CFD SIMULATION OF NON-NEWTONIAN EFFECT ON HEMODYNAMICS CHARACTERISTICS OF BLOOD FLOW

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This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled “CFD Simulation of non-Newtonian Effect on Hemodynamics Characteristics of Blood Flow” is the result of my own work except as cited in the references

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SUPERVISOR DECLARATION

I hereby declare that I have read this project report and in my opinion, this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Honours.

Signature	:	…...............................
Name of Supervisor	:	Dr. Mohamad Shukri Bin Zakaria
Date	:	…..............................

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ABSTRACT

Computational fluid dynamics (CFD) is a part of engineering in the mechanical field to study the pattern flow of fluid, heat transfer and anything that related to the operation of computer-based simulation. This project is to study Newtonian and non-Newtonian model of viscosity consequence on hemodynamic characteristics when blood flows through the nozzle by using CFD simulation. For the current study, it focusses on low Reynolds number (laminar) only. The current study focusses to compare between Newtonian and non-Newtonian and select which model is close to blood behavior. The results for this study will be on the axial velocity along the centerline of the nozzle, wall shear stress and pressure. For the validation process, a previously published paper was selected to performed test for validation by using Computational Fluid Dynamics software ANSYS FLUENT. After validation is done, it can be concluded that the work shows in this report served as early goals to provide simulation to use patient data by using implanted in-body medical devices that can obtain from CT scans or MRI technique. Hence, this report shows that CFD predictions can be validate and verify by axial velocity along centreline of the nozzle. Axial velocity for Newtonian viscosity is higher than non-Newtonian viscosity model. Besides that, Newtonian blood viscosity has a high number of wall shear stress and it will cause blood clots and thrombosis to the patient. When blood clot and thrombosis occurred, it can disturb the flow of blood from the recirculating system. When the process of transporting oxygen to the heart and the release of carbon dioxide from our body is being obstructed it can cause high blood pressure, high cholesterol and a heart condition, the rhythm of heart disturbance.

ABSTRAK

Dinamik bendalir komputasi (CFD) adalah sebahagian daripada kejuruteraan mekanikal yang diajukan untuk menganalisis aliran bendalir, pemindahan haba dan berkaitan dengan penggunaan simulasi berasaskan komputer. Projek ini adalah untuk mengkaji kesan Newtonian dan non-Newton pada ciri hemodinamik aliran darah dengan menggunakan simulasi CFD. Untuk kajian ini, ia memberi tumpuan kepada nombor Reynolds yang rendah (lamina) sahaja. Kajian ini memberi tumpuan untuk membandingkan antara Newtonian dan bukan Newtonian dan memilih model mana yang hampir dengan tingkah laku darah. Keputusan untuk kajian ini akan berada pada halaju paksi di sepanjang pusat muncung, tegasan dan tekanan geseran dinding. Untuk proses pengesahan, kertas yang telah diterbitkan sebelum ini dipilih untuk ujian pengesahan yang dilakukan dengan menggunakan perisian ANSYS FLUENT Computational Fluid Dynamics. Selepas pengesahan dilakukan, dapat disimpulkan bahawa kerja yang ditunjukkan dalam laporan ini berfungsi sebagai tujuan awal untuk menyediakan simulasi untuk alat-alat medis dalam tubuh yang diimplan dengan menggunakan data pesakit yang dapat diperolehi dari scan CT atau teknik MRI. Oleh itu, laporan ini menunjukkan bahawa ramalan CFD boleh diverifikasi dan disahkan oleh halaju paksi di sepanjang pusat muncung. Halaju aksial bagi halaju Newton adalah lebih tinggi daripada model kelikatan non-Newtonian. Selain itu, kelikatan darah Newton mempunyai banyak tekanan ricih dinding dan ia akan menyebabkan bekuan darah dan trombosis kepada pesakit. Apabila bekuan darah dan trombosis berlaku, ia boleh menyekat aliran darah dari sistem peredaran darah. Apabila proses mengangkut oksigen ke jantung dan pelepasan karbon dioksida dari badan kita yang terhalang dapat menyebabkan tekanan darah tinggi, kolesterol tinggi dan keadaan jantung, irama gangguan jantung.

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CHAPTER 1

INTRODUCTION

1.1 Background

Computational fluid dynamics (CFD) is a branch of engineering field in mechanical for widely studying the flow pattern of fluid, heat transfer, and related studies with the use of computer-based simulation (Lee, 2011). Examples are streamlined features and hydrodynamics of vehicles, turbines for power generation plants, engineering for electronics, chemical engineering, external and internal environmental architectural design, marine, and environmental engineering. In the biomechanical field, CFD is still in a phase of developing technologies. The primary cause why CFD in the biomedical field has collapsed behind is the incredible complexity of human life structures and behavior fluid in the human body. Lately, biomedical research with CFD is more open since the technologies have great performance equipment and software product are effortlessly accessible with advances in software engineering. This project aims to study the Computational Fluid Dynamic (CFD) Simulation of Non-Newtonian consequence blood flow on hemodynamics characteristic.

CFD is generally committed to liquids that are in movement, and how the liquid flow performance impacts process. Furthermore, physical attributes of fluid movement can ordinarily be defined through the basic mathematical equation, normally in fractional form, which governs the procedure of interest and is regularly named as governing equations. CFD has been used to created or analyze the medical device (Borse & Giri, 2016), (Izraelev et al., 2009). The mathematical equation is tackled by being changed over by computer scientist utilizing service of high-level computer programming languages. The calculations reflected the investigation of fluid pattern through simulation of numerical, which includes utilizing high-speed digital computers to achieve numerical solutions. Utilizing CFD, medical researchers can pick up expanded information on how body fluids and systems parts are expected to perform, to make the essential upgrades for bio-liquid physiology studies, and to make a medical device (Vierendeels, 2007). CFD gives suggestions for simulations before a genuine responsibility is attempted to implement any medicinal design alteration and may give the right direction to create medical involvements.

The FDA interlaboratory study (Paterson, Burgreen, Hariharan, Food, & Day, 2012) state that an idealized medical equipment must have of a small nozzle, which can contribute same characteristics as others blood-carrying medical devices, such as blood tubing, hemodialysis sets, catheters, cannulas, syringes, and hypodermic needles. The nozzle device was made to contain the blood flow with accelerating flow, decelerating flow, variations in shear stress, velocities, recirculating flow and all that may be related to blood damage in medical devices. These sizes of the nozzle features make complex flow phenomena including adverse pressure gradients, recirculating flow, and high and low shear stress area, which have same pattern features of cardiovascular devices such as found in the diffuser areas of blood pumps and ventricular support equipment (Hariharan et al., 2017).

In early research, the research found that the blood is a Newtonian fluid, yet blood vessel stream and stress pattern can be influenced by rheological properties of the blood. Anyway, in late research (Gijsen, Vosse, & Janssen, 1999) found from their examination on bloodstream in a carotid bifurcation demonstrate the speed dispersion of stream could be influenced by shear diminishing the characteristics blood for non- Newtonian viscosity. Based on variable applied stress or force, fluid viscosity for Non- Newtonian fluid can be determined. The physical behaviour of non-Newtonian fluid depends on the forces acting on it from time to time.

1.2 Problem Statement

Every researcher and industry of the medical device keep doing research about the medical device to produce the latest technology capable of addressing the problems faced by the previous medical device. The existing medical device for the hemodynamics of blood flow causes blood to clot (Zakaria et al., 2017). Hemolysis and thrombosis can happen when blood flowing through medical devices. The harmful effects of high shear stresses on blood have been widely known for many years. Relationship between hemolysis and time often stated that shear stress/exposure time relationship, which shows that increasing shear stresses can only be endured for short times before blood damage occurs, while decreasing shear stresses can be endured for longer times (Paterson et al., 2012). Therefore, the effect of hemodynamic characteristics of blood flow under CFD simulation will be a focus on this project

Computational fluid dynamics (CFD) is normally utilized for medicinal device advancement, its helpfulness for exhibiting device safety has not been proven yet. Dependable institutionalized strategies for detailed need are lacking and are constraining the use of computational methods in the controlling review of medical devices. To address this issue, participants from academia, industry, and the U.S. Food and Drug Administration recently finished a computational interlaboratory study to determine the suitability and approach for simulating fluid pattern in an ideal medical device (Paterson et al., 2012). This project will be studying the relationship between FDA nozzle and blood clot.

Regardless of whether the presumption that blood can remain demonstrated as a Newtonian fluid is permissible is under debate. A few numerical studies show that the impact of shear diminishing properties of blood is not effective for the low in large arteries (Gijsen et al., 1999). When to improve or change the current medical device to the new one, many aspects need to analyses and to consider. Since the technology still growing in this field, many parameters need to be considered in this research such as Non- Newtonian fluid. The representative of Non-Newtonian will be studied in this research.

1.3 Objective

The research focuses on the CFD simulation of Non-Newtonian effect on hemodynamics characteristics of blood flow. The main objectives of this study are:

i. To study the effect of Hemodynamics characteristic of blood flow in the FDA Nozzle.

ii. To simulate Newtonian and Non-Newtonian

iii. To compare between Newtonian and Non-Newtonian effect on hemodynamics characteristics of blood flow and suggest which model close to blood behavior.

1.4 Scope of Project

The scope or limitation of this project will be listed in this project. The first scope is, this paper state that condition for this blood flows through the nozzle to be in low Reynold number which is Re=500 in the laminar regime. This is because when to study the non-Newtonian performance (non-constant viscosity) the condition must be in low Reynold number. Secondly, using non-Newtonian performance on the viscosity of blood is the Carreau-Yasuda. This model was chosen because of the ability to keep the rise in blood viscosity when at low shear rates. This model also has a steady conversion role between low viscosity at the high shear amount and the high shear amount at decreasing shear rates. Thirdly, the numerical simulation that solves and provide the answer for behavior of the blood when the mathematical model is too complicated to solve it. Specifically, this paper used the Navier Stokes equations for numerical simulation. Navier Stokes equation increases the opportunity to add the viscosity of the blood. Lastly, the scope of this paper is the condition of the bloodstream. In this paper, the condition of the bloodstream will be transient flow.

CHAPTER 2

LITERATURE REVIEW

2.1 Blood Properties

Blood is a part body fluid that flows in individual and other creatures that can transfers essential substances, for example, supplements and oxygen to the cells and carriage metabolic waste things from those equivalent cells. Blood is coursed around the body through veins by the drawing activity of the heart. Creatures function for lungs, transfer oxygen through blood vessel blood from breathing in fresh air to the tissues of the body, and venous blood carries carbon dioxide, a waste result of absorption delivered by cells, to be breath out from the lungs. Many types of research define blood is modeled as an incompressible fluid, which kinematic constraint on velocity profile from (dynamics) continuity equation. However, to obtain a profile for the pressure it will go through difficulty process (J. H. Ferziger, 2002) specifically when running for finite-difference or finite volume method.

A different method is to assumed blood as a slightly compressible method, where the continuity equation was applied to this. An equation of state can calculate the value for pressure and from the continuity equation, it can determine the value for the density of blood. By following the FDA’s regulation blood is with a density of 1056 kg/m^3. It is simulated with a dynamic viscosity of 0.0035 N.s/m^2 for Newtonian fluid as per the guidelines from the late research (Stewart, 2011). References value for pressure is 1200 Pa (Min et al., 2014). The setting for boundary condition for the slightly compressible fluid model is recommended for non-reflecting boundary condition. By evaluating separately the outgoing and incoming over the boundaries were the results that obtain from non-reflecting boundary conditions (Yoo, Wang, Trouvé, & Im, 2005)

2.2 Newtonian vs Non-Newtonian

Newtonian fluids are the stream performance of fluids with a simple linear relation between shear stress [mPa] and shear rate [1/s]. Newtonian fluids the stress feedback to a basic shear rate is linear. The linearity steady μ relies upon the thermophysical states of the fluids (temperature and pressure) (Aldi, Buratto, Pinelli, Ruggero, & Casari, 2016).

Water, natural solvents, and liquor are some case of Newtonian liquids. Those fluids viscosity is just reliant on temperature. Based on the graph of shear stress versus shear rate (See Figure 1) we can see a straight increment in stress with expanding shear rates, where the grade is given by the viscosity of the liquid. This infers the viscosity of Newtonian liquids will remain an unfaltering (see Figure 2) regardless of how fast they are constrained to course through a pipe or channel (for example viscosity is free of the rate of shear).

An exception to the standard is Bingham plastics, which are liquids that require the least stress to be associated before they stream. These are carefully for non- Newtonian, yet once the stream starts, they act fundamentally as Newtonian fluids (for example shear pressure is direct with shear rate). Mayonnaise is one of the instances of this sort of conduct.

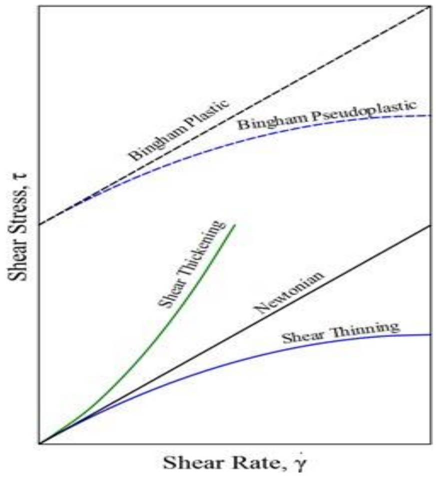

Figure 2.1: Shear stress as a component of shear rate for several kinds of fluids

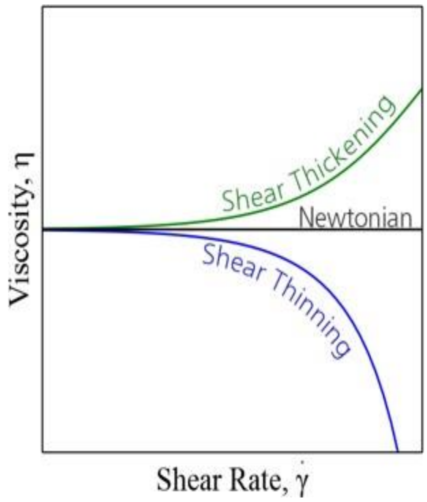

Figure 2.2: Viscosity of Newtonian, Shear Thinning and Shear thickening as an element of shear rate

In presence, most liquids are non-Newtonian, which infers that their viscosity is liable to shear rate (Shear Thinning or Thickening). As opposed to Newtonian liquids, non-Newtonian liquids show either a non-straight association between shear pressure and shear rate (see Figure 1), have yield stress, or viscosity that is needy to time or distortion history (or a blend of all the above mentioned).

The non-Newtonian liquid dealt with is a shear-diminishing fluid (the conspicuous viscosity reduces with increment stress) (Aldi et al., 2016). A liquid is shear thickening if the viscosity of the liquids augments as the shear rate increment (see Figure 2). A typical instance of shear thickening liquids is a blend of corn starch and water. Fluids are shear diminishing if the consistency lessens as the shear rate increases. Shear diminishing liquids, generally called pseudo-plastics, are universal in modern and organic procedures. Regular models incorporate ketchup, paints, and blood (Boyd, Buick, & Green, 2007).

Non-Newtonian sort of liquids can be brought about by a couple of components, all of them identified with structural reorganization of the fluid's molecules because of flow. In polymer melts and courses of action, it is the plan of the exceptionally anisotropic chains what results in a diminished viscosity. In colloids, it is the detachment of the various stages in the stream that causes a shear diminishing conduct.

The complex nature of the blood flows in the individual body is a principal cause for concern for the accuracy of the outcomes of bloodstream simulation. For the simulation of the human right arteries supply routes, (Johnston et al., 2004; Chen and Lu, 2006; O'Callaghan et al., 2006) demonstrated that "when studying the wall shear stress distribution for transient bloodstream in arteries, the application of a Newtonian bloodstream model is a reasonably good approximation. However, to study the stream inside the artery in greater detail, a non-Newtonian model is more appropriate". The non-Newtonian features are commonly validated at low shear rates which can exist close bifurcation sites and at recirculation zones creating in the arteries. Since the generation of atherosclerosis, i.e. atherogenesis, has been related with low (< 0.5 Pa) WSS values, it turns out to be certain that non-Newtonian models should be utilized to acquire more reliable estimates. Many types of research about blood have been simulated as a Newtonian fluid, however, due to rheological properties of blood, it will effect arterial flow and stress pattern (Gijsen et al., 1999) find that shear diminishing of non-Newtonian can be damaged by velocity transportation.

Blood is a non-Newtonian liquid, particularly at low shear rates. A couple of studies show that the numerical aftereffect of divider shear pressure (WSS) circulation in a vein might be unmistakable when blood was dealt with in an unexpected way (for example Newtonian or non-Newtonian), especially at low shear rates (Johnston et al., 2004; Chen and Lu, 2006; O'Callaghan et al., 2006).

Non-Newtonian models have been used with rising recurrence for stream simulation of other vascular segments, for instance, the aorta, the cerebral, and the coronary arteries. In every one of these cases, summed up Newtonian expressions are grasped which can more likely catch the complex behavior of the fluid under steady state condition. Regardless, while there is strong confirmation to demonstrate that the Carreau-Yasuda model is the most proper among constitutive equation for the depiction of bloodstream reliably, repeating the two its yield pressure and shear diminishing viscoplastic qualities, specialists routinely use various models, for instance, the Carreau–Yasuda or a general power law. The distinctions in the