Modeling the Treatment Effect on Atherosclerotic Blood Flow with Metabolic Heat, Radiation, Chemical and Magnetic Field

K.W. Bunonyo [1], E. Amos [2] and C. Nwaigwe [3]

[1]*Department of Mathematics & Statistics, Federal University Otuoke, Nigeria*
[1, 2, 3] *Department of Mathematics, Rivers State University, Nigeria*

***Abstract*: In this article, we proposed some mathematical models to investigate the treatment effect of low density lipoprotein-Concentration and atherosclerotic blood flow in a porous micro-channel with metabolic heat and magnetic field. The heat contribution was through the hydrolysis of adenosine which aid blood circulation, and the lipid concentration was as a result of the excessive intake of Tran's fat and other saturated fats. Blood is assumed to be a mixture of formed elements and lipid, which exhibits Newtonian and incompressible characteristics, flow through a permeable solid matrix. The geometric of an atherosclerosis was formulated by incorporating the growth rate of cholesterol and treatment through the drug intake to prevent the liver from producing excessive cholesterol in the bloodstream. Following the aforementioned considerations, the proposed coupled partial differential equations were scaled using the dimensionless parameters and the resulting dimensionless equations are reduced to a system of ODE using perturbation methods involving the periodic terms due to the systolic behavior of the heart.**

The perturbed nonlinear ordinary differential equations were solved directly using the method of undetermined coefficient, where the blood velocity, LDL-C concentration and temperature profiles was obtained. An analytical solution for flow rate, rate of heat transfer, Sherwood number, and shear stress were also obtained respectively. Numerical computation was carried out with the aid of Mathematica, and simulation was done for flow profiles by varying the governing parameters. Graphical results are presented, showing the effect of each simulated parameters such as radiation parameter, Schmidt number, Prandtl number, Grashof number, solutal Grashof number, the treatment parameter, Hartmann number, the oscillatory frequency parameter, the pulse rate, Soret number, permeability parameter, and the height of stenosis appearing on each result. It is observed from the numerical computation that the pertinent parameters influenced the flow profiles which clearly depicts that this investigation is of immense importance for clinicians and scientists in studying cardiovascular system and pathology.

***Keywords*: Modeling, Treatment, Metabolic Heat, Blood, Atherosclerosis, Radiation & Magnetic Field, LDL-C**

I. INTRODUCTION

Atherosclerosis is the condition in which an artery wall thickens as a result of the buildup of fatty materials such as cholesterol [4, 20].This syndrome often occurs in micro vessel where the blood pressure is relatively slow as compared to the pure systemic circulation, and it takes place in response to chronic inflammatory processes [4]. Many factors have been suspected in triggering the inflammatory process [5, 21]. One of these is the accumulation of macrophages and white blood cells promoted by low-density lipoproteins (LDL-C). Inadequate removal of lipids and cholesterol from the macrophages results in the formation of fatty streaks which ultimately lead to fibrous plaques [6]. In humans, highly oxidized and degraded substances caused adverse biological effects including growth retardation, diarrhea, cellular damage, and even death [7–11]. Studies have also shown that heating edible fats at high temperatures and feeding these to animals increase the development of atherosclerotic lesions [8, 12–14]. Several observations suggest that a diet rich in oxidized fat can lead to atherosclerosis [2] and ultimately cardiovascular disease [3]. The edible oils and fats constitute our daily diet and as such stands the risk of consuming oxidized fat. They provide a large portion of our energy needs, supply essential fatty acids, and act as carriers for fat-soluble vitamins. However, chemical changes can lead to the production of oxidized products [1]. Palm oil is one of the world's most widely consumed oils. Palm oil contains equal portions of saturated and unsaturated fatty acids [15]. Palm oil also has a significant level of natural antioxidants and has little tendency to form gums and off-flavors [16, 17]. This article focuses on (1) the study of the effect of saturated fats (cholesterol) we consume through diets, which flows as waxy particles in the bloodstream and the clogging of these particles on the walls of the vessel could cause an inflammatory disease called atherosclerosis; (2) the treatment effects on the blood velocity such as the body metabolism, heat radiation, magnetic therapy and chemical reaction through medications. Motivated upon the aforementioned review, we remodeled the region of atherosclerosis following the concept of Amos and Ogulu [23] by incorporating the treatment and the growth rate on the initial volume of the cholesterol; modify the momentum, partially couple with the energy equation and LDL-C concentration equations to ascertain the radiation and mass concentration effects on the blood velocity. In addition, we reduced the partially differential equations using long wavelength method by Noren and Qasim [26], and solve the

ordinary differential equations using the method of undermine coefficients.

II. MATHEMATICAL FORMULATION

It is considered that blood is made up of formed element mixed with cholesterol, incompressible, viscous and electrically conducting fluid, flowing through a porous microchannel. It is also said that the through arteries is three dimensional, but at the capillary level the radius of the vessel it is too small and it can be approximated to be a channel, Misra & Adhikary [25]. Statin as a medication is used for treatment and controlling excess cholesterol in bloodstream. If not treated and allowed into circulation, excess cholesterol derived from Trans fats could lead to morbidity and mortality due to its adverse effect in human body. It is considered that blood is pumped through blood vessel and back flow is prevented by the valves in the body; we also assumed that the flow is unidirectional and on the axial direction. See Figure 2.1, diagram showing the channel with atherosclerotic region.

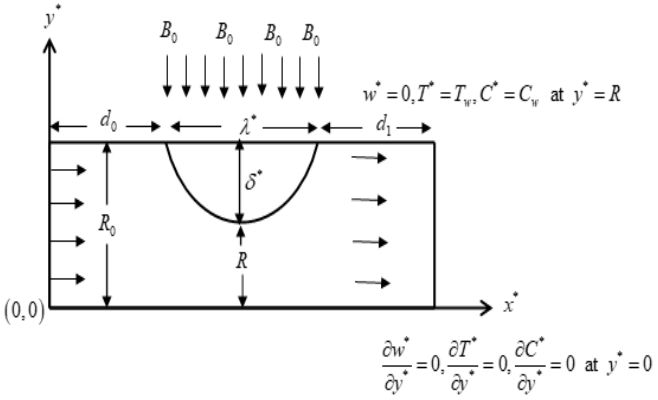

Figure 2.1: Schematic Diagram Showing Atherosclerotic Region

Following the Figure 2.1, and considering the modification of the region in Amos and Ogulu [23], Midya *et. al*. [24], Bunonyo and Amos [22], the geometry of atherosclerosis with treatment and growth rate is modeled as:

$$\frac{R}{R_0}=\begin{cases}1-R_T+\dfrac{\delta e^{at}}{R_0}\left(cos2\dfrac{\pi x^*}{\lambda^*}\right) & \text{at} \quad \dfrac{d_0}{\lambda^*}\le x\le 1\\ 1 & \text{at} \quad 0\le x\le \dfrac{d_0}{\lambda^*}\end{cases} \tag{3.1}$$

where $x^*=\left(d_0+\dfrac{\lambda^*}{2}\right)$

III. GOVERNING EQUATION

3.1 Blood Momentum Equation

$$\rho_b\frac{\partial w^*}{\partial t^*}=-\frac{\partial P^*}{\partial x^*}+\mu_b\frac{\partial^2 w^*}{\partial y^{*2}}-\sigma_e B_0^2 w^*-\frac{\mu_b\varphi}{k^*}w^*+\rho_b g\beta_T\left(T^*-T_\infty\right)+\rho_b g\beta_C\left(C^*-C_\infty\right) \tag{3.2}$$

3.2 Energy Equation

$$\rho_b c_{bp}\frac{\partial T^*}{\partial t^*}=k_{bT}\frac{\partial^2 T^*}{\partial y^{*2}}+Q_0\left(T^*-T_\infty\right)+Q_1\left(C^*-C_\infty\right) \tag{3.3}$$

3.3 LDL-C Concentration Equation

$$\frac{\partial C^*}{\partial t^*}=D_m\frac{\partial^2 C^*}{\partial y^{*2}}-k_0\left(C^*-C_\infty\right) \tag{3.4}$$

The corresponding boundary conditions are

$$\left.\begin{aligned}&\frac{\partial w^*}{\partial y^*}=0,\frac{\partial T^*}{\partial y^*}=0,\frac{\partial C^*}{\partial y^*}=0 \ \text{ at } \ y^*=0\\ &w^*=0,T^*=T_w,C^*=C_w \quad \text{ at } \ y^*=R\end{aligned}\right\} \tag{3.5}$$

We introduce the following dimensionless quantities in order to scale the governing equations and boundary conditions in equation (3.1)–(3.5), they are:

$$\left.\begin{aligned}&\theta=\frac{T^*-T_\infty}{T_w-T_\infty},\phi=\frac{C^*-C_\infty}{C_w-C_\infty},Gr=\frac{g\beta_T\left(T_w-T_\infty\right)R_0^3}{\upsilon^2},Gc=\frac{g\beta_C\left(C_w-C_\infty\right)R_0^3}{\upsilon^2},\\ &Rd_2=\frac{Q_1\left(C^*-C_\infty\right)R_0^2}{k_T\left(T_w-T_\infty\right)},Rd_3=\frac{k_0R_0^2}{\upsilon},M=B_0R_0\sqrt{\frac{\sigma_e}{\mu_b}},x=\frac{x^*}{\lambda},y=\frac{y^*}{R_0},w=\frac{w^*R_0}{\upsilon},\\ &t=\frac{\upsilon t^*}{R_0^2},\delta^*=-\delta,\frac{1}{k}=\frac{\varphi R_0^2}{k^*},Pr=\frac{\mu_b c_b}{k_T},Rd_1=\frac{Q_0R_0^2}{\mu_b c_b}Sc=\frac{\upsilon}{D_m},\end{aligned}\right\} \tag{3.6}$$

Using the dimensional quantities in equation (3.6), the governing equations (3.1) to (3.5) are reduced to:

Blood Momentum Equation

$$\frac{\partial w}{\partial t}=-\frac{\partial P}{\partial x}+\frac{\partial^2 w}{\partial y^2}-M^2w-\frac{1}{k}w+Gr\theta+Gc\phi \tag{3.7}$$

Modified Energy Equation

$$Pr\frac{\partial\theta}{\partial t}=\frac{\partial^2\theta}{\partial y^2}+\theta PrRd_1+\phi Rd_2 \tag{3.8}$$

Modified LDL-C Concentration Equation

$$\frac{\partial\phi}{\partial t}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}-Rd_3\phi \tag{3.9}$$

The corresponding boundary conditions are as:

$$\left.\begin{aligned} &\frac{\partial w}{\partial y}=0,\frac{\partial \theta}{\partial y}=0,\frac{\partial \phi}{\partial y}=0 \quad \text{at } y=0\\ &w=0,\theta=1,\phi=1 \qquad \text{at } y=\frac{R}{R_0}\end{aligned}\right\} \tag{3.10}$$

IV. METHOD OF SOLUTIONS

The flow is oscillatory due to the pumping action of the heart, thus, we seek a oscillatory (periodic) solution in the form below:

$$\left.\begin{aligned} &w(y,t)=w_0(y)e^{i\omega t}\\ &\theta(y,t)=\theta_0(y)e^{i\omega t}\\ &\phi(y,t)=\phi_0(y)e^{i\omega t}\\ &-\frac{\partial P}{\partial x}=P_0e^{i\omega t}\\ &\chi=\frac{y}{h}\end{aligned}\right\} \tag{3.11}$$

Considering the long wavelength approximation method, Noreen and Qasim [26], and using equation (3.11), the dimensionless governing equations (3.7)-(3.9) and the corresponding boundary condition in equation (3.10) are reduced to:

$$\frac{\partial^2 w_0}{\partial \chi^2}-\beta_{11}w_0=P_0h-Grh\theta_0-Gch\phi_0 \tag{3.12}$$

$$\frac{\partial^2 \theta_0}{\partial \chi^2}+\beta_{22}\theta_0=-\phi_0 hRd_2 \tag{3.13}$$

$$\frac{\partial^2 \phi_0}{\partial \chi^2}-\beta_{33}\phi_0=0 \tag{3.14}$$

The corresponding boundary conditions are as:

$$\left.\begin{aligned} &\frac{\partial w_0}{\partial \chi}=0,\frac{\partial \theta_0}{\partial \chi}=0,\ \frac{\partial \phi_0}{\partial \chi}=0 \qquad \text{at } \chi=0\\ &w_0=0,\theta_0=e^{-i\omega t},\phi_0=e^{-i\omega t} \qquad \text{at } \chi=1\end{aligned}\right\} \tag{3.15}$$

where $\beta_{11}=h\left(M^2+\frac{1}{k}+i\omega\right)$, $\beta_{22}=h\left(Rd_1-i\omega\right)Pr$ and $\beta_{33}=h\left(Rd_3+i\omega\right)Sc$

To study the effect the treatment on LDL-C concentration and temperature with metabolic heat, we solve equation (3.14) and substitute the result into equation (3.13), which is:

$$\phi_0(\chi)=\left(\frac{e^{-i\omega t}}{cosh\left(\sqrt{\beta_{33}}\right)}\right)cosh\left(\sqrt{\beta_{33}}\chi\right) \tag{3.16}$$

To study the effect of treatment and LDL-C concentration on temperature, we substitute equation (3.16) into the energy equation (3.13), which is simplified as:

$$\frac{\partial^2 \theta_0}{\partial \chi^2}+\beta_{22}\theta_0=\beta_{44}cosh\left(\sqrt{\beta_{33}}\chi\right) \tag{3.17}$$

where $\beta_{44}=-\left(\frac{Rd_2he^{-i\omega t}}{cosh\left(\sqrt{\beta_{33}}\right)}\right)$

Solving the non-homogenous differential equation (3.17) using the corresponding boundary condition in equation (3.15), we have:

$$\theta_0(\chi)=B_{22}cos\left(\sqrt{\beta_{22}}\chi\right)+\left(\frac{\beta_{44}}{\left(\beta_{22}+\beta_{33}\right)}\right)cosh\left(\sqrt{\beta_{33}}\chi\right) \tag{3.18}$$

where

$$A_{22}=0,B_{22}=\frac{e^{-i\omega t}}{cos\left(\sqrt{\beta_{22}}\right)}-\left(\frac{\beta_{44}}{\left(\beta_{22}+\beta_{33}\right)}\right)\frac{cosh\left(\sqrt{\beta_{33}}\right)}{cos\left(\sqrt{\beta_{22}}\right)}$$

Solving to obtain the effect of treatment, LDL-C concentration and temperature with metabolic heat on blood velocity, we substitute equations (3.18) and (3.16) into the blood momentum equation (3.12), we have:

$$\frac{\partial^2 w_0}{\partial \chi^2}-\beta_{11}w_0=P_0h-GrhB_{22}cos\left(\sqrt{\beta_{22}}\chi\right)-\beta_{55}cosh\left(\sqrt{\beta_{33}}\chi\right) \tag{3.19}$$

where $\beta_{55}=\left(\left(\frac{\beta_{44}hGr}{\left(\beta_{22}+\beta_{33}\right)}\right)+\left(\frac{Gche^{-i\omega t}}{cosh\left(\sqrt{\beta_{33}}\right)}\right)\right)$

Solving for the blood velocity profile in the non-homogenous equation (3.19) and applying the boundary conditions in equation (3.15), we have:

$$w_0 = B_{33}\cosh\left(\sqrt{\beta_{11}}\chi\right) - \frac{P_0 h}{\beta_{11}} + \left(\frac{GrhB_{22}}{\left(\beta_{11}+\beta_{22}\right)}\right)\cos\left(\sqrt{\beta_{22}}\chi\right) + \left(\frac{\beta_{55}}{\left(\beta_{11}-\beta_{33}\right)}\right)\cosh\left(\sqrt{\beta_{33}}\chi\right) \tag{3.20}$$

where

$$B_{33} = \frac{P_0 h}{\beta_{11}\cosh\left(\sqrt{\beta_{11}}\right)} - \left(\frac{GrhB_{22}}{\left(\beta_{11}+\beta_{22}\right)}\right)\frac{\cos\left(\sqrt{\beta_{22}}\right)}{\cosh\left(\sqrt{\beta_{11}}\right)} + \left(\frac{\beta_{55}}{\left(\beta_{33}-\beta_{11}\right)}\right)\frac{\cosh\left(\sqrt{\beta_{33}}\right)}{\cosh\left(\sqrt{\beta_{11}}\right)}$$

Since the flow is purely oscillatory due to the pumping action of the heart, we substitute equation (3.20) into equation (3.11) and obtain the blood velocity profile with metabolic heat as:

$$w(\chi,t) = \left(B_{33}\cosh\left(\sqrt{\beta_{11}}\chi\right) - \frac{P_0 h}{\beta_{11}} + \left(\frac{GrhB_{22}}{\left(\beta_{11}+\beta_{22}\right)}\right)\cos\left(\sqrt{\beta_{22}}\chi\right) + \left(\frac{\beta_{55}}{\left(\beta_{11}-\beta_{33}\right)}\right)\cosh\left(\sqrt{\beta_{33}}\chi\right)\right)e^{i\omega t} \tag{3.21}$$

In a similar vein, we substitute equation (3.18) into equation (3.11) where we obtain the oscillatory temperature of the fluid with metabolic heat as:

$$\theta(\chi) = \left(B_{22}\cos\left(\sqrt{\beta_{22}}\chi\right) + \left(\frac{\beta_{44}}{\left(\beta_{22}+\beta_{33}\right)}\right)\cosh\left(\sqrt{\beta_{33}}\chi\right)\right)e^{i\omega t} \tag{3.22}$$

In a like manner, we substitute equation (3.16) into equation (3.11) and obtain the LDL-C concentration equation with metabolic heat as:

$$\phi(\chi,t) = \left(\left(\frac{e^{-i\omega t}}{\cosh\left(\sqrt{\beta_{33}}\right)}\right)\cosh\left(\sqrt{\beta_{33}}\chi\right)\right)e^{i\omega t} \tag{3.23}$$

where Q_0 is the dimensional heat source term, Q_1 is the dimensional metabolic radiation term, k_{bT} is the thermal conductivity of the fluid, D_m is the molecular diffusivity, T_∞ is far field temperature of the fluid, D_T is the thermal diffusivity of the fluid, ρ_b is the density of blood, σ_e is electrical conductivity, B_0 is the magnetic induction, k_0 is the chemical reactant, c_{bp} is the specific heat capacity of blood, β_T is the volumetric expansion, β_C is the volumetric expansion due to concentration, μ_b is the dynamic viscosity of blood, φ is the porosity, and k^* is the permeability of the porous medium, Rd_1 is the radiation parameter, Rd_2 is the metabolic heat parameter, Rd_3 is the chemical reaction parameter.

Flow Rate with Metabolic Heat

The volumetric flow rate with metabolic heat is obtained analytically by integrating over the interval using equation (3.21), which is presented as:

$$Q_3 = e^{i\omega t}\int_{\chi=0}^{\chi=1}\left(B_{33}\cosh\left(\sqrt{\beta_{11}}\chi\right) - \frac{P_0 h}{\beta_{11}} + \left(\frac{GrhB_{22}}{\left(\beta_{11}+\beta_{22}\right)}\right)\cos\left(\sqrt{\beta_{22}}\chi\right) + \left(\frac{\beta_{55}}{\left(\beta_{11}-\beta_{33}\right)}\right)\cosh\left(\sqrt{\beta_{33}}\chi\right)\right)d\chi \tag{3.24}$$

Integrating equation (3.24), we have:

$$Q_3 = e^{i\omega t}\left(\frac{B_{33}}{\sqrt{\beta_{11}}}\sinh\left(\sqrt{\beta_{11}}\right) - \frac{P_0 h}{\beta_{11}} + \frac{GrhB_{22}}{\sqrt{\beta_{22}}\left(\beta_{22}+\beta_{11}\right)}\sin\left(\sqrt{\beta_{22}}\right) + \frac{\beta_{55}}{\sqrt{\beta_{33}}\left(\beta_{11}-\beta_{22}\right)}\sinh\left(\sqrt{\beta_{33}}\right)\right) \tag{3.25}$$

Shear Stress with Metabolic Heat

The shear stress rate with metabolic heat is obtained analytically by differentiating blood velocity profile, equation (3.21), which is:

$$Cf_3 = -\left.\frac{\partial w}{\partial \chi}\right|_{\chi=1} = -e^{-i\omega t}\left(B_{33}\sqrt{\beta_{11}}\sinh\left(\sqrt{\beta_{11}}\right) - \left(\frac{\sqrt{\beta_{22}}GrhB_{22}}{\left(\beta_{11}+\beta_{22}\right)}\right)\sin\left(\sqrt{\beta_{22}}\right) + \left(\frac{\beta_{55}\sqrt{\beta_{33}}}{\left(\beta_{11}-\beta_{33}\right)}\right)\sinh\left(\sqrt{\beta_{33}}\right)\right) \tag{3.26}$$

Rate of Heat Transfer with Metabolic Heat (Nusselt Number)

The rate of heat transfer with metabolic heat can be solved analytically by differentiating the temperature profile, equation (3.22), the result is:

$$Nu_3 = -\left.\frac{\partial \theta}{\partial \chi}\right|_{\chi=1} = \left(B_{22}\sqrt{\beta_{22}}\sin\left(\sqrt{\beta_{22}}\chi\right) - \left(\frac{\beta_{44}\sqrt{\beta_{33}}}{\left(\beta_{22}+\beta_{33}\right)}\right)\sinh\left(\sqrt{\beta_{33}}\chi\right)\right)e^{i\omega t} \tag{3.27}$$

LDL-C Mass Transfer with Metabolic Heat (Sherwood Number)

The rate of mass transfer with metabolic heat can be solved analytically by differentiating the LDL-C profile, equation (3.23), the result is:

$$Sh_3 = -\left.\frac{\partial \phi}{\partial \chi}\right|_{\chi=1} = -\left(\left(\frac{\sqrt{\beta_{33}}e^{-i\omega t}}{\cosh\left(\sqrt{\beta_{33}}\right)}\right)\sinh\left(\sqrt{\beta_{33}}\chi\right)\right)e^{i\omega t} \tag{3.28}$$

V. RESULTS AND DISCUSSION

Numerical computation was carried out using Mathematica, version 10.1, to study the effect of treatment parameter and

other pertinent parameters values on blood velocity profile, temperature and LDL-C concentration respectively. The parameters are: the treatment parameter R_T, radiation parameter Rd_1, chemical parameter Rd_3, Grashof number Gr, solutal Grashof number Gc, Hartmann number M, Schmidt number Sc, Soret number S_0, oscillatory frequency ω, pulse rate f, and metabolic heat parameter R_2. The parameters considered are: $0 \le \omega \le 5$, $0 \le Sc \le 10$,

$k_{bT} = 2.2\times10^{-3}$ J/ms °K, $0 \le k \le 1, 0 \le x \le 2$,

$0 \le \delta \le 1$, $c_{bp} = 14.65$J/kg°K, $0 \le M \le 5$,

$\mu_b = 3.2\times10^3$ $Pr = 21, 0 \le R_T \le 2, 0 \le Rd_1 \le 5$. The data were collected from the Chato [27] and Valvano *et al.* [28], also considering the Prandtl number $Pr = 21, 22, 23, 24, 25$, Bunonyo and Amos [20, 21, 22 and 23]. The results are:

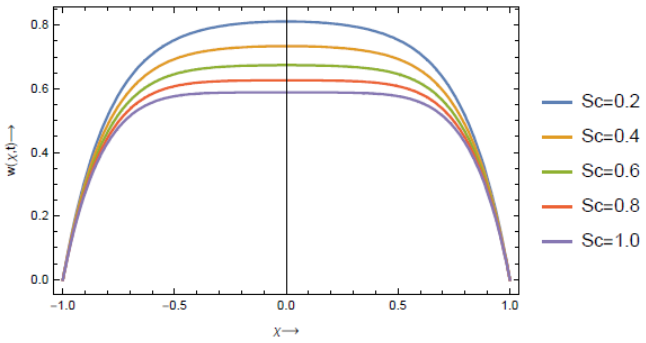

Figure 4.1: Effect of Schmidt number Sc Values on Velocity $w(\chi,t)$

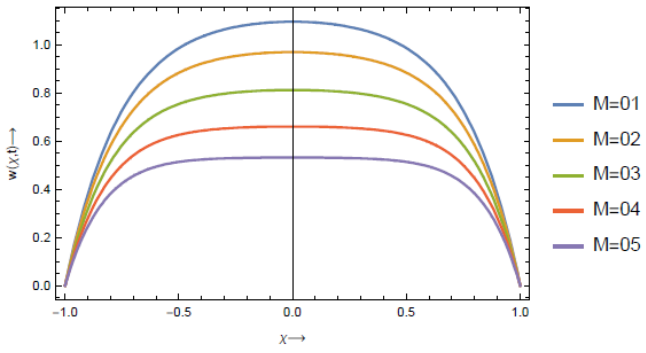

Figure 4.2: Effect of Hartmann number M Values on Velocity $w(\chi,t)$

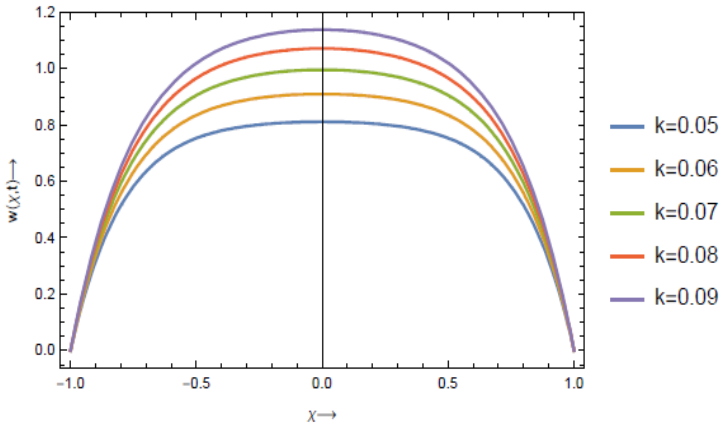

Figure 4.3: Effect of Permeability Parameter k Values on Velocity $w(\chi,t)$

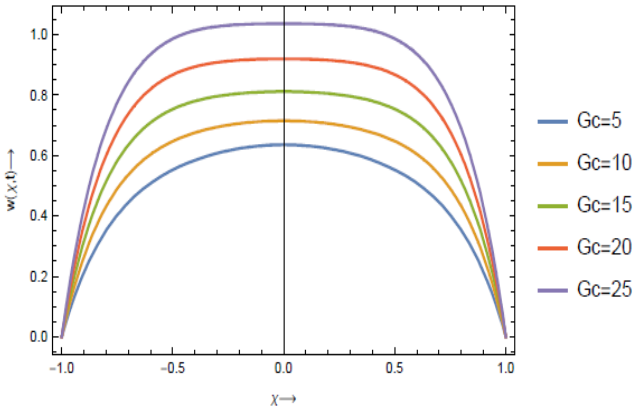

Figure 4.4: Effect of solutal Grashof Parameter Gc Values on Velocity $w(\chi,t)$

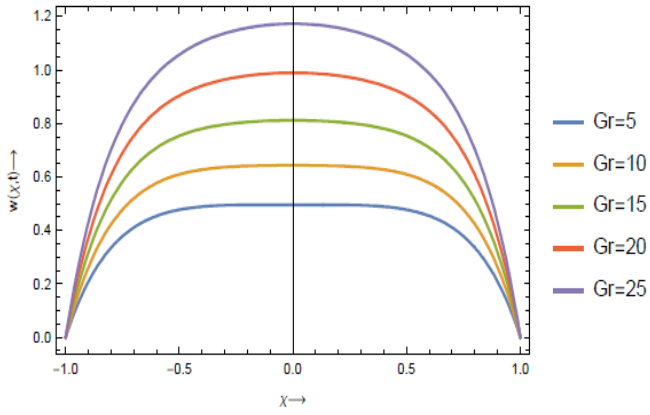

Figure 4.5: Effect of Grashof Parameter Gr Values on Velocity $w(\chi,t)$

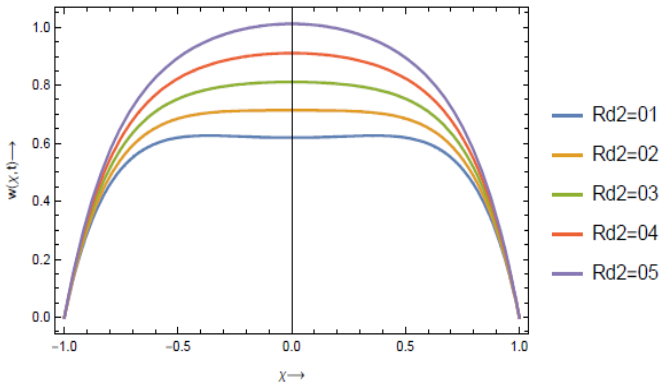

Figure 4.6: Effect of Metabolic Heat Rd_2 Values on Velocity $w(\chi,t)$

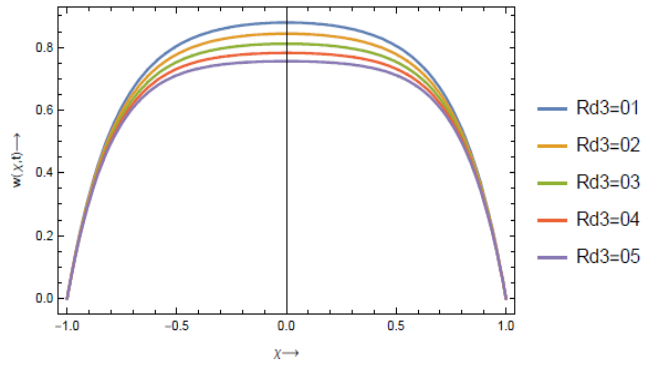

Figure 4.7: Effect of Chemical Parameter Rd_3 Values on Velocity

$w(\chi,t)$

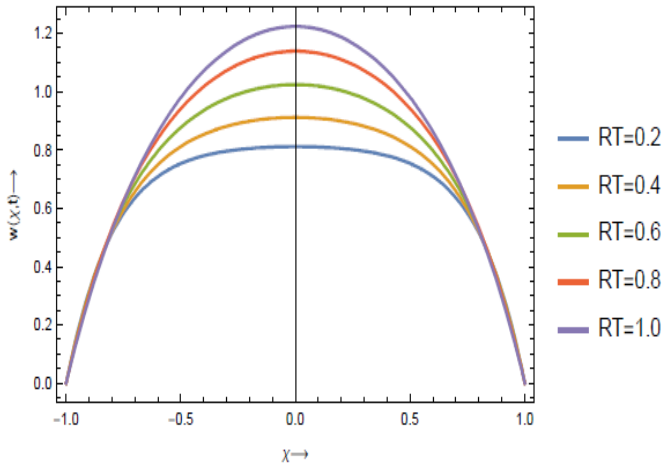

Figure 4.8: Effect of Treatment Values R_T on Velocity $w(\chi,t)$

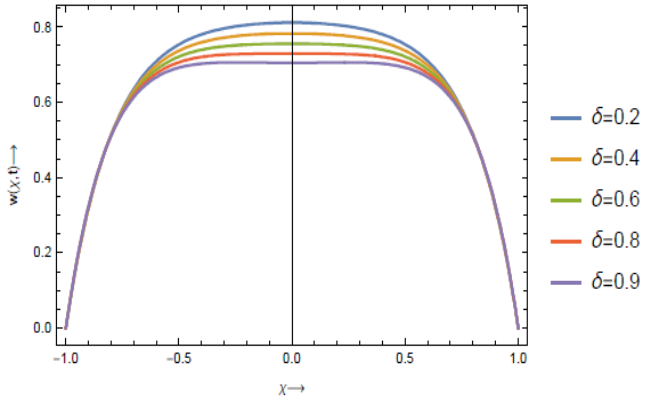

Figure 4.9: Effect of Stenotic Height δ Values on Velocity $w(\chi,t)$

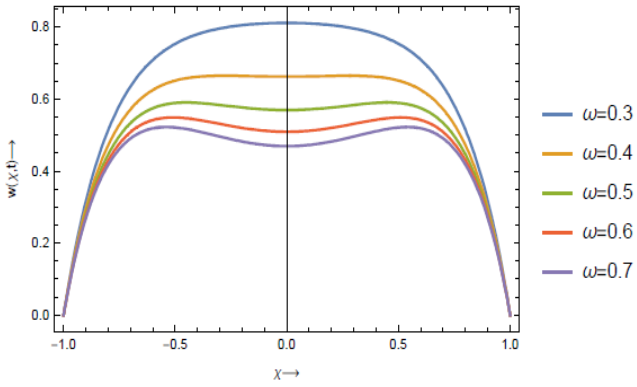

Figure 4.10: Effect of Oscillatory Frequency ω on Velocity $w(\chi,t)$

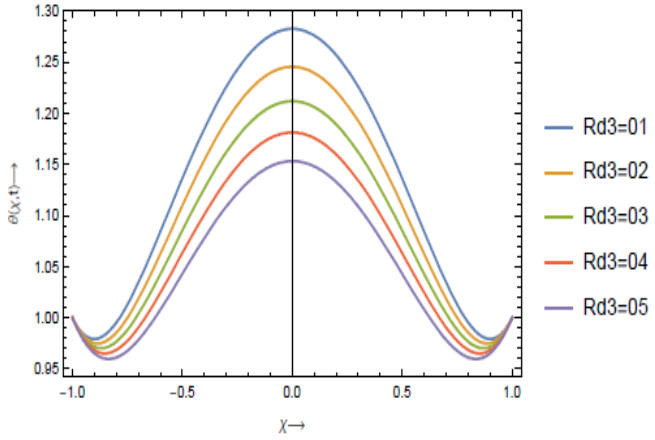

Figure 4.11: Effect of Chemical Reaction Rd_3 Values on Temperature

$\theta(\chi,t)$

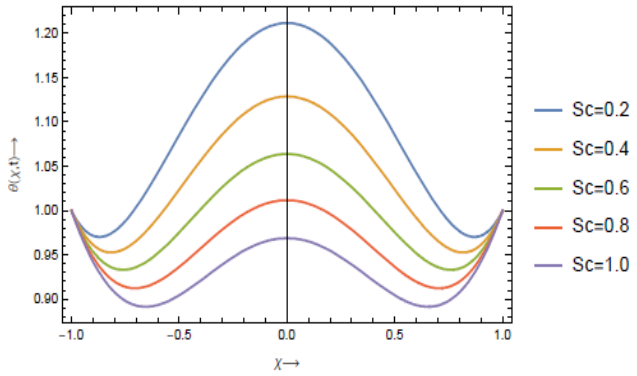

Figure 4.12: Effect of Schmidt number Sc Values on Temperature $\theta(\chi,t)$

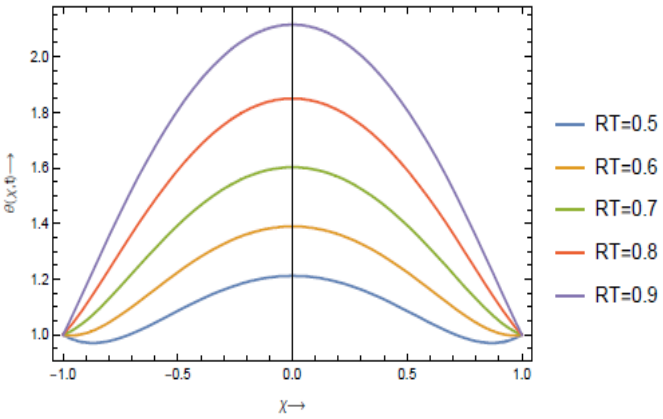

Figure 4.13: Effect of Treatment Parameter R_T Values on Temperature $\theta(\chi,t)$

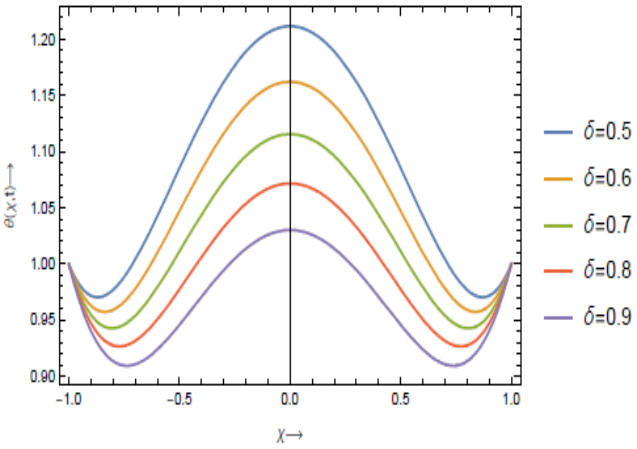

Figure 4.14: Effect of Stenotic Height δ Values on Temperature $\theta(\chi,t)$

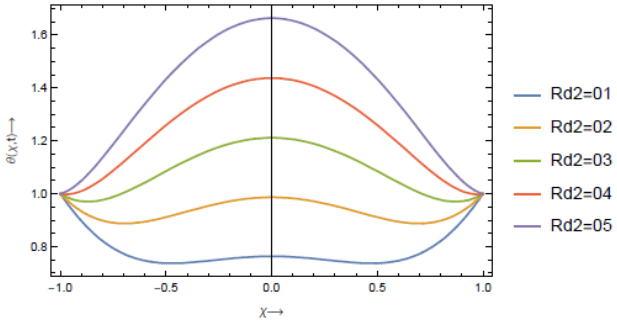

Figure 4.15: Effect of Metabolic Heat Rd_2 Values on Temperature $\theta(\chi,t)$

VI. DISCUSSION/CONCLUSIONS

The biological fluid models were formulated to investigate the treatment effect on LDL-C and atherosclerotic blood flow micro-channel with metabolic heat in this research. The modeled differential equations were solved analytically under some setout boundary conditions where the blood velocity, LDL-C and temperature profiles were obtained independently. Numerical computation was done using Mathematica by varying the pertinent parameters such as: $Rd_2 = 0.5, Gr = 10, Gr = 15, \delta = 0.5, R_T = 0.5, Rd_3 = 03, Sc = 0.5, Pr = 21, k = 0.01, M = 0.3, \omega = 0.2,$ and the following observations were reached:

Figure 4.1: It is observed from the numerical computation that the blood velocity decreases for the increasing values of the Schmidt number $Sc = 0.1, 0.2, 0.3, 0.4, 0.5$

Figure 4.2: The velocity of blood is observed to be creasing for an increasing value of the Hartmann number $M = 0.3, 0.4, 0.5, 0.6, 0.7$. This decrease is as a result of the Lorentz force which inhibits and retards blood velocity flow.

Figure 4.3 clearly depicts an increase in blood velocity through the channel, for an increase in permeability $k = 0.01, 0.02, 0.03, 0.04, 0.05$. This result is of the view that, as the medium gets more porous the velocity passage also increases throughout the channel irrespective of the occlusion. It simply means, the occlusion has some level of porosity. The impact of the solutal Grashof number $Gc = 5, 10, 15, 20, 25$ was also investigated, and it is observed in Figure 4.4 that the velocity increases for an increase in solutal Grashof number. Similar result was also investigated the Grashof number $Gr = 5, 10, 15, 20, 25$, which is the buoyancy parameter and result shown in Figure 4.5. It is noticed that the blood velocity increases for the increase in Grashof number.

In Figure 4.6, it is seen that blood velocity increases, for an increases in the metabolic heat parameter

$Rd_2 = 0.2, 0.4, 0.6, 0.8, 1.0$, this of the obvious conclusion that as increased adenosine hydrolysis increases the blood velocity. The chemical reaction effect on blood velocity was also investigated and result shown using Figure 4.7, this result depicts that the blood velocity profile decreases for the increasing values of the chemical reaction $Rd_3 = 0.3, 0.4, 0.6, 0.8, 1.0$. The study also investigated the effect of the treatment on blood velocity, and found out that blood velocity increases for the increasing values of the treatment $R_T = 0.1, 0.2, 0.3, 0.4, 0.5$ as shown in Figure 4.8. Figure 4.9 is the result for the investigation of increase in height of stenosis $\delta = 0.1, 0.2, 0.3, 0.4, 0.5$ together with other pertinent parameters values. It is noticed in Figure 4.9 that blood velocity decreases for an increase in stenotic height. Blood velocity decreases for an increase in an oscillatory frequency $\omega = \frac{2\pi}{T_c} = 0.1, 0.3, 0.5, 0.7, 0.9$; this in turn means an increase in the period of cardiac cycle as depicted in Figure 4.10. We also investigated the impact of the pertinent parameters on blood temperature and in turn how the temperature increase affects blood velocity. It is seen in Figure 4.11 that blood temperature decreases for an increase in chemical reaction $Rd_3 = 0.2, 0.4, 0.6, 0.8, 1.0$, this is of the view that the chemical reaction negatively affects the temperature and as such it affects circulation. It is also noticed that for an increase in Schmidt number variation $Sc = 0.2, 0.3, 0.4, 0.5, 0.6$ decreases blood temperature, as seen in Figure 4.12. Figure 4.13 depicts an increase in temperature for the increase in the treatment $R_T = 0.1, 0.2, 0.3, 0.4, 0.5$. It simply means an application of treatment with temperature is very effect in treatment hyperlipidemia. Finally, the study showed the role of the increase height of stenosis on temperature. It is seen in Figure 4.14 that the temperature increases for an increase in stenotic height $\delta = 0.1, 0.2, 0.3, 0.4, 0.5$.

REFERENCES

[1]. Giua, L., Blasi, F., Simonetti, M. S., & Cossignani, L. (2013). Oxidative modifications of conjugated and unconjugated linoleic acid during heating. *Food chemistry*, *140*(4), 680-685.

[2]. Xian, T. K., Omar, N. A., & Ying, L. W. (2013). Reheated Palm Oil Consumption and Risk of Atherosclerosis: Evidence at Ultrastructural Level. Evid Based Complement Alterante Med 2012. Publication.

[3]. Ng, C. Y., Leong, X. F., Masbah, N., Adam, S. K., Kamisah, Y., & Jaarin, K. (2014). Heated vegetable oils and cardiovascular disease risk factors. *Vascular pharmacology*, *61*(1), 1-9.

[4]. Baradaran, A., Nasri, H., & Rafieian-Kopaei, M. (2014). Oxidative stress and hypertension: Possibility of hypertension therapy with antioxidants. *Journal of research in medical sciences: the official journal of Isfahan University of Medical Sciences*, *19*(4), 358.

[5]. Hausding, M., Jurk, K., Daub, S., Kröller-Schön, S., Stein, J., Schwenk, M. & Daiber, A. (2013). CD40L contributes to angiotensin II-induced pro-thrombotic state, vascular inflammation, oxidative stress and endothelial dysfunction. *Basic research in cardiology*, *108*(6), 1-16.

[6]. Swirski, F. K., & Nahrendorf, M. (2013). Leukocyte behavior in atherosclerosis, myocardial infarction, and heart failure. *Science*, *339*(6116), 161-166.

[7]. Kock, J. L. F., Pohl, C. H., & Venter, A. (2002). Super-oxidized soups and the health risks to poor South Africans: News an views. *South African journal of science*, *98*(9), 413-414.

[8]. Jaarin, K., Masbah, N., & Nordin, S. H. (2016). Heated cooking oils and its effect on blood pressure and possible mechanism: a review. *Int J Clin Exp Med*, *9*(2), 626-636.

[9]. Venkata, R. P., & Subramanyam, R. (2016). Evaluation of the deleterious health effects of consumption of repeatedly heated vegetable oil. *Toxicology reports*, *3*, 636-643.

[10]. Zhou, Z., Wang, Y., Jiang, Y., Diao, Y., Strappe, P., Prenzler, P., ... & Blanchard, C. (2016). Deep-fried oil consumption in rats impairs glycerolipid metabolism, gut histology and microbiota structure. *Lipids in health and disease*, *15*(1), 1-11.

[11]. Falade, A. O., Oboh, G., & Okoh, A. I. (2017). Potential health lmplications of the consumption of thermally-oxidized cooking oils–a review. *Polish journal of food and nutrition sciences*, *67*(2).

[12]. Kritchevsky, D., & Tepper, S. A. (1967). Cholesterol vehicle in experimental atherosclerosis: Part 9. Comparison of heated corn oil and heated olive oil. *Journal of atherosclerosis research*, *7*(5), 647-651.

[13]. Staprãns, I., Rapp, J. H., Pan, X. M., Hardman, D. A., & Feingold, K. R. (1996). Oxidized lipids in the diet accelerate the development of fatty streaks in cholesterol-fed rabbits. *Arteriosclerosis, Thrombosis, and Vascular Biology*, *16*(4), 533-538.

[14]. Staprans, I., Pan, X. M., Rapp, J. H., & Feingold, K. R. (1998). Oxidized cholesterol in the diet accelerates the development of aortic atherosclerosis in cholesterol-fed rabbits. *Arteriosclerosis, thrombosis, and vascular biology*, *18*(6), 977-983.

[15]. Odia, O. J., Ofori, S., & Maduka, O. (2015). Palm oil and the heart: a review. *World journal of cardiology*, *7*(3), 144.

[16]. Ong, A. S. H. (1994). Nutritional aspects of palm oil: an introductory review. *Asia Pacific J Clin Nutr*, *3*, 201-206.

[17]. Taghvaei, M., & Jafari, S. M. (2015). Application and stability of natural antioxidants in edible oils in order to substitute synthetic additives. *Journal of food science and technology*, *52*(3), 1272-1282.

[18] Bunonyo, K. W., Israel-Cookey, C., & Amos, E. (2017). MHD Oscillatory Flow of Jeffrey Fluid in an Indented Artery with Heat Source. *Asian Research Journal of Mathematics*, 1-13.

[19] Bunonyo, K. W., & Amos, E. (2020). Lipid Concentration Effect on Blood Flow Through an Inclined Arterial Channel with Magnetic Field. *Mathematical Modelling and Applications*, *5*(3), 129.

[20] Bunonyo, K. W., Amos, E., & Goldie, J. B. (2020). Mathematical Modelling of an Atherosclerotic Blood Flow Through Double Stenosed Region with Application of Treatment. *International Journal of Applied Mathematics and Theoretical Physics*, *6*(2), 19.

[21] Bunonyo, K. W., & Eli, I. C. (2020). Mathematical Modeling of an Oscillatory MHD Blood Flow through a Lipid Saturated Porous Channel with Metabolic Heat and Magnetic Field. *Communication in Physical Sciences*, *6*(1).

[22] Bunonyo, K. W., Amos, E., & Eli, I. C. (2018). Unsteady oscillatory couette flow between vertical parallel plates with constant radiative heat flux. *Asian Research Journal of Mathematics*, 1-11.

[23] Amos, E., & Ogulu, A. (2003). Magnetic effect on pulsatile flow in a constricted axis-symmetric tube. *Indian Journal of Pure & Applied Mathematics*, *34*(9), 1315-1326.

[24] Midya, C., Layek, G. C., Gupta, A. S., & Mahapatra, T. R. (2003). Magnetohydrodynamic viscous flow separation in a channel with constrictions. *J. Fluids Eng.*, *125*(6), 952-962.

[25] Misra, J. C., & Adhikary, S. D. (2015). MHD oscillatory channel flow, heat and mass transfer in a physiological fluid in presence of

chemical reaction. *Alexandria Engineering Journal*, *55*(1), 287-297.

[26] Noreen, S., & Qasim, M. (2015). Influence of Hall current and viscous dissipation on pressure driven flow of pseudoplastic fluid with heat generation: a mathematical study. *Plos one*, *10*(6), e0129588.

[27] Chato, J. C. (1980). Heat transfer to blood vessels. *Journal of biomechanical engineering*, *102*(2), 110-118.

[28] Valvano, J. W., Nho, S., & Anderson, G. T. (1994). Analysis of the Weinbaum-Jiji model of blood flow in the Canine Kidney cortex for self-heated thermistors.

Nomenclature

x^*	Dimensional coordinate along the channel
y^*	Dimensional coordinate perpendicular to the channel
R	Radius of an abnormal channel
R_0	Radius of normal channel
R_T	Treatment parameter
d_0	Onset of stenosis
Rd_1	Heat radiation parameter
Rd_2	Metabolic heat parameter
Rd_3	Chemical reaction parameter
k_b	Thermal conductivity of blood
k	Permeability term
w^*	Dimensional blood velocity
w	Dimensionless blood velocity
w_0	Perturbed blood velocity
C	LDL-Concentration of lipoprotein-C
C_w	LDL-Concentration at the wall
C_∞	LDL-Concentration at far field
c_{bp}	The specific heat capacity of blood
t^*	Dimensionless time
T	Blood Temperature
T_∞^*	Far field blood temperature
T_w^*	Temperature at the wall
D_m	Molecular diffusivity of lipoprotein-C concentration
B_0	Magnetic induction

Q_0 Dimensional thermal radiation term

Q_1 Dimensional Metabolic heat term

Greek Symbols

υ Kinematic viscosity of blood

μ_b Dynamic viscosity of blood

Pr Prandtl number for blood

g Acceleration due to gravity

δ^* Height of stenosis

σ_e Electrical conductivity

λ^* Length of stenosis

T_c The periodic cardiac cycle

$\omega = \frac{2\pi}{T_c}$ Oscillatory frequency

ϕ Dimensionless LDL-Concentration

ϕ_0 Perturbed LDL-Concentration

θ Dimensionless Blood Temperature

θ_0 Perturbed Blood Temperature

ρ_b Density of the fluid

Subscripts

w Wall

b Blood

p Pulse