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DEVELOPMENT OF GAS TURBINE COMBUSTORS FOR FUEL FLEXIBILITY

Tomohiro Asai*, Keisuke Miura*, Yoshinori Matsubara*, Yasuhiro Akiyama*, Mitsuhiro Karishuku, Satoschi Dodo**, Teruyuki Okazaki*, Satoshi Tanimura*****

***Research & Development Center, Mitsubishi Hitachi Power Systems, Ltd.**
****Gas Turbine Technology & Products Integration Division, Mitsubishi Hitachi Power Systems, Ltd.**
*****Turbine Technology Development Integration Division, Mitsubishi Hitachi Power Systems, Ltd.**

*832-2 Horiguchi Hitachinaka-shi, Ibaraki 312-0034 Japan
Phone: +81-294-20-7835, Email: tomohiro3_asai@mhps.com
**3-1-1 Saiwai-cho Hitachi-shi, Ibaraki 317-8585 Japan
***2-1-1 Arai-cho Shinhama Takasago-shi, Hyogo 676-8686 Japan

ABSTRACT

Growing global energy demands are motivating the gas turbine industry to seek fuel-flexible gas turbines capable of burning various fuels. The purposes of this paper are to explain the concept and development of a dry low nitrogen oxide (NOx) and flashback-resistant combustor for fuel flexibility and present its applications to hydrogen content syngas fuels in a coal-based integrated gasification combined cycle (IGCC) and to dual gaseous fuels of natural gas and petroleum gas. First, in order to demonstrate the feasibility for IGCC, the combustor was tested with a practical syngas fuel in a multi-can configuration in a pilot plant. The test results demonstrated the feasibility for achieving dry low NOx and flashback-resistant combustion of the syngas fuel in the plant. Next, in order to demonstrate the feasibility for dual gaseous fuels, the combustor was tested in a single-can combustor test stand at a medium pressure. In the test, the combustor achieved dry low NOx and flashback-resistant combustion of both fuels. The test results showed that the combustor possesses the capability to achieve dry low NOx combustion of dual gaseous fuels of natural gas and petroleum gas. In conclusion, the developed combustors are applicable to a wide variety of fuels for fuel-flexible gas turbines.

INTRODUCTION

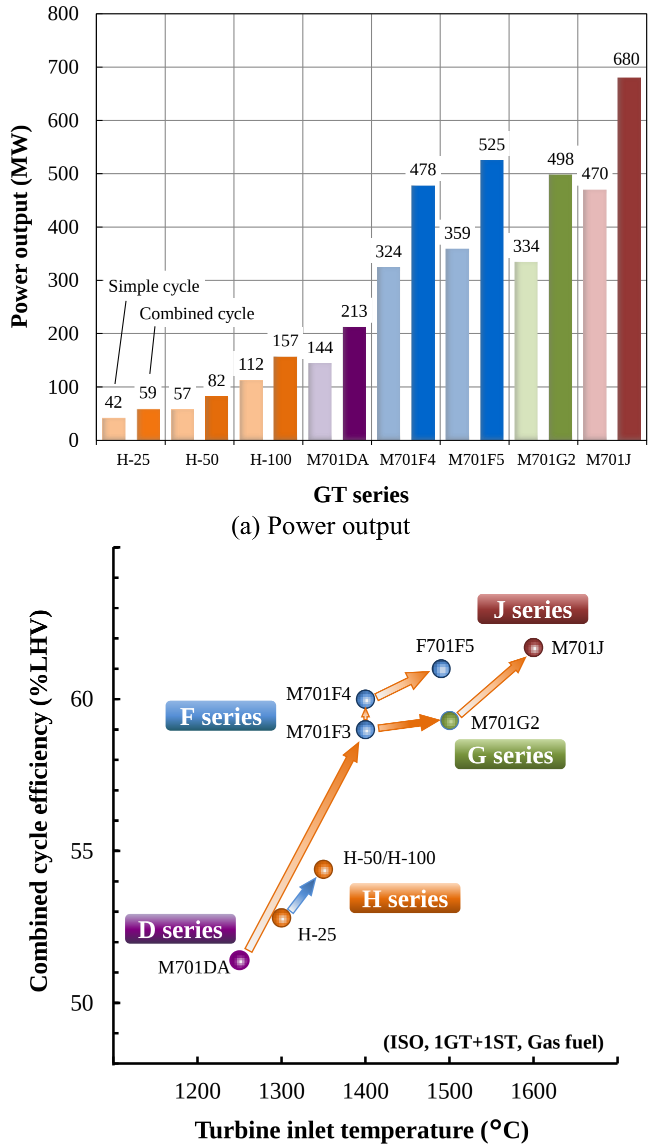
Growing global energy demands are motivating the gas turbine industry to seek fuel-flexible gas turbines capable of burning a wide variety of fuels as a means of increasing energy supply stability and security. These fuel-flexible gas turbines offer such benefits as low-cost power generation, the reutilization of natural resources, and environmental friendliness. The fuel-flexible gas turbines are required to achieve low NOx emissions and high plant efficiency with various fuels in order to mitigate global warming by decreasing emissions of greenhouse gases, especially carbon dioxide (CO_2).

This paper describes the development of gas turbine combustors for fuel flexibility. In particular, this paper focuses mainly on a dry low NOx and flashback-resistant combustor for fuel flexibility and explains its concept and its applications to hydrogen content syngas fuels in the IGCC and to dual gaseous fuels of natural gas and petroleum gas. This paper also overviews a natural gas-fueled dry low NOx combustor (DLNC) for a 1600°C-class gas turbine and a diffusion-flame combustor for low Btu fuels.

THE MHPS LINE-UP OF GAS TURBINES AND THEIR PERFORMANCE

Mitsubishi Hitachi Power Systems, Ltd. (MHPS) offers a wide range of gas turbines. Figure 1 shows the line-up of gas turbines and their performance (power output and combined cycle efficiency) for 50 Hz regions. MHPS offers the H-series gas turbines with middle and small capacities and the D, F, G, and J-series gas turbines with large capacities. The H-50 and H-100 series gas turbines are heavy-duty, dual-shaft machines. They are designed for power generation and cogeneration power plants. They are also suited to mechanical drive applications, especially as the compressor drive for liquefied natural gas (LNG) plants. The large capacity D, F, G, and J-series gas turbines have enhanced efficiencies due to their high firing temperatures. The state-of-the-art machine, the J-series gas turbine, is capable of achieving over 60% combined cycle efficiency at a turbine inlet temperature (TIT) of 1600°C by utilizing advanced 1700°C-class technologies developed in the

Japanese national project (Takiguchi et al., 2011; Tanaka Y. et al., 2013).



(a) Power output

(b) Combined cycle efficiency

Fig. 1 MHPS line-up of gas turbines and their performance (50 Hz)

ADDRESSING FUEL FLEXIBILITY

Figure 2 shows suitable gaseous fuels for fuel-flexible gas turbines based on the volumetric net calorific value of fuel and the laminar flame speed. Gaseous fuels are broadly classified into three main categories by net calorific value: low Btu fuels, medium Btu fuels, and high Btu fuels. The available fuels include by-product gases, IGCC syngas, and hydrocarbon fuels. By-product gases range from low to medium Btu fuels. They include blast furnace gas (BFG), Linz-Donawitz converter gas (LDG), coke oven gas (COG) from ironworks, and oil refinery gas. BFG is a typical low Btu fuel. IGCC syngas fuels range from low to medium Btu fuels. Air-blown IGCC syngas fuels are low Btu fuels due to the large amount of an inert gas, nitrogen (N_2), contained in the fuels. Oxygen-blown IGCC syngas fuels are medium Btu fuels. They consist mainly of hydrogen (H_2) and carbon monoxide (CO). In oxygen-blown IGCC with carbon dioxide capture and storage (CCS), the syngas fuels increase flame speed with increasing carbon capture rate because the hydrogen content increases. Hydrocarbon fuels are high Btu fuels. They include natural gas, petroleum gas, butane (C_4H_{10}), butene (C_4H_8), and higher hydrocarbons. Petroleum gas in liquid form is referred to as liquefied petroleum gas (LPG). LPG is composed mainly of propane and butane. Most LPG is produced as an associated gas in production of shale gas and oil. LPG production has been increasing with increasing shale gas/oil production. The increasing LPG production may increase the demand for LPG use as a gas turbine fuel. LPG provides a benefit of easier handling because petroleum gas can be stored as a liquid at ambient temperatures by modest pressurization of the fuel tank.

The next sections describe a natural gas-fueled dry low NOx combustor for the 1600°C-class gas turbine, a diffusion-flame combustor for low Btu fuels, especially BFG, and dry low NOx and flashback-resistant combustors for hydrogen content syngas fuels in oxygen-blown IGCC with CCS and dual gaseous fuels of natural gas and petroleum gas.

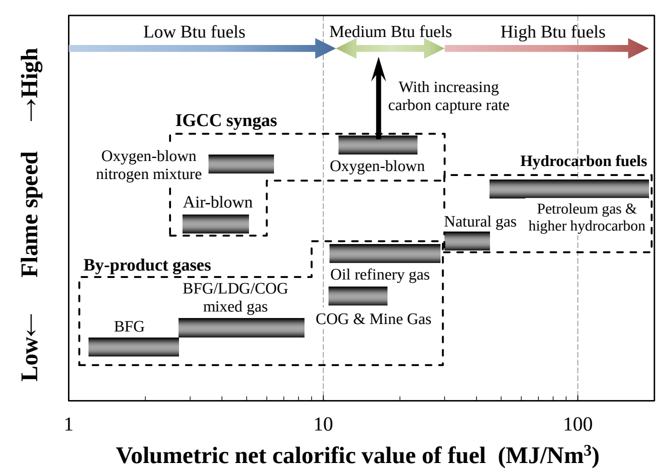


Fig. 2 Suitable gaseous fuels for fuel-flexible gas turbines

Natural gas

A gas turbine combined cycle (GTCC) is the most efficient and cleanest of all fossil fuel-based power generation systems. Natural gas is the main gaseous fuel for GTCC. With increasing global demand for electric power, as well as with expanding supply sources of natural gas, such as that resulting from the exploitation of shale gas fields, the demand for natural gas has been increasing as the fuel.

For the state-of-the-art J-series gas turbine operating on natural gas, the dry low NOx combustor was developed on the basis of the proven can-annular dry low NOx combustor for the G-series gas turbines. Each can combustor is equipped with a center pilot fuel nozzle and eight main fuel nozzles. The pilot fuel nozzle generates a stable flame that can maintain the stability of the premixed flame in the main fuel nozzles.

The J-series combustor was designed on the basis of the following concepts (Hada et al., 2012; Yuri et al., 2013; Hada et al., 2015).

- The J-series combustor employs the proven steam-cooled technology applied to the G-series combustor (Tanimura et al., 2008; Tsukagoshi et al., 2011). Steam is a more effective heat transfer medium for cooling than air, and it does not mix with and dilute the hot gas flow the way air does. Thus, steam is used to cool the combustion liner in order to maintain the metal temperature below the allowable limit without consuming cooling air.

- The J-series combustor employs an advanced fuel nozzle in order to maintain NOx emissions to levels equivalent to those from the G-series combustor at a turbine inlet temperature of 1600°C, which is 100°C higher than the G-series. Figure 3 compares the advanced fuel nozzle "V-nozzle" with the conventional fuel nozzle. The V-nozzle locates fuel injection holes on the swirler in order to minimize NOx emissions by decreasing localized high temperature spots due to homogeneous mixing of fuel and air.

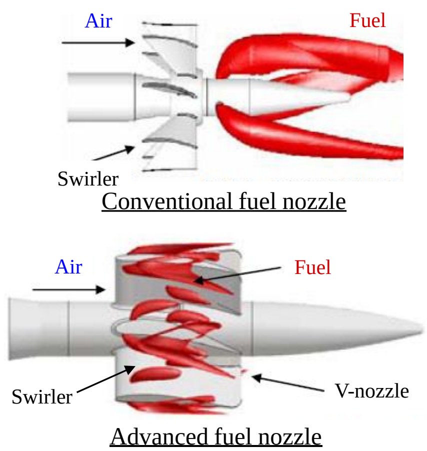


Fig. 3 Advanced fuel nozzle for J-series combustor

Low Btu fuels

Use of by-product gases, such as BFG, LDG, and COG, as a fuel can offer low-cost power generation because it provides fuel cost economy. This subsection describes a combustor for a typical low Btu fuel, BFG.

Low Btu fuels raise the following four main technical issues for the combustor design: a limited stable combustion range, a low flame speed, a large amount of combustion air, and a large amount of fuel flow. The limited stable combustion range and the low flame speed require a low Btu-fueled combustor to ensure flame stability rather than low NOx combustion because combustion of low Btu fuels including a large amount of inert gas generates less NOx due to lower peak flame temperatures.

Thus, the BFG-fueled combustor is a diffusion-flame type to ensure flame stability (Tanaka K. et al., 2009). Figure 4 shows the diffusion-flame combustor for BFG. The combustor has an increased diameter of the basket in order to balance the air flow velocity with the low flame speed for flame stability by decreasing the air flow velocity. The combustor is equipped with a swirler nozzle in order to decrease excessive fuel nozzle pressure loss due to a large amount of fuel flow.

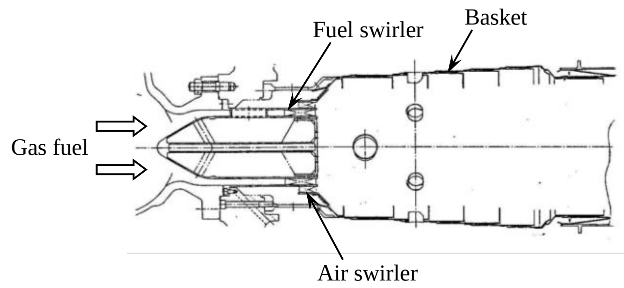


Fig. 4 Diffusion-flame combustor for BFG

Hydrogen content syngas fuels in oxygen-blown IGCC with CCS

In oxygen-blown IGCC with CCS, hydrogen content syngas fuels are supplied to gas turbines. Table 1 compares properties of typical IGCC syngas fuels and natural gas (NEDO, 2005). When the carbon capture rate varies from 0% to 90%, the hydrogen content of the syngas fuels varies from approximately 25 vol. % to over 80 vol. %. Consequently, the flame speed increases significantly from over three to six times higher than that for natural gas. The flammability limits for the IGCC syngas fuels are much broader especially for the upper limit than that for natural gas. These properties of hydrogen, its higher flame speed and broader flammability limits, increase the risk of flashback.

Premixed combustors, particularly which are highly tuned to operate on natural gas, are incapable of achieving the stable combustion of hydrogen content syngas fuels due to the risk of flashback into their large premixing section. This flashback characteristic thus hinders the application of premixed combustion technology to combustion of hydrogen content syngas fuels. Diffusion-flame combustors have thus far been employed for hydrogen content syngas fuels in oxygen-blown IGCC with CCS. However, diffusion-flame combustors decrease plant efficiency because of the additional energy required to inject a diluent (e.g., water, steam, and nitrogen) into the combustion zone to suppress increased NOx emissions.

The successful development of oxygen-blown IGCC with CCS requires a state-of-the-art dry low NOx and flashback-resistant combustor for widely variable hydrogen content syngas fuels in order to achieve both lower NOx emissions and higher plant efficiency. The next section describes the development of the state-of-the-art combustor.

Table 1 Comparison between properties of typical IGCC syngas fuels

Properties		Unit	Syngas in O_2-blown IGCC with CCS: Carbon capture rate 0%	30%	50%	90%	Natural gas
Constituents	H_2	vol%	26.0	45.5	58.0	83.5	—
	CO	vol%	60.0	43.0	30.5	5.0	—
	CH_4	vol%	1.0	1.0	1.0	1.0	90.6
	C_2H_6	vol%	—	—	—	—	5.1
	C_3H_8	vol%	—	—	—	—	2.8
	C_4H_{10}	vol%	—	—	—	—	1.4
	N_2	vol%	10.5	10.5	10.5	10.5	—
Density		kg/Nm^3	0.96	0.72	0.57	0.28	0.80
Net calorific value		MJ/Nm^3	10.7	10.7	10.5	10.0	40.0
Flammability limit	lower	vol%	8.7	6.7	5.8	4.7	4.5
	upper	vol%	81.7	79.7	79.9	80.2	14.5
Normalized flame speed (-)			3.4	4.6	5.2	6.2	1.0

STATE-OF-THE-ART DRY LOW NOX AND FLASHBACK-RESISTANT COMBUSTOR WITH HIGH FUEL FLEXIBILITY

Combustor configuration

Figure 5 shows the configuration of the state-of-the-art dry low NOx and flashback-resistant combustor. The combustor consists of multiple fuel nozzles and multiple air holes. The key elements of the combustor each consist of one fuel nozzle and one air hole that are installed coaxially. A cluster of key elements constitutes one burner, which forms one flame. The air holes are embedded in one plate. Multiple cluster burners constitute a can combustor, and several can combustors are installed on a gas turbine. This burner is called a “cluster burner,” and this combustor is called a “multi-cluster combustor.”

The multi-cluster combustor is equipped with a pilot burner at the center and six identical main burners surrounding the pilot burner. The combustor forms seven individual flames, each of which is anchored to the corresponding burner. The combustor assigns operational stability to the pilot burner and low-NOx operation to the main burners. The pilot burner increases combustion stability over the entire operating range by generating a well-stabilized flame in the center region of the combustion chamber. The main burners achieve low-NOx combustion by mixing fuel and air homogeneously. The combustor can be used for dual-fuel operation with gaseous fuel and oil fuel. The combustor operates on gaseous fuel with the burners and on oil fuel with an air-assisted oil spray nozzle installed at the center of the pilot burner.

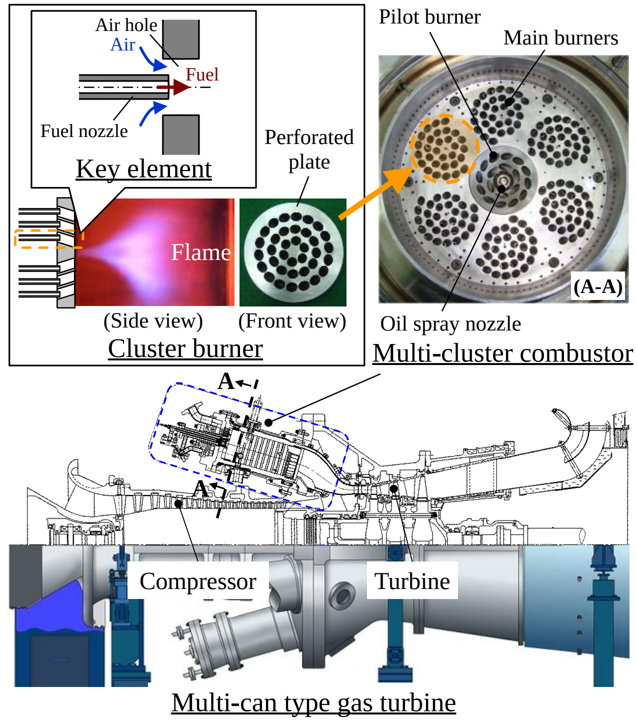


Fig. 5 Configuration of a multi-cluster combustor

Burner concept

The concept of the cluster burner is based on the integration of two key technologies: low NOx combustion and flashback-resistant combustion. The cluster burner provides both the advantage of the premixed combustor of low-NOx combustion and the advantage of the diffusion-flame combustor of flashback-resistant combustion. Figure 6 illustrates the concept.

The burner achieves low NOx combustion by mixing fuel and air rapidly and dispersing fuel with multiple fuel-air coaxial jets. Each coaxial jet in a single air hole is comprised of a central fuel jet surrounded by an annular air stream. The coaxial jet generates turbulence through the abruptly-expanding flow just downstream from the exit of the air hole. The turbulence increases the disturbance at the boundary between fuel and air steams just downstream from the exit, thus mixing fuel and air rapidly. Moreover, the burner disperses fuel by multiplying the coaxial jet, thereby enhancing fuel-air mixing. Homogeneous mixing achieves low NOx combustion by eliminating high-temperature and NOx-generating regions.

The burner achieves flashback-resistant combustion due to the following three effects: a short premixing section; an air-stream-surrounded fuel jet; and a lifted flame. First, the short premixing section of the air hole decreases the risk of flashback. The short premixing section serves as a space free from flame anchoring points. In addition, the short premixing section decreases the risk of autoignition of a fuel-air mixture in the section because the residence time of the fuel-air mixture there is shorter than the ignition delay time. Second, a fuel jet surrounded by an annular air stream decreases the risk of flashback. The air-stream-surrounded fuel jet provides the fuel-air mixture outside the flammable range in the air hole, thus preventing flames from propagating upstream into the air hole. Third, the lifted flame prevents flashback because the lifted flame is held stably at a point away from the burner. The burner lifts the flame by producing converging and diverging swirl flows just downstream from it. The converging flow induces a favorable pressure gradient, and the diverging flow induces an adverse pressure gradient in the flow direction. The adverse pressure gradient induces a vortex breakdown at the boundary between the converging and diverging flows, thereby producing a recirculation flow in the diverging flow. The recirculation flow stabilizes the flame by providing a stable heat source of combustion gas. The reverse flow of combustion gas from the boundary is suppressed by the favorable pressure gradient in the converging flow. Consequently, the flame can be lifted with the flame-anchoring point on the boundary. The lifted flames are effective in preventing flashback, especially in hydrogen content fueled combustion.

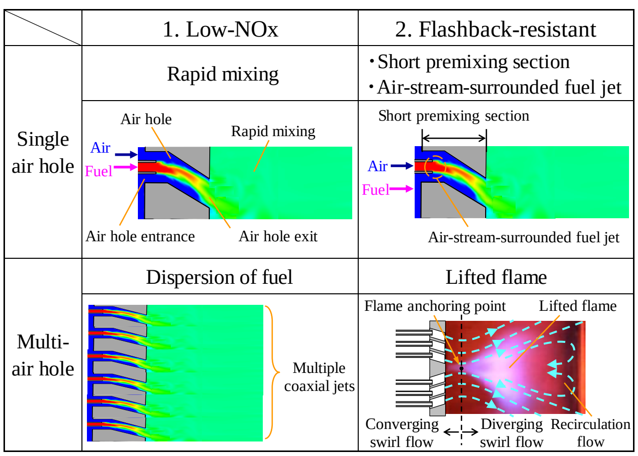


Fig. 6 Cluster burner concept

APPLICATIONS OF MULTI-CLUSTER COMBUSTOR

Oxygen-blown IGCC syngas fuels

The multi-cluster combustor is especially suitable for hydrogen content fuels because the combustor is capable of suppressing flashback even for fuels with high flame speeds. Here, application of this combustion technology to oxygen-blown IGCC syngas fuels is described.

In order to demonstrate the feasibility of achieving dry low NOx combustion of hydrogen content syngas fuels, a prototype multi-cluster combustor was tested in a single-can combustor test stand at a medium pressure on hydrogen content surrogate test fuels simulating practical syngas fuels. The test fuels consisted of three components: hydrogen, methane, and nitrogen. The fuels contained 40%, 55%, and 65% hydrogen by volume, simulating the practical syngas fuels at carbon capture rates of 0%, 30%, and 50%, respectively. The test results demonstrated the feasibility of achieving the dry low NOx combustion of hydrogen content fuels with hydrogen content ranging from 40% to 65% (Dodo et al., 2013).

Demonstrating the feasibility for IGCC plants requires an evaluation of combustor performance by a real gas turbine test in a multi-can combustor configuration with practical syngas fuel in practical IGCC plants. In order to demonstrate the feasibility for IGCC plants, the combustor was tested with a practical syngas fuel in a multi-can combustor configuration in an IGCC pilot plant (Asai et al., 2015a; Asai et al., 2015b).

The plant was an oxygen-blown integrated coal gasification power generation pilot plant named EAGLE (an acronym for “coal Energy Application for Gas, Liquid and Electricity”) located at the Wakamatsu Research Institute of the Electric Power Development Co., Ltd., Japan (J-POWER). The EAGLE pilot plant is shown in Fig. 7. This plant was a test facility for developing coal gasification technologies with innovative CO_2 capture. The EAGLE plant consisted of five main components: an air separation unit (ASU); a gasifier; a gas cleanup unit; a gas turbine; and CO_2 capture units. In this pilot plant, the produced syngas was supplied separately to the gas turbine and the CO_2 capture units. The syngas fuel contained approximately 50% carbon monoxide, 20% hydrogen, and 20% nitrogen by volume. Distillate oil was also burned for oil fuel operation between ignition and a part load.

The fuel supply systems supplied syngas fuel and oil fuel to the combustor. Figure 8 shows the fuel supply systems for the combustor. The combustor was equipped with one pilot burner and six main burners. The main burners were divided into two groups (F2 and F3) consisting of three burners each, and they were arranged alternately surrounding the pilot burner (F1) at the center. The syngas fuel was distributed into five fuel circuits: F1 fuel to the F1 pilot burner; F2-1 fuel to the inner region; F2-2 fuel to the outer region of the F2 main burners; F3-1 fuel to the inner region; and F3-2 fuel to the outer region of the F3 main burners. The oil fuel was supplied to the oil spray nozzle.

Figure 9 shows the test results on NOx emissions as a function of the gas turbine load. The pilot plant test was conducted from startup on distillate oil to the maximum load (corresponding to 80% of the gas turbine load) on syngas. The multi-cluster combustor was able to achieve low NOx combustion and high operability over the entire operating range by switching combustion modes according to operating conditions. The combustor switched the combustion modes by manipulating the combination of operating burners for which the fuel circuit was fueled. This fuel staging consisted of three distinct combustion modes. The combustor operated on oil fuel in the oil mode with the oil spray nozzle from ignition until a pre-determined part load was reached. The combustor operated on syngas fuel in the partial mode with the pilot burner, the inner regions of the main burners, and the outer regions of the F2 main burners at the pre-determined part load. The combustor operated on syngas fuel in the final mode with all the burners until the base load was reached. The test results showed that the combustor periodically increased and decreased NOx emissions with the load and achieved dry low NOx at the maximum load. The multi-cluster combustor experienced no flashback throughout the test. The test results demonstrated the feasibility of the multi-cluster combustor for achieving dry low NOx and flashback-resistant combustion of the hydrogen content syngas fuel in the IGCC pilot plant.

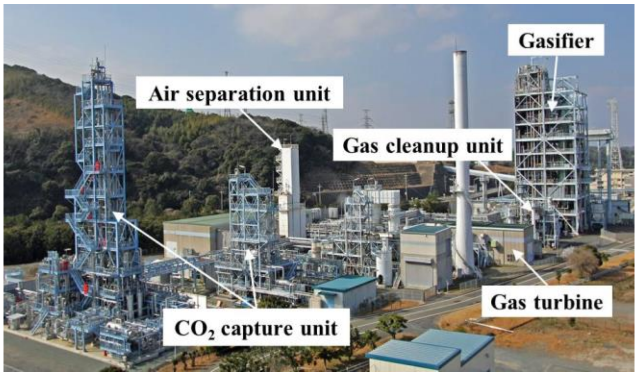


Fig. 7 EAGLE pilot plant (photo courtesy of J-POWER)

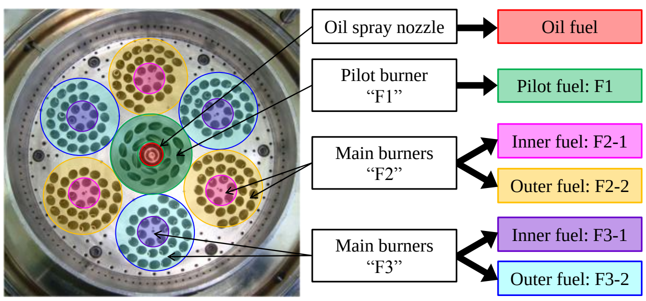


Fig. 8 Fuel supply systems

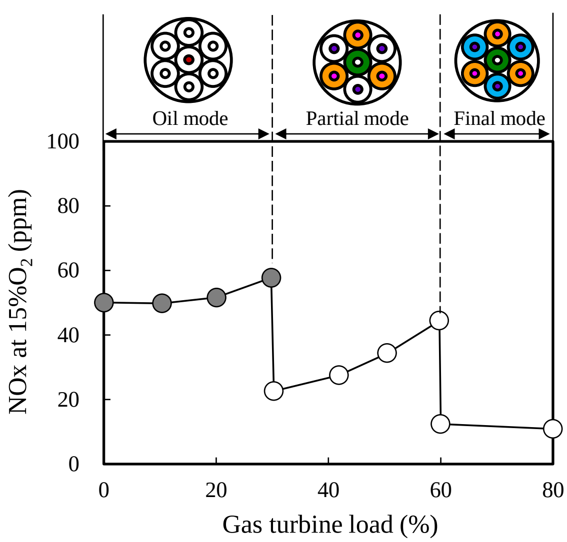


Fig. 9 Variations in NOx emissions with gas turbine load

Dual gaseous fuels of natural gas and petroleum gas

The multi-cluster combustor is applicable for a wide variety of fuels due to its high fuel flexibility. Here, application of this combustion technology to dual gaseous fuels of natural gas and petroleum gas in order to expand its fuel flexibility is described.

Table 2 compares properties of natural gas and petroleum gas used in the tests. They were vaporized LNG and vaporized LPG, respectively. Natural gas contained 91% methane by volume, and petroleum gas contained 99% propane by volume. Petroleum gas features a higher net calorific value, higher stoichiometric flame temperature, and lower ignition temperature than those for natural gas. The higher net calorific value implies less volumetric fuel flow required to produce equivalent heat input, thus affecting pressure losses in fuel nozzles. Higher stoichiometric flame temperature leads to the increase in NOx emissions. Lower ignition temperature increases the risk of autoignition in premixing sections. The flame speed for petroleum gas is approximately equivalent to that for natural gas. Higher dew point for petroleum gas requires vaporized LPG to be heated in order to prevent liquefaction of petroleum gas because the gas may be easily liquefied at elevated supply pressures.

Figure 10 shows the multi-cluster combustor for dual gaseous fuels of natural gas and petroleum gas. This dual gas fueled combustor arranged the burners in the same configuration as the combustor for the IGCC did. This combustor was equipped with a pilot burner at the center burning only gaseous fuels, whereas the IGCC combustor was equipped with the pilot burner including the oil spray nozzle for oil fuels in the center.

Table 2 Comparison between properties of natural gas and petroleum gas

Properties		Unit	Natural gas	Petroleum gas
Constituents	H_2	vol%	—	—
	CO	vol%	—	—
	CH_4	vol%	90.6	—
	C_2H_6	vol%	5.1	0.7
	C_3H_8	vol%	2.8	98.9
	C_4H_{10}	vol%	1.4	0.4
	N_2	vol%	—	—
Density		kg/Nm^3	0.80	1.96
Net calorific value		MJ/Nm^3	40.0	91.1
Flammability limit	lower	vol%	4.5	2.1
	upper	vol%	14.5	9.5
Stoichi. flame temp.[a] (at atmospheric press. & room temp.)		°C	1937	1994
Minimum ignition temp.[b]		°C	537	466
Normalized flame speed		-	1.0	1.1
Dew point[c] at 3.0 MPa(A)		°C	-96	78

References: [a]Glassman et al., 2014; [b]Zabetakis, 1965; [c]L'Air Liquide, 1976

The combustor was tested in a single-can combustor test stand at a medium pressure with natural gas and petroleum gas. Figure 11 shows the single-can combustor test stand. Gaseous fuels were supplied from fuel outlet ports through flexible hoses to the single-can combustor installed in the test stand. The flexible hoses were covered with heat insulators in order to prevent liquefaction of petroleum gas flowing inside the hoses.

Figure 12 shows fuel supplying facilities. Gaseous fuels were supplied from fuel supplying facilities to the fuel outlet ports at the test stand. LNG was vaporized at a LNG satellite station and the vaporized LNG was supplied from there through LNG supplying lines to the fuel outlet ports. The LPG supplying facility consisted of four main components: a LPG supply source, a vaporizer, a steam supplying system, and LPG supplying lines. The LPG supply source transferred LPG stored in a LPG tank to the vaporizer with a booster pump. The vaporizer generated vaporized LPG. The steam supplying system supplied steam to the vaporizer to operate it, and provided steam-tracing on the LPG supplying lines in order to maintain the heated vaporized LPG. The LPG supplying lines transferred vaporized LPG to the fuel outlet ports of the test stand.

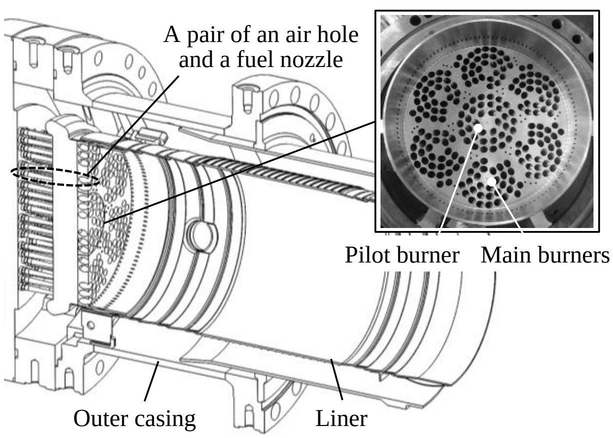


Fig. 10 Multi-cluster combustor for dual gaseous fuels of natural gas and petroleum gas

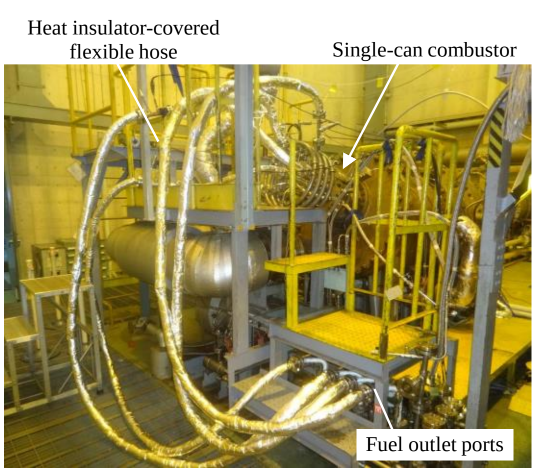


Fig. 11 Single-can combustor test stand

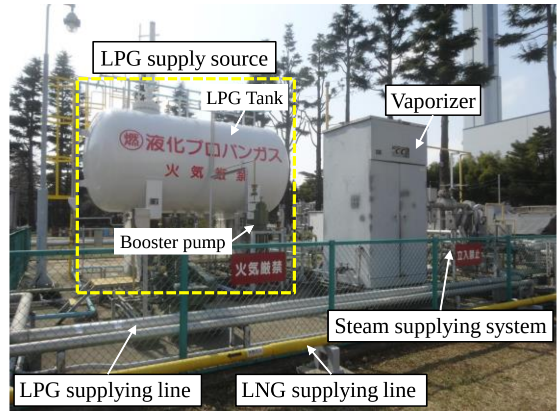


Fig. 12 Fuel supplying facilities

The multi-cluster combustor was loaded by switching combustion modes according to operating conditions. The fuel staging may depend on some factors, such as operating conditions, operating requirements, and environmental regulations. This paper shows an instance of the fuel staging for dual gaseous fuel combustion. Figure 13 shows mode sequences and flame images for natural gas and petroleum gas in this fuel staging. This fuel staging consisted of four distinct modes: pilot mode, partial mode A, partial mode B, and final mode. The combustor operated the pilot burner in the pilot mode from ignition to a part load. Next, the combustor operated the pilot burner and the inner parts of the main burners in the partial mode A, and operated the pilot burner, the inner parts of the main burners and the outer parts of the F2 main burners in the partial mode B at part load. Finally, the combustor operated all the burners in the final mode to base load. This figure shows that the operating burners formed their respective stable flames in each combustion mode for natural gas and petroleum gas combustion. The multi-cluster combustor experienced no flashback throughout the tests for both gases.

The tests examined the variation in NOx emissions by changing the "inner fuel ratio" while the combustor exit gas temperature was maintained as constant. The inner fuel ratio was defined as the ratio of the mass flow rates of the inner fuel (F2-1 and F3-1) to all fuel supplied to the main burners (F2-1, F2-2, F3-1, and F3-2). Figure 14 shows variations in NOx emissions with the inner fuel ratio for natural gas and petroleum gas combustion. The ordinate denotes the relative NOx value normalized by the minimum NOx for natural gas within the stable range. From this figure, the NOx emissions decreased with decreasing inner fuel ratio for both fuels. The decrease of these NOx emissions with the inner fuel ratio was limited because the combustion for both fuels became unstable at inner fuel ratios below the respective limit values. The NOx emissions for petroleum gas were higher than those for natural gas in the test range. The stable range for petroleum gas was limited compared with that for natural gas. The test results indicated that the combustor possesses the capability to achieve dry low NOx and flashback-resistant combustion of dual gaseous fuels of natural gas and petroleum gas. The completion of the multi-cluster combustor for dual gaseous fuels of natural gas and petroleum gas requires more test data to be accumulated.

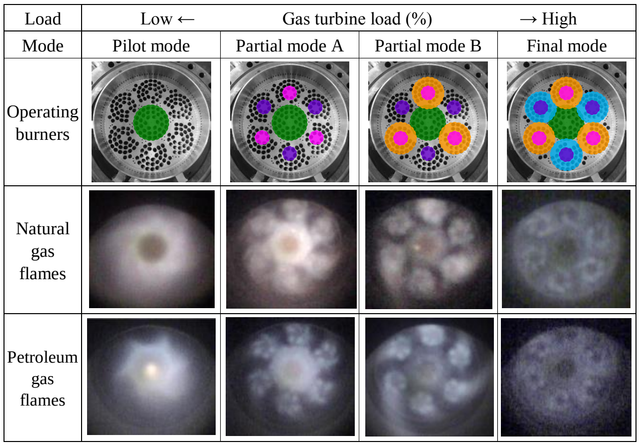


Fig. 13 Natural gas and petroleum gas flames in fuel staging

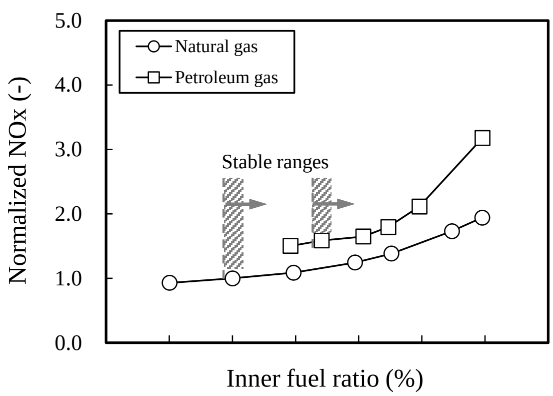


Fig. 14 Variations in NOx emissions with inner fuel ratio for natural gas and petroleum gas combustion

CONCLUSIONS

This paper described the development of a specific multi-cluster combustor for dry low NOx and flashback-resistant combustion for fuel flexibility. This paper focused mainly on the applications to IGCC syngas fuels and dual gaseous fuels of natural gas and petroleum gas. The main findings from the tests are summarized as follows.

- The test results in the IGCC pilot plant demonstrated the feasibility of the multi-cluster combustor for achieving dry low NOx and flashback-resistant combustion of the hydrogen content syngas fuel.

- The single-can combustor test results for natural gas and petroleum gas at a medium pressure showed that the multi-cluster combustor achieved dry low NOx and flashback-resistant combustion of both fuels in their stable ranges. The test results indicated that the multi-cluster combustor possesses the capability to achieve dry low NOx and flashback-resistant combustion of dual gaseous fuels of natural gas and petroleum gas.

The multi-cluster combustors are expected to be applicable for dry low NOx and flashback-resistant combustion of a wide variety of fuels for fuel flexible gas turbines.

NEXT STEPS

Based on the experience in the IGCC pilot plant, a multi-cluster combustor was developed and installed on a 100 MW class gas turbine in an oxygen-blown IGCC demonstration plant of the OSAKI CoolGen Corporation, Japan (Nagasaki and Akiyama, 2014; Dodo et al., 2015). This demonstration plant is part of a project funded by the Japanese Government. Its demonstration test will start in March 2017.

The multi-cluster combustors have so far been developed for the gas turbines with middle and small capacities. The development of multi-cluster combustors will proceed to the application to the gas turbines with large capacities.

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