



Effects of kerosene heating on dynamic characteristics of GO_x /kerosene combustor

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ABSTRACT

The objective of this study was to observe low-frequency instabilities caused by heating of kerosene under supercritical operating conditions. Gaseous oxygen and liquid kerosene were injected using a shear-coaxial injector. Under specific heating conditions, the fuel heating system induced an extremely low frequency pressure fluctuation ranging from 9.9 to 11.4 Hz. When pressure oscillation occurred in the heating system, low-frequency combustion instability was subsequently induced in the range of 30–200 Hz. To understand the effects of the fuel heating temperature on the combustion instability, the dynamic pressure and OH^* chemiluminescence intensity were measured in a combustion chamber at high speed. Further, the reacting spray of the combustion was visualized by a shadowgraph technique. In this experiment, an approximate fuel pressure of 3.0 MPa was employed in order to attain a supercritical condition of kerosene. The measured dynamic pressure and chemiluminescence intensity in the time domain were converted to frequency-domain spectra by fast Fourier transform. Analysis of the dynamic pressure and chemiluminescence intensity measurements confirmed that the low-frequency pressure oscillation in the heating system had an influence on the combustion instability. From the visualization data, it was also revealed that there existed varying amplitude levels of flow rate fluctuation. This fluctuation in turn caused a periodic injection of kerosene at a frequency similar to both the combustion instability frequency and the OH^* chemiluminescence intensity frequency.

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1. Introduction

Combustion instability continues to be a critical issue in that it impedes the development of liquid propellant rocket engines. The phenomenon of the combustion instability is observed in certain systems such as liquid-fueled rocket engines [1]. Unstable combustion causes serious damage on account of pressure oscillation and unsteady-heat-release fluctuations, which can be attributed to resonant modes of the combustor. At the initiation moment of a combustion reaction, an unsteady energy emission occurs, which induces a pressure perturbation [2,3]. In other words, the mechanism of the combustion instability is the feedback processes that are responsible for flow oscillation or thermodynamic variability which induces a heat release fluctuation that in turn excites acoustic fluctuations. These acoustic fluctuations affect the flow or thermodynamic variability, which implies the occurrence of a closed-feedback system [4,5]. Furthermore, oscillations manifest rapidly in time, which results in a large thermal transfer that

progresses rapidly over a short period of time, and this transfer is often sufficient to melt and destroy the combustor parts of a rocket engine [6].

Various methods have been employed to observe unstable combustion [7]. Typically, combustion instability is measured using a dynamic pressure transducer, which gives a quantitative value of the unstable state. Another approach to measuring this instability is to measure the intensity of the chemiluminescence, which occurs during the combustion reaction [8]. Chemiluminescence intensity is associated with the heat release rate. The chemiluminescence intensity of certain radicals can be measured using a photomultiplier tube, which provides qualitative measurements of light intensity, and a band-pass filter. The instability phenomenon can be analyzed quantitatively by making use of the dynamic pressure and chemiluminescence intensity, which represent the acoustic fluctuation and heat release oscillation, respectively [9].

In many previous studies, kerosene has been employed as a fuel to observe the performance of liquid rocket engines [10,11]. An example of a liquid rocket engine fuel based on kerosene is RP-1, which is a highly refined form of kerosene. Following the development of

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RP-1, numerous investigative studies have been conducted in many countries by using this form of kerosene [12,13]. Fuel instability occurs when a point of vaporization is reached with an increase in the fuel temperature. Vaporization at a high temperature is more active than that under the subcritical condition, and this affects the combustion instability [14–16]. Under the supercritical condition, combustion involving hydrocarbon fuels becomes unstable under the effect of higher heat release [17]. For these reasons, the fluid in a tube becomes unstable, and this in turn affects the combustion. Therefore, the objective of the present work is to observe both fuel and combustion instabilities, which are caused by an increase in fuel temperature.

The experiment in this study is designed using a lean fuel mixture ratio. To measure the combustion instability, a supercritical condition was imposed by adopting an approximate pressure of 3.0 MPa. The effects of pressure fluctuations from a dynamic pressure transducer and photomultiplier tube are observed at a low frequency of the combustion instability and are subsequently confirmed to cause evaporation owing to an increased fuel temperature.

2. Experimental setup and approach

2.1. Combustor assembly

Fig. 1 shows a schematic of the combustion chamber. The combustion chamber is designed to have two parts: a main chamber and a downstream chamber. The nozzle is located at the end of the downstream chamber. The combustion chamber and nozzle are both made of stainless steel. Geometrical dimensions of the combustion chamber and injector are listed in Table 1. The combustion chamber diameter D_c is 22 mm; its length L_c is 150 mm; and the diameter at the nozzle throat, D_t , is 6.4 mm. The employed shear-coaxial injector is made of brass. The outer diameter D_p of the liquid injector is 3 mm, its inner diameter D_L is 1.5 mm, the gap between gas and the liquid injector is 0.5 mm, and the length of the recess R is 2.0 mm. The windows are manufactured with dimensions of 30 mm (diameter) $\times$ of 40 mm (thickness). The propellants are injected into the combustion chamber by using the recess. The kerosene inlet is located at the center of the injector. Gaseous oxygen for the oxidizer is located on both sides of the center. A dynamic pressure transducer is inserted at the center of the combustion chamber in order to measure the flame frequency. A spark plug used for ignition is fixed on the wall on the other side of the chamber.

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

2.2. Dynamic pressure measurement

A piezoelectric type dynamic pressure transducer is used to measure the dynamic pressure in the combustion chamber and the fuel supply line. In this study, the acquired dynamic pressure data was longitudinal mode instability. The sampling frequency was 10 kHz, and the data acquisition duration set to 3 s. Fast Fourier transform (FFT) was performed on the data each second.

2.3. OH^* chemiluminescence

Chemiluminescence refers to the phenomenon of a spontaneous emission of photons from an excited species, and the resulting light includes both ultraviolet and infrared rays. Chemiluminescence is an important tool from a viewpoint of a diagnostic strategy for lean premixed gas-fueled combustions. Measurement of the chemiluminescence intensity is one approach to observing heat release oscillation, since it is proportional to the occurring chemical reaction. The representative species during the combustion process are OH, CH, and C_2 . In this study, only the OH^* chemiluminescence intensity is measured. The photomultiplier tube used to measure the OH^* chemiluminescence intensity with a collimator includes a 310 nm band pass filter.

2.4. Shadowgraph technique

The shadowgraph technique is considered for flame visualization. This technique provides data for flame figures in a chamber with a very short time interval; thus, it is possible to confirm instabilities by observing the flame directly during the combustion process. A high speed CCD camera of Photron Fastcam SA1.1 was employed, and the camera was setup with a resolution of 512×512 pixels and an acquisition rate of 10,000 fps.

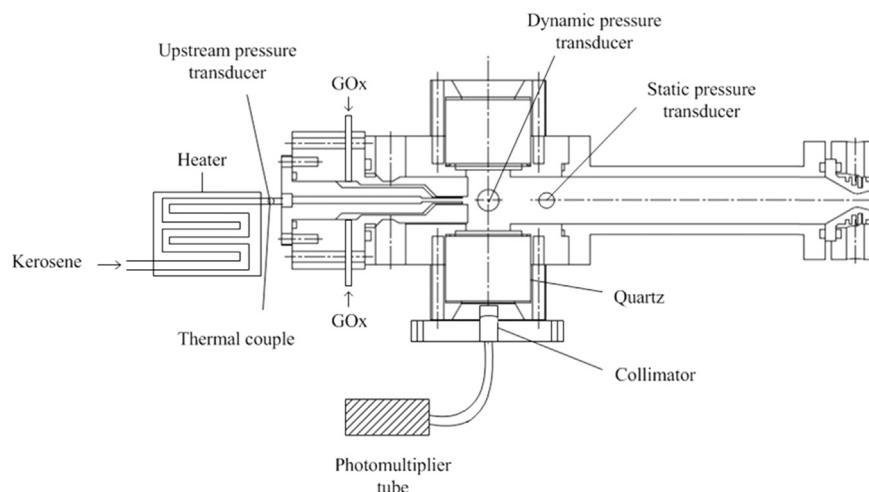


Fig. 1. Schematic of combustion chamber and heater.

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