GENERALIZED POWER-LAW MODEL OF MAGNETOHYDRODYNAMIC BLOOD FLOW IN AN INCLINED STENOSED ARTERY WITH BODY ACCELERATION

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***To my beloved wife*.**

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ABSTRACT

This thesis focuses on the development of a mathematical model to investigate the effect of magnetic field and body acceleration on blood flow characteristics, heat and mass transfer from a stenosed artery, a condition due to the abnormal narrowing of a blood vessel. The arterial segment is assumed to be a cylindrical tube in an inclined position with oscillating boundary condition and the stenosis taking the shape of a cosine function. The momentum equation is based on the generalized power law model which is expected to handle the variations in blood rheology as blood flows through a different-sized vessel, with the index $n < 1, n > 1$ and $n = 0$ describing the shear-thinning, shear-thickening and Newtonian fluid respectively. The full governing equations comprising the generalized power-law equation, heat and mass equations are non-linear partial differential equations whose numerical procedure involves the discretization of the equations using the Marker and Cell (MAC) method, where pressure along the tube is calculated iteratively using the Successive-Over-Relaxation (SOR) technique. The results have been compared and validated with existing results in certain limiting cases. New results in terms of pressure, streamlines, heat and mass distribution are obtained for various parameter values of each of the external body forces. Specifically, for a stenosis with 48% occlusion, separation is seen to occur for Newtonian fluids at $Re = 1000$ and this region can be seen to increase in the case of shear thickening fluids, while the shear-thinning fluid is shown to be free of separation region. Moreover, blood velocity, wall shear stress and pressure drop decrease with increase n, while heat and mass transfer increase. It is also demonstrated through the simulations that under the influence of magnetic field, the velocity in the centre of the artery and the separation region are reduced with a sufficient strength of magnetic field, depending on the severity of stenosis. For a 75% and 84% occlusion, the separation zones entirely disappear with magnetic strength 8 and 12 Tesla respectively, while the pressure drop, wall shear stress, heat and mass transfer increase. On the other hand, increasing periodic body acceleration leads to increase velocity and the pressure drop while reducing heat and mass transfer. Inclination angle increases the velocity and wall shear stress but decreases the pressure drop and heat and mass transfer. Based on the results, patients with blood vessel disease are advised not to do a high-intensity exercise; it can put extra strain on the heart leading to a risk in chest pain or even cardiac arrest. Regular exercise and suitable intensity of magnetic field could enhance vascular health.

ABSTRAK

Tesis ini memberi tumpuan kepada pembangunan model matematik untuk mengkaji kesan medan magnet dan pecutan jasad terhadap ciri-ciri aliran, pemindahan haba dan pemindahan jisim bagi aliran darah di dalam arteri berstenosis, iaitu suatu keadaan di mana saluran darah menyempit secara abnormal. Segmen arteri diandaikan suatu tiub silinder kedudukan condong dengan syarat sempadan berayun dan stenosis sebagai berbentuk fungsi kosinus. Persamaan momentum adalah berdasarkan kepada model hukum kuasa teritlak yang boleh mengendalikan variasi reologi darah yang mengalir melalui saluran darah pelbagai saiz, dengan indeks $n < 1, n > 1$ dan $n = 0$ masing-masing mencirikan bendalir penipisan ricih, penebalan ricih dan Newtonan. Persamaan menakluk yang terdiri daripada persamaan hukum kuasa teritlak, persamaan haba dan persamaan jisim adalah persamaan pembezaan separa tak linear dengan prosidur pengiraan berangkanya melibatkan pendiskretan persamaan tersebut menggunakan kaedah Marker dan Cell (MAC), di mana tekanan di sepanjang tiub dikira secara lelaran menggunakan teknik Successive-Over-Relaxation (SOR). Keputusan kajian telah dibanding dan disahkan keputusan dengan hasil kajian sedia ada bagi beberapa kes mengehadkan. Keputusan baru bagi tekanan, garis arus, taburan haba dan jisim diperoleh untuk pelbagai nilai parameter bagi setiap daya jasad luaran. Khususnya, bagi stenosis yang tersumbat sebanyak 48%, pemisahan dilihat berlaku untuk bendalir Newtonan pada nilai $Re = 1000$ dan rantau ini diperhatikan meningkat bagi bendalir penebalan ricihan, manakala bagi bendalir pencairan ricihan, didapati bebas dari rantau pemisahan. Selain itu, halaju darah, tekanan ricih dinding dan kejatuhan tekanan menurun dengan peningkatan n, sebaliknya, pemindahan haba dan jisim bertambah. Melalui simulasi juga ditunjukkan bahawa di bawah pengaruh medan magnet, halaju di pusat arteri dan rantau pemisahan menurun dengan kekuatan medan magnet yang sesuai, bergantung kepada tahap stenosis. Untuk arteri yang tersumbat 75% dan 84%, zon pemisahan hilang sepenuhnya masing-masing dengan kekuatan magnet 8 dan 12 Tesla, manakala kejatuhan tekanan, tekanan dinding ricih, pemindahan haba dan jisim meningkat. Sebaliknya, peningkatan berkala pecutan jasad membawa kepada peningkatan halaju dan kejatuhan tekanan di samping pengurangan pemindahan haba dan jisim. Sudut kecondongan meningkatkan halaju serta tegasan ricih dinding tetapi mengurangkan kejatuhan tekanan dan pemindahan haba dan jisim. Berdasarkan keputusan, dijangkakan pesakit dengan masalah saluran darah dinasihatkan untuk tidak melakukan senaman berintensiti tinggi; ia boleh memberikan tekanan tambahan ke atas jantung yang boleh membawa kepada risiko sakit dada atau serangan jantung. Senaman yang kerap dan intensiti medan magnet yang sesuai boleh meningkatkan kesihatan vaskular.

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LIST OF ABBREVIATIONS

CFD	-	Computational fluid dynamics
FHD	-	Ferrohydrodynamics
KE	-	Kinetic Energy
LDL	-	Low-density lipoprotein
MAC	-	Marker and Cell method
MHD	-	Magnetohydrodynamic
MRI	-	Magnetic Resonance Imaging
SOR	-	Successive-Over-Relaxation method
WHO	-	World Health Organization

LIST OF SYMBOLS

β	-	Combination factor
δ	-	The critical height of the stenosis
$\dot{\gamma}$	-	Shear rate
Δz	-	Increment in the axial directions
Δx	-	Increment in the radial directions
Δt	-	Time increment
ΔP	-	Pressure drop
μ	-	Blood viscosity
ω_u	-	Under relaxation parameter
ω_o	-	Over relaxation parameter
ϕ	-	Phase difference of the acceleration
ρ	-	Density of blood
σ	-	Electrical conductivity
$\boldsymbol{\tau}$	-	Stress tensor
τ_w	-	Wall Shear stress
τ_{xx}	-	Shear force at x-axis
I_0	-	Bessel function
$\mathbf{J}$	-	Current density
k	-	Thermal conductivity
k_R	-	Wall oscillation
K_T	-	Thermal diffusion ratio
L	-	The finite difference arterial segment
M	-	Hartmann number
g	-	Gravitational force

a_0	-	Amplitude
B_0	-	Uniform magnetic field
B_1	-	Induced magnetic field
C	-	Mass concentration
C_s	-	The reference concentration at the inlet
C_p	-	The specific heat
D_m	-	coefficient of mass diffusion
E	-	Electric field
F	-	Body force
Fr	-	Froude number
f_b	-	Body acceleration frequency
$G(t)$	-	Periodic body acceleration
p	-	Pressure
P_a	-	Pressure at the beginning of the throat
P_b	-	Pressure at the end of the throat
Pr	-	Prandtl number
R_0	-	Constant radius of the non-stenotic artery
$R(z,t)$	-	Radius of the arterial segment in the stenotic region
Re	-	Reynolds number
Sc	-	Schmidt number
Sh_D	-	Sherwood number
Sr	-	Soret number
T	-	Blood temperature
T_i	-	The respective temperatures at the inlet
T_m	-	The mean blood temperature
θ	-	Angle between the force vector F and the x direction
$u(r,z,t)$	-	The radial velocity component
U	-	Cross-sectional average velocity
$\mathbf{V}$	-	Fluid velocity field
$w(r,z,t)$	-	The axial velocity component

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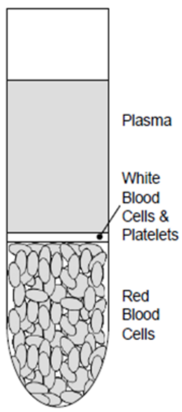
CHAPTER 1

INTRODUCTION

1.1 Research Background

The understanding of the dynamics of blood flow is important in the investigation of the vascular disease development and in the modelling of blood flow. The mathematical depiction of blood flow can be very complicated, yet some simplified models provide a fairly good understanding of the behaviour of blood when flowing through the vessels. The study of the behaviour of blood flow in the blood vessels provides an understanding of the connection between flow and the development of diseases such as atherosclerosis, aneurysms and thrombosis and how the characteristics of the blood flow are changed under these conditions. The understanding of the flow dynamics in the presence of external forces such as gravity, body acceleration and magnetic field will help improve the design of the model. The affecting of several properties of blood and vessels can be improved if the blood flow behaviour through certain conditions is well understood.

Blood is essential for life. It receives oxygen from the lungs and nutrients from the intestine and delivers them to whole body cells. Blood is mainly composed of plasma, which carries proteins, platelets (thrombocytes), red blood cells (erythrocytes) and white blood cells (leukocytes). Red blood cells contain a protein called hemoglobin, which has a high affinity for iron. The average hemoglobin iron concentration is 17% by volume for males and approximately 15% by volume for females (Ramsay, 1957). The main constituent of the blood is red blood cells, which make about 45$\%$ by volume of the blood, while the platelets and white blood cells are less than 1%. At rest, the red blood cell shape is biconcave disks with a diameter of roughly $8\mu m$ and across at its thickest point $2.5\mu m$. The membrane of the cell is quite flexible so that in the flow, the cell shape is less defined.



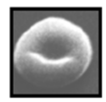
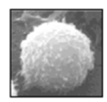
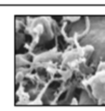
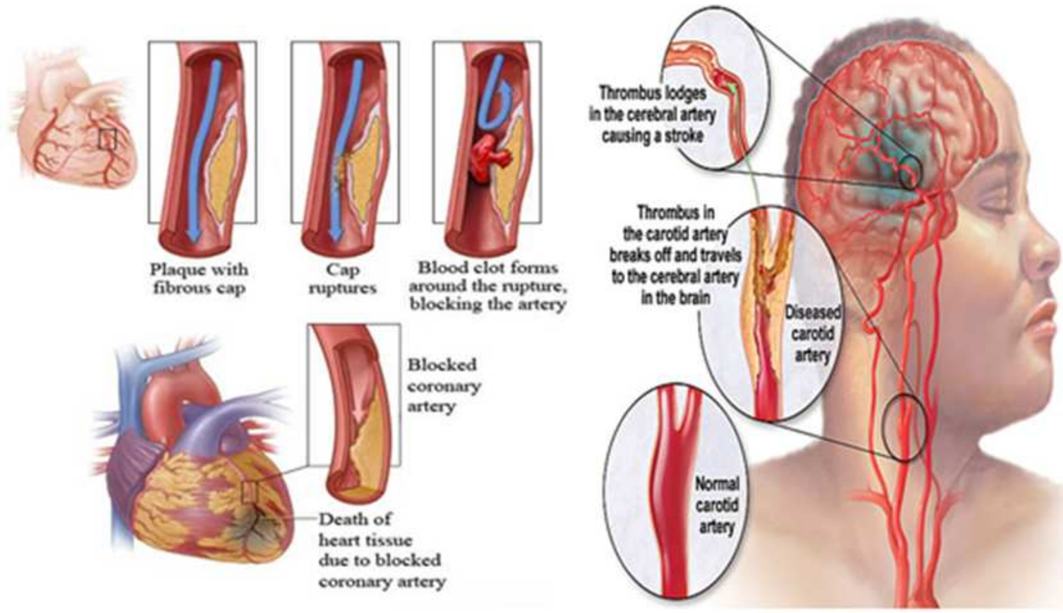
Cell Type	Shape		Number Density (per mm^3)	% Volume of Blood
Red Blood Cells Erythrocytes	Biconcave Disk		4-6 x 10^6	45
White Blood Cells Leucocytes	Spherical		4-11 x 10^3	1
Platelets	Various		250-500 x 10^3	

Figure 1.1: Blood constituents (Caro *et al.*, 1978).

Blood rheology can be described as a non-Newtonian viscosity model and may depend on the size of blood vessel. The assumption of Newtonian behaviour is acceptable for high shear rate flow, as in larger arteries with radius greater than $1mm$. However, this supposition is not valid when the shear rate is low as in smaller arteries and in the downstream of the stenosis, blood exhibits non-Newtonian in small arteries (Mandal, 2005). From a biomechanics perspective, blood would not obey the simple, one parameter and linearized law of viscosity established by Newton. Fluids that exhibit a non-linear relationship between the shear stress and the rate of shear strain are called Non-Newtonian. According to Enderle *et al.* (2000), the non-Newtonian behaviour of blood must be modelled by higher order constitutive equations. Investigations have showed that the shear-thinning blood rheology can be represented as a function of shear rate by various commonly used mathematical models, such as, power law, Casson, Carreau and their derivatives Cross, Walburn-Schneck, Carreau-Yasuda and the generalized power law models (Cho and

Kensey, 1991; Ballyk *et al.*, 1994). However, power-law and the Walburn-Schneck models estimate the blood behaviour well at low shear rates; but at high shear rates they predict decreasing viscosities and hence fail to hold the Newtonian behaviour at such high shear rates (Johnston *et al.*, 2004). According to Pries *et al.* (1992), Carreau-Yasuda and Casson models hold the experimental blood behaviour well at both low and high shear rates. Moreover, a modified Casson model also can be utilized to represent the haematocrit of the blood (Das *et al.*, 2000). According to Ballyk *et al.* (1994), the generalized power law model can be considered to be a general non-Newtonian model for blood viscosity. It encompasses the power law model at low shear rates, the Newtonian model at mid-range and high shear rates, (more than $200s^{-1}$) and has the Casson model as a special case for a given haematocrit value. In addition, there is a close agreement between the generalized power law and Carreau model at low shear rate (between 0.5 and $50s^{-1}$). Hence, for this study, blood rheology is adequately described by the generalized power law model.

Recently there are many types of research have been carried out on stenosed arteries: arteries with a blockage caused by atherosclerosis, which literally implies the solidifying of the arterial walls. The artery walls are normally smooth to allow blood flow easily through the artery and for easy transportation of oxygen, nutrients and other vital substances from blood to the body tissues. Stenosis tends to cause a hardening of the walls as well as a narrowing of the vessels (Young, 1968; Biswas, 2000; Biswas and Chakraborty, 2009; Sankar and Lee, 2009). Therefore, it is no wonder that this topic is of a significant concern to the community and numerous researchers. Stenosed artery is one of the widespread diseases that lead to serious circulatory complaints, by narrowing or occluding the blood vessels. Stenosis in arteries providing blood to the cerebrum can lead to a diseased condition called cerebral strokes, likewise, in the coronary arteries; it can bring myocardial infarction that cause a heart attack (heart failure) (Sinha and Singh, 1984). Furthermore, it was observed by researchers, that the resistance of the stenosis was basically reliant on its minimum cross-sectional area instead of its length (Chakravarty and Datta, 1989).



(a) Heart failure (b) Stroke

Figure 1.2: Vascular disease.

(http://www.mayoclinic.org/diseases-conditions/stroke/symptoms-causes/dxc-20117265)

The study of magnetohydrodynamic (MHD) blood flow problems has found applications in numerous fields like blood stream estimations, MHD power generation, etc. The utilization of MHD principles in medication and biological science is of interest in the literature of biomathematics (Vardanyan, 1973; Sud *et al.*, 1974; Sud *et al.*, 1978). Blood has been recorded to have different magnetic susceptibility values depending on its oxygenation state. Deoxygenated blood, which travels through veins towards the heart, behaves as a paramagnetic solution and has a magnetic susceptibility of 3.5×10^{-6}. Oxygenated blood, which is found in arteries and is pumped from the heart, has diamagnetic properties, with a magnetic susceptibility of -6.67×10^{-7} (Haik *et al.*, 1999a). The magnetic relaxation of blood has been experimentally measured to be in the order of a few seconds, meaning that it will take at least a second for blood to reach its equilibrium magnetization when exposed to a magnetic field (Higashi, 1993). The externally applied magnetic field to the blood flow is governed by MHD principles. By Lenz's law, the Lorentz's force will contradict the stream of conducting liquid and the mathematical model ignores the impact of magnetization. The principles of MHD can be utilized to reduce the blood flow in the arterial system and therefore it may be used in the treatment of certain cardiovascular diseases that accelerated blood flow such as hypertension and haemorrhages (Korchevskii and Marochunik, 1965). MHD can also be used in the improvement of magnetic tools for cell separation, as targeted drugs transport i.e. utilizing magnetic particles as drug bearers, magnetic injury treatment, reduce bleeding during surgery, and cancer tumor treatment using magnetic hyperthermia (Haik *et al.*, 1996; Plavins and Lauva, 1993; Ruuge and Rusetski, 1993). As opposed to the MHD, Ferrohydrodynamics (FHD) which deals with electrically poor conductors fluid (no induced electric current), and takes into account the magnetization effects on the flow in the magnetic field. Thus, the FHD equations consider the magnetization of the fluid. The rising force subject to magnetization depends on the presence of a spatially varying magnetic field and with a uniform magnetic this force disappears (Haik *et al.*, 1999a; Haik *et al.*, 1999b; Haik *et al.*, 1996; Haik *et al.*, 2001; Haik *et al.*, 2002). However, blood exhibits substantially high static electrical conductivity (Frewer, 1974; Gabriel *et al.*, 1996; Jaspard and Nadi, 2002). Magnetic tools sold to patients usually use uniform magnetic fields produced by permanent magnets and not varying magnetic fields.

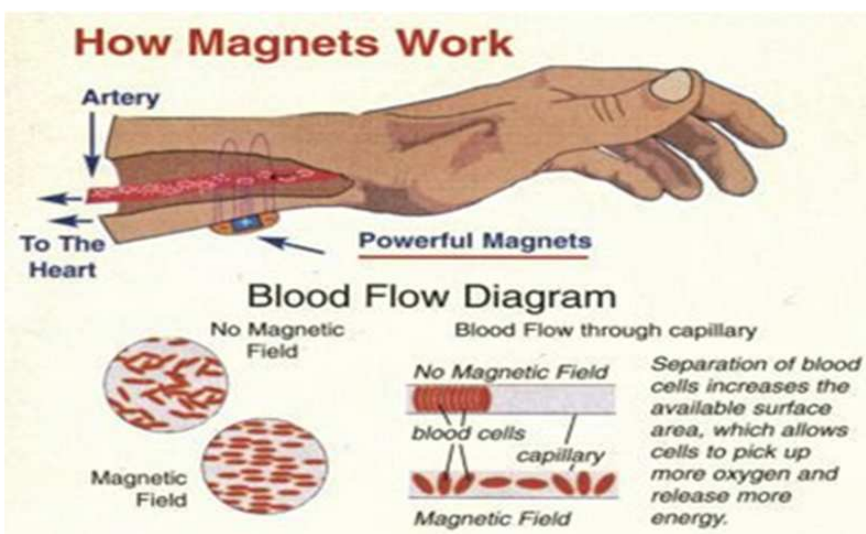


Figure 1.3: Effect of magnetic field on blood flow.

(http://www.frequencyrising.com/magnettherapy.htm)

Figure 1.4: Magnetic therapy.

(http://alaml-algaded.com/google150cc6a3ffa5c10e.html/magnetic-therapy/)

In some conditions the human body is subject to external body accelerations or variations, for example, when vibration treatment is applied to a patient with coronary disease, during flying in a spacecraft, or sudden movement of the body during sports actions, etc. In all such cases, a specific portion of the whole body may be exposed to an external acceleration that may cause disturbance to the blood flow. Though human body has the natural capacity to adapt to the changes, but long exposure to such variations may lead to some serious health problems like headaches, nausea, abdominal pain, abnormal pulse rate, and hemorrhage in the face, lungs and brain (Majhi and Nair, 1994). So the investigation of the impact of the magnitude, duration and frequency of the periodic acceleration may play a critical part in the finding, diagnosis and treatment of heart disease.

The normal temperature of the human blood is about $37°$C. When it increases above $41°$C, irreversible ill effects occurs in the proteins of blood and this is the cause of death after such high fever (Cokelet, 1987). When magnetic field was imposed the temperature increase of more than $3°$C and injuries of 12 and $20cm^2$ closed after $21 - 26$ days. Similar injuries that were not imposed to magnetic field showed sores and scabs even after 50 days. Moreover, hypothermia or hyperthermia is widely used for many purposes such as open heart surgeries and cancer treatment. Especially for the tumor treatment, the role of the temperature is substantially important (Ahuja and Hendee, 1978). For rising of $1°$C the time of cure is reduced to the half for a particular biological result like the decrease of cancer cells of a tumor (Lin *et al.*, 1999).

Although it was reported that oscillatory and low wall shear stress are often positively associated with localized atherosclerosis (Ku *et al.*, 1985; Friedman *et al.*, 1981), the correlation between wall shear stress and formation of atherosclerotic is yet to be persuasively established. It has been proposed that wall shear stress is not the only mechanism responsible for enhancing the formation and develop atherosclerosis (Joshi *et al.*, 2004; Steinman *et al.*, 2002; Kaazempur-Mofrad *et al.*, 2004). Mass transport is a movement of atherogenic molecules and dissolved gases such as Low-density lipoprotein (LDL), oxygen (O_2) and carbon dioxide (CO_2) within the blood flow and arterial wall or vice versa. This action has been proved to contribute to the formation of atherosclerosis (Fry and Vaishnav, 1980; Kaazempur-Mofrad *et al.*, 2005). Caro *et al.* (1971) proposed that atherosclerosis may occur as a result of shear dependent mass transport mechanism of cholesterol between blood and the arterial wall. In order to make an appropriate assessment regarding the possible relationship between the spots of atherosclerotic lesions and the mass transfer patterns, an accurate characterization of mass transfer behaviour is very important. Moreover, a clear knowledge of mass transfer in stenosed artery is of considerable medical interest in the investigation of the formation and development of atherosclerosis. The presence of stenosis in the artery causes blood flow separation and complex hemodynamic features and these in turn affect mass transfer phenomenon.

1.2 Problem Statement

Blood flowing in stenosis artery possess serious Pathophysiological problems because it has numerous arterial diseases such as endothelial damage, hemolysis, thrombosis and other injuries. These can lead to the malfunction of the cardiovascular system which is in close correlation with blood flow characteristics and deformability of the vessel wall.

It is well-known that numerous vessels in physiological systems are not horizontal, but have a certain inclination to the axis. The force of gravity comes into blood flow due to the consideration of inclined artery. On the other hand, blood flow patterns, pressure, mass concentration as well as temperature are often affected by external forces such as magnetic field and body acceleration and various pathological conditions which include stenosis causing serious problems in the cardiovascular system but these conditions have not been fully investigated by previous investigators. Studying the effect of these forces on the blood flow characteristics with heat and mass transfer will help in better understanding of the roles of blood dynamical factors in the development and progression of arterial diseases.

An important factor which needs to be considered in blood flow analyses is the heat transfer. Lack of proper investigation of this parameter will result in irreversible damage in the blood proteins and hence causes high fever and probably loss of life. Therefore, it is important to consider the energy equation where the blood temperature can be calculated to determine the behaviour of heat transfer through an inclined stenosis artery in the presence of a magnetic field and body acceleration.

Blood exhibits various types of rheology behaviour depending on the size of the vessel, and the presence of stenosis will change the size of the vessel in a specific location. Therefore to handle these variations, the blood flow is characterized by the generalized power law model taking into account the shear-thinning, shear-thickening and Newtonian contrarily to other blood models which cannot handle all these blood rheology behaviour.

Pressure has not been calculated previously but this research applied Marker and Cell (MAC) method to discretize the governing equations where the pressure equation is derived and solved iteratively using successive over relaxation (SOR) technique. The main advantage of MAC method is that the pressure boundary conditions at the inlet and outlet are not needed.

1.3 Research Objectives

The main objective of this research is to develop a mathematical model of the unsteady two-dimensional blood flow with heat and mass transfer in inclined stenosed artery subject to a magnetic field and body acceleration and the specific objectives are:

1. Determine the effect of a magnetic field on the characteristics of blood flow modelled as a generalized power law in a stenosed artery.
2. Determine the response of blood flow to body acceleration in an inclined stenosed artery.
3. Investigate the effects of body acceleration and magnetic field on the heat and mass transfer in an inclined stenosed artery.
4. To develop a matlab code based on the mathematical model that can simulate the behavior of the blood flow characteristics with heat and mass transfer.

1.4 Scope of the Study

In this study, the artery having stenosis is taken as an inclined cylindrical tube with elastic wall containing an incompressible non-Newtonian electrically conducting fluid. This involves the consideration of realistic situations which often give rise to complex mathematical equations. The blood flow is considered to be unsteady, laminar, two-dimensional, axisymmetric and fully developed, characterized by the generalized power-law model with energy and mass conservation equations. The blood flow is considered to take place in presence of external forces (magnetic field, body acceleration and inclination angles). As a numerical technique, the MAC method is developed in the cylindrical coordinate system in order to tackle the highly nonlinear governing equations of motion.

1.5 Significance of the Study

Cardiovascular disease is the main killer disease in almost all countries around the world. World Health Organization (WHO) reported that about 75% of all deaths in the industrialized world are caused due to circulatory disease. Almost 9.4 million people die annually from cardiovascular disease. Thus, cardiovascular diseases are the number one cause of death in the world. Cardiovascular disease causes 17.3 million deaths in 2008 about 30% of all global deaths. It is estimated that nearly 23.6 million people will die from cardiovascular diseases, mostly from stroke and heart disease by 2030 (WHO, 2003). Moreover, Heart disease, stroke and other cardiovascular diseases accounted for more than $786,641$ deaths of all 2515458 deaths, approximately one in three American deaths (Mozaffarian *et al.*, 2015). Thus, intensified efforts need to prevent and control this disease.

The present research can estimate the behavior of blood flow, wall shear stress, pressure, temperature and mass concentration and this in turn can help to predict and diagnosis certain problems such as heart attacks non-invasively, and suitable alternative treatment can then be given. In addition, some diseases such as arthritis, gout etc. patients are often advised to take protective pads or tractions and by applying proper magnetic field attached with those instruments we may enhance their activities. Again, in the case of magnetotherapy, by maintaining a proper magnetic field, blood flow velocity and pressure drop may be regulated. Furthermore, The present temperature profiles distributed over the various locations of the stenosed artery may have some implications in hyperthermia in a way to initiate and help develop more accurate models of ablative therapies and improve ablation procedures.

1.6 Thesis Organization

This thesis is divided into seven chapters including this introductory chapter that presented a general introduction of the research background containing the basic information about blood, cardiovascular system diseases, the external forces (inclination, magnetic field and body acceleration) as well as heat and mass transfer. Then in this introduction chapter the problem statements, the objectives, scope and the significance of the study were presented.

In Chapter 2 a brief review of literature that related to the considered problems is provided. It consists of discussions of generalized power law model in blood flow, the external forces, heat and mass transfer, and MAC method. All the problems throughout of this thesis considered the generalized power law and were solved using MAC method.

Chapter 3 describes the mathematical model and the differential form of equations that governed the flow streaming namely the generalized power law model with energy and mass concentration equations. This chapter also presents the solution procedure to solve the problems using the numerical method MAC which is carried out in staggered grid.

Chapter 4 accounts for the unsteady blood flow, behaving as generalized power law model in a stenosed artery, under the effect of an externally applied magnetic field. The effects of the generalized power law index, Hartmann number and the severity of stenosis on the axial velocity, wall shear stress, pressure and streamlines are studied. The MAC method is validated with the previous works for the axial velocity and pressure drop. New results in terms of pressure, streamlines and wall shear stress are presented for different values of Hartmann number, Reynolds number and area occlusion of stenosis.

Chapter 5 addresses the generalized power law model for a two-dimensional unsteady blood flow, in an inclined stenosed artery subject to body acceleration. The solution procedures are the same as in Chapter 4.

Chapter 6 is an improvement from problems encountered in the previous chapters by considering mass concentration and the energy of the fluid in order to investigate the effect of severity of stenosis and the external forces on the heat and mass transfer to blood flowing through inclined stenosed artery. Chapter 7 is the last chapter which consists of a summary of the study, conclusion and several suggestions for future work.

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