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Study of physical property of micro droplet impacted on substrate through observation of vibration behavior.

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1. Introduction

In the paint industry, spray coating is one of versatile tools. In addition, not only various types of spray coating system, but inkjet system has become popular. It is important to study micro-sized droplets' behavior at the phenomenon to control properly. However, current viscosity measurement systems, such as rotational rheometer or capillary rheometer are not necessarily suitable for analysis of spray coating system. What is common problem is that paint droplets are generated under very high shear rate. According to the previous studies, the order of it is around 10^5 to $10^6 s^{-1}$ [1]. In addition, it takes a huge impact when it lands. Afterward, the droplet deforms and vibration on the substrate for a while. In this process, a new air-liquid interface is formed. At that time, a droplet with a diameter of several tens of micrometers is generated from the tube and the droplet flies through the air and then lands on a substrate in microsecond to millisecond order time. In this process, the chemical composition of the droplet can keep changing at each process. Therefore, monitoring physical properties that have changed from moment to moment can close to actual phenomenon, and this is expected to be used as a method of verifying existing theories and gaining new knowledge.

To meet these requirements, some measurement methods have been developed in Sakai laboratory. It can observe directly micro-sized droplets produced by inkjet nozzle with high spatial and temporal resolution. Moreover, some studies proposed that the measurement methods of the dynamic surface tension and viscosity of the droplets in flying process [1,2].

Surface tension works as a spring to recover the sphericity. Droplet deformed by external force oscillates due to this restorative force. On the other hand, viscosity works as a resistance force as a same time. The angular frequency ω is given by,

$$\omega_l = \left(l(l-1)(l+2)\sigma/\rho {R_0}^3\right)^{1/2}, \quad (l \geq 2) \qquad (1)$$

where ρ is the density, R_0 is the droplet radius, and σ is the surface tension. The fundamental mode indicating the oscillation between the prolate and the oblate spheres is expressed by l=2, which indicates that the length of the great circle of the spherical droplet is twice the wavelength. For the hemisphere on a solid substrate, the boundary condition represents that the amplitude at the droplet contact line and substrate is fixed. When the radious of area at which the droplet contacts substrate r is given by,

$$r = (h(2R-h))^{1/2} \qquad (2)$$

where R is curvature radius of the droplet, and h is the height of hemisphere.

The previous studies suggested that the half of the length of the great circle is 3/2 of the wavelength, donated as l=3 [3,4]. This assumption does not provide a strict solution for the oscillation of a hemisphere, in which the boundary condition should be that the flow velocity is zero in all regions of the contact plane between the droplet and substrate.

The surface energy of a surfactant solution is lower than that of a pure solvent because amphiphilic solutes absorb at the surface. Therefore, the diffusion from bulk to surface occurs as liquid flows to form new surfaces to cover the lack of surfactant. This diffusion process is observed as a time variation of the surface tension.

In this study, we have measured surface tension of micro-sized droplet by observing vibration behavior over time just after landing on the substrate.

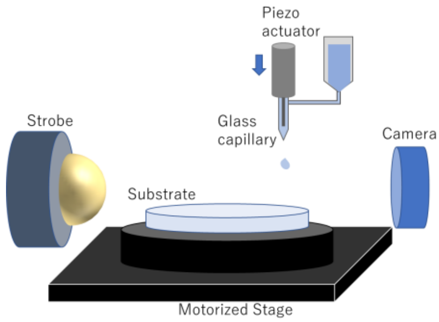

Fig. 1 The schematic diagram of the generative system of micro-sized droplets and the observation system.

2. Experiment

Figure 1 shows the schematic diagram of the generative system of micro-sized droplets and the observation system[5]. The LED strobe light is employed for lighting to observe micro-sized droplet with high temporal resolution instead of the halogen

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light whose heat causes damage to droplet. In the stroboscopic method, a different droplet is observed for each strobe flash.

In this system, the substrate material was glass, and the nozzle diameter was 30 μ m.

We used 1mM, 10mM Sodium dodecyl sulfate aqueous solution (SDS aq.), and distilled water as samples.

Figure 2 shows the diagram of overlapping droplet outlines. The droplet changes its shape with vibration. The diagram shows that the droplet has a joint on each shoulder of the circle. This phenomenon indicates that this droplet behaved as nearly l=3 oscillation mode. The contact angle of the droplet and substrate was around 60 degrees. The rest of two samples showed similar behavior.

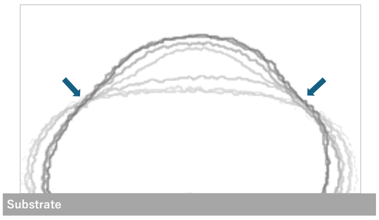

Fig.2 Time variation of droplet's shape.

Figure 3 shows the conversion from each droplet's behavior to coordinates.

The analysis of the oscillation is shown in **Fig. 3**, in which the horizontal axis is the time variation after landing on the substrate. In **Fig.3(a)**, the vertical axis is the displacement of the top of the droplet, i.e., the height of the droplet. On the other hand, in **Fig.3(b)**, the vertical axis is cross section of the area in contact with the substrate, i.e., the width of the droplet. **Fig.3(a)** shows that the height decreases with droplet vibration. This damping behavior can be caused by viscos resistance of each sample. **Fig.3(b)** shows that the expansion and contraction of droplet of each sample. Although the width of distilled water droplet remains constant throughout the observation time, while in SDS aq., the width spreads just after landing due to the impact of landing and hardly changes after that. This result indicates that the surface tension of SDS aq. slightly decreased because SDS migrated to the air-liquid interface in an extreme short time. Similar results by measuring surface tension from the vibration of a droplet in flight have been reported in the previous research[2].

Furthermore, we studied the migration of SDS to the air-liquid interface over time with respect to droplet. The migration tendency was determined by calculating frequency for each position period and assessing the rate of change relative to the first frequency. The results show in **Fig.4**. For example, No.1 means the frequency of droplet just after landing on the substrate. Although the width of distilled water droplet remains constant throughout the observation time, while in SDS aq., the value of frequency tends to decrease with time. In addition, the higher concentration of SDS is, more prominent change has been appeared. This result indicates that SDS move to the air-liquid interface.

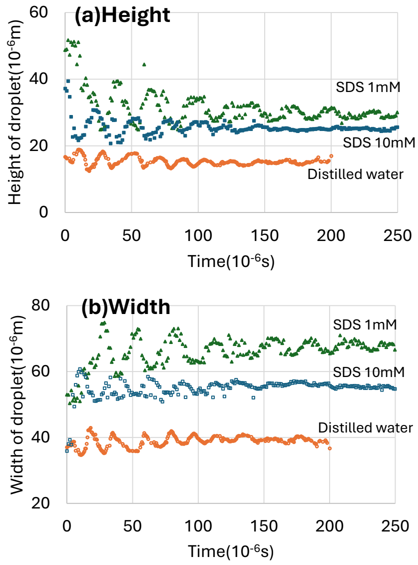

Fig.3 Time variation of droplet's vibration behavior **(a)**Height, **(b)**Width.

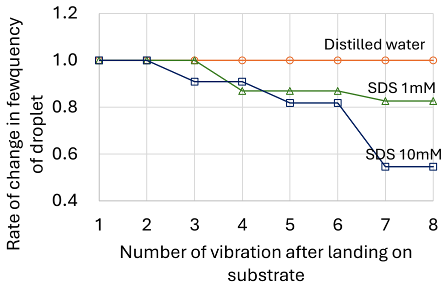

Fig.4 Rate of change in frequency of droplet.

3. Conclusion

With observing the vibration behavior of micro-sized droplet after injection and landing on the substrate with high resolution and time resolution, we captured surfactant migration from the bulk to the air-liquid interface in a very short time.

References

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