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Concentration of the suspension particles using the ultrasonic standing wave field.

超音波の定在波音場を用いた懸濁粒子の濃縮

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1. Introduction

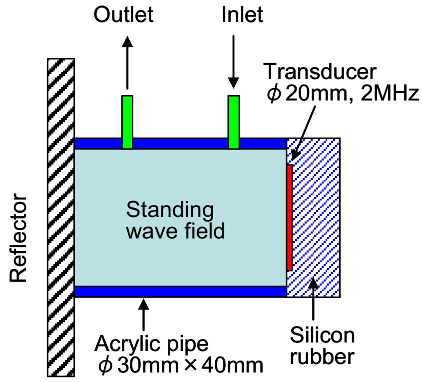
Noncontact micromanipulation technique is needed in micromachine technology, biotechnology, and other fields. Cerium oxide particles which are made of rare earth metal are used as an abrasive in the lens factory. In order to reuse the particles, it is necessary to eliminate dust and fragmented particles. The radiation pressure of ultrasound may be used for this purpose [1]. There may be two steps. The first one is to eliminate dust glass particles. The second one is to eliminate small fragmented seria particles. In other words, it is to concentrate larger unaffected ceria particles.

The authors have realized an acoustic manipulation technique for transporting particles using a standing wave field in water or air [2-3]. In the present study, an ultrasonic standing wave generated in a pipe. When the suspension liquid through the pipe, solid particles were trapped in the sound pressure nodes of the sound field. It realized to concentration of the suspension particles.

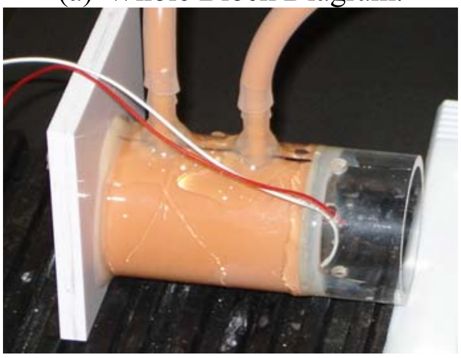
2. Experiment and Result

Figure 1(a) shows a basic experimental system. The acrylic pipe length is 40 mm, and the inner diameter is 26 mm. An ultrasonic transducer is set at the right side with silicon rubber as a back hold. A reflector was set at the left side of the pipe. In addition, two connectors as the liquid inlet and outlet was set at the upper side of the curved pipe wall. The transducer was driven with a electric power of 2.1 MHz in frequency and 3 W. A standing wave field was generated between the transducer and the reflector in the pipe. The liquid flowed from the inlet to the outlet connected to a bottle using a pump.

Two kinds of particles were used. One is glass particles with mean diameter of 7 micron, and the concentration of 1 wt%. The other is cerium oxide particle used in a lens factory with the diameter of about one micron. The flow speed was 10 mL/min by a syringe pump.



(a) Whole Block Diagram.



(b) The experimental setup.
Fig. 1. Experimental apparatus.

Table 1. Experimental results.

	Glass particle		Cerium oxide particle	
	with US	without US	with US	without US
in pipe [mg]	1160	200	552	279
Output [mg]	27	300	1030	1324
trapped rate [%]	97	40	34	17

After the experiment, the suspension liquid was collected, and the liquid was evaporated to dry the particles. Table 1 shows the experimental results on the particles weight in the acrylic pipe and that in the bottle connected to the outlet. The quantity of extraction doubles with ultrasound.

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3. Discussion

The direct sound pressure from the sound source is calculated by the Rayleigh's formula. The sound pressure of a standing wave field is calculated by adding the reflected sound [3]. Figure 2(a) shows the sum of the four sound waves that are the direct sound wave, reflected sound wave in the reflector, reflected sound wave in the sound source surface and the second reflected sound wave in the reflector. It is a complicated sound field. In addition, the reflection at the side wall of the acrylic pipe was neglected, because the ultrasound directionality is high.

The particle in the sound field is forced from the anti-node to the node. According to Nyborg and Gor'kov, the force acting on a small sphere due to radiation pressure can be given by the following equation, provided the radius a of the sphere is sufficiently small compared to the wave length λ:

$$F = V\left[D\nabla\langle e_k\rangle - (1-\gamma)\nabla\langle e_p\rangle\right] \qquad (1)$$

Where $V=(4/3)\pi a^3$, $D=3(\rho_s-\rho_0)/(2\rho_s+\rho_0)$, $<e_k>$ and $<e_p>$ are the time averaged kinetic energy and potential energy of sound acting on the small sphere, respectively.

Figure 2(b) shows the calculated force on a particle along the sound beam axis. The particle is made of glass with diameter of 10 micron and the density of 2400 kg/m^3. The force changes periodically with a half wavelength in the standing wave field. Figure 2(c) shows calculated force on a particle perpendicular to the sound beam axis. The force is more than one order of magnitude smaller than that along the sound beam axis. The particles are trapped at the sound pressure nodes in the sound beam direction, then they are precipitated by gravity.

4. Conclusion

A standing wave field was generated in an acrylic pipe to concentrate the suspension particles. When the suspension liquid flowed through the pipe, solid particles were trapped in the sound pressure nodes of the sound field. It realized the concentration of the suspension particles.

References

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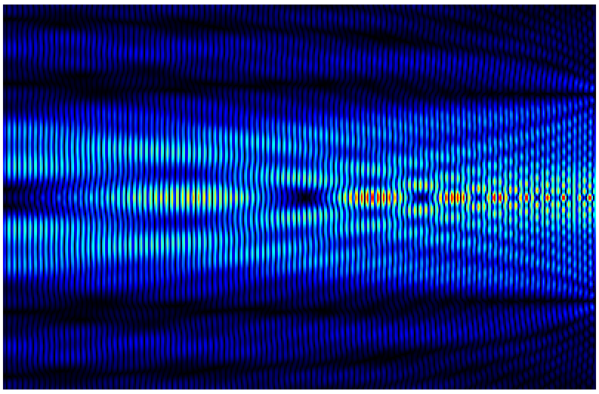
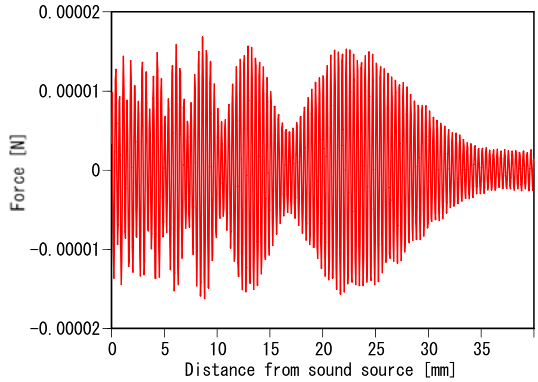
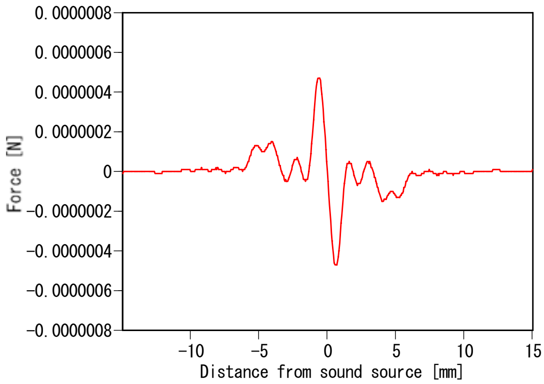


Fig. 2. Calculated sound pressure distribution.



(a) Along the sound beam axis.



(b) Perpendicular to the sound beam axis.
Fig. 3. Calculated force on a glass particle.