Development of M701F Gas Turbine for Integrated VR Gasification Combined Cycle Plants

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1. Introduction

Although the demand for major heavy oil products such as asphalt has been decreasing in the oil industry recently due to changes in domestic industry and economic structure, new applications of these oils as fuel for power generation plants have been on the increase. In particular, much attention has been given recently to Integrated Gasification Combined Cycle (IGCC) power generation systems, which can cope with strict environmental controls in cities, as a way of applying of Vacuum Residue (VR). To meet the needs of this kind, Mitsubishi Heavy Industries, Ltd. (MHI) started to develop the system to be applied to a more efficient high-temperature gas turbine based on extensive operating experience in low calorific gas-fired turbines using a gas similar to the gas produced by gasifying VR (hereafter referred to as VR gasification gas). In this study, an outline is presented of the design and operating track record of the 1350•‹C class gas turbine that was developed for use in Japan's first VR gasification combined cycle power generation plant (Gross plant power output: 431 MW), which went into commercial operation on June 30, 2003 at the Negishi Refinery of the Nippon Oil Corporation Ltd.

2. VR gasification gas-fired IGCC system

2.1 Major specifications

The major specifications of the power generation equipment in the integrated IGCC power generation plant are shown in **Table 1**, and an outline of the system is shown in **Fig. 1**. The integrated power generation equipment which was produced by MHI consists of a M701F gas turbine with a combustion temperature of 1350ºC, a single-casing downward exhaust reheat mixed pressure condensing type steam turbine, and a reheat triple pressure vertical natural circulation type heat recovery steam generator. The gas turbine fuel supplied is formed by mixing VR gasification gas with nitrogen gas, and the steam turbine governor controls the pressure on its upstream side in order to supply steam with a constant pressure to the gasification furnace.

2.2 Outline of system

In the air separator air is separated into nitrogen gas and oxygen gas, and the nitrogen gas is fed to the gas turbine while the oxygen gas is fed to the gasification

Table 1 Major Specifications of Integrated Power Generation Equipment

Net plant power output	342 MW
Gross plant power output	431 MW
Gas turbine	1 350°C class
Fuel	VR gasification gas
Nitrogen/VR gasification gas ratio (weight ratio)	1.5
Steam conditions (steam turbine inlet)	
Main steam Pressure (Temperature)	9.8 MPaG × 538°C
Reheat steam Pressure (Temperature)	2.9 MPaG × 538°C
Medium pressure steam Pressure (Temperature)	0.7 MPaG × 313°C

Atmospheric temperature: 15°C, Atmospheric pressure: 0.1013MPaA, Relative humidity: 60%

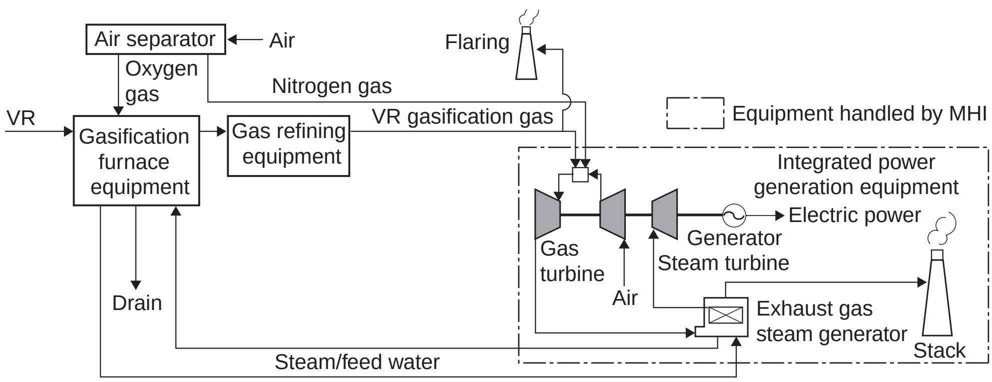

Fig. 1 Outline of plant system
This figure shows an overview of the overall IGCC plant system and the equipment provided by MHI.

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furnace. In the gasification furnace, the oxygen gas supplied from the air separator is mixed with VR and steam supplied from the integrated power generation equipment to produce low calorific VR gasification gas consisting mainly of CO and H_2. This plant is an integrated power generation system in which VR gasification gas, nitrogen gas, steam, and water are integrated with each other. The VR gasification gas is injected into the gas turbine after being mixed with the nitrogen gas supplied from the air separation equipment to generate power, while steam and water required in the gasification furnace are supplied to the system.

3. Design of VR gasification gas-fired gas turbine

The components of the gas turbine, which is the main system of the plant, (**Fig. 2**) were modified based on the proven M701F standard system as described below.

3.1 Combustor section

Since the VR gasification gas generated in the gasification furnace has a high adiabatic flame temperature, a large amount of NOx will be generated if it is burned without being treated. To prevent this problem, the nitrogen gas fed from the air separator in this plant is mixed with the VR gasification gas, and the mixed gas is used as gas turbine fuel. Compared with natural gas (LNG), well known as a common gas turbine fuel, the mixed gas is lower in heating value and adiabatic flame temperature and, as a result, the amount of NOx generated can be reduced. In addition, since its ratio of hydrogen gas is higher, it has other features such as the burning rate is higher and the inflammable range is wider.

Based on these characteristics of fuel, it can be found that, even if a diffusion combustor is adopted, the concentration of NOx emission at the outlet of the gas turbine can be reduced to a level equivalent to that produced by the adoption of a natural gas premixed combustor. In this plant, a diffusion combustor is adopted to allow stable combustion as a measure against variations in fuel properties.

In addition, since the gas turbine must first be started by kerosene firing before the gasification furnace is started in this plant, the combustor is so designed that it can cope with the dual fuel firing of gas and oil.

3.2 Compressor section and turbine section

When the turbine inlet temperature is constant, fuel consumption for low calorific gas firing is higher than that for normal high calorific fuel firing. Accordingly, the amount of combustion gas passed through the turbine is increased. In the conventional low calorific gas fired turbine using a blast furnace gas, the compressor is downsized more than that of the standard device in order to reduce the amount of suction air so as to lower the flow passed through the turbine to that of the standard device. In this plant, however, the amount of suction air is made equal to that of the standard device in order to increase the output of the turbine. As a result, the pressure ratio becomes higher than that of the standard device due to the increase of the amount of fuel used, which places strict conditions on the surging of the compressor. In this gas turbine for IGCC, pressure is regulated by changing the mounting angle of the 1st-stage vane of the turbine, and the compressor is changed to a high-pressure ratio type system.

4. Operation procedure of VR gasification gas-fired IGCC

When starting-up this plant, the power generation equipment is first started in order to start the air separator with the power generated. Thus, large power consumption by the air separator can be suppressed, and preparations for the start-up of the gasification furnace can be performed at the same time.

Once the start-up of the air separator is completed, it is integrated with the steam and feed water supply on the integrated power generation system, the gasification furnace equipment is started and built up, and the load is increased to a level where the gas turbine fuel is converted from kerosene to VR gasification gas. In this case, the VR gasification gas produced from the gasification furnace is burned until fuel conversion is completed. After the fuel is converted, the gas turbine uses the VR gasification gas produced from the gasification furnace for fuel, and burns the gas formed by mixing the fuel with the nitrogen gas supplied from the air separator on the upstream side of the combustor in order to rotate the generator to generate power.

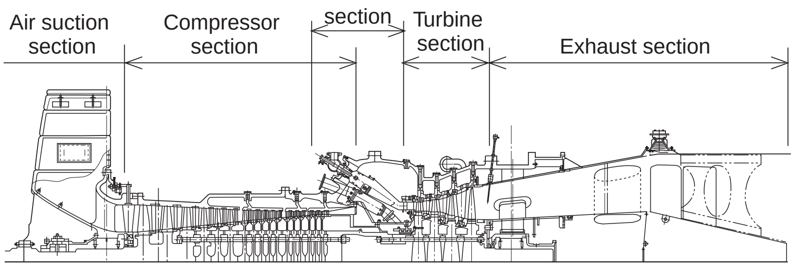

Fig. 2 Cross section of M701F gas turbine for IGCC
This figure shows the cross section of the M701F gas turbine for IGCC.

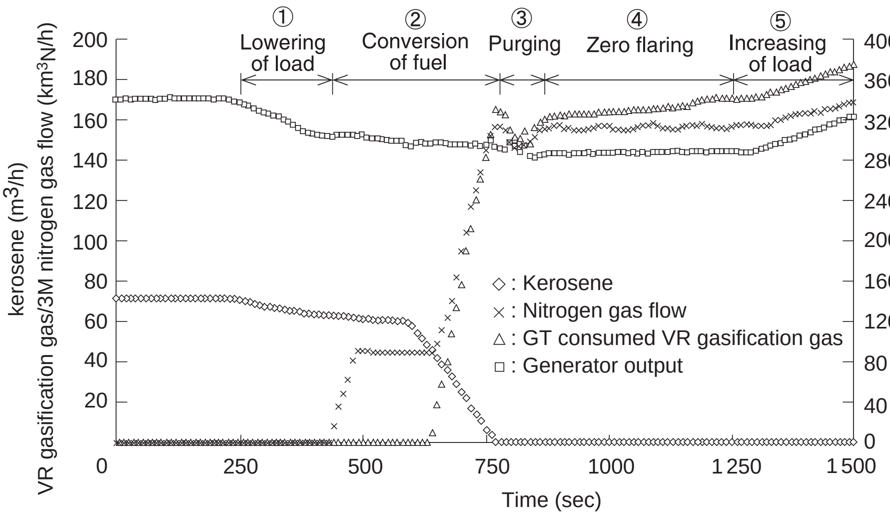

Fig. 3 Results of operation when fuel is converted
This shows the time-series variation in plant behavior when fuel is converted.

Table 2 Results of Measurement of Gas Turbine Exhaust Gas in Environment

Environmental Value	NOx density	Soot and dust density	SOx density
Unit	ppm vol dry (Converted into that at 16% O_2)	$mg/m^3{}_N$ dry	ppm vol dry (Converted into that at 16% O_2)
Control value	2 or lower	1 or lower	2 or lower

Under operating conditions in which VR gasification gas is fired at the maximum load: Power generation output: 431MW

5. Operational actual results of VR gasification gas-fired IGCC

The operation data obtained during operation using kerosene as a fuel to start-up the gas turbine and after conversion operation to the use of VR gasification gas is shown in **Fig. 3**. The outlined procedure for converting the fuel is outlined below.

(1) Lowering of load

The load is lowered to a fuel conversion load of GT200 MW (Gross plant power output: Approx. 300 MW) through kerosene-firing operation.

(2) Conversion of fuel

The gas turbine fuel is converted from kerosene to a gas mixture consisting of VR gasification gas and nitrogen gas. There was no large load variation during fuel conversion, and the conversion is performed satisfactorily.

(3) Purge after fuel conversion

After the fuel is converted to VR gasification gas, the kerosene pipe on the upstream side of the gas turbine is purged.

(4) Zero Flaring

Since VR gasification gas supplied from the gasification furnace is incinerated while the fuel is being converted, the incineration treatment of VR gasification gas is discontinued once fuel conversion is completed.

(5) Increase in load

The load is increased to the operational load.

The environmental control values for exhaust gas from the gas turbine during VR gasification gas firing operation are shown in **Table 2**. The environmental conditions were measured under operating conditions in which VR gasification gas was fired at the maximum load (Gross plant power output: 431 MW). As a result, excellent results could be obtained in which the requirements for controlled values were all satisfactorily met.

6. Conclusion

The design procedure and operational actual results for the operation of an integrated VR gasification gas-fired IGCC combined power generation plant having the world's largest unit capacity that went into commercial operation in June 2003 were described. In order to meet the needs for the effective use of energy resources and to reduce loads on the environment, MHI is making every effort to develop new technologies ever further and play a pioneering role in this field in the future.


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