ATOMIZATION OF HIGH-VISCOSITY MATERIALS BY ONE POINT CONVERGENCE OF SOUND WAVES RADIATED FROM AN AERIAL ULTRASONIC SOURCE USING A TRANSVERSE VIBRATING PLATE

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Miura, Hikaru
Department of Electrical Engineering, College of Science and Technology, Nihon University; 1-8-14, Kanda Surugadai, Chiyoda-ku, Tokyo, 1018308, Japan; miura@ele.cst.nihon-u.ac.jp

ABSTRACT
It is difficult to atomize high-viscosity materials such as oil without contact; however, it is possible to do so using intense aerial ultrasonic waves. As a sound source for that purpose, an aerial ultrasonic source with 20 kHz resonance frequency was used along with a square transverse vibrating plate that has the nodal mode of vibration amplitude in the shape of a lattice. The source radiates four-directional sound waves in the far field. To obtain high sound pressure in the near field, radiated sound waves were converged using several flat boards and four parabolic reflective boards placed near the source. Sound pressure reaches 6.5 kPa (S.P.L. 170 dB), a very high level, at the convergent point. Scattering and atomization of the high-viscosity materials were examined at the point of convergence. Results show the following. Atomization by a sound wave is possible in the case of high-viscosity materials. The higher the sound pressure, the shorter the beginning time of atomization becomes. The distribution of the atomized particles’ diameter is 0.05–0.22 mm at the movement viscosity of 10000 cSt.

1. INTRODUCTION
The utilization of ultrasound is one of the methods for the dispersion and atomization of materials with a high kinematic viscosity, such as oil, without direct contact with the viscous materials. The dispersion and atomization of materials with a high kinematic viscosity by a noncontact method requires a high ultrasonic-wave energy. However, the relationship between the kinematic viscosity and sound pressure level required for dispersion and atomization has not yet been examined.

In this study, to clarify the dispersion and atomization behavior with respect to the difference in kinematic viscosity, the time between an ultrasonic wave emission and the beginning of dispersion, the time required for a viscous material to be completely dispersed, and the relationship between these time lengths and sound pressure level were examined using strong aerial ultrasonic waves converging at one point. Also, the relationship between the distribution of particle diameter after the dispersion and atomization of the material and the kinematic viscosity was examined.

2. ULTRASONIC SOURCE
Figure 1 shows the schematic of the ultrasonic source used in this experiment. This ultrasonic source consisted of a square transversely vibrating plate with a mode in which the nodes of its amplitude distribution appear in a lattice pattern. A 20 kHz bolt-clamped Langevin-type transducer was connected to an exponential horn for expanding the amplitude and a resonance rod for regulating the resonance frequency of longitudinal vibration, the tip of which was screwed into the center of the lattice-mode square transversely vibrating plate (length of one side: 216.2 mm and 3 mm in thickness). The drive frequency was 19.8 kHz. Figure 2 shows a photograph of the vibrating plate on which sand was sprinkled. Sand collects at the nodal position of lattice pattern of transverse vibration when the plate is driven.
3. EXPERIMENTAL SETUP AND CONVERGING ULTRASONIC WAVES

Flat, auxiliary, and curved reflective boards, as shown in Fig. 3, were used to converge the ultrasonic waves generated by the ultrasonic source (Fig. 1) at one point [1],[2]. When the ultrasonic waves converged at the point of X=0 mm, Y=0 mm, and Z=70 mm on the axes shown in Fig. 1.

![Figure 1.- Ultrasonic source using a square vibrating plate](image1)

![Figure 2.- Transverse vibrating plate in a lattice pattern](image2)

![Figure 3.- Source for one point convergence of sound waves](image3)
4. RELATIONSHIP BETWEEN KINEMATIC VISCOSITY AND DISPERSION TIME

Sample stages for setting viscous materials were prepared to disperse the viscous materials at the convergence point using the converging ultrasonic waves described above. Each sample stage was an aluminum plate consisting of one of the five types of pillar-shaped hollow, which were 6.0 mm in diameter and 0.5, 1.0, 1.5, 2.0 or 2.5 mm in depth. These hollows were fabricated to examine the difference in dispersion time depending on the amount of materials with various viscosities. A viscous material was poured into a hollow such that the surface of the material was flush with the surface of the aluminum plate, and the sample stage was placed so that the hollow was positioned at the convergence point of the ultrasonic waves. The experiment was video-recorded to observe the dispersion behavior of the material in the five types of hollows and to measure the dispersion time. Experiments were conducted in triplicate for each material with the sound pressure level of 170 dB. Liquid materials with nine different kinematic viscosities in the range of 50 - 100,000 cSt were used in this experiment. The time between the ultrasonic wave emission and the beginning of dispersion (hereafter called the dispersion
beginning time) and that between the ultrasonic wave emission and the end of the dispersion (hereafter called the dispersion time) were calculated on the basis of the recorded data.

Figure 5 shows the results of the dispersion beginning time in relation to the kinematic viscosity. As shown in the figure, dispersion began almost simultaneously with the ultrasonic wave emission when the kinematic viscosity was in the range of 50-1000 cSt. However, the dispersion beginning time gradually increased when the kinematic viscosity was 3000 cSt or higher.

Figure 6 shows the dispersion time in relation to the kinematic viscosity. The dispersion of the material was completed in a very short time when the kinematic viscosity was in the range of 50-500 cSt. However, when the kinematic viscosity was 1000 cSt, the dispersion time was long in the hollows with depths of 0.5 and 1.0 mm, and the dispersion of the material was incomplete in the hollows with depths ranging from 1.5 - 2.5 mm. When the kinematic viscosity was 3000 cSt or higher, the dispersion of the material was incomplete in all hollows.

Figure 7 shows the dispersion beginning time in relation to the sound pressure level when the depth of the hollow was 1.0 mm. As shown in the figure, for any kinematic viscosity, the dispersion beginning time decreased as the sound pressure level increased. At the sound pressure level of 160 dB, no materials were dispersed regardless of their kinematic viscosity. Also, materials with a kinematic viscosity of 50000 cSt or higher did not disperse at the sound pressure level of 161 dB or lower.
After the articles were collected, the particle diameters were measured using a microscope. The y was 5.6% for the particle diameter of 0.22 mm. As shown in Fig. 8(b), when the kinematic viscosity was 10000 cSt, the particle diameter was approximately in the range of 0.05 mm - 0.25 mm. The maximum frequency was 12.7% for the particle diameter of 0.13 mm.

The particle diameters of materials with different viscosities were also measured and observed to be approximately in the range of 0.05 mm - 0.45 mm.

5. CONCLUSIONS
The dispersion and atomization of materials with high kinematic viscosity using strong aerial ultrasonic waves was examined. The results were as follows. (1) The dispersion and atomization of materials with various kinematic viscosities was observed after the emission of ultrasonic waves. (2) No significant difference in dispersion time with respect to the depth of hollows was observed. (3) The dispersion beginning time was short when the sound pressure level was high. (4) The distribution of particle diameters was approximately in the range of 0.05 mm - 0.45 mm, although it varied depending on the kinematic viscosity of the material.


5. DISTRIBUTION OF PARTICLE DIAMETER
To examine the relationship between the diameter of particles after dispersion and atomization and the kinematic viscosity of viscous materials, the particle diameter was measured. The sample stage with a hollow of 0.5 mm depth was used to examine the relationship using a small amount of viscous materials. The atomized particles were collected using a glass slide that was installed 50-75 mm away from and 42 mm below the hollow on the sample stage. After the particles were collected, the particle diameters were measured using a microscope.

Figure 8 shows the results. Figures 8(a) and 8(b) show the relationship between the particle diameter and the number of particles of a particular size in percent (frequency) at the viscosities of 100 cSt and 10000 cSt, respectively. As shown in Fig. 8(a), when the kinematic viscosity was 100 cSt, the particle diameter was approximately in the range of 0.07 mm - 0.45 mm. The maximum frequency was 5.6% for the particle diameter of 0.22 mm. As shown in Fig. 8(b), when the kinematic viscosity was 10000 cSt, the particle diameter was approximately in the range of 0.05 mm - 0.25 mm. The maximum frequency was 12.7% for the particle diameter of 0.13 mm. The particle diameters of materials with different viscosities were also measured and observed to be approximately in the range of 0.05 mm - 0.45 mm.

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