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Behavior of liquid in elongated pore under high-intensity aerial ultrasonic irradiation

強力空中超音波照射下の細孔内液体の挙動

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1. Introduction

We have verified a method by which a liquid that has entered an elongated pore could be removed by using the acoustic radiation force produced by high-intensity aerial ultrasonic waves (at the frequency 20 kHz) [1)-3)]. In a previous study, we observed that a part of the liquid was gathered in the shape of stripes at the inside wall in the elongated pore, while the liquid was removed under aerial ultrasonic wave irradiation. A striped pattern changed in complex ways during the process of liquid removal. In this report, we attempted to clarify this phenomenon.

2. Experimental setup and method

We consider that acoustic radiation force applied by a standing wave formed in the pore after removal of the liquid under aerial ultrasonic irradiation gathers the part of the liquid in the shape of stripes at the inside wall in the elongated pore. Therefore, we compared the result of the shape of the standing wave in the simulated pore by using a simulated audible sound wave, and the liquid removal behavior under aerial ultrasonic wave irradiation.

2.1 Experimental device with ultrasonic waves

Figure 1 shows a schematic view of the experimental device used for liquid removal. A point-converging acoustic source with a stripe-mode vibration plate[4)] (19.65 kHz) is used to generate high-intensity aerial ultrasonic waves. **Figure 2** shows the characteristics of sound pressure at the convergence point for a free field, analyzed using a fast Fourier transform spectrum analyzer. The sound pressure is measured by using a 1/8 inch condenser microphone. In the figure, the intensity of the aerial ultrasonic waves is about 5 kPa at an input power of 50 W. In addition, the ratio of the second harmonic component to the sound pressure of the fundamental frequency is 59%. Moreover, the ratio of the third harmonic component is 45%, that of the fourth harmonic component is 29%, and that of the fifth harmonic is 16%. As shown in Fig. 1, the opening of the elongated pore is irradiated with such nonlinear ultrasonic waves, and the liquid is removed.

2.2 Experimental device with audible sound

In this experiment, the size of the elongated pores was increased by a factor of 10 and the sound wave frequency was multiplied by 1/10, and the opening of the elongated pore was then irradiated with the sound wave. An acrylic pipe with a rectangular section (dimensions: 20 mm × 20 mm; length: 200 mm) was adopted as a simulated elongated pore, and a 5-mm-thick acrylic lid (diameter: 19.65 mm) was used as a simulated surface for removing the liquid in the pore. In addition, the sound pressure of each frequency of the irradiating sound wave (1.965, 3.931, 5.896, 7.862, and 9.828 kHz) is made the same as the rate of sound pressure at an input power of 50 W (Fig. 2) . The sound pressure distribution of the cavity side in the acrylic pipe is measured by using a probe microphone (diameter: 2 mm; length: 400 mm).

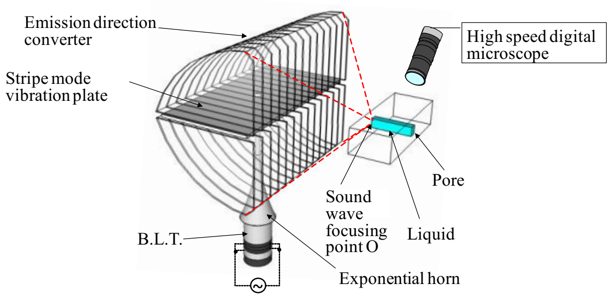

Fig. 1 Schematic of the experiment device

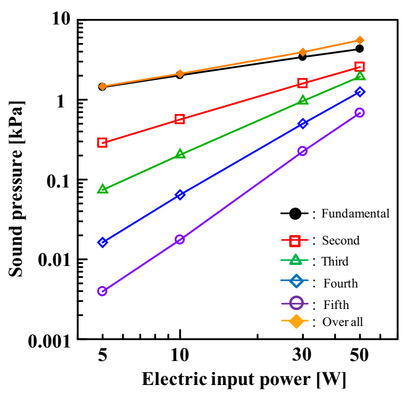

Fig. 2 Relationship between sound pressure and electric input power

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3. Results

We compared the liquid removal behavior under aerial ultrasonic irradiation and the results of the synthetic standing wave at the fundamental frequency and harmonics in the simulated elongated pipe. **Figure 3** shows the result of the synthetic standing wave distribution of each frequency in the acrylic pipe. In the figure, the synthetic wave results correspond to the results when the acrylic lid is set at 55, 100, and 140 mm from the pipe opening. Some comparative results are shown below.

3.1 Liquid surface 5.5 mm from the pore opening

Figure 4 shows the liquid behavior when the position of the liquid surface is 5.5 mm from the elongated pore opening. The liquid stripe is 2.7 (B1´) mm from the elongated pore opening. The corresponding results are shown as a blue line in Fig. 3. In the figure, the position of the sound pressure node is 31 mm (B1). For both results, the position of the liquid stripe and the sound pressure distribution node is almost the same. In addition, the size of the adjacent sound pressure antinode across sound pressure node differs greatly. Therefore, we consider that the liquid stripe has been retained slightly closer to the elongated pore opening.

3.2 Liquid surface 10 mm from the pore opening

Figure 5 shows the liquid behavior when the position of the liquid surface is 10 mm from the elongated pore opening. The liquid stripes are 3.3 (R1´) and 6.3 (R2´) mm from the elongated pore opening. The corresponding results are shown as a red line in Fig. 3. In the figure, the positions of sound pressure nodes are 33 mm (R1) and 80 mm (R2). For both results, while there is some disagreement, the position of the liquid stripes and sound pressure node largely agree.

3.3 Liquid surface 14 mm from the pore opening

Figure 6 shows the liquid behavior when the position of the liquid surface is 14 mm from the elongated pore opening. The liquid stripes are approximately 7.3 mm (G1´) and 11.1 mm (G2´) from the elongated pore opening. The corresponding result, a complicated distribution, is shown as a green line in Fig. 3. In the figure, the positions of sound pressure nodes are 45 mm (G1), 61 mm (G2), and 118 mm (G3). Points G1 and G2 are close together, and the antinode of sound pressure between the two points is very small. Therefore, we considered the liquid stripe of point G1´ to be wide in Fig. 6. In addition, points G3 and G2´ nearly correspond in Figs. 3 and 6.

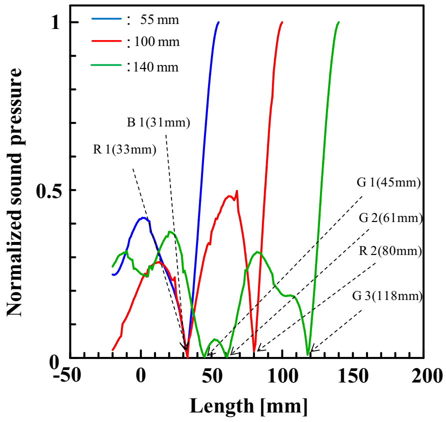

Fig. 3 Standing wave distributions in simulated pore

Fig. 4 Behavior of liquid in the pore (liquid surface : 5.5 mm)

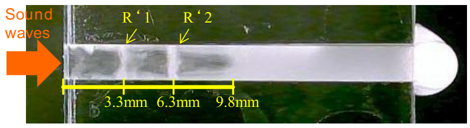

Fig. 5 Behavior of liquid in the pore (liquid surface : 10 mm)

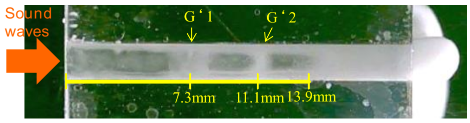

Fig. 6 Behavior of liquid in the pore (liquid surface : 14 mm)

4. Conclusion

We observed that the part of the liquid was gathered in the shape of stripes at the inside wall in the elongated pore. The striped pattern changed in complex ways during the process of liquid removal under aerial ultrasonic waves irradiation. We also compared the results of liquid removal using aerial ultrasonic waves and the standing wave in a simulated pore by using audible sound waves in simulation. As a result, it was confirmed that the position of liquid stripe under aerial ultrasonic waves irradiation and the shaped standing wave distribution in the simulated pore agreed well.

References

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