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A Novel Approach for Determination of Red Blood Cells Concentration based on Beer Lambert Law

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ABSTRACT

This paper investigates a novel method for determining the concentration of Red Blood Cells in blood vessels. COMSOL Multiphysics software is used to create the geometric model of blood vessels and their elements. The blood movement is considered a computational fluid dynamics problem, and the movement of Red Blood Cells and other components within the blood vessel is mathematically modelled using the Navier – Stokes equations. The Beer-Lambert Law is then applied to determine the concentration of Red Blood Cells in the blood. The effective wavelength absorption of Red Blood Cells in medium determines this concentration. To demonstrate the effectiveness of the proposed approach, numerical results are obtained using computational Multiphysics software.

Keywords: *Absorption, Beer Lambert Law, Red Blood Cells, Computation Fluid Dynamics, Navier-Stokes Equations, Particle Tracing, Radiative Beam.*

1. INTRODUCTION

The blood is considered as a homogeneous fluid composed by plasma (~55% of blood), red blood cells RBCs known as Erythrocytes (~45% of blood) and white blood cells WBCs known as Leucocyte and Platelets (<1% of blood). The measurement and control of these elements gives us possibility to investigate different diseases and anomalies.

This paper makes the focus on RBC element which is responsible to transport the oxygen to the whole of body cells, for this reason several research is concentrated to measure the RBC concentration in blood and to analyse its deformation.

One of new techniques to measure the concentration of RBC in blood is the absorption of effective wavelength. Beer Lambert law gives a relationship between concentration and intensity of light absorbed by chemical elements.

The purpose of this paper is to introduce a novel approach for determination of RBC concentration in blood. In fact, a computation fluid dynamic model is developed and the movement of RBC cells inside the veins is discussed. Next, the beer lambert law is applied to measure the intensity of light absorbed by these cells and finally, the concentration is deduced.

Last decades, several research on the modelling of movement of RBC cells and their deformation are developed. For example, the analyse of deformation of RBC is determined by a particle method. To measure the concentration of RBC cells metabolite profiling is a particularly important tool as shown in [1]. One other method based on dielectric properties of red blood cells at microwave frequencies is discussed in [2]. Therefore, the RBC cells and plasma are discretized to a set of particles, a time varying electric field is applied to biological medium to determine the concentration of particle in blood. To track the particles movement inside vessels the minimum energy principle is applied. In [3] and [6] two-dimensional particle model for RBC cells was designed to monitor cells deformation during its movement inside capillaries.

In [2] the authors determine the velocity and deformation of RBC in capillaries by using a high-speed camera system and an intravital microscope.

The lattice Boltzmann method is used in [4] and in [10] to derive the LBM-DLM/FD method. This is used to compute the velocity and shape of RBC cells from the

initial conditions. Another technique uses lattice-Boltzmann method based on separation process and trajectories in [5] illustrates the development of multiple RBC flows through a symmetric microvascular bifurcation.

The proposed method is based on the developed patent published in WIPO [8]. The Beer Lambert Law used in this paper is defined in [9].

The rest of the paper is organized as follows: section 2 explains the different steps of the proposed methods used in this work. Section 3 presents the numerical simulation, the geometric model, the computational fluid dynamics, the particles tracing module, and the radiative beam of absorbing blood flow. Section 4 illustrates the results and discussion of proposed method to determine the concentration of RBC in blood. Conclusion and prospects are exposed in sections 5.

2. METHOD

This part of article concerns the method proposed to determine the concentration of RBC in blood. We start by the presentation of geometric model of vein. The blood is assumed as a laminar fluid therefore the computational laminar fluid is added to study the blood fluid characteristics. Next, the application of particle tracing module examines the behavior of RBC cells inside vein. After that, Beer lambert law is applied to measure the absorption of photon beam by the RBC cells through blood flow.

2.1. Geometric model

The vein is designed as a 2D model, composed by a long tube of 140 mm from its end tow small tube branches. The thickness of this vein is just about 8 mm illustrated by the figure 1.

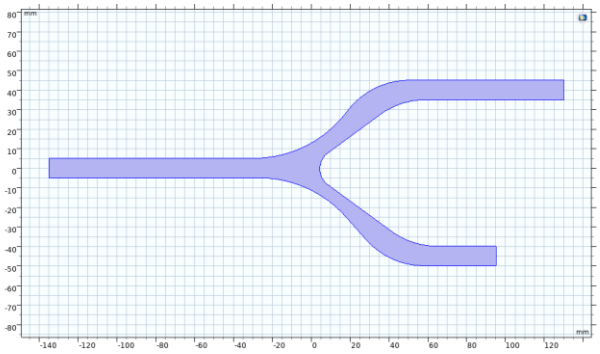

Figure 1: The proposed model of vein.

To compute and study the blood flow we use a finer mesh distribution. The figure 2.a gives the presentation of this mesh, and the figure 2.b demonstrates the mesh details in a critical domain.

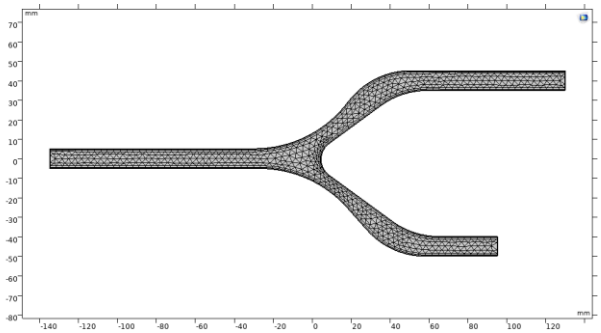

Figure 2.a: The mesh of whole vein.

For this study we consider the blood as a blank material defined by the parameters given by Table 1. The density of blood is $\rho = 1060\, kg/m^3$, its dynamic viscosity is $\mu = 0.004\text{Pa.s}$ and the absorption coefficient is $\kappa = 0.2m^{-1}$.

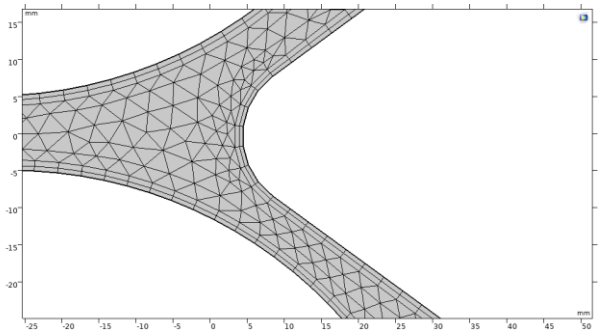

Figure 2.b: The mesh details of a critical domain.

The blood parameters like the density, the dynamic velocity and the absorption coefficient are presented in the Table 1. The blood is considered as a homogeneous fluid when is study for macroscopic fluid and is considered as a heterogeneous fluid composed by particles when is studied for microscopic fluid.

Table 1: The parameters of blood.

Property	Variable	Value	Unit
Density	rho	1060	kg/m^3
Dynamic viscosity	mu	0.004	Pa·s
Absorption coefficient	kappaR	0.2	1/m

2.2. Computational Fluid Dynamic Study

This part of this paper concerns the study of blood flow. In fact, the laminar fluid flow is considered to model the behaviour of blood.

The blood is considered as a Newtonian and incompressible fluid. It is governed by the Navier-stocks equations (1):

$$\rho\frac{\partial u}{\partial t}+\rho(u\cdot\nabla)u=\nabla\cdot[-pI+K]+F$$
$$\rho\nabla\cdot u=0 \quad (1)$$
$$K=\mu\left(\nabla u+(\nabla u)^{T}\right)$$

The initial values of velocity and pressure taken for this study are set to zero.

The start point of blood flow is taken from the inlet with a velocity defined by the equation (2).

$$u=-U_0\cdot n \quad (2)$$

Where U_0 is the cardiac rhythm function.

The end point of blood flow is defined as two outlets defined by the equation (3).

$$[-pI+K]n=-p_0 n \quad (3)$$

where the initial pressure $p_0=13300Pa$.

2.3. Particle Tracing Model Study

In this part we study the particles of blood which composed by 55% of RBCs. First, the particle tracing for blood flow is configured. The particle properties include the equation that governed the movement of particles given in (4).

$$\frac{dq}{dt}=v$$
$$\frac{dd_p}{dt}=\frac{2R}{\pi\rho_p d_p^2} \quad (4)$$

For particles realize and propagation we consider the formulation massless of particles. The outlet is added to this study of particle tracing with velocity $v=v_c$ where v_c is the particle velocity when striking the well. The inlet is realized from grid and the parameters of particles like diameters is fixed to $d_{p,0}=10\mu m$.

2.4. Beer Lambert Law

The Beer Lambert Law indicated that there is a proportionality between RBC concentrations and the attenuation of travelling light through given zone. Consequently, the radiative beam in absorbing media study is set up. This study is governed by the Beer-Lambert law given in Equation (5):

$$A=-\log\frac{I}{I_0}$$
$$A=\kappa\cdot d\cdot C \quad (5)$$

where A is the Absorbance, I_0: the incident intensity of photon beam, I: the transmitted light intensity through tissue, κ: absorption coefficient, d: the length travel by the photon beam and C the concentration of particles to be measured.

To make dependent time study of beam absorption the equation is defined as (6).

$$\frac{e_j}{\|e_j\|}\cdot\nabla I_j=-\kappa I_j \quad (6)$$

e_j here represents the unit vector of incident beam in absorbing media, which is the blood particles inside the vein. The initial value of radiative intensity is fixed to $I_0=8.9W/m^2$.

We define the incident intensity which is characterized by the Gaussian distribution defined in equation (7).

$$f(o,e)=\frac{1}{2\pi\sigma^2}\exp\left(-\frac{d^2}{2\sigma^2}\right)$$
$$d=\frac{\|e\times(x-o)\|}{\|e\|} \quad (7)$$

where the standard deviation of this distribution is fixed to $\sigma=0.7e^{-3}$.

To determine the concentration of RBC in blood flow, we start by sending the radiative beam through the model of vein. The particles tracing allows us to determine its concentration by the mean of Beer Lambert law.

3. NUMERICAL SIMULATION

To examine the improvement of the proposed approach, three studies are performed.

The first study is a dependent time study have as aim to simulate the blood flow velocity and the blood flow pressure.

The second study is a time dependent study and have as objective to simulate the behaviour of particles tracing for blood flow. This study is based on the results of the first study.

The third study concerns the radiative beam of absorbing particles. It is a time dependent study and is dependent to results of first and second studies.

Figure 3 illustrates the blood flow velocity field and show the stress (red colour) in the critical zone of vein.

Figure 4 demonstrates the distribution of blood pressure field inside the vein.

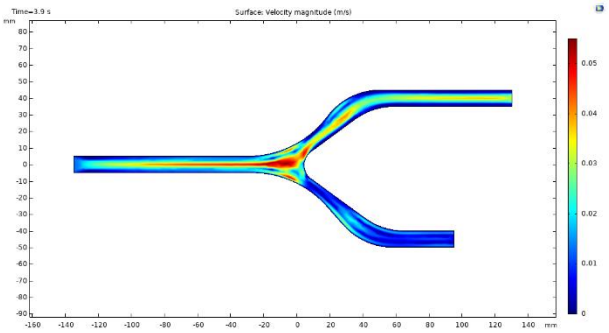

Figure 3. The blood flow velocity field.

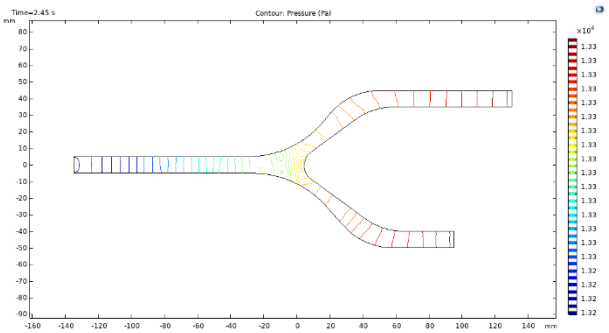

Figure 4. The blood flow pressure field.

Next paragraph presents the results of the proposed approach to determinate the concentration of RBC in blood and give up a discussion of these results. First, the particle tracing of blood flow is exanimated, next, the radiative intensity of absorption beam is applied to the system to determine the intensity of light absorbed by blood particles, and then the bear lambert law is applied to determine the concentration by take the ration between incident beam light and intensity of light in the end of vein.

4. RESULTS AND DISCUSSION

The main result of this paper concerns the examination of beer lambert law to determine the concentration of RBC cells inside the blood flow by the mean of computation fluid dynamic and the particles tracing module.

Figure 5 presents the particles tracing of blood flow.

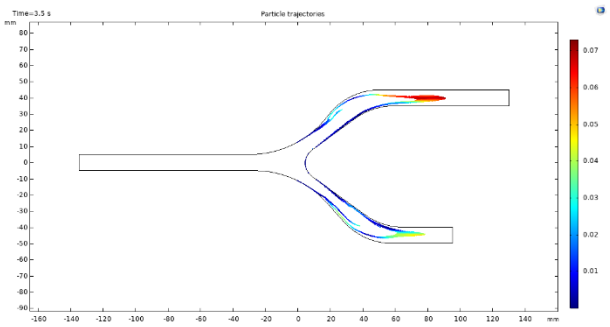

Figure 5. The particle tracing of blood flow.

Considering the velocity of this particles we can determine the flow rate of RBC in blood.

Figure 6 illustrate the intensity absorption by the particles of blood flow through the vein.

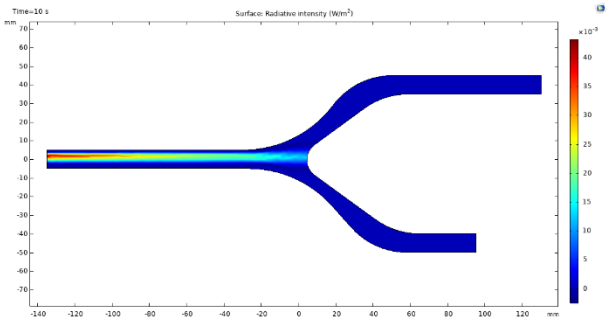

Figure 6. The radiative intensity of absorption beam.

As shown in the figure 6, the intensity is attenuated through the length of branch vein by the particles. To determine the concentration of RBC cells we take two value of intensity the incident one and another value from the x-axis. The ratio between these two intensities gives us the absorption value. Considering the absorption coefficient and the beam length inside the vein, we deduce the value of concentration.

Table 2: Results.

Properties	Value	Description
I0	1 W/m^2	Incident intensity
I	30 mW/m^2	Intensity at point x
A	0.5228	Absorption
K	1.45	Absorption coefficient
d	40 mm	Beam length
C	9 mol/L	Particle concentration

5. CONCLUSION

The proposed approach for determination of RBC concentration in blood is discussed in this paper. Beer Lambert Law is used to determine the absorption of radiative beam by the particles of blood which is in movement and considered as a dynamic fluid.

The main contribution of this paper is the application of Fluid dynamics to model the behaviour of blood flow inside veins and the interaction of RBC cells with the blood flow. In fact, the measure of the velocity and viscosity of RBC in interaction with the photon beam gives the possibility to apply the beer lambert law to determine the concentration of RBC in blood.

In future work, we will design an intelligent sensor based on neural network to detect the intensity absorbed by the RBCs cells in blood vessel and the deep learning will be applied to improve the accuracy of the device designed.

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