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Geometric optimization in 20kHz probe sonoreactors for the enhancement of sonochemical oxidation activity

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1. Introduction

The 20 kHz probe type sonicator is a device commonly used in laboratories. It is known that ultrasonic waves are irradiated at the end of the tip, so that a high cavitational activity zone is formed only at the corresponding part. In order to improve and optimize cavitation activities, variables such as input power, dissolved gas and continuous/pulse mode have been mainly studied. The effect of geometric elements on the cavitation activity was also carried out in the probe type sonicator. The depth of immersion of the probe, the sound pressure generated under various conditions including the shape of the reactor, and the flow rate were simulated. Chemical oxidation/decomposition and precipitation were analyzed sonophysically and sonochemically under various immersion depth conditions of the probe. Ye et al reported different tendencies for chemical and physical effects depending on the immersion depth conditions of the probe. Son et al reported a significant difference in oxidation power according to the immersion depth. When the probe was close to the bottom of the reactor, it showed high oxidation power, and the cavitation activation area was observed in a circular shape.

Most of the prior studies have been conducted in a small volume of 250 to 1000 mL, and research on an influence range of the cavitational activity at a relatively larger capacity is required to improve applicability of the ultrasonic technology. This study is a follow-up study of optimization of vertical position conditions of 20 kHz probe type sonicator and aims to compare and analyze the changes in the cavitational activity zone in a reactor with various conditions.

2. Materials and Methods

In this study, a 20 kHz horn-type sonicator (VCX-750, Sonics & Materials Inc., USA) was used. The diameter of the circular acrylic vessel is 5, 10, 20, and 30 cm, respectively, and the liquid height is 12 cm, which is set to a height without affecting the probe. The volume conditions change depending on the position of the probe, and in consideration of this, about 0.2, 0.92, 3.6, and 8.4 L were applied. The depth of the probe immersion was 1-11 cm. 50% of the input power is displayed as the power level of the device.

The cavitational oxidation reaction was quantified using a KI solution (1g/LKI) and visualized using a luminol solution (0.1g/L luminol and 1g/L NaOH). When ultrasonic waves are irradiated to the KI solution, iodine (I_2) is produced by reaction between iodide ions (I^-) and highly reactive radicals such as hydroxyl radicals (OH) and hydrogen peroxide (H_2O_2) formed by ultrasonic waves. The iodine reacts spontaneously with excess iodide ions to form triiodide ions (I_3^-). The concentration of triiodide ions was measured using a UV-vis spectrophotometer (Vibra S60, Biochrom Ltd., UK). The luminol solution method is a method of qualitatively confirming the region of oxidation radicals generated by ultrasonic waves through visual expression. The luminol molecule is transformed into a fluorescent 3-aminophthalate (3-APA) in an excited state in response to the radicals produced by the cavitational activity, and then stabilized with 3-APA by emitting a visible light called Sonochemiluminescence (SCL). SCL images were obtained from exposure photography for 10 seconds using a digital camera (DSC-RX100M7; Sony Corp., Japan) under darkroom conditions.

3. Results and Discussions

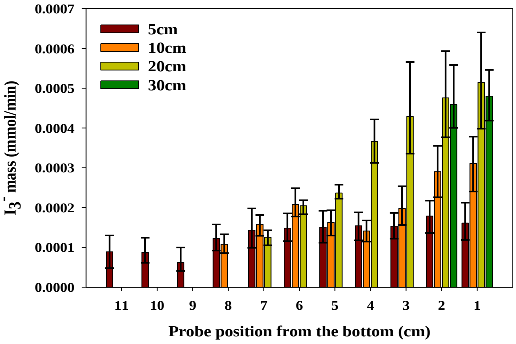

Fig. 1 I_3^- concentration for various volumes and probe position from the bottom

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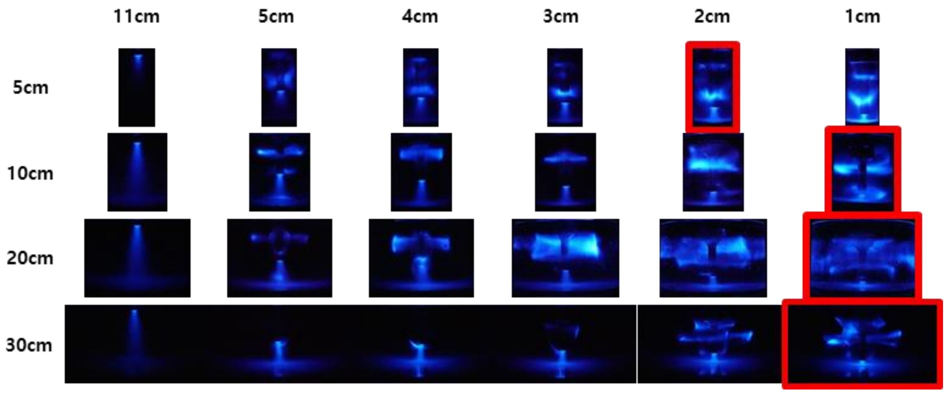

Fig. 2 Sonochemiluminescence (SCL) images for various volumes and probe position from the bottom

Figure 1 compares the ultrasonic chemical effects of the KI solution method at each probe immersion depth. Since the volume of each vessel is about 5 to 40 times different, it is not appropriate to compare it with a concentration, so it was compared with a mass.

It was confirmed that oxidation power was increased when the probe was located close to the floor under all vessel conditions. At 5 cm in diameter, the lowest oxidation was shown under the condition of 9 cm in the vertical position and the highest oxidation was shown under the condition of 2 cm, and the difference was about 2.9 times. At the 10 cm diameter condition, the lowest oxidation was shown under the 8 cm condition in the vertical position, the highest oxidation was shown under the 1 cm condition, and the difference was about 2.9 times. At 20 cm in diameter, the lowest oxidation was shown at 7 cm, the highest oxidation power was shown at 1 cm, and the difference was about 4.1 times. In particular, the highest oxidation was shown under the condition that the diameter of the vessel was 20 cm.

In previous studies, the difference in oxidation power from surface of the liquid to specific immersion conditions was insignificant, but the oxidation was improved under specific immersion conditions, and the same trend was confirmed in this study.

Figure 2 is the SCL image for the same conditions as the graph above. At 11cm, an activity zone was formed just below the tip and showed the same tendency as previous studies. On the other hand, from the immersion depth conditions below that, it was greatly influenced by the diameter of the reaction vessel being irradiated with ultrasonic waves, and a very different cavitation activity distribution was observed. At a 5 cm diameter, it shines brightly around a thin portion of the probe, and activation near the surface was not observed by the probe. It was activated at the middle of the probe at 10 cm diameter vessel. The image of 20cm diameter was also observed in the form of a band, and the activation area was formed with an are larger than the 10cm diameter. At 30 cm diameter, an activation area was observed near the probe. It is considered that the sound wave energy was reflected from the wall surface and attenuated during progress, showing this result.

In this study, the cavitation activity zone was observed around the middle of the immersed probe body located in the opposite direction to ultrasonic irradiation. As the immersion depth increased, the activity zone around the probe body was expanded. In previous studies, it was observed in the form of a sphere, whereas in this study, it was observed in the form of a band. It is considered that the change in the cavitation activity zone is caused by the progress of ultrasonic waves at the bottom and the reflected sound waves proceed to the wall surface of the vessel and are reflected.

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