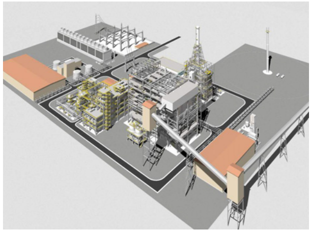
Development of IGCC Commercial Plant with Air-blown Gasifier



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The development of integrated coal gasification combined-cycle (IGCC) power generation, a coal-based high-efficiency power generation system, and its commercialization with the capture and sequestration of the CO_2 produced during electric power generation has received special attention. This will reduce CO_2 emissions and prevent global warming while providing a stable energy supply. This paper reports on the development of a commercial IGCC plant and efforts to apply CO_2 capture technology to Mitsubishi Heavy Industries' (MHI's) IGCC.

1. Introduction

The consumption of coal, a fossil fuel with a long-term stable supply and low cost, will continue to increase significantly in step with the global increase in energy consumption. On the other hand, the use of coal is becoming increasingly difficult, mainly due to global warming. The development of highly efficient technology to reduce CO_2 emissions, therefore, has become an urgent priority. Studies are globally underway to develop the technology required to capture and sequester CO_2 generated during power generation as a step in reducing CO_2 emissions. This has focused special attention on integrated coal gasification combined-cycle (IGCC) power generation as a thermal power generation technology that can capture CO_2 with the highest efficiency and economy; i.e., it is one of the cleanest coal technologies. This paper first outlines the status of IGCC development, and then reports on the current development program for IGCC commercial plants and the accompanying CO_2 capture technology.

2. IGCC development status

IGCC is a power generation system designed to run more efficiently than conventional pulverized coal-fired systems by combining coal gasification with a gas turbine combined-cycle system. In collaboration with the government, nine electric utility companies, J-POWER, and the Central Research Institute of Electric Power Industry (CRIEPI), Mitsubishi Heavy Industries (MHI) has been making efforts to develop a highly efficient and reliable air-blown IGCC plant optimized for power generation. A 250 MW IGCC demonstration plant, which is called "Nakoso" according to the place name where the plant is located, was constructed as the final step before commercialization following the operation of a 2 t/day Process Development Unit (PDU) and testing at a 200 t/day (equivalent to 25 MW) pilot plant.

The IGCC demonstration plant project was led by Clean Coal Power R&D Co. Ltd., which was founded in the collaboration in June 2001. MHI concluded an EPC single-point turn-key contract for all the IGCC plant, by supplying the gasifier, gas cleanup system, gas turbine, steam turbine, and exhaust heat recovery steam generator (HRSG). After all of the effort, MHI successfully completed the design, construction, and delivery of the equipment in 2007.

A series of demonstration test started in the "Nakoso" IGCC plant in September 2007 and successfully proceeded on schedule. The plant reached its rated load of 250 MW in March 2008, and completed more than 2,000 hours of long-term continuous operation in September 2008. **Figure 1** shows its operational performance compared with the other IGCC plants in western countries. They use oxygen-blown gasifiers originally developed for the application to chemical plants, and many of them could not achieve long-term continuous operation even 10 years after the initial start of operations. The achievement of such operation by "Nakoso" only one year after startup demonstrated extremely high reliability of MHI's air-blown IGCC system.

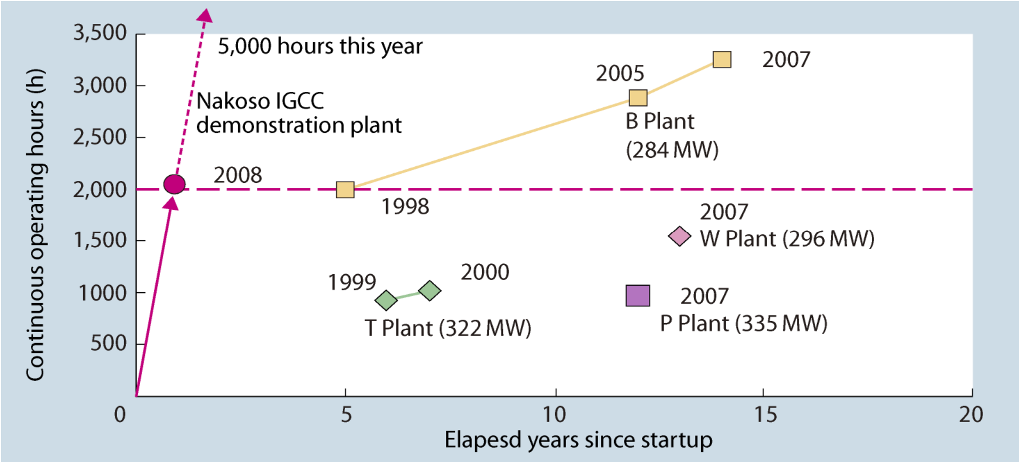

Figure 1 Consecutive operating hours of IGCC plants as a function of years after startup

Table 1 lists the plant performance measurement results and shows that the targeted power output and efficiency were fully achieved. The carbon conversion rate was almost 100% because of perfect gasification reaction without any carbon in the slag. The obtained environmental emission values, which were much better than planned, show that its environmental performance is much higher than that of conventional pulverized coal-fired systems. Testing for more improved efficiency and reliability as well as the verification of long-term reliability and maintainability will take place shortly during a 5,000 hour continuous endurance test which is planned to start in 2009.

Table 1 IGCC demonstration test results

Ambient temperature		13.1°C
Gross power output		250 MW (planned: 250 MW)
Gas turbine output		124 MW
Steam turbine output		126 MW
Net plant efficiency		42.9 % (lower heating value, LHV) (planned: 42% minimum)
Cold gas efficiency		77.2%
Carbon conversion rate		> 99.9%
Produced gas HHV wet		5.4 MJ/m^{3}N (1,290kcal/ m^{3}N)
Produced gas composition	CO	30.5%
	CO_2	2.8%
	H_2	10.5%
	CH_4	0.7%
	N_2 and others	55.5%
Environmental value (16% O_2 basis)	SOx	1.0 ppm (planned: 8 ppm maximum)
	NOx	3.4 ppm (planned: 5 ppm maximum)
	Particulate matter	<0.1 mg/ m^{3}N (planned: 3.3 mg/m^{3}N maximum)

3. IGCC commercial plant development program overview

3.1 Air-blown IGCC commercial plant

Table 2 summarizes the principal specifications of the IGCC demonstration plant and an IGCC commercial plant. The commercial plant uses the air-blown gasifier, which will have approximately twice the capacity of that used in the demonstration plant. The increase in the gasifier diameter, however, remains by approximately 20% which allows full application of the scale-up law because the operating pressure in the gasifier of the commercial plant comes to be higher than the demonstration plant.

Table 2 Specifications of the IGCC demonstration plant and commercial plants

Parameter		Units	IGCC demonstration plant	Commercial plant (50Hz / 60Hz)
Gross Power Output		MW	250	600 / 500
Type of coal		-	Bituminous	Bituminous
Gasifier		-	Dry feed, air-blown	Dry feed, air-blown
Gas cleanup system		-	Wet desulfurization	Wet desulfurization
Gas turbine		-	M701DA	M701G / M501G
Gross Power Plant efficiency		%, LHV	48	53
Environmental Targets (16% O_2 basis)	SOx	ppm	8	8
	NOx	ppm	5	5
	Particulate matter	mg/m^{3}N	4	4
Start of operation		-	2007	2014, at the earliest

The commercial plant uses the same dry feed system, in which inert gas such as nitrogen is used as the carrying medium, as in the IGCC demonstration plant. The adoption of this system brings various advantages, which include the use of wide variety of coal and the increase in plant efficiency. The usable coal types include low-grade coal, such as high-moisture sub-bituminous. It is difficult to be used in a slurry feed system through which the slurry, a mixture of coal and water, is supplied to the gasifier.

A highly reliable combustor for coal gasification is used for the gas turbine. It is based on a proven, natural gas-fired, high-efficiency G-series gas turbine with a combustion temperature of 1,500°C class, and builds on our experience with low-calorie gas-fired gas turbines, such as those using blast furnace gas. The IGCC commercial plant with the latest gas turbines can dramatically improve the net plant efficiency, allowing a significant reduction in the CO_2 emission compared to conventional pulverized coal-fired plants.

3.2 Coal gasifier design

The design of the standard air-blown coal gasification equipment for IGCC has already been completed and is ready for application to commercial plants. **Figure 2** shows a full view of the standard coal gasification facility, which is compatible with the model M501G (one of the G-series) gas turbine. Equipment plans corresponding to customers' needs can thus be prepared very quickly.

In addition, further improvement of the reliability and operation flexibility is underway based on all the lessons learned from the IGCC demonstration plant. Especially, the experience gained during the site construction and commissioning were utilized in the "Design for X" approach, in which the input from everyone involved in the project and proposals for the improvement based on the design reviews were incorporated to increase the product reliability of the commercial plants.

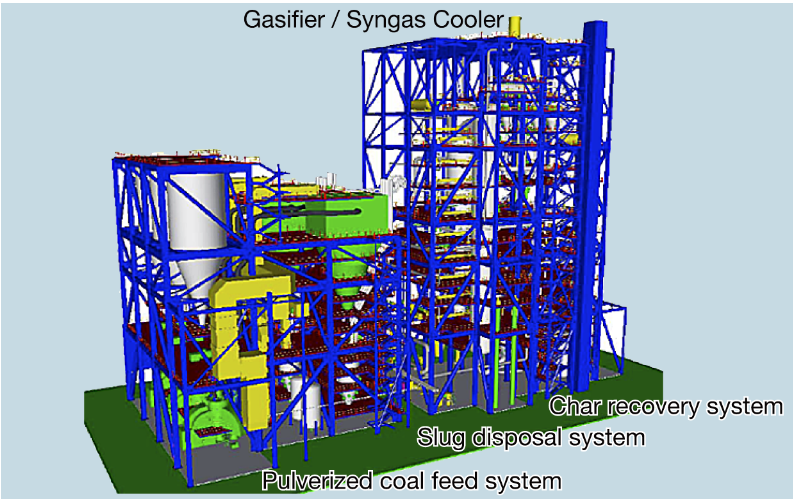

Figure 2 Standard coal gasification facility compatible with the M501G gas turbine

4. CO_2 capture by IGCC

4.1 Present status of CO_2 capture projects in Japan and abroad

Since the CO_2 emissions from coal-fired power plants presently count one third of the world's total, a significant improvement in the efficiency of coal-fired power plants and their CO_2 Capture and Sequestration (CCS) capability is essentially the most effective measure against global warming over the short and medium terms.

In May 2007 at the Heiligendamm Summit, the former Japanese Prime Minister Abe gave his long-term vision for cutting the world's carbon emissions down to half by 2050 in his presentation "Cool Earth 50." The CCS combined with IGCC, to realize a zero-emission coal-fired power generation system, is positioned as one of the "Innovative Technology Developments". In addition, Japan CCS Co., Ltd., was founded in May 2008 with investment from 29 companies, including electric utility companies and oil companies, in order to promote a full-scale investigation of CCS and a large-scale demonstration test program for a system combining IGCC and CCS.

In the United States, the Future Gen project, mainly supported by the U.S. Department of Energy (DOE), started in February 2003 to develop a zero-emission IGCC plant that could capture

90% or more of the CO_2. However, a change in the project policy was announced in January 2008 to fund only the CCS equipment for the IGCC with CO_2 capture , which will start operation by 2015. Under the Obama administration, the policy focuses on the development of clean coal technology that includes CCS, and plans for multiple projects dedicated to the construction of IGCC commercial plants with CO_2 capture are underway.

In Europe, a program to promote the construction of up to 12 CCS demonstration plants by 2015 was established in the "Energy Policy for Europe", announced by the European Commission in January 2007, and with funding of approximately 3 billion Euros for CCS-related projects.

In addition, the commercialization of an Enhanced Oil Recovery (EOR) method that injects CO_2 into oil wells to increase oil production is underway worldwide, and is expected to be an effective way to utilize CO_2 captured from coal-fired plants.

4.2 IGCC system with CO_2 capture

Standing on the situation of much more interest in CO_2 reduction, including CCS in Japan and foreign countries, MHI has been making efforts to realize commercial IGCC plants which can contribute worldwide reduction in CO_2 emission.

There are two methods in capturing CO_2 from coal-fired power plants: (1) to capture CO_2 from syngas before combustion (pre-combustion capture) or (2) to capture CO_2 from boiler tail-end flue gas (post-combustion capture). The IGCC uses the pre-combustion capture because of the highest capability in capturing CO_2 at the condition of a small amount of process gas under higher pressure; this results in higher plant efficiency than using the post-combustion capture method and leads to higher economical merit.

Figure 3 shows a block flow diagram of the air-blown IGCC system combined with CO_2 capture. Carbon monoxide (CO) in syngas produced in the gasifier is converted to CO_2 and hydrogen (H2) in the CO shift reactor by a chemical reaction with water or steam (H_2O). The CO_2 is then separated from the syngas and captured in the acid gas removal (AGR) system used for desulfurization and CO_2 capture. The H2-rich syngas remaining after the removal of CO_2 is used as fuel for the gas turbine. MHI's gas turbines, with abundant supply records, have achieved considerable success over a wide range of operating conditions using H2-rich gas. The captured CO_2 is pressurized by the compressor and transported for sequestration. In the IGCC system with CO_2 capture, the optimization of the CO shift converter and the entire CO_2 capture system are necessary according to the required capture rate of CO_2 and the purity of the captured CO_2.

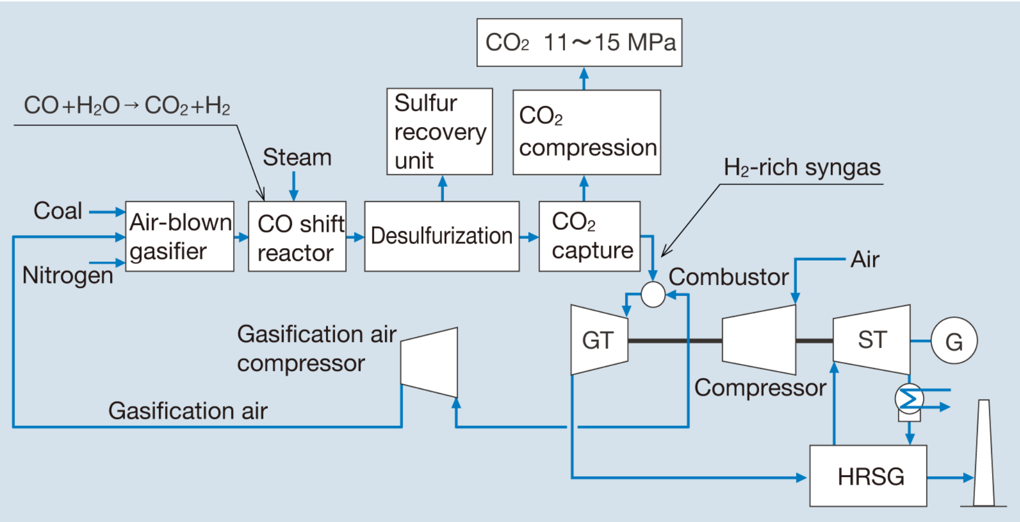

Figure 3 Block flow diagram of air-blown IGCC system with CO_2 capture

Figure 4 shows a relation between the CO_2 capture rate and net plant efficiency. The air-blown IGCC performs better than the oxygen-blown at all capture rates. This is because the net plant efficiency of the oxygen-blown IGCC is significantly reduced by the power required for oxygen production in the air separation unit (ASU). In addition, the net plant efficiency decreases as the CO_2 capture rate increases for both air-blown and oxygen-blown IGCCs. This is due to the increase in energy consumed by the auxiliary equipments in the AGR system and the CO_2 compressor. However, the superiority of the air-blown IGCC compared to the oxygen-blown is kept in all conditions, and there is an absolute efficiency difference of 4%–5%

Figure 5 compares a capital cost of the air-blown IGCC plant with CO_2 capture and that of the oxygen-blown. Finally, in terms of capital cost ($/kW), the air-blown IGCC is better than the oxygen-blown which has significant drawbacks in the ASU cost and its auxiliary power consumption.

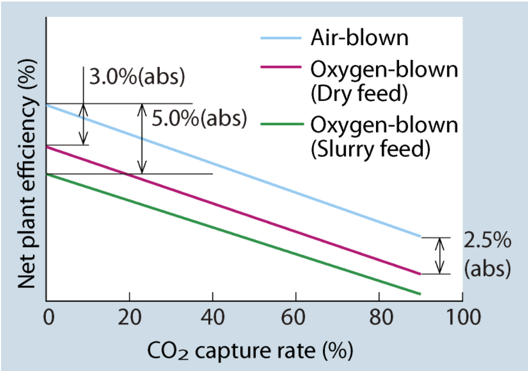

Figure 4 Comparison of net plant efficiency with CO_2 capture for air-blown and oxygen-blown IGCCs

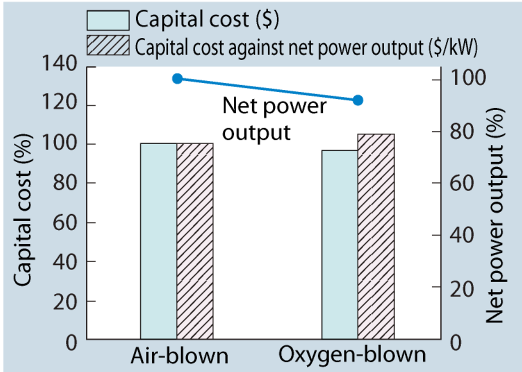

Figure 5 Comparison of capital cost and net power output with CO_2 capture for air-blown and oxygen-blown IGCCs

5. Conclusion

IGCC is a power generation method that will play the most important role in coal-fired power generation in the 21st century because of the growing importance of coal resources and their utilization. The high efficiency and reliability of MHI's air-blown IGCC have been ensured through the various activities like the successful long-term continuous operation in the IGCC demonstration plant. More sophisticated high-efficiency high-reliability air-blown IGCC commercial plants have been already in the course of development and are ready for realization.

MHI will make every effort to realize the commercial plants which contributes to combating global warming. Although it significantly reduces CO_2 emissions, the incorporation of the CCS into IGCC poses challenges, including the reduction in the plant efficiency and the increase in the capital cost. Nevertheless, we believe that the IGCC with or without CO_2 capture based on MHI's technology will play a key role in the field of saving climate change.

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