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Frequency Dependence of Threshold Values for White Noise, Chemical and Mechanical Effects

ホワイトノイズ、化学・機械的効果のしきい値の周波数依存性

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1. Introduction

Acoustic cavitation originating from interaction between sound waves and bubbles in liquid is the initiation of the chemical and mechanical effects of ultrasound, and therefore has increasingly been used in the wide range of applications such as sonochemistry, cleaning, food processing, medical diagnostic and therapy.[1)] However, a sufficient understanding and control of acoustic emissions from cavitating bubbles are of considerable importance to applied ultrasonic technologies, since they might cause significant damage on objects during ultrasonic treatment or the healthy cells of human bodies. For this reason, this work was carried out with the aim of investigating the cavitation threshold from 24 kHz to 5 MHz by measuring BIV (Broad Integrated Voltage) of white noise emitted from acoustic cavitation.

Additionally, the thresholds of chemical and mechanical effects produced by ultrasonic energy were experimentally studied together with cavitation threshold. KI (Potassium iodide) oxidation dosimetry was used to examine the threshold of chemical effect. Mechanical effect threshold was quantified by observing the degradation of PEO (Polyethylene oxide) in *t*-BuOH (tert-butanol) aqueous solution.

2. Experiment

2.1. Materials

Prior to each experiment, distilled water was bubbled to air-saturated condition and kept constant at 298 K. All chemicals, analytical grade were used without any further purification. KI concentration was 0.1 mol dm^{-3}. PEO with a molecular weight of 900,000 was used as concentration of 2 g dm^{-3} dissolved into *t*-BuOH solution (100 mM) as a radical scavenger. Sample volumes were 50 and 25 cm^3 for experiments at 24 – 500 kHz and 1 – 5 MHz, respectively. All experiments were performed at 298 K.

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2.2. Experimental setup

A variety of directly sonochemical reactors were utilized in this study including Langevin transducer 45 mm in diameter for 24, 43 and 129 kHz, disc transducer 50 mm for 493 kHz and 20 mm for 1 and 5 MHz.

In order to measure generated acoustic pressure and BIV, the tip of the calibrated hydrophone (ONDA – HRN 0500) was located at the position where the highest acoustic pressure was achieved in the reaction vessel. The schematic diagram of this experiment is illustrated in **Fig. 1**. All experiments were conducted in the set of increasing applied power to avoid hysteresis effect.

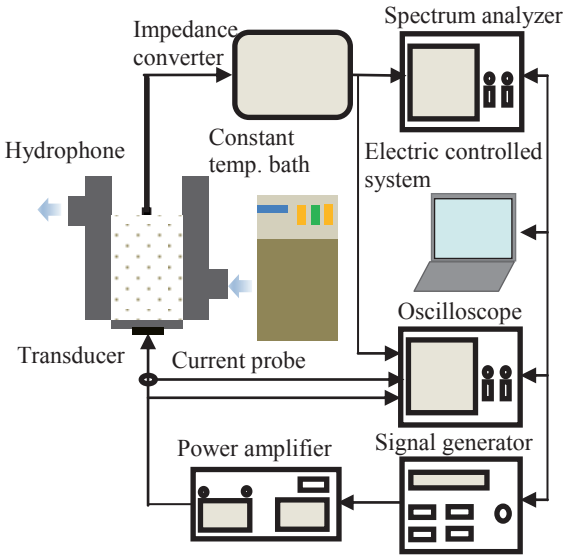

Fig. 1 Experimental setting for acoustic pressure and BIV measurement.

KI oxidation reaction and PEO degradation were performed using experimental setting in **Fig. 1** except for hydrophone, impedance converter and spectrum analyzer.

I_3^- concentration in KI solution after sonicated in 5 minutes was measured by a UV spectrometer (UV-1600 Shimadzu) at 352 nm.

Viscosity of 5 minutes irradiated PEO solution in the presence of *t*-BuOH was measured at 298 ± 0.1 K by using an Ubbelohde viscometer.

3. Results and discussion

White noise of acquired signals from the hydrophone was manually extracted first and then BIV was calculated.[2)] Acoustic pressure increases linearity with the increasing of square root of electric input power, but as white noise appears, it becomes unstable. Thus, cavitation threshold is considered to be the beginning of acoustic noise appearance as shown in **Fig. 2**.

Fig. 3 represents the identifying of threshold of chemical effect at 493 kHz. It is regarded as acoustic pressure when KI oxidation reaction first takes place by increasing electric input power applied to transducer. In other words, when chemical reaction rate calculated from measured absorbance of liberated I_3^- starts to be perceived, threshold value is able to be received.

In **Fig. 4**, the viscosity ratio of sonicated and non-sonicated solutions is assessed so as to determine mechanical effect threshold at the smallest applied electric power for degrading polymer chains under sonication condition.

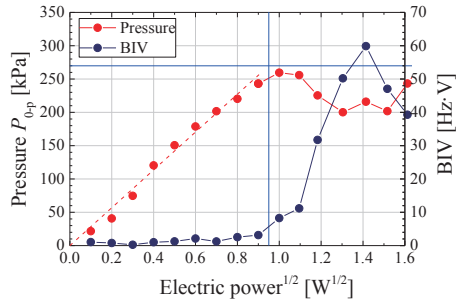

Fig. 2 Acoustic pressure and BIV against square root of electric power at 129 kHz.

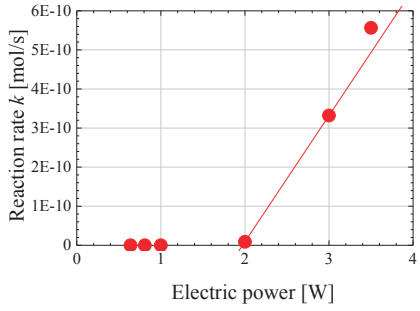

Fig. 3 KI reaction rate against electric power at 493 kHz.

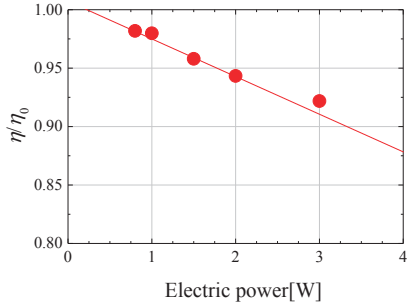

Fig. 4 Viscosity ratio of PEO in *t*-BuOH against electric power at 43 kHz.

Practically, the chemical and mechanical effect thresholds were obtained from the relationship of acoustic pressure and electric power.

Results indicate that cavitation threshold increases with increasing ultrasonic frequency. As the frequency increases, duration of pressure oscillation decreases, that is, the period of rarefaction phase caused by the ultrasonic waves comes to be shortened. Consequently, it becomes more difficult to generate acoustic cavitation at high frequencies.

Fig. 5 also shows that increasing in frequency leads to the increment of thresholds of chemical and mechanical effects. However, as compared to cavitation threshold those data are relatively higher at low frequency range (from 24 kHz to 500 kHz). This is because a certain amount of cavities is needed to produce ultrasonic effects in terms of providing reactive radicals, shock wave or micro-jet. On the other hand, mechanical or physical effect threshold at very high frequencies slightly changes perhaps due to the elevated acceleration in solution.

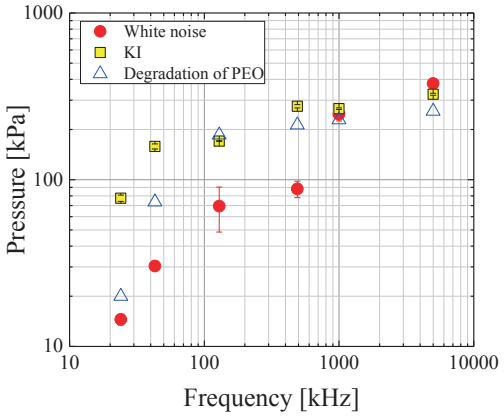

Fig. 5 Dependence of threshold of cavitation, chemical effect and mechanical effect on frequency.

4. Conclusion

The thresholds of cavitation, chemical effect and mechanical effect induced by ultrasound were investigated in the sonic frequency range of 24 kHz – 5 MHz. The result presented the increasing tendency of those thresholds as frequency increased. Values of three thresholds here, however, differed markedly, especially at low frequency region.

References

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2. T. Uchida, H. Sato, S. Takeuchi and T. Kikuchi: Jpn. J. Appl. Phys. **49** (2010) 07HE03.