Deployment of World’s Largest Post-combustion Carbon Capture Plant for Coal-fired Power Plants

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\textbf{CO}_2 Capture and Storage (CCS) is expected to be useful for the reduction of \textbf{CO}_2 emissions from thermal power stations. Mitsubishi Heavy Industries, Ltd. (MHI), together with Southern Company of the U.S., participated in an integrated demonstration test of capture, transportation, and storage of \textbf{CO}_2 from the flue gas of a coal-fired power plant. The project attained a cumulative operation time of 10,000 hours and a \textbf{CO}_2 storage amount of 100,000 tonnes or more by October 2013. In addition, in July 2014 MHI also received an order for the world’s largest post-combustion \textbf{CO}_2 capture plant (with a \textbf{CO}_2 capture capacity of 4,776 tonnes per day) from an Enhanced Oil Recovery (EOR) project mainly promoted by NRG Energy Inc. and JX Nippon Oil & Gas Exploration Corporation. This paper presents the results of the \textbf{CO}_2 capture and storage demonstration test and MHI’s future actions.

\section{1. Introduction}

MHI adopts the KM CDR Process\textsuperscript{®} (Note), a \textbf{CO}_2 capture process that uses the unique amine-absorption liquid “\textsuperscript{TM}KS-1” developed together with the Kansai Electric Power Co., Inc.\textsuperscript{1} Figure 1 outlines the flow of MHI’s \textbf{CO}_2 capture plant. MHI has put \textbf{CO}_2 capture technologies into practical use for emissions from natural gas-fired and heavy oil-fired plants. There are eleven commercial \textbf{CO}_2 capture plants currently in service including the first commercial plant delivered in 1999. Recovered \textbf{CO}_2 is commonly delivered for the enhancement of fertilizer production, etc. However, a \textbf{CO}_2 capture plant (with a capacity of 500 tonnes per day) delivered to Qatar in 2014 has also started operation for the enhancement of methanol production.

Technology for the capture of \textbf{CO}_2 from the combustion flue gas of fossil fuel is also attracting attention as a countermeasure to global warming. According to the latest Energy Technology Perspectives released by International Energy Agency (IEA), if current energy consumption continues as is, the annual amount of \textbf{CO}_2 emissions in 2035 is estimated at 40 gigatonnes, with a further increase to 50 gigatonnes or more by 2050. As a result, it is projected that the average temperature will rise by 3.6 to 5.3 degrees Celsius. To limit the predicted temperature increase to 2 degrees Celsius by 2050, reduction in \textbf{CO}_2 emissions is paramount. By 2050 it is expected that the amount of \textbf{CO}_2 emissions reduced due to the spread of \textbf{CO}_2 Capture and Storage (CCS) technology will likely increase to around 14 percent of all \textbf{CO}_2 emissions.\textsuperscript{5} In particular, the amount of \textbf{CO}_2 emissions from thermal power stations accounted for 39 percent of all \textbf{CO}_2 emissions in 2011. Again, for example plans for regulations to be imposed on \textbf{CO}_2 emissions from thermal power plants in the U.S. are moving forward.

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MHI collaborated with Southern Company, which is a major electric power company in the southeastern U.S., and the Electric Power Research Institute (EPRI) to construct a demonstration facility for the capture of CO₂ from the flue gas of a coal-fired plant (with a capacity of 500 tonnes per day) at Southern Company subsidiary Alabama Power’s Plant Barry in Mobile County, Alabama, and conducted a demonstration test of CO₂ capture and storage technologies.

Note: KM CDR Process® is the trademark of the CO₂ capture process developed together with the Kansai Electric Power Co., Inc., and is registered in Japan, the U.S., the European Community (CTM), Norway, Australia, and China.

Figure 1  Flow of MHI’s CO₂ capture process (KM CDR Process®)

2. Demonstration project of integrated CO₂ capture and storage process

(1) Project outline

The CO₂ capture demonstration project, in which MHI constructed the facility together with Southern Company, was the world’s first integrated demonstration test for the capture, compression, transportation, and storage of CO₂ from the flue gas of a coal–fired power plant.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
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<tbody>
<tr>
<td>Plant location</td>
<td>Mobile County (Alabama, U.S.A.)</td>
</tr>
<tr>
<td>Plant owner</td>
<td>Southern Company subsidiary Alabama Power</td>
</tr>
<tr>
<td>Process</td>
<td>KM CDR Process®</td>
</tr>
<tr>
<td>Absorption liquid</td>
<td>KS-1TM solvent</td>
</tr>
<tr>
<td>Plant scale</td>
<td>Corresponding to 25 megawatts (MW)</td>
</tr>
<tr>
<td>Flue gas amount</td>
<td>116,800 Nm³/h</td>
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<tr>
<td>CO₂ capture ratio</td>
<td>90 percent</td>
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<tr>
<td>CO₂ capture amount</td>
<td>500 tonnes/day (150,000 tonnes/year)</td>
</tr>
<tr>
<td>CO₂ concentration</td>
<td>10.1 mol%-wet</td>
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Table 1 shows an outline of Southern Company’s CO₂ capture demonstration facility and Figure 2 shows the external view of the demonstration facility. The CO₂ transportation and storage was conducted as part of the Regional Carbon Sequestration Partnership Phase III
Program of the Department of Energy (DOE) and the Southeast Regional Carbon Sequestration Partnership (SECARB), which is a partnership between the governments of eleven Southern states.

(2) Operation status

This demonstration facility started the capture of CO$_2$ from the plant in June 2011 and subsequently the underground storage of captured CO$_2$ in August 2012. The CO$_2$ capture plant attained a CO$_2$ capture amount of 500 tonnes per day and a CO$_2$ capture ratio of 90 percent, according to the initial plan, and verified its energy saving performance requiring steam consumption of 1 ton per CO$_2$ ton or less through a test conducted while changing the main operation parameters.\(^{(1)}\) Figure 3 shows the trend of CO$_2$ capture and storage results from the start of operation through to the end of October 2013. The total operation time exceeded 10,000 hours by the end of October 2013 and the cumulative CO$_2$ capture amount reached approximately 200,000 tonnes.

(3) Verification test of amine-emission reduction technology

The flue gas discharged from the CO$_2$ absorption column commonly contains a small amount of amine solvent, resulting in the loss of amine solvent to the atmosphere. In a pilot test plant in MHI’s research and development center in 2010, MHI found a phenomenon whereby SO$_3$ mist included in flue gas caused an increase in amine emissions. Since then MHI has been developing an amine-emission reduction technology ahead of its competitors. In the demonstration project in the U.S., the developed amine-emission reduction technology was verified. Figure 4 shows the verification test results. It was demonstrated that the amine-emission reduction technology can reduce amine emissions by approximately 1/10 in comparison with the existing process of MHI.

(4) Verification test of load-following control system

The operational load of a coal-fired power plant is adjusted according to daily electric power demand. As a result, operating conditions in the boiler are always changing and therefore...
the properties of flue gas, such as CO₂ concentration, changes. For this reason, an automatic load-following control system is effective for maintaining the optimum operating conditions of the CO₂ capture plant. MHI developed an optimum operation control system for the CO₂ capture plant and conducted a verification test of the control system in the U.S. demonstration project. Figure 5 shows the operational trend without the control system, and Figure 6 shows the operational trend with the control system. Both Figure 5 and Figure 6 exhibit the CO₂ capture amount and the CO₂ capture ratio on the left, and the CO₂ concentration included in the flue gas and flow volume of the flue gas on the right. Figure 5 shows the CO₂ capture amount and the CO₂ capture ratio change along with change of flue gas conditions. Figure 6, in contrast, shows that the CO₂ capture amount and the CO₂ capture ratio is constantly maintained. In this way, it was verified that the control system is effective for stable operation.

![Figure 5](image1.png)

**Figure 5** Operation trend (with load-following control system turned off)

![Figure 6](image2.png)

**Figure 6** Operation trend (with load-following control system turned on)

(5) Future efforts

Before attaining a CO₂ storage amount of 100,000 tonnes in October 2013, various evaluations and verification tests in addition to the tests described above were conducted. Therefore, knowledge of the operation of CO₂ capture plants and the practical application of this to large CO₂ capture plants, used for the flue gas of coal-fired plants, was obtained. Today the CO₂ capture demonstration facility in the U.S. is used to develop and verify new technologies. Currently (2014-2015) the CO₂ capture demonstration facility is proceeding with a project integrated with a power generation system, looking at a reduction in the lowering of the power generation efficiency that occurs when the CO₂ capture technology is applied. This is part of a verification program of the DOE.

**Figure 7** shows the block flow diagram of the verification project. In this verification program, the existing boiler water is heated by the waste-heat recovery from the existing flue gas with MHI’s advanced flue-gas treatment system (HES)³ and from the CO₂ capture plant. With the utilization of HES in MHI’s process, an improvement of 30 percent or more is expected in terms of efficiency in power generation compared to competitor’s existing technologies where 90 percent of the CO₂ in flue gas is captured. In addition, the introduction of HES enables further elimination of impurities such as SO₃ from flue gas, resulting in the reduction of the load on the CO₂ capture plant.
3. Efforts for larger CO$_2$ capture plant

Since starting the operation of a 2 tonnes per day pilot test plant together with the Kansai Electric Power Co., Inc. in its Nanko Power Plant in 1990, MHI has been conducting CO$_2$ capture tests from various flue gases and improving CO$_2$ capture performance. As described above, there are eleven commercial CO$_2$ capture plants currently in service. In addition, MHI has accumulated knowledge of CO$_2$ capture plants used for coal-fired power plants using a pilot test plant with a capacity of 1 ton per day at the MHI Hiroshima Research & Development Center and a verification test plant with a capacity of 10 tonnes per day in the Matsushima Thermal Power Plant of Electric Power Development Co., Ltd. For CCS and CO$_2$ EOR, a larger CO$_2$ capture plant with a capacity of thousands of tonnes per day needs to be applied, therefore further scale-up of CO$_2$ capture plants is required. MHI has made it possible to construct a reliable plant with a capacity of thousands of tonnes per day by utilizing knowledge about scalability obtained in the practical application of the flue-gas desulfurization equipment (a product of the present Mitsubishi Hitachi Power Systems, Ltd.) as well as the invaluable knowledge obtained in multiple verification tests of various scales.

MHI received an order for the world’s largest CO$_2$ capture plant (with a CO$_2$ capture capacity of 4,776 tonnes per day) from an EOR project mainly promoted by NRG Energy Inc. and JX Nippon Oil & Gas Exploration Corporation in July 2014. Table 2 shows an outline of the plant, and Figure 8 shows a conceptual drawing of the completed plant. This CO$_2$ capture and storage project is partially funded by a grant from the Clean Coal Power Initiative (CCPI) of the DOE, and is scheduled to start operation around the fourth quarter of 2016. The plant will capture CO$_2$ from flue gas corresponding to a 240 MW slipstream and inject the captured CO$_2$ into an oil field approximately 130 km away from the power generation plant. Due to the CO$_2$ EOR effect, enhancement in oil production from 500 barrels per day to 15,000 barrels per day is expected.
Table 2  Outline of CO\textsubscript{2} capture plant for EOR project in Texas, U.S.A

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
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<tbody>
<tr>
<td>Plant location</td>
<td>Thompsons (Texas, U.S.A.)</td>
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<td>Plant owner</td>
<td>Petra Nova (joint venture between NRG Energy Inc. and JX Nippon Oil &amp; Gas Exploration Corporation)</td>
</tr>
<tr>
<td>Gas source</td>
<td>NRG WA Parish power generation plant 610 MW(Net) coal-fired power generation facility</td>
</tr>
<tr>
<td>Process</td>
<td>KM CDR Process®</td>
</tr>
<tr>
<td>Absorption liquid</td>
<td>KS-1\textsuperscript{TM} solvent</td>
</tr>
<tr>
<td>Plant scale</td>
<td>Corresponding to 240 MW</td>
</tr>
<tr>
<td>CO\textsubscript{2} capture ratio</td>
<td>90 percent</td>
</tr>
<tr>
<td>CO\textsubscript{2} capture amount</td>
<td>4,776 tonnes/day</td>
</tr>
</tbody>
</table>

Figure 9 shows the process structure of this CO\textsubscript{2} capture plant and the related facilities.\textsuperscript{4} The steam and electricity required for the operation of the CO\textsubscript{2} capture plant are supplied from the auxiliary gas turbine and exhaust heat recovery boiler, and therefore CO\textsubscript{2} can be recovered without decreasing the power generation output from existing power generation facilities.

It is expected that CO\textsubscript{2} EOR, which is a combination of EOR and CO\textsubscript{2} capture from a power generation plant or a chemical plant, will be widely used and the market for utilizing CO\textsubscript{2} capture plants will grow. MHI continues to improve the technologies for CO\textsubscript{2} capture plants and promotes the commercialization of large CO\textsubscript{2} capture plants that are suitable for the CO\textsubscript{2} EOR and CCS markets.

Figure 9  Process structure of CO\textsubscript{2} capture plant for EOR project in Texas, U.S.A

4. Conclusion

MHI, together with Southern Company, operated a CO\textsubscript{2} capture demonstration test facility with a capacity of 500 tonnes per day constructed at Southern Company subsidiary Alabama Power’s Plant Barry in Mobile county, Alabama, and attained a cumulative CO\textsubscript{2} underground storage amount of 100,000 tonnes. Through the demonstration project, the reliability of the KM CDR Process® for a coal-fired plant was proven and various new technologies, including amine-emission reduction technology, were also verified. These verification results are reflected in large CO\textsubscript{2} capture plants, enhancing their reliability. MHI continues technological development for the deployment of the large scale CO\textsubscript{2} capture plants.

References