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Sonochemical Reactions under Single and Dual Frequency in Different Geometry

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1. Introduction

Dual-frequency ultrasonic irradiations have been applied to a variety of sonochemical and sonophysical reactions Combinations of various frequencies ranging 20 kHz to 1MHz were optimized. Sonochemical and sonophysical reactions were enhanced significantly more by the dual-frequency system than by the single-frequency system, so it was concluded that the reactions were enhanced by the synergistic effects of the dual-frequency irradiation [1-5].

However there was rarely research on analysis of the energy consumption. Thus it was required to estimate the degree of reactions in single and dual frequency systems with respect to economy and engineering, that is, electric energy consumption for the industrial use. Ultrasonic reactions were affected substantially by the geometry of sonoreactors because geometrically different sonoreactors produce different ultrasonic /cavitational energy fields. Especially a slight variation of the irradiation distance from the source to the opposite wall, acting as a reflector, could result in significant change of the sonochemical reactions [6].

Thus the purpose of this study was to estimate the sonochemical reactions based on the analysis of energy consumption and to optimize the geometry of sonoreactors for dual frequency irradiation systems.

2. Experimental Methods

Figure 1 shows a schematic of the dual-frequency sonoreactor used in this study. It consisted of an acrylic bath and one ultrasonic transducer modules (Mirae Ultrasonic Tech.) at each side. The transducer module contained one lead zirconate titanate (PZT) transducer (Tamura). Applied frequency was 35, 72, 170, 300, 500, and 1000 kHz. Input electric power was measured by a multi-meter (METEX M-4660M) and fixed at about 70 W for one transducer.

The temperature in the solution was measured at several locations during ultrasound irradiation using a thermometer (Tecpel DTM-318) and ultrasonic power modified by calorimetry was obtained as follows:

$$Ultrasonic\ Power = (dT/dt)\, c_p\, M \qquad (1)$$

where dT/dt was the rate of temperature increase in the solution, c_p was the heat capacity of the solution (water), and M was the mass of the solution.

Sonochemical reactions were estimated under various conditions using a potassium iodide (KI) solution. When ultrasound is irradiated to a potassium iodide solution, iodine (I_2) can be liberated from the iodide ion (I^-) due to radicals generated by cavitation event. Subsequently, the liberated iodine and the excess iodide ion react spontaneously and form a triiodide (I_3^-) ion. The concentration of the KI solution in this study was 10 g/L. The irradiation time was 60 min. The concentration of triiodide ion was measured at 350 nm using an ultraviolet/visible (UV/vis) spectrophotometer (Analyticjena SPECORD 40).

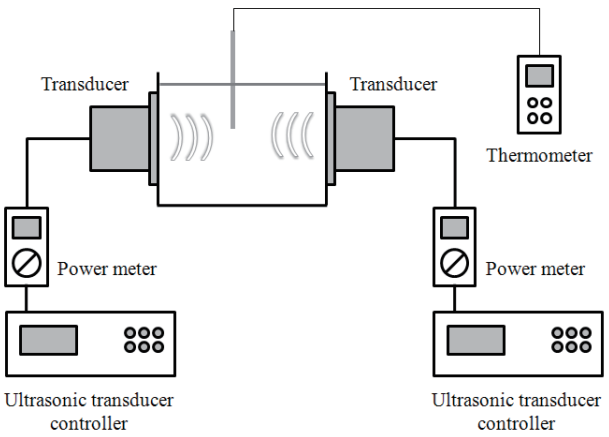

Fig. 1 Schematic of dual-frequency sonoreactor.

3. Results and Discussion

Fig. 2 shows triiodide ion concentrations under single and dual frequency conditions. In the single frequency the highest values were obtained at 35, 72, and 1000 kHz while combination of 35 and 500 kHz was optimal in the dual frequency. The

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value of 35/500 kHz in dual frequency was larger than algebraic sum of 35 and 500 kHz in single frequency. However it was found that the combination of 35 and 500 kHz did not result in synergistic effect because the normalized value of 35 kHz in the single frequency by electric energy was slightly larger than the value of 35/500 kHz in dual frequency. Thus no synergistic effect was obtained for these combinations of frequency in this geometry.

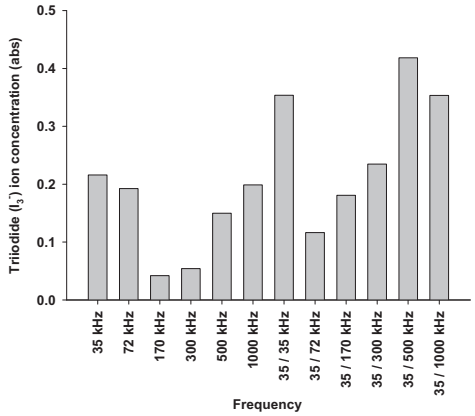

Fig. 2 Triiodide ion concentrations under single and dual frequency conditions.

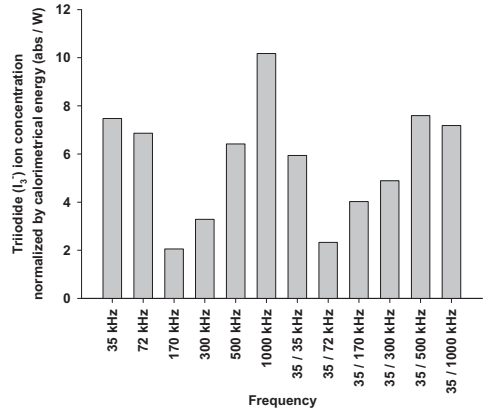

Fig. 3 Triiodide ion concentrations normalized by calorimetric energy under single and dual frequency conditions.

Table 1 shows ultrasonic power by calorimetry, the input electric power by multi-meter, and the ratio of ultrasonic power to input electric power for single frequency and dual frequency. Fig. 3 and Fig. 4 show triiodide ion concentration normalized by calorimetrical energy and electrical input energy, respectively.

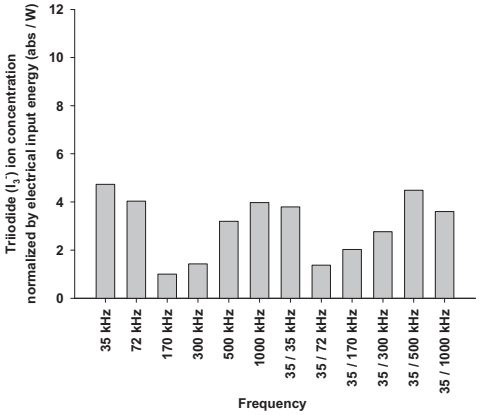

Fig. 4 Triiodide ion concentrations normalized by electric input energy under single and dual frequency conditions.

Acknowledgment

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Table 1. Ultrasonic energy, electric energy and ratio of ultrasonic energy to electric energy under single and dual frequency conditions

Frequency	Single frequency (kHz)						Dual frequency (kHz)					
	35	72	170	300	500	1000	35/ 35	35/ 72	35/ 170	35/ 300	35/ 500	35/ 1000
Ultrasonic energy by calorimetry (W)	48.0	46.6	33.9	27.4	38.8	32.5	98.8	82.9	74.7	79.8	91.5	81.7
Electric energy by multi-meter (W)	75.8	79.2	70.0	63.2	77.8	83.1	154.7	140.4	148.4	141.0	154.8	163.1
Ratio of ultrasonic energy to electric energy (%)	63	59	49	43	50	39	64	59	50	57	59	50