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主論文の要旨

論文題目 Characterization and application of chemical and mechanical effects induced by ultrasonic cavitation (超音波キャビテーションによる化学的および機械的効果の特性と応用)

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論文内容の要旨

1. Introduction

Acoustic cavitation is a phenomenon when tiny bubbles are created through the irradiation of ultrasound into a liquid, and then these tiny bubbles oscillate and collapse. Acoustic cavitation makes high local pressure, temperature, and velocity fields in a liquid. Consequently, chemical effect is produced during the process of free radical production and pyrolysis owing to local high temperature and pressure. Mechanical effect is generated by shockwaves and microjets with high velocity. This study focused on studying the ultrasonic cavitation and its effects in a sonochemical reactor.

2. Theory

Broadband integrated pressure (BIP) was utilized as the broadband noise to estimate the ultrasonic cavitation generated in water. An example of a sound pressure spectrum at a driving frequency of 304 kHz and electric input power of 4 W was illustrated in Fig. 1. The value of BIP was figured out by the following equation:

$$\mathrm{BIP} = \int_{f_s}^{f_e} [P_S(f) - P_N(f)]\, df \qquad (1)$$

where $P_S(f)$ represents broadband sound pressures excluding the fundamental, harmonic, subharmonic, and ultraharmonic components and $P_N(f)$ represents sound pressures of the background noise. The start frequency of the integration region, f_s, was decided as 20 kHz and the end frequency, f_e, was 20 MHz for all driving frequencies. The broadband sound pressure represented in decibels (dB) and was employed to calculate the BIP identified as the shaded area in Fig. 1.

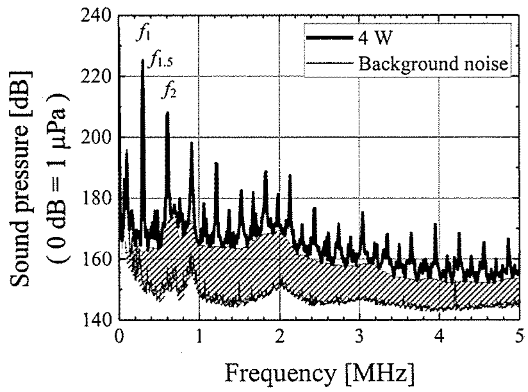

Fig. 1. Sound pressure spectrum at 304 kHz, 4 W

3. Sound pressure and cavitation threshold

As regards the affect of ultrasonic cavitation in the solution, the sound pressures at various frequency components such as the fundamental, second harmonic and first ultraharmonic, and the BIP at 22, 43, 98, 304, and 488 kHz were measured. For the fundamental frequency, firstly if cavitation bubbles were not generated in the water yet, sound pressure rose linearly with the upward of the electric power. Afterward as continually increasing the electric power, the sound pressure drastically dropped at around the electric power giving cavitation threshold. Finally, the sound pressure went up again when the electric power became higher than that of the cavitation threshold. At a high electric power, even the sound pressure increased, but its value was lower than the value extrapolated from the linear relationship between the sound pressure at the fundamental frequency and the square root of electric power below the electric power of cavitation threshold. The second harmonic signal began to appear at the electric power comparably lower than that of the cavitation threshold. The first ultraharmonic signal was noticed at the electric power near to that of cavitation threshold at 304 and 488 kHz. At lower frequencies, the first ultraharmonic component appeared at higher electric power compared with cavitation threshold.

The cavitation threshold was examined from 22 kHz to 4880 kHz by broadband noise. The cavitation threshold got higher as ultrasonic frequency increased. The effect of occurrence of bubbles in a liquid was determined by measuring the thresholds of the second harmonic and the first ultraharmonic frequencies. The threshold of the second harmonic component was in harmony with the cavitation threshold below 1000 kHz. At low frequencies below 98 kHz, the threshold of the first ultraharmonic was greater than the cavitation threshold. At high frequencies, the threshold of the first harmonic was consistent with the cavitation threshold.

4. Thresholds of chemical and mechanical effects

Thresholds of chemical and mechanical effects were determined by KI oxidation and aluminum foil erosion, respectively. The tendency of those thresholds showed to be same as the tendency of cavitation threshold. The chemical effect threshold was nearly same as the cavitation threshold at every frequency. The mechanical effect threshold and the cavitation threshold were almost close to each other at frequencies lower than 98 kHz, whereas the mechanical effect threshold was comparatively higher than the cavitation threshold at high frequencies.

5. Distribution of broadband noise and sound pressures in sonochemical reactor

To study the sonochemical reaction field in a sonochemical reactor, the cross-sectional area distribution of broadband noise was measured using a needle-type hydrophone at 130 and 43 kHz. Two directions in the sonochemical reactor horizontal and vertical directions were scanned at one-millimeter interval. At 130 kHz, the ellipse shape of reaction fields were obtained. Along the vertical direction, the sonochemical reaction field was more powerful in the upper part of the reactor. In the distribution of the sound pressure at the fundamental frequency, standing waves were obtained and reaction fields were weak at pressure antinodes. In the distribution of the sound pressure at the second harmonic frequency, the data showed that the pattern of bubbles distribution resembled to that of reaction fields closely. At 43 kHz, the distribution of reaction fields and sound pressures were more complicated. The data also pointed out that the areas of reaction fields were comparably weak in areas where high sound pressures at the fundamental frequency were obtained.

6. Application of ultrasonication and silica gel on removal of silicic acid in geothermal water

Ultrasonication combining silica gel seed was used for removing silicic acid in geothermal water. Ultrasonication was proven the ability of enhancing the removal of silicic acid by silica gel seed and the enhancement ratio increased with increase silica gel concentration. All the parameters of pH, ultrasonic frequency, particle diameter of silica gel, and pore size of silica gel largely affected the removal of silicic acid. The switching frequency of 500 kHz and 28 kHz indicated higher efficiency in removing silica acid compared to single frequency.