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Multibubble sonoluminescence enhancement by fluid flow

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Abstract

Forced fluid flow can cause the enhancement of multibubble sonoluminescence (SL) under suitable conditions. The effect of directional flow with a circulator is similar to that of rotating flow with a stirrer. The mechanism of the enhancement is that both flows prevent cavitation bubbles from coalescing and clustering, which are responsible for the quenching of SL. The intensity of sonochemiluminescence (SCL) in an aqueous luminol solution increases with flow speed at higher ultrasonic powers more significantly than that of SL in distilled water. However, in the range of low ultrasonic power, the intensities of SL and SCL decrease with flow speed. Therefore, an optimum flow speed exists in relation to ultrasonic power and frequency.

Keywords: Multibubble sonoluminescence; Sonochemiluminescence; Cavitation bubble cluster; Bjerknes force; Circulation; Stirring

1. Introduction

Sonochemistry refers to the chemical effects of ultrasound through the process of acoustic cavitation, which generates extremely high temperatures and pressures in cold liquids [1]. In sonochemistry, many interesting topics have been reported; for example, advanced materials such as nanoclusters of amorphous iron [2], fullerene [3] and carbon nanotubes [4] have been synthesized in cold liquids. In spite of the very promising effects described on the laboratory scale, sonochemical reactions have not been yet developed into industrial applications. It is necessary that scale-up problems should be solved for larger-scale sonochemistry.

Successive flow operation and uniformly stirring operation are important for scale-up in sonochemistry [5]. However, applied fluid flow inevitably affects the behavior of acoustic cavitation bubbles, which are the sources of sonochemical reactions. Therefore, fluid flow should also change sonochemical reaction fields. Recently, Yasuda et. al. have reported that the sonolysis of porphyrin increased when carrying out flow and stirring operations [6]. If fluid flow enhances sonochemical reactions, it should contribute scale-up in sonochemistry.

Then, we show that fluid flow can cause the enhancement of sonochemical reactions under suitable conditions through measurement of multibubble sonoluminescence (SL) [7] and sonochemiluminescence (SCL) [8,9], which correspond to sonochemical reactions inside and outside cavitation bubbles, respectively. Furthermore, its mechanism is clarified by the detailed observation of the corresponding behavior of cavitation bubbles.

2. Experiment

The experimental setup is shown in Fig. 1. A continuous sinusoidal signal generated using a function generator (NF Electronic Instruments 1942) through a 55-dB power amplifier (ENI, 1140LA) was fed to six Langevin-type transducers, which were parallel-connected. The net power input to the transducers was measured with a power meter (Towa Electric, TAW-60 A). The transducers were fixed to the stainless steel plates of a rectangular vessel of $100 \times 100 \times 140\ mm^3$ internal dimensions; four transducers were attached to the bottom and two to the facing side. The

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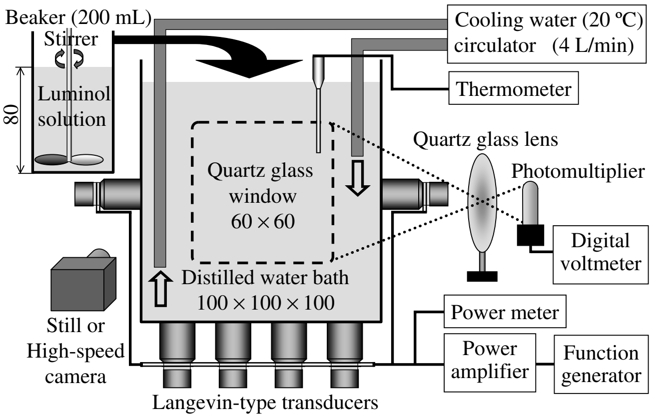

Fig. 1. Experimental setup.

other sides of the vessel had quartz glass windows of $60 \times 60\ mm^2$ through which observation and measurement were performed. Air-saturated distilled water was filled to 100 mm depth in the vessel and circulated at 4 L/min and controlled at 20 °C with a cooling water circulator. The circulator's pump was turned on or off for experiments with or without flow, respectively. The intensity of SL was measured with a photomultiplier tube (Hamamatsu Photonics, R928) through a converging lens to ensure that all of the luminescent positions were detectable. The distributions of cavitation bubbles were photographed with a still camera. The motions of cavitation bubbles were observed with a high-speed video camera (Redlake Imaging, PCI8000S). The liquid temperature was in situ monitored with a thermometer (Advantest, TR-1101-130 [K(Ca)]). The distribution of sound pressure was measured with a hydrophone (RESON, TC4038). Experiments for stirring were performed using a 200 mL beaker set in the vessel filled with degassed water. In the beaker, air-saturated distilled water or 0.01 mM luminol solution was filled to an 80 mm depth and stirred with a rotating stirrer. The intensities of both SL and SCL were measured at various rotational speeds of the stirrer.

3. Results and discussion

Fig. 2 shows the dependence of SL intensity on the power input to the transducers at 23 kHz for the cases with and without the flow operations. Fig. 2(a) is the case of a directional flow with the circulator and Fig. 2(b) is that of rotating flows with the stirrer. Afterward, we refer to these types of flow as "circulation" and "stirring," respectively. In both cases, the intensity of SL increases by applying flow operations to a certain power input. At higher power inputs, the SL intensity with the flows decreases to the level without the flows. The effect of circulation on SL intensity is similar to that of stirring. Therefore, the flow effect on SL may not significantly depend on flow pattern.

Fig. 3 shows the photographs of the distribution of cavitation bubbles at 50 W under the condition shown in Fig. 2(a). Fig. 3(a) is the case without circulation and Fig. 3(b) is that with circulation. Cavitation bubbles were visualized by scattering of a slit light through the center

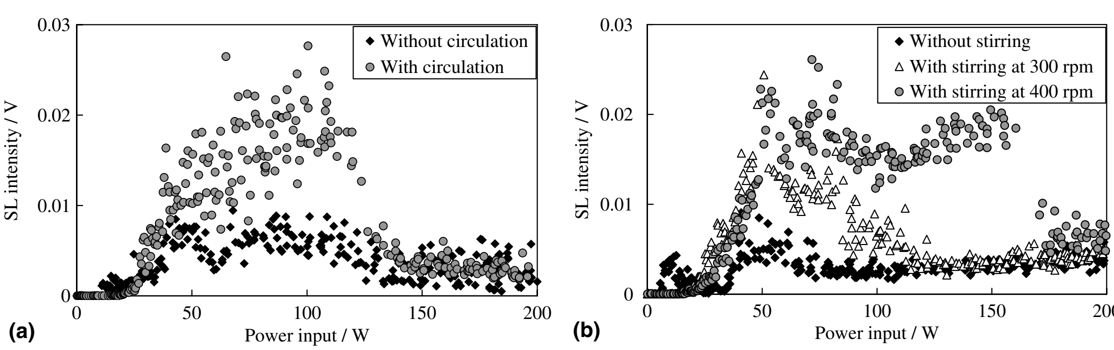

Fig. 2. Comparison of flow effects on sonoluminescence (SL) between circulation and stirring at 23 kHz.

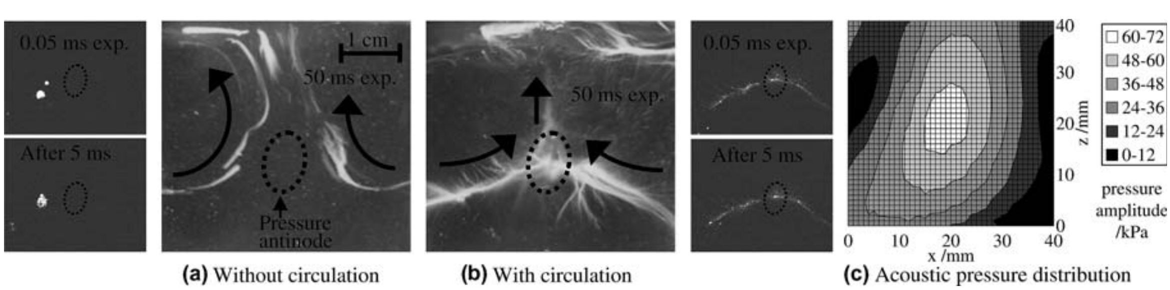

Fig. 3. Comparison of behaviors of cavitation bubbles between case without circulation (a) and that with circulation (b) at 23 kHz, 50 W. The acoustic pressure distribution (c) is also shown.