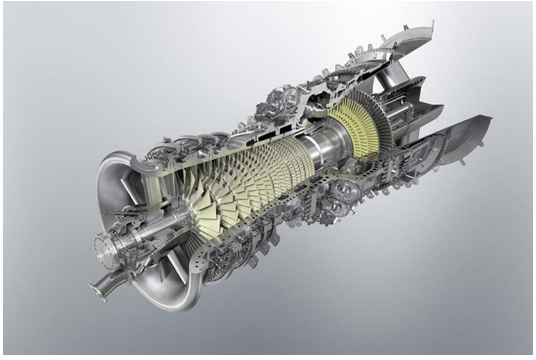
Development of Hydrogen and Natural Gas Co-firing Gas Turbine



KEI INOUE[*1] KENJI MIYAMOTO[*2]
SHOHEI DOMEN[*2] ISSEI TAMURA[*3]
TOMO KAWAKAMI[*4] SATOSHI TANIMURA[*5]

The nonuse of fossil fuels through the introduction of hydrogen energy is an effective option indispensable for the sustainable development of economic activity. The Mitsubishi Heavy Industries Ltd. (MHI) Group is promoting the research and development of a large gas turbine for which a mixed fuel of natural gas and hydrogen can be used with support from the New Energy and Industrial Technology Development Organization (NEDO). Currently, with the newly developed combustor, etc., we succeeded in a co-firing test of 30 vol% of hydrogen. This co-firing makes it possible to reduce CO_2 emissions during power generation by about 10% in comparison with conventional natural gas thermal power generation.

1. Introduction

In order to continue economic activities sustainably, it is essential to secure and supply energy that is stable and has low environmental impact. In response to issues such as global warming and the depletion of fossil fuels, the maximum acceleration of introduction and dissemination of renewable energy and the effective utilization of fossil fuels with maximum consideration for environmental impact are required. In addition to electricity and heat, hydrogen is expected to play a central role as future secondary energy, and the MHI Group is developing technology to fully utilize it.

Regarding the introduction of renewable energy, for example, the amount of wind power generation introduced globally has been increasing at a pace of 40.5 GW annually since 2011 and is predicted to expand to a maximum of about 2,500 GW in 2030. Because renewable energy has large output fluctuations, the utilization of surplus electric energy, in addition to the increase of renewable energy power generation facilities, is considered to be an issue. In order to effectively utilize such surplus electric energy, energy storage technology that converts into a storage battery or hydrogen, etc., is necessary. In particular, when the fluctuation cycle is long and a significant amount of energy capacity is required, it is considered effective to convert it to hydrogen, etc.

One promising power generation method using hydrogen fuel is power generation with a gas turbine. Current gas turbines generally use natural gas that is distributed as a general-purpose product for fuel. Since CO_2 generated during the combustion of natural gas is considered to be one of the factors of global warming, there is a movement to regulate its emission worldwide. Since the combustion of hydrogen does not generate CO_2, the amount of CO_2 generated during power generation can be reduced by replacing a part of the hydrocarbon components in the fuel with hydrogen.

*1 Combustion Research Department, Research & Innovation Center
*2 Large Frame Gas Turbine Engineering Department, Gas Turbine Technology & Products Integration Division, Mitsubishi Hitachi Power Systems, Ltd.
*3 Combustion Research Department, Research & Innovation Center
*4 Chief Staff Manager, Large Frame Gas Turbine Engineering Department, Gas Turbine Technology & Products Integration Division, Mitsubishi Hitachi Power Systems, Ltd.
*5 Senior Manager, Large Frame Gas Turbine Engineering Department, Gas Turbine Technology & Products Integration Division, Mitsubishi Hitachi Power Systems, Ltd.

Figure 1 shows the hydrogen rich fuel operating experience in the MHI Group. Due to the fuel use of off gas (exhaust gas generated in refinery plants, etc.), the use results include fuels with various hydrogen content ratios. In addition, at the time of participation in World Energy NETWORK, the MHI Group succeeded in a combustion test of pure hydrogen fuel firing. However, these are results from small power generation facilities. In order to realize the full-scale introduction of hydrogen in the power generation field, large-scale and high-efficiency energy conversion methods are required like the current natural gas.

Therefore, the MHI Group is promoting the development of a large gas turbine capable of co-firing natural gas and hydrogen at the introduction stage of hydrogen infrastructure. This paper presents the outline and future prospects of technological development enabling hydrogen co-firing.

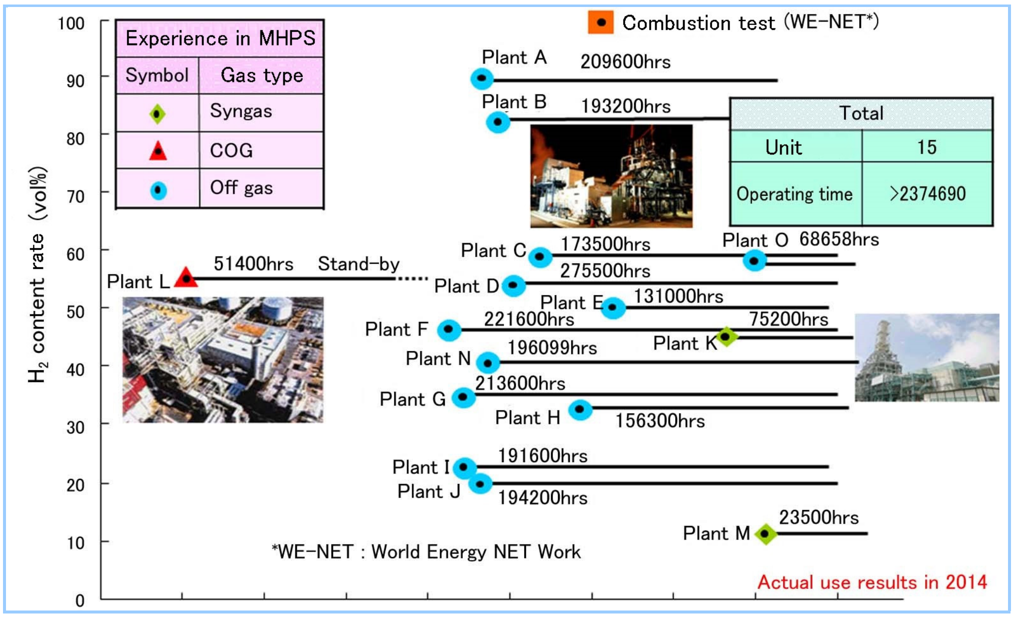


Figure 1 Hydrogen rich fuel operating experience

2. Issue of hydrogen co-firing

The Dry Low NOx (DLN) combustor installed in our large gas turbine adopts the premixed combustion method to reduce NOx (nitrogen oxide causing acid rain). **Figure 2** compares the premixed combustor and the diffusion combustor. Since premixed combustion can reduce the flame temperature compared with diffusion combustion, NOx can be reduced without steam/water spraying, and it is a technology currently widely applied to low NOx combustor. On the other hand, the stable combustion range is narrower than that of the conventional diffusion combustor, and the flashback phenomenon tends to occur. Flashback is a phenomenon in which a flame moves upstream in the fluid when the propagation speed of the flame (hereinafter referred to as the combustion speed) is higher than the speed of the fluid (hereinafter referred to as the flow velocity). If flashback occurs inside the gas turbine combustor, there is a possibility of burning the upstream non-cooled part, so it is important to prevent its occurrence. **Figure 3** provides an overview of the flashback phenomenon.

When natural gas and hydrogen are mixed, the properties of the flame change due to the change in the fuel component. Particularly, in order to stably operate the gas turbine, it is necessary to develop a technology to deal with the change in the combustion speed. It has been confirmed that hydrogen has a higher combustion speed rate in comparison with natural gas. For this reason, when hydrogen is mixed, it is considered that the risk of the flashback phenomenon is higher compared with the case where only natural gas is burned. Therefore, for the development of a hydrogen co-firing gas turbine, the improvement of the combustor for the prevention of flashback occurrence is important.

Inside the MHI Group's DLN combustor, swirling flow is formed to promote the mixing of fuel and air. Several articles[1, 2] reported that in order to prevent the occurrence of flashback in such swirling flow, it is necessary to raise the flow velocity at the center portion of the swirling flow beyond the rise in the combustion speed.

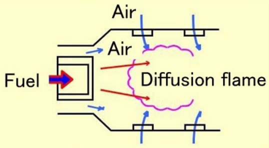
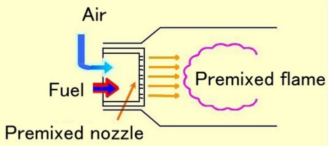
Type	Diffusion combustion	Premixed combustion
Configuration		
Combustion characteristics	Separately injects fuel and combustion air High gas temperature (high NOx) Stable flame	Injects mixed fuel and air Low gas temperature (low NOx) Unstable Flame (risk of flashback)
Features	Wide Allowable range of fuel Simple fuel supply system Low efficiency due to steam or water injection (measure against NOx)	Establishing Both high efficiency and low NOx Complicated Fuel supply system

Figure 2 Comparison of combustion type

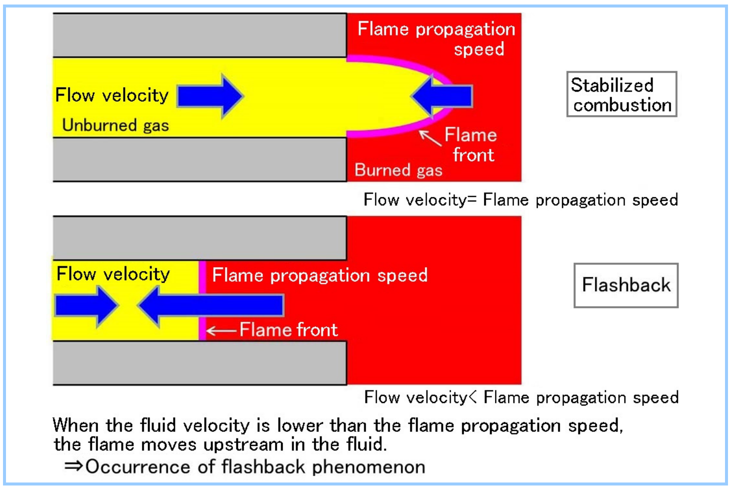


Figure 3 Overview of flashback phenomenon

3. Outline of flashback prevention technology

3.1 Concept of new combustor

Figure 4 illustrates the outline of a combustor newly developed with the purpose of preventing an increase in the risk of flashback caused by hydrogen co-firing. The air supplied from the compressor to the interior of the combustor passes through the swirler and becomes a swirling flow. Fuel is supplied from a small hole provided on the blade surface of the swirler and mixed rapidly with the surrounding air due to the swirling flow effect. On the other hand, it is clear that a region with a low flow velocity exists in the central part (hereinafter referred to as swirling center) of the swirling flow. It is considered that the flashback phenomenon in the swirling flow is caused by the flame moving upstream in the portion of the swirling center where the flow velocity is slow. In the new combustor, in order to increase the flow velocity at the swirling center, air is characteristically injected from the tip of the nozzle. The injected air compensates for the low flow velocity region of the swirling center and prevents flashback.

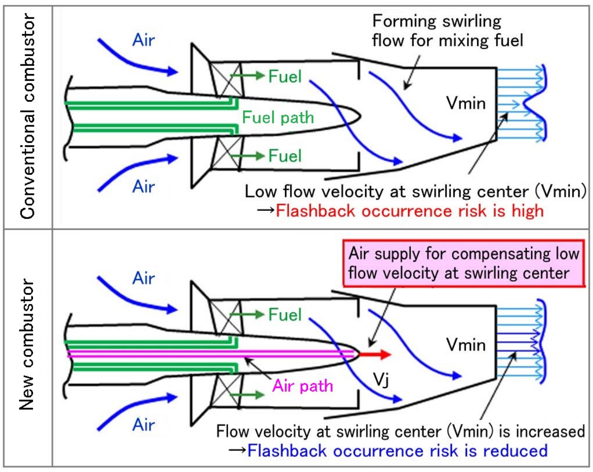


Figure 4 Outline of new combustor

3.2 Verification by non-combustion test

In order to confirm the effect of the new combustor, flow velocity distribution was measured with an air flow test. **Figure 5** is a photograph of the equipment used for the air flow test. The swirling center does not remain at a certain position, and its position changes from moment to moment. For this reason, in flow velocity measurement, it is necessary to perform measurement at the moment when the flow velocity lowers while the swirling center passes through the measurement point. Therefore, by applying a hot wire current meter (Kanomax 7000 Ser and φ5 μ I-type linear probe made of tungsten) for the flow velocity measurement and by achieving high time resolution, the evaluation of the instantaneous minimum flow velocity at the measurement position was made possible.

Figure 6 compares the flow velocity distributions of the conventional combustor and the new combustor in the region close to the swirling center. Paying attention to the minimum flow velocity, which is thought to dominate the occurrence of the flashback phenomenon, it was confirmed that the new combustor realized a flow velocity of 2.5 times or higher than that of the conventional combustor. Since the new combustor injects a very small amount of air from a small hole provided at the tip of the nozzle, regions other than the vicinity of the swirling center are hardly affected, and the flow velocity distribution is the same as that of the conventional combustor.

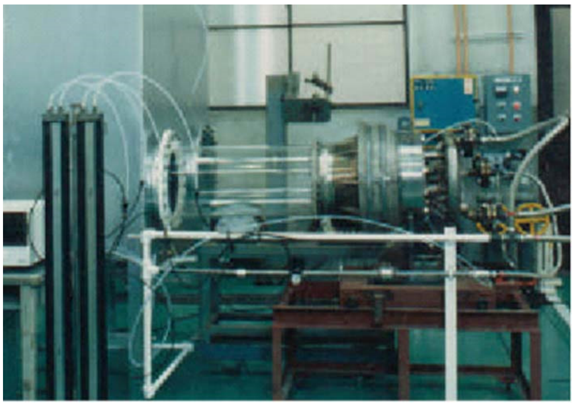


Figure 5 Photograph of air flow test equipment

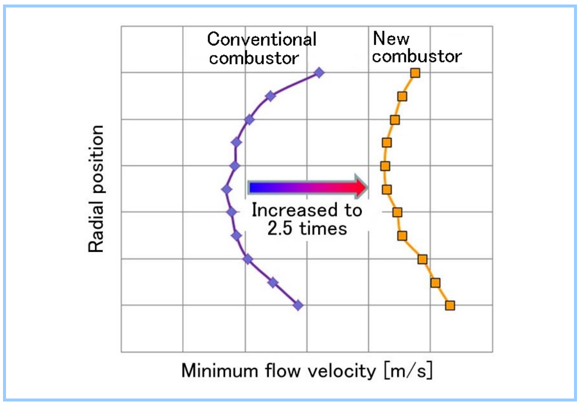


Figure 6 Comparison of flow velocity distributions in region close to swirling center

3.3 Confirmation of combustion characteristics by actual pressure combustion test

Representative items related to combustion characteristics of a gas turbine combustor include NOx and combustion vibration. Since NOx is one of the factors of acid rain, there is a regulation on the amount of emissions in terms of the environmental aspect. On the other hand, combustion instability needs to be kept below a certain level in order to operate gas turbines stably. Since both NOx and combustion instability are affected by the combustion pressure conditions, testing under pressure conditions corresponding to the actual machine is necessary. Therefore, through the actual machine pressure combustion test (hereinafter referred to as the actual pressure combustion test) using one full-scale combustor (in the actual machine 16 to 20 combustors are used), the influence of hydrogen co-firing on combustion characteristics was confirmed. For the actual pressure combustion test, an actual pressure combustion test facility at the Mitsubishi Hitachi Power Systems, Ltd. Takasago Plant was used. **Figure 7** gives the facility configuration of the actual pressure combustion test equipment. The high pressure and high temperature air used in the combustion test equipment is supplied by a two-shaft gas turbine and is guided to a test sector simulating the casing shape of the gas turbine (for one combustor) installed in the combustion test pressure vessel. The exhaust gas after combustion is discharged from the exhaust tower together with the exhaust gas of the compressor driving gas turbine. In order to simulate the fuel of the actual plant, hydrogen is added in the upstream part of the natural gas supply line and supplied to the actual pressure combustion test facility. Since hydrogen is added sufficiently upstream of the test facility, it is evenly mixed with natural gas before reaching the combustor.

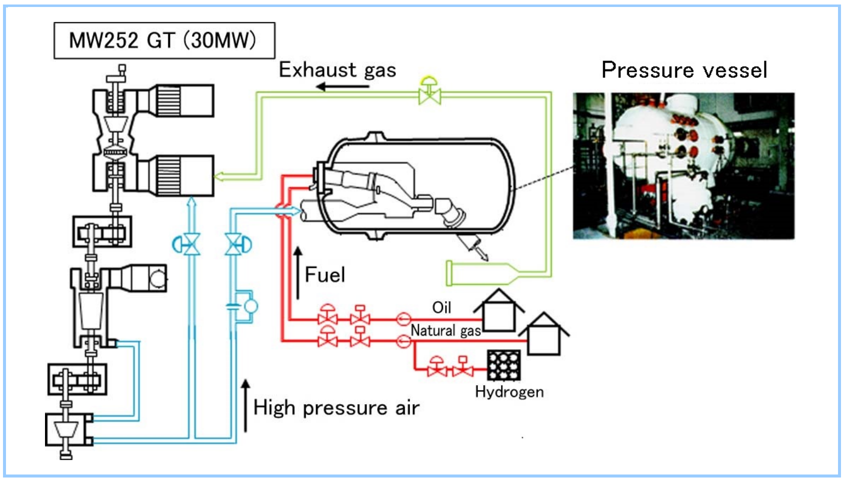


Figure 7 Configuration of actual pressure combustion test equipment

Figure 8 shows the change in NOx with respect to the hydrogen mixing ratio under conditions equivalent to the rated conditions of a turbine inlet temperature 1600-degree class gas turbine. It was confirmed that as the hydrogen mixing ratio increased, NOx tended to increase slightly. This is thought to be because of the fact that the combustion speed increased due to the mixing of hydrogen in the fuel and the flame position in the combustor moved upstream. However, it was confirmed that even under the conditions with the hydrogen mixing ratio of 30 vol%, NOx was within the operable range. **Figure 9** provides the change in combustion instability pressure level under the same conditions. It was confirmed that combustion instability pressure level was not significantly affected by the change in the hydrogen mixing ratio. From the above results, it can be considered that gas turbine operation under up to 30 vol% hydrogen co-firing conditions without the occurrence of flash back or a significant increase in the internal pressure fluctuation is made possible by applying the new combustor, even though there is an increase in NOx due to the increase in the hydrogen mixing ratio.

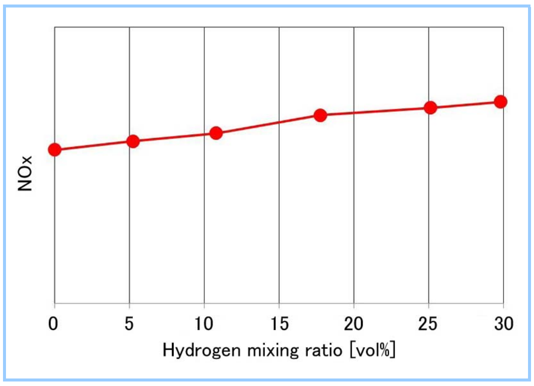


Figure 8 Change in NOx with respect to hydrogen mixing ratio

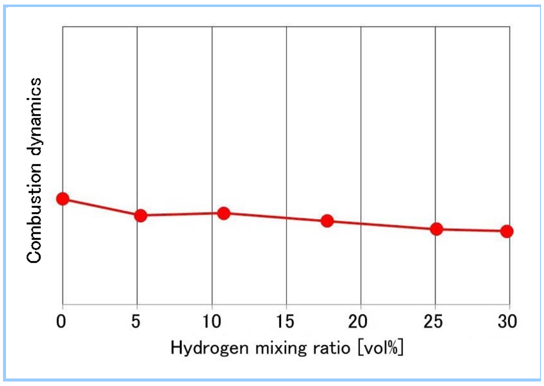


Figure 9 Change in internal pressure fluctuation level with respect to hydrogen mixing ratio

4. Future prospects

In order to realize a hydrogen and natural gas co-firing gas turbine plant, it is necessary to further consider other auxiliary equipment attached to the plant and operation methods in parallel with the development of a combustor. Since current gas turbines mainly use natural gas distributed as a general-purpose product, piping materials and plant auxiliary equipment are selected on the premise of using natural gas. Hydrogen tends to leak and is easy to diffuse in comparison with natural gas, so it is necessary to devise safety measures suitable for the characteristics and to reselect specifications. In addition, since the hydrogen content rate may not be stable in actual plant operation, we will also work on the development of plant operation technology that can deal with an unsteady change in the hydrogen mixing ratio.

5. Conclusion

In order to respond to the use of hydrogen fuel targeting reduced CO_2 emissions in the field of thermal power generation, the MHI Group is working on the development of a hydrogen and natural gas co-firing gas turbine with support from the New Energy and Industrial Technology Development Organization (NEDO). For the prevention of the occurrence of the flashback phenomenon caused by hydrogen co-firing, a new combustor that suppresses the generation of the low flow velocity in the swirling center region was developed, and the prospect for gas turbine operation under 30 vol% hydrogen co-firing conditions was obtained. We are planning to develop plant operation technology in the future and to promote the development of a gas turbine that enables further higher concentration hydrogen co-firing for plant verification operation targeted to be implemented in fiscal 2025.

References

1. M.Kroner, T.Sattelmayer, J.Fritz, F.Kiesewetter, and C.Hirsch,“Flame Propagation in Swirling Flows - Effect of Local Extinction on the Combustion Induced Vortex Breakdown”, Combust. Sci. and Tech., vol.179, pp.1385-1416, 2007
2. B.Dam, G.Corona, M.Hayder, A.Choudhuri, “Effects of syngas composition on combustion induced vortex breakdown (CIVB) flashback in a swirl stabilized combustor”, Fuel, vol.90, pp.3274-3284, 2011