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微小重力場を用いた室温高圧雰囲気中での単一アンモニア液滴の蒸発速度定数計測

Measurement of vaporization rate of single ammonia droplets in room-temperature high-pressure air in microgravity

松浦勇翔 [1], 原侑花 [1], 三上真人 [1],
Yuto Matsuura[1], Yuka Hara [1], Masato Mikami [1]
[1] 山口大学大学院，Yamaguchi University#1,

1. Introduction

Spray combustion is often used in combustors. However, the detailed mechanism has not been clarified because various phenomenon proceeds simultaneously. In order to improve understanding of its mechanism, many studies on combustion of a single droplet, which is a component of spray, have been conducted from a fundamental viewpoint. In addition, in recent years when the movement of carbon neutral is becoming popular, many studies on combustion using carbon neutral fuels are being conducted. Ammonia is one of them. Another merit of using ammonia as a fuel is that the cost of changing the existing system can be minimized. Okafor et al. succeeded in stabilizing ammonia spray combustion using a high-temperature swirling air flow[1)]. However, since ammonia is in gaseous state at normal temperature and atmospheric pressure, it is difficult to handle it as a liquid. So, any researches using single ammonia droplets have not yet been conducted. In this study, at the first step, an ammonia droplet was generated at a pressure higher than saturation pressure of ammonia at room temperature. Since spray combustion proceeds in the form of igniting the vaporized fuel component, the vaporization of fuel is important in spray combustion. Therefore, we measured vaporization-rate constant of a single ammonia droplet in normal gravity and estimated that in microgravity.

2. Experimental apparatus and procedure

To supply ammonia as liquid, we constructed a liquid ammonia supply path, as shown in **Fig. 1**. The ammonia supply path is connected to a high-pressure syringe which is a part of the ammonia droplet generation system. A N_2 pressurization path and a vacuuming path are also connected to the ammonia supply path. First, the inside of the ammonia supply path and the tube attached to the ammonia droplet generation system is evacuated. Then, liquid ammonia was introduced into the path from an ammonia cylinder turned upside down and was pressurized by N_2. The purpose of N_2 pressurization is to completely change the gaseous ammonia remained inside the path into liquid. The pressurizing pressure was 1.5 MPa. After N_2 pressurization, the droplet generation system was disconnected and installed in a pressure vessel. In order to keep ammonia in liquid state, it must be treated at high pressure or low temperature. This study used high-pressure condition to realize it. The pressure vessel was pressurized at 1.5 MPa using dry air (N_2 79%, O_2 21%).

Figure 2 shows the ammonia droplet generation system, which is equipped with a three-axis traverse stage that moves the glass tube and pushes out the syringe with liquid ammonia, a fiber base with crossed SiC fibers, a self-designed syringe, and a solenoid valve. An ammonia droplet was generated by depressurizing. After pressurizing the pressure vessel, solenoid valve was opened, and liquid ammonia is extruded. After that, the pressure vessel is depressurized until an ammonia droplet is generated.

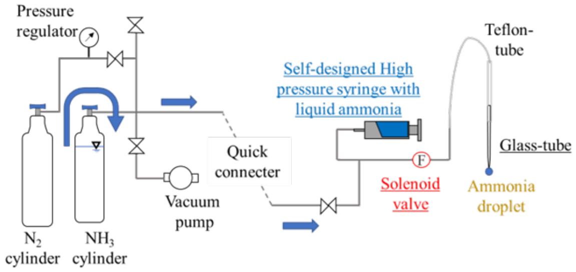

Figure 1. Liquid ammonia supply path

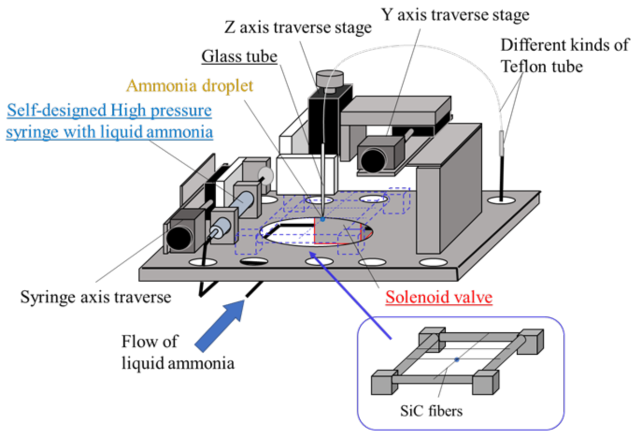

Figure 2. Ammonia droplet generation system

3. Results and discussion

3.1 Ammonia droplet generation

Figure 3 shows a generated droplet. The initial droplet diameter is 1.15 mm. The cause of this droplet generation method is a slight leak in the self-designed syringe. When it is depressurized, the gaseous ammonia in the stainless-steel tubes was 1.5 MPa, but the pressure vessel was lower than that. So, liquid ammonia was extruded and droplets were generated by differential pressure.

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

The instantaneous diameter of an ammonia droplet in a normal gravity was measured. 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)[2),

$$d^2 = {d_0}^2 - Kt \quad (1)$$

In this study, K is defined as vaporization-rate constant. **Figure 4** shows the variations of squared droplet diameter over time for three droplets. One of them was generated at 1.08 MPa and an ambient temperature of 300 K, the others were generated at 1.43 MPa and an ambient temperature of 302 K. Since the initial droplet diameter differs from each experiment, the droplet diameter is normalized by the initial droplet diameter, and the time is normalized by square of the initial droplet diameter. **Figure 4** shows that the vaporization rate constant of ammonia droplets in normal gravity is 0.0260~0.0284 mm^2 / s.

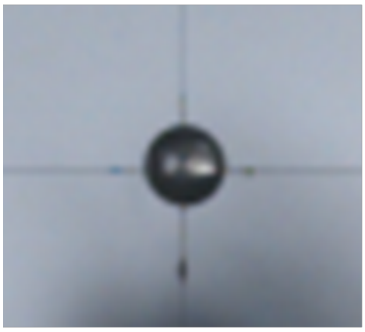

Figure 3. A generated ammonia droplet

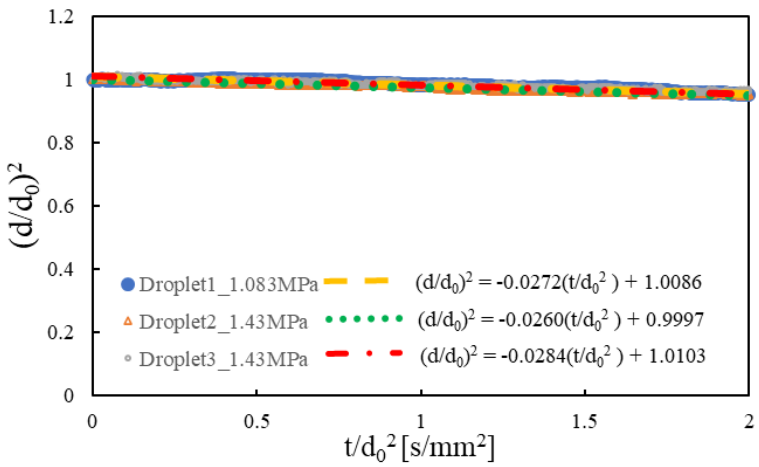

Figure 4. The variation of squared droplet diameter over time in normal gravity

3.3 Estimation of vaporization-rate in microgravity

This section estimates the vaporization-rate constant in microgravity based on that in normal gravity measured in Section 3.2. Here, it is known that effects of natural convection on the burning rate constant is evaluated by the following equation [3].

$$K = K_0\left(1 + C{G_r}^{1/4}\right) \quad (2)$$

Also, Grashof number is evaluated using Eq. (3), through which we can evaluate the effect of natural convection.

$$G_r = \frac{\Delta\rho}{\rho} g \frac{{d_0}^3}{\nu^2} \quad (3)$$

Here, to evaluate the effect of natural convection on the mixed gas of ammonia vapor vaporized from an ammonia droplet and the air around the droplet, the initial droplet diameter is used as the representative length. In addition, as the dimensionless density difference, $\frac{\Delta\rho}{\rho}$, the density average of the ammonia-air mixed gas and air the denominator, and the density difference between the ammonia-air mixed gas and air as the numerator used to calculation. By using the Grashof number of Eq. (3), the vaporization-rate constant, K, in normal gravity and Eq. (2), we estimated the vaporization rate constant, K_0, in microgravity, where we suppose Eq. (2) holds in the case for droplet vaporization, too.

Table 1 shows the initial droplet diameter d_0, the Grashof number G_r, and the estimated vaporization-rate constant K_0 in the three conditions in Section 3.2, where it is calculated with $C = 0.85$ [2]. The estimated vaporization-rate constant is 0.00358~0.00465 mm^2/s. This suggests that the estimated vaporization-rate constant in microgravity is about one order smaller than that in normal gravity. In future, we need to verify that and measure vaporization-rate constant in microgravity.

Table 1. Estimated vaporization-rate in microgravity K_0 and various parameters

	Initial droplet diameter [mm]	**Pressure [Mpa]**	**Tempeature [K]**	**Grashof number**	$\boldsymbol{K_0}$ **[mm^2/s]**
Droplet1	0.859	1.08	300	1403	0.00439
Droplet2	1.10	1.43	302	2946	0.00358
Droplet3	0.838	1.43	302	1302	0.00465

References

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