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High Sensitive Detection of Red Blood Cell Aggregation with Ultrasonic Peak Frequency

超音波スペクトルピーク周波数による赤血球凝集サイズの高感度検出

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1. Introduction

It is known that blood viscosity has a close relationship with diabetes and circulatory system disease. A standard testing device of the blood viscosity, named as MC-FAN, can be utilized with a collecting blood using a syringe needle, involving an injecton pain and a high cost. Improvements of the drawbacks would permit a frequent measurement of the blood viscosity, which was regarded as an index with circadian variation.

Based on the facts that the blood viscosity highly correlates with a degree of phenomenon of red blood cell (RBC) aggregation and the aggregation size is reflected in ultrasonic scattering spectrum, several trials have been conducted on the ultrasonic estimation of the diameter of aggregation[1)].

The reflection coefficient between the RBC and the serum is very small, because the both of them have similar acoustic impedances. Thus, a high sensitivity measurement, which can aquire the reflection signals from each single RBC, is desired to estimate the aggregation size distribution. And due to a wide distribution from the single RBC to large aggregation consisted of hundreds of RBCs[2)], it is impossible to include enough samples of the aggregations by using an ultrasonic transducer with a small focal diameter, therefore, the extracted samples are considered to be biased.

In this study, in order to resolve these problems, a high sensitivity detection method, in which the aggregation size is estimated from the peak frequency of the reflection spectrum aquired with a non-focus transducer ,is proposed.

2. Method

The estimation method proposed in this study is based on two assumptions as follows: (1) The aggregation consisted of many RBCs can be substituted by a single large partigle with the equivalent diameter. Thus, the concept of effective particle size, which is the basis of the laser diffraction method, is adopted. (2) Due to the Rayleigh scattering spectrum is varied with the size of the substituted large particle, the reflected wave is affected by the particle size. This concepts are drawn in Fig. 1. Each curve in Fig. 1 are the entire spectrum of the reflected wave with the same peak

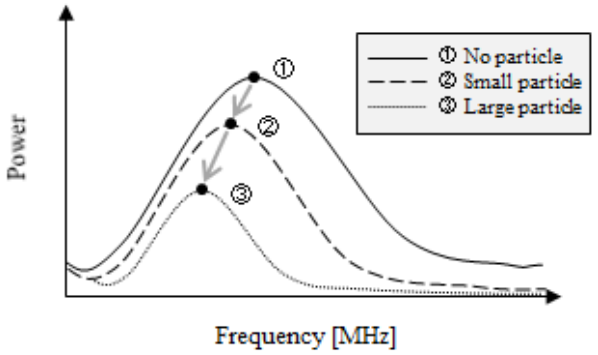

Fig. 1 A concept diagram of Peak Frequency Shift.

as the center frequency of the transducer (①), the attenuated spectrum scattered by small particle (②), and the attenuated spectrum scattered by large particle (③), respectively.

Rayleigh scattering is observed, when the following α has the condition of α << 1:

$$\alpha = \frac{\pi D}{\lambda} \qquad (1)$$

where α is a size parameter, D is the diameter of the particle, and l is the wavelength.

The larger the particle size is, the scattering intensity in the lower frrequency increases. Thus, a larger attenuation in the lower band in ③ is observed, as compared with ②. As the result, the peak of the spectrum is shifted to the lower frequency, as the particle size increases.

The peak frequency can be obtained not only from the reflected wave but also from the transmitted wave. However, aquiring the reflection spectrum, which accompanies a round trip of the incident wave inside the suspension, can generate an emphasizing effect of the attenuation character-istics.

This study aims to realize a high sensitivity detection , the reflection spectrum is investigated.

3. Results

3.1 Particle size estimation of monodisperse suspension with peak frequency

Monodisperse suspension was prepared by dispersing 2 wt% graphite powder in deionized

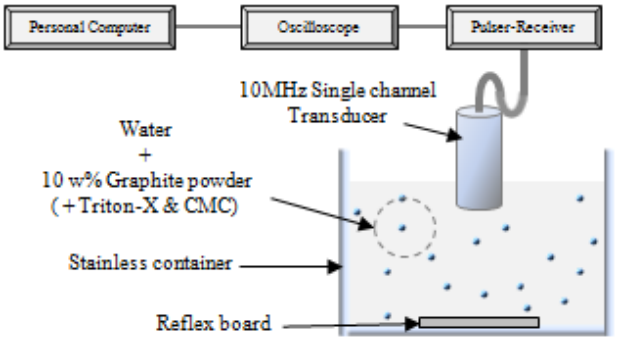

Fig. 2 Experimental setup of peak frequency detection in stagnant suspension.

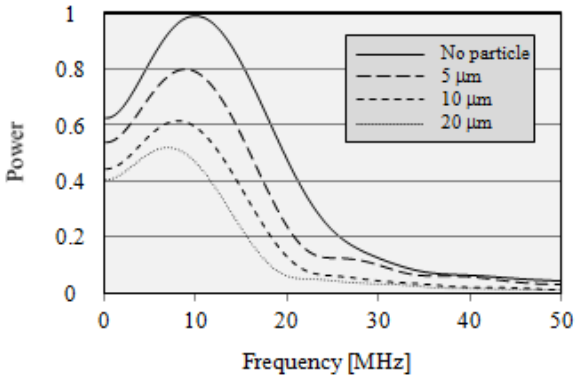

Fig. 3 Peak frequency shift of reflected spectra in 10 wt% suspension

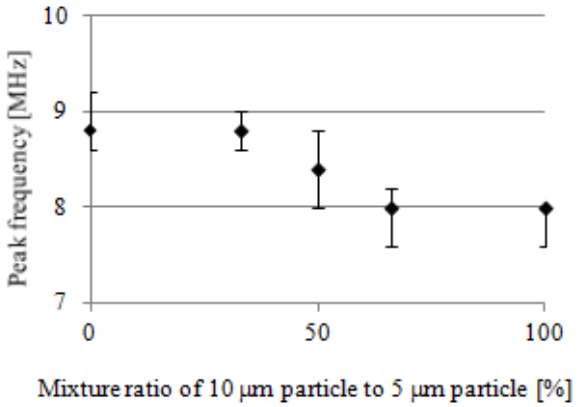

Fig. 4 Changes in peak frequency of reflected spectra in bidisperse suspension.

water. To prevent a sedimentation and a formation, a suitable amount of a thickener (carboxymethyl-cellulose) and a nonionic surfactant (Triton-X) were added to the suspension. Then, the suspension was degased and gently filled in a stainless container, and a reflection board was placed on the bottom of the container, as shown in Fig. 2. The diameters of the sample powders were 5, 10, and 20 μm. A broadband transducer with the center frequency of 10 MHz was immersed in the suspension, and the aquired signal was analyzed by Fast Fourier Transform (FFT).

The reflected spectra were shown in Fig. 3. According to the increase of the particle size, the peak shifts from the center frequency to the lower frequency were observed, and the relationship between the particle size d [m] and the peak frequency f_p [MHz] was expressed as $f_p = -3.14\log_{10}d - 7.79$. This relationship was maintained in the case of acryl powder instead of the graphite powder. Therefore, it was demonstrated that the particle size could be estimated from the peak frequency of the reflected spectrum under the certain concentration independently of the material of the particle.

3.2 Peak frequency shift of reflected spectra in bidisperse suspension

It is possible that a wide distribution of the aggregation sizes of RBC exists in a blood of highly advanced diabetes. In order to prove an effectiveness of this estimation technique to a various distribution of the aggregation, experiments with bidisperse suspension were conducted.

The both of 5 μm and 10 μm particle sample had a common overlapped region in the particle size distribution. The peak frequency of reflected spectrum obtained by varying the mixture ratio between the two samples from 0 to 100 % was shown in Fig. 4. A decline of the peak frequency caused by the increase of the mixture ratio of 10 μm was observed. Thus, the possibility of high sensitivity detection was demonstrated.

4. References

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