYPE III (d) TYPE IV

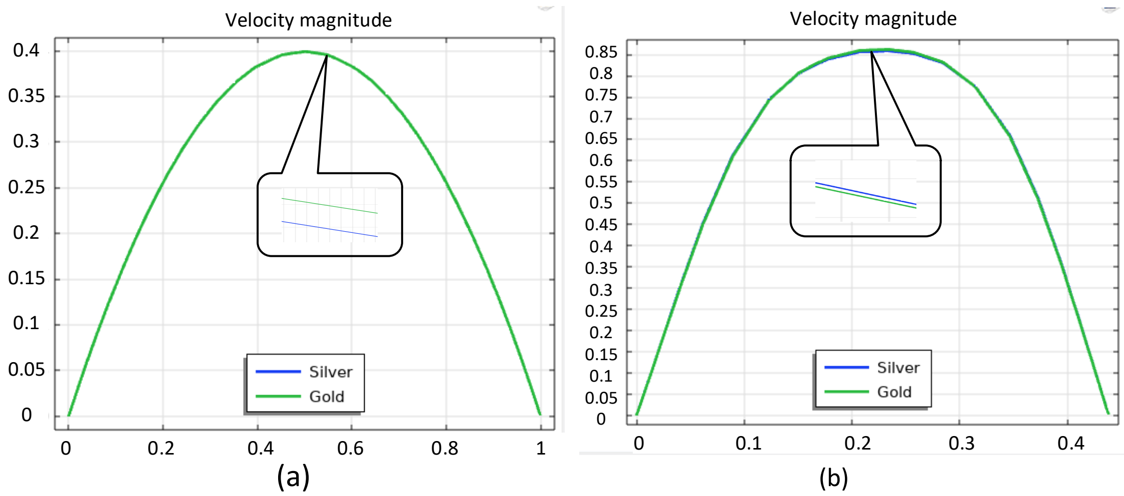



**Fig. 6.** Volume Fraction Magnitude (a) TYPE I (b) TYPE IV

## 4. Conclusions

In conclusion, the influence of stenosis geometry on MHD HNF blood flow and heat transfer gives useful data about how the impact MHD and HNF to stenosis. The key findings from this study are summarised below:

- Different types of stenosis change flow in a significant way, which causes backflow and recirculation downstream.
- Flow formation becomes harder and maximum velocity is increased as stenosis severity increases.
- The most critical condition is TYPE IV stenosis which shows the largest heat flux, the strongest disturbances, and the highest velocity.
- When compared to pure blood and Ag-blood, Au-blood offers the highest enhancement in heat transfer.
- In cases of severe stenosis, the distribution of nanoparticles becomes extremely irregular, particularly in the throat area.

The study in medical might be useful in evaluating the effects of MHD and HNF from the various magnetic therapies on patients. It thought that this study will have an impact because combining HNF and MHD could lead to new less invasive treatment.

**Acknowledgement**
This work was supported by Universiti Teknologi Malaysia (UTM), UTM Fundamental Research Vote No Q.J130000.3854.23H57 and the Ministry of Higher Education Malaysia under Fundamental Research Grant Scheme (FRGS) (FRGS/1/2022/TK05/UTM/02/11)

## References

[1] Zaman, A., N. Ali, M. Sajid, and T. Hayat. "Effects of unsteadiness and non-Newtonian rheology on blood flow through a tapered time-variant stenotic artery." *AIP advances* 5, no. 3 (2015). https://doi.org/10.1063/1.4916043.

[2] Khan, Muhammad Salim, Shafee Ahmd, Zahir Shah, Mansoor H. Alshehri, and Elisabeta Antonescu. "Computational investigations of nanofluid blood flow in stenosed artery with effects of inflammation and viscous dissipation via finite element method." *Chinese Journal of Physics* 92 (2024): 453-469. https://doi.org/10.1016/j.cjph.2024.09.013.

[3] Shankar, G., and E. P. Siva. "A Numerical Investigation of Thermal and Mass Exchange of Blood Along Porous Stenosis Arterial Flow With Applied Magnetic Field." *IAENG International Journal of Applied Mathematics* 54, no. 3 (2024).

[4] Roy, Mukesh, Basant Singh Sikarwar, Mohit Bhandwal, and Priya Ranjan. "Modelling of blood flow in stenosed arteries." *Procedia Computer Science* 115 (2017): 821-830. https://doi.org/10.1016/j.procs.2017.09.164.

[5] Kumar, Sumit, and Surendra Kumar. "Blood flow with heat transfer through different geometries of stenotic arteries." *Trends in Sciences* 20, no. 11 (2023): 6965-6965. https://doi.org/10.48048/tis.2023.6965.

[6] Abd Aziz, Azyante Erma, Muhammad Sabaruddin Ahmad Jamali, and Zuhaila Ismail. "Numerical simulation of generalized power law blood flow model through different angles of stenosed bifurcated artery." *Journal of Mathematics and Computing Science* 7, no. 2 (2021): 1-14. https://doi.org/10.24191/jmcs.v7i2.

[7] Waqas, Hassan, Umar Farooq, Ali Hassan, Dong Liu, Sobia Noreen, Roa Makki, Muhammad Imran, and Mohamed R. Ali. "Numerical and Computational simulation of blood flow on hybrid nanofluid with heat transfer through a stenotic artery: Silver and gold nanoparticles." *Results in Physics* 44 (2023): 106152.https://doi.org/10.1016/j.rinp.2022.106152.

[8] Jalili, Payam, Ahmad Sadeghi Ghahare, Bahram Jalili, and Davood Domiri Ganji. "Analytical and numerical investigation of thermal distribution for hybrid nanofluid through an oblique artery with mild stenosis." *SN Applied Sciences* 5, no. 4 (2023): 95. https://doi.org/10.1007/s42452-023-05312-z.

[9] Saeed, Anwar, Abdelaziz Alsubie, Poom Kumam, Saleem Nasir, Taza Gul, and Wiyada Kumam. "Blood based hybrid nanofluid flow together with electromagnetic field and couple stresses." *Scientific reports* 11, no. 1 (2021): 12865.

https://doi.org/10.1016/j.physleta.2014.12.013.
[10] Nadeem, S., and S. Ijaz. "Theoretical analysis of metallic nanoparticles on blood flow through stenosed artery with permeable walls." *Physics Letters A* 379, no. 6 (2015): 542-554. https://doi.org/10.1016/j.physleta.2014.12.013.
[11] Imoro, Issah, Christian John Etwire, and Rabiu Musah. "MHD flow of blood-based hybrid nanofluid through a stenosed artery with thermal radiation effect." *Case Studies in Thermal Engineering* 59 (2024): 104418. https://doi.org/10.1016/j.csite.2024.104418.
[12] Shahzad, Faisal, Wasim Jamshed, Farheen Aslam, Rasheeda Bashir, El Sayed M. Tag El Din, Hamiden Abd El-Wahed Khalifa, and Agaeb Mahal Alanzi. "MHD pulsatile flow of blood-based silver and gold nanoparticles between two concentric cylinders." *Symmetry* 14, no. 11 (2022): 2254. https://doi.org/10.3390/sym14112254.
[13] Alsaedi, A., K. Muhammad, and T. Hayat. "Numerical study of MHD hybrid nanofluid flow between two coaxial cylinders." *Alexandria Engineering Journal* 61, no. 11 (2022): 8355-8362. https://doi.org/10.1016/j.aej.2022.01.067.
[14] Sharma, Bhupendra Kumar, Madhu Sharma, R. K. Gaur, and Abhishek Mishra. "Mathematical modeling of magneto pulsatile blood flow through a porous medium with a heat source." *International Journal of Applied Mechanics and Engineering* 20, no. 2 (2015): 385-396. https://doi.org/10.1515/ijame-2015-0025.
[15] Arshad, Mubashar. "MHD hybrid nanofluid flow in a rotating system with an inclined magnetic field and thermal radiation." *Case Studies in Thermal Engineering* 62 (2024): 105182. https://doi.org/10.1016/j.csite.2024.105182.
[16] Vaidya, H., C. Rajashekhar, K. V. Prasad, S. U. Khan, F. Mebarek-Oudina, A. Patil, and P. Nagathan. "Channel flow of MHD bingham fluid due to peristalsis with multiple chemical reactions: an application to blood flow through narrow arteries." *SN Applied Sciences* 3, no. 2 (2021): 186. https://doi.org/10.1007/s42452-021-04143-0.
[17] Zain, Norliza Mohd, and Zuhaila Ismail. "Hartmann and Reynolds numbers effects in the Newtonian blood flow of a bifurcated artery with an overlapping stenosis." *Matematika* (2019): 213-227. https://doi.10.11113/matematika.v35.n2.1177.
[18] Hussain, Azad, Lubna Sarwar, Aysha Rehman, Sobia Akbar, Fehmi Gamaoun, Hasan Huseyin Coban, Abdulrazak H. Almaliki, and Maram S. Alqurashi. "Heat transfer analysis and effects of (silver and gold) nanoparticles on blood flow inside arterial stenosis." *Applied sciences* 12, no. 3 (2022): 1601. https://doi.org/10.3390/app12031601.