Large-scale Carbon Dioxide Capture Demonstration Project at a Coal-fired Power Plant in the USA

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Economically less-burdensome and drastic carbon dioxide (CO_2) reduction methods are required to mitigate global warming and facilitate sustainable social activities. CO_2 capture and storage (CCS) technologies provide an answer to reduce CO_2 emissions from coal-fired thermal power plants, which have the highest level of CO_2 emissions in the power-generation sector. Large-scale CCS projects are being planned for implementation in developed countries. Mitsubishi Heavy Industries, Ltd. (MHI) and Southern Company, a major U.S. electric power company, have jointly constructed the world's largest CO_2 recovery demonstration plant at an existing coal-fired thermal plant located in Alabama. The CCS demonstration plant has the capacity to capture 500 metric tons of CO_2 per day, and has recently begun operation. In this paper, we present the current operational status of the CO_2 recovery demonstration plant in U.S., and the test program scheduled for the plant.

1. Introduction

Because of its promise as an environmental countermeasure for reducing greenhouse gas emissions, CO_2 capture and storage (CCS) has attracted global attention in recent years. According to the World Energy Outlook 2009 issued by the International Energy Agency (IEA), world energy demand in 2030 is predicted to be 1.4 times that in 2007. Furthermore, the use of fossil fuels is expected to increase and will continue to be the primary energy source of the future. The continued use of fossil fuels, however, leads to further production of greenhouse gases.

In anticipation of the expected increase in CO_2 emissions, the IEA announced two CO_2 reduction scenarios to be implemented in the power sector by 2050. In the first scenario, which is called the Act Scenario, the IEA suggested that by making practical use of existing and/or under-development technologies, CO_2 emissions by 2050 could be curbed to 2005 emission levels. In the other scenario, called the Blue Scenario, the IEA suggested that cutting CO_2 emissions to the 2005 level might be insufficient to curb global warming, and instead recommended that the 2050 target should be reduced to half of the current CO_2 emission level.

Figure 1 shows the breakdown of CO_2 emission reductions in these two scenarios. As illustrated by the figure, CCS technologies are critical to the success of CO_2 reduction in the power-generation sector; CCS accounts for 21% of the CO_2 reduction in the Act Scenario and as much as 26% in the Blue Scenario.

CCS includes separation and recovery of CO_2 from large-scale CO_2 emissions sources, such as power plants; transportation of the CO_2 through pipelines or similar; and storage of the CO_2 in subterranean aquifers. **Figure 2** shows a conceptual illustration of CCS. Candidate sites for CO_2 storage include depleted oil fields, depleted gas fields, and underground or seabed aquifers.

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For the purpose of CO_2 emission reductions from coal-fired thermal power plants, large-scale CCS demonstration projects backed by government initiatives, especially in Europe and North America, are now being planned. In addition, European governments have announced plans to impose a CO_2 Capture Ready duty on new power plants to ensure space for retrofitting CO_2 recovery facilities and to present prospective beds for CO_2 storage. Prior to these moves, Mitsubishi Heavy Industries, Ltd. (MHI), Southern Company, and the Electric Power Research Institute (EPRI) jointly constructed a large-scale CO_2 recovery demonstration plant with a capacity of 500 metric tons of CO_2 per day at a coal-fired flue gas plant in Alabama. The demonstration plant has begun verification operations.

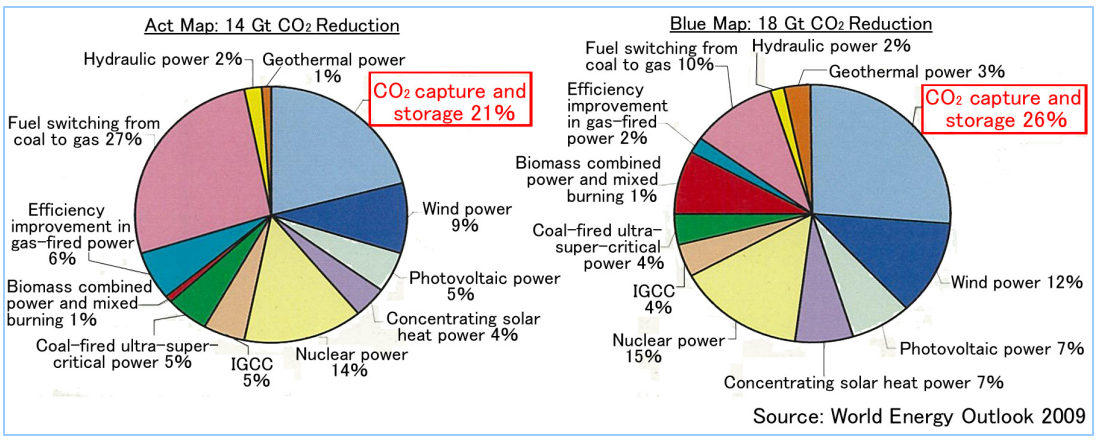
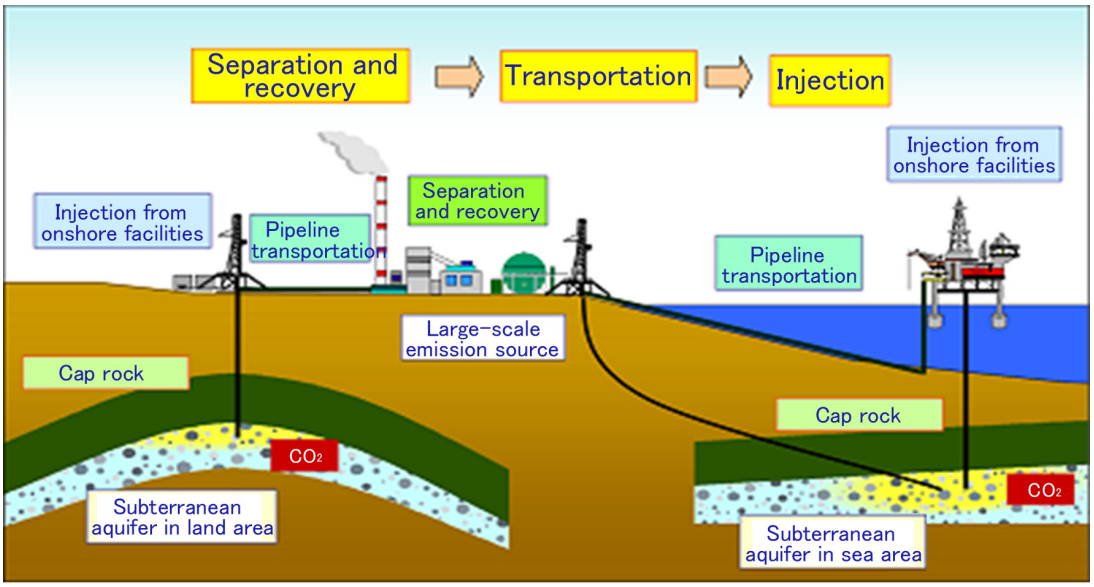


Figure 1 IEA CO_2 reduction scenarios in the power-generation sector by 2050



Source: Ministry of Economy, Trade, and Industry, CCS 2020

Figure 2 Conceptual illustration of CO_2 underground storage

2. Overview of the Demonstration Project in U.S.

An overview of the demonstration project undertaken by MHI and Southern Company is shown in **Table 1**, and an exterior view of the plant is shown in **Figure 3**. The demonstration plant was constructed at Alabama Power's Plant Barry (**Figure 4**). Alabama Power is an electric power company under the umbrella of Southern Company that supplies electricity to 1.40 million households, offices, and workplaces across approximately two thirds of Alabama. Alabama Power plans to conduct the various tests for CO_2 recovery at the plant.

A portion of the flue gas from the stack-gas desulfurization unit downstream of the existing coal-fired thermal Barry Power Plant is introduced into the demonstration plant, and its CO_2 gas is recovered. The recovered CO_2 is then dehydrated, compressed, transferred via pipeline to the injection location 18km away, where it is injected into a saline aquifer and safely stored.

The demonstration test operation began in 2011, and is scheduled to be conducted for four years. Mitsubishi Heavy Industries America (MHIA) and Southern Company Service (SCS)

oversee the CO_2 recovery, compression, and dehydration processes, and the Southern Regional Carbon Sequestration Partnership (SECARB) manages the storage process. SECARB receives a subsidy from the United States Department of Energy, and is conducting geological surveys of CO_2 storage and CO_2 injection experiments in the southeastern region of the U.S.

The demonstration plant utilizes the KM CDR Process® (described in Section 3), which was jointly developed by MHI and The Kansai Electric Power Co. Inc., and which has the following requirements: CO_2 recovery capacity of 500 metric tons per day, CO_2 recovery ratio of 90 percent, and capacity to process flue gas from the power plant equivalent to about 25 MW. Energy saving points for process modification and the effect of impurities contained in the coal-fired exhaust gas on the CO_2 recovery plant and its absorption solvent will be studied during the demonstration operation. With the aim of ensuring development of large-scale CCS demonstration and commercial plants, the behavior of impurities will be understood and countermeasures for the impurities-related difficulties will be validated.

Table 1 Overview of the CO_2 recovery demonstration plant in U.S.

Item	
Location	Bucks, Alabama
Customer	Southern Company (Alabama Power)
Process	KM CDR™ process
Absorbing solution	KS-1™ Solvent
Output	Equivalent to 25 MW
Flue gas quantity	73,800 SCFM (116,800 Nm^3/h)
CO_2 recovery ratio	90%
CO_2 recovery capacity	500 metric ton/day (150,000 metric ton/year)
CO_2 concentration in flue gas	10.1 mol.%-wet

Figure 3 Exterior view of the 500 metric tons per day CO_2 recovery demonstration plant in U.S.

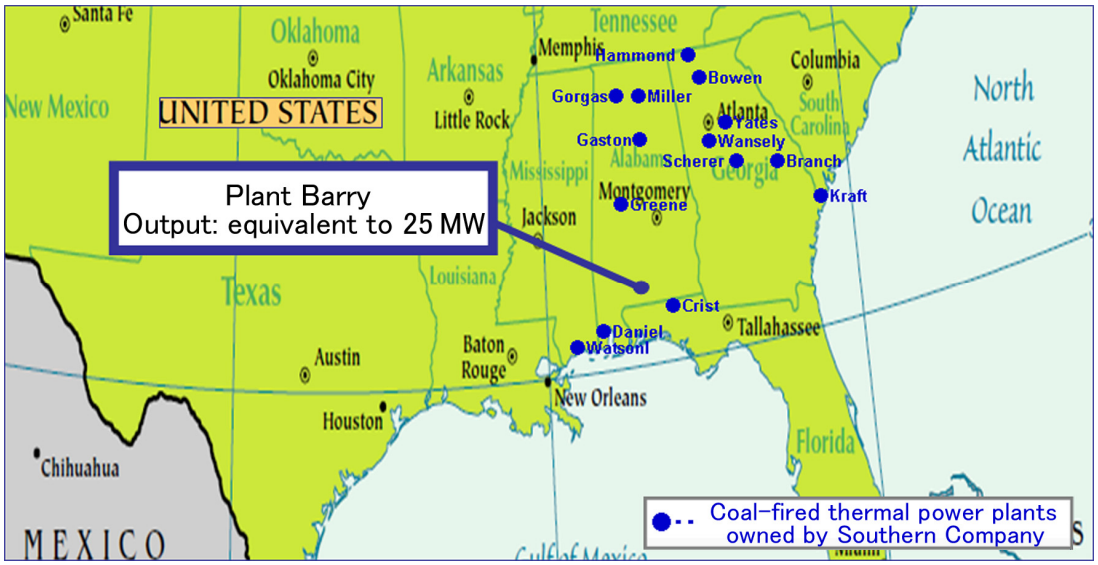


Figure 4 Location of the Plant Barry
Locations of coal-fired thermal power plants owned by Alabama Power under the umbrella of Southern Company are shown in the figure. At the Plant Barry, continuous demonstration tests for CO_2 recovery and underground storage are conducted.

3. MHI's CO_2 Recovery Process

As noted above, the demonstration plant has adopted the KM CDR Process®.[Note] MHI and Kansai Electric Power Co. Inc. have worked on the development of a process for CO_2 recovery from combusted flue gas since 1990, and the first commercial plant was delivered in 1999.

Note : The KM CDR Process® is an MHI trademark registered in Japan, the U.S., the European Community (CTM), Norway, Australia, and China.

(1) Process Flow of the Demonstration Plant

Figure 5 contains a schematic flow diagram of the MHI CO_2 recovery plant. The flue gas containing CO_2 is introduced into the flue gas quencher, cooled therein, and then pressurized by

the blower, which is installed downstream of the quencher and delivered into the CO_2 absorber. The flue gas delivered into the bottom section of the absorber makes contact with the alkaline absorption solvent KS-1™, which was jointly developed by MHI and Kansai Electric Power Co. Inc., and CO_2 is absorbed into the absorption solvent. After CO_2 is absorbed, the flue gas exhausts into the atmosphere as a clean flue gas. On the other hand, the absorption solvent, now rich in CO_2, is discharged into the regenerator, in which CO_2 is stripped by steam, resulting in regeneration of the absorption solvent. In the regeneration process, the latest energy-saving process developed by MHI is used, which enables the greatest possible reduction in the amount of steam required. The regenerated absorption solvent is circulated back to the absorber and reused.

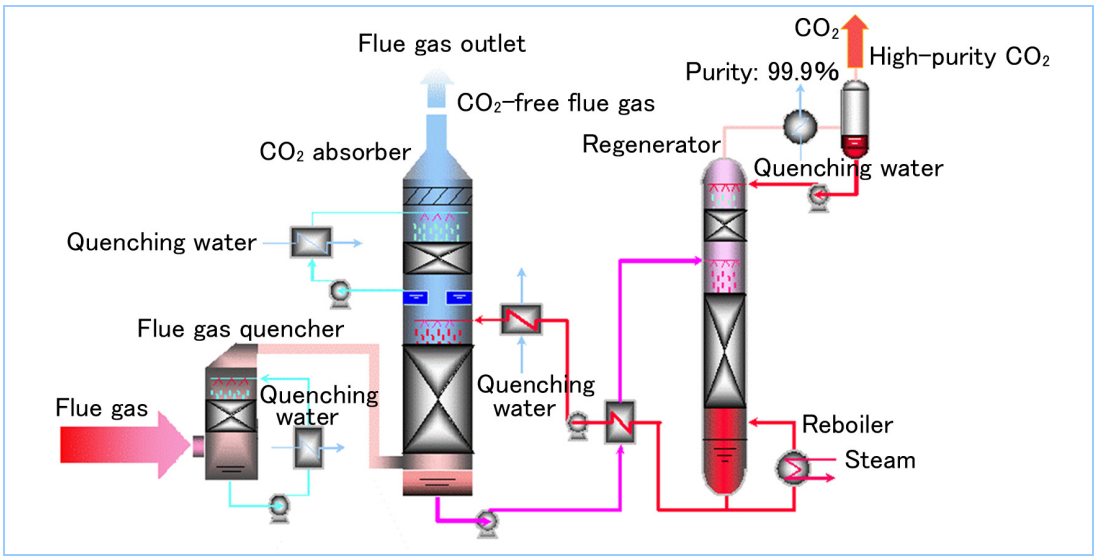


Figure 5 Process flow diagram of MHI's CO_2 recovery process (KM CDR Process®)

(2) Commercialization Track Record

MHI has implemented the CO_2 recovery process for flue gas from natural gas-fired boilers and gas turbines, and has thus far supplied 10 commercial plants (with another on order). The first plant was delivered to Malaysia in 1999 and had a capacity of 200 metric tons per day of CO_2. The recovered CO_2 has been used to increase the production of urea, and the plant has been in operation for more than ten years. Additional commercial plants have been supplied for chemical production use and/or general use all over the world. For example, a CO_2 recovery plant (400 metric tons of CO_2 per day) was delivered to Abu Dhabi in 2009. At the Abu Dhabi plant, the first energy-saving regeneration system was introduced (described below), which allowed the plant to reduce energy consumption per unit of CO_2 recovered compared to other conventional regeneration systems.

(3) Pilot Plant for Coal-fired Flue Gas

Flue gas from coal-fired power plants typically contains large quantities of impurities, such as sulfur oxides, nitrogen oxides, and solid particulates. Therefore, it is necessary to precisely understand the effects of these impurities on CO_2 recovery technologies. Prior to implementation of the MHI/Southern Company large-scale CCS demonstration project, MHI conducted demonstration tests using various small pilot plants. **Table 2** contains a list of the demonstration test plants.

Table 2 Demonstration plants for CO_2 recovery from coal-fired flue gas

Location	CO_2 recovery capacity	Customer	Flue gas source	Start of operation
Japan MHI R&D center	1 metric ton/day	–	Coal-fired boiler	April 1999
Japan Matsushima Power Plant	10 metric ton/day	Electric Power Development Co. (J-Power)	Coal-fired boiler	July 2006
U.S.A. Southern Company Plant Barry	500 metric ton/day	Southern Company	Coal-fired boiler	June 2011

As a first step, MHI fabricated a demonstration pilot plant in its research center with a capacity of one metric ton of CO_2 per day, and began demonstration tests on CO_2 recovery from coal-fired flue gas.

Subsequently, with the support of the Research Institute of Innovative Technology for the Earth (RITE) and the cooperation of the Electric Power Development Co., Ltd., MHI constructed a pilot plant with a capacity of ten metric tons of CO_2 per day in an existing coal-fired thermal power plant in Matsushima, Nagasaki Prefecture, and conducted demonstration tests from 2006 to 2008. In long-run demonstration tests in Matsushima, MHI achieved continuous operations of more than 5,000 hours, acquired operational expertise, investigated the effects of impurities in flue gas upon the pilot plant, validated the countermeasures, and collected data for medium-scale CO_2 recovery from coal-fired flue gas.

4. Operational Results of the Demonstration Plant

The operational status of the CO_2 recovery demonstration plant in U.S. is described below.

(1) Course of the Operation from Startup

The CO_2 recovery demonstration plant in U.S. began receiving feed gas in June 2011. It has achieved stable operation for 1,612 hours in total by August 2011. Total CO_2 recovery for this period is approximately 28,680 tons.

(2) Trend of CO_2 Recovery Ratio and Capacity

Figures 6 and **7** show the 72-hour operational trends for the CO_2 recovery capacity and CO_2 recovery ratio, respectively. The demonstration plant stably achieves the rated operational conditions: CO_2 recovery capacity of 500 metric tons per day and CO_2 recovery ratio of 90%.

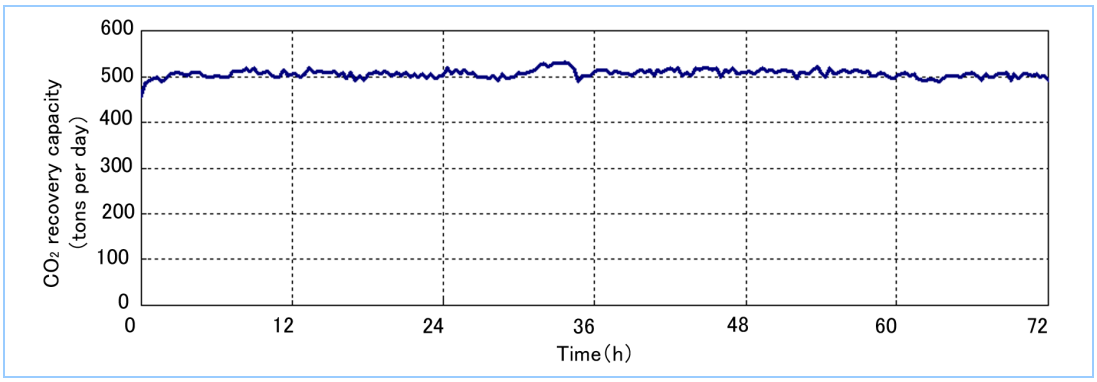


Figure 6 CO_2 recovery capacity

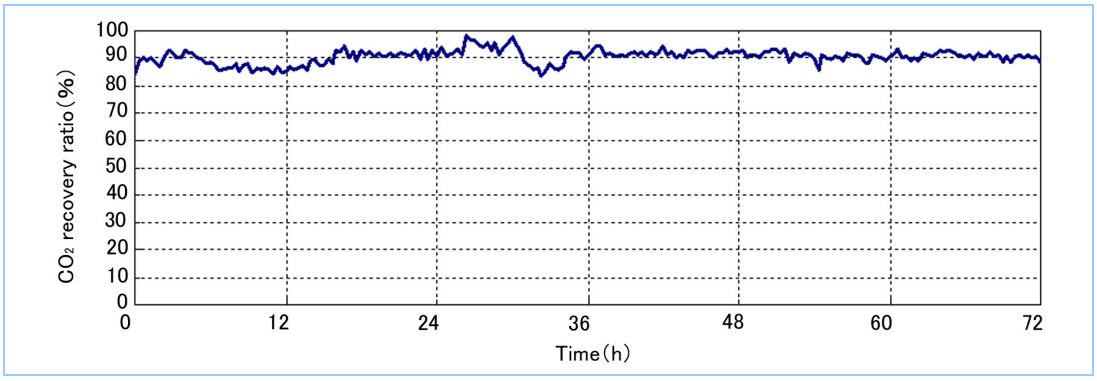


Figure 7 CO_2 recovery ratio

(3) Energy-saving Performance

The demonstration plant adopted MHI's energy-saving process, which was proved to exhibit much higher energy saving performance than conventional processes. For reference, the energy-saving process is the same as at the Abu Dhabi commercial plant, for which the process was adopted for the first time. But because of further improvements implemented at the CCS demonstration plant in U.S., the demonstration plant achieves even lower steam consumption (**Figure 8**).

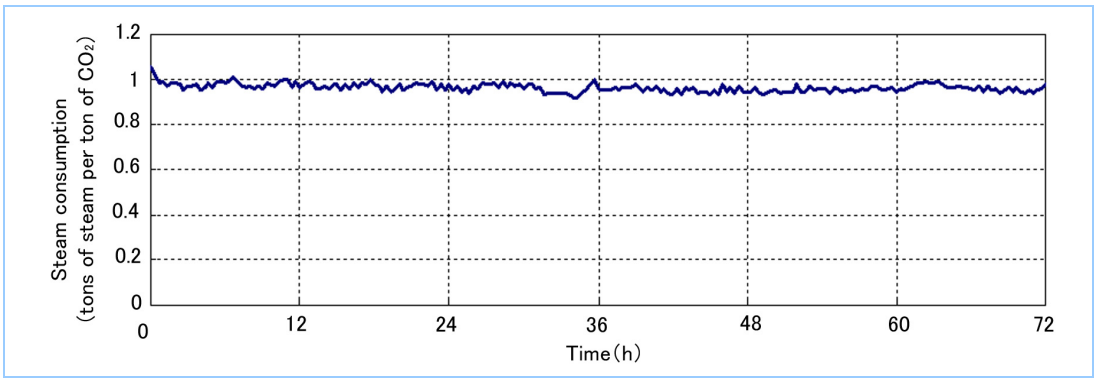


Figure 8 Steam consumption

(4) Behavior of Trace Components

Trace components in flue gas that accumulate within the system have the potential to cause corrosion and degradation of the solvent. Due to the high quantities of impurities contained in coal-fired flue gas, it is essential to investigate the effects of impurities and to design and implement countermeasures against corrosion. Since its startup, however, the MHI/Southern Company CCS demonstration plant for CO_2 recovery from coal-fired flue gas has never exhibited negative effects caused by trace components in the flue gas. Instead, the plant continues to operate in a stable manner. Thus, MHI's CO_2 recovery technologies have proven practical for implementation on a commercial scale, even for feed gas from coal-fired power plants.

During the demonstration operations, various futher testing programs (described below) are planned, including tests with the aim of further reducing both the energy consumption per unit of CO_2 recovery and the consumption of absorption solvent.

5. Future Testing Program

Demonstration operations at the MHI/Southern Company CCS plant are planned for four years from startup. The demonstration plant continues to be in stable operation since its startup, despite the fact that the feed gas contains a lot of impurities. MHI and Southern Company have planned a comprehensive testing program on the CO_2 recovery system for this period. An example of the testing program is shown below.

(1) Acquisition of material and heat balance

(2) Flue gas and wastewater component measurements

Measurement of the trace components of treated flue gas and wastewater are planned.

(3) Accuracy improvements

Tests will be conducted with varied operating conditions to accumulate meaningful data with the aim of improving the accuracy of simulation tools.

(4) Optimization of operation conditions

In an effort to determine optimized conditions, the operational costs will be measured for various operational conditions.

(5) Load-following operation test

The system, which automatically controls the operating load of the CO_2 recovery plant in response to load fluctuations from the existing power plant, will be verified.

(6) Long-term reliability of plant

Through long-term operation, along with monitoring the effect of impurities contained in the flue gas from coal-fired power plant, the reliability of the impurity countermeasures that have been undertaken will be validated.

(7) Test operation with high-particulate concentration

The type of coal burned will be varied in order to change the particulate concentration in the feed gas flowing into the CO_2 recovery plant. The effect of high particulate concentration upon the CO_2 recovery plant will be investigated, and the effectiveness of countermeasures will be verified.

6. Conclusion

MHI and Southern Company have completed construction of the world's largest CO_2 recovery demonstration plant, with a capacity of 500 metric tons of CO_2 per day, at the Plant Barry in Alabama. Demonstration operations were begun in Jun 2011. The demonstration plant has achieved both the rated CO_2 recovery capacity and ratio, and also exhibited lower steam consumption by adopting the MHI energy-saving process. In addition, the plant has been operating in a stable manner since startup, demonstrating the high reliability of MHI's technologies for CO_2 recovery.

Through application of know-how gained at the demonstration plant into a comprehensive design review of the CO_2 recovery process, MHI is advancing the development of optimized CO_2 recovery technologies. This process will enable the realization of larger-scale CO_2 recovery projects at commercial coal-fired thermal power plants.

References

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