Effects of Ignition Delay by Nitrogen Film Cooling on Ignition Transition of Gaseous Oxygen/Kerosene Spray Combustor

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1 Introduction

Unstable ignition such as an ignition delay and overshoot is very dangerous situation enough to destroy a rocket engine system[1,2]. Over-peak pressure at the initial ignition affects the combustion chamber and propellant injection system and this causes the performance degradation of the liquid rocket engine. Therefore, these situations should be avoided to protect the liquid rocket engine. Additionally, the combustion chamber undergoes numerous hot fire tests, thus it should be protected from a combustion gas of the high pressure and temperature. In other words, a hard ignition in repetitive fire tests has an impact on the combustion chamber. In many previous studies, methods to avoid the destruction of the rocket engine system have been researched [3,4]. Typically, the film cooling with a regenerative cooling system used in a first stage engine in that the film cooling is helpful to reduce the convective heat transfer to a surface like the combustion chamber wall[5,6]. In this study, a gaseous nitrogen as the film coolant was injected into the combustion chamber. The objective of this paper is to observe effects of ignition delay by nitrogen film cooling on ignition transition. In order to measure dynamic characteristics, dynamic pressure used, and the film coolant was injected before the ignition to observe effects of the film cooling.

2 Experimental Setup and Approach

The combustion chamber was established as shown in Fig. 1. The shear-coaxial injector was used to inject propellants. Geometrical dimensions of combustion chamber and shear-coaxial injector was shown in Table 1. The combustion chamber diameter, D_c, is 22 mm: its nozzle throat diameter, D_t, is 6.4 mm: and

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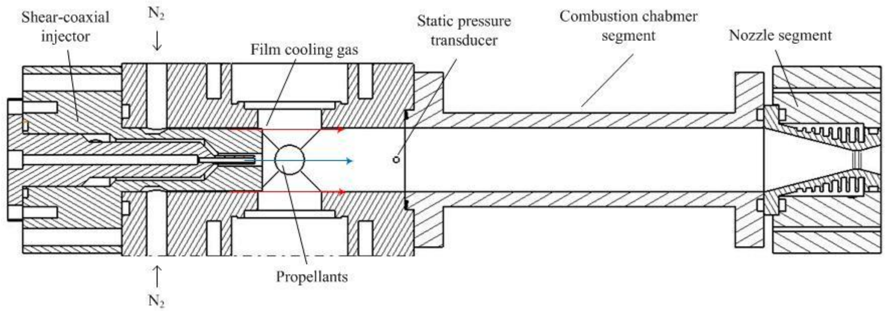


Figure 1. Schematic of combustion chamber

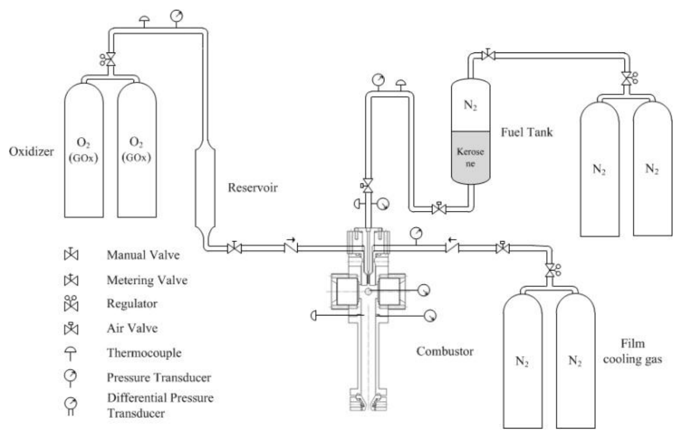


Figure 2. Schematic of propellants supply lines

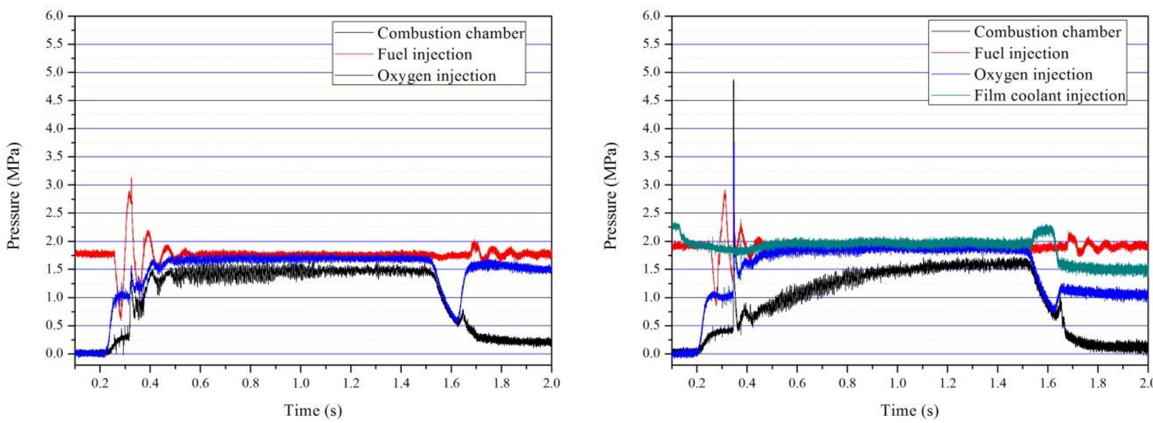
Table 1: Geometrical dimensions of combustion chamber and shear-coaxial injector

Combustion chamber		**Shear-coaxial injector**	
Inner diameter, D_C	22 mm	Outer diameter of liquid center post, D_P	3.0 mm
Length of chamber, L_C	167 mm	Inner diameter of liquid center post, D_L	1.5 mm
Nozzle throat diameter, D_t	6.4 mm	Annular gap width, t_{AG}	0.75 mm
-	-	Diameter of body, D_G	4.5 mm
-	-	Recess length, R	3.0 mm

the length, L_c, is 150 mm. The outer diameter, D_p, of the shear-coaxial injector is 3 mm, its inner diameter D_L is 1.5 mm. In addition, recess length, R, is 2.0 mm, the slit, t_{AG}, for the nitrogen film cooling gas is 0.75 mm. Fig. 2 shows the schematic of propellants supply lines. For propellants gaseous oxygen and liquid kerosene were injected using the shear-coaxial injector. The experiments focused on effects of the film coolant injection before the ignition with the different conditions on the ignition transition. Dynamic characteristics during the ignition transition were analyzed using data collected from the dynamic pressure transducer. The injection pressure of the nitrogen film coolant was varied to change the differential pressure between the combustion chamber and propellants injection, but all conditions except the film coolant were the same in tests.

3 Experimental Results and Discussions

Experiments results was represented in Table 2. The combustion chamber pressure was around 1.7 MPa. The oxygen injection pressure was around 2.0 MPa and fuel injection, and the differential pressure was varied from 0.19 MPa to 0.64 MPa. In order to confirm the effect of the nitrogen film cooling on the ignition delay, the injection pressure of the nitrogen film coolant was changed from 0.19 MPa to 2.4 MPa. The differential between the oxygen injection and combustion chamber pressure was existed with the nitrogen injection pressure. Fig. 3 (a) shows the combustion chamber pressure in the case without the film cooling, and Fig. 3 (b) represents the case of the film cooling injection before the ignition. Cases of the nitrogen film cooling were detected the overshoot. The combustion chamber pressure during the steady state was the same for both the presence and absence of the nitrogen film cooling. The ignition delay time, which was defined between the initial pressure peak and oxygen injection time, was calculated to confirm the unstable ignition as shown in Fig. 4 (a). In the presence of the nitrogen film cooling gas, the ignition delay occurred 100 – 160 ms. In the opposite case, the ignition delay was calculated to be less than 30 ms. Also, the initial pressure peak increased as the ignition delay time increased as shown in Fig. 4 (b).



(a) (b)

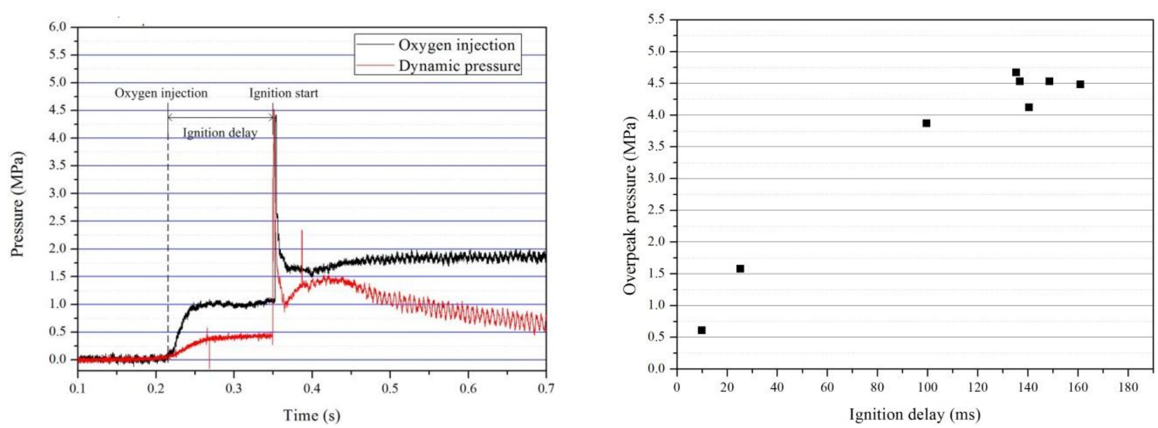
Figure 3. Combustion chamber pressure of (a) presence and (b) absence film coolant

Table 2: Experimental results

	Without film cooling		With film cooling					
	test1	test2	test3	test4	test5	test6	test7	test8
Combustion pressure (MPa)	1.70	1.58	1.69	1.66	1.73	1.76	1.78	1.81
Oxygen injection pressure (MPa)	2.17	2.22	2.00	2.00	2.10	2.00	1.97	2.02
Differential pressure (MPa)	0.47	0.64	0.31	0.34	0.37	0.24	0.19	0.21
Oxygen mass flow rate (g/s)	9.26	9.58	9.02	9.02	9.76	9.76	9.53	9.60
Fuel mass flow rate (g/s)	3.27	3.19	3.25	3.21	3.12	3.04	3.10	3.05
Oxidizer-to-fuel- mass ratio	2.83	3.00	2.77	2.81	3.12	3.21	3.07	3.14

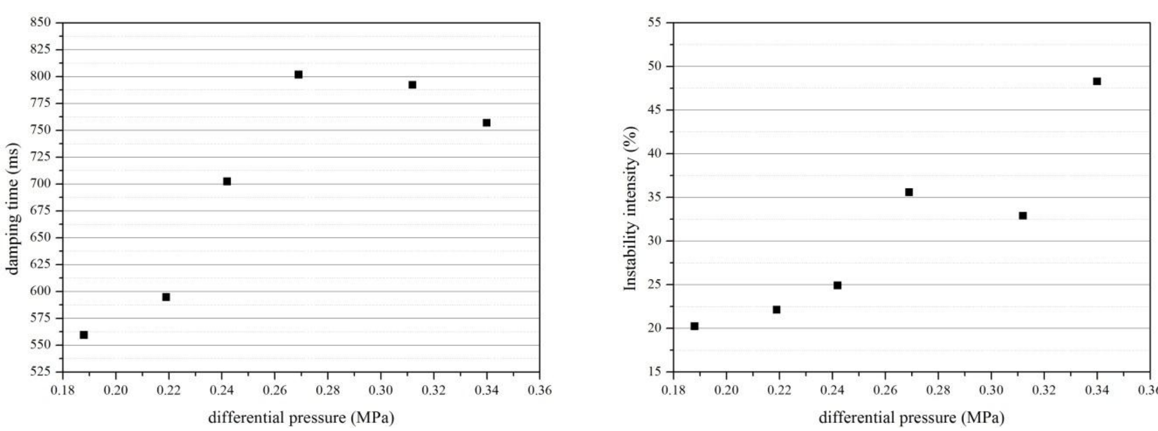
The reason is that the propellants injection time increases when the ignition delay occurs, as a result, the amount to be converted to chemical energy increases[7]. To measure the combustion instability in the ignition transition, damping time and combustion instability intensity was calculated[8]. The damping time was defined as the time from the pressure peak value to the steady state. Fig. 5 (a) represents the damping time according to the differential pressure between the propellant injection pressure and the combustion chamber pressure. The damping time was calculated as 559.3 ms for differential pressure of 0.19 MPa and 756.8 ms for 0.34 MPa. The damping time had the tendency to increase with increasing differential pressure. This is because that the propellant injection was disturbed due to higher combustion pressure than propellant injection pressure. **Eq. 1** was used to calculate the combustion instability intensity[7]. As with the damping time trend, the combustion instability intensity decreased as the differential pressure increased as shown in Fig. 5 (b). When the differential pressure was 0.19 MPa, the combustion instability intensity was calculated as 20.23 %, and 48.27 % for 0.34 MPa. At high differential pressure conditions, the combustion instability intensity increases due to the sudden pressure change[9]. Therefore, this is considered to be the cause of the tendency in this experiment.

$$f = \frac{p_1}{p_2} \times 100 \qquad (1)$$



(a) (b)

Figure 4. (a) calculation method of ignition delay (b) overpeak pressure by ignition delay



(a) (b)

Figure 5. Influence of differential pressure on (a) damping time and (b) instability intensity

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