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Trapping of Microparticles in the Cylindrical Standing Wave Field

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1. Introduction

For purification of water suspended various micro-solids or biological particles, the physical filtering is one of the primary processes. Those filtering methods include several kinds of filters such as sands, sieves, and membranes. If the particles were trapped and aggregated each others on particular positions, the filtration might be easier because of relatively high density and big size. Although many previous researchers have reported on the microparticle trapping by ultrasound[1,2], the cylindrical standing wave seems not to be used generally so far. The standing waves by a cylindrical ultrasonic transducer is expected to be more convenient to apply to water purification. The purpose of this study is to figure out how the microparticles, including biological one such as Chlorella, are trapped and how the aggregated pattern is changed along to the lapse time after exposure to ultrasound in a cylindrical standing wave field.

2. Theory and Simulation

For one dimensional standing wave, the cylindrical sound pressure and particle velocity fields are given by Bessel functions as following:

$$p(r,t) = 2P_i J_0(kr)\cos\omega t, \qquad (1)$$

$$u(r,t) = 2U_i J_1(kr)\sin\omega t. \qquad (2)$$

In addition, the radiation force on a small sphere in standing wave field is given by[3]

$$F_r = V\{R_\rho \nabla \langle D_k \rangle - (1-\gamma)\nabla \langle D_P \rangle\} \qquad (3)$$

Using these equations, the radiation force and the potential energy of the standing wave can be calculated as following:

$$F_r = V\{R_\rho + (1-\gamma)\}\frac{\omega P_i^2}{\rho_w c^3} J_1(kr)\{J_0(kr) - J_2(kr)\} \qquad (4)$$

$$U = V\{R_\rho + (1-\gamma)\}\frac{P_i^2}{\rho_w c^2} J_1^2(kr) \qquad (5)$$

The trapped position of the particles, where the radiation force is zero and the potential is minimum, is determined by these equations.

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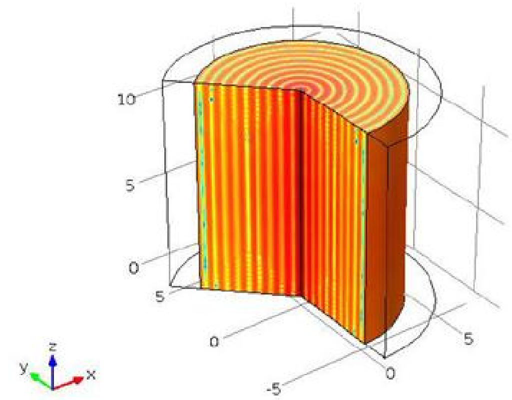

Fig. 1 Simulated cylindrical standing wave field.

The transducer for optimized ultrasonic standing wave generation was designed by 3D simulation with COMSOL, commercial finite element analysis software. The water-filled tube type piezoelectric PZT-4 transducer with 13.8 mm outer diameter, 10.5mm inner diameter, and 12 mm height respectively, showed the standing wave field pattern as shown in **Fig. 1**. The transducer worked in the radial mode with resonance frequency of 1.25 MHz. For trapping it was operated with continues sine wave signal.

Fig. 2 shows the simulation results of the variation of trapped pattern for polystyrene spheres along to the lapse time after the transducer operation. The diameter of particles was assumed as 10 μm, much smaller than wavelength, and density was 1050 kg/m³, little higher than water. The

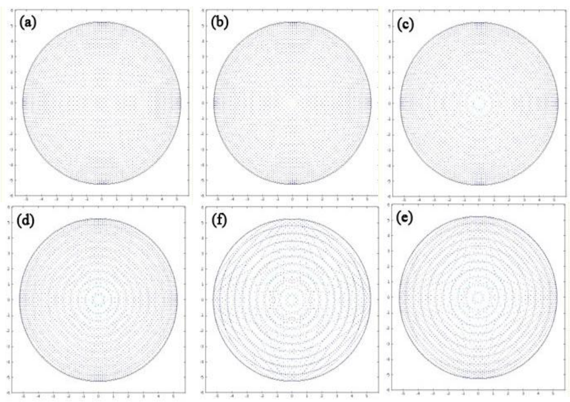

Fig. 2 Simulation of trapped patterns for polystyrene spheres. (a) before driving, (b) on driving, (c) after 5s, (d) after 10s, (e) after 20s, (f) after 30s.

particles were sufficiently small compared to the wave length, so the radiation force that caused by standing wave affected on the particles. According to the time, the particles gather and gather near the nodal lines of the standing wave because of the lower potential energy. The aggregation densities near the central nodal lines were higher than those of the outer region.

3. Measurement Method and Results

The tube type PZT-4 transducer was adhered on the slide glass using silicon rubber, and its inside was filled with water including particles. As the particles, polystyrene spheres with 10 μm diameter (55463, Sigma-Aldrich) and green algae, Chlorella, were used. The electrical sine wave with 10 V_{pp} from a function generator (33250A, Agilent) was applied to the transducer. The movement of the particles was observed and the images were recorded by the microscope with a CCD camera (EGVM35B, Eztech).

Fig. 3 shows the trapped pattern variation of the polystyrene particles with dark blue color. The result of the measurement agreed well with that of COMSOL simulation. Both of the particles made very similar circular pattern. In Fig. 3, the blue lines are group of particles and the occurrence of white areas mean that the water was purified from the polystyrene microparticles. As the same way, this phenomenon happened for a biological micro-organism, Chlorella, as shown in **Fig. 4**. The organism has green color and elliptic shape but resembling a sphere. The size of the chlorella is about 5 to 10 μm. Those two particles made the same pattern of circular lines by the standing wave. However, after time went, some of the chlorella became massive lump by aggregation and sunk on the bottom of the cylinder. On the other hand, some of chlorella escaped from the circle pattern of near the central region which has stronger radiation force compared the surrounding areas.

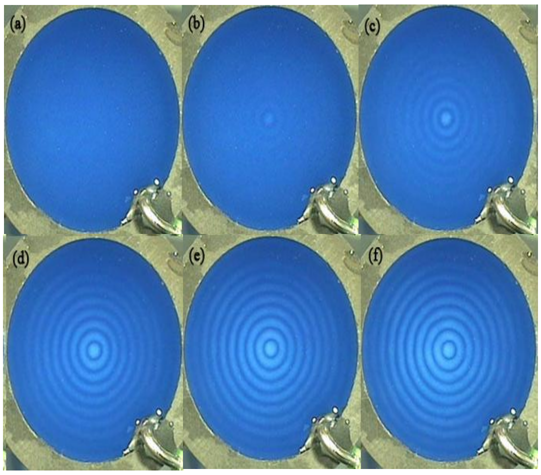

Fig. 3 Trapping of 10μm polystyrene spheres.
(a) before driving, (b) on driving, (c) after 5s,
(d) after 10s, (e) after 20s, (f) after 30s.

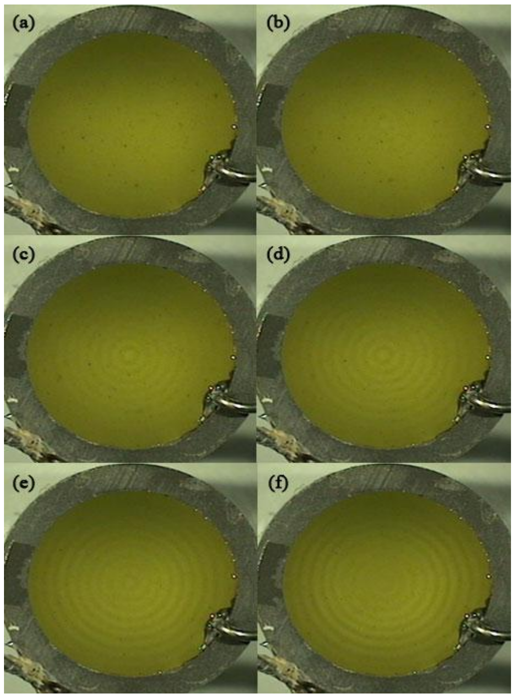

Fig. 4 Trapping of green algae, Chlorella.
(a) before driving, (b) on driving, (c) after 5 s,
(d) after 10 s, (e) after 20 s, (f) after 30 s.

4. Conclusion

In this study, standing wave fields, radiation force, and trapping patterns of microparticles in a cylindrical transducer were simulated and the results were compared with those of measurment. For the both of the solid polystyrene particles and the biological micro-organism Chlorella, the simulation and measurement results were well agreed. Consequently, it is noted that the variation of trapped pattern along the time after standing wave generation can be calculated using the finite element method, and the results of this study showed the possibility of the effective purification by cylinderical standing waves.

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