Current Status of Integrated Coal Gasification Combined Cycle Projects

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Regarding the situation of integrated coal gasification combined cycle (IGCC) in Japan, a 250 MW power generation plant applying air-blown gasification technology started domestic commercial operation for the first time in April 2013, and construction of two large IGCC 543 MW units is advancing as a Fukushima IGCC project. On the other hand, a demonstration test operation of 166 MW in First Step of the Osaki CoolGen Project using oxygen-blown gasification technology was completed in October 2018, and a CO_2 *separation and capture facility to be installed in Second Step is under construction. This paper introduces the most recent situation of the IGCC project of Mitsubishi Hitachi Power Systems, Ltd. (MHPS).*

1. Introduction

IGCC is a thermal power generation system that combines a combined cycle system and a coal gasification process to achieve higher efficiency and lower carbonization than conventional pulverized coal-fired thermal power generation. Efficiency can be improved through combined power generation combining power generation with a gas turbine using coal gasification gas and power generation with a steam turbine using exhaust heat from a gas turbine. As a result, fuel consumption is reduced and CO_2 emissions can be reduced (lower-carbonization emissions). It is also advantageous in that low-grade coal such as low-ash melting point coal, which was difficult to use in conventional pulverized coal-fired thermal power generation, can be used, and that ash can be effectively used (raw materials for cement, etc.) and warm drainage can be reduced in terms of environmental load reduction.

Since the 1980s, MHPS has been working on the development and practical application of IGCC using two coal gasification technologies, air blowing and oxygen blowing, to improve efficiency, operability (i.e., fast load change rate and minimum load), reliability (i.e., operation rate and continuous operation time), safety and environmental performance. The development of IGCC is expected to contribute to the effective use of coal resources, which have large reserves and are cheaper than other fuels, and to the reduction of environmental impact through the reduction of CO_2 emissions achieved through higher efficiency.

2. Current status of the Osaki CoolGen project

The Osaki CoolGen Project has been implemented by Osaki CoolGen Corporation (established in 2009 by The Chugoku Electric Power Co., Inc. and Electric Power Development Co., Ltd.) since fiscal 2012 as a subsidized project by the Ministry of Economy, Trade and Industry, and since fiscal 2016 as a subsidized project by the New Energy and Industrial Technology Development Organization (NEDO). This project consists of three steps as shown in **Figure 1**, and the First Step is the Oxygen-blown IGCC demonstration test, the Second Step is the Oxygen-blown IGCC with CO_2 Capture demonstration test in which CO_2 capture facility is added

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to this IGCC, and the Third Step is the Integrated coal Gasification Fuel Cell combined cycle (IGFC) with CO_2 Capture demonstration test in which a fuel cell is further combined. The First Step demonstration test began in March 2017 and the Second Step demonstration test will begin in December 2019.

In the large demonstration experiment of oxygen blown coal gasification technology in the First Step, MHPS carried out the design, manufacture, installation and trial run of a single-chamber, two-stage spiral flow entrained-bed gasifier with 1,180 tons/day coal throughput, a 166 MW combined cycle power generation facility, electric and control facilities. It is also in charge of engineering for general management of the demonstration plant.

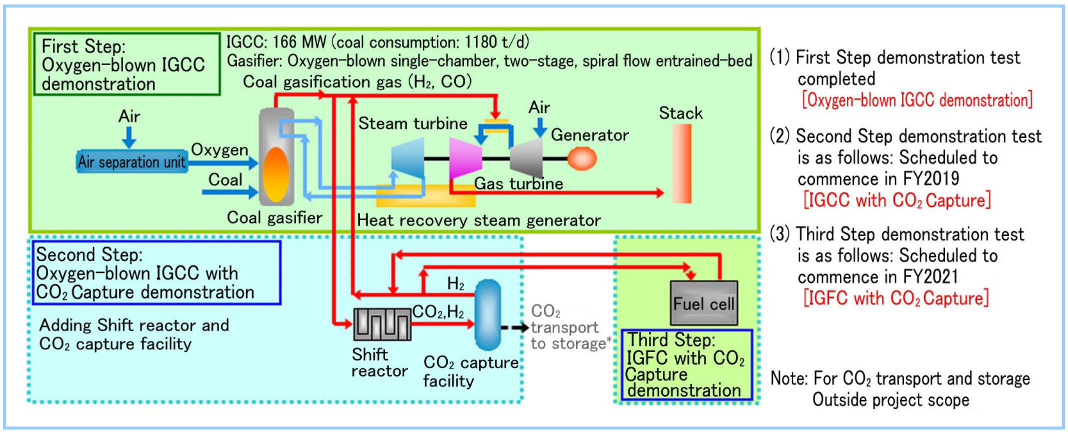

Figure 1 Facility configuration of Osaki CoolGen project

Table 1 gives the main specifications of First Step of this project and **Figure 2** is a panoramic view of the site. The demonstration test of 166MW class oxygen blown IGCC was the first in Japan, and the following were verified in First Step: Basic performance related to plant performance and environmental performance, facility reliability, plant controllability and operability, multi-coal applicability and economic efficiency. The achievement of all the items of the development goals was confirmed. In terms of basic performance, a net thermal efficiency of 40.8% (higher calorific value base) was achieved, and in terms of environmental performance, the exhaust gas property was less than 8 ppm of SOx, less than 5 ppm of NOx and less than 3 mg/m^3N of soot at a conversion of oxygen (O_2) concentration of 16%. In the reliability confirmation through the long-term durability test, a maximum of 2,168 continuous operation hours and 5,119 cumulative operation hours was recorded, and the demonstration test operation was completed in October 2018.

The oxygen blown IGCC consists of a coal gasifier, gas clean-up unit and gas turbine (1300°C class H-100 series), steam turbine, generator and HRSG (Heat Recovery Steam Generator).

Table 1 Main specifications of First Step of Osaki CoolGen Project

Main Specifications	
Rated output	166 MW (gross)
Gasifier	Oxygen-blown single-chamber, two-stage spiral flow entrained bed
Gas purification	Wet chemical absorption method (MDEA)
Gas turbine	H-100 (1 on 1)
Generating efficiency	Net efficiency 40.8% (Higher calorific value base and actual value)
Schedule	
Commencement of construction	March 2013
Commencement of demonstration tests	March 2017 (First Step)

Figure 2　A panoramic view of Osaki CoolGen Site

MHPS has been developing a gasification system of oxygen blown IGCC for practical application since the 1980s as seen in **Figure 3**. Starting with the gasification element test using the PDU (Process Development Unit) with a coal throughput of 1 ton/day, we participated in the HYCOL project (project on commission from NEDO/HYCOL Association) with 50 tons/day and the EAGLE project (joint research project with NEDO/Electric Power Development Co., Ltd.) with 150 tons/day, and steadily carried out the scale-up verification of the gasifier.

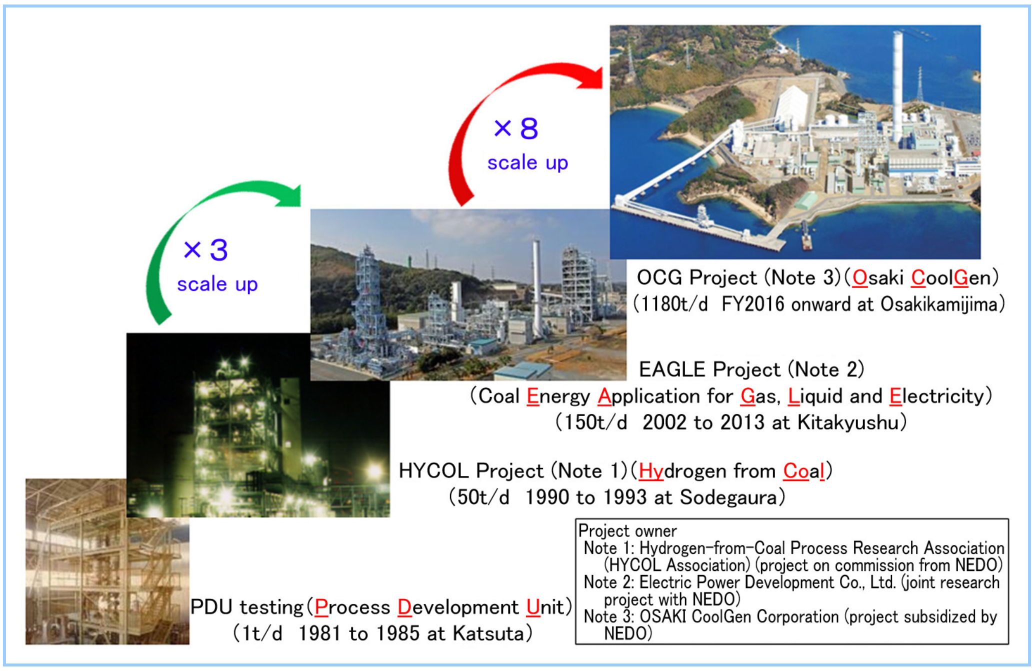

Figure 3　Development of oxygen blown gasification system

The oxygen blown gasifier is a system using high-concentration oxygen as a gasifying agent for coal, and as shown in **Figure 4**, MHPS's original single-chamber, two-stage spiral flow entrained-bed with multiple burners installed in the upper and lower stages of a vertical cylindrical gasifier is adopted. The characteristics of this gasifier are: (1) the temperature necessary for melting the ash in the lower part and the ratio of oxygen and coal in the upper and lower parts are appropriately allocated so that the gasification reaction condition becomes highly efficient in the upper part according to the coal type, (2) the retention time of coal particles is ensured by generating a spiral flow in the gasifier to promote the gasification reaction, and the upward scattering of char and molten slag is suppressed, and (3) the slag discharge hole in the bottom of the gasifier is kept warm and heated by high-temperature gas flow (auto-circulation flow) in the gasifier to achieve the stable flow of slag. Therefore, technical issues in the leading systems in Europe and United States were improved. Its actual cold gas efficiency (= calorific value of gasification gas/calorific value of coal) of 82.7% is at the highest level in the world. In addition, as for the quench gas for cooling to be supplied to the outlet of the gasification part, although other overseas companies require almost the same quantity as the gasification gas, MHPS has achieved the reduction of power consumption by drastically reducing this amount to about 1/10.

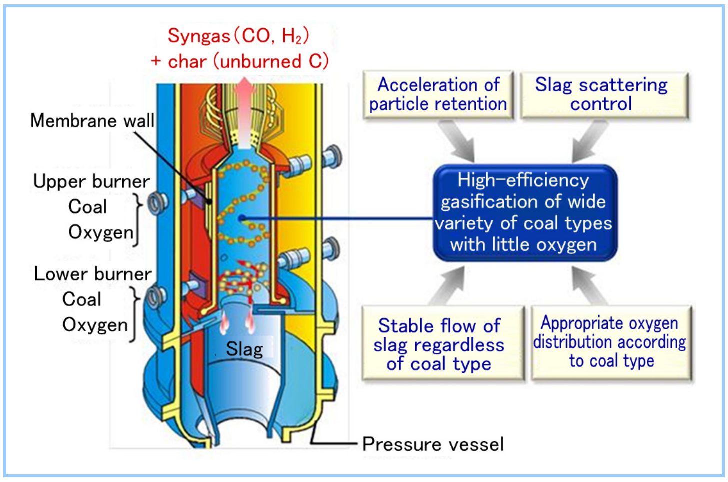

Figure 4 MHPS oxygen blown gasifier

In gas-clean up unit, impurities (ammonia, hydrogen sulfide, hydrochloric acid, etc.) contained in coal gasification gas are removed in a gas turbine to conform to the environmental standards of exhaust gas after combustion, and power is generated in a gas turbine using purified coal gasification gas as fuel. The retained heat of the combustion exhaust gas is recovered by HRSG to generate steam, and power is also generated in a steam turbine.

The advantage of IGCC is that a wide variety of coal types can be used. Since ash is melted in a gasifier and discharged as slag, it is especially suitable for coal with a low ash melting point, and low-grade coal (including sub-bituminous coal and brown coal), the use of which has been restricted in conventional coal fired power generation, can also be applied. Through the improvement of the efficiency of the system, the CO_2 emissions per generated electric power are reduced in comparison with conventional coal fired power generation. It is also possible to reduce the water consumption and drastically reduce the warm drainage, and this technology has high environmental applicability.

The advantage of oxygen blown IGCC is that its load change rate is high and its response is fast. This technology can fulfill the load adjustment function required for thermal power generation plants in the current electric power grid system stability situation where renewable energy has become common, though countermeasures are required for power grid system to ensure its stability, as the electric power supply quantity fluctuates with changes in the weather. By establishing this technology, a social contribution in environmental load reduction can be expected by replacing decrepit conventional coal fired power generation plants with oxygen blown IGCC.

In addition, oxygen blown gasification technology is expected to have wide applications and spread, because the higher efficiency of the power generation system can be expected by combining it with fuel cell technology. This is also because of its affinity with the CO_2 separation and capture technology in carbon dioxide capture, utilization and storage (CCUS), which constitutes part of the global warming countermeasures for the realization of the Paris Agreement is high and due to the fact that application to the chemical industry is also possible. Brown coal is one of the unused resources that can be mined in large quantities. Making use of brown coal to produce hydrogen in coal producing countries and supply it to the market can be a fundamental technology for realizing a hydrogen society, and as such it can be said to be a technology with high ripple effects in the future.

3. Current status of the Fukushima IGCC project (Nakoso, Hirono)

The joint enterprise (comprised of four companies: MHPS, Mitsubishi Heavy Industries Engineering Ltd., Mitsubishi Electric Corporation and Mitsubishi Hitachi Power Systems Environmental Solutions Ltd.) with MHPS as the managing company received orders for two 543MW IGCC plants from Nakoso IGCC Power GK and Hirono IGCC Power GK through an EPC construction contract (including civil engineering work) in December 2016. In this project, one IGCC plant adopting air blown technology will be constructed at Nakoso IGCC Power GK on land adjacent to the Nakoso Power Station (Iwaki City, Fukushima Prefecture) of Joban Joint Power

Co., Ltd., and at Hirono IGCC Power GK on the premises of JERA Co., Inc.'s Hirono Power Station (Futaba-gun, Fukushima Prefecture). This project resulted in the "world's most advanced coal-fired power plant" in Fukushima, and aims at leading the world in clean coal technology while contributing to the economic revitalization of Fukushima Prefecture and the creation of an industrial base. **Table 2** lists the main specifications of the Fukushima IGCC project.

Table 2 Main specifications of Fukushima IGCC project

Main Specifications	
Rated output	543 MW (gross)
Gasifier	Air-blown two-chamber, two-stage spiral flow entrained bed
Gas purification	Wet chemical absorption method (MDEA)
Gas turbine	M 701 F (1 on 1)
Schedule	
Start of operation	2020 Nakoso IGCC 2021 Hirono IGCC

In this project, the experience of Nakoso No. 10 of Joban Joint Power Co., Ltd. is incorporated in various parts to improve reliability, and drastic output and efficiency improvements are attempted through the adoption of a high-efficiency gas turbine. The former IGCC demonstration plant for the "Entrained bed coal gasification power plant demonstration project (under the direct control of the Ministry of Economy, Trade and Industry) (fiscal 1999 to fiscal 2009)" was converted into a commercial plant of Nakoso No.10 in fiscal 2013.

The gasifier adopts Japan's original air blown coal gasification technology, CORe GASIFICATION TECHNOLOGY™, and the gas clean up unit mainly treating H_2S gas in the gas from the gasifier adopts the wet chemical absorption method by MDEA (Methyl diethanol amine) as a solvent same as Nakoso No. 10.

The gas turbine adopts a combustor for coal gas which applies low calorie gas firing technology such as blast furnace gas (BFG) to the high-efficiency M 701 F series gas turbine with abundant achievements. In the 500 MW class IGCC combined with the latest high-efficiency gas turbine, the CO_2 emission intensity can be drastically reduced compared with conventional coal-fired steam power generation.

With regard to the manufacturing of coal gasifier, a "coal gasifier shop" was constructed at the Nagasaki Works of MHPS, and an integrated IGCC production system was established to prepare for mass production (**Figure 5**). To cope with high temperature and high pressure operation condition, in addition to elemental technologies such as welding cultivated through the production of conventional boilers for coal fired plants, we developed automatic welding equipment and introduced a production system utilizing IT. The coal gasifier is modularized to the maximum weight which can be transported to simplify the construction work at the construction site.

The gasifier pressure vessels manufactured for Nakoso IGCC were shipped sequentially from June 2018 (**Figure 6**), transported by sea to Onahama Port and transported inland to the site(1). The gas turbine, steam turbine and generator were transported in December 2018 (**Figure 7**), and large equipment transportation was completed in April 2019. Construction work, mechanical work and electric work are progressing smoothly at present. The commissioning will commence in fiscal 2019, and the related parties are working together for the start of commercial operations in September 2020. Hirono IGCC is also under construction and will start operations in September 2021. The construction situation of Nakoso IGCC as of the end of March 2019 is presented in **Figure 8**, and an overview of the construction area is depicted in **Figure 9** (1).

Figure 5 Coal gasifier shop

Figure 6 Gasifier pressure vessel

Figure 7 Transportation of large equipment

Figure 8 Construction of Nakoso IGCC

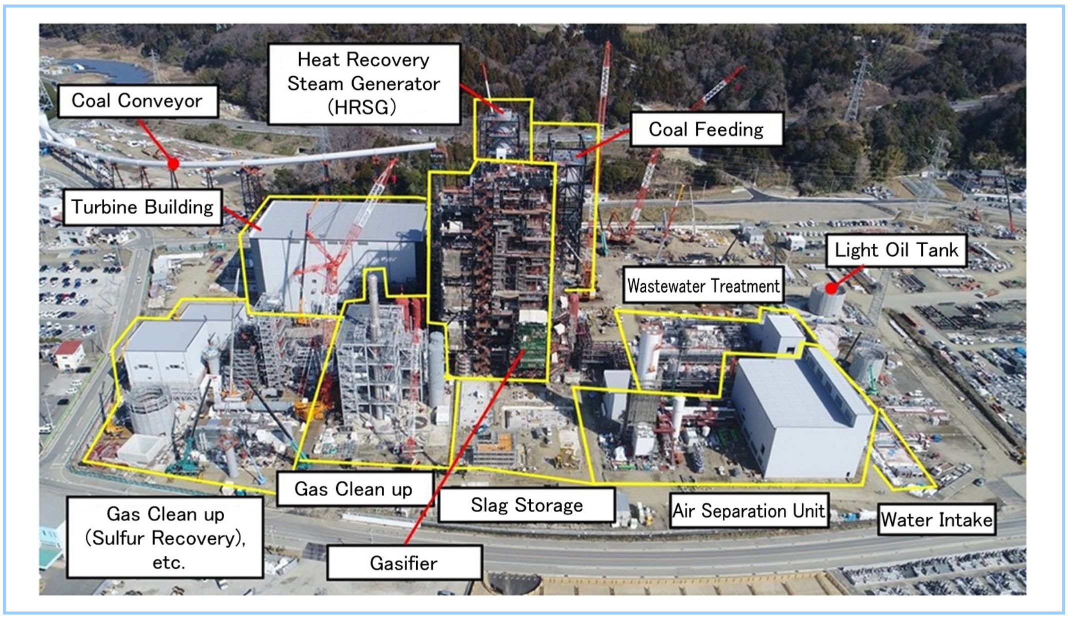

Figure 9 Overview of Nakoso IGCC Construction Area

4. Future developments

MHPS will promote IGCC in Japan and overseas, and will continue to enhance the sophistication of its air-blown and oxygen-blown IGCC technologies to contribute to the reduction of global environmental impact and CO_2 emissions, as well as to the enhancement of economic development.

References

(1) Nakoso IGCC Power GK, http://www.nakoso-igcc.co.jp/en/