COMBUSTION INSTABILITY FREQUENCY MODE SHIFT OF H2/CH4 RATIO AND COMBUSTOR LENGTH IN A MODEL GAS TURBINE

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Abstract

Recently, the interests for energy depletion and rapid climate change have emerged around the world. Alternative and sustainable fuels (called clean fuel) and gas turbine using the fuel are the appropriate method to solve the problems. However, combustion instability is another problem for fuel-lean combustion to reduce exhaust emission in gas turbine combustor using gaseous fuel. For this reason, there are many research groups studying about combustion instability characteristics of various fuel composition. However there are not enough studies about reason of instability mechanism such as mode transition. In this paper, experimental studies on the combustion instability characteristics at various composition were conducted in a partially premixed model gas turbine combustor. The fuel composition composes of H_2 and CH_4.

To figure out the combustion characteristics of various test conditions, combustor length, heat load and H_2/CH_4 ratio were selected. NOx emission was not affected with varying combustor length and high H_2 ratio and heat load affect the high NOx emission.

On the other hand, instability frequency was affected on combustor length because the combustion zone was narrow. Furthermore, combustion instability mode shift phenomenon occurred at high H_2 content and it was confirmed that the combustion instability frequency was longitudinal mode of the combustor. The results are would be attributed to key parameters for the combustor design and operation conditions.

1 Introduction

In gas turbine society, to meet the energy regulation of international energy agency, the interest of improving efficiency reduction of NOx emission of gas turbine system is spotlighted. In addition, alternative fuel such as synthetic natural gas and biomass are the another resources to solve these problems. Several gas turbine companies have renovated the fuel and air injection nozzle and operation method like dilution position. However, alternative fuel consists of different fuels generally. For example, syngas consists of H_2 and CO mainly, synthetic natural gas (SNG) consists of H_2 and CH_4 in large portion. Combustion characteristics of these various fuel composition is relatively complex.

Recently, many research groups have been studying the combustion characteristics of various fuel composition in gas turbine. D. Noble of Georgia institute of technology investigated flashback [1] and blowout of H2 and CO mixture and Q. Song of Chinese academy of science studied thermoacoustic oscillation in premixed multi nozzle combustor [2]. J. Yoon conducted that experimental study of effect of convection time on the high harmonic combustion instability in a partially premixed combustor [3] and K. Kim studied interference mechanisms of acoustic convective disturbances in a swirl-stabilized lean-premixed combustor [4].

However, there is not enough experimental study of the mechanism of the combustion instability. Furthermore, relation between the combustion instability and fuel composition is very complex phenomenon especially. In this study, instability frequency mode shift was focused at various parameters kinds of combustor length, heat load and H_2/CH_4 ratio. Frequency mode analysis was applied to analyze the shifting phenomenon and time lag analysis.

Nomenclature

p'	pressure fluctuation
q'	heat release fluctuation
NOx	nitrogen oxide
f	frequency
L_c	combustor length
c	speed of sound

2 Experimental apparatus and condition

2.1 Model gas turbine combustor

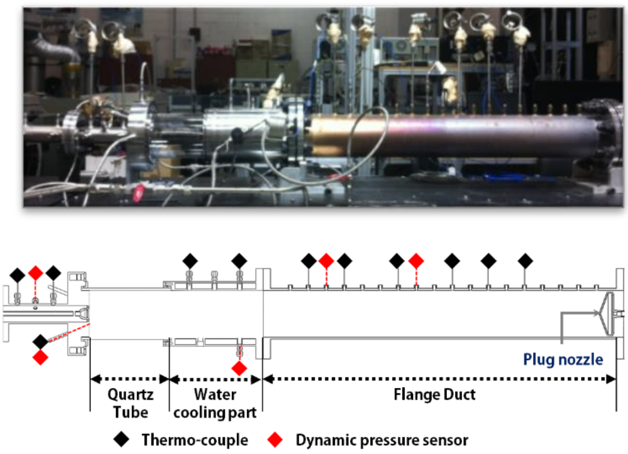


Figure. 1 Schematic of model combustor and sensor location.

A model gas turbine combustor was manufactured to investigate this experimental study like Figure 1. Several dynamic pressure sensors (PBC 102A05) were installed in the combustor to study combustor instability pressure characteristics and thermocouples (K-type and R-type) were also installed to measure the combustor liner and flame temperature as described like Figure 1.

A gas analyzer (TESTO 350K) set up on the combustor rear part to measure exhaust gas such as NOx and CO. A quartz tube was installed on the combustor dump plane to capture the flame to investigate the combustion characteristics. High temperature of the combustion zone near the dump plane could make damage the quartz tube, therefore side cooling air is injected the quartz outside with air flow rate 900 slpm. Water cooled movable plug nozzle blocked the combustor inside to make similar to the environment of turbine blade blockage ratio.

Figure. 2 TESTO 350K gas analyzer

Fuel and air supply system supplied H_2, CH_4, N_2 and combustion air. Combustion air was heated up to 200 deg. C. The flow rate of these gases were controlled by mass flow rate controller (MFC) with volumetric flow rate and, static mixer was used to make uniform fuel mixture. Partially premixed fuel and air injector was installed on dump plane and its mixing length is approximately 3 mm. Combustion fuel injected onto air flow in the form of jet in cross flow with angle 45 deg.

2.2 Test condition

Table. 1 Experimental condition

Parameters	Values
Fuel	H_2, CH_4
Air flow rate	1,100slpm
Air temperature	200°C (473 K)
Heat Load	35kW, 40kW, 45kW
Combustor length	1,160slpm ~ 1,400slpm
H_2 ratio $[\frac{H_2}{H_2+CH_4}]$	0% ~ 100%

Variables of this study are the combustor length and fuel composition (H_2/CH_4 ratio). Heated air mass flow rate was fixed at 1,100slpm (0.02kg/s) and H_2 ratio changed from 0% to 100 % based on sum of H_2 and CH_4 in increment of 12.5%. In addition, combustor length changed from 1,160mm to 1,400mm in increment of

15mm. Combustor length is important factor of gas turbine combustor. NOx emission and combustion characteristics could be affected on the combustor length. Heat loads of fuel composition are 35kW, 40kW and 45kW. Equivalence ratio of these conditions are the range of from 0.48 to 0.58 as fuel lean condition and these test conditions is summarized in Table 1.

3 Result and discussion

3.1 Emission characteristics

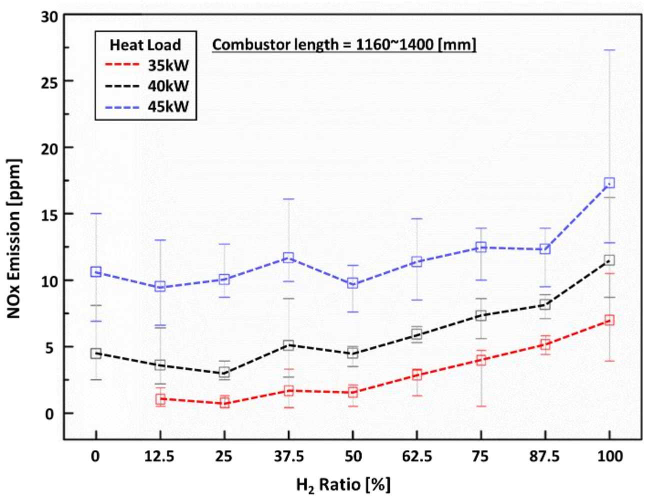


Figure. 3 NOx emission trend with respect to the H_2 ratio and heat load

Exhaust gas emission (NOx and CO) was measured in the combustor rear duct part to investigate the emission characteristics as shown in Figure 3. Blow-off occurred at H_2 ratio 0% and heat load 35kW because of the low heat input value and H_2 fuel concentration. Dotted lines are the NOx emission trend each heat load respectively.

Relative high NOx emission emitted under high heat load. Blank rectangular is the average value of each H_2 ratio test conditions. Maximum and minimum value are also denoted on the Figure 3. NOx emission of the test condition is thermal NOx due to the heat load and H_2 ratio that H_2 have higher calorific value than the CH_4.

Various combustor length did not influence the NOx emission characteristics. NOx emission is the function of flame temperature and residence time in the combustion zone. However, combustor length is relatively very long compared to the flame. Therefore the residence time of this study did not affected in combustor length. In addition, CO emission emitted under 3ppm under the all test conditions. CO emission is the incomplete combustion products. All equivalence ratios of test condition are nearly at 0.5 which air volumetric rate in combustion zone is exceeded. Thus almost H_2 and CH_4 fuel are burned in combustion zone. According to the above mentioned results, fuel and air mixed well near the partially swirl premixed nozzle.

3.2 Combustion instability mode shifting phenomenon at various combustor length and H_2/CH_4 composition

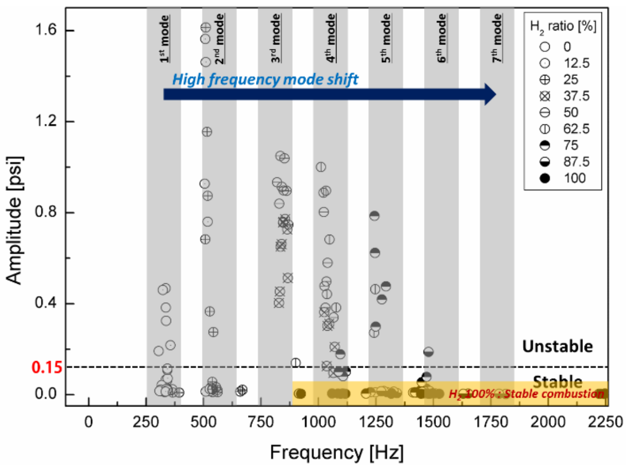


Figure. 4 Mode analysis based on amplitude of dynamic sensor with respect to the H_2/CH_4 ratio and combustor length

Figure 4 shows the root mean square (RMS) amplitude of third placed dynamic pressure sensor from dump plane. These data were acquired for 1 second each experimental conditions. Combustion instability of industrial gas turbine is defined as higher than 3~5% oscillation of static pressure of the combustor liner. However, 0.15 psi was defined the criteria of combustion instability because there is a possibility that the instability intensity could be much higher [8].

Combustion instability did not occurred on fuel H_2 100% composition compared to the fuel composition of including CH_4. H_2 is relatively stable fuel that only two hydrogen atoms are bonded. To take apart between the carbon and hydrogen in CH_4, it requires relatively more energy than hydrogen. This energy represents the enthalpy. Therefore H_2 dissipates more heat than CH_4 and more stable.

Figure 4 shows high frequency mode shifting phenomenon occurred from 1st mode to 7th mode except for the H_2 100% composition. The 1st mode is the fundamental instability mode and it can be represented under equation (1).

$$f = \frac{n \cdot c}{2L_c} \qquad (1)$$

Equation (1) is longitudinal mode calculation of close and close boundary condition. Dump plane and plug nozzle formed the acoustic close-close condition. L_c is combustor length, c is speed of sound in combustor and n is mode number, respectively. In other word, capital n of fundamental mode is 1 and second mode is 2. Fundamental mode of this combustor range is between 250 Hz to 310 Hz because the temperature in combustor liner has temperature range depend on the combustor length or heat load, etc.

H_2 and CH_4 ratio affect the combustion instability mode shift from Figure 4. High H_2 composition in fuel mixture makes higher frequency shift. High burning velocity of H_2 is the key parameter of the mode shift phenomenon. According to time lag analysis of Tim. Lieuwen [10], convective time and ignition time are important for total time lag in combustion instability. Laminar flame speed of H_2 is higher compared to CH_4 and it can affect the time lag, also (S_L: H_2 = 170 cm/s, CH_4 = 35cm/s at stoichiometric condition with air).

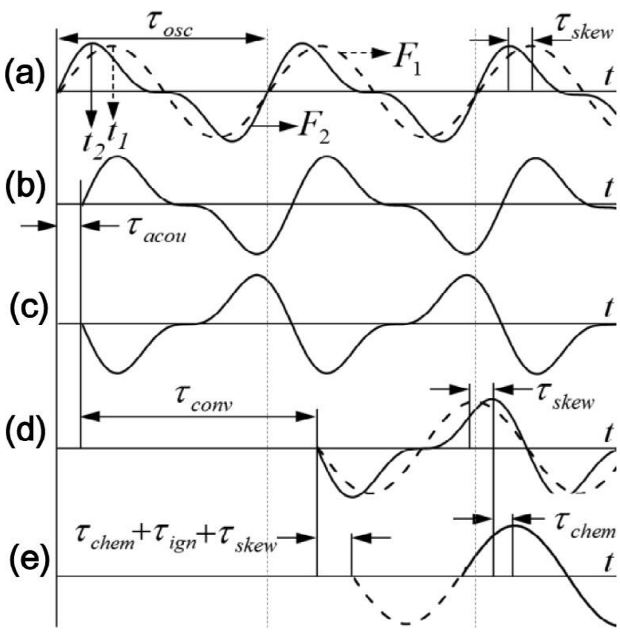
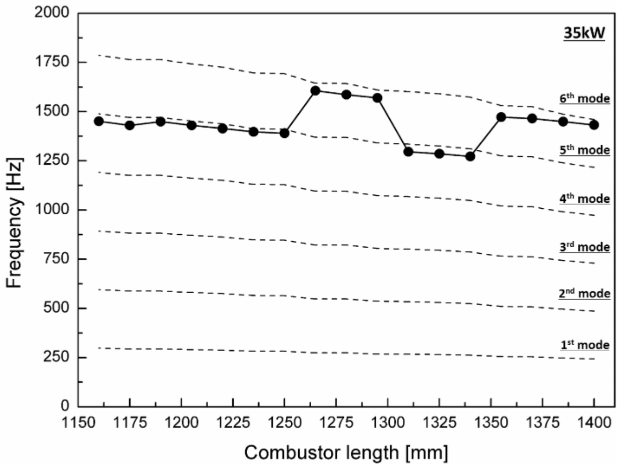
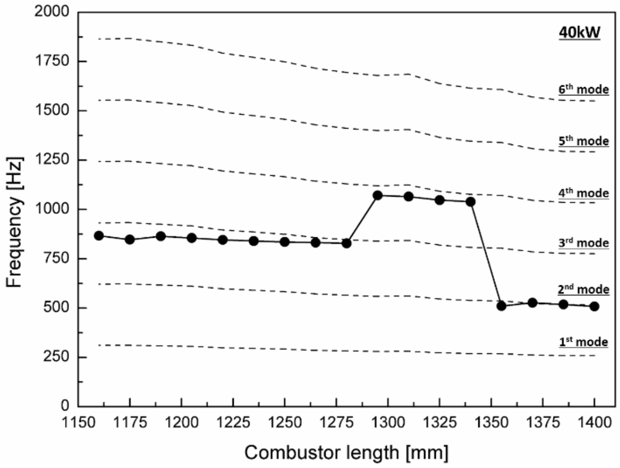


Figure. 5 Evolution of multi-mode pressure disturbance. (a) p' at the flame, (b) p' at the injector (c) equivalence perturbation at the flame, (e) q' at the flame [9]

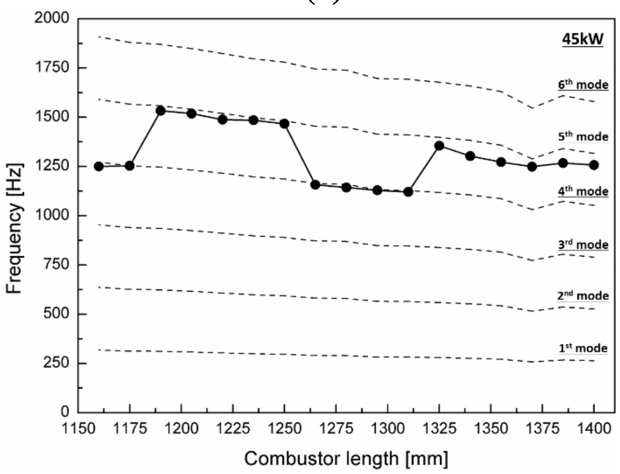
Figure 6 shows the instability frequency trend with respect to the combustor length each heat load from 35kW to 45kW. Dotted line is calculated longitudinal instability frequency of each combustor length. Combustion frequency and combustor length are adverse proportional relationship. Black circles are measured points of each combustor length. Measured value is underestimated compared to the calculated value from Figure 6. Combustor temperature distribution is assumed that only third thermos-couple is used. Therefore real temperature distribution in combustor is under measured third thermo-couple value. Frequency transition phenomenon in some combustor length requires further study.



(a)



(b)



(c)

Figure. 6 Instability frequency trend with respect to the combustor length each heat load (a) 35kW, (b) 40kW, (c) 45kW at H_2 50%

4 Conclusion

Combustion characteristics of various experimental conditions was conducted in a model gas turbine combustor. To investigate the reason of frequency mode shift phenomenon, combustor length and fuel composition are varied and the results are summarized below.

1) NOx emission mechanism is thermal NOx and it is generated higher at the test condition of high heat load, however combustor length effect was negligible.
2) Combustion instability occurred and it was longitudinal mode of combustor. Instability mode shift was appeared from fundamental mode to 7th mode and H_2/CH_4 fuel composition affects the shift phenomenon. Furthermore, the combustor length reduced the instability frequency. According to the time-lag analysis, convective time effect is main parameters of the mode shift.

Acknowledgment

This work was supported by National Research Foundation of Korea(NRF) grant funded by Korea government(MSIP) (No. 2015R1A2A2A010043) and the New & Renewable Energy Core Technology Program(No. 201195101001C) of the KETEP grant funded by the MOTIE

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