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Measurement of attenuation and backscattering coefficients of bubble suspension in low-velocity steady flow

低流速定常流における気泡懸濁液の減衰, 後方散乱係数の測定

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1. Introduction

The use of microbubbles as contrast agents improves the visualization of blood flow in the human body and significantly enhances contrast of B-mode images and Doppler signal. Recently, microbubbles have been applied to novel selective imaging, e.g. Kupper imaging and molecular imaging for diagnosing liver tumor. In these techiniques, we suppose that the size and the number density of bubbles in tissue have related to the functional information of cell. Thus, this study focus on the non-contact measurement of size and number density of microbubbles. A previous study investigated the attenuation and backscattering of bubble suspension relating to the size and the number density based on the analysis of image data, not RF signal[1]. This paper shows the experimental data of attenuation and backscattering coeffients based on the analysis of the RF signal from bubble suspension obtained using linear phased array.

2. Methods

Sonazoid™, which was typically applied for diagnosis of liver tumor, was used as microbubbles. The size and the number of bubbles was measure by using a counting chamber(A107, Asone). **Fig. 1** shows the distribution of bubble radius. The radius was ranged from 0.5 µm to 2 µm.

The steady-flow system was constructed. Doppler phantom (Model 525, ATS Laboratories) with 8 mm was used in flow channel. The steady flow was formed by using a siphon. The flow volume was 39.7±0.4 mL/min. Assuming that the flow velocity was constant in the flow channel, the velocity was estimated to be 3.29±0.03 mm/s. Flow system The commercially available ultrasound sonography was used for data acquisition. The ultrasound with center frequency of 5 MHz was emitted from a linear array transducer. RF signal was recorded at the sampling frequency of 40 MHz. The total distant range was set at 40 mm. The focal depth was 25

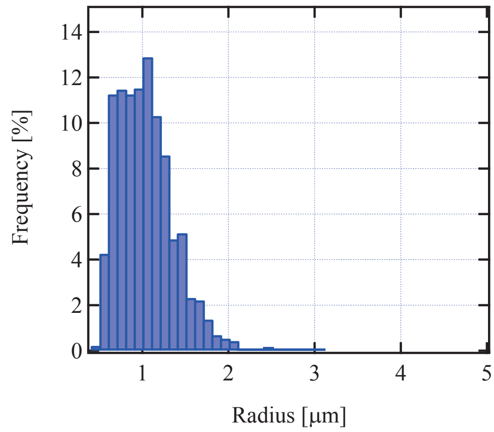

Fig. 1 Distribution of radii of microbubbles.

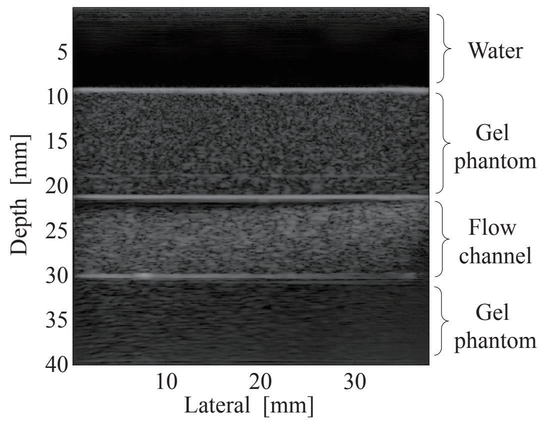

Fig. 2 B-mode image of flow phantom in presence of microbubbles. Bubbles flow from right to left in the images.

mm corresponding to the center of the flow channel. The gain and dynamic range were 80 dB and 90 dB. The beam width is 0.4 mm and the pulse length is 1.2 mm. **Fig. 2** shows the typical B mode image of flow channel in the presence of microbubbles. The total volume of liquid in flow system was 550 mL. Assuming that microbubbles were homogeneously
suspended, the number density of microbubbles was estimated to be 1.2×10^5 bubbles/mm^3.

Backscatter and attenuation coefficients of microbubble suspension in flow channel were calculated from the analysis of power spectrum of RF signal in Ref [2]. In absence of microbubbles,

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we could obtain the power spectra of RF echo signals form the interface and flow channel-gel (FC-G) interface. P is written as

$$P(f) = G(f)R(f)X(f), \quad (1)$$

where X is the power spectrum of incident ultrasound and G is frequency response the transmitting and receiving transducer and R is the reflecting property. In presence of microbubbles, the power spectrum P' of signal reflected at FC-G interface and the power spectrum P_{BS} of backscattered signal from microbubbles in flow channel are written as,

$$P_{BS}(f) = G(f)BS(f)e^{-4\alpha x}X(f), \quad (2)$$

$$P'(f) = G(f)R(f)e^{-4\alpha d}X(f), \quad (3)$$

where BS and a are the backscattering and attenuation coefficients for microbubble suspension. x and d are the distance from G-FC interface and the diameter of the flow channel, respectively. From eqs. (1)-(3), α and BS are written as

$$\alpha = -\frac{1}{4d} log \frac{P'}{P}, \quad (4)$$

$$BS = \frac{P_{BS}}{P'} R(f) e^{4\alpha(x-d)}. \quad (5)$$

In this paper ,*BS*/*R* was measured because the reflection property R was unknown.

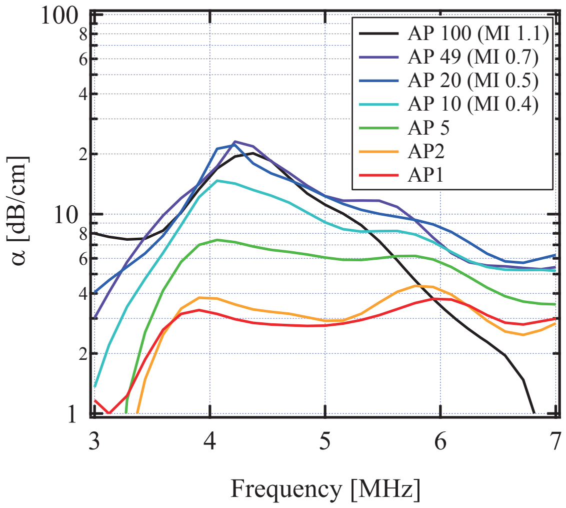
3. Results and discussions

Backscattering and attenuation characteristic of bubble suspension should depend on the sound pressure because of the resonation of microbubbles. Thus, α and *BS/R* were measured in different conditions for acoustic power (AP=1, 2, 5, 10, 20, 49 and 100). **Fig. 3** shows the result. In case of high acoustic power, it is found α reaches a peak value near 4.2 MHz. The frequency is consistent with the measurer value of resonance frequency of Sonazoid™[3]. On the other hand, the peak is also confirmed near 4.2 MHz in the characteristic of *BS/R* although it is unclear compared with the result for α. We suppose that the attenuation coefficient is appropriate for estimating the size and number density of bubbles.

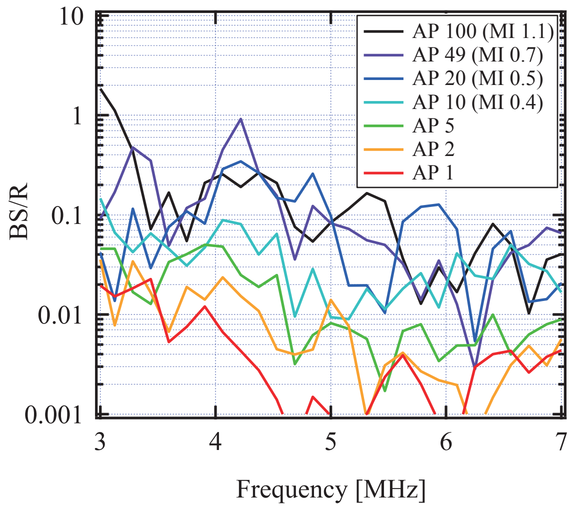
To preciously evaluate the bubble size and density, there are some issues. First we need to make the model function for attenuation and backscattering coefficients of suspension containing many coating bubbles with various radii. Second, we need to correct the effect of complicated sound field of array transducer.

4. Conclusions

The attenuation and backscattering coefficients of micro bubbles suspension in flow channel were measured based on the analysis of power spectrum of RF echo signals. Some



(a) α



(b) BS/R

Fig. 3 Attenuation coefficient α and back scatter coefficient *BS/R* of microbubbles suspension in different sound pressure condition.

problems have remained in the analytical model and correction method to investigate the size and the number density of bubbles.

Acknowledgment

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