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A study for measurements of human blood viscosity using sound attenuation in micro-channels

Young-taek Cha[1)], Sung-joon Choi[1)], Hong-seok Jang[1)], Hong-seok Lee[1)], Dae-young Shin[1)]

[1]*Korea Institute of Industrial Technology*

chayt3@kitech.re.kr

Abstract
A recently proposed micro-viscometer measures the viscosity of fluids inside micro-channels using sound-wave attenuation. This micro-viscometer has the advantages of portability and real-time measurements owing to its micron-order size and small quantity of object fluid. Because of these advantages, the device can be applied for the pre-diagnosis of several diseases, such as anaemia and plethora, which use blood viscosity as an indicator. However, this micro-viscometer has been modelled for homogeneous fluids, like water, and the sound attenuation effects caused by particles in the fluid, like red blood cells, have not been considered. Whole human blood consists of plasma and red blood cells and its total viscosity and attenuation characteristics are influenced by plasma viscosity and the number of red blood cells per unit volume. Therefore, the micro-viscometer must be redesigned for viscosity measurements of human blood and an appropriate attenuation coefficient must be considered in the design process. In this study, a new design of the micro-viscometer is proposed, for which the attenuation coefficient for human blood in micro-channels was obtained. The new design parameters were deducted and analysed with finite element analysis. Finally, the new-type micro-viscometer was fabricated and the feasibility of human blood viscosity measurements was verified by experimental results.

Key words: Micro-viscometer, Sound attenuation, viscosity, Micro-channels

1. Introduction

The micro-viscometer is a recently proposed device [1] that measures the viscosity of a fluid using sound-wave attenuation. This device has the advantages of portability and real-time measurement owing to its micron-order size and usage of very small quantities (13 nl) of object fluids. Because of these, the application of the micro-viscometer for viscosity measurements of human blood could lead to its implementation in pre-diagnosis kits for several diseases, like anaemia and plethora, which use blood viscosity as an indicator.

However, the micro-viscometer was modelled for homogeneous fluids [1], and the acoustic attenuation of whole blood was modelled according to the Zinin model [2] without considering boundaries, like the channel's inner walls. Therefore, a new model is required for its application to viscosity measurements of whole blood (non-homogeneous fluid), which consists of red blood cells and plasma. The model should describe the sound attenuation effects for red blood cells and plasma inside the micro-channels.

In this study, such a new sound attenuation model is proposed and analysed with finite elements analysis (FEA). A new micro-viscometer was fabricated using the results of the FEA, and experiments were conducted using whole human blood. The experimental results verified that viscosity measurements of whole human blood are possible using sound-wave attenuation in micro-channels.

2. The sound wave attenuation modelling

2.1. Measurements concept

The principle of the viscosity measurements is explained in Figure 1. An electrical signal is applied to the piezoelectric layer of the driving part, which then creates a sound wave in Chamber 1. This sound wave is attenuated when passing through the micro-channel. At the sensing part, the attenuated sound wave is detected and the generated electrical signals are used to estimate the viscosity of the fluid.

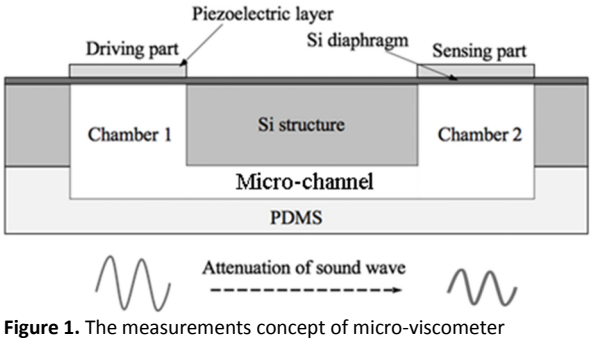

Figure 1. The measurements concept of micro-viscometer

The attenuation occurs because the attenuation coefficient of the sound wave is proportional to the viscosity of the fluid. As shown in equation (1), the coefficient is inversely proportional to the radius of the micro-channel.

$$\alpha \propto \frac{1}{r}\left(\frac{2\pi\eta f}{2\rho_o}\right) \quad (1)$$

where α is the attenuation coefficient, η is the viscosity of the fluid, f is the driving frequency, r is the equivalent radius of the micro-channel, and ρ_o is the density of the fluid.

2.2. Sound wave attenuation model for whole blood

As shown in Figure 2, the causes of sound attenuation for whole blood within a micro-channel are as follows [2]: drag losses between the whole blood and the inner wall of the channel ($\alpha_{w\eta}$) and between the plasma and the inner wall due to the viscosity of the red blood cells (α_{η}); losses due to the absorption of sound waves in the plasma between the red blood cells (α_{ς}); scattering losses by the surfaces of the red blood cells (α_{s}); heat transfer loss caused by the temperature difference between the red blood cells and the plasma (α_{T}) and between the whole blood and the channel inner wall (α_{wT}). The attenuation coefficient for whole blood is given by the sum of equation (2).

$$\alpha = \alpha_{w\eta} + \alpha_{wT} + \alpha_{s} + \alpha_{\eta} + \alpha_{\varsigma} \tag{2}$$

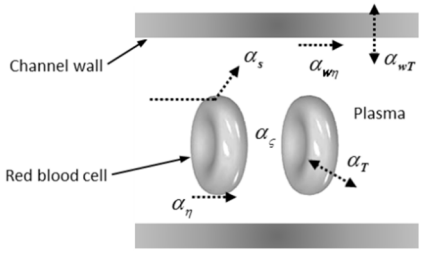

Figure 2. Finite element analysis model of the micro-viscometer; the displayed parameters are described in Table 1

3. The design of micro-viscometer

The previously derived sound attenuation coefficient, α is applied to FEA as seen in Figure 3. The input sound acceleration of driving part is 10m/s, and applied design parameters as shown in Table 1. The results of FEA is same as Figure 4, and acoustic pressures are evaluated according to driving frequencies.

It is observed that the peak pressures at the resonance frequency of sensing and driving part are varied by viscosity changes. Through these result, measurements of viscosity for whole blood is possible in the micro-channel.

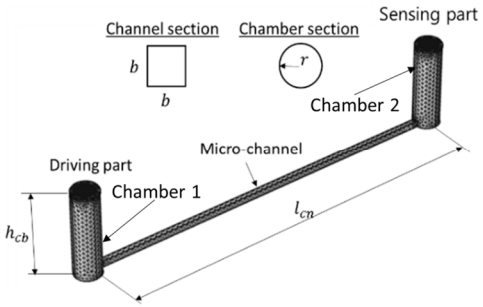

Figure 3. Finite element model of micro-viscometer

Table 1 The applied design parameters

Design variables	Values
Radius of chambers(r)	95 μm
Height of chambers($\boldsymbol{h_{cb}}$)	430 μm
Width and depth of channel(b x b)	30 μm × 30 μm
Length of channel($\boldsymbol{l_{cn}}$)	2 150 μm

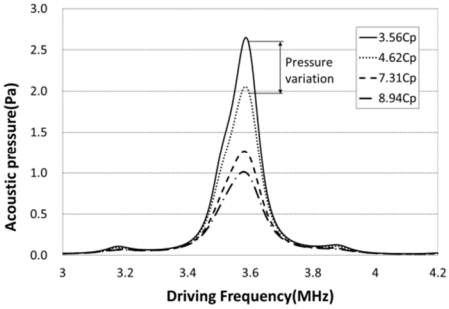

Figure 4. Finite element analysis results for the sound attenuation in whole blood in the micro-viscometer for different viscosities

4. Experimental results

The micro-viscometer was fabricated using the design variables obtained from the FEA (Table 1). Whole blood was injected into the micro-viscometer, and the viscosity variations were observed with the change of temperature, as shown in Figure 5. The reason why temperature change is used for experiments is due to difficulties in obtaining whole blood with different viscosity. The quantities V_{in} and V_{out} denote the input and output voltages measured at the driving and sensing parts, respectively. These findings are consistent with the results of the FEA. The different driving resonance frequency compared with that of the FEA results was caused by the different channel dimensions due to errors in the production process. The peak gain for each temperature varies, which means that the variation of viscosity with temperature was measured. Therefore, the feasibility of viscosity measurements for whole blood was confirmed by the experimental results.

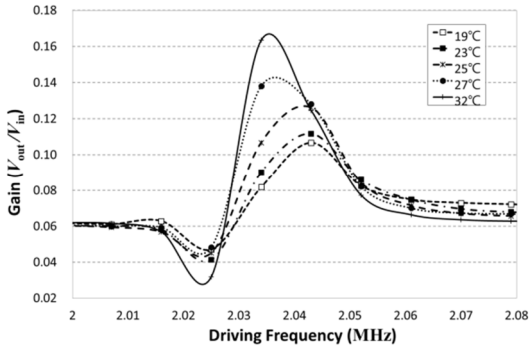

Figure 5. Experimental results

5. Conclusions

In this study, a new method is proposed and examined regarding viscosity measurements of whole blood using sound attenuation with a micro-viscometer. The sound attenuation for whole human blood inside a micro-channel was modelled, the design variables for a new micro-viscometer were deducted, and the device was fabricated and tested. The experimental results obtained with the manufactured micro-viscometer verified that whole blood viscosity measurements using the proposed method are possible. Therefore, the proposed micro-viscometer can be implemented for the diagnosis of diseases like anaemia and plethora.

References

[1] Sungjoon Choi Wonkyu Moon Geungbae Lim 2010 A micro-machined viscosity-variation monitoring device using propagation of acoustic waves in microchannels, *Journal of micromechanics and microengineeing*, **20(8)** 1-13

[2] Zinin P V 1992 Theoretical analysis of sound attenuation mechanics in blood and in erythrocyte suspensions *Ultrasonics,* **30** 26-34