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Ultrasonic atomization using a vibrating small gap

微小振動空隙を用いた超音波霧化法

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1. Introduction

Ultrasonic atomization has been utilized as an inhaler and a humidifier since it can generate mist with particle size of several µm or around 10 µm without elevating temperature. However, it is difficult to produce a large amount of fine mist, because there is an inverse proportionality between the driving frequency and the particle size. High frequency transducer of MHz region can produce fine mist, but its radiation surface is too small to process a large volume. Until now, various studies have been performed for increasing the volume with keeping the samll particle size[1-3].

In this study, we investigated an ultrasonic atomization principle using a small gap between a vibrating surface and a rigid wall. The particle size in the method is determined mainly by the gap and is smaller than that in the conventional dependence on the frequency[4]. A large volume of small particles of around 10 µm of diameter can be produced by the vibrating gap even at lower frequencies in several 10 kHz.

2. Principle

Figure 1 illustrates the concept of the working mechanism of the proposed atomization. A vibrator surface is faced to a rigid wall via a small gap. The gap is filled with water to be atomized. The gap width is changed periodically at the ultrasonic frequency as the vibration, where the vibration displacement amplitude has finite quantity in comparison with the gap width. In the figure, a cycle of the vibration is divided into four phases (a)-(d). In the compression state, (b)-(c), a film of water is squeezed by the vibrator displacement, and a droplet is teared off from the edge of the film. Water is automatically guided to the top end of the gap due to the vibration.

3. Configuration

Atomization system used in the experiments is shown in **Fig. 2**. The vibration system is composed of a duralumin ring of 69.1 mm in inner diameter and a Langevin transducer with a stepped exponential horn for the amplification of the vibration displacement amplitude. The vibration system is fixed at the flange installed at the node of the horn. The ring's thickness is tapered to have a higher vibration displacement at the top edge of the ring. The seventh twist-flexural mode is excited along the circumference of the ring. The straight part of the ring is 10 mm, and the taper is 13.5°. The vibration amplitude at the top end is almost three times higher than the bottom due to the tapered cross-section. A duralumin cup is inserted into the ring with the gap of 10-100 µm. The mist is generated from the top end of the gap, while water is automatically conveyed from the bottom to the top of the ring due to the vibration. Water is conveyed at the anti-node of the vibration. Since the seventh twist-flexural mode was excited, the water is pumped up at 14 places along the circumference.

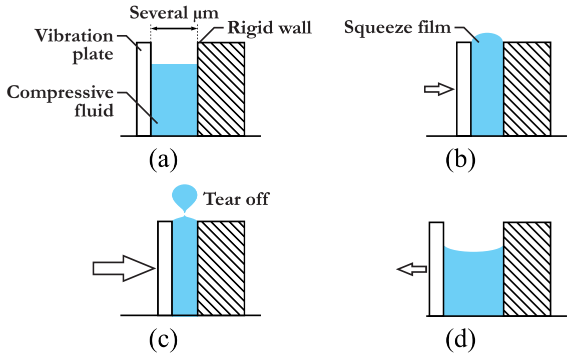

Fig. 1 Sequence of the atomization in the vibrating gap.

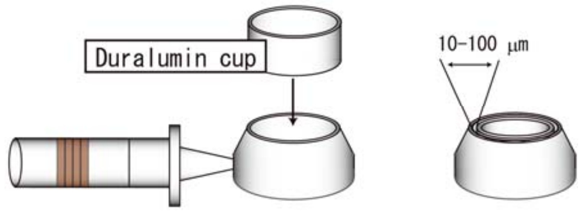

Fig. 2 Vibration system using gap formation between the ring's inner surface and the duralumin cup.

4. Atomization experiment

The transducer is fixed at the flange of horn and the vibration ring is made in parallel to a base. Electrical power is fed by a power amplifier and a function generator. The ring's bottom is dip to water bath. The vibration velocity at the top of the ring is

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kept at 0.6 m/s. The gap was changed between 10-100 μm, and the particle size of the mist was measured at the several driving frequencies.

The particles were captured by silicon liquid placed on the slide glass and observed by using a microscopic camera connected to PC. The pictures were analyzed, and the diameters of 1000 particles were measured.

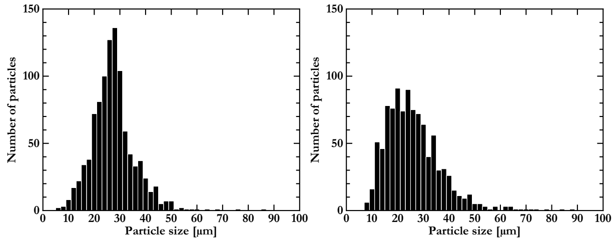
5. Results

Figures 3 shows particle distribution for the frequency of 33 kHz. The standard deviation are (a) 8 μm, (b) 11 μm, (c) 13 μm and (d) 19 μm. As shown in **Fig. 4**, the particle size is dependent on the gap width and the driving frequency. Smaller particles are obtained at 37 kHz than 26 kHz. The particle size of 21 μm was obtained for 37 kHz and the gap width of 31 μm. By fitting the measured data with an assumed experimental curve $D = A\{1-\exp(-G/\alpha)\}$, α can be determined by the least-square method using the measured values. Here, D is the particle size, G is the gap width and A is the measured size at the infinite gap. The calculated particle sizes at the assumed gap of 20 μm are compared with Lang's experimental formula[4] as shown in **Fig. 5**.

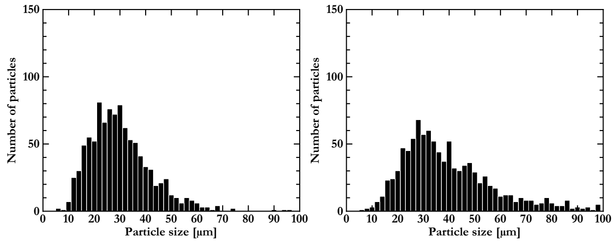
Atomization volume at 26 kHz was measured as shown in **Fig. 6** for the gap width of several 10 μm. From the figure we can see that the smaller gap width, the smaller amount of the atomization volume. The atomization volume of 7 cm^3/min was obtained for the gap width of 25 μm. Using the approximate equations the measured data can be expressed as $V = 0.38G$ at 26 kHz, where V is the atomization volume and G is the gap width.

6. Conclusions

We studied the setup for ultrasonic atomization using a small gap between a vibrating ring and a wall. The models with different frequencies were made for trial and the experiments were carried out. Water was drawn up along the gap by the vibration and mist with the small particles could be generated at the outlet of the gap. Smaller particle size was achieved at lower frequency than the conventional methods. In the present configuration, the area for atomization can be easily enlarged for higher volume of mist generation. However, the actual demonstration for the increase in the atomization area and the atomization volume is left for future study.



(a) Gap width of 31 μm. (b) Gap width of 69 μm.



(c) Gap width of 76 μm. (d) Infinite gap.

Fig. 3 Particle distribution at 33 kHz.

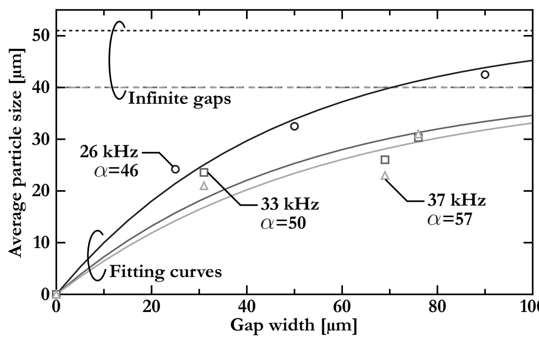


Fig. 4 Particle size as functions of the gap width.

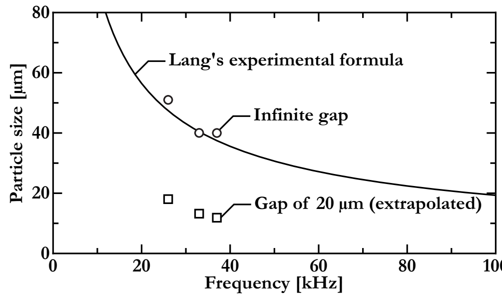


Fig. 5 Comparison between the calculated Particle size and Lang's experimental formula.

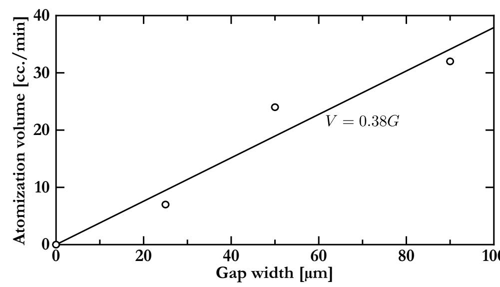


Fig. 6 Atomization volume versus gap width at 26 kHz.

References

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