Development of High Efficiency Gas Turbine Combined Cycle Power Plant

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The reduction of carbon dioxide (CO₂) to prevent global warming has become a serious issue for power plants. Since power plants account for one third of the total CO₂ emissions, improvements in their efficiency will greatly contribute to the reduction of CO₂ emissions. This paper focuses on the gas turbine combined cycle power plant, and introduces the approaches for the improvement of its efficiency.

1. Introduction

Methods of CO₂ reduction to prevent global warming can be divided into two types: reduction of CO₂ emissions and recovery of CO₂.

Over the last one or two years CO₂ recovery has been studied for a combined system of hydrogen gas turbine combined cycle and EOR (enhanced oil recovery), where petroleum coke is gasified and the gas is shifted by reforming to CO₂ and hydrogen.

It is well-known that power plants are responsible for one third of the total CO₂ emissions. Improving the heat efficiency of a power plant by introducing a high-efficiency gas turbine combined plant with an advanced gas turbine leads directly to the reduction of CO₂ emissions, and is therefore an effective means of CO₂ reduction.

This paper reports the gas turbine combined cycle plant to reduce CO₂ emissions, and describes its future prospects of high efficiency.

2. Transition of the heat efficiency of combined cycle plant and CO₂ reduction

Thermal power plants are broadly divided into two types: the conventional type with a combination of a boiler and steam turbine and the combined cycle type which consists of a gas turbine and a steam turbine that uses high-temperature steam obtained through heat recovery from the gas turbine exhaust gas.

Unlike a conventional thermal power plant, a combined cycle power plant was adopted for power generation in Japan for the first time in 1984 in Unit No. 3 at Higashi Niigata Thermal Power Station of Tohoku Electric Power Co., Inc., where a D-type gas turbine with an inlet temperature of 1,100°C was adopted.

With the rise in turbine inlet temperature, a 1,300°C class F-type gas turbine was developed, followed by a 1,500°C class G-type gas turbine (see Fig. 1). The state-of-the-art G-type gas turbine combined plant has an efficiency exceeding 59% (LHV base) and 53% (HHV base). Figure 2 shows a comparison between the combined cycle power plant and a conventional thermal power plant, while Fig. 3 shows the transition of reductions in CO₂ emissions per kWh due to improvement of efficiency.

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The CO₂ emissions have consistently been reduced since 1950, but because of the slowdown of the improvement in efficiency, the amount of CO₂ reduction in conventional thermal power plants is not so much compared with the combined plant.

On the contrary, because of the drastic improvements made in the efficiency of the combined cycle plant, the CO₂ emissions have been greatly reduced and are expected to be further reduced in the future due to improvement of efficiency.

3. Outline of 1,700°C class high-efficiency gas turbine

As mentioned above, it is necessary to raise the cycle temperature in order to improve the efficiency of the combined cycle plant. Figure 4 shows the relationship between the maximum cycle temperature (gas turbine inlet temperature) and efficiency.

The efficiency of the combined cycle plant with a 1,700°C class gas turbine with its inlet temperature improved to 1,700°C compared with the F-type and G-type with inlet temperatures of 1,500°C has reached the level of 62% - 65% (LHV base), and is expected to stand at a higher level than the efficiency of the conventional combined cycle plant.

The design concept of 1,700°C class gas turbine is shown in Fig. 5.

Mitsubishi Heavy Industries, Ltd. (MHI) has joined the development program of the 1,700°C class gas turbine, a national project, which requires six component technologies (combustor, cooling technology, heat-resisting materials, heat-shielding coating, turbine aerodynamics and compressor aerodynamics).

For realization of the 1,700°C class gas turbine with an inlet temperature far higher than the latest 1,500°C gas turbine,
the basic design of high performance compressor, low NO\textsubscript{X} combustor and turbine capable of withstanding the 1,700°C inlet temperature is under development.

4. CO\textsubscript{2} reduction due to high-efficiency gas turbine combined cycle plant

The world's gross power generation amounted to 15,000 T (tera) Wh in 2000, and is estimated to exceed 20,000 TWh in 2010 and 30,000 TWh in 2030.

It is estimated that the power generation due to natural gas, the main fuel of power generation equipment, will be 5,000 TWh in 2010 and double to about 10,000 TWh in 2030 (see Fig. 6).

Supposing it is planned that all of the power generation (10,000 TWh) for 2030 will use natural gas firing high-efficiency gas turbine combined cycle G-type or 1,700°C class turbines, the CO\textsubscript{2} reduction due to fuel reduction because of the efficiency difference from the F type turbine will amount to 200 million tons for G-type turbines and approximately 500 - 700 million tons for 1,700°C class turbines (see Fig. 7).

In view of the present total annual CO\textsubscript{2} emissions of approximately 1.3 billion tons in Japan, this figure shows a remarkable progress in CO\textsubscript{2} reduction.

Thus, it is considered that the large CO\textsubscript{2} reduction for high-efficiency gas turbine combined cycle plants is possible before the implementation of CO\textsubscript{2} recovery and reservoir systems.

5. Conclusion

Gas turbine combined cycle power plants mainly using MHI D, F and G-type gas turbines are currently in operation in large numbers, and there are many under construction or planned both in Japan and abroad. The development and introduction of this new technology responds to the need for the effective utilization of energy and countermeasures against global warming, thus contributing greatly to society. MHI is determined to continue efforts to develop new technology as a pioneer company in this field.

References


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