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## PS35

# 室温・高圧におけるアンモニア液滴生成精度の向上と予蒸発抑制の試み

# Improvement of ammonia droplet generation accuracy and suppression of pre-vaporization at room temperature and high pressure

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### 1. Introduction

In recent years when the movement of carbon neutral is becoming popular around the world, many studies on combustion using carbon neutral fuels are being conducted. Ammonia is one of them. Since ammonia is relatively easy to operate in the liquid state and the supply infrastructure is well-developed, ammonia is a promising fuel for practical use. Among combustion research using ammonia, spray combustion using liquid ammonia has been studied. The advantage of liquid ammonia spray combustion is that it requires minimal modification of existing equipment and reduces installation costs. Okafor et al. [1)] succeeded in stabilizing ammonia spray combustion using a high-temperature swirling air flow. However, the detailed mechanism has not been clarified completely because various physical and chemical processes proceed simultaneously. To improve understanding of its mechanism, it is necessary to clarify the mechanism from a fundamental perspective using droplet combustion, which is a component of spray combustion. In a study on ammonia droplet combustion, Matsuura et al. [2)] generated a single ammonia droplet at room temperature and 1.5 MPa condition and investigated its burning behavior. However, the initial droplet diameter could not be controlled well. In the study of droplet combustion, the initial droplet diameter is used to normalize the spatial and time scales, so it is important to control the initial droplet diameter. Therefore, this study modified the ammonia droplet generation system devised by Matsuura et al. [2)] to improve the accuracy of droplet diameter generation. In addition, we attempted to suppress pre-evaporation of ammonia droplet so that it could maintain a controlled diameter as much as possible.

## 2. Experimental apparatus and procedure

**Figure 1** shows the ammonia-droplet- generation system, which is equipped with a three-axis traverse stage, a fiber base with crossed SiC fibers, a high-pressure syringe, a glass needle for fuel supply, thermocouple, valves, and pipes. The valves controlling the fuel supply to the glass needle were either solenoid valves used by Matsuura et al. [2] or servomotor-driven ball valve developed in this study. After evacuating the high-pressure syringe and piping with the solenoid valve or ball valve closed, filling of the high-pressure syringe with liquid ammonia was performed at high pressure. In addition, $N_2$ pressurized the same area to completely liquefy the gaseous ammonia present in the syringe and pipes, so that the syringe was filled only with liquid ammonia. The droplet generation system was inserted into the pressure chamber pressurized at 1.5MPa using mixed air ($N_2$ 79% and $O_2$ 21%). When generating a droplet, the solenoid valve or the ball valve was opened, and a syringe plunger was pushed out by a stepper motor. The pushed liquid ammonia reached the glass needle in the following order: syringe, pipe, solenoid valve or ball valve, and pipe, and was suspended at the intersection of SiC fibers with a diameter of 14 μm. Images of the droplets were captured at 1000 fps using a high-speed camera (IDT, iN8-S2) in a back-illumination system.

For the verification of droplet diameter control, 20 pulses were input to the stepper motor for a target diameter of 1.0 mm. Non-measuring droplet were generated prior to generation of the measuring droplet to prevent bubbles from forming in the glass needle and errors in the diameter of the generated droplets. The droplet diameter was calculated using the MATLAB code. The calculated values were compiled into a histogram, and the average and standard deviation of the generated droplet diameters were calculated and used to evaluate the accuracy of the droplet generation.

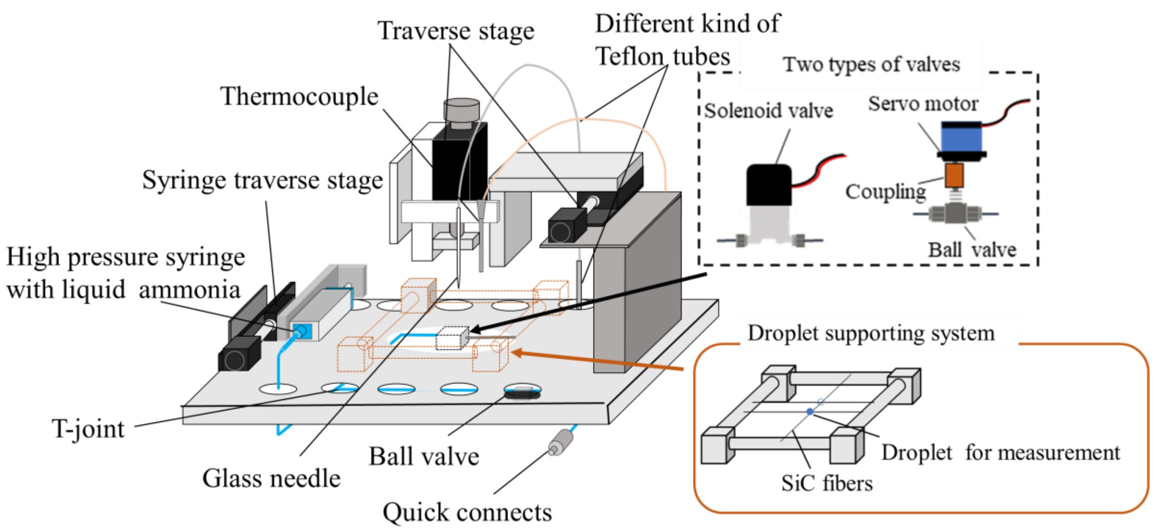


**Figure 1** Ammonia-droplet-generation system placed in a high-pressure chamber

### 3. Results and discussion

3.1 Verification results of droplet diameter control of a droplet-generation system using a solenoid valve

**Figure 2** shows the droplet diameter distribution for 15 data in the droplet-generation system using a solenoid valve. Figure 2 shows that many droplets with diameters larger than 1.0 mm were generated, indicating that the amount of liquid ammonia supplied from the glass needle did not correspond to the amount of liquid ammonia pushed into the plunger of the syringe. This is considered to be due to the continuous dripping observed after the syringe plunger was pushed out. The average and standard deviation of the produced droplet diameters were 1.20 mm and 0.12 mm, respectively.

3.2 Consideration of the cause of uncontrolled droplet diameter and improvement of the system

According to the results of Section 3.1, the uncontrollable droplet diameter was caused by the continuous dripping when a solenoid valve was used. We investigated the cause of the continuous dripping and confirmed that many air bubbles entered the supply path during the syringe plunger push. The air bubbles in the supply path were pressed by the syringe plunger push. The bubbles were expanded after the plunger push was finished, and this expansion pushed the liquid in the path toward the glass needle, which caused the continuous dripping. The solenoid valve is considered to be the cause of this bubble entry. Solenoid valves use magnetic force to open and close the valve, so they have a coil that generates heat when energized. When liquid ammonia passed close to the coil, it may have been affected by the heat and vaporized. Therefore, we substituted a ball valve without a heat source for the solenoid valve. A servo motor and coupling components were used to rotate the shaft of the ball valve to open and close the ball valve in the pressure chamber, which cannot be handled manually.

3.3 Consideration of the cause of uncontrolled droplet diameter and improvement of the equipment

**Figure 3** shows the droplet diameter distribution for 15 data after the improvement of the system. In the case of the improved system, the continuous drop formation was not observed after the improvement. The average and standard deviation of droplet diameters were 1.06 mm and 0.06 mm, respectively, suggesting an improvement in droplet diameter control compared to the results in Section 3.1.

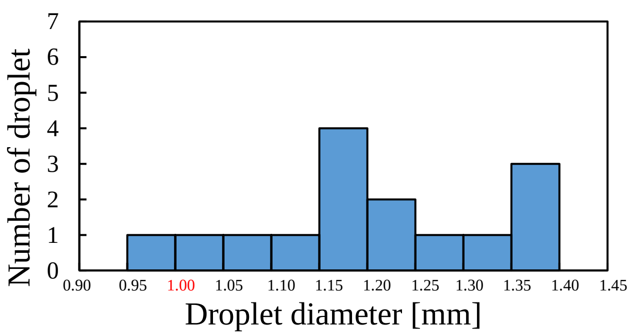


**Figure 2** Droplet diameter distribution for droplet-generation system with solenoid valve (target diameter: 1.0 mm)

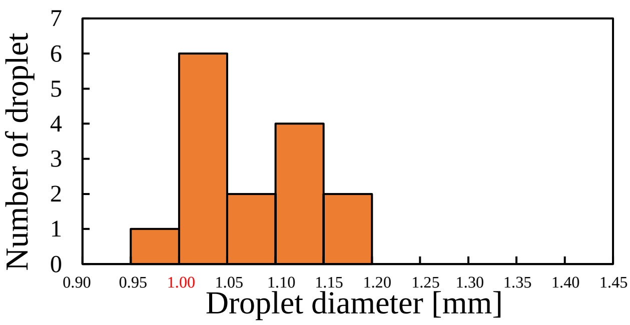


**Figure 3** Droplet diameter distribution for droplet-generation system with ball valve (target diameter: 1.0 mm)

3.4 Vaporization-rate constant of a single ammonia droplet in normal gravity

As an indicator of pre-vaporization, the instantaneous diameter of an ammonia droplet was measured under normal gravity. Furthermore, the vaporization-rate constant was measured based on the $d^2$- law in which the squared value of the droplet diameter decreases linearly, and expressed as Eq. (1) [3],

$$d^2 = {d_0}^2 - Kt \tag{1}$$

In this study, $K$ is the vaporization-rate constant. **Figure 4** shows the change of the squared diameter of three droplets over time for a target diameter of 1.0 mm. **Table 1** shows the initial droplet diameter, the ambient temperature around droplet, the vaporization-rate constant for three droplets. As a result, the vaporization-rate constant of a droplet with an ambient temperature around 310 K is 0.0231~ 0.0285 mm$^2$ / s.

Next, we attempted to suppress pre-vaporization by lowering the ambient temperature near the droplet by attaching a Peltier element to the droplet generation system. However, it became clear that the ambient temperature could not be lowered to a level that would contribute to suppressing pre-vaporization, as only about 3 K of cooling could be achieved due to the high-pressure environment and the enclosed space. In the future, it will be necessary to use another cooling method.

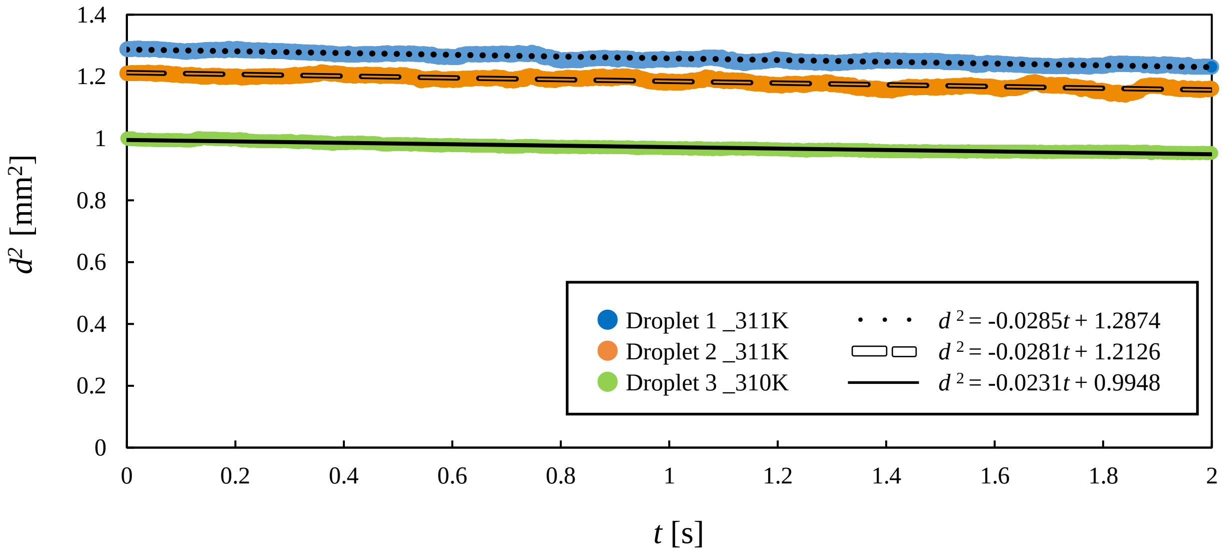


**Figure 4** The variation of squared droplet diameter over time in normal gravity

**Table 1** Vaporization-rate constant $K$ in normal gravity

| | Initial droplet diameter [mm] | Tempeature [K] | $K$ [mm$^2$/s] |
|---|---|---|---|
| Droplet 1 | 1.14 | 311 | 0.0285 |
| Droplet 2 | 1.10 | 311 | 0.0281 |
| Droplet 3 | 1.00 | 310 | 0.0231 |

## 4. Conclusions

1. The droplet diameter could not be controlled when a solenoid valve was used to controll the fuel supply to the glass needle. The cause of the problem was considered to be that air bubbles got mixed in the route due to the heat generated by the solenoid valve.

2. Using a ball valve instead of the solenoid valve and a target droplet diameter of 1.0 mm, the mean and standard deviation were 1.06 mm and 0.06 mm.

3. In a normal gravity condition and an ambient temperature around 310 K, the vaporization-rate constant of a single ammonia droplet is 0.0231~ 0.0285 $mm^2$ /s.

4. Pre-vaporization suppression was attempted by lowering the ambient temperature using a Peltier element, but it became clear that the ambient temperature could not be lowered to a level that would contribute to pre-vaporization suppression. In the future, it will be necessary to use another cooling method.

## 5. Acknowledgements

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## 6. References

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