Research and development of ammonia combustion, low-NOx, rich-lean gas turbine combustor

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Keywords

Ammonia combustion, Gas Turbine, Low NOx, Rich-lean combustion

1. Introduction

Ammonia fuel is expected to be a hydrogen energy carrier of sustainable energy. The problem in combustion is that ignition energy is high, and the burning velocity is much lower than that of a conventional hydrocarbon fuel [1]. In 2015, National Institute of Advanced Industrial Science and Technology (AIST), Japan, successfully performed gas turbine power generation using 50 kWe-class micro gas turbine for ammonia combustion. Although NOx emissions from the gas turbine combustor were extremely high, selective catalytic reduction (SCR) reduced it to less than 10 ppm. For widespread production of ammonia gas turbine power generation, it is necessary to develop low NOx combustion technology. Hayakawa [2] and Kunkuma [3] reported using numerical simulations in fundamental research through collaboration with Tohoku University that low NOx combustion in a gas turbine such as a swirl combustor was possible when adopting both two-stage combustion and control of equivalence ratio of the primary zone. Finally, Okafor [4] achieved 40 ppm (16 % O_2), low-NO combustion in laboratory scale test rig using the AIST gas turbine combustor, whose dilution holes were modified to realize rich-lean, two-stage combustion. In this report, results of the combustor test rig in real size are presented, and then, based on the results, newly designed rich-lean combustors were manufactured and installed in the gas turbine. The results of NO emissions and combustor liner temperature are also reported.

2. Results in combustor test rig in real size

At first, no modification was applied to the combustor. Instead, air flow rate was changed to one-third, and the fuel flow rate was changed to two-thirds; however, low NO emission was not observed. Second, air flow rate was fixed to the rated value, and the fuel flow rate was changed to 14/10; however, low NO emission was again not observed. Then, in order to obtain a fuel-rich primary combustion zone, it was performed that filling the holes of the primary zone, decreasing the area of air swirler, and extending the holes of the secondary zone (Fig. 1). Consequently, low NO emission was observed (Fig. 2). By combining these modifications, the primary zone became fuel-richer, and the thermal power input decreased when the lowest NO emission was observed. Additionally, decreasing the areas of both sleeve-fitting gap and small cooling holes decreased the lowest NO emission.

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3. Results in gas turbine

Based on the results obtained in the combustor test rig in real size, the modification method to be applied to the gas turbine combustor was planned. Since the shape and size of the gas turbine combustor are protected by intellectual propriety, collaboration with Toyota Energy Solutions Inc. ensured rapid designing and manufacturing of the combustor.

The test facility consisted of an ammonia supply facility, 50kWe-class micro gas turbine, selective catalytic reduction (SCR), and the loading equipment.

Fig.1 How to modify the combustor

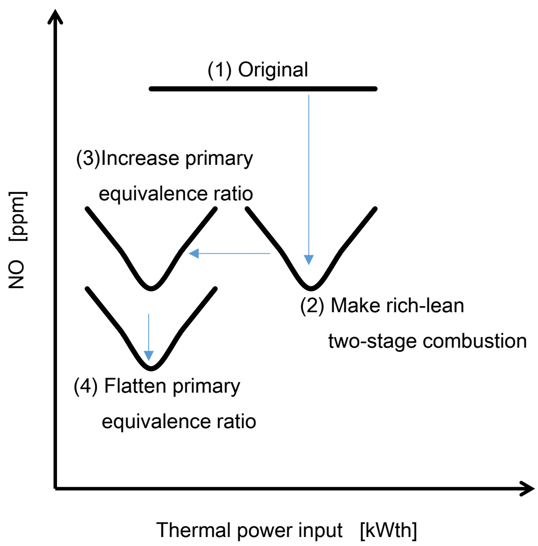


Fig.2 Concept of rich-lean low-NOx combustion

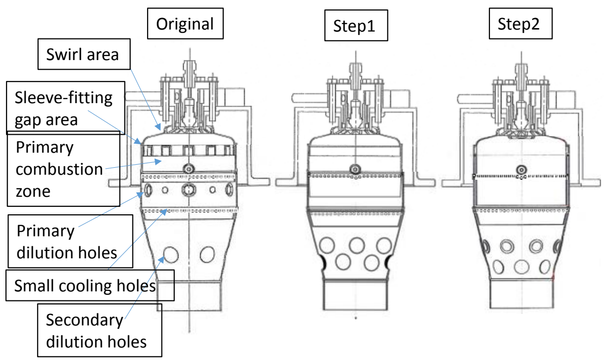


Fig.3 Newly designed and manufactured combustor

3.1. Step 1 (2017/09-12) [5]

Based on the results obtained in the combustor test rig, Step 1 combustors were designed and manufactured by adopting rich-lean combustion by filling the holes of the primary zone, decreasing the area of the air swirler, extending the holes of the secondary zone, decreasing the areas of sleeve-fitting gap and small cooling holes. In addition, based on the results obtained by Hayakawa [2], Kunkuma [3], and Okafor [4], it was decided that the primary zone equivalence ratio should be 1.1 so that the combustors were properly designed and manufactured. Fig. 4 shows the NO (16% O_2) emission and Fig. 5 shows the maximum combustor liner temperature. The combustor liner temperature was measured using thermocouples situated on the surface of the combustor liner. It is preferred that the combustor liner temperature be below 1000°C; therefore, the experiments were cut off over 1000°C. In Step 1 in Fig. 4, the lowest NO emission of 337 ppm was observed in the case of a fuel nozzle angle of 45°, area ratio of secondary dilution holes of 1.5, and electric power output of 32 kWe. Although it seems that the NO emission existing at the higher electric power output is low, the experiment was cut off because the combustor liner temperature exceeded 1000°C. It is assumed that in the case of a rich-lean combustion, the higher-temperature region in the combustor exists in the fuel-rich side where the equivalence ratio is close to 1.0. Homogenizing the primary zone equivalence ratio will decrease the temperature of the high-temperature region. Additionally, because the results of Okafor [4] showed that low NO emission was observed in a premixed combustion, homogenizing the primary zone equivalence ratio would be preferred.

3.2. Step 2 (2018/01-03) [6]

The flaws of the Step 1 combustor were then addressed in this step. The applied modifications include the following. (1) The sleeve-fitting gap area was reduced to 0 by integrating the air-swirler with a cooling inner-liner of the combustor. (2) The air entering the small cooling holes was emitted into the secondary combustion zone using the integrated cooling inner-liner. (3) The positions of the secondary dilution holes were slightly shifted downward to increase the volume of the primary combustion zone. Figs. 4 and 5 show NO emissions and maximum combustor liner temperature. A lower NO emission of 222 ppm was observed in the Step 2 combustor. The combustor liner temperature reached 1000°C. The NO emission was still higher than 40ppm that Okafor marked in the experiments of the premixed combustion. The conditions of Okafor's [4] experiments differed from ours in terms of premixed combustion, laboratory scale experiments, and no cut off temperature of the combustor liner over 1000°C. These points may affect the fact that our NO emission exceeded 40ppm.

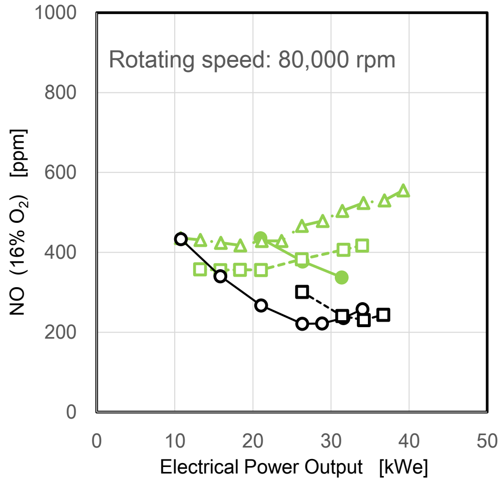
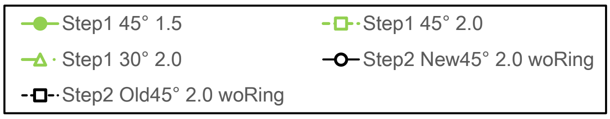


Fig.4 NO emissions in gas turbine operation



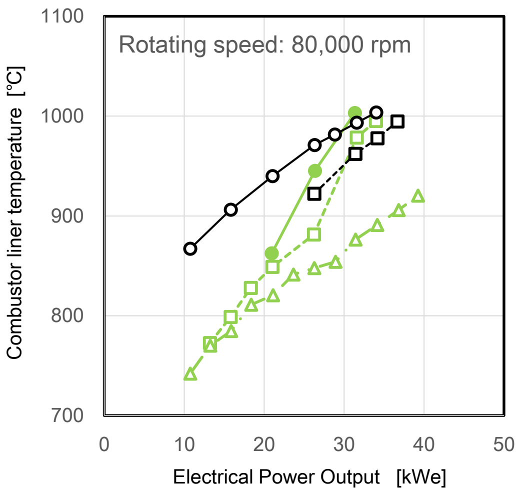


Fig.5 Combustor liner temperature

4. Conclusion

A rich-lean combustor was researched and developed. A low NOx combustor was developed using ammonia combustion gas turbine power generation.

5. Acknowledgements

This work was supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), "Energy Carriers" (Funding agency : Japan Science and Technology Agency (JST)).

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