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Noncontact Mixing of Droplets Using Ultrasonic Levitation
超音波浮揚による微小液滴の非接触混合

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1. Introduction

Noncontact techniques for handling liquids are highly required in pharmacy industry and in biotechnolgy. We have so far demonstrated noncontact transportation of liquid droplets using ultrasonic levitation [1,2].

In this study, we tried, for the first time, a noncontact mixing of two types of liquid droplets using ultrasonic levitation. The two droplets, levitated at the different nodes of the standing wave, were mixed by slightly moving the reflective object.

2. Principle

The liquid droplets are levitated at the nodes of the standing wave field generated with a ring-type vibrator outside and a concentric ring-type reflector inside (See **Fig. 1**).

There are four methods for mixing the levitated droplets: (1), generation of circumferential traveling wave by exciting the degenerate modes by 90º phase difference; (2), switching of the sound field mode by controlling the driving frequency; (3), controlling the sound field mode or its intensity by moving the vibrator or the reflector; and (4), controlling the sound field mode or its intensity by modulating the driving voltage.

We tried the method (3) for the first demonstration, where the balance between the acoustic radiation force and the gravity is controlled by moving the vibrator or the reflector, resulting in the movement of the droplets. The two droplets, levitated at the different nodes, are circumferentially moved and mixed by changing the sound field.

3. Experimental setup

Figure 1 shows the experimental setup. A Langevin transducer with a horn excites an expansion vibration mode of an aluminum ring at 25.9 kHz, and an acrylic reflector is fixed in the ring. The droplets, injected using automatic gathering nature of the atomized liquids, were levitated between the aluminum ring and the acrylic ring. The sound field mode used in the experiment had one nodal circle and twelve nodal lines, as depicted in **Fig. 2**.

The sound field distribution is measured as the modulation in optical path length using a laser Doppler vibrometer (LDV) with a wavelength of 633 nm. The sound pressre p is known to be expressed as [3]

$$p = \frac{n}{n-1} \cdot \frac{c^2 \rho}{2\pi f l} \cdot v_{\mathrm{LDV}}, \qquad (1)$$

where n is the refractive index of air (= 1.0002764), c the sound velocity (= 346.51 m/s at 25ºC), ρ the density of air (= 1.184 kg/m^3), f the frequency of the sound field, l the sound field length (= 30 mm), and v_{LDV} the velocity measured by the LDV. The sound fields in the circumferential direction from 0 to 180º (See **Fig. 2**) are measured by changing the reflector position. The gap L between the vibrator and the reflector is defined at the angular position of 90º.

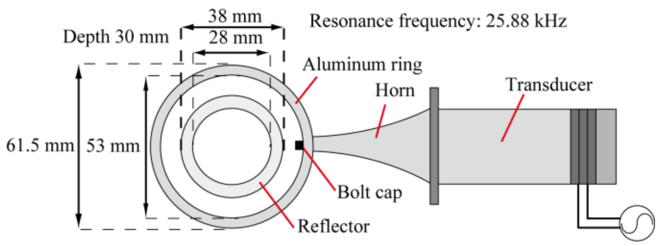

Fig. 1 Experimental setup.

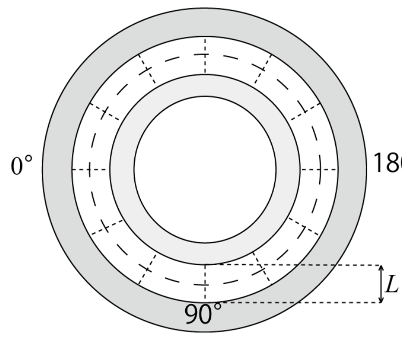

Fig. 2 Sound field modes between the two rings.

4. Experimental results

4.1. Levitation and mixing of two droplets

In the experiments, water was used as droplets. By atomizing water near one of the nodes, two droplets were generated and levitated at different nodes as shown in **Fig. 3(a)**. Then, the two droplets

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were mixed using the method (3). By slightly shanking the vibration ring outside, the sound field magnitude was modulated. **Figs. 3(b)-(d)** represent the process of the mixing.

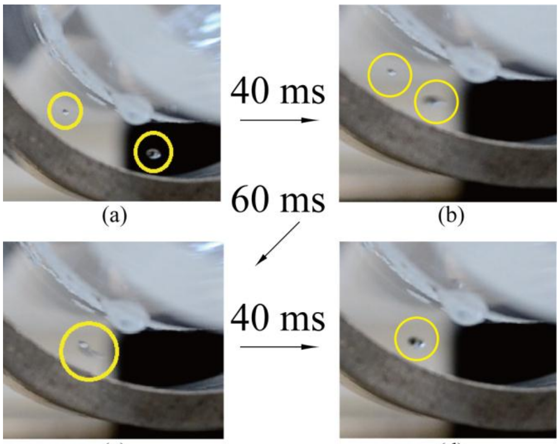

Fig. 3 Process of droplet mixing: photos of (a), droplets levitated at different nodes; (b), droplets moved by the modulated sound field intensity; (c), droplets that have begun to mix induced by surface tension; and (d), a mixed droplet.

4.2. Sound field measurement

Figure 4 shows the measured sound field intensity in the circumferential direction. When the angle (See Fig. 2) was 90º, the sound pressure for L = 7.5 mm (when the two rings are concentric) was higher than that for L = 10 mm. Around 90º, where the mixing was performed, hardly any shift of the nodes was obtained. **Figure 5** shows the measured maximum sound pressure as a function of the gap L. Significant change in the maximum pressure was observed around L = 7 mm.

Therefore, the principle of the mixing should be as follows: (1) when the vibration ring moved downward, the sound pressure was reduced, the acoustic radiation force became lower, and the droplets moved in the circumferential direction due to the relatively large gravity, leading to the mixing of the two droplets; and then, (2) when the vibration ring returned to its initial position, the sound pressure was recovered, and consequently, the mixed droplet was trapped by the strong sound field around 90º.

4.3. Observation of mixed droplet state

We added black ink to the levitated droplet, and observed its temporal change, as shown in **Figs. 6(a)-(c)**. The droplet appeared to be rotating (flow was not clarified) [4]. On adding the ink, it concentrated on the center of the droplet for the first several seconds (**Fig. 6(b)**); and then diffused throughout the droplet, but still the ink concentration seemed to be higher at the center of the droplet than that around the surface (**Fig. 6(c)**).

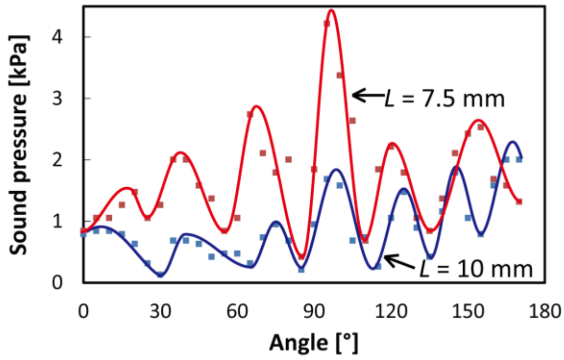

Fig. 4 Sound pressure vs. angle.

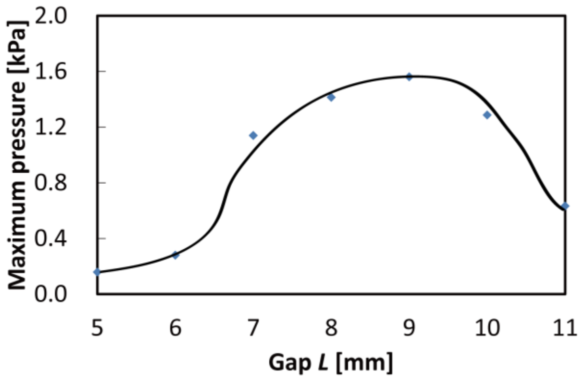

Fig. 5 Maximum sound pressure vs. gap between the vibration ring and the reflector.

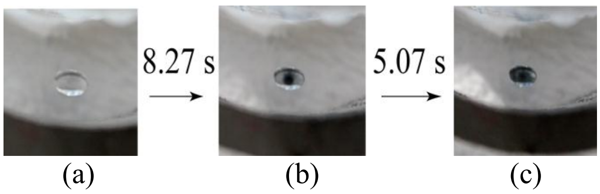

Fig. 6 Observation of ink diffusion.

5. Conclusion

Ultrasonic noncontact mixing of liquid droplets was demonstrated, for the first time, based on the modulation of the sound field intensity. We also confirmed that the mixed droplet might have stirring effect. Since this method is not stable due to atomization of the droplets themselves, we will investigate the other methods (1), (2), and (4).

References

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