Hydrogen Utilization – Development of Hydrogen Fueled Power Generation Technologies

Hydrogen is used as fuel for transport machinery such as rockets and FCV (fuel cell vehicles/buses).

To realize low carbonization and a future hydrogen-based society, Kawasaki is developing hydrogen combustion technology and power generation technologies for gas turbine engine, which is excellent in fuel flexibility. In 2018, we successfully operated the world's first hydrogen fueled power generation in an urban area, and we have been improving such technologies to achieve higher performance and cleaner power generation.

Introduction

To realize a hydrogen energy supply chain, it is important to lower the price of hydrogen to around the current price of fossil fuels such as oil and natural gas. The demand and consumption of large amounts of hydrogen will lead to a hydrogen cost reduction though economies of scale.

1 Background

Hydrogen has long been used as fuel for rocket propulsion and FCVs (fuel cell vehicles/buses), as well as for gas turbine power generators and boilers. According to Japan's Strategic Roadmap for Hydrogen and Fuel Cells, hydrogen fueled power generation will enter the mainstream around 2030. If hydrogen can be utilized as fuel for power generation in place of natural gas, that will lead to mass hydrogen utilization and contribute greatly to the realization of a hydrogen energy supply chain.

In preparation for the spread of hydrogen utilization, every gas turbine manufacturer is working on projects to make use of the excellent fuel flexibility of gas turbine engines, for instance, projects to develop combustion technology that can run on either a mix of hydrogen and natural gas or 100% hydrogen, and to realize practical application of gas turbine power generation systems.

Kawasaki is currently developing clean hydrogen combustion technology and in the process of verifying that technology for hydrogen fueled power generation, with the aim of achieving hydrogen fueled power generation using small- and medium-sized gas turbine power generation systems.

2 Challenges facing hydrogen utilization in gas turbines

Figure 1 shows the structure of a small gas turbine. Fuel is injected into the combustor where it is ignited in air pressurized by a compressor to generate high-temperature pressurized combustion gas. The flow of this combustion gas rotates a turbine, allowing power output to be obtained. The combustor's role is to stably and cleanly generate combustion gas whose temperature exceeds the melting point of metals.

Many different kinds of fuel can be used with gas turbines, including hydrogen, but it requires combustion technology adapted to hydrogen's unique combustion properties. The key to realizing hydrogen fueled power generation is to develop combustion technology and combustor parts that can achieve both stable hydrogen combustion and low emission of nitrogen oxides (NOx), an air pollutant [1].

(1) Stable hydrogen combustion

Hydrogen has higher reactivity than natural gas and the flames of its combustion come very close to combustor parts, which is more likely to cause the temperature of the parts to rise and combustion instability. **Figure 2** shows the state of flames inside of a combustor in combustion tests

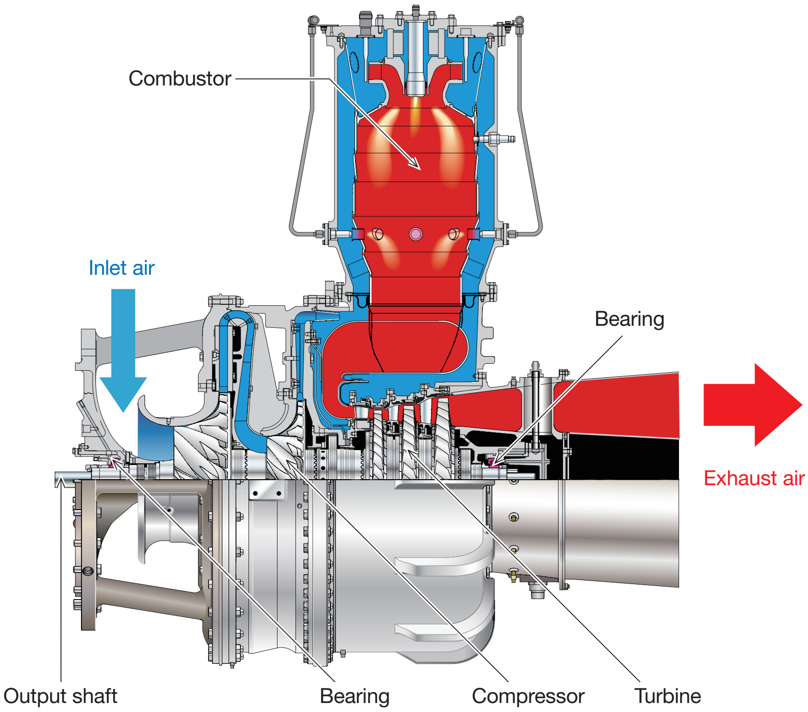
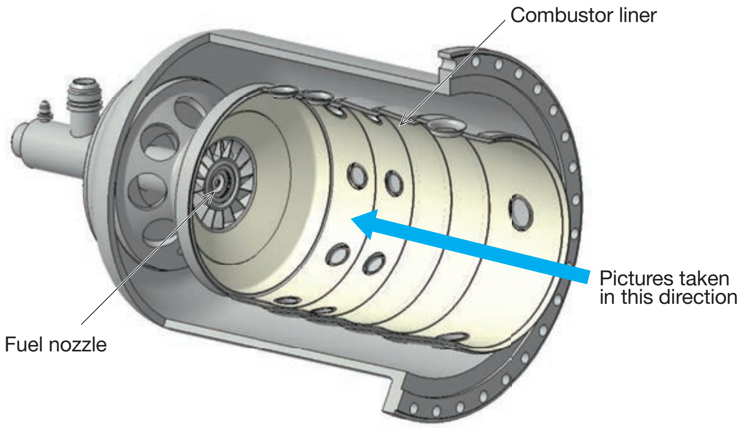
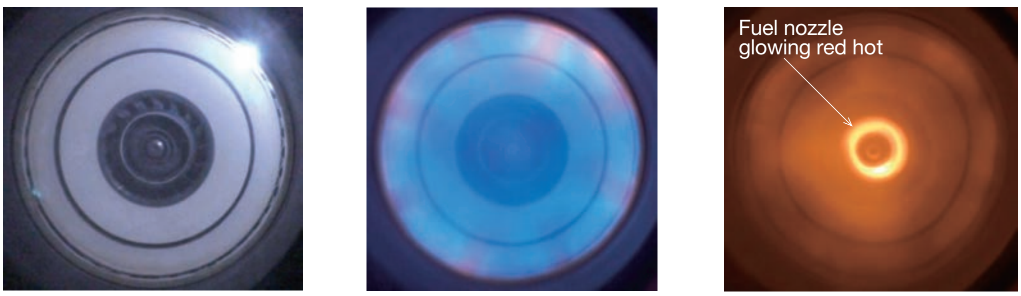


Fig. 1 Small-scale gas turbine (M1A-17D)



(a) Structure of combustor



(b) No combustion (c) Natural gas combustion (d) Hydrogen combustion

Fig. 2 Combustor structure and combustion state

using natural gas and hydrogen with a fuel nozzle for natural gas. In the hydrogen combustion test, hydrogen flames and combustion gas got too close to the fuel nozzle parts, making them so hot they glowed red.

Because there is a high-speed turbine rotation in the stage after the combustor, if the combustor is damaged in any way, such as a part falling off and entering the next stage, the turbine may be broken and the engine will stop. For this reason, it is important to take measures such as giving combustor parts shapes that make it possible to maintain stable combustion even with hydrogen.

(2) Reduction of nitrogen oxides

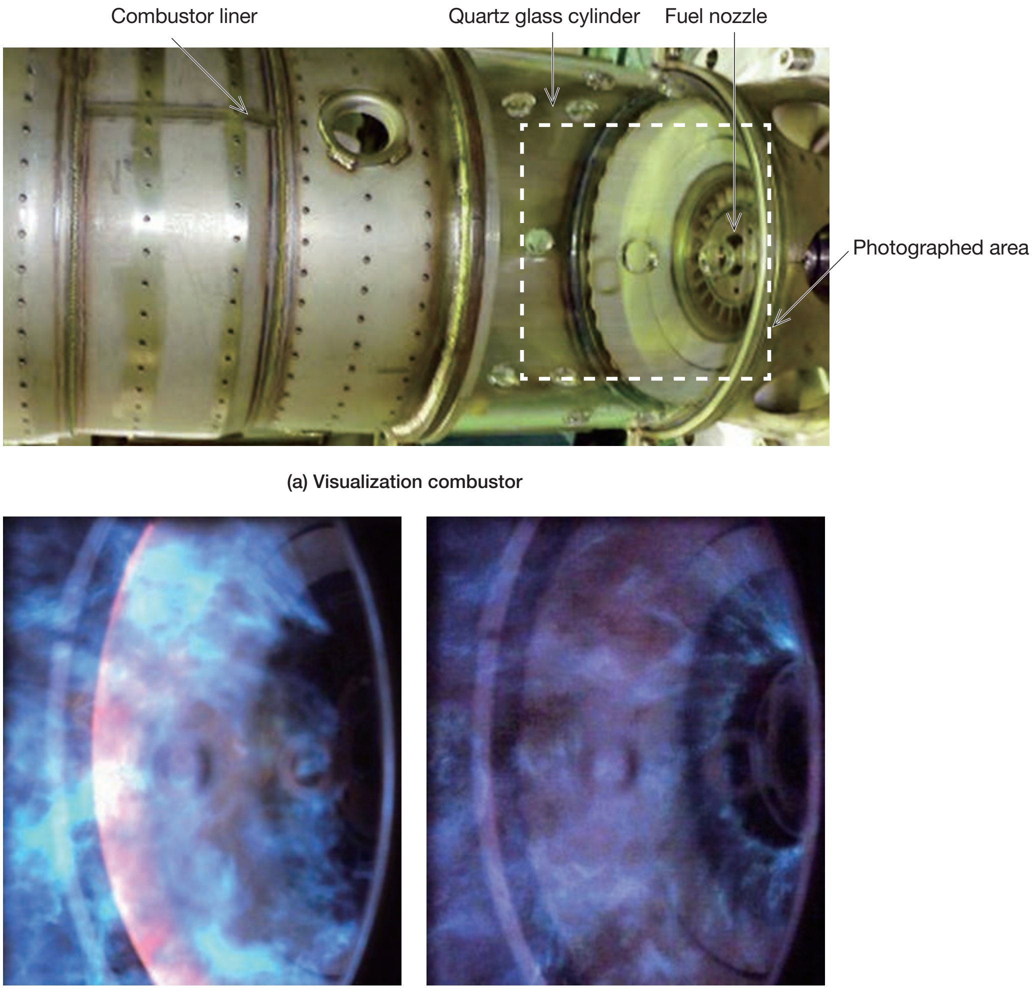
Figure 3 shows images of a visualization combustor in which part of the combustor was replaced with a quartz glass cylinder to make it possible to research the flames generated by igniting a hydrogen/natural gas mixture in the combustor; and the appearance of the flames taken with a high speed camera. When the proportion of natural gas was larger, as shown in **Fig. 3** (b), the flames were formed farther away from the fuel nozzle. On the other hand, when the proportion of hydrogen was larger, as shown in **Fig. 3** (c), the flames were formed closer to the fuel nozzle. Due to this difference in reaction areas and the rise in local flame temperature, when hydrogen is combusted in a gas turbine combustor, nearly 2 to 2.5 times more NOx is produced than with natural gas. Reducing the amount of NOx produced is also a major issue.

3 Development progress on hydrogen fueled gas turbines

There are mainly two types of combustion technologies for NOx reduction in gas turbine. One is diffusion flame combination with water injection that reduces NOx by spraying water or steam into a combustor, which has high combustion stability, and the other is dry low emission that reduces NOx by other methods such as adjusting the way air and fuel are mixed together.

In the case of diffusion flame combustion in which fuel gas is injected into the air and ignited, all that is required in order to accommodate hydrogen combustion is to take measures for the temperature rise of combustor parts. Kawasaki adopted water injection to establish technologies for the entire hydrogen fueled gas turbine power generation system.

However, with water injection, pure water production equipment must be installed to supply water and steam



(a) Visualization combustor

(b) 80 vol% natural gas to 20 vol% hydrogen

(c) 5 vol% natural gas to 95 vol% hydrogen

Fig. 3 Visualization combustor and flame behavior

and so running costs will rise. That is why we are also implementing research and development on a new dry low emission combustor suited to hydrogen combustion.

(1) Technology demonstration for hydrogen fueled gas turbine power generation

In a grant project by the New Energy and Industrial Technology Development Organization (NEDO), called the Smart Community Technology Development Project Utilizing Hydrogen Cogeneration Systems, Kawasaki worked on a hydrogen cogeneration system with a focus on the development of hydrogen-fueled and natural gas and hydrogen mixture-fueled gas turbines[1), 2)].

In this project we employed a 1MW-class PUC17D Generator for Ordinary Use, which is equipped with our M1A-17D Gas Turbine Engine, which has a hydrogen combustion-compatible combustor. This generator has high fuel flexibility to allow for operation with 100% hydrogen fuel, natural gas, and natural gas/hydrogen blends mixed at any desired ratio.

Figure 4 is an overall view of our hydrogen gas turbine cogeneration system demonstration plant installed on Port Island in Kobe City. After completion of the plant in December 2017, we carried out trial operation of the gas turbine power generation system alone and operation tests using natural gas, and then conducted demonstration tests to supply both heat and power with a natural gas/hydrogen blend and 100% hydrogen.

In a demonstration test held on April 19 and 20, 2018, this system was fueled with 100% hydrogen at a rate of approximately 2,200 Nm^3/h, and it successfully supplied 2,800 kW of heat (steam) to two neighboring facilities and 1,100 kW of electricity to four neighboring facilities at the same time, which is the world's first successful example of cogeneration using hydrogen fueled gas turbine power generation in an urban area. **Figure 5** is a picture of a monitor for the operation monitoring system during this demonstration test. We achieved NOx 50 ppm (O_2-16%) by

(a) Exterior of facility

(b) PUC17 Generator for Ordinary Use

Fig. 4 Hydrogen gas turbine cogeneration system demonstration plant

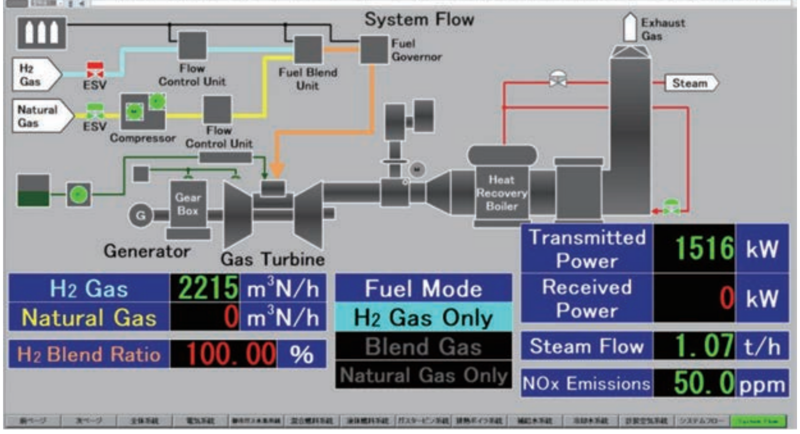


Fig. 5 Operation monitoring system (when operating on 100% hydrogen gas)

water injection, which met the threshold of 70 ppm (O_2-16%) set by Japan's Air Pollution Control Act.

(2) Development of hydrogen dry low NOx combustion technology

Natural gas achieves dry low NOx combustion by lean premixed combustion, in which the air and natural gas are mixed in advance and then the mixed gas is combusted. On the other hand, as hydrogen has high reactivity and causes combustion instability like flash-back, it is very difficult to use dry low NOx combustion with it.

For this reason, Kawasaki has studied the application of micro-mix hydrogen combustion technology to industrial gas turbines. This is a hydrogen dry low NOx combustion technology that uses small hydrogen flames. As shown in **Fig. 6**, hydrogen injected from small hydrogen injection holes less than a millimeter in diameter is rapidly mixed with a cross jet flow of air, which forms small hydrogen

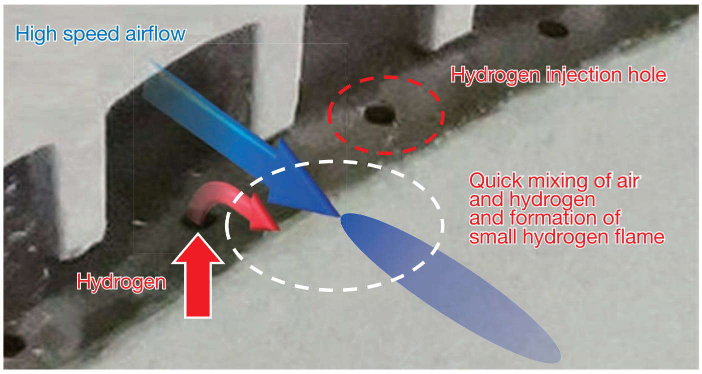


Fig. 6 Micro-mix hydrogen combustion technology

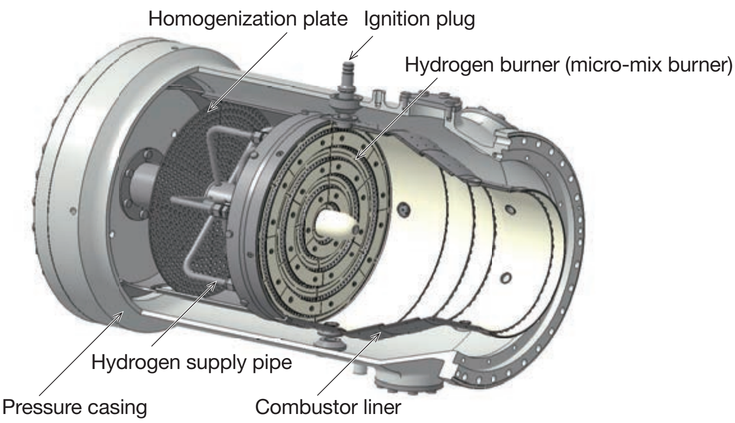
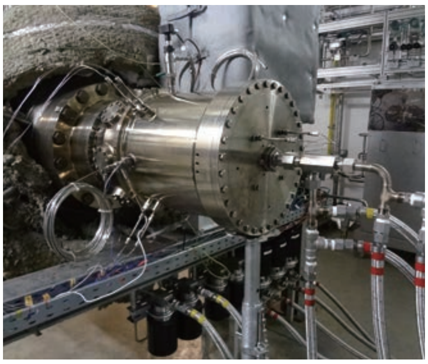


Fig. 7 Hydrogen dry low NOx combustor for 2MW class gas turbine



(a) Trial combustor

(b) Inside of combustor in design condition equivalent

Fig. 8 Tests of hydrogen combustor

flames with high flame stability, and also reduces NOx by shortening the reaction time.

Figure 7 is a hydrogen dry low NOx combustor for a 2MW class gas turbine. The hydrogen burner is in the shape of a ring, and the number of rings can be changed according to the hydrogen flow rate (operation conditions) [3), 4)]. This enables both high combustion efficiency from the time the engine starts to lower load operation conditions and low NOx combustion during higher load operation conditions.

We used trial combustor test parts to obtain ignition and flame stability performance, and combustion characteristics, NOx emissions in design conditions. **Figure 8** (a) shows a trial combustor installed in a facility that can replicate high temperature and high pressure combustor inlet boundary conditions that are the same as a 2MW class gas turbine, and **Fig. 8** (b) shows the hydrogen flame behavior inside the combustor under conditions equivalent to 100% of the design load.

In this test we confirmed stable hydrogen combustion and achieved less than NOx 35 ppm (O_2-16%), which is half of the regulation value, in the range of 50% load to 100% design load operation equivalent.

In May 2020, we started demonstration operation of the gas turbine engine installed in this combustor in the hydrogen gas turbine cogeneration system demonstration plant shown in **Fig. 4**, and successfully generated power using hydrogen dry low NOx power generation for the first time in the world.

Our next step has been proceeding with performance verifications such as stable operation and power generation efficiency, and to reduce the environmental load.

Conclusion

As part of the realization of a hydrogen energy supply chain, Kawasaki is developing technology for hydrogen combustion and a hydrogen fueled gas turbine. We believe such technologies will make it possible to use hydrogen as fuel for gas turbines, like natural gas, and can greatly contribute to the realization of a low-carbon society and a hydrogen-based society in the future.

The contents in this chapter include the results achieved with NEDO's support, namely, two grant projects, the Demonstration Project for Establishment of Mass Hydrogen Marine Transportation Supply Chain Derived from Unused Brown Coal, and the Smart Community Technology Development Project Utilizing Hydrogen Cogeneration Systems, and the commissioned project, Research and Developments of Hydrogen Combustion Technology for Hydrogen Gas Turbines. We would like to express our deep gratitude to NEDO.

Reference

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