Mixture Distribution of Solid-Gas-Two-Phase Flow for Gaseous Detonation with Aluminum particles

Ryunosuke Shimizu*, and Toshiharu Mizukaki**
*Graduate School of Engineering
**Dept. of Aerospace and Aeronautics
Tokai University
Hiratsuka 4-1-1, Kanagawa 259-1292, Japan

1 Introduction

Recently, many countries have been studying Mars aircraft. However, carbon dioxide accounts for 95% of the atmosphere of Mars, and Oxygen do for only approximately 0.1%. Therefore, it is impossible to use a propulsion device that utilizes Oxygen, which is widely used on earth, as an oxidant. Because a metal with high activity can be burned in carbon dioxide, it is used as a fuel for jet engines in Carbon Dioxide [1]. However, when a metal particle is used as fuel in an engine, such as a turbojet engine with a turbine inside the engine, it will be damaged by combustion products. The internal structure of the combustion chamber must be simple to prevent this problem. This effect can be reduced by using a pulse detonation engine (PDE) because the inside of the combustion chamber is a simple straight pipe. The PDE achieves thrust by intermittently generating detonation waves in a straight pipe with one end closed. The detonation waves generated inside the engine are combustion waves that propagate at supersonic speeds. Because the PDE is a straight pipe with a simple internal structure, it is not easily affected by solid combustion products. Zhang et al. investigated the dependence of Aluminum particle–air detonation waves on the initial pressure [2]. They show that a long deflagration-to-detonation transition (DDT) length is required to achieve metal particle detonation. In this study, as a preliminary experiment of detonation generation using light metal fine particles as fuel in a carbon dioxide atmosphere, fine particles were diffused inside the PMMA tube simulating a detonation tube, the flow conditions of the compressed air used for diffusion were examined, and the dust concentration inside was measured by the light transmission method.

2 Measurement of Corn-Starch Concentration

Before these detonation experiment, we researched aluminum concentration inside the detonation tube. We used light transmission method for it. Figure 1 shows the theory of light transmission method. Light beam is blocked by dust. From Lambert-Beer theory, these equations are obtained that we think an element piece inside of light beam.

$$I_0 = IA \tag{1}$$

$$I_{1,1} = I\{A - (cross\ section\ area\ of\ particles)\}$$
$$= I\left\{A - k\sum_{0}^{d} k_x N d_x^2\right\} \tag{2}$$

(I:Incident intensity, A:Cross section area of light beam, k:Coefficient of particle shape, k_x:Coefficient of absorption, N:Number of particles, dx:Particles diameter). Number fo particles are show equation (3).

$$N = A \cdot \delta l \cdot c \cdot n \tag{3}$$

The energy that output from an element piece is show equation (4).

$$(Energy\ output\ of\ a\ elemrnt\ pices) = A(I + \delta I) \tag{4}$$

The following equation is obtained by equation (2), (3) and (4).

$$A(I + \delta I) = I(A - k \cdot c \cdot A \cdot \delta l \sum_{0}^{d} kx \cdot n \cdot d_x^2$$

$$\frac{\delta I}{I} = -k \cdot c \cdot \delta l \sum_{o}^{d} kx \cdot n \cdot d_x^2 \tag{6}$$

The following equation is obtained by equation (6).

$$\ln \frac{I_0}{I} = k \cdot c \cdot l \sum_{0}^{d} k_x \cdot n \cdot d_x^2 \tag{7}$$

We can presume dust concentration by light intensity between an element piece.

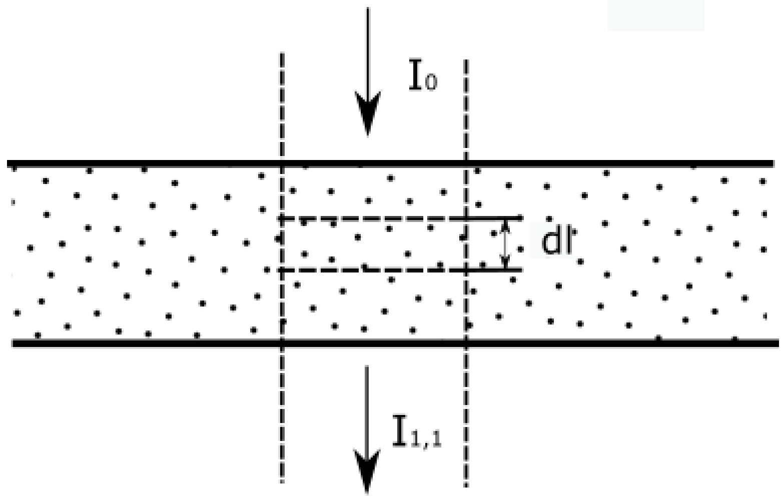

Fig.1 Principle of measuring dust concentration by light transmittance.

3 Experimental Setup

Figure 2 shows the experimental setup. The experimental system consisted of a PMMA tube with an internal diameter of 54 mm and a length of 1 m. This tube is a same size as the detonation tube. In this experiment used corn-starch that is the similar diameter and density as the aluminum particles. Figure 7 shows the particle dispersion nozzle located 5 mm from the bottom of the detonation tube. It contained 17 holes, each with a diameter of 1 mm, through which Air was ejected to diffuse the particles. The ejected time was controlled to 750 ms by solenoid valve. The dust concentration was measured by light transmission method at 250, 500 and 750 mm from the upstream. He-Ne Laser (Thorlab, S1FC635, Wavelength 635 nm, Output 0.2 mW) was used as the light source. The light that has passed through the optical fiber becomes parallel light through the lens and passes through the PMMA tube. The light that has passed through the lens passes through the lens and is focused on the photodetector (Thorlab, DET10A, PD). The output voltage from the PD and the control signal of the solenoid valve were measured with an oscilloscope (RIGOL, DS2202A). The dust concentration was measured from the output voltage of PD. Table.1 shows the experimental conditions. The experimental conditions are listed in Table 1. The dust weight was 1.4, 2.1 and 2.8 g. Preliminary experiments were conducted to clarify the relationship between dust concentration and output voltage ratio, and the results are shown in Fig. 3. The relationship between dust concentration and output voltage ratio was nonlinear, and the decrease in voltage became slower as dust concentration increased. The decrease in voltage became slower as the dust concentration increased. This was due to the overlapping of particles and the scattering of light. Therefore, the dust concentration was calculated from the approximate formula.

Table.1 Experimental condition.

ϕ_n [-]	w [g]	ρ [g/m3]
1.0	1.4	624
1.5	2.1	937
2.0	2.8	1250

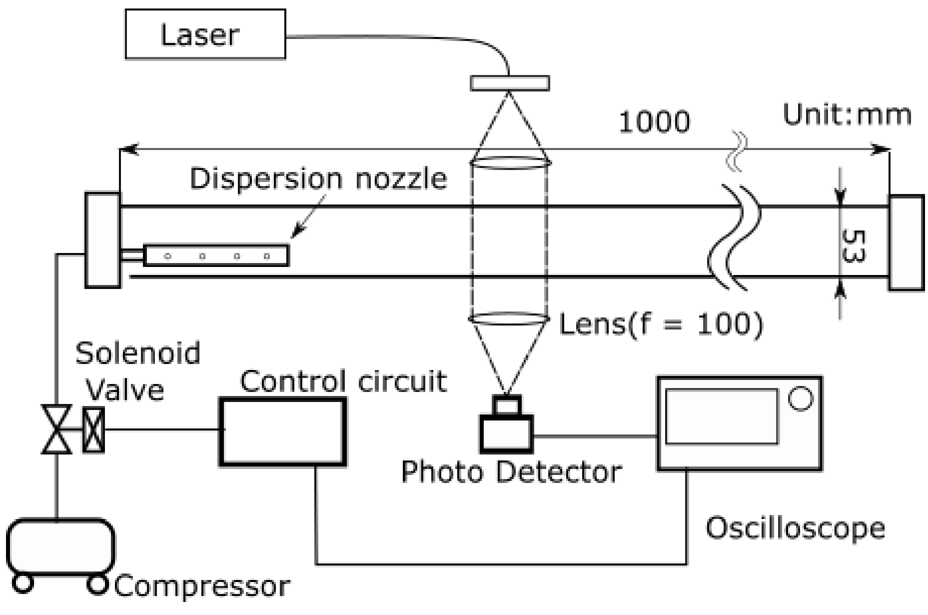

Fig.2 : Experimental setup of Dust concentration measurement inside PMMA tube.

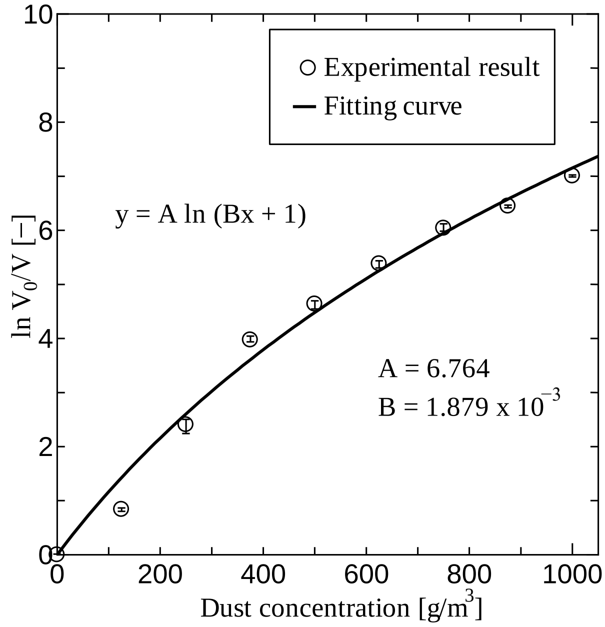

Fig.3 : Relationship between dust concentration and light transmittance.

4 Experimental results

Figure 4 shows output voltage ratio of Photodiode when Corn starch wight 2.8 g and solenoid valves was opened 750 ms. Dust reached the 250 mm point about 313 ms after the solenoid valve opened, and dust reached the 750 mm point about 742 ms after the solenoid valve opened. The average dust velocities between the measurement points were 1.66 m/s and 0.899 m/s, respectively. The velocity decreased by about 46% toward the downstream. The largest drop in voltage was observed at the upstream measurement point in terms of dust amount, with a maximum voltage drop of approximately 91.6% at a theoretical equivalent ratio of 2.0. This is due to the increase in the dust concentration and the increase in the ratio of particles blocking the light. The voltage dropped smaller downstream, decreasing by a maximum of about 30%. Figure 5 shows the ratio of the maximum dust concentration to the equivalent ratio at each measurement point. L is the equivalent ratio calculated from the dust concentration obtained by the optical transmission method. For theoretical equivalent ratios of 1.0 and 1.5, the dust amount was less than 0.4 even at the 250 mm position, where the dust amount was the highest. For theoretical equivalent ratios of 1.5 and 2.0, the equivalent ratio reached about 0.8 at the 250 mm position. Therefore, when an equivalent ratio of 1.0 is targeted, metal particles can be diffused uniformly at close to the desired equivalent ratio if the particles are diffused within 250 mm from the closed end. However, when the equivalent ratio is increased, the desired uniform diffusion is difficult to achieve.

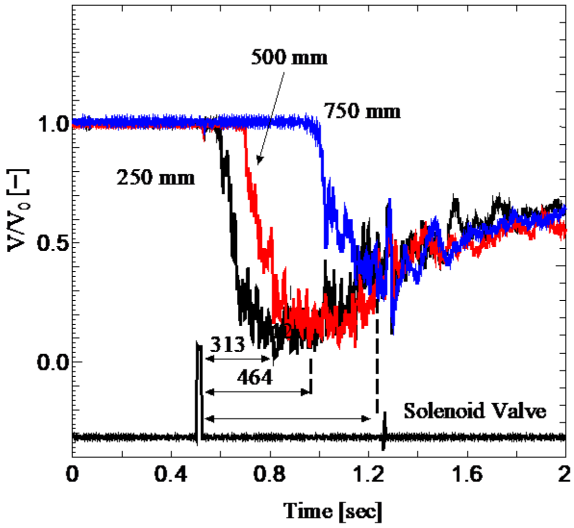

Fig.4: Photodiode voltage output history at each measurement points.

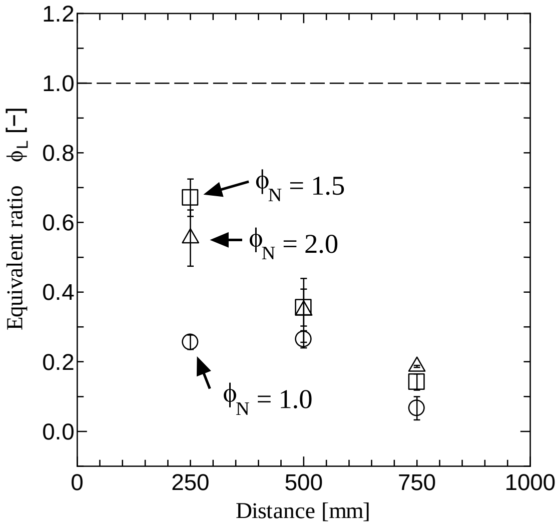

Fig.5: Ratio of dust concentration to equivalent ratio at each measurement point

5 Conclusions

In this study, as a preliminary experiment of detonation generation using light metal fine particles as fuel in a carbon dioxide atmosphere, fine particles were diffused inside the PMMA tube simulating a detonation tube, the flow conditions of the compressed air used for diffusion were examined, and the dust concentration inside was measured by the light transmission method. When an equivalent ratio of 1.0 targeted, uniform diffusion of metal particles close to the desired equivalent ratio will be achieved if the particles diffuse within 250 mm from the closed end. However, when the equivalent ratio is increased, the desired uniform diffusion is difficult to achieve.

References

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