A Study to the Blood Flow Model in the Micro-Channels Based on the Video and Image Processing Technology

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Abstract—Micro-fluidic-System plays a great role in the blood processing. The blood flow properties are very difficult to describe with mathematic models because there are a mount of cells in it. The models of blood flow which pass through the micro-channels with varied size and shape must be studied to design the appropriate micro-structure and optimize operation. The laminar flow model and two-phase flow model are compared in this paper. The micro-channels-chip in the experiment system was made of silicon and glass using MEMS technology. The states of blood flow in the micro-channels are observed and recorded with a high speed CCD camera. We adopt the digital video and image processing technology to analyze those image data obtained from the experiment. In contrast to the theoretical model, the experiment results showed that the two-phase flow model of the blood in the micro-channels is much more exact than the laminar flow. This result will be helpful to the structural design of the micro-fluidic system aiming to blood process.

Keywords: image processing; blood cell; two-phase model; velocity

I. INTRODUCTION

Micro-fluidic-System manufactured in MEMS technology has been more and more popular for the blood processing in vitro now[1-2]. In order to design the appropriate micro-structure, the blood which flows in the micro-channels with varied size and shape must be studied. A good micro blood flow mathematical model can be a theoretical guide to the structural optimization design and robust control of the micro-fluidic-system. In many cases the blood is treated as the Newtonian fluid[3]. It is obviously too rough to the blood flow in the micro-channels. It is well known that the blood is a kind of mixed-liquid containing a variety of cells, and the red blood cell (RBC) will deform as the blood flow across the micro-channels. So the blood flow shows more complicated fluid characteristics in the micro-structure. There is not an identical model suited to the micro blood flow so far [4]. We are now researching and developing a new micro device for the blood cells separation. In the studying period we observed and recorded the states of blood flowing through the micro-channels. Adopting the digital video and image processing technology to analyze those image data, we find that the two-phase flow model of the blood in the micro-channels is much more exact than the laminar flow.

II. EXPERIMENT APPARATUS

Particle Image Velocimetry (PIV) technology has become a powerful tool which can obtain many internal flow field properties such as instantaneous velocity and related movement properties[5]. We use the method of PIV for references to study the blood flow in micro-channel without adding the tracer particles into the flow. From the videos and images which have recorded the blood flow in micro-channel, the red blood cells in blood were focused as tracer particles. The experiment microchip was made of glass and silicon wafer using standard photolithography, ICP etching and anode bonding to format the micro-channels[6]. Figure 1 shows the SEM images of the etched channel with the height 25μm. The channels were etched in a silicon wafer (400μm thick).

In order to inject the blood into the microchip stably, a syringe pump was used to perfuse blood through the micro-channels at various flow rate. In the experiment, the fresh whole blood was obtained from healthy adult and was anticoagulated with heparin. Then the diluted blood sample was injected into the micro-channel with flow rate of 1μl/min and a high speed CCD camera was operated to record flow images when the blood flow in the micro-channel steadily. Figure 2 shows the flow image of the 20μm and 30μm channel.
III. Blood Flow Models in Micro-Channels

1. Blood micro-channels laminar flow model

Assuming that the blood flow in the micro-channels with the length $L$ and the height $h$, the flow state of the blood is unsteady laminar[7]. The pressure difference between import and export is $\Delta p$. The velocity of the blood is $\mu$ and the viscosity of the blood is $\eta$ where the distance from the origin is $y$. In the micro channels the velocity of the blood can be defined as $\mu$:

$$\mu = \frac{\Delta p}{2\eta L} \left( \frac{h^2}{4} - y^2 \right) \quad (1)$$

Through this expression, the velocity distribution curve of the blood flow in micro-channels should be a parabola shape.

2. Blood micro-channels solid-liquid two-phase flow model

According to the fluid dynamics equations, regarding the red blood cell as the solid phase and the plasma as the liquid phase, we model the blood as solid-liquid two-phase flow[8]. We can calculate the theoretical speed and obtain the motion trajectory of the red blood cell through the two-phase flow model.

The equation of the red blood cell under the force is defined by:

$$\frac{du_p}{dt} = F_D (u - u_p) + g \left( \frac{\rho_f - \rho}{\rho} \right) + F_s \quad (2)$$

In the upper equation, $u$ is the velocity of the fluid and $u_p$ is the velocity of the particle, $\rho$ stands for the density of the fluid and $\rho_p$ stands for the density of the particle, $F_D (u - u_p)$ is a Stokes drag of the particle, $F_D$ is defined as:

$$F_D = \frac{18\mu C_D R_e}{\rho_p d_p^2 24} \quad (3)$$

In which $\mu$ is the viscosity of the blood, $d_p$ is the diameter of the particle, $R_e$ is the relative Reynolds number, $C_D$ is the drag coefficient. $R_e$ is defined by:

$$R_e = \frac{\rho_d |u - u_p|}{u} \quad (4)$$

To the spherical particle, $C_D$ is defined as:

$$C_D = \frac{24}{R_e} (1 + b_1 R_e^{0.8} + \frac{b_2 R_e}{b_3 + R_e}) \quad (5)$$

Where

$$b_1 = e^{(2.3288 - 6.541\phi + 2.4486\phi^2)}$$

$$b_2 = 0.0964 + 0.5565\phi$$

$$b_3 = e^{(4.905 - 13.8944\phi + 18.4222\phi^2 - 10.2599\phi^3)}$$

$$b_4 = e^{(0.4681 - 12.2584\phi - 20.7322\phi^2 + 15.8855\phi^3)}$$

[9], and $\phi$ represents the particle shape factor and defined as $\phi = \frac{s}{S}$, in which $s$ is the surface area of the spherical particle which size is equal to the actual particle size and $S$ is the surface area of the actual particle.
In (2), to the red blood cells, the effects of gravity and other forces to the red blood cells are considered, in which one of the most important is the additional force $F_x$ when the red blood cell accelerates, $F_x$ is defined by

$$F_x = \frac{1}{2} \rho \frac{d}{dt} \left( \mu - \mu_p \right).$$

So, the velocity relation curves between the blood and the red blood cell can be gained from (2), and the trajectory of the red blood cells can be calculated.

**IV. RESULTS AND DISCUSSION**

One of the micro-channel showed in Figure 1 has been chosen to study the blood flow properties adopting the image processing technology. Figure 3 describes the identification processing procedure aiming to the red blood cells of the blood flow image. Firstly it is inevitable to enhance the interested image details with subtracting the background, denoising and adjusting contract. Then the image was converted to black and white in order to determinate the cells edge with the Canny arithmetic operator. The mathematical morphology expansion and corrosion arithmetics were adopted to dilate the image, fill interior gaps, remove connected region on border and small region, and smoothen the cells edge to make it look natural[10]. So the cells edge in whole image is fully detected.

Then, the template matching method was adopted for pattern recognition of RBC and two red blood cells were chosen as tracer particles to study the blood flow. The cells match processing is very complicated because the red blood cell in the movement will deform and roll. We introduced artificial cognition method to resolve this problem.

Figure 4 shows two chosen RBC positions in the serial of images, whose interval is 1 second. Calibrated with actual size of RBC (the diameter is 8μm), the actual displacement of RBC in adjacency image can be obtained and the RBC velocity can be calculated.

$$v = 41.35 \mu m/s, \quad v_{\text{max}} = 41.65 \mu m/s, \quad v_{\text{min}} = 39.12 \mu m/s.$$
The theoretical velocity of the red blood cells is calculated from (2) and shown in the Figure 6. The initial velocity of the blood is defined as $v_m = 41.35 \mu m/s$ which is the average velocity from the experiment data. The velocity of the red blood cell in the micro-channels changes, $v_{\text{max}} = 42.41 \mu m/s$ and $v_{\text{min}} = 40.42 \mu m/s$. Through the blood solid-liquid two-phase flow model, the velocities of RBC are significantly different from the blood flow initial velocity. The calculated velocity is close to the experiment result showed in Figure 5 and Table 1. Compared with the experiment data, the percentage error of $v_{\text{max}}$ and $v_{\text{min}}$ is 1.8%, 3.3%.

![Image](image.png)

**Figure 6.** The velocity of the red blood cell for the two-phase model

In the experiment, as the depth and thickness of the rectangular micro-channels is so small that the thickness of the plasma increases and the red blood cells deform more apparently. Due to the interaction between plasma and red blood cells, the viscosity of the blood, the shear stress and shear rate all change. The velocity of the red blood cell is not constant, and changes apparently. The velocities of the red blood cells are different from the blood flow. The flow state of the blood in the micro-channels is not laminar apparently, but almost the two-phase flow. So it is more exact to model the blood flow in the micro-channels with solid-liquid two-phase flow.

### V. CONCLUSION

As the complex deformation and rolling of red blood cells in the blood flow, it is difficult to model the blood flow through the micro-channels. In this paper, we have compared two kind of models (laminar and the solid-liquid two-phase model) and applied the image processing to measure the velocity field of the blood in the micro-fluidic-system. The experiment results show that the flow state of the blood in the micro-channels is not laminar and it is more exact with two-phase flow model to describe. It is a useful reference for the structural design in the micro-fluidic system aiming to blood process.

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### VII. REFERENCE


