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Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 101-102
3-5 December, 2014

Capture of nano particle by using ultrasonic nebulizing

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1. Introduction

It is very important to obtain a single state of nano particle for practical application of nano technology. In order to improve the functionality of products using nano particles, more precise control over particle size distribution is required in their synthesis process. However, synthesized nano particles are agglomerated due to physical and chemical reasons, and it veils the unique properties of nano particles and disturbs their practical use[1,2]. Therefore, extensive studies have been carried out on the dispersion method of nano particle. However, it is hard to obtain non-agglomerated nano particles by the conventional methods. Recently, ultrasonic atomizing method for water droplet has been reported[3]. In this study, we propose a collecting method for non-agglomerated nano particles from suspension by using the droplets as the separation space. The condition to include nano particles in the droplet scattered by an ultrasonic nebulizer is derived theoretically, and the particle size distribution of the particles is calculated with different surface tensions of the suspension. The theoretical results are compared with the experimental one with TiO_2 nano particle.

2. Theory

When a nano particle is in a droplet from an ultrasonic nebulizer, the nano particle has relative acceleration because the droplet is catapulted out of the ultrasonic capillary wave with acceleration a. The force acting on the nano particle, F_e is given by Eq. (1) when the nano particle is assumed to be a sphere.

$$F_e = \frac{4}{3}\pi r^3 \rho_s a\,, \tag{1}$$

where ρ_s and r are the density and the radius of the sphere, respectively. **Figure 1** shows that due to the surface tension, a nano particle is suspended at the interface between air and the droplet scattered by the ultrasonic nebulizer. The total surface tension force F_s, acting around the perimeter, can be presented by

$$F_s = (\tau\cos\beta)(2\pi r\cos\delta) = 2\pi r\tau\cos\delta\cos(\pi-\theta-\delta), \tag{2}$$

where τ is the surface tension of the droplet, θ is the angle of contact between the droplet and the surface of the sphere and δ is the angle between the lines that are joining the point of contact with the droplet at the sphere surface and the center of the sphere. By differentiating Eq. (2), the maximum value of F_s can be obtained as follow:

$$F_{smax} = 2\pi r\tau\cos^2\left(\frac{\pi-\theta}{2}\right), \text{ when } \delta = \frac{\pi-\theta}{2} \tag{3}$$

The buoyancy force, F_b, can be evaluated from the mass of liquid which is contained in the spherical portion above BC, as following equation.

$$F_b = \rho_l \frac{\pi}{3} x^2 (3r-x)(a-g), \tag{4}$$

where ρ_l is the density of the liquid, g the gravitational acceleration, x the height of the spherical segment. From the relationship

$x = r(1-\sin\delta)$,

the buoyancy force can be represented by

$$F_b = \rho_l \frac{\pi}{3} r^3 (1-\sin\delta)^2 (2+\sin\delta)(a-g). \tag{5}$$

If the acceleration is sufficiently large to satisfy the condition,

$$F_e + F_b \geq F_s\,, \tag{6}$$

the particle must be separated from the droplet. From Eqs. (1), (2), (5) and (6), the critical radius to attach the particle on the droplet is determined by

$$0 < r < \sqrt{\frac{6\tau\cos\delta\cos(\pi-\theta-\delta)}{4\rho_s a + \rho_l (1-\sin\delta)^2 (2+\sin\delta)(a-g)}}\,. \tag{7}$$

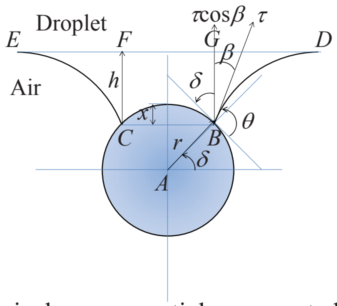

Fig. 1 Spherical nano particle supported by surface tension at the interface between air and a droplet.

3. Experiment

Figure 2 shows the experimental setup. The droplets with nano particles that are scattered by an ultrasonic nebulizer are taken into the condensation chamber by an air pump. Nano particles under a certain size can be captured in the scattered droplets and then the particles can be collected in the condensation chamber. Then, the size of the collected nano particles can be controlled by changing the surface tension of the suspension, as shown in Eq. (7). TiO_2 powder with the standard diameter of 30 nm was used for nano particles, and the suspension was made by stirring up 0.5 g of TiO_2 powder and 500 mL of distilled water. The particle size distribution of the collected nano particles was measured with Scanning Mobility Particles Sizer (SMPS, TSI 3080). To control the surface tension of the suspension, methanol was added to the suspension and the concentration of methanol was 5%, 10%, and 30%. The surface tensions from different concentration of methanol

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were measured with a tension meter (514-B2 Du Nouy Tensionmeter) and the values are listed in **Table I**.

Table I. Change of the surface tension with different methanol concentrations

	Concentration of Methanol[%]	Surface tension[N/m]
Distilled Water	0	72.75×10^{-3}
TiO_2 suspension	0	70.54×10^{-3}
TiO_2 suspension	5	64.17×10^{-3}
TiO_2 suspension	10	59.25×10^{-3}
TiO_2 suspension	30	46.25×10^{-3}

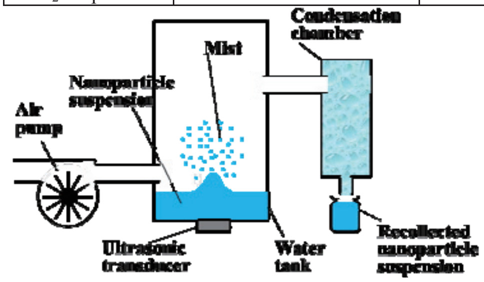

Fig. 2 Schematic of ultrasonic nebulizer.

4. Result

As an example, the size distribution of catchable particles with different surface tensions was calculated using Eq. (7), as shown in **Fig. 3**. Here, the possible contact angle between the nano particle and the droplet surface was given from 0 to 90 degree. This figure demonstrates that the size of the catchable nano particles in the droplet becomes the maximum when the contact angle is 45 degree, and the size of the collectable particles decreases as the surface tension of the suspension decreases. In the calculation, for the values of θ and a, 90° and 15×10^{8} m/s^2 were put respectively.

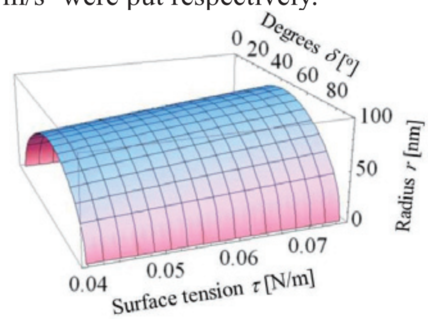

Fig. 3 Distribution of catchable particles with different surface tension.

Figure 4 shows the measurement of the distribution of the collected nano particles by using ultrasonic nebulizer with different surface tension of TiO_2 suspension. In this result, the number of particle in the unit volume is small in the given range, and the particle size distribution shows two peaks at 49.6 nm and 40 nm in the suspension before ultrasonic nebulizing, as shown in Fig. 4(a). It is because most nano particles are agglomerated, and do not appear in the given range. The distribution shows a normal distribution with a peak at 42.9 nm when the TiO_2 suspension with 5% methanol was scattered by the ultrasonic nebulizer, and the number of particle in the unit volume increases, as shown in Fig. 4(b). It means that the particles that are sufficiently small to be captured in the droplets are collected. In the case of 10% methanol suspension, the peak of normal distribution appears at 37.2 nm, and the number of the particle also increases, as shown in Fig. 4(c). It is considered that the possibility of relatively small nano particles being captured in the scattered droplets increases as the surface tension decreases. When the concentration of methanol is 30% in the suspension, the number of the collected nano particles increases, and the peak of the particle size moves to 35.9 nm. From these results, we can see that the peak of collected particle size approaches the standard diameter of the particle, as the surface tension decreases. The tendency in the Fig. 4 coincides with that of Fig. 3.

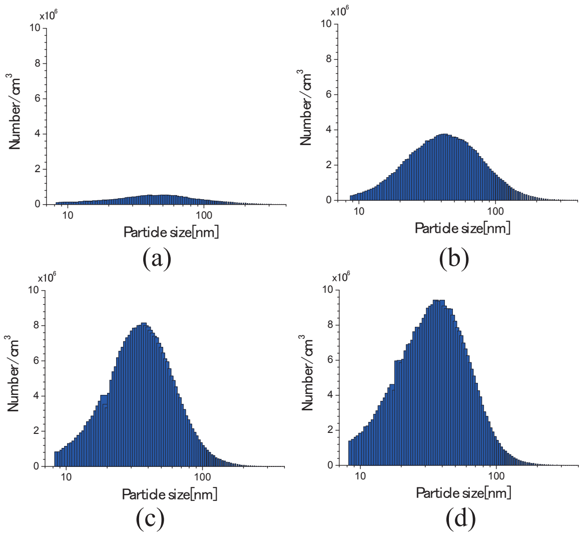

Fig. 4 Particle size distribution of collected nano particle from suspension with different surface tension

5. Summary

In this study, with the ultrasonic nebulizing, a collecting method for the nano particles with intended size from TiO_2 suspension with agglomerated particles was proposed. The relationship between the size distribution of the nano particles, which can be included in the droplets, and the surface tension of the suspension was derived theoretically. The surface tension of the suspension was controlled with methanol, and the particle size distribution of the collected nano particles was measured with different concentration of the methanol. As the surface tension is decreased by the concentration of methanol, mode value of the nano particle diameter decreased and the particle number per unit volume increased. This result agrees with the tendency from the theoretical calculation, thus we can confirm that the nano particles with intended size can be captured from the suspension by controlling of the surface tension of the suspension.

Acknowledgment
This work was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2012R1A1B5001048).

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