Thermo-acoustic Instability in a Combustor with Branch Tube

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Abstract: Thermo-acoustic instabilities occur in confined geometries and can result in serious problems on industry combustor. FGR (Flue gas recirculation) system may be regarded as branch tube in the main duct as combustion chamber. The branch tube is to modify geometry of combustor and can affect on pressure field in the combustor. Thus, understanding of thermo-acoustic instability created by modifying geometry of combustor is necessary for designing and operating combustor with FGR system. An experimental study was conducted in the combustor with branch tube in order to model the industry combustor with FGR system and to study acoustic instability generated by a branch tube. Direct images and instantaneous images were observed according to volume ratio of branch tube and combustion chamber (*V.R.*). Dynamic pressure and flame chemiluminescence were measured with microphone and PMT simultaneously. It was found that branch tube affected the characteristics of flame behavior inside a combustion chamber and frequency and magnitude of pressure and heat release rate fluctuation. Also, heat release rate fluctuation was agreed with flame surface fluctuation.

1. Introduction

The combustion driven oscillation (for example, Dibenedetto et al. (2002)) is undesirable phenomenon because it cause high level of acoustic noise and serious damage to the combustor. Since the singing flame by Higgins in 1777, many researches of combustion driven oscillation were conducted. The combustion driven oscillation, sometimes called thermo-acoustic instability, originates from an unsteady interaction and a feedback among flow, heat input, and the acoustics of the system.

For the past decades to reduce or eliminate thermo-acoustic instability, active or passive control technique was typically used. Passive control technique (for example, Culick. (2006)) is to modify the propellant supply system or to change of the combustor geometry, for example, installation of baffles, helmholtz resonator known as acoustic cavity, and liners. Meanwhile, active control technique (for example, McManus et al. (1993); Hathout et al. (1998)) consists of the actuator of some external forcing disturbances into the combustor and an actuator sensor. A pair of these units change an boundary condition at the combustor-end and lead phase creating acoustic energy associated with spontaneous oscillation of flame to shift. Accordingly, the geometry of combustor and phase difference between pressure and heat release rate fluctuation are important factors on the thermo-acoustic instability.

FGR(Flue gas recirculation) system (for example, Baltasar et al. (1997); Kim et al. (2007)) which is used to reduce NOx emission and acquire high concentration of CO_2 in the flue gas may be regarded as branch tube in main duct as combustion chamber. Branch tube is an attaching additive in the combustor to obtain various effect, namely, the passage of flue gas to combustor or pressure wave guide from outlet boundary to inlet boundary. The representative branch tube used is Herschel-Quincke (HQ) tube (for example, Stewart. (1928, 1928)). The HQ tube as branch tube is used to attenuate noise generated from noise source. The plane wave passing through branch tube interferes with wave passing through main duct at the interaction point between branch tube and main tube and then the noise cancels out.

Thus improved understanding on effect of geometry of combustor on thermo-acoustic instability is necessary for the design and operation of combustor with FGR system.

In this paper, the experiments focused on the effect of geometry of the combustor on the thermo-acoustic instability and the phase difference between pressure and unsteady heat release rate by adding branch tube on the combustion chamber. Flame behaviour in the thermo-acoustic instability and relation of flame surface area and heat release rate were investigated.

2. Experimental Apparatus and Conditions

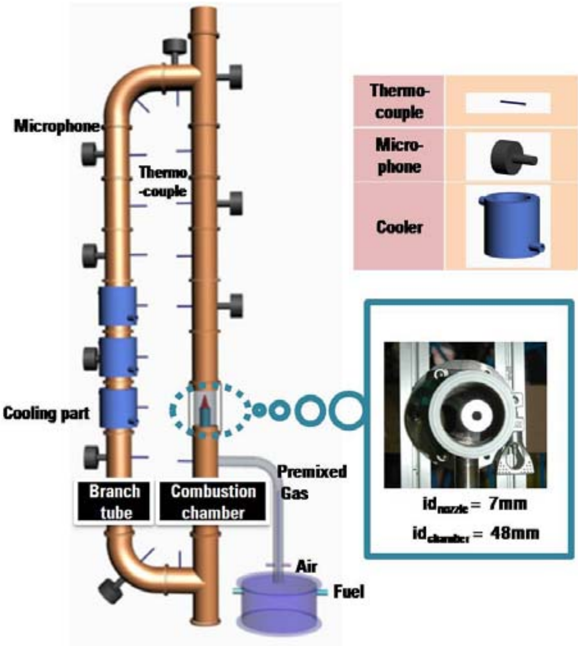

Figure 1. Schematic diagram of Experimental setup

Fig. 1 shows the experimental setup used in this study. Propane gas was used as fuel and air was used as oxidizer. The fuel and air were controlled with MFC(mass flow controller).

Combustion chamber is cylindrical and consists of nine interchangeable SUS tubes of each 100mm in length and 48mm inner diameter. Branch tube has from six to nine replaceable segments. The length of combustion chamber is fixed as 1,144mm and the lengths of branch tube are 810, 862, 914, 966, 1018, 1070, 1122, 1174, and 1226mm.

For visualization, quartz tube is set around the flame. Inner diameters of nozzle and quartz tube are 48mm and 7mm respectively.

In each test, the pressure fluctuation and heat release rate fluctuation were measured simultaneously. For measurement of the dynamic pressure in the combustion chamber, a microphone (Bruel & kjar, 4190) was used. Its sensitivity is 49.8mV per 1Pa and its dynamic range is from 1Hz to 20kHz in response time. To measure the relative magnitude of heat release rate by measuring the global chemiluminescence, a photomultiplier tube (PMT, R212, Hamamatsu) was installed near the flame and connected to an oscilloscope (DL 1640E, Yokogawa).

An intensified high-speed camera(FASTCAM Ultima APX, Photron Ltd.) was used to observe the behaviour of the flame and successive images were recorded at the rate of 2000 frames/second.

The used equivalence ratio and mean velocity was fixed at 1.24 and 1.75m/s respectively. This condition is apt to cause spontaneous oscillation of flame in the combustor with branch tube. The experimental parameter which is calculated by equation 1 was volume ratio of branch tube and combustion chamber.

$$V.R. = \frac{volume\ \ of\ \ branch\ tube}{volume\ of\ \ combustion\ chamber} \quad (eq\ 1)$$

3. Results and discussion

3.1 Flame behavior in the thermo-acoustic instability

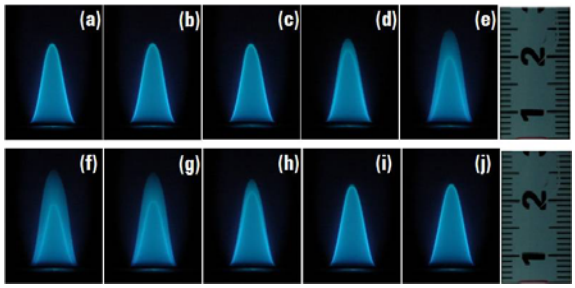

Figure 2. Direct images of flame according to *V.R.* ((a) *V.R.* = 0.68, (b) 0.72, (c) 0.76, (d) 0.81, (e) 0.85, (f) 0.89, (g) 0.93, (h) 0.98, (i) 1.02, (j) 1.06))

Fig. 2 shows direct flame images according to *V.R.*. The images indicate *V.R.* = 0.68 ~ 1.06 from top left to bottom right image. The images of flame in the thermo-acoustic instability are blurred and have not accurate edge of flame. As shown in Fig. 2, thermo-acoustic instability is generated approximately from *V.R.*=0.81 to 0.98. Especially, at *V.R.* = 0.89, flame fluctuation is the highest.

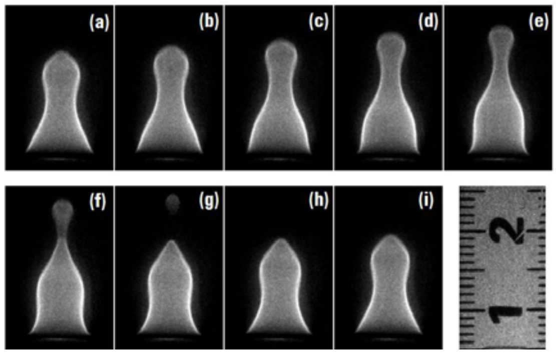

Figure 3. Instantaneous images of flame in the thermo-acoustic instability at *V.R.* = 0.89

The instantaneous images of flame are given in the fig. 3 at *V.R.*= 0.89. The surface of flame in the thermo-acoustic instability was changed by pressure fluctuation in the combustion chamber. The time interval between each image was 0.0005sec and one period of instability is 0.00427sec. The figures show flame behavior during one period.

3.2 Amplitude of pressure and heat release fluctuation and resonance frequency in the thermo-acoustic instability

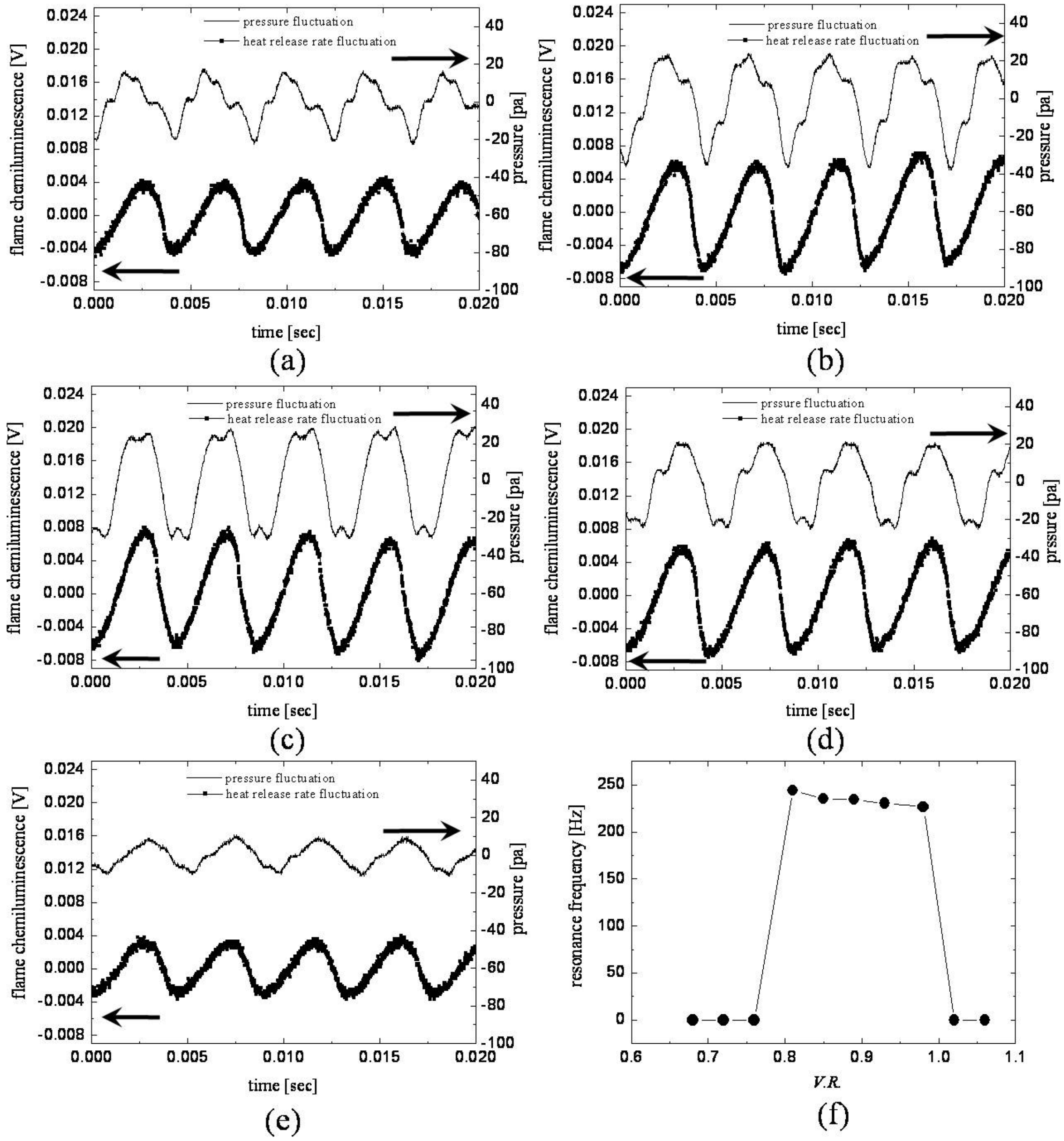

Figure 4. Pressure and flame chemiluminescence according to time. ((a)*V.R.*=0.81, (b) 0.85, (c) 0.89, (d) 0.93, (e) 0.98) (f) resonance frequency according to *V.R.*

The pressure and heat release fluctuation are shown from fig. 4 (a) to fig. 4 (e) according to time from *V.R.* =0.81 to 0.98 which is the region in spontaneous oscill ation of flame. In each graph, upper signal is corresponding to pressure fluctuation from microphone and lower signal is the flame chemiluminescence from PMT. The flame chemiluminescence is proportional to the the global heat release and indicates the relative or qualitative, not absolute or quantitative magnitude of heat release rate(for example, Price et al. (1968); Schuller et al. (2002)).

As *V.R.* increased from fig. 4(a) to fig. 4 (c), amplitude of pressure and heat release rate fluctuation increased. However, as *V.R.* increased from fig. 4(c) to fig. 4 (e), amplitude of pressure and heat release rate fluctuation decreased. When fig. 4 (a) and fig. 4 (e) is compared, phase difference of pressure fluctuation and heat release rate fluctuation is different although magnitude of pressure fluctuation and heat release rate fluctuation is similar to each other. The phase differences between pressure and heat release rate at *V.R.*=0.81 and 0.98 are 1.18msec and -0.35msec on the basis of pressure signal respectively. It is evident that pressure wave passing through branch tube affects the phase difference between pressure and heat release rate fluctuation from the flame in the combustion chamber.

Fig. 4 (f) shows the resonance frequency of thermo-acoustic instability according to *V.R.* *T*he resonance frequency is changed from 225Hz to 239.21Hz according to *V.R.*. Resonance frequency of thermo-acoustic instability is decreased because the length that pressure wave passing through is increased when *V.R.* is increased.

3.3 Flame surface area and heat release rate

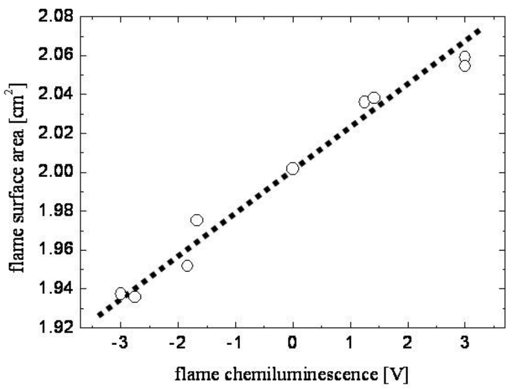

Figure 5. Flame surface area vs the flame chemiluminescence at *V.R.*=0.98

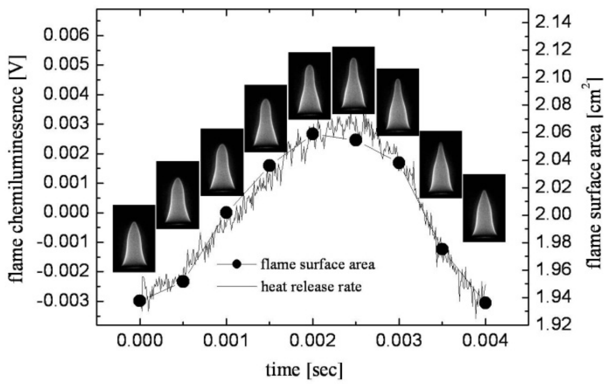

Figure 6. Flame chemiluminesence and flame surface area fluctuation according to time at *V.R.*= 0.98

Fig. 5 shows the correlation of flame surface area and flame chemiluminescence from PMT for the conditions corresponding to the smallest amplitude variation of the flame surface area : at *V.R.* = 0.98. In the thermo-acoustic instability, flame surface is varied by pressure fluctuation. The variation of flame surface area makes the variation of heat release rate from the flame. Therefore, the inspection of the flame surface variation enables us to determine how much is the heat release rate from the flame. Considering the attached flame in the nozzle, the reactant consumption rate is proportional to the total flame surface area. A linear relation between the flame surface area and heat release rate is shown (see, Fig. 5). Flame surface area from instantaneous flame images and simultaneous heat release rate from PMT according to time at *V.R.*=0.98 are given in Fig. 6. Good agreement is obtained between flame surface area and flame light intensity according to time at *V.R.*=0.98

4. Conclusions

An experimental investigation of the thermo-acoustic instability in the combustor with branch tube has been conducted. It has been shown that the volume ratio of branch tube and combustion chamber affects the frequency and the amplitude of thermo-acoustic instability and flame surface area fluctuation was related with heat release rate fluctuation. In this paper, we have reached the following conclusions.

(1) From the results of resonance frequency and direct photo according to *V.R.*, thermo-acoustic instability is generated from *V.R.*=0.81 to *V.R.*=0.98 and amplitude of thermo-acoustic instability is highest at *V.R.*=0.89.
(2) The resonance frequency and phase difference between pressure fluctuation and heat release rate fluctuation is changed by *V.R.*.
(3) Heat release rate fluctuation is proportional to flame surface area fluctuation.

Acknowledgments

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