1P4-27

Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 139-140
18-20 November, 2009

Dispersion method using focused ultrasonic field
集束音場を用いた超音波分散

Misun Jo[1‡], Jungsoon Kim[2], Moojoon Kim[1], Kanglyeol Ha[1], and Mincheol Chu[3] ([1]Dept. Physics, Pukyong National Univ., [2]Dept. Media Eng., Tongmyong Univ.; [3]Korea Research Institute of Standard and Science)
趙美宣[1‡], 金正順[2], 金茂俊[1], 河康烈[1] ([1] 韓国釜慶大 物理; [2] 韓国東明大 情通)

1. Introduction

Dispersion is one of the most important techniques in the High-tech industries.The mixing of powders into liquids is a common step in the formulation of various products, such as paint, ink, shampoo, beverages, and polishing media. The individual particles are held together by attraction forces of various physical and chemical natures, including van der Waals forces and liquid surface tension[1]. The attraction forces must be overcome in order to deagglomerate and disperse the particles into liquid media. The conventional dispersion methods such as ball-mill have a problem that the dispersed material includes impurities from mixing process. The dispersion with high purity is required in the high technology such as semiconductor production[2]. To overcome this problem, ultrasonic dispersion has been suggested and developed. However, the low frequency of about 20kHz used in the conventional ultrasonic dispersion is not appropriate to disperse the nano-particles. Moreover, the acoustic field distribution is not uniform in the water because of limited container size, and it makes the ununiformity in the dispersion. In this study, a new dispersion method is suggested using the focused ultrasonic field. The acoustic fields and the shock wave pulse from the cavitations are investigated. Some nano particles are dispersed with the focused fields, and the effectiveness is confirmed.

2. Theory

To calculate the acoustic pressure in center of cylindrical piezoelectric vibrator, the coordinate system is shown in **Fig. 1**. For the simplification, it is assumed that the vibration of the transducer has symmetry to *z*-axis, and the wave number of *z*-direction could be ignored. Therefore the acoustic pressure is assumed to be a function of only *r*. Under these assumptions, the acoustic pressure could be given by[3],

$$p(r,t) = j\omega\rho \frac{J_0(kr)}{kJ_1(ka)} v_0 e^{j\omega t} \tag{1}$$

Here, ρ is density of acoustic medium, v_0 is particle velocity on the surface of the transducer, k is wave number of r-direction, $J_0(kr)$, and $J_1(ka)$ are Bessel function.

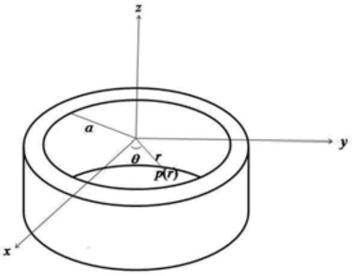


Fig. 1 Coordinate system for the cylindrical piezoelectric vibrator

The time required for a spherical cavity of initial radius R_0 to expand to a radius R_m is given by[4],

$$t_e = \sqrt{6\rho R_0^3}\int_{\arcsin\sqrt{R_0/R_m}}^{\pi/2} f(\phi)d\phi \tag{2}$$

Here, ρ is the density of the water, α is the surface tension of the water,

$\phi = \arcsin\sqrt{R_0/R_m}$, and

$$f(\phi) = \frac{1}{\sin^3\phi\sqrt{-(\sin^4\phi + \sin^2\phi)(pR_0 + 3\alpha) - pR_0}} \tag{3}$$

Using eq.(2), we can estimate the maximum radius of cavity with driving frequency f_r because of the following relation.

$$t_e = \frac{1}{2f_r} \tag{4}$$

Therefore, we can obtain the relation the driving frequency and maximum cavity radius. The time required by bubble to collapse from radius R_m to R_0 is given by,

$$t_c = R_0\sqrt{6\rho/p}\int_{\arcsin\sqrt{R_0/R_m}}^{\pi/2} g(\phi)d\phi \tag{5}$$

Here, $\phi = \arcsin\sqrt{R_0/R_m}$, and

$$g(\phi) = \frac{\sin^4\phi}{\sqrt{\sin^4\phi + (\sin^2\phi + 1)\left(1 + \frac{3\alpha}{pR_m}\right)}} \tag{6}$$

---

kimmj@pknu.ac.kr;kimjs@tu.ac.kr

The particle velocity $U(t)$ on the surface of the bubble can be obtained by differentiating the radius R. In pulsating sphere, the acoustic pressure is given by,

$$p(r,t) = -\rho\frac{\partial\Phi}{\partial t} \qquad (7)$$

Here, velocity potential is

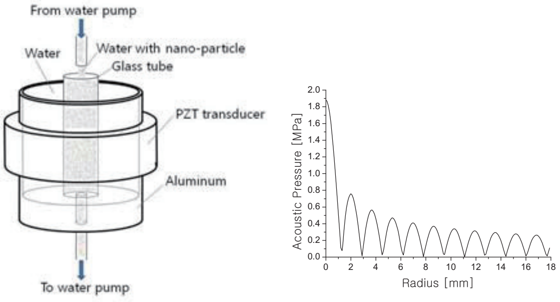
$$\Phi(r,t) = -\frac{R_m c_0}{r} e^{-c_0 t/R_m}\int_{-\infty}^{t} e^{c_0\tau/R_m}U(\tau)d\tau\,, \qquad (8)$$

and c_0 is sound speed of water.

Substituting eq.(6) into eqs. (7) and (8), the pulse shape from the cavitation could be calculated. The frequency spectrum is obtained by Fourier transform of the result of eq. (7).

3. Experiment and Results

To focus the ultrasonic field, a cylindrical PZT vibrator and aluminum pipe are used as shown in **Fig. 2(a)**.

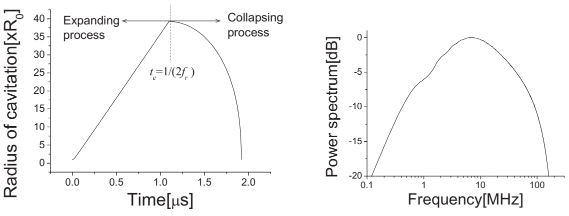


(a) (b)

Fig. 2 (a) Ultrasonic dispersion system (b) Acoustic field distribution in the cylinder

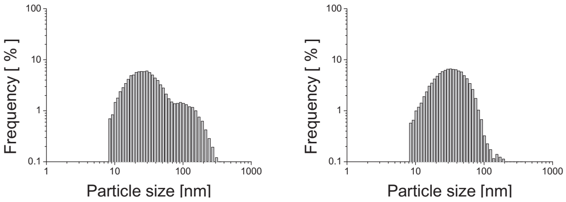
A cylindrical aluminum shell is inserted to inner space of a cylindrical PZT transducer. The polarization direction of the transducer is along to the radial direction. A glass tube is located in the center of aluminum shell and the water with nano-particles is filled in the tube because the acoustic field is focused in the center of the aluminum shell. The thickness, diameter and length of glass tube are 0.5 mm, 14.1 mm and 66 mm, respectively. The glass tube and water pump are connected with plastic pipe lines to circulate the water with nano-particles. The current velocity is about 2 mL/s. The distilled water is filled in between the glass tube and the aluminum shell. The resonant frequency of this system is 456.33 kHz.

For the resonant frequency of the transducer, the radius of cavitation bubble is calculated as a function of time using eqs. (2) and (5). These results are shown in **Fig. 3(a)**. In this calculation, the surface tension is $\alpha = 0.072$ N/m, the radius of capitation nuclei is $R_0 = 10^{-6}$ m, and pressure amplitude in the center of cylinder is $p = 1.9$ MPa. This result shows the collapsing time is very short comparing to expanding time. Using eqs. (7) and (8), the pulse from the collapsing process is calculated as a time function, and the frequency spectrum can be obtained by Fourier transform of this result as shown in **Fig. 3(b)**. The spectrum shows the acoustic energy is distributed in high frequency range of about 10MHz. The TiO_2 particles of 0.05 g are mixed in distilled water of 200 mL, and 20 mL of the solution is filled in the glass tube. The ultrasonic wave is radiated to the solution for 8 min. To investigate the dispersion effect, the particle size distribution is measured by a particle counter (GRIMM Aerosol Technik) as shown in **Fig. 4**. The particle size distribution shows two peaks in Fig. 4(a) because of the agglomerate. The second peak near the 90 nm disappears in Fig. 4(b) by ultrasonic dispersion effect.



(a) (b)

Fig. 3 (a) Change of cavitation radius
(b) Spectrum of collapsing pulse



(a) (b)

Fig. 4 Particle size distribution
(a) before dispersing (b) after dispersing

4. Summary

A new dispersion system is suggested using focused ultrasonic field for pure nano-particle dispersion. The frequency spectrum of the pulse from collapsing cavitation is analyzed theoretically. It is confirmed that TiO_2 solution can be dispersed effectively by this system.

References

1. J. Stoffer and M. Fahim: J. Coatings Tech. Rep. **63** (1991) 61.
2. Y. Lee: Proc. IEEE LEO, (1997) 57.
3. Hayasaka: Onkyousindouron Maruzen (1974) [in Japanese].
4. W. Gaertner: JASA. 26 (1954) 977.