2P3-6

Analysis of the Distribution of the Ultrasonic Field Transmitted into a Solid Cylinder from the Outside

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1. Introduction

In the field of sonochemistry, which utilizes ultrasound to promote chemical reactions or induce changes in physical properties, it is common practice to avoid direct contact between the radiating surface of the ultrasonic transducer and the liquid sample to maintain sample purity[1,2]. To achieve this, samples contained in glass vessels receive ultrasonic energy through an acoustic transmission medium, typically water. When high-intensity ultrasonic energy is required, it is customary for the ultrasonic energy to be transmitted through the side of the cylindrical container holding the sample in order to focus the energy. The plane waves radiated from the ultrasonic transducer reflect and transmit through the sides of the cylindrical container, creating an acoustic field inside the container. The distribution of this acoustic field depends on factors such as the frequency of the ultrasound, the size and thickness of the cylindrical container, and the distance between the radiating surface of the transducer and the surface of the cylinder. This study experimentally examines the ultrasonic field distribution formed inside a cylindrical glass container by plane wave ultrasound as a foundational investigation for the optimal design of ultrasonic generation systems used in sonochemistry.

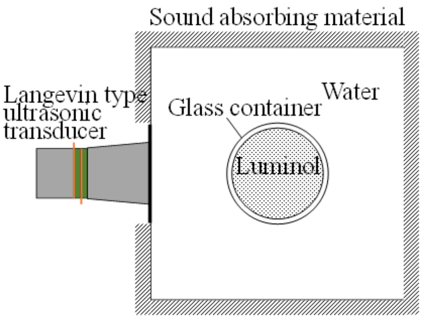

Fig. 1 Experimental apparatus for measuring ultrasonic energy transmitted into a cylindrical container (top view).

2. Experiment

To investigate the energy distribution of ultrasonic waves transmitted through a cylindrical container submerged in water, an experimental apparatus as shown in Fig. 1 was constructed. The container is made of acrylic with internal dimensions of 300 mm × 300 mm × 300 mm and a wall thickness of 10 mm. To minimize wall reflection waves, sponge sound-absorbing material with an average thickness of 15 mm was applied to the internal walls and bottom surface of the container. The ultrasonic transducer depicted on the left side of the figure is a Langevin-type transducer with a resonant frequency of 40 kHz. To prevent the transmission of acoustic and vibrational energy to the walls, it was constructed and mounted as shown in Figure 2. A glass container with an outer diameter of 50 mm was used as the cylindrical container. To examine variations in thickness and distance from the transducer, measurements were taken with thicknesses ranging from 12 mm to 32 mm. The distance between the radiating surface of the transducer and the center of the glass container was varied from 40 mm to 85 mm to investigate changes in energy transmission. To investigate the distribution of acoustic energy transmitted into the container, a solution containing 10 liters of water, 1 gram of luminol, and 5 grams of Na_2CO_3 powder was prepared and filled into the container. A 40 kHz sinusoidal signal generated by a signal generator is amplified by a power amplifier (ROCHESTER, N.Y. MODEL 2100L) and input to the transducer as 130 W of electrical energy. The ultrasound radiated by the transducer passes through the cylindrical glass container, causing a luminescent reaction in the luminol solution within the container. The light energy generated during this process was captured by a camera (Canon 350D) fixed above the glass container to investigate the ultrasonic energy distribution inside the glass container. The camera settings were ISO 1600 and an exposure time of 270 seconds.

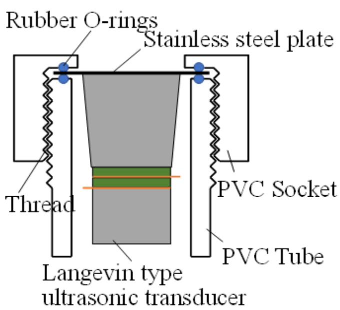

Fig. 2 Structure of the ultrasonic transducer used in the experiment.

3. Results

In Fig. 1, the thickness and outer diameter of the cylindrical glass container were 2.5 mm and 50 mm, respectively. Figure 3 presents the results of observing luminol luminescence as the distance between the radiating surface of the transducer and the center of the cylindrical container was varied. These results indicate that the luminescence intensity of luminol decreases as the cylindrical container moves further from the transducer. Considering that the wavelength of the plane wave radiated from the transducer is approximately 38 mm, a periodic distribution of ultrasonic energy is expected with distance variations between 40 mm and 80 mm. However, considering the scattering effects on the surface of the cylindrical container and its very thin wall compared to the wavelength, a linear decrease in transmitted acoustic energy with distance is anticipated and can be confirmed by the decrease in luminescence intensity. Figure 4 shows the results of observing the changes in transmitted acoustic energy through the cylindrical container with varying thicknesses. The distance between the center of the glass cylinder and the radiating surface of the transducer was 50 mm. From the results in Fig. 4(a), it can be seen that when the thickness of the container is 1.2 mm, the area near the opposite wall of the glass cylinder is brighter compared to the luminol solution on the side where the ultrasound is incident. This is believed to be due to the increased reflection coefficient of the left glass wall caused by the scattering of acoustic energy within the glass container and subsequent transmission through the left glass wall. In Fig. 4(b), which shows the results when the glass cylinder thickness is increased to 1.8 mm, the transmission coefficient of the right wall of the glass container decreases due to the relationship between the wavelength of the ultrasound in the glass medium and the glass thickness, resulting in a decrease in the amount of transmitted ultrasonic energy. Fig. 4(c) shows the case where the glass cylinder thickness is 2.5 mm, indicating a slight increase in luminescence intensity within the cylindrical container compared to Fig. 4(b). When the glass cylinder thickness is further increased to 3.2 mm, Fig. 4(d), the highest luminescence intensity is observed, suggesting the highest density of acoustic energy. From these results, it is evident that the thickness of the glass container significantly affects the transmission coefficient. Therefore, it can be concluded that an optimal thickness exists for transmitting ultrasonic energy through a cylindrical container, depending on the ultrasound frequency.

Acknowledgment

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References

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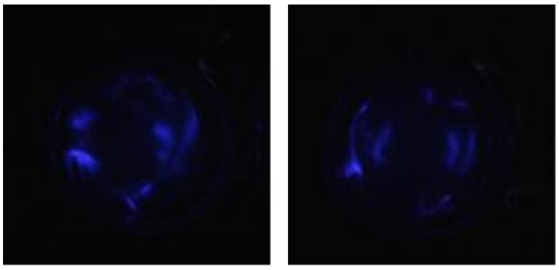
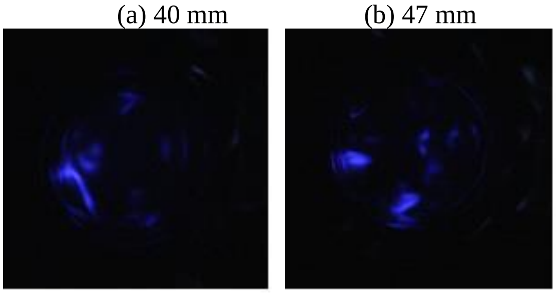
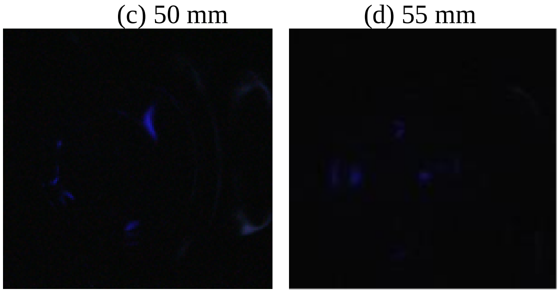


(a) 40 mm (b) 47 mm

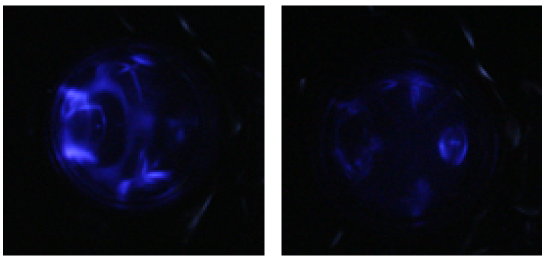


(c) 50 mm (d) 55 mm

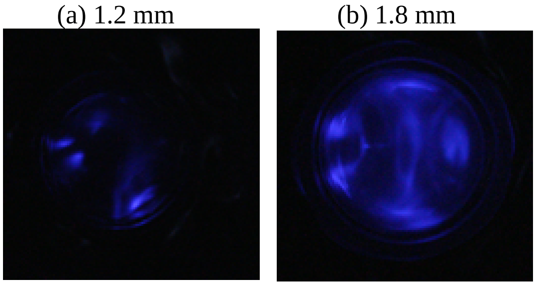


(e) 70 mm (f) 85 mm

Fig. 3 Variation in luminol luminescence images with distance from the radiating surface of the transducer.



(a) 1.2 mm (b) 1.8 mm



(c) 2.5 mm (d) 3.2 mm

Fig. 4 Variation in luminol luminescence images with different thicknesses of the glass container.