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Review Article

A Review on "Non-Newtonian Mathematical Models for Blood Flow through Constricted Artery"

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Abstract *- Mathematical modeling is critical for understanding and predicting blood flow in the circulatory system, particularly in the presence of stenosed arteries. Cardiovascular Disorders, particularly Atherosclerosis, are major public health concerns globally and the main cause of death. Non-Newtonian Blood viscosity features have a substantial impact on blood flow dynamics, particularly in constricted arteries. Researchers usually use more complex models that account for the unique rheological features of blood in the setting of blood flow via stenosed arteries. These could include models that combine the shear-thinning tendency observed in blood with yield stress. Furthermore, realistic geometries and fluid characteristics in Computational Fluid Dynamics (CFD) simulations can provide valuable insights into flow behavior. This study discusses and compares several mathematical models commonly used by researchers to analyze blood flow, including the Carreau model, Casson model, Power-law model, and Herschel-Bulkley model. These models enable researchers to comprehend the complexity of blood flow dynamics better and make more accurate predictions in clinical practice and research. The insights gathered from these non-Newtonian models can help develop successful therapeutic strategies for controlling cardiovascular illnesses.*

Keywords *- Blood Flow, Stenosis, Non-Newtonian Fluid, Shear Rate, Shear Stress, Yield Stress, Viscosity.*

1. Introduction

Mathematical modeling is the process of representing real-world systems using mathematical structures and procedures. It comprises transforming complex events into mathematical formulas, allowing researchers to carefully and deliberately explore and analyze various system components. A model can help to understand the system, investigate the effects of various components, and make behavioral predictions. Blood flow refers to the steady flow of blood throughout the circulatory system. The blood, heart, and blood vessels are the three components of the body's cardiovascular system. This process of blood flow in the circulatory system filters nutrients, hormones, metabolic waste products, oxygen, and land carbon dioxide throughout the body to maintain cell-level metabolism, pH regulation, osmotic pressure, body temperature, and protection from microbiological and mechanical harm. The cardiovascular system is the body's hardest-working organ [Dimmeler (2011) and Gerard et al. (2011)].

Cardiovascular disease, in all of its forms, is a serious and sometimes fatal ailment that is the leading cause of death globally [Schmid-Schönbein (1971)]. A variety of illnesses and traumas impact the cardiovascular system, which includes the heart and blood vessels. These conditions are together known as Cardiovascular Disease. Cardiovascular disease was the leading cause of death globally in 2003, accounting for 16.7 million fatalities, or 29.2% of all deaths. While the number of heart attack fatalities has declined by more than 50% in many affluent nations since the 1960s, low- and middle-income countries, including the majority of Asian countries, now account for 80% of all heart disease-related deaths globally [Walsh (2004)]. People 65 and older have a higher incidence of CVD, which can be explained by the age-related tendency to Atherosclerosis [Carrilho and Patricio (2010)]. However, in males, it steadily progresses with age until age 60, whereas in women, it begins to progress after menopause at age 50 [Rocha and Rodrigues (2010)]. The World Health Organization (WHO) published research in 2019 that forecasted 17.9 million deaths from CVDs in 2019, accounting for 32% of all mortality. Heart attacks and strokes were responsible for 85% of these deaths (WHO, 2019) [Soares et al. (2023)]. The chief causes of this situation include a lack of physical activity, stress, junk food consumption, smoking, and alcohol usage [Prasad and Sudha (2019)]. Plaque formation in blood vessels is one of the primary causes of reduced blood flow in arteries, resulting in insufficient blood delivery to many human organs. Increased velocities occur at the stenosed region of the blood vessel (where the plaque is located), resulting in a significant pressure reduction. Understanding stenosis, which encompasses a variety of conditions affecting the heart and blood vessels, necessitates the use of mathematical modeling. Many researchers explore stenosis under various conditions [Bali et al. (2016)]. Given the widespread interest in this

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subject among researchers worldwide, the purpose of this study is to highlight and debate current breakthroughs in blood flow modeling, particularly in constricted arteries. It begins with a review of hemorheology and its non-Newtonian properties, which are essential to selecting the suitable mathematical model for a specific situation.

2. Hemorheology

Hemorheology is the study of blood flow properties and components. It entails an understanding of how blood viscosity, elasticity, and other rheological properties affect its circulation throughout the body. These characteristics are crucial in many physiological processes, including tissue perfusion, oxygen delivery, and blood coagulation [Javadi and Jamali (2021)].

Understanding hemorheology is essential for recognizing and treating a wide range of medical conditions, particularly cardiovascular diseases, in which abnormalities in blood flow dynamics can have catastrophic repercussions. Researchers and physicians routinely investigate hemorheological aspects to understand better blood flow patterns, viscosity changes, and potential clotting hazards, hence improving diagnostic techniques and therapeutic approaches. The numerical and mathematical study of Newtonian and non-Newtonian fluid models is critical for clinical analysis and treatment planning because they represent the rheological reactions of blood under various flow conditions [Lowe (1988); Mekheimer et al. (2012); Mekheimer and Kot (2012); Mekheimer and Kot (2012); Mekheimer and Kot (2015); Akbar et al. (2014); Elnaqeeb (2016); Pryzwan(2024)].

2.1. Blood

Blood is a fascinating fluid that keeps the body alive by performing a range of important functions. Blood contains three fundamental components: Red Blood Cells (erythrocytes), White Blood Cells (leukocytes), and Platelets. These cells float in a liquid matrix known as plasma, a yellowish liquid component of blood that makes up around 55% of its volume. It is largely made up of 3% particles and 93% water, although it also contains several proteins (Globulins, Fibrinogen, and Albumin), Electrolytes, Hormones, and Waste products [Karsheva (2009). Plasma aids in the transportation of dissolved substances, wastes, nutrients, and cellular elements throughout the circulatory system, hence regulating blood pressure and pH equilibrium [Brust et al.]. (2013) ; Fatahian et al. (2018)].

Human red blood cells have an average diameter of 6–8 µm and a maximum thickness of approximately 2 µm. RBC sizes may differ slightly between animals and people. RBCs are Biconcave Discs, which means they are concave on both sides. They resemble a donut or a flattened disk, with a little depression in the center on both sides. Effective gas exchange is enabled by its unique shape, which provides a high surface area-to-volume ratio [Nunna (2022)]. A single human red blood cell has an average capacity of approximately 90 femtoliters, or 0.00000000000009 liters. This volume measurement is necessary for determining metrics such as hemocrit, which is the percentage of blood volume occupied by red blood cells. They account for 40 to 45 percent of the usual volume of human Blood [Poiseuille (1841)].

Blood has non-Newtonian properties, which means that the amount of applied stress or shear rate determines how viscous (or resistive to flow) it is. Blood has a higher viscosity and behaves more like a viscous fluid at low shear rates than like a less viscous fluid at high shear rates. The presence of Red Blood Cells (RBCs) and other components in blood plasma is the primary cause of this non-Newtonian behavior.

2.2. Blood Viscosity

The definition of viscosity is a fluid's resistance to flow. Friction between the blood components and between the blood and the vessel lumen constitutes a portion of the barrier to blood circulation. It needs an energy application to create a fluid flow. As a result, the circulatory system's energy expenditure is correlated with the blood's viscosity level. The circulatory system's energy forms are blood pressure and blood flow velocity. Poiseuille's equation can be used to calculate the velocity of the blood flow (v) and pressure as $v = 1/4\eta L(F_1 - F_2)(a^2 - r^2)$, where$\eta$ is the fluid's viscosity, $F_1$and $F_2$are the blood's initial and ultimate cross-sectional pressures, L is the length, a is the radius of the vessel, and r is the distance from the center of the vessel for a flowing particle[Fahey (1965), Caro (1977)]. Because blood has a higher viscosity than plasma, and the viscosity of the suspension increases with an increase in hemocrit, blood's non-Newtonian feature becomes increasingly prominent, especially at low shear rates when the ratio of shear stress to shear rate varies. When approaching a rate of shear of less than 1 s^{-1}The apparent viscosity gradually increases before abruptly increasing [Stuart and Kenny (1980); Begg and Hearns (1966)]. The most important factor regulating blood viscosity is hemocrit [Strumia and Phillips (1963)]. With increasing hemocrit, blood viscosity rises exponentially and rapidly. Changes in shear rate have a significant impact on this relationship: the more extreme the viscosity changes that occur as hematocrit varies. Variations in mean cellular volume or RBC concentration are unimportant if the hemocrit remains constant [Wajihah and Sankar (2023)]. Blood's non-Newtonian properties, such as shear-thinning viscosity, occur in stable recirculating regions like the venous system and arterial vasculature, unlike the Newtonian rheology in most arterial systems under normal physiological conditions.

2.3. Blood's Yield Stress

Experts believe that there is a stress threshold number below which no fluid will move due to the behavior of many fluids, including blood, under low shear stress. This essential stress level, which is commonly considered a continuous fluid material feature, is also known as the yield value or yield stress. In order for the fluid to flow or deform (shear), the yield stress must be exceeded. If the externally imposed stress is less than the yield stress, the substance behaves like an elastic solid or flows as a rigid body. If the external yield stress exceeds the yield stress, the fluid may behave in a Newtonian (constant value of η) or shear-thinning mode. A Bingham plastic fluid is defined as having a constant viscosity value. $\eta_B$and a linear flow curve for shear stress greater than the yield stress. Consequently, the Bingham model in one-dimensional shear is expressed as [Chhabra (2010)]:

$$\sigma_{yx} = \sigma_0^B + \eta_B \dot{\gamma}_{yx} |\sigma_{yx}| > |\sigma_0^B|, \tag{1}$$

$$\dot{\gamma}_{yx} = 0 |\sigma_{yx}| < |\sigma_0^B|, \tag{2}$$

Conversely, a yield-pseudoplastic fluid is a viscoplastic material that exhibits shear-thinning behavior at stress levels higher than the yield stress. This fluid's behavior is commonly modeled using the so-called Herschel–Bulkley fluid model, which is expressed as follows for 1-D shear flow:

$$\sigma_{yx} = \sigma_0^H + m\left(\dot{\gamma}_{yx}\right)^n |\sigma_{yx}| > |\sigma_0^H|, \tag{3}$$

$$\dot{\gamma}_{yx} = 0 |\sigma_{yx}| < |\sigma_0^H|, \tag{4}$$

Another popular viscosity model for visco-plastic fluids is the "Casson model," which was developed to simulate blood flow. It can be expressed as [Møller (2006)]:

$$\sqrt{|\sigma_{yx}|} = \sqrt{|\sigma_0^C|} + \sqrt{\eta_C |\dot{\gamma}_{yx}|} |\sigma_{yx}| > |\sigma_0^C|, \tag{5}$$

$$\dot{\gamma}_{yx} = 0 |\sigma_{yx}| < |\sigma_0^C|. \tag{6}$$

Blood, yogurt, tomato puree, cosmetics, nail paints, foams, and suspensions are all instances of viscoplastic behavior (yield stress). There is a wealth of literature containing in-depth assessments of visco-plastic fluid rheology and fluid mechanics. These features play an important role in determining the blood flow rate in both normal and stenosed arteries.

2.4. Non-Newtonian Behavior of Blood

The mechanical properties of blood can be investigated using a fluid containing particle dispersion. When a fluid obeys Newton's law of viscosity, it is said to be Newtonian (the rate of shear is proportional to the shear stress, and viscosity is the proportionality constant). Because blood plasma is mostly water, it is classified as a Newtonian fluid. The entire blood, on the other hand, has sophisticated mechanical properties that become exclusively critical when the particle dimension is much larger, or at the very least, equal to the size of the lumen, as in small-diameter arteries. Blood is not a homogeneous fluid that can be simulated in this situation (blood flow in capillaries and microscopic arterioles); instead, it must be viewed as a suspension of blood cells (especially RBCs) suspended in plasma. Blood cell contents alter blood rheological properties, demanding detailed microstructural model measurements. A Newtonian or non-Newtonian fluid model can be used, with a low shear rate in stenosis regions, indicating that the blood is non-Newtonian. Many experimental and theoretical studies [Galdi, Robertson, and Turek (2008); Robertson et al. (2008); Sequeira and Janela (2007); Kumar et al. (2020)] have demonstrated that the shear rate of blood in the stenosis area is low, showing that the Blood in that region is not Newtonian. Given the above rationale, many researchers have treated blood as a non-Newtonian fluid while examining its motion properties within a confined artery.

2.5. Stenosis

In medicine, the term "stenosis" refers to the narrowing of any tube-like structure in the body, such as the GI tract, heart valves, blood arteries, and spinal canal. The accumulation of cholesterol and other fatty compounds is the cause of this [Caro (2001)]. One of the most common heart conditions is stenosis. Stenosis causes partial or total blockage of blood arteries, which can result in heart attacks, strokes, hypertension, and other conditions. Reduced blood flow prevents oxygen and nutrients from reaching the tissues that require them. Severe circulatory disorders can result from stenosis [Carpenter et al. (2020); Murray and Lopez (1997)]. According to the World Health Organization (2018), stroke and ischemic heart disease jointly accounted for 15.2 million fatalities in 2016, accounting for more than 27 percent of all yearly deaths [Moayeri and Zendehbudi (2003)]. Their consequences are currently bigger than communicable diseases in both poor and developed countries. Ischemic Heart Disease and associated cardiovascular disorders are now recognized to be among the most significant economic burdens on society worldwide. When excessive cholesterol builds up on the inner wall of an artery, it may cause stenosis. This build-up is known as Atherosclerosis. Atherosclerosis is a long-term inflammatory condition that thickens the arterial walls, constricts the lumen, and obstructs blood flow [Mortazavinia (2012); Khatib et al. (2019)]. Coronary artery atherosclerosis results in a deficiency of oxygen in the heart tissue, which leads to arrhythmia, fibrillation, and thrombus formation [Awan et al. (2023)]. Stroke can be caused by blood clots that go to the brain.

Ruptures to the atherosclerotic cap around the inflammatory site may cause blood clotting and thrombosis. Furthermore, if certain plaque fragments are broken off by the flow, they may obstruct downstream vessels and result in another stroke or heart attack. One of the main causes of death and morbidity in industrialized nations is Atherosclerosis [Xie (2023)]. Numerous organs, such as the heart, lungs, brain, kidneys, and limbs, are susceptible to Atherosclerosis. One of the main causes of death in the world is Atherosclerosis. Diabetes, hypertension, high blood cholesterol, a high-fat diet, and smoking are risk factors for Atherosclerosis. The situation is exacerbated by the fact that 463 million Americans have diabetes, which raises inflammation linked to Atherosclerosis. Patients with diabetes have twice the risk of experiencing a heart attack or stroke [Younes et al.]. (2023)]. Numerous scholars, such as Ali et al.(2021), developed a mathematical model to analyze blood flow through a stenotic circular blood artery. The numerical flow of blood in Intracranial Artery Stenosis (IAS), the condition that causes ischemic stroke, was examined by Fatahillah et al. (2019). Nasha et al. (2022) and other researchers offered a non-Newtonian model of blood flow via stenotic blood vessels that took into account different stenosis forms.

3. Mathematical Models

Any event, phenomenon, or process that occurs in real life can be effectively represented using a mathematical technique called mathematical modeling [Dundar and Soylu (2012)]. A model is a sketch or a scale replica of the real work that we are expected to do. Examples of models include those for buildings, airplanes, bridges, fashion designs, and medical equipment [Voskoglou (2006)]. The use of mathematical techniques to systematically illustrate real-world phenomena is mathematical modeling [Galbraith and Clatworthy (1990)]. There are several fields where mathematical modeling is important. It helps us to analyze survey results and make more accurate predictions about various situations. Among the various domains in which it finds practical applications are artificial intelligence, robotics, epidemiology, biological transport, economics, engineering, software development, and many more. For example, more precise and effective predictions of the epidemic scenario are made using mathematical models. The SIR Model, or Mathematical Model of Susceptible(S)-Infected(I)-Recovered(R), is an important tool for forecasting historical disease dynamics, including the impact of the HIV pandemic. Recently, the behavior of the coronavirus and its propagation have been predicted using this model [Tiwar et al. (2020)]. With this in mind, mathematical modeling plays a crucial role in illustrating how blood flows through stenosed arteries in various circumstances.

In biomedical engineering, non-Newtonian models are widely used to investigate blood flow, especially in conditions such as stenosed (narrowed) arteries. The intricate dynamics of blood flow through stenosed arteries can be better understood with the use of non-Newtonian models. Particularly in tiny passageways like stenosed arteries and at high shear rates, blood defies Newton's rule of viscosity due to its complicated nature. Non-Newtonian models have several uses in clinical practice and research, helping to improve the diagnosis and treatment of cardiovascular disorders. They are essential in helping us understand the behavior of blood flow in stenosed arteries.

3.1. Power Law Model

One common viscosity model for non-Newtonian fluids in hydraulic analysis is the Power Law model. The underlying premise of this model is that all fluids behave in a pseudoplastic manner. For non-Newtonian fluids that are independent of time, the power law model can be applied and is expressed as follows:

$$\tau = (K\dot{\gamma})^n, \tag{7}$$

where τ is a shear stress, K is the consistency index, $\dot{\gamma}$ is shear rate, n is power law index.

Blood and other non-Newtonian fluids are frequently described by the comparatively straightforward power law model. It works well at low to moderate shear rates. The Power Law model may shed light on how stenosis affects blood viscosity and flow characteristics in the context of blood flow in stenosed arteries. Because it can capture non-Newtonian behavior, it is widely used and relatively simple.

Understanding the hemodynamic and blood flow characteristics in stenosed arteries is made easier with the aid of the power law model. Clinicians can evaluate the effects of arterial narrowing on blood flow velocity, pressure distribution, and shear stress along the vessel walls by using the power law and fluid dynamics principles. This knowledge is essential for assessing the degree of stenosis and anticipating any side effects like ischemia or thrombosis.

Table 1. The table provides a summary of a study conducted using the power law model.

Author	Year	Findings
Ismail et al. (2008)	2008	The study analyzed three distinct artery taper angles: diverging, non-tapered, and converging, emphasizing the importance of non-Newtonian behavior in small blood vessels.
Nadeem et al. (2011)	2011	The velocity profile falls as the stenosis shape and power law index rise.
Basu Mallik et al. (2013)	2013	The theoretical analysis explores the rheological properties of Blood

		flow through narrow, circular, stenosed arteries using the power law fluid model. It highlights the influence of rheological parameters, such as radius, height, and length, on flow characteristics. The study also considers slip velocity at the stenosis wall, revealing its dominating role in arteriosclerotic conditions.
Solangi et al. (2015)	2015	The Carreau model validates the model as it agrees well with the Power Law model. However, the Power Law Model resides in minimal vortex intensity compared to the Carreau model.
Bakheet et al. (2016)	2016	The degree to which the inclination angle in an artery with an irregular cross-section influences blood flow velocity and wall shear stress has been calculated and reported.
Bakheet et al. (2017)	2017	Body acceleration should be given special attention in the current model under consideration since it causes major physiological issues such as backflow, the creation of flow separation areas, and an increase in pressure drop.
Ahmad et al. (2019)	2019	The study provides an exact solution for the governing equation for the steady flow of a power law fluid through a tapered non-symmetric stenotic tube, correcting an error in Nadeem et al.'s previous results due to an incorrect sign choice.
Nasrin et al. (2020)	2020	Stenotic areas experience increased pressure and velocity due to increased blood inlet velocity, resulting in a rise in shear rate and blood pressure with increasing magnetic field intensity.
Gujral and Singh (2020)	2020	This paper explores the impact of viscosity variation on blood flow characteristics in overlapping atherosclerotic arteries. Graphs show that larger stenosis sizes decrease flow rate, increase flow resistance, and increase wall shear stress. Linear viscosity variation has slightly higher flow rate and flow resistance values, while wall shear stress remains constant. Future research could consider external magnetic fields and hematocrit values.
Talib et al. (2021)	2021	An artery becomes narrower and more constricted when stenosis is present. Compared to Newtonian fluids, the Power Law fluid has a greater wall shear stress profile. The profiles of increasing wall shear stress are led by the Hartmann number, M.
Nasha et al. (2022)	2022	The study reveals that rectangular shapes exhibit higher flow resistance than cosine and trapezoidal shapes in non-Newtonian blood behavior. Compared to the trapezoidal form, the cosine shape exhibits more skin friction over axial distance. The geometry of stenosis and non-Newtonian blood characteristics both affect non-dimensional skin friction in stenosed arteries.
Sharma et. al. (2025)	2025	In this study, they represent the exact analytical expressions relating the pressure drop and volumetric flow rate for steady and laminar flow of power law fluids in complex geometries.

3.2. Casson Model

A rheological model called the Casson model is used to explain the flow characteristics of non-Newtonian fluids, especially those that include yield stress, such as pastes, paints, and some food items. The concept, which was created in 1959 by R. W. Casson, is especially helpful in explaining the flow of materials that have a yield stress, or do not flow until a specific stress threshold is crossed. The Casson model, which is extensively utilized in the study of blood rheology across a wide range of shear rates, was not applied to the fluid-solid interaction in an artery. The Casson model can be stated mathematically as:

$$\tau^{\frac{1}{2}} = (K\dot{\gamma})^{\frac{1}{2}} + \tau_0^{\frac{1}{2}}, \tag{8}$$

where K_c is Casson plastic viscosity, $\dot{\gamma}$ *is shear rate*, τ_0 is the Casson yield stress.

Hemodynamic characteristics in stenosed arteries, such as shear stress, velocity profiles, and pressure gradients, can be predicted using the Casson model. Grasping the effects of stenosis on blood flow dynamics and the resulting implications for vascular health requires a grasp of this information.

Table 2. An inventory of various studies carried out using the Casson model

Author	Year	Finding
Srivastav et al. (1994)	1994	A two-fluid model of blood, consisting of a Casson fluid core and a Newtonian plasma peripheral layer, explores the impact of peripheral layer viscosity on blood flow in mildly stenotic arteries.
Misra et al. (2008)	2008	The velocity decreases with radius growth and axial distance increase, while the wall shear stress rises with axial distance and time at a specific distance.
Siddiqui et al. (2009)	2009	The model can be useful for studying blood flow through stenosed tubes, particularly in diseased stages when blood becomes yield stress. It also considers the oscillatory wall shear stress, which can cause fatigue and loss of tube wall elasticity. More interesting models should consider non-symmetric stenosis and viscoelastic effects.
Sankar (2010)	2010	The analysis of pulsatile blood flow in mildly stenotic narrow arteries using the perturbation method reveals that pressure drops, plug core radius, wall shear stress, and resistance to flow increase with increasing yield stress or stenosis size.
Bali and Awasthi (2012)	2012	The study reveals that the magnetic field, stenosis height ratio, normal tube radius, and fluid yield stress significantly influence blood flow. The presence of a magnetic field decreases velocity, wall shear stress, and flow rate, making it useful for diseased blood flow control.
Venkatesan et al. (2013)	2013	Stenosis affects blood flow by increasing resistance to flow, with bell-shaped arteries having less skin friction than cosine curve-shaped arteries.
Sarifuddin, Chakravarty, and Mandal (2014)	2014	The study highlights the importance of addressing flow separation zones and high wall shear stress in arterial stenoses to prevent further development and plaque disruptions in Atherosclerosis. It is beneficial for theoretical modelers and experimentalists who regularly update their models and closely monitor updated theoretical models.
Sharma and Yadav (2017)	2017	Permeability affects flow velocity in peripheral and core locations, decreasing with increasing permeability. Skin friction decreases in stenosed areas with increased permeability and plasma layer thickness.
Sarifuddin(2020)	2020	Stenosis affects arteries in opposite directions, while atherosclerosis forms, indicating increased damage due to plaque disturbances and high wall shear stress.
Dubey et al. (2020)	2020	The concentration of nanoparticles in the core region increases with a higher Brownian motion parameter, while a smaller number or a more significant parameter causes a higher velocity field.
Elgendi S.G. (2024)	2024	This study examines the characteristics of an incompressible viscous Casson fluid when it passes through a permeable and convectively heated elastic surface in the presence of slip velocity. It holds significant relevance in theoretical advancements in mathematical modeling of Casson fluid flow and heat mass transfer in engineering systems.

It makes the assumption that blood functions as a Bingham fluid, which means that blood only flows when a specific threshold shear stress is exceeded. In large arteries with high blood viscosity and relatively low shear rates, the Casson model is frequently employed to simulate blood flow.

3.3. Herschel–Bulkley Model

In rheology, the Herschel-Bulkley model is mostly used to characterize non-Newtonian fluids, especially those that show shear-thinning behavior, like some kinds of blood. It extends the idea of Newtonian viscosity to materials that do not adhere to Newton's law of viscosity. It is named for Ralph Hershel and Richard Bulkley, who created the model in the 1920s. It basically tells us how a fluid's viscosity changes in response to the applied shear rate. The Herschel-Bulkley model can be applied to a stenosed artery, which is a constricted or narrowed blood vessel, to get insight into the blood flow characteristics within the confined area. Typically, the Hershel-Bulkley Model is written as:

$$\tau = \tau_0 + K(\dot{\gamma})^n, \quad (9)$$

where τ is shear stress, τ_0 is fluid yield stress, K is consistency Index, n is Flow Index, $\dot{\gamma}$ is shear rate.

For fluids that exhibit both shear thinning (decreasing viscosity with increasing shear rate) and yield stress (a minimum stress required to commence flow), the Herschel-Bulkley model extends the Power Law model to incorporate yield stress behavior. This concept may be especially applicable in the case of stenosed arteries if there are areas where blood flow is restricted and needs a specific amount of stress to start. It is helpful to characterize complex fluids that behave both viscously and elastically using the Herschel-Bulkley model.

Table 3. An inventory of various studies carried out using the Herschel-Bulkley model

Author	Year	Finding
Chaturani and Ponnalagar(1985)	1985	The Herschel-Bulkley fluid exhibits lower velocities near the axis compared to power-law, Bingham, and Newtonian fluids, but increases wall shear stress with increasing n and K, or τ_H.
Chakravarty and Datta (1989)	1989	Blood exhibits non-Newtonian rheological behavior in pathological circumstances, leading to higher erythrocyte aggregation and stiffness in artery diseases, causing circulatory system dysfunction.
Sankar and Lee (2007)	2007	As stenosis size increases, resistive resistance and plug core radius increase, and shear stresses at the wall progress alongside yield stress spikes, affecting peripheral layer effects.
Sankar and Hemalata (2007)	2007	For fixed values of n, k, A, and θ, the breadth of the plug flow zone drops as t increases from 0° to 90°, then increases as t increases from 90° to 270°, and then declines as t increases further from 270° to 360°.
Shah (2013)	2013	The non-Newtonian blood model shows that resistance to flow and wall shear stress increase with stenosis size, but these are negligible due to the blood's non-Newtonian behavior. Viscosity rises with yield stress and falls with stenosis shape parameter, impacting outcomes in diabetic patients.
Priyadarshini andPonalagusam(2015)	2015	The study reveals that the pressure gradient analytical equation is valid for yield stress values up to 2.4, with a maximum error of less than 1.4% in the stenotic region and less than 6% in the dilatation region.
Neeraja et al. (2017)	2017	The peripheral layer of arteries, including carotid, femoral, coronary, and arterioles, exhibits non-Newtonian activity, leading to mass-flux reduction due to increased pseudoplastic blood.
Ponalagusamy and Priyadharshini (2019)	2019	As magnetic field, particle mass, and concentration parameters increase, fluid velocity and nanoparticles decrease, leading to hypertension, coronary disorders, and artery plaque growth. Understanding body acceleration, Hartmann number, and magnetic particles impacts blood flow.
Abidin et al. (2021)	2021	Blood flow behavior is influenced by the power-law index and the yield stress. Increases in yield stress and power-law index led to increased red blood cell concentration, resulting in decreased blood velocity, effective axial diffusivity, and relative axial diffusivity. The solute's relative axial diffusivity increases with increased mobility.
Metri R. et al. (2025)	2025	They study the peristaltic transport of Herschel-Bulkley fluids through uniform cylindrical tubes, accounting for slip velocity and wall porosity. The novelty of their work lies in integrating wall slip and effects on porous structure.

3.4. Carreau Model

The mathematical model known as the Carreau model, after the French rheologist Pierre-Yves Carreau, is used to explain the non-Newtonian behavior of fluids, especially those that show shear-thinning characteristics. The non-Newtonian behavior of fluids, especially ones with complicated viscosities like blood, is described by the rheological model known as the Carreau model. When used on stenosed arteries, it can provide information on blood flow patterns and how blood behaves in constricted spaces. Arterial narrowing, or stenosis, can drastically change how blood flows. Clinicians can forecast how blood will flow through stenosed arteries by using Computational Fluid Dynamics (CFD) simulations built on the Carreau model. Understanding the risk of thrombosis, plaque rupture, and tissue perfusion following stenosis depends on this knowledge. The following equation represents the Carreau model:

$$\eta = \eta_\infty + (\eta_0 - \eta_\infty)(1 + (\lambda\dot{\gamma})^a)^{\frac{n-1}{a}}, \tag{10}$$

where η is the viscosity of the fluid, η_∞ is the viscosity at high shear rates, η_0 is the viscosity at low shear rates, λ is the relaxation time, $\dot{\gamma}$ is the shear rate, n is the power-law index, and a is the Carreau-Yasuda constant.

Table 4. A list of the numerous research projects that have been implemented with the Carreau model

Author	Year	Finding
Akbar et al.(2014)	2014	This analysis examines the two-dimensional stagnation-point flow of an incompressible Carreau fluid towards a shrinking surface. The Carreau fluid model is developed for the first time, and the simplified boundary value problem is solved using the Runge-Kutta method.
Khan and Hashim (2015)	2015	The article examines the Carreau viscosity model and its application in defining boundary layer equations for Carreau fluids, revealing physical aspects of flow and heat transfer, with fluid velocity decreasing for shear-thinning fluids.
Elmaboud et al.(2015)	2015	The study examines the natural convection of a Carreau fluid in a vertical channel with rhythmically contracting walls. The Navier-Stokes and energy equations are reduced to a nonlinear PDE system using the long-wavelength approximation. Numerical calculations and graph analysis are conducted.
Raju and Sandeep (2016)	2016	The study investigates the influence of nonlinear thermal radiation and heat source/sink on unsteady three-dimensional flow of Carreau and Casson fluids, revealing good accuracy and high heat and mass transfer rate.
Mamun et al.(2016)	2016	The study investigates the effects of non-Newtonian modeling on physiological flows in a rigid artery with a single 85% severity stenosis. The study uses a Fourier series with sixteen harmonics and a Reynolds number range of 96 to 800. The study characterizes two non-Newtonian constitutive equations of blood and compares the Newtonian model with non-Newtonian models. Results show differences in pressure, wall shear stress distributions, and streamlines contours.
Abdollahzadeh et al.(2018)	2018	A SIMPLE method code simulates non-Newtonian Carreau-Yasuda fluid in stented artery tubes, better predicting temperature distributions and wall shear stresses. The study suggests using a magnetic field to control blood flow behavior and monitor blood temperature in tapered arteries, as monitoring blood temperature is crucial for maintaining living conditions.
Ahmad et al.(2021)	2021	This study analyses blood flow through a stenosed artery using the Carreau fluid model, considering the blood as non-Newtonian. Regular perturbation techniques are used to investigate solutions up to the second order in dimensionless Weissenberg number (We). Results show fluid velocity increases with parameter m, while the opposite behavior is observed with We. This non-Newtonian Carreau fluid model can be applied to other bio-mathematical studies.
Alsemiry et al.(2022)	2022	This study investigates the effect of a catheter on blood flow and heat transfer characteristics in a Carreau fluid model. It relates to the surgical technique of eccentric catheter injection into an artery. Results show that eccentric catheters have higher axial velocity, wall shear stress, and temperature. The study also shows that the risk and complications associated with catheterization are alleviated when the catheter's eccentric position is considered.
Pepe V. et al. (2024)	2024	Their work focuses on the design of self-similar branched flow networks. They summarize that the flow is incompressible and stationary with the Carreau model viscosity, which is important for the study of complex flow systems.

Since the Carreau model can simulate both Newtonian and non-Newtonian fluid characteristics, it is frequently chosen for simulating blood flow in stenosed arteries because it may be more accurate.

4. Comparison

Through the use of non-Newtonian models to simulate blood flow through stenosed arteries, researchers are able to assess the effectiveness of various treatment approaches. In these kinds of situations, non-Newtonian models—like the Casson model or the power-law model—are better at capturing the behavior of blood flow. The power law model is simpler and requires fewer parameters compared to the Carreau model and Casson model, making it easier to match experimental data. The Power Law model may benefit from an analysis of the shear thinning behavior of blood flow as it encounters varying degrees of stenosis. The Carreau model is typically selected because of its ability to capture more intricacies in the behavior of blood flow, especially in scenarios where flow conditions may differ significantly, like stenosed arteries, even though the power law model may be sufficient in other circumstances. When studying blood flow via stenosed arteries, both the Casson and Carreau models are employed, especially in Computational Fluid Dynamics (CFD) simulations. The Carreau model is generally regarded as more appropriate because it can capture shear-thinning behavior and provide more accurate predictions of blood flow characteristics in the context of stenosed arteries, where blood flow can be highly complex and influenced by factors like vessel geometry and flow rate. The precise flow behavior seen, the degree of stenosis, and the required degree of model complexity and accuracy all play a role in which model—the Herschel-Bulkley or Carreau—is used to describe blood flow in stenosed arteries. Insights into non-Newtonian fluid behavior can be gained from both models, which can be useful in comprehending blood flow dynamics under such physiological circumstances.

5. Conclusion

Non-Newtonian models like Power-law, Casson, Carreau, and Herschel-Bulkley help understand blood flow behavior in stenosed arteries, improving the diagnosis and treatment of cardiovascular diseases. These models account for nonlinear and time-dependent blood viscosity behavior, with each model having its own equations and parameters. Researchers often use more complex models that consider rheological characteristics of blood in stenosed arteries. Non-Newtonian fluids exhibit various characteristics like viscoelasticity, thixotropy, shear-thinning, and shear-thickening. Choosing the right model requires understanding the fluid's behavior, accurate experimental data collection, and balancing computational efficiency and model fidelity. Models can be complex, ranging from simple empirical equations to intricate constitutive equations. The problem's shape and boundary conditions also influence model selection. Numerical stability is crucial for accurate simulation results. Validating non-Newtonian models against analytical solutions or experimental data is challenging due to the fluid's complexity and the scarcity of benchmark cases.

Non-Newtonian models provide a more accurate description of blood flow behavior in arteries, taking into account parameters such as blood viscosity, shear-thinning, and yield stress. These models assist doctors and researchers in understanding blood flow in stenosed arteries and the effects of treatment options such as stent implantation or angioplasty. They also help to create medical devices for stent treatment, evaluate their interaction with blood flow, and reduce potential problems. Non-Newtonian models also forecast how changes in blood flow patterns may influence patient care and follow-up methods. Overall, non-Newtonian models improve simulation, treatment plan optimization, device design, and hemodynamic change prediction by effectively capturing the dynamics of blood flow in stenosed arteries. Future stenosis patients may benefit as a result of this.

Non-Newtonian models have numerous other clinical uses in addition to aiding in the diagnosis and treatment of stenosis. Some of them are:

1. Non-Newtonian fluid behavior is important in drug delivery systems, especially for understanding how medicines distribute and flow throughout biological tissues. Models based on non-Newtonian fluid mechanics aid in the optimization of drug compositions and delivery systems, providing successful treatment with few side effects.
2. Under mechanical stress, biological tissues such as muscles, tendons, and cartilage exhibit non-Newtonian behavior. The use of non-Newtonian models facilitates the study of these tissues' mechanical properties, which is critical for the development of prosthetics, implants, and rehabilitation approaches.
3. Mucus is a non-Newtonian fluid present throughout the respiratory tract. To study respiratory disorders such as cystic fibrosis, Chronic Obstructive Pulmonary Disease (COPD), and asthma, it is necessary to understand the material's rheological properties. Non-Newtonian models aid in the development of treatments such as inhaled medicines and airway cleaning procedures.
4. In joints, synovial fluid acts as a non-Newtonian lubricant. The study of joint lubrication mechanisms using non-Newtonian models is critical for understanding disorders such as osteoarthritis, as well as developing prosthetic joints and lubricating drugs.

To recapitulate, non-Newtonian models are critical in many medical fields, ranging from sophisticated diagnostics and treatment planning to understanding basic physiological processes. In medical research and treatment, their ability to capture the complicated activities of biological fluids and tissues makes them invaluable tools.

References

[1] Siti Nurul Aifa Mohd Zainul Abidin, Nurul Aini Jaafar, and Zuhaila Ismail, “Herschel-Bulkley Model of Blood Flow through a Stenosed Artery with the Effect of Chemical Reaction on Solute Dispersion,” *Malaysian Journal of Fundamental and Applied Sciences*, vol. 17, no. 4, pp. 457-474, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[2] Riaz Ahmad et al., “An Analytical Approach to Study the Blood Flow over a Nonlinear Tapering Stenosed Artery in Flow of Carreau Fluid Model,” *Hindawi Complexity*, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[3] Riaz Ahmad et al., “Steady Flow of a Power Law Fluid through a Tapered Non-symmetric Stenotic Tube,” *Applied Mathematics and Nonlinear Sciences*, vol. 4, no. 1, pp. 255-266, 2019. [CrossRef] [Google Scholar]

[4] Noreen Sher Akbar, S. Nadeem, and Kh. S. Mekheimer, “Rheological Properties of Reiner-Rivlin Fluid Modelfor Blood Flow Through Tapered Artery with Stenosis,” *Journal of the Egyptian Mathematical Society*, vol. 24, no. 1, pp. 138-142, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[5] N.S. Akbar et al., “MHD Stagnation Point Flow of Carreau Fluidtoward a Permeable Shrinking Sheet: Dual Solutions,” *Ain Shams Engineering Journal*, vol. 5, no. 4, pp. 1233-1239, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[6] A. Ali et al., “Mathematical Modeling and Parametric Investigation of Blood Flow through a Stenosis Artery,” *Applied Mathematics and Mechanics*, vol. 42, pp. 1675-1684, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[7] Reima D. Alsemiry, Hamed M. Sayed, and Norsarahaida Amin, “Mathematical Analysis of Carreau Fluid Flow and Heat Transfer within an Eccentric Catheterized Artery,” *Alexandria Engineering Journal*, vol. 61, no. 1, pp. 523-539, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[8] Aziz Ullah Awan et al., “Analysis of Pulsatile Blood Flow Through Elliptical Multi-stenosed Inclined Artery Influenced by Body Acceleration,” *Engineering Science and Technology, an International Journal*, vol. 47, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[9] Ahmed Bakheet et al., “The Effect of Body Acceleration on the Generalized Power Law model of Blood Flow in a Stenosed Artery,” *AIP Conference Proceedings*, vol. 1830, no. 1, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[10] Ahmed Bakheet et al., “Blood Flow through an Inclined Stenosed Artery,” *Applied Mathematical Sciences,* vol. 10, no. 5, pp. 235-254, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[11] Rekha Bali, and Usha Awasthi, “A Casson Fluid Model for Multiple Stenosed Artery in the Presence of Magnetic Field,” *Applied Mathematics,* vol. 3, pp. 436-441, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[12] T.B. Begg, and J.B. Hearns, “Components in Blood Viscosity. The Relative Contribution of Haematocrit, Plasma Fibrinogen and Other Proteins,” *Clinical Sciene,* vol. 31, no. 1, pp. 87-93, 1996. [Google Scholar] [Publisher Link]

[13] M. Brust et al., “Rheology of Human Blood Plasma: Viscoelastic Versus Newtonian Behavior,” *Physical Review Letter,* 2013. [CrossRef] [Google Scholar] [Publisher Link]

[14] C.G. Caro, “Vascular Fluid Dynamics and Vascular Biology and Disease,” *Mathematical Methods in the Applied Sciences*, vol. 24, no. 17-18, pp. 1311-1324, 2001. [CrossRef] [Google Scholar] [Publisher Link]

[15] C.G. Caro et al., *The Mechanics of the Circulation*, Cambridge University Press, 2012. [Google Scholar] [Publisher Link]

[16] Harry J. Carpenter et al., “A Review on the Biomechanics of Coronary Arteries,” *International Journal of Engineering Science*, vol. 147, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[17] Maria José Carrilho, and Lurdes Patrício, “The Recent Demographic Situation in Portugal,” *Journal of Demographic Studies*, vol. 44, pp. 35-80, 2010. [Google Scholar]

[18] S. Chakravarty, and A. Datta, “Effects of Stenosis on Arterial Rheology Through a Mathematical Model,” *Mathematical and Computer Modelling,* vol. 12, no. 12, pp. 1601-1612, 1989. [CrossRef] [Google Scholar] [Publisher Link]

[19] P. Chaturani, and R. Ponnalagar Samy, “A Study of Non-newtonian Aspects of Blood Flow through Stenosed Arteries and Its Applications in Arterial Diseases,” *Biorheology,* vol. 22, no. 6, pp. 521-531, 1985. [CrossRef] [Google Scholar] [Publisher Link]

[20] Rajendra P. Chhabra, “Non-Newtonian Fluids: An Introduction,” *Rheology of Complex Fluids,* pp. 3-34, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[21] Stefanie Dimmeler, “Cardiovascular Disease Review Series,” *EMBO Molecular Medicine,* vol. 3, no. 12, 2011. [Google Scholar] [Publisher Link]

[22] Anita Dubey et al., “Computational Fluid Dynamic Simulation of Two-fluid Non-Newtonian Nanohemodynamics through a Diseased Artery with a Stenosis and Aneurysm,” *Computer Methods in Biomechanics and Biomedical Engineering,* vol. 23, no. 8, pp. 345-371, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] Sefa Dundar, Burcin Gokkurt, and Yasin Soylu, “Mathematical Modeling at a Glance: A Theoretical Study,” *Procedia-Social and Behavioral Sciences,* vol. 46, pp. 3465-3470, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[24] S.G. Elgendi et al., “Computational Analysis of the Dissipative Casson Fluid Flow Originating from a Slippery Sheet in Porous Media,” *Journal of Nonlinear Mathematical Physics*, vol. 31, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[25] Y. ABD Elmaboud, Kh. S. Mekheimer, and Mohamed S. Mohamed, “Series Solution of a Natural Convection Flow for a Carreau Fluid in a Vertical Channel with Peristalsis,” *Journal of Hydrodynamics*, vol. 27, no. 6, pp. 969-979, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[26] Thanaa Elnaqeeb, Khaled S. Mekheimer, and Felwah Alghamdi, “Cu-blood Flow Model Through a Catheterized Mild Stenotic Artery with a Thrombosis,” *Mathematical Biosciences,* vol. 282, pp. 135-146, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[27] John L. Fahey, Werner F. Barth, and Alan Solomon, "Serum Hyperviscosity Syndrome," *JAMA*, vol. 192, no. 6, pp. 464-467, 1965. [CrossRef] [Google Scholar] [Publisher Link]

[28] Esmaeel Fatahian, Naser Kordani, and Hossein Fatahian, "A Review on Rheology of Non-Newtonian Properties of Blood," *IIUM Engineering Journal,* vol. 19, no. 1, pp. 237-250, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[29] A. Fatahillah et al., "Numerical Analysis of Blood Flow in Intracranial Artery Stenosis Affected by Ischemic Stroke using Finite Element Method," *Journal of Physics: Conference Series,* vol. 1218, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[30] P.L. Galbraith, and N.J. Clatworthy, "Beyond Standard Models - Meeting The Challenge Of Modelling," *Educational Studies in Mathematics,* vol. 21, pp. 137-163, 1990. [CrossRef] [Google Scholar] [Publisher Link]

[31] Giovanni P. Galdi et al., *Hemodynamical Flows: Modeling, Analysis and Simulation*, Springer Link, 2008. [Google Scholar] [Publisher Link]

[32] Gerard J. Tortora, *Principles of Anatomy & Physiology*, The Cardiovascular System: The Blood, 13th ed., Wiley, 2011. [Google Scholar] [Publisher Link]

[33] Kanika Gujral, and S.P. Singh, "Effect on Flow Characteristics of Blood in Overlapping Stenosed Artery Considering the Axial Variation of Viscosity using Power-law non-Newtonian Fluid Model," *International Journal Computing Science and Mathematics,* vol. 11, no. 4, pp. 397-409, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[34] Zuhaila Ismail et al., "A Power-law Model of Blood Flow Through a Tapered Overlapping Stenosed Artery," *Applied Mathematics and Computation,* vol. 195, no. 2, pp. 669-680, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[35] Mohammad Yaghoub Abdollahdeh Jamalabadi et al., "Modeling and Analysis of Biomagnetic Blood Carreau Fluid Flow through a Stenosis Artery with Magnetic Heat Transfer: A Transient Study," *PLoS ONE*, vol. 13, no. 2, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[36] Elahe Javadi, and Safa Jamali, "Hemorheology: The Critical Role of Flow Type in Blood Viscosity Measurements," *Soft Matter,* no. 37, pp. 8446-8458, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[37] M. Karsheva et al., "Blood Rheology-Akey for Blood Circulation in Human Body," *Journal of the University of Chemical Technology and Metallurgy,* vol. 44, no. 1, pp. 50-54, 2009. [Google Scholar] [Publisher Link]

[38] Masood Khan, and Hasim, "Boundary Layer Flow and Heat Transfer to Carreau Fluid Over a Nonlinear Stretching Sheet," *AIP Advances*, vol. 5, no. 10, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[39] N. El Khatib et al., "Mathematical Modelling of Atherosclerosis," *Mathematical Modelling of Natural Phenomena*, vol. 14, no. 6, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[40] Sushil Kumar et al., "Mathematical Model for Behaviour of Blood Flow in Artery through Stenosis," *Iconic Research and Engineering Journal,* vol. 4, no. 1, 2020. [Google Scholar] [Publisher Link]

[41] Gordon D.O. Lowe, *Clinical Blood Rheology*, 1st Edition, CRC Press, 1988. [CrossRef] [Publisher Link]

[42] B. Basu Malik et al., "A Non-Newtonian Fluid Model for Blood Flow using Power-Law through an Atherosclerotic Arterial Segemrnt having Slip Velocity," *International Journal of Pharmaceutical, Chemical and Biological Sciences,* vol. 3, no. 3, pp. 752-760, 2013. [Google Scholar] [Publisher Link]

[43] Khairuzzaman Mamun et al., "Physiological Non-Newtonian Blood Flow Through Single Stenosed Artery," *AIP Conference Proceedings*, vol. 1754, no. 1, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[44] Kh. S. Mekheimer, and M.A. El Kot, "Mathematical Modeling of Axial Flow Between Two Eccentric Cylinders: Application on the Injection of Eccentric Catheter through Stenotic Arteries," *International Journal of Non-Linear Mechanics,* vol. 47, no. 8, pp. 927-937, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[45] Kh. S. Mekheimer, and M.A. El Kot, "Mathematical Modelling of Unsteady Flow of a Sisko Fluid through an Anisotropically Tapered Elastic Arteries with Time-variant Overlapping Stenosis," *Applied Mathematical Modelling,* vol. 36, no. 11, pp. 5393-5407, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[46] Kh. S. Mekheimer, and M.A. El Kot, "Suspension Model for Blood Flow through Catheterized Curved Artery with Time-variant Overlapping Stenosis," *Engineering Science and Technology, an International Journal (JESTECH),* vol. 18, no. 3, pp. 452-462, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[47] Kh. S. Mekheimer, M.H. Haroun, and M.A. El Kot, "Influence of Heat and Chemical Reactions on Blood Flow through an Anisotropically Tapered Elastic Arteries with Overlapping Stenosis," *Applied Mathematics & Information Sciences,* vol. 6, no. 2, pp. 281-292, 2012. [Google Scholar] [Publisher Link]

[48] Revanasidda Metri et al., "Dynamics of Herschel-Bulkley Fluids in Porous Media: A Peristaltic Transport Analysis," *Journal of Umm Al-Qura University for Engineering and Architecture*, vol. 16, pp. 1477-1486, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[49] J.C. Misra, S.D. Adhikary, and G.C. Shit, "Mathematical Analysis of Blood Flow through an Arterial Segment with Time-dependent Stenosis," *Mathematical Modelling and Analysis,* vol. 13, no. 3, pp. 401-412, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[50] M.S. Moayeri, and G.R. Zendehbudi, "Effects of Elastic Property of the Wall on Flow Characteristics Through Arterial Stenoses," *Journal of Biomechanics,* vol. 36, no. 4, pp. 525-535, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[51] Pedar C.F. Møller, Jan Mewis, and Daniel Bonn, "Yield Stress and Thixotropy: On the Difficulty of Measuring Yield Stresses in Practice," *Soft Matter*, vol. 2, pp. 274–283, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[52] Z. Mortazavinia, A. Zare, and A. Mehdizadeh, “Effects of Renal Artery Stenosis on Realistic Model of Abdominal Aorta and Renal Arteries Incorporating Fluid-structure Interaction and Pulsatile Non-Newtonian Blood Flow,” *Applied Mathematics and Mechanics,* vol. 33, pp. 165-176, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[53] J. L. Murray, and, and Alan D. Lopez, *The Global Burden of Disease*, pp. 1-27, 1997. [Publisher Link]

[54] S. Nadeem et al., “Power Law Fluid Model for Blood Flow through a Tapered Artery with a Stenosis,” *Applied Mathematics and Computation,* vol. 217, no. 17, pp. 7108-7116, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[55] Vinay Nasha, and Surendra Kumar, “Non-Newtonian Blood Flow Model with The Effect of Different Geometry of Stenosis,” *Journal of Mathematical and Computational Science*, vol. 12, 2022. [Google Scholar] [Publisher Link]

[56] R. Nasrin, Amzad Hossain, and I. Zahan, “Blood Flow Analysis Inside A Stenotic Artery Using Power-Law Fluid Model,” *Research & Development in Material science,* vol. 13, no. 1, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[57] G. Neeraja et al., “Peripheral Layer Viscosity on the Stenotic Blood Vessels for Herschel-Bulkley Fluid Model,” *Informatics in Medicine Unlocked,* vol. 9, pp. 161-165, 2017. doi:https://doi.org/10.1016/j.imu.2017.08.004[CrossRef] [Google Scholar] [Publisher Link]

[58] Bharath Babu Nunna et al., “Capillary Flow Dynamics of Blood With Varied Hematocrit in Microfluidic Platforms,” *IEEE Healthcare Innovations and Point of Care Technologies (HI-POCT)*, 2022. [Google Scholar]

[59] Vinicius Pepe et al., “Numerical Study of Carreau Fluid Flow in Symmetrically Branched Tubes,” *Symmetry,* vol. 17, no. 1, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[60] Poiseuille, *Recherches Expérimentales Sur le Mouvement Des Liquides Dans Les Tubes de Très-petits Diamètres*, Des Seances de L'Acade mie des Science, 1841. [Google Scholar] [Publisher Link]

[61] R. Ponalagusamy, and S. Priyadharshini, “A Numerical Model on Pulsatile Flow of Magnetic Nanoparticles as Drug Carrier Suspended in Herschel–Bulkley Fluid Through an Arterial Stenosis Under External Magnetic Field and Body Force,” *International Journal of Computer Mathematics,* vol. 96, no. 9, pp. 1763-1786, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[62] K. Maruthi Prasad, and T. Sudha, “Mathematical Computation of Couple Stress Fluid Flow through Stenosed Artery with Suspension of Nanoparticles,” *International Journal of Engineering and Advanced Technology*, vol. 9, no. 1S5, 2019. [CrossRef] [Publisher Link]

[63] S. Priyadharshini, and R. Ponalagusamy, “Biorheological Model on Flow of Herschel-Bulkley Fluid through a Tapered Arterial Stenosis with Dilatation,” *Applied Bionics and Biomechanics*, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[64] Tomasz Pryzwan et al., “Blood Rheological Properties and Methods of Their Measurement,” *Annales Academiae Medicae Silesiensis,* vol. 78, pp. 1-10, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[65] C.S.K. Raju, and N. Sandeep, “Unsteady Three-dimensional Flow of Casson–Carreau Fluids Past a Stretching Surface,” *Alexandria Engineering Journal*, vol. 55, no. 2, pp. 1115-1126, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[66] Rocha, and Teresa Maria Rodrigues, “*Perfil De Risco Cardiovascular Em Amostras De Estudantes Do Ensino Secundário Da Região De Lisboa*,” University of Lisboa, Portugal, 2010. [Google Scholar] [Publisher Link]

[67] D.S. Sankar, and Usik Lee, “Two-phase Non-linear Model for the Flow Through Stenosed Blood Vessels,” *Journal of Mechanical Science and Technology*, vol. 21, pp. 678-689, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[68] D.S. Sankar, and K. Hemalatha, “Pulsatile Flow of Herschel–Bulkley Fluid through Catheterized Arteries – A Mathematical Model,” *Applied Mathematical Modelling*, vol. 31, no. 8, pp. 1497-1517, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[69] D.S. Sankar, and Usik Lee, “Two-fluid Casson Model for Pulsatile Blood Flow through Stenosed Arteries: A Theoretical Model,” *Communications in Nonlinear Science and Numerical Simulation*, vol. 15, no. 8, pp. 2086-2097, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[70] Sarifuddin, “CFD Modelling of Casson Fluid Flow and Mass Transport Through Atherosclerotic Vessels,” *Differential Equations and Dynamical Systems*, vol. 30, pp. 253-269, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[71] Santabrata Chakravarty Sarifuddin, and Prashanta Kumar Mandal, “Numerical Simulation of Casson Fluid Flow Through Differently Shaped Arterial Stenoses,” *Zeitschrift für angewandte Mathematik und Physik,* vol. 65, pp. 767-782, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[72] H. Schmid-Schonbein, and R.E. Wells, “Rheological Properties of Human Erythrocytes and Their Influence Upon the “Anomalous” Viscosity of Blood,” *Ergebnisse der Physiologie Reviews of Physiology*, vol. 63, pp. 146-219, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[73] Adelis Sequeira, and Joao Janela, “An Overview of Some Mathematical Models of Blood Rheology,” *A Portrait of State-of-the-Art Research at the Technical University of Lisbon*, pp. 65-87, 2007. [Google Scholar] [Publisher Link]

[74] Sapna Ratan Shah, “An Innovative Study for non-Newtonian Behaviour of Blood Flow in Stenosed Artery using Herschel-Bulkley Fluid Model,” *International Journal of Bio-Science and Bio-Technology,* vol. 5, no. 5, pp. 233-240, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[75] Bhupesh Dutt Sharma, and Pramod Kumar Yadav, “A Two-Layer Mathematical Model of Blood Flow in Porous Constricted Blood Vessels,” *Transport in Porous Media*, vol. 120, pp. 239-254, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[76] Nidhi Sharma, and Ashish Garg, “Power Law Fluid through Various Converging-diverging Geometries of Corrugated Channels,” *Fluid Dynamics Research*, vol. 57, no. 5, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[77] S.U. Siddiqui et al., "Mathematical Modelling of Pulsatile Flow of Casson's Fluid in Arterial Stenosis," *Applied Mathematics and Computation*, vol. 210, no. 1, pp. 1-10, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[78] Luisa Soares et al., "Cardiovascular Disease: A Review," *Biomedical Journal of Scientific and Technical Research*, vol. 51, no. 3, pp. 42696-42703, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[79] M.A. Solangi et al., "Analysis of Recirculation Flow Rate in Partially Plaque Deposited Capillaries by Power Law Model," *Journal of Applied Environmental and Biological Sciences,* vol. 5, no. 5, pp. 254-259, 2015. [Google Scholar] [Publisher Link]

[80] V.P. Srivastav, and M. Saxena, "Two-Layered ModeL of Casson Fluid Flow Through Stenotic Blood Vessels: Applications to the Cardiovascular System," *Journal of Biomechanics*, vol. 27, no. 7, pp. 921-928, 1994. [CrossRef] [Google Scholar] [Publisher Link]

[81] Max M. Strumia et al., "Effect of Red Cell Factors on the Relative Viscosity of Whole Blood," *American Journal of Clinical Pathology*, vol. 39, no. 5, pp. 464-474, 1963. [CrossRef] [Google Scholar] [Publisher Link]

[82] J. Stuart, and M.W. Kenny, "Blood Rheology," *Journal of Clinical Pathology*, vol. 33, no. 5, pp. 417-429, 1980. [CrossRef] [Google Scholar] [Publisher Link]

[83] Amira Husni Talib, Ilyani Abdullah, and Nik Nabilah Nik Mohd Naser, "The Influence of Magnetic Field on Wall Shear Stress in Power Law Fluid Flow of Blood," *AIP Conference Proceedings*, vol. 2365, no. 1, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[84] Vipin Tiwar, Namrata Deyal, and Nandan S. Bisht, "Mathematical Modeling Based Study and Prediction of COVID-19 Epidemic Dissemination Under the Impact of Lockdown in India," *Frontiers in Physics*, vol. 8, pp. 1-8, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[85] J. Venkatesan et al., "Mathematical Analysis of Casson Fluid Model for Blood Rheology in Stenosed Narrow Arteries," *Journal of Applied Mathematics*, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[86] Michael Gr. Voskoglou, "The Use of Mathematical Modeling as a Tool for Learning Mathematics," *Quaderni di Ricerca in Didattica*, 2006. [Google Scholar] [Publisher Link]

[87] S. Afiqah Wajihah, and D.S. Sankar, "A Review on non-Newtonian Fluid Models for Multi-layered Blood Rheology in Constricted Arteries," *Archive of Applied Mechanics*, vol. 93, pp. 1771-1796, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[88] Bryan Walsh, "*Asia's War with Heart Disease*," TimeAsia, 2004. [Google Scholar] [Publisher Link]

[89] Xuming Xie, "Steady Solution and Its Stability of a Mathematical Model of Diabetic Atherosclerosis," *Journal of Biological Dynamics*, vol. 17, no. 1, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[90] G. Abi Younes, N. El Khatib, and V. Volpert, "A Free Boundary Mathematical Model of Atherosclerosis," *Applicable Analysis*, vol. 103, no. 1, pp. 240-262, 2024. [CrossRef] [Google Scholar] [Publisher Link]