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Non-contact atomizer of droplets changing surface tension and viscosity by aerial intense ultrasonic waves

液滴の表面張力及び粘度が異なる場合の強力空中超音波による非接触微粒化

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1. Introduction

Currently, mass spectrometers require atomization of the liquid to be analyzed. There are several ways to atomize liquids, such as evaporation by heating and contact with an ultrasonic vibration surface [1]. However, these methods can cause changes in the liquid's properties (heating), introduce contaminating impurities (contact ultrasonication), or result in degradation of the device by the liquid. We have previously considered non-contact atomization by ultrasound as a means to solve these problems. However, the formerly proposed equipment is large. Here, we report development of an ultrasonic sound source, operating at 28 kHz, that has been miniaturized. We conducted a study of particle size distribution by measuring particle diameters of droplets atomized by the ultrasonic sound source [2].

In this paper, the atomized particle diameter distributions of water, ethanol, and glycerin are compared to study cases of liquids with different surface tensions and viscosities.

2. Ultrasonic Sound Source

Figure 1 shows a schematic diagram of the ultrasonic source. The ultrasonic source is structured by connecting an exponential horn for expanding the amplitude to 28 kHz with a bolt-clamped Langevin-type ultrasonic transducer and combining two small rectangular transverse-vibrating plates to the point of the horn by inserting them between two resonance rods. The two vibrating plates are placed at equal distance from the antinode of the longitudinal wave that propagates between the resonance rods, and a space is inserted between the plates to form a standing wave field in which half-wavelength sound wave propagates in the air. The vibrating plates have length 46 mm, width 25 mm, and thickness 3 mm. The X-axis is along the length of the vibrating plate, the Y-axis is along the width of the plate, and the Z-axis is normal to the vibrating plate.

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3. Sound Pressure Distribution in Vibrating Plates

Figure 2 shows the sound pressure distribution in the XZ-plane of the standing wave field from the vibrating plates. In the figure, the X-axis is horizontal and the Z-axis is vertical. The sound pressure is indicated in normalized values. The sound pressure has its node at Z = 3.25 mm (at the center of the Z-axis) and antinodes at the vibrating plate surfaces. From this result, it is clearly seen that a standing wave field is formed between the vibrating plates.

4. Study of particle diameter distributions with different surface tensions and viscosities

The distribution of particle diameters was determined by measuring the diameters of particles atomized by aerial ultrasonic field. Water, ethanol, and glycerin were used as the liquid. The surface tension, viscosity, and density of these liquids are shown in **Table I**. The insertion position for each

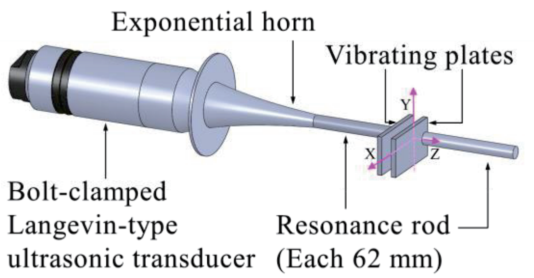


Fig. 1 Schematic diagram of the ultrasonic source.

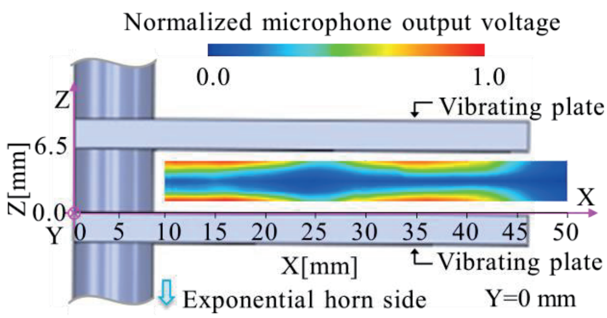


Fig. 2 Sound pressure distribution in the XZ-plane.

sample liquid droplet (5 μL) is the position where atomization happens most easily, at X = 35.0 mm, Y = 0.0 mm, Z = 3.25 mm.

4.1. Method of measuring particle diameter

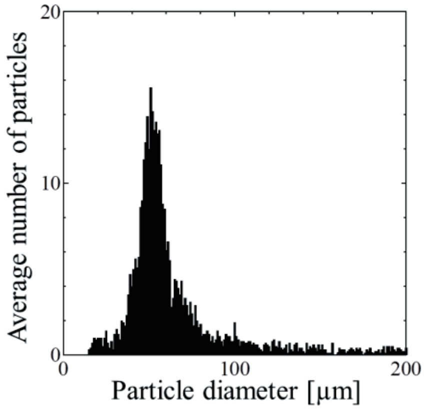
The constant input power is 7 W, and the atomized particles are received by silicone oil (viscosity: 1000 mPa·s), and these were photographed by the camera. The collected samples are a part of the atomized particles. All measurement was carried out within 60 s of atomization in order to prevent evaporation or precipitation of the droplets. To improve reliability, 10 sets of measurements were collected under the same conditions for each liquid, and the averages were taken.

4.2. Measurement results

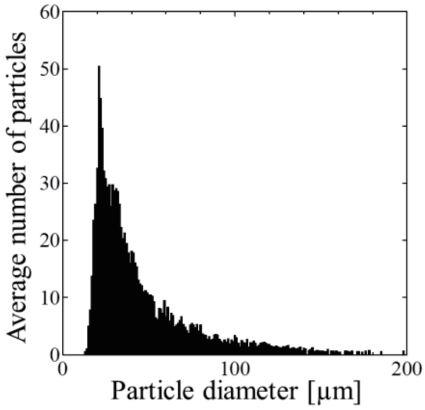
Figures 3 (a)–(c) show the particle diameter distributions for water, ethanol, and glycerin, respectively. From the figure, it can be seen that the median diameter is 54 μm for water, 35 μm for ethanol, and 45 μm for glycerin. In addition, these can be checked by comparison with the result from Lang's equation [3]. This is given by

$$D = 0.34\left(\frac{8\pi T}{\rho f^2}\right)^{1/3},$$

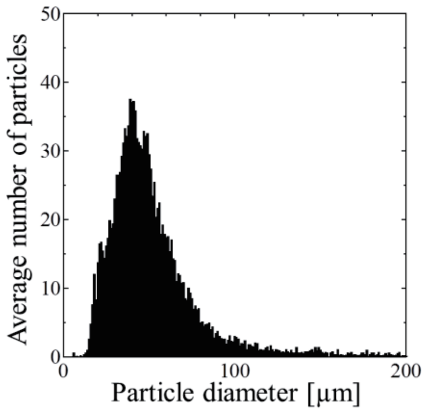
where T is the surface tension, ρ is the density, and f is the drive frequency. The results of calculating the median particle diameter D in this way are shown in Table 1. The calculated median is 45 μm for water, 32 μm for ethanol, and 39 μm for glycerin. These agree closely with the median values found by measurement. From these, the median diameter of fine particles is low when surface tension is low. The reason is considered to be because the particles are easy to atomization when the surface tension is low. The average number of particles was observed to differ by the density of the liquid. In spite of high viscosity, the median particle diameter of glycerin changes only with changes in surface tension.



(a) Water



(b) Ethanol



(c) Glycerin

Fig. 3 Particle diameter distributions.

Table I Characteristics of tested liquids.

	Water	Ethanol	Glycerin
Surface tension [mN/m]	72.8	22.4	57.3
Viscosity [mPa•s]	1.0	1.2	81
Density [g/cm^3]	1.0	0.8	1.2
Median particle [μm] (Measured value)	54	35	45
Median particle [μm] (Lang of empirical formula)	45	32	39
Average number of particles (Measured value)	383	1167	1474

5. Conclusions

The particle diameter distributions were compared for three liquids with different characteristics. As the results, the median diameter of particles from each atomized droplet becomes close to the values theoretically calculated with Lang's equation. In addition, the median particle diameter was smaller when surface tension was low.

References

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