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On the influence of surface active solute on ultrasonic waveform distortion in liquid containing air bubbles
界面活性剤が空気気泡含有液体中の超音波波形に与える影響

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1. Introduction

It is expected that the pressure waveform of sound is distorted when propagating in a liquid containing bubbles. These bubbles can absorb and transform the sound energy to pulsating motions. A pulsating bubble can act as a multi frequency sound source and it is the acoustic emission from these pulsating bubbles that is responsible for the distortion of waveforms. Little is known on the distortion of pressure waveforms in a standing wave containing bubbles in a system containing surface active solutes. Surface active solutes such as sodium dodecyl sulfate (SDS) can result in a uniform distribution of active bubbles in the sound field[1], leading to an effective use of the entire vessel on the point of view of a higher sonochemical reaction efficiency.

The influence of the addition of SDS on the sound-pressure waveform propagating through 141-kHz ultrasonic standing wave in liquid containing bubbles is investigated through the measurement of pressure waveforms when varying the applied power to the ultrasonic transducer.

2. Experiment and Results

Figure 1 shows the experimental apparatus. A continuous sinusoidal signal of 141 kHz from a function generator was amplified by a power amplifier to drive a Langevin-type transducer of 45mm in diameter. The transducer is attached to a circular stainless steel plate with a diameter of 100 mm (1 mm in thickness) set at the bottom of a rectangular glass vessel(the larger vessel in figure 1 has inner dimensions of 170×170×150 mm). A smaller glass vessel, which has 50×50×140 mm inner dimensions and a base thickness of 1mm, is positioned above the larger vessel. Each air-saturated liquid of pure water and aqueous solution of 1 mM-SDS was poured into the larger vessel to a liquid height of 69 mm. The smaller vessel is filled with degassed water to a liquid height of 40 mm. The liquid temperature was 25 °C. If a measurement of the pressure waveform is performed using a hydrophone that is directly immersed in the sound field containing bubbles, it is difficult to avoid the possibility of attachment of bubbles on the hydrophone. This has a significant effect on the measurements as the pressure variation of sounds from bubbles close to the hydrophone can be intense compared with those of the surrounding sounds. Indeed, Neppiras showed that subharmonic noise was reduced after cavitation bubble attached on a hydrophone was removed.[2] Therefore, in this study the hydrophone was set at an antinode nearest to the surface of degassed water in the upper small vessel far from bubbles in the lower in the present experiment. The pressure waveform was measured with a digital oscilloscope. Frequency spectra of the pressure waveform were recorded by a spectrum analyzer at different applied powers to the transducer. Each component of fundamental(f: f =141kHz) and high harmonics(2 f, 3 f, 4 f, and 5 f) was determined by the magnitude from its background level.

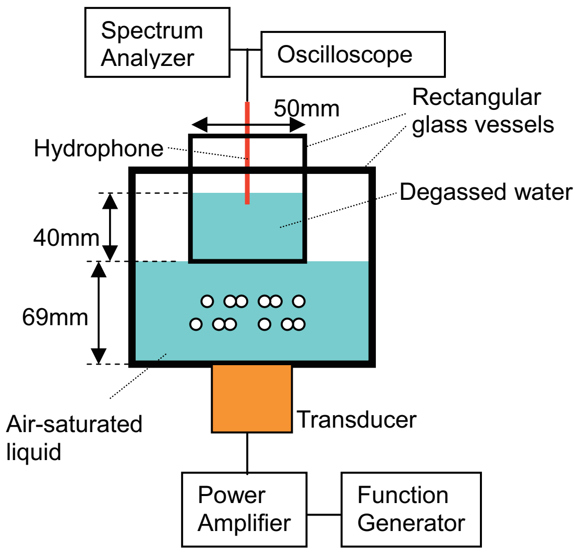


Figure 1. Experimental apparatus.

Figure 2 shows a comparison in measured pressure waveform between water and 1mM-SDS at around 10W. The shape of the measured distorted waveform in water has a feature of a curve with a steeper gradient at the positive pressure and a broadened minimum at the negative pressure. This trend about the waveform measured is similar to that at 200 kHz, shown numerically by Vanhille and Campos-Pozuelo.[3] Figure 3 shows the difference in FFT spectra between water and 1mM-SDS. It is interpreted that the waveform at high applied voltage is distorted in the case of water. It is shown in Fig.3a that, as the applied power increases, the acoustic intensity of each component increases and saturates, and all of the intensities do not turn to decreasing at the same power. This indicates that the acoustic amplitude is relatively low or there is low void fraction in the present experiment and there are few large coalesced bubbles present in the water system that can strongly scatter and attenuate the sound wave. In the case of 1mM-SDS, it is remarkable that the waveform is hardly distorted even at high applied powers.

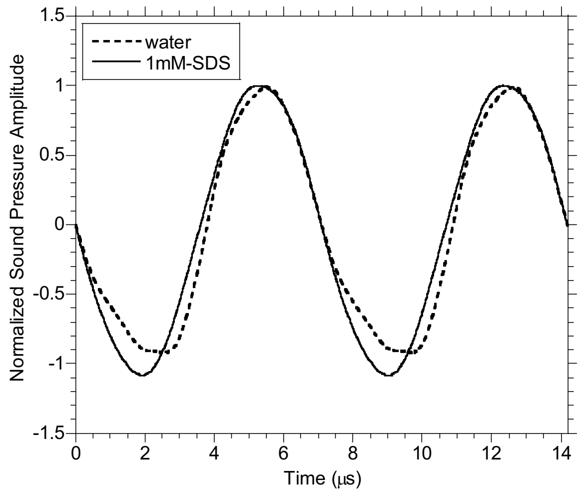
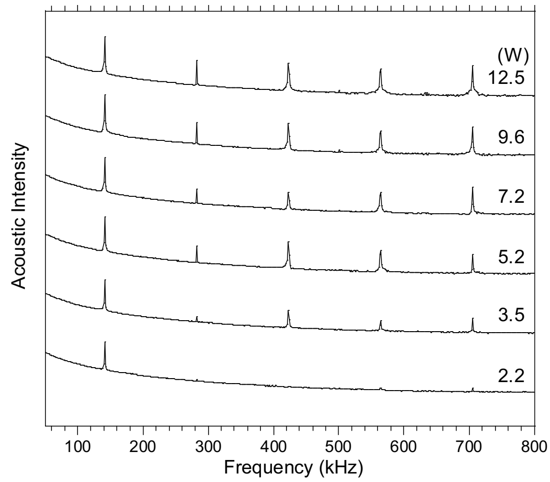
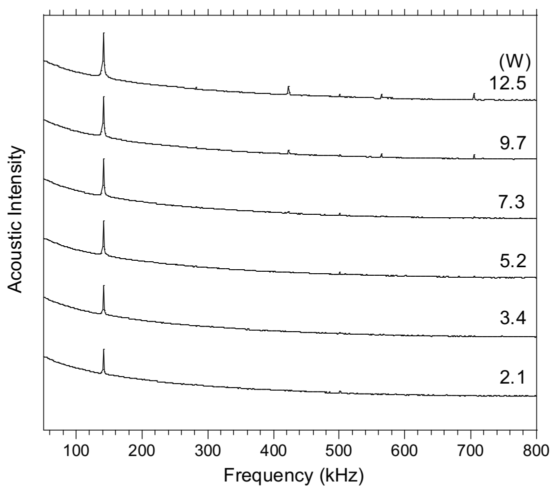


Figure 2. An example of measured waveforms.



(a) water



(b) 1mM-SDS

Figure 3. Change in FFT spectra at different power.

3. Discussion and Conclusions

According to the concept by Ashokkumar et al.,[4] the electrostatic repulsion between bubbles is marked at around 1mM-SDS as SDS is an ionic surfactant and bubbles which are covered with SDS are charged. This effect inhibits bubble-bubble coalescence and keeps the bubble size small. It is known that under the condition of micronmeter-sized bubbles, viscous resistance is effective at the bubble surface and adsorption and desorption of surfactants to the bubble surface can cause acoustic energy loss in radial motion of a bubble.[5] This leads to decreasing the acoustic amplitude and suppressing the development of nonlinearity in the waveform at relatively low acoustic amplitude.[6] That is why little distortion of the waveform appeared in the case of SDS addition. It is noteworthy that the feature of the waveform in water agrees with that of theoretically predicted waveform.

Acknowledgment

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