Behavior and Structure of Internal Fuel-Jet in Diffusion Flame under Acoustic Excitation

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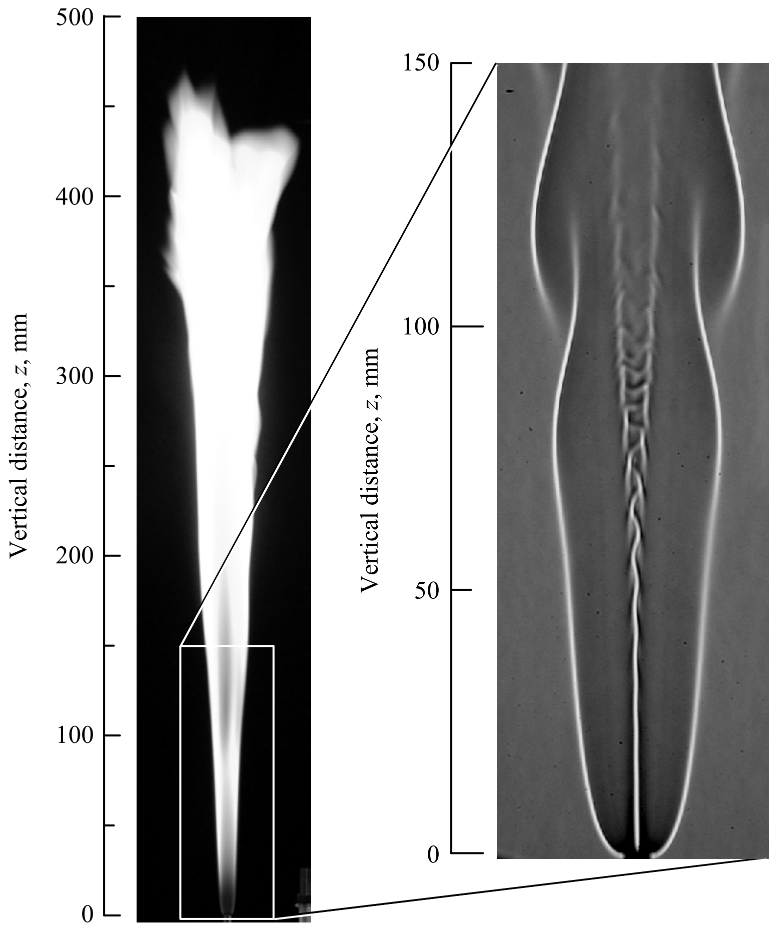
1. Introduction

It is known that pressure waves have an ability to influence on jet diffusion flames. Recently, the effects have been investigated under the condition that the sound waves propagate transversely across the jet of the diffusion flame [1–5]. It is expected that the phenomenon of acoustic excitation can be applied for the suppression of soot formation [2] or the enhancement of mixing [3]. For the further investigation, the understanding of fluid-dynamical behavior is indispensable. The authors have explored the behavior of the fuel-jet inside a diffusion flame [4, 5] and found that the jet injected from a nozzle branches into "Y" shape under a certain condition. It is also noted that it meanders before it diverges into two branches. It is obvious that this behavior of the fuel-jet inside the flame is the key of the acoustic excitation on the flame. However, its detailed process and mechanism are still uncertain. In order to understand the mechanism of this effect, further observation is required. Thus, the movement of the meandering of the jet is examined by means of high-speed video camera. Shadowgraphy is adopted for the visualization. Multi-directional observation is also conducted. Based on the results, three-dimensional structure is proposed.

2. Experimental

Figure 2 shows the arrangement of a speaker and a fuel-ejecting nozzle used in the experiment. In this figure, the origin of the



(a) Direct image (b) Shadowgraph

Fig. 1 Typical images of the luminous flame and internal jet under acoustic excitation (u_0 = 10 m/s, f = 1.5 kHz) coordinate is placed at the center of the nozzle edge. Axes x, y, and z represent, the horizontal direction normal to the propagating direction of the sound wave, the direction parallel to it, and the vertical direction, respectively. Methane gas is used as fuel. The nozzle is a vertical tube of 3 mm in inner diameter. Its length L is determined to be more than 100 times longer than its diameter so that the disturbance upstream does not affect the flow at the nozzle edge. The speaker unit with a cone of 100 mm in diameter is used to generate acoustic waves. The center of the cone of the speaker is placed at $y = -245$ mm and $z = 50$ mm. Electric sine-wave signals are generated by a signal generator, amplified by a power amplifier, and transmitted to the speaker unit which produces acoustic waves. The intensity of the acoustic waves is controlled to be of 110 dB in sound pressure level at $z = 50$ mm on the z-axis. It is confirmed that the uniformity of the sound pressure level is within ±1 dB in the observing region, $0 \leq z \leq 100$ mm.

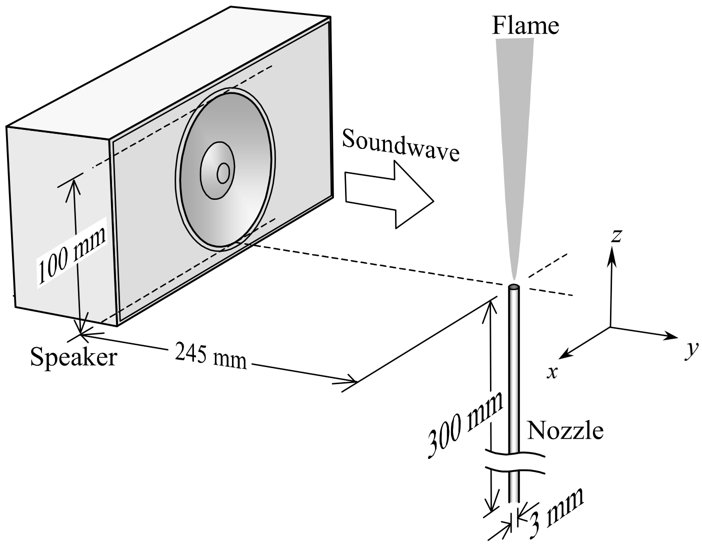
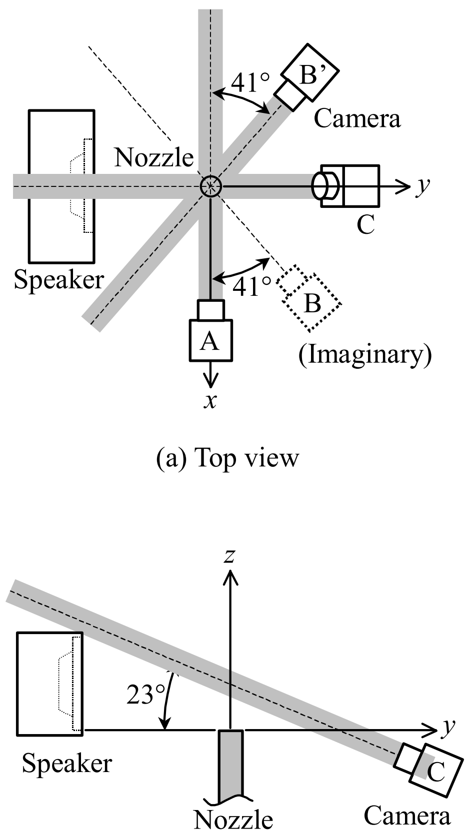


Fig. 2 Arrangement of speaker and nozzle

In order to observe the three-dimensional structure of the internal jet, shadowgraph images are recorded on a high-speed video camera. The measurements are done for three directions. Figure 3 shows the directions of the observation adopted in the experiment. The symbols A, B, and C represent the directions at angles of 0°, 41°, and 90° from the x-axis, respectively. Because of the problem of optical arrangement in the laboratory, the images in the direction B is obtained by taking the photographs in direction B’ as mirror images. The optical path of the direction C is declined at an angle of 23° so that the speaker box does not interfere with the optical path.



(a) Top view

(b) Side view

Fig. 3 Directions of observation

3. Results and Discussion

Figure 4 shows the photographs indicating the behavior of a bifurcated jet under the condition of $u_0 = 7.3$ m/s and $f = 1.0$ kHz. The symbols u_0, f, θ, and t represent, mean velocity of ejecting fuel, sound frequency, a phase of the sound wave, and time from a moment of $\theta = 0$, respectively. It is seen that the phenomenon is periodic at the same frequency of the sound wave. The ascending velocity of the movement of the jet image is estimated as 10 m/s from the trace of the photographs as shown in Fig.5. This value is 40 % higher than u_0. Considering the effect of buoyancy, it is plausible that the actual jet moves at the velocity just as shown in the photograph, although there is a possibility that the movement of the jet image on a shadowgraph does not correspond with the flow of the actual jet, since the image shows just the outline.

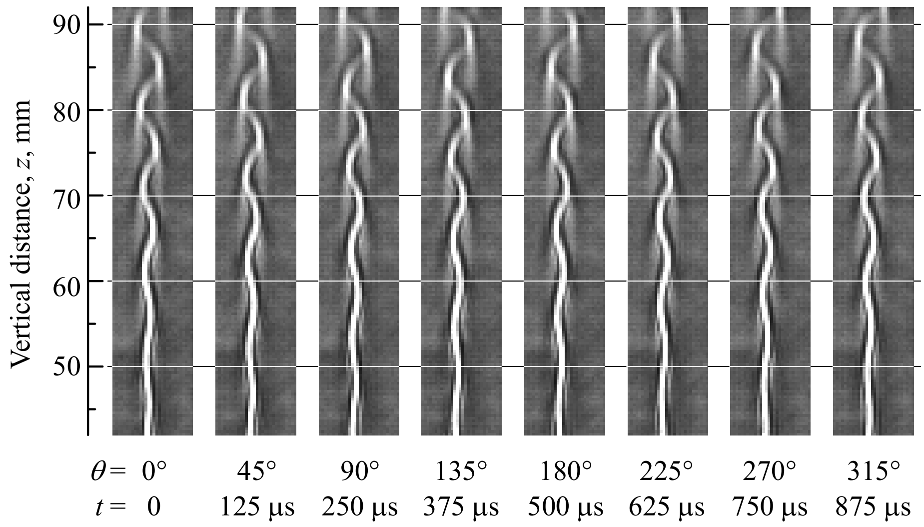


Fig. 4 Behavior of the internal jet (u_0 = 7.3 m/s, f = 1.0 kHz)

Figure 6 shows the photographs taken in three-directions. All of them are synchronized with the same phase of the sound wave. It is seen in Fig. 6 (c) that the jet has a symmetric structure in the x direction. In the region of $z < 50$ mm, the jet meanders in the y direction (Fig. 6 (a)) without notable movement in the x direction (Fig. 6 (c)). In the region of $z \geq 50$ mm, where branching of the jet seems to appear in the y direction (Fig. 6 (a)), it is recognizable that two symmetrical "arms" split from the mainstream of the jet in the x direction (Fig. 6 (c)). Comparing the photographs of (a), (b), and (c), these two "arms" in Fig. 6 (c) seem to correspond to a single branch seen in Fig. 6 (a).

Figure 7 shows the three-dimensional structure of the fuel jet presumed from Fig. 6. During the branching process of the jet from a single stream into two, it is inferred that two "arms" grow from the stream and then the mainstream separates the z-axis.

4. Conclusions

Detailed behavior of the internal fuel-jet of a jet diffusion flame under the acoustic excitation has been examined by means of adopting multi-directional observations of the internal fuel-jet. It was found that the phenomenon is periodic

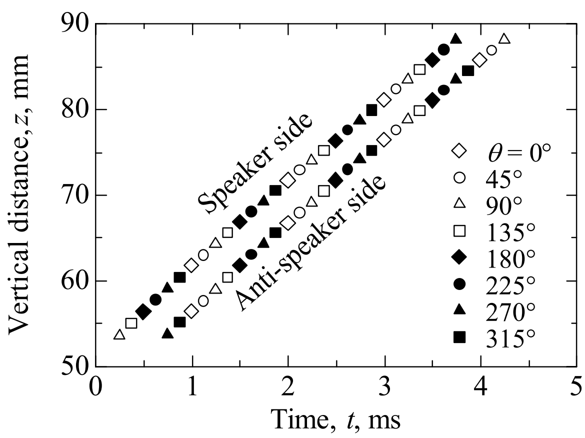


Fig. 5 Movement of the jet in z-direction (u_0 = 7.3 m/s, f = 1.0 kHz)

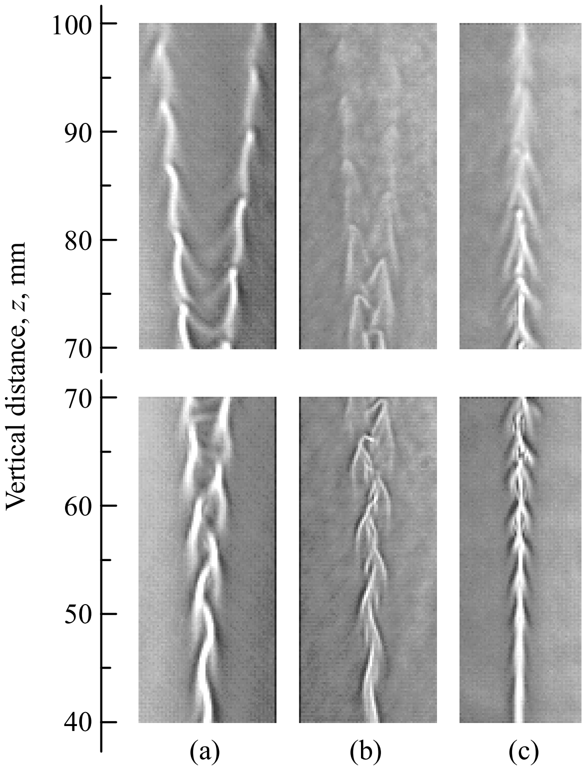


Fig. 6 Shadowgraphs of the internal jet taken in three directions (u_0 = 10 m/s, f = 2.0 kHz)

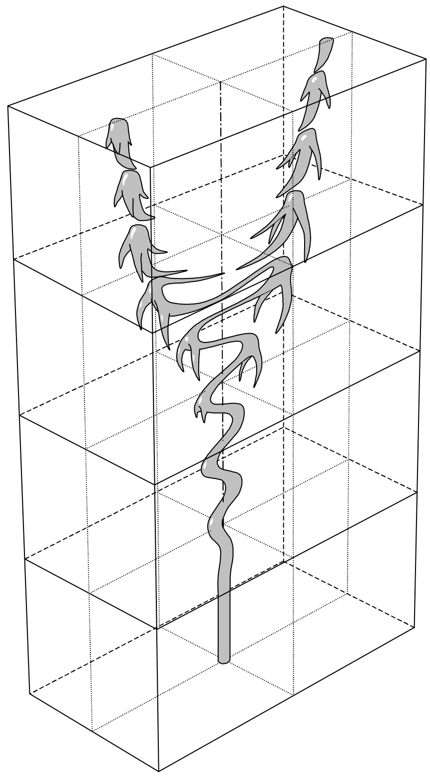


Fig. 7 Inferred three-dimensional structure of the fuel jet inside the diffusion flame

at the same frequency of the sound wave. A three-dimensional structure of the fuel-jet is presented by examining the synchronized observation from three directions. It is shown that the jet has a x-directional structure symmetric on y-z plane. These results obtained would be helpful for the further understanding of the mechanism of acoustic excitation.

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