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Visualization of cavitation behavior and sonochemical efficiency of a rectangular sonochemical reactor
直方体ソノリアクターの可視化によるキャビテーション挙動とソノケミカル効率

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1. Introduction

The bubbles generated by irradiating ultrasound in liquids and solutions repeat the expansion and contraction, and finally collapse. This leads to formation of a localized sonochemical reaction field with high temperature and pressure. There are many investigations of acoustically induced cavitation bubbles theoretically and experimentally. In the laboratory level, it is well known that the sonochemical reaction field is very useful for synthesis of nano-particles, degradation of organic compounds and so on.[1-2)] Recently, the industrial application attracts considerable attention. In order to apply the sonochemical effects to a practical chemical process, the development of efficient and controllable sonochemical reactors is desirable. The sonochemical efficiency depends not only on the reaction media but also on the sonication conditions, such as the ultrasonic frequency, ultrasonic power, and liquid volume.[3)] The sonochemical efficiency is also influenced by cavitation behavior and the flow field. However, information about the cavitation behavior and the sonochemical efficiency is little. In this study, we investigate the relation between the sonochemical efficiency and the liquid flow under sonication with and without a mechanical stir.

2. Experimental

A glass vessel of a rectangular parallelepiped with the inner dimensions of 20 cm×20 cm×65 cm was employed as a reactor. A disk-shaped PZT transducer was attached to a vibration plate of a stainless-steel at the reactor bottom. The diameter of a PZT transducer was 50 mm. The transducer was driven by a power amplifier (L-400BM-H, Honda Electronics Co., Ltd.) and a signal generator (W1974, NF Corp.) to emit a continuous sinusoidal wave with the frequency of 490 kHz. Figure 1 shows the schematic diagram of the experimental apparatus. In the measurement of the flow velocity by LDV (INNOVA 70, TSI), nylon particles (4 μm) were added to water. Moreover, by irradiating the water with seated laser light from the reactor side, we visualized cavitation behavior induced by ultrasound. We observed cavitation behavior, acoustic streaming and standing wave by digital video camera (HDR-SR11, Sony). We also visualized the sonochemical reaction field by observation of sonochemical luminescence. A mechanical stirrer (LR500A, Yamato Scientific Co., Ltd.) was used to generate a mechanical flow. The acoustic pressure was measured with a hydrophone (HNR-1000, ONDA). All measurements were carried out at room temperature. The sonochemical efficiency was evaluated by using the KI method and calorimetry.[4)]

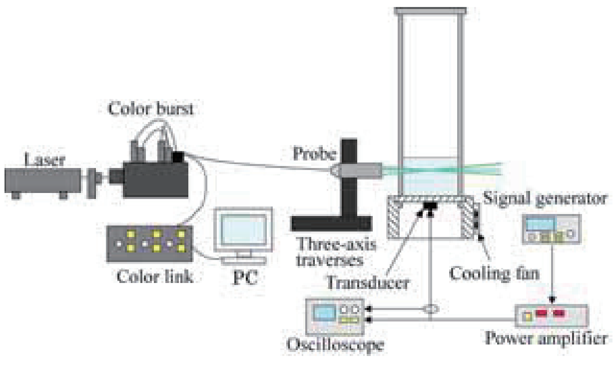

Fig.1 Experimental setup for LDV measurement.

3. Result and discussion

Figure 2 shows the cavitation behavior under sonication with and without a mechanical stir. In the case of sonication without a mechanical stir, as shown in Fig. 2(a), the fountain was observed. In our previous paper,[5)] we reported that up to the 10 W electric power, the liquid surface fluctuated and the bubbles trapped at the standing wave were formed near the liquid surface. It is instructive to note that the sonochemical luminescence is observed in the region where the standing wave is formed. As the electric power increased to 50 W,

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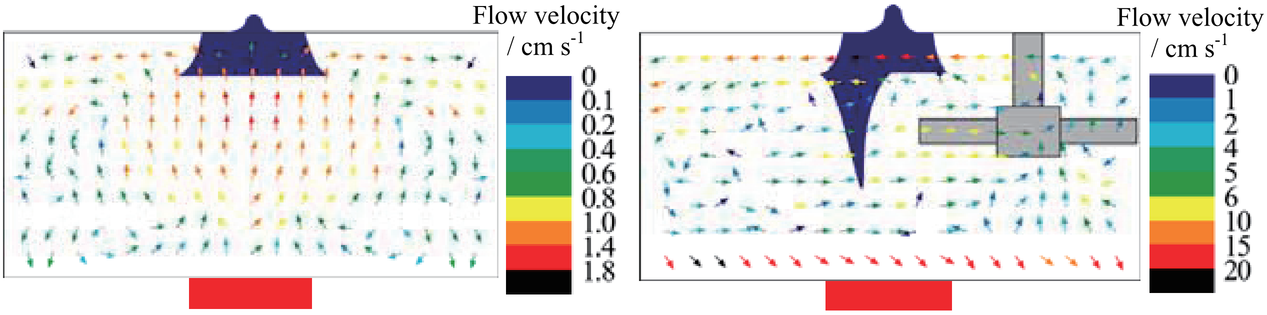
(a) (b) (c)

Fig.2 Effect of the mechanical stir on cavitation behavior. (a) 0 rpm, (b) 200 rpm, (c) 350 rpm (30 W).



(a) (b)

Fig.3 Effect of the mechanical stir on distribution of flow velocity induced by ultrasound. (a) 0 rpm, (b) 200 rpm (30 W).

the violent movement of cavitation bubbles was observed with the intense atomization.

As shown in Fig. 2(b) and (c), the increase of revolution of a stir leads to complex asymmetrical cavitation behavior due to obstruction of the mechanical stirrer, as expected. By a mechanical stir, strong vortex was formed. As the revolution of the stir increased, the violent vortex was formed and the liquid flow was accelerated. Atomization was enhanced as increasing the revolution.

Figure 3 shows the distribution of flow velocity and the region of sonochemical reaction field. The black reign like a bell shape indicates the field showing the sonochemical luminescence and the arrow means the direction and the average magnitude of the flow velocity. In the case of sonication without a mechanical stir, liquid and bubbles moved upward along with the central axis, moved parallel to the surface, and they descended parallel to the reactor wall. In this fluid circulation, the large flow rate was obtained above the transducer due to the ultrasound directivity of the used transducer. Sonication with a mechanical stir induced the liquid and bubbles flow from a left wall to a right wall. The region showing the sonochemical luminescence expanded with an increase in the revolution. It is clear that new reaction field is created by a mechanical stir. This result is corresponding to that of Yasuda et al.[6)]

Figure 4 shows the quantitative effect of a mechanical stir on sonochemical efficiency. As the revolution increased, sonochemical efficiency increased up to about 2 times than the value obtained without a mechanical stir. From these results, the suitable construction of the flow field leads to enhance the sonochemical efficiency.

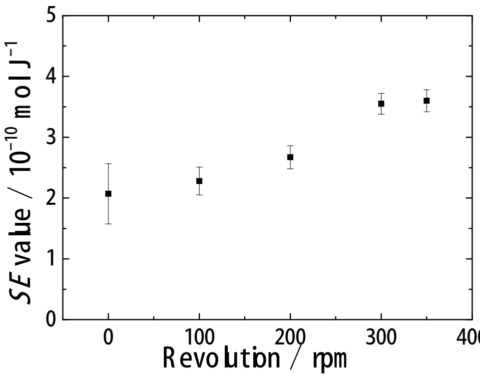


Fig.4 Sonochemical efficiency against revolution.

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