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Study on Efficiency of Transducers for Sonochemistry by Calorimetry

カロリメトリーによるソノケミストリー用振動子の評価

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1. Introduction

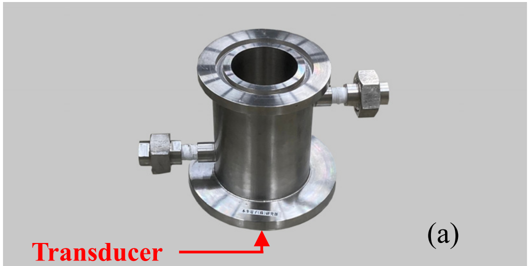
Sonochemistry is expected to be used in chemical processes such as synthesis and decomposition. In this case, the relationships between the electrical energy applied to the ultrasonic transducer, the ultrasonic energy applied to the sample solution and the amount of substance reacted by the synthesis or decomposition are important. The ultrasonic energy per unit time is defined as the ultrasonic power.

The ultrasonic power can be obtained by the balance method. However, the balance method cannot be used in sonochemistry, because vessels of various shapes are used and the transducer is driven by high electric power. Therefore, in sonochemistry, the ultrasonic power is obtained by calorimetry. When the liquid height of the sample is low, the ultrasonic power decreases[1)]. Uchida et al. measured the ultrasonic power in the absence of reflected wave by using a device with a transducer mounted on the side of a cylindrical vessel. They reported that ultrasonic power by the calorimetry was good agreement with that by balance method[2-3)]. The ratio of the ultrasonic power applied to the sample to the effective electric power applied to the transducer is defined as the efficiency of the transducer. It was found that when a cylindrical vessel with the transducer mounted on the side was used, the true efficiency of the transducer, which was independent of the liquid height, could be obtained.

The purpose of this study is to obtain the true efficiencies of transducers for sonochemistry at various frequencies using a cylindrical vessel with a transducer mounted on the side.

2. Experiment

In the experiments with direct irradiation for sonochemistry, a vessel A shown in the photograph in **Fig. 1 (a)** was used. The vessel A had an inner diameter of 56 mm and a double structure for circulating cooling water. A vessel B with an inner diameter of 180 mm, shown in the photograph in **Fig. 1 (b)**, was used to obtain the true efficiency of the transducer. A vibration plate with a transducer was mounted on the bottom of vessel A or the side of vessel B. The vessels and the vibration plates were



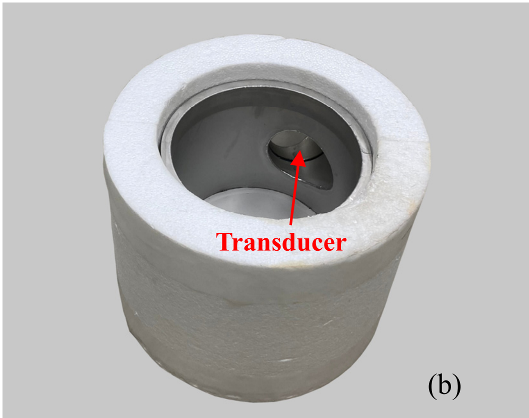


Fig. 1 Photographs of (a) vessel A and (b) vessel B

made of SUS304 stainless steel. The transducers were disk-type transducers (Honda Electronics) with a 50 mm diameter at frequencies of 500, 750 kHz, 1 and 2 MHz. The transducer was driven by a power amplifier (1040L, E&I) which amplified a continuous sine wave generated by a signal generator (WF1942, NF). A matching circuit was inserted between the power amplifier and the transducer, except for 500 kHz. An effective electric power applied to transducer was calculated from a voltage at both ends of the transducer and a current measured by an oscilloscope (TDS3014B, Tektronix) and a current probe (TCP202, Tektronix), respectively. In order to keep the effective electric power constant, an electrical control system (Honda Electronics) was used. The system read the value of the effective electric power from the oscilloscope to the personal computer via the general-purpose interface bus (GPIB), and set the optimum signal generator output voltage from the personal computer to the signal generator via GPIB to keep the effective electric power constant.

The ultrasonic power, which was defined as the energy applied to the sample per unit time, was determined by calorimetry. The temperature of the sample in the vessel was measured using a platinum resistor (pt100, Netsushin) and a thermometer (NR500, Keyence). Ultrapure water (Milli-Q Reference & Elix Essential UV5, Merck) was used as the sample. The ultrasonic power P_U was calculated from the following equation.

$$P_U = \frac{\Delta T}{\Delta t} C_p M, \quad (1)$$

where $\Delta T / \Delta t$ was the rate of temperature rise, C_p was the specific heat capacity of water and M was the mass of water. The rate of temperature rise was determined from the temperature change at the initial stage of ultrasonic irradiation or the temperature change before and after ultrasonic irradiation[3]. The sample temperature before ultrasonic irradiation was 298 ± 0.1 K and the sample was saturated with air.

3. Results and discussion

Fig. 2 shows the relationship between the effective electric power applied to the transducer and the ultrasonic power applied to the sample when the sample volume are 50 and 150 mL in vessel A, which has a transducer with a 1 mm thick vibration plate at a frequency of 500 kHz. The ultrasonic power is proportional to the effective electric power. This proportionality constant, which is the gradient of the ultrasonic power with respect to the effective electric power, is defined as the efficiency of the transducer. The reflected wave from the water surface returns to the transducer. If the sample volume is small and the liquid height is low, the transmitted wave into the transducer, which is part of the reflected wave, will be larger, and the energy dissipation in the transducer will be larger. Therefore, as the sample volume decreases, the efficiency of the transducer decreases. In order to obtain the true efficiency of the transducer, the reflected wave from the water surface or wall must be eliminated. Ultrasonic power to effective electric power without reflective wave were added in Fig.2, using the vessel B with a sample volume of 3500 mL. These results show that the true efficiency of the transducer is 93 %, however, for sample volumes of 50 and 150 mL, the efficiencies are 54 and 65 % respectively. It was found that the true efficiency of the transducer could be obtained by using vessel B.

Fig. 3 shows the efficiencies of the transducers with different thicknesses of the vibration plate at frequencies of 500, 750 kHz, 1 and 2 MHz using vessel B. When the thickness of the vibration plate is thicker or the frequency is higher, the efficiency of the transducer decreases. At frequencies of 750 kHz, 1 and 2 MHz, the efficiency of the transducer increases when the thickness of the vibration plate is 0.1 mm compared to a half-wavelength ($\lambda / 2$).

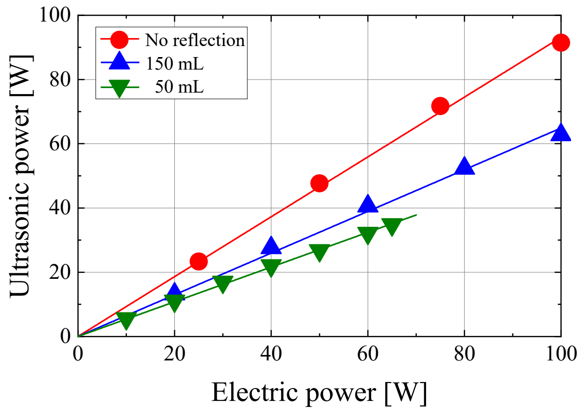


Fig. 2 The relationship between effective electric power and ultrasonic power at 500 kHz

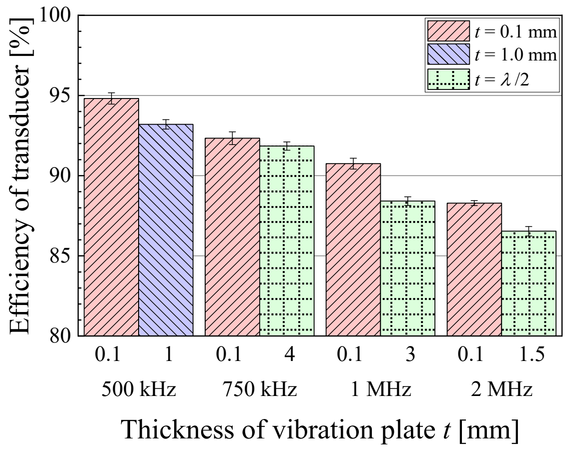


Fig. 3 Efficiencies of the transducers with different thickness of vibration plate at frequencies of 500, 750 kHz, 1 and 2 MHz using vessel B

4. Conclusion

By using a cylindrical vessel with the transducer mounted on the side, it was possible to obtain the true efficiency of the transducer. The true efficiencies of the transducer depend on the thickness of the vibration plates in the frequency range from 500 kHz to 2 MHz. For the future development of high efficiency transducers, the cylindrical vessel used in this study is useful for the evaluation of transducers.

References

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