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# Estimation of Particle Aggregation Degree in High Concentration Suspension with Ultrasonic Peak Frequency Shift

超音波ピーク周波数シフトを用いた高濃度懸濁液中の粒子凝集度推定

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## 1. Introduction

We researched the relationship between the aggregation size and peak frequency of the reflection spectrum by using blood mimicking suspensions with low concentrations of acryl particles with the aim of establishing an ultrasonic method for estimating blood viscosity, which is strongly correlated with the aggregation degree of red blood cells (RBCs). However, blood is regarded as a thick suspension, i.e. 40%, of RBCs, and estimating particle dispersion and aggregation in a high concentration suspension has been a difficult problem in the whole engineering field.

## 2. Principles

On the basis of the relationship between the diameter of an RBC and the center wavelength of medical ultrasonic transducers of several MHz, the main factor of the ultrasonic attenuation in human blood is described by the following equation.

$$\mathbf{k_s} = \frac{2\pi^5}{3}\mathbf{n}\left(\frac{\mathbf{m}^2-1}{\mathbf{m}^2+2}\right)\frac{\mathbf{d}^6}{\lambda^4} ,$$

, where $k_s$ is the scattering coefficient, $n$ is the number of particles, $m$ is the reflection coefficient, $d$ is the particle diameter, and $\lambda$ is the wavelength.

By subtracting the Rayleigh scattering from the transmission spectrum of a transducer, the peak frequency is shifted to the lower side with the increase in particle diameter (Fig. 1).

## 3. Materials and Methods

We prepared monodisperse suspensions with various diameters of acryl powders namely, 6, 15, 32, 46, and 110 µm, and aggregation suspensions consisting of the 6-µm acryl powder with several aggregation degrees controlled by adding coagulant (Aronfloc C510, MT Aqua Plymer Inc.). Two particle concentrations of these suspensions, 5% and 40%, were prepared. To prevent sedimentation and formation of aggregation, suitable amounts of a thickener (carboxymethyl cellulose) were added to the suspensions. The experimental setup used in this study is shown in Fig. 2. Reflection waves acquired by an ultrasonic transducer with a center frequency of 20 MHz were sampled in an oscilloscope. A reflection spectrum could be obtained by conducting a fast Fourier transform (FFT) on the sampled data.

## 4. Results and Discussion

### 4.1 Low-concentration measurement

Changes in the aggregation diameter of the acryl powder with the coagulant concentration were

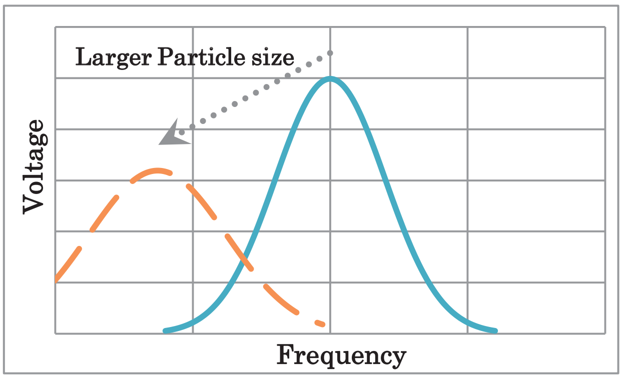


Fig. 1 Peak frequency shift caused by Rayleigh scattering

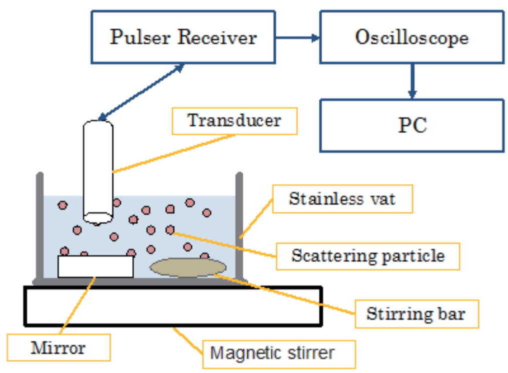


Fig. 2 Experimental setup for detecting peak frequency in a particle suspension

measured in both optical and acoustic ways, i.e., with a microscope and an ultrasonic particle size analyzer (DT-1200, Dispersion Technology). The relationships between the results obtained with these different ways are drawn in Fig. 3. Through these experiments, the ability to control the aggregation diameter with the coagulant concentration was found.

The reflection spectra of the suspensions with the various particles and aggregations were acquired, and the peak frequencies of each suspension were plotted against the particle or aggregation diameter in Fig. 4.

### 4.2 High-concentration measurement

The aggregation degree of acryl particles in thick suspensions was increased along with an increase in coagulant concentration; however, quantitative measurement has been considered to be a difficult problem. In this study, the effect of the coagulant in thin suspensions was confirmed as the first step. As shown by the results mentioned above, a quantitative relationship between the particle diameter dispersed in the suspension and the reflection spectral peak was found, as drawn in Fig. 5.

## 5. Conclusion

Using low concentration suspensions, the aggregation degree and the reflection spectrum were confirmed to be controlled by the concentration of the coagulant. In addition, the same controllability was also confirmed with high concentration suspensions. Through these results, the possibility that the aggregation diameter in a thick suspension such as human blood can be estimated with an ultrasonic spectral peak frequency was demonstrated. Future work would be to construct a system capable of estimating the aggregation degree of RBCs in actual human blood in extracorporeal circulation and so on.

## 6. References


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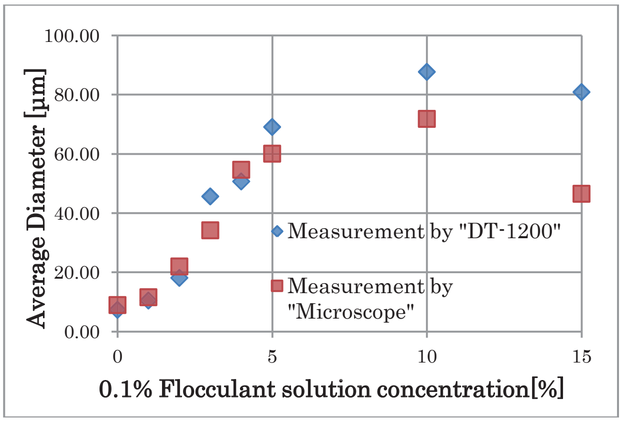


Fig. 3 Changes in aggregation diameter of acryl particles with coagulant concentration

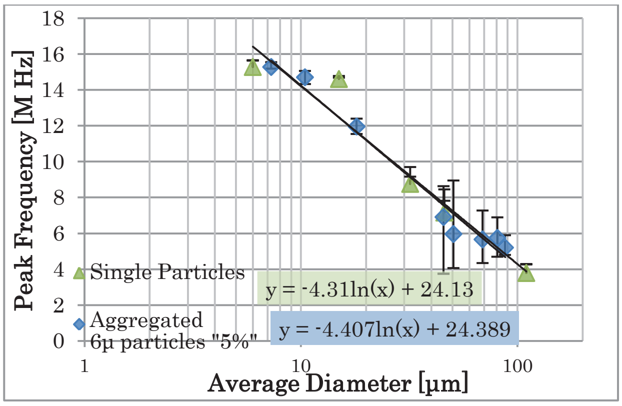


Fig. 4 Relationship between particle or aggregation diameters and peak frequency of reflection spectra

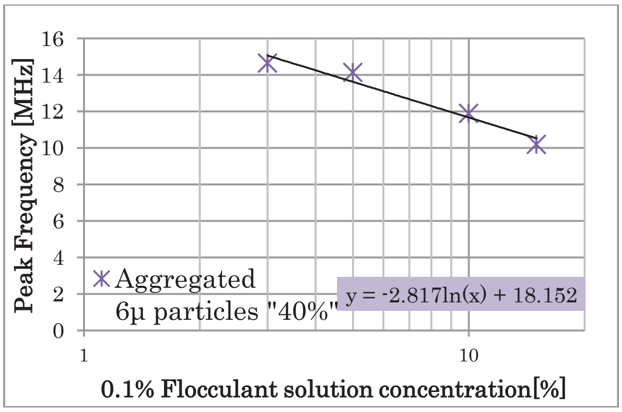


Fig. 5 Changes in peak frequency of reflection spectra with coagulant concentration