

Oscillating propagation of near-limit detonations of CH₄/O₂ system in a small diameter tubes

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1 Introduction

There is a pressure limit where the detonation cannot propagate for various kind of gaseous fuel. In such a regime, decoupling of the shock and flame in the detonation structure leads to the failure of the detonation. However defining such a pressure limit experimentally is not easy. Because propagating speed of the detonation at conditions near pressure limit sometimes very unstable and flaring. Oscillating behavior of detonation contains many processes such as deflagration to detonation transition(DDT), decoupling the shock and the flame and also energy loss processes by viscosity and heat transfer. In this study, we observed the oscillating behavior of methane and oxygen system experimentally near the pressure limit using a small diameter glass tube.

Oscillating behavior of detonation was first reported by A. J. Mooradian and W. E. Gordon^[1]. In some particular conditions, following rapid failures of detonation, strong re-initiation of detonation occurred repeatedly. R. E. Duff^[2] also reported that such re-initiation behaviors were observed after the spinning mode failure. Many authors, N. Manson^[3], I. O. Moen^[4], J. H. Edwards^[5], J. J. Lee^[6] have examined same kind of oscillating behavior of detonations.

In the near-limit conditions, the mode of propagating detonation changes from multi-headed mode to single spinning mode^[7]. In some particular conditions, the speed of detonation propagation fluctuates. Depending on the stabilities of the speed, J. J. Lee classified propagating behavior into six types of modes. Those six modes were “stable”, “rapid fluctuation”, “stuttering”, “galloping waves”, “low-velocity stable”, “failure”. Stuttering and galloping modes are characterized by fluctuation of speed, re-initiation of detonation. Microwave Doppler technique was demonstrated to be suitable to examine those unstable regimes as reported by J. J. Lee^[6] and D. H. Edwards^[5]. Especially, low velocity mode which expresses very large velocity deficit from C-J value was reported by J. J. Lee^[6].

The objective of this study is to clarify these regime experimentally using optical fiber technique and soot foil technique. The failure process and re-initiation process are very interesting because these processes are related to the limit of propagating detonation and DDT. By changing internal diameter of detonation tube and initial pressure, we demonstrated which conditions are related to each process.

2 Experimental Methods

Schematic diagram of our present study is shown in Figure 1. The detonation tube was nearly 5 m in length and 3, 4, 6 and 10 mm in inner diameter. The tube was made of PYREX[®] glass. Premixed sample gas was prepared in a stainless mixing tank. After evacuating the tank by a rotary pump, CH₄ and O₂ gas was introduced into the tank up to 1000 Torr and was kept about 1 day and night to wait complete mixing of gases by diffusion. We confirmed that the detonation velocities of the mixed gas in the upside part, center and bottom part in the mixing tank was nearly the same within 5 m/s errors after 1 day mixing. Gas purity was 99.9% for CH₄ gas (Taiyo Nippon Sanso Corp.) and 99.999% for O₂ gas (Taiyo Nippon Sanso Corp.). The pressure of the gas line was monitored by a capacitance manometer (MKS Baratron[®]). Before ignition, glass tube was evacuated more than 15 min to obtain high vacuum for high voltage discharge. Next Pre-mixed gas was introduced to the glass tube from the mixing tank ranging from 60-400 Torr. High voltage, typically 3 kV was applied to the needle to ignite. Triggering signal was transferred by coaxial cable (RG-58 A/U) to digital oscilloscope. Stainless ignition chamber was heated to avoid quenching the flame at low pressures. After ignition, flame was accelerated in the glass tube to obtain detonation. Self-luminescence of detonation front was captured by optical fibers (OFS Specially Photonics Division; All Silica 365, core clad of 400 μ m with numerical aperture of 0.22), which were placed along the quartz tube with 10 cm interval. Total of 45 fibers were placed and introduced to photoelectric surface of two photo-multipliers (PMT: HAMAMATSU R1527). Sharp peaks were obtained in consequence of narrow view angle of the optical fiber as shown in Figure 2. Detonation velocities were calculated by these intervals of the peaks as shown in Figure 3. After DDT was occurred, overdriven detonation was observed and immediately converged to steady speed or moved to the unsteady mode. When only deflagration occurred, self-luminescence peaks were not observed. Finally PMT signal was recorded in the digital oscilloscope.

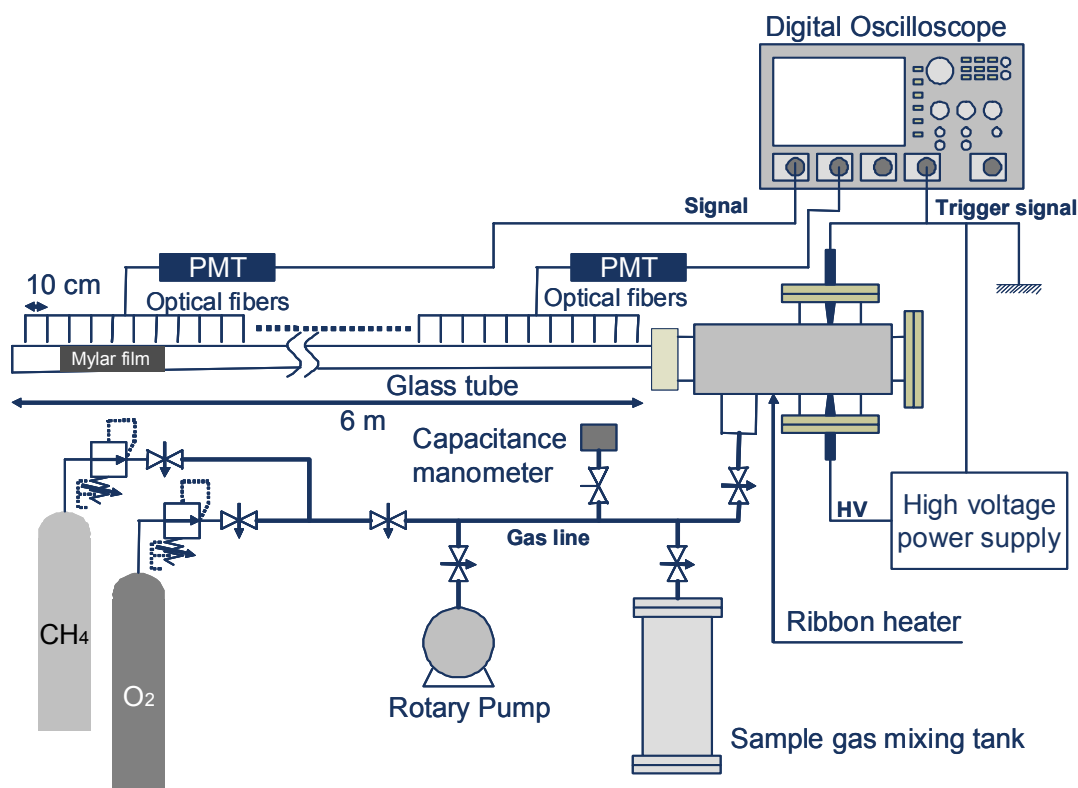


Figure 1. Experimental apparatus for detonation velocity measurements

3 Results and discussions

Typical raw data are shown in Figure 2. The intervals of these sharp peaks are translated to the velocities of each section as shown in Figure 3.

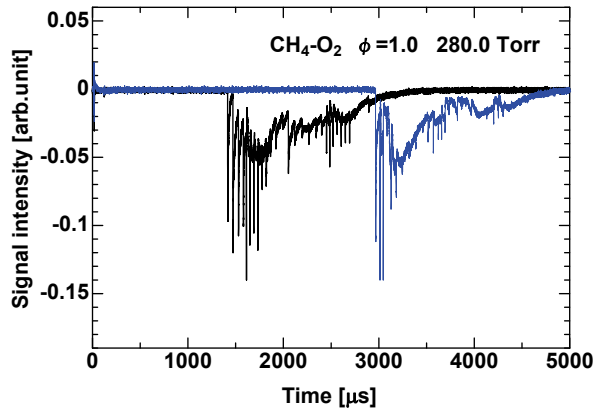


Figure 2. Self-luminescence peaks of propagating detonation

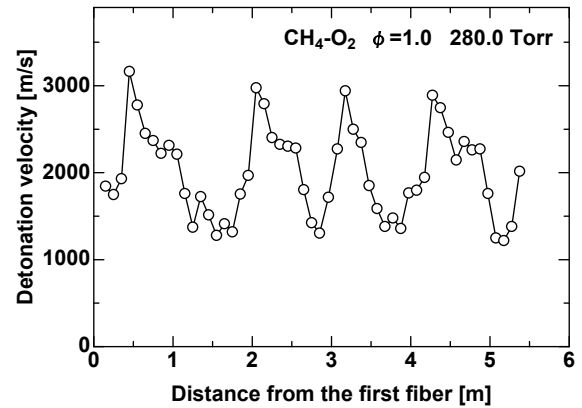


Figure 3. Detonation velocities obtained from the data in Figure 2

As shown in the Figure 3, galloping detonation was observed for wide range of initial pressure. At higher initial pressures, steady detonations were observed. As the initial pressure decreased the cyclic length of the galloping oscillation increased. The dividing point of steady detonation from galloping detonation seemed very sensitive to a disturbance such as caused by glass chips. Although low velocity detonation whose velocities were 0.6-0.7 times of the C-J value was also observed, disturbance of glass chips also strongly influenced on whether low velocity detonation was observed or not. From our experimental results, galloping mode seemed to be able to avoided by a kind of disturbance caused by glass chips in the detonation tube.

Table 1: Types of propagating mode for initial conditions and tube diameter

	Steady detonation	Galloping detonation	Low velocity detonation
d=3 mm	> 400 Torr	350-80 Torr	100-60 Torr disturbance by glass chip or metal wire
d = 4mm	> 350 Torr	350-100 Torr	NA
d= 6 mm	400-225 Torr	225-50 Torr	NA
d=9 mm	350-150 Torr	145 Torr	NA

So far as galloping detonation occurred, we can estimate the length of the failure and the length of re-initiation. The number of galloping cycle seemed to decrease as the initial pressure decreased and the tube diameter increased. The definitions of the length of the failure x_d and re-initiation x_a are shown in the Figure 4. The processes of oscillation were divided to failure process and the re-initiation process and their value were averaged respectively. The length of the re-initiation process and the failure process are plotted against initial pressure in Figure 5 and 6. The length of the failure process was strongly dependent on the initial pressures and the tube diameter.

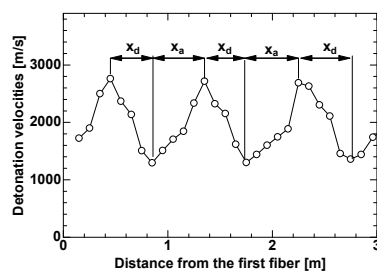


Figure 4. length of the failure and re-initiation process

4 Conclusions

Our present results indicate that the failure process of overdriven detonation in the oscillating cycle strongly dependent on the initial pressure and the tube diameter. As smaller diameter tube increased the energy loss of detonation per unit volume, decoupling the shock and flame was accelerated. Disturbance such as glass chips or metal wire avoided the oscillating behavior of detonation, which means that the disturbance encouraged the explosion of unburned gas behind the shock wave.

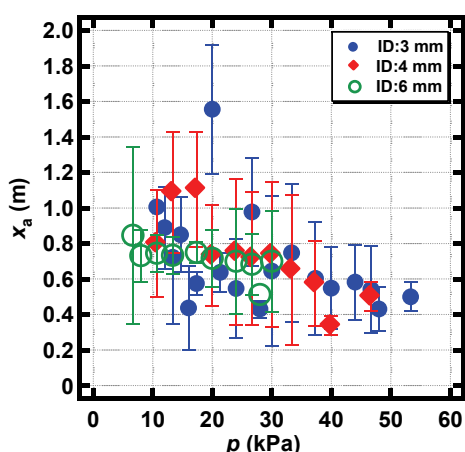


Figure 5. Length of re-initiation process

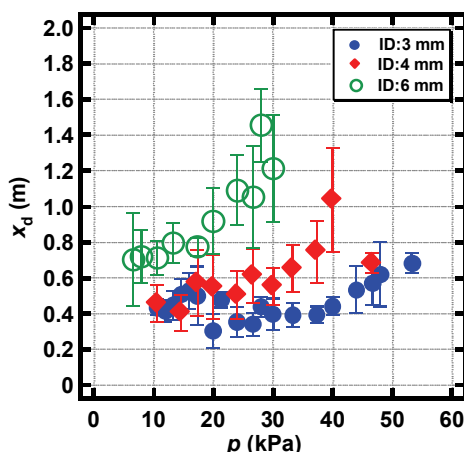


Figure 6. Length of failure process

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Acknowledgement

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