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Sound Speed of Nano Particle Suspension Depending on Concentration

Jungsoon Kim[1†], Jihyang Kim[2], Minkun Bae, Kanglyeol Ha[2], Moojoon Kim[2] and Mincheol Chu[3]
([1]Tongmyong University, Korea; [2]Pukyong National University, Korea;
[3]Korea Research Institute of Standards and Science, Korea)

Introduction

As the application fields of nano particles become broad, it is required to measure the concentration of nano particle suspensions precisely[1)]. Even though there are many methods to measure the concentration of suspensions, these methods have many problems in measuring precisely because they could be affected by pH, color, transparency, and electric conductivity of the specimens. To overcome the problems, ultrasonic methods have been developed[2)]. Many studies about acoustic characteristics change in the suspension with concentration of micro particles have been reported[3)]. Even though the theoretical analyses, based on multi-scattering theory, of the acoustic characteristics change have been clarified through experiments, the object of the studies was the suspension of micro particles[4)]. In this study, the sound speed change is observed experimentally in a suspension of TiO_2 nano particles with an average diameter 50 nm. From the results, the possibility to measure the concentration of nano particle suspension can be confirmed.

Theory

The sound speed of the suspension is given by a function of concentration based on multi-scattering theory as shown in the following equation[4)].

$$v = \frac{v_0}{\sqrt{\left(1+\phi \operatorname{Re}\{a_0\}\right)\left(1+3\phi \operatorname{Re}\{a_1\}\right)+6\phi^2\left(\operatorname{Re}\{a_1\}\right)^2}} \quad (1)$$

Here, v_0 is the sound speed in pure solution, ϕ is the concentration, and the coefficient a_n is given by

$$a_n = -\frac{3iA_n}{k^3r^3},$$

and k and r are wavenumber, particle radius, respectively.

The coefficients of the order n = 0 and 1 can be given by

$$A_0 = -i\frac{k^3r^3}{3}\left(1-\frac{\rho k'^2}{\rho' k^2}\right) - \frac{k^2 r v_0 T\rho\tau\left(\dfrac{\beta}{\rho C_p}-\dfrac{\beta'}{\rho' C_p'}\right)^2}{\dfrac{1}{1-iz}-\dfrac{\tau\tan z'}{\tau'\tan z'-z'}},$$

$$A_1 = -i\frac{k^3r^3}{3}\frac{\rho-\rho'}{\dfrac{2(\rho-\rho')}{1+3(1+i)\dfrac{\delta_v}{2r}+i\dfrac{3\delta_v^2}{2r^2}}+3\rho}.$$

In the above equations τ is the thermal conductivity, C_p is the specific heat capacity, ρ is the density, T is the absolute temperature, r is the particle radius, β is the coefficient of cubic expansion, and $z=(1+i)r/\delta_t$ when $\delta_t=\sqrt{2\tau/\omega\rho C_p}$ and $\delta_v=\sqrt{2\eta/\omega\rho}$, ω and η are the angular frequency and the viscosity, respectively.

Variables with primes refer to the properties of the particles, whereas variables without primes refer to properties of the continuous phase.

Experiment

Figure 1 is an experimental system to measure the sound speed change with nano particle concentration. The two identical ultrasonic transducers (A332S-SU, Olympus) with aperture 38.1×6.35mm^2 were used as both transmitter and receiver. The burst wave from signal generator consisted of 20 cycles of 5 MHz. The electric signal was transferred into ultrasound in the transmitter, and the ultrasound was radiated to an acoustic medium in the water tank with 60×30×120 mm^3. The radiated ultrasound was observed in an oscilloscope after it was received by the receiving transducer. The sound speed was measured for different concentrations of TiO_2 nano particle suspensions, acoustic medium, range from 0 to 0.02 wt. % when the distance between the transmitter and the receiver was kept at 80 mm. To make the suspension, TiO_2 powder was mixed with required ratios in 200 g of distilled water, and was exposed to ultrasound of 50 kHz for 30 minutes to disperse.

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kimmj@pknu.ac.kr

Results

To investigate the TiO_2 particle size in the suspension, particle distribution was measured with a particle size distribution analyzer (ELS8000, Otsuka Electronics). Figure 2 shows the particle distribution for the suspension with 0.002 wt. %. The average diameter of the particles can be considered to be 55 nm because the main peak appears at around 55 nm in the results, even though there is a small peak with broad distribution at around 200 nm due to the agglomeration of particles. The distribution result shows well dispersed particles in the suspension. The sound speed of suspension was measured for different concentrations as shown in Fig. 3. The solid line in the figure refers to the theoretical results. The material constants of distilled water and TiO_2 in the calculation are shown in Table 1, and the radius of the particle was 27.5 nm. In the results in Fig.3, as the concentration of the nano particle increases, the sound speed decreases. The tendency of the change in sound speed shows good agreement with the theoretical results. The decrease of sound speed can be explained by the sound scattering effect on the particles, and it shows that the conventional multi-scattering theory can be applied to the nano order particles.

Summary

To estimate the low concentration of nano particle suspensions, the sound speed was measured for TiO_2 suspension. As the concentration of the suspension increased from 0.002 wt. % to 0.02 wt. %, the sound speed of 5 MHz ultrasound decreased. The theoretical calculation result shows good agreement with the measured one. It can be confirmed that the nano particle concentration in suspensions can be estimated by measuring the sound speed.

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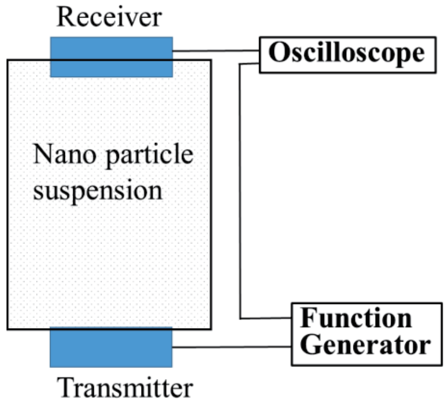

Fig.1 Experimental setup for sound speed measurement in suspension.

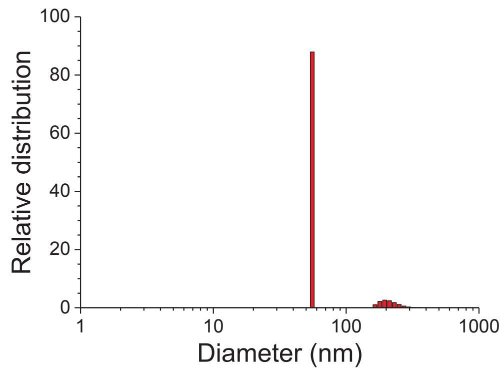

Fig. 2 Particle distribution of TiO_2 suspension.

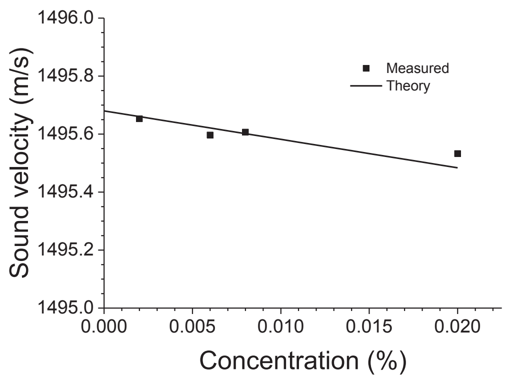

Fig. 3 Sound speed in suspension depending on concentration of TiO_2 nano particle.

Table 1 Material constant for water and TiO_2 used in calculation.

	Water	TiO_2
Thermal conductivity [W/m.K]	0.591	8.3
Density [kg/m^3]	998.2	3980
Sound speed [m/s]	1495.6	7332
Specific heat [J/kg.K]	4182	690
Thermal expansion [10^{-6}/K]	210	10.1
Viscosity [Pa.s]	0.001	-
Shear modulus [GPa]	-	101.4