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

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CO_2 Capture and Storage (CCS) is expected to be useful for the reduction of 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 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 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 CO_2 capture plant (with a 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 CO_2 capture and storage demonstration test and MHI's future actions.

1. Introduction

MHI adopts the KM CDR Process® (Note), a CO_2 capture process that uses the unique amine-absorption liquid "KS-1™" developed together with the Kansai Electric Power Co., Inc.[1] **Figure 1** outlines the flow of MHI's CO_2 capture plant. MHI has put CO_2 capture technologies into practical use for emissions from natural gas-fired and heavy oil-fired plants. There are eleven commercial CO_2 capture plants currently in service including the first commercial plant delivered in 1999. Recovered CO_2 is commonly delivered for the enhancement of fertilizer production, etc. However, a 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 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 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 CO_2 emissions is paramount. By 2050 it is expected that the amount of CO_2 emissions reduced due to the spread of CO_2 Capture and Storage (CCS) technology will likely increase to around 14 percent of all CO_2 emissions.[2] In particular, the amount of CO_2 emissions from thermal power stations accounted for 39 percent of all CO_2 emissions in 2011. Again, for example plans for regulations to be imposed on 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 southerneastern U.S., and the Electric Power Research Institute (EPRI) to construct a demonstration facility for the capture of CO_2 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 CO_2 capture and storage technologies.

Note: KM CDR Process® is the trademark of the CO_2 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.

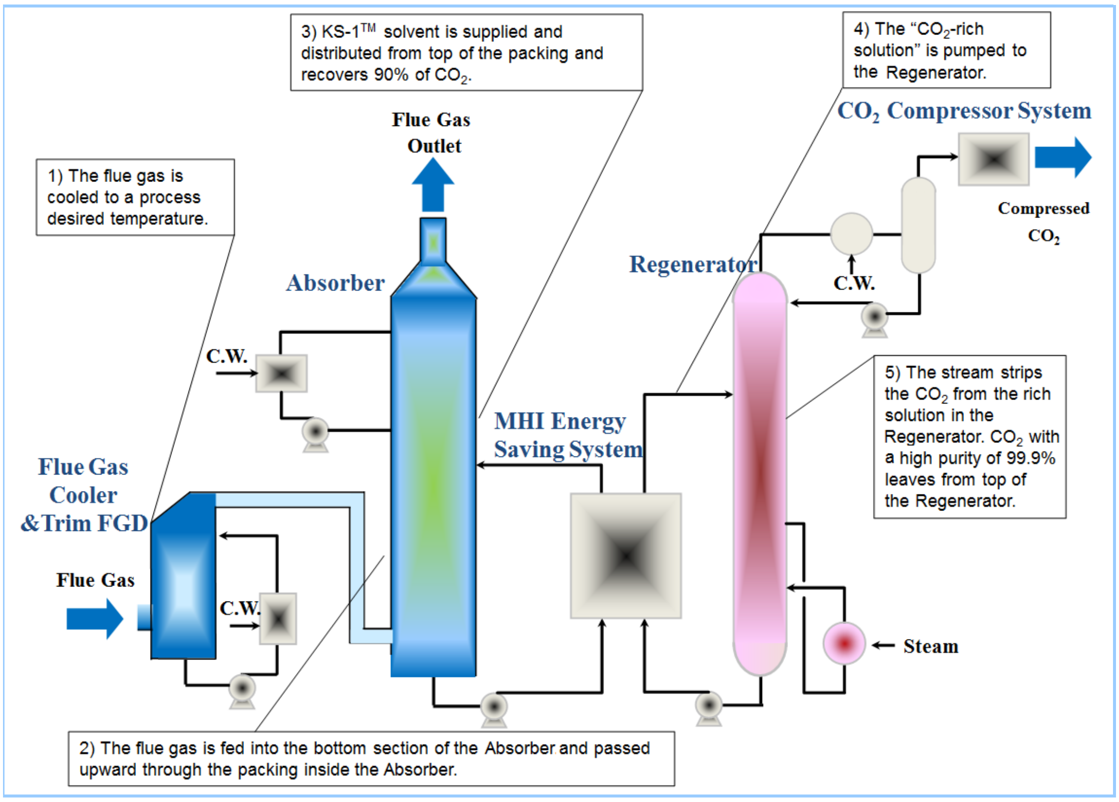

Figure 1 Flow of MHI's CO_2 capture process (KM CDR Process®)

2. Demonstration project of integrated CO_2 capture and storage process

(1) Project outline

The CO_2 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 CO_2 from the flue gas of a coal-fired power plant.

Table 1 Outline of CO_2 capture demonstration facility for Southern Company

Item	Description
Plant location	Mobile County (Alabama, U.S.A.)
Plant owner	Southern Company subsidiary Alabama Power
Process	KM CDR Process®
Absorption liquid	KS-1™ solvent
Plant scale	Corresponding to 25 megawatts (MW)
Flue gas amount	116,800 Nm^3/h
CO_2 capture ratio	90 percent
CO_2 capture amount	500 tonnes/day (150,000 tonnes/year)
CO_2 concentration	10.1 mol%-wet

Figure 2 External view of CO_2 capture demonstration facility for Southern Company

Table 1 shows an outline of Southern Company's CO_2 capture demonstration facility and **Figure 2** shows the external view of the demonstration facility. The CO_2 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.

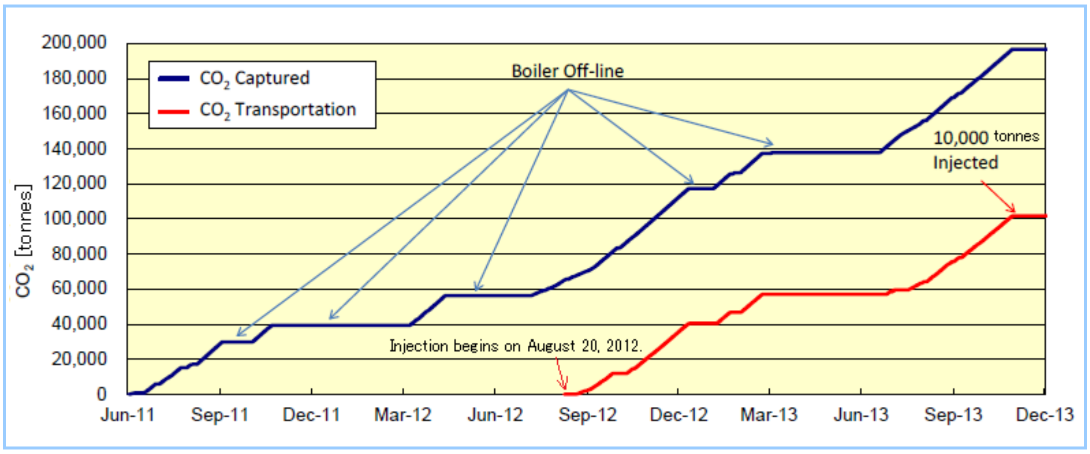

Figure 3 Operational trend results

(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.

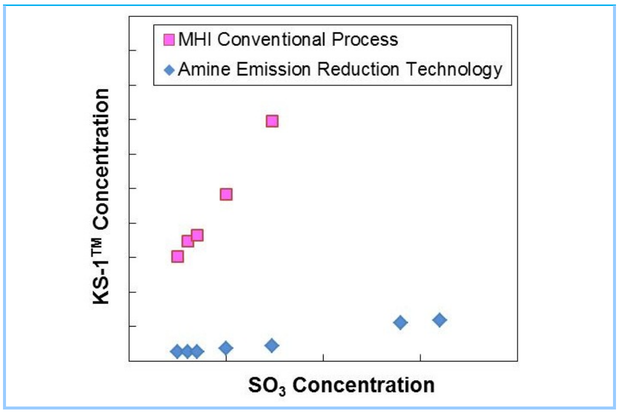

Figure 4 Verification test results of amine-emission reduction technology

(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 CO_2 concentration, changes. For this reason, an automatic load-following control system is effective for maintaining the optimum operating conditions of the CO_2 capture plant. MHI developed an optimum operation control system for the CO_2 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 CO_2 capture amount and the CO_2 capture ratio on the left, and the CO_2 concentration included in the flue gas and flow volume of the flue gas on the right. Figure 5 shows the CO_2 capture amount and the CO_2 capture ratio change along with change of flue gas conditions. Figure 6, in contrast, shows that the CO_2 capture amount and the CO_2 capture ratio is constantly maintained. In this way, it was verified that the control system is effective for stable operation.

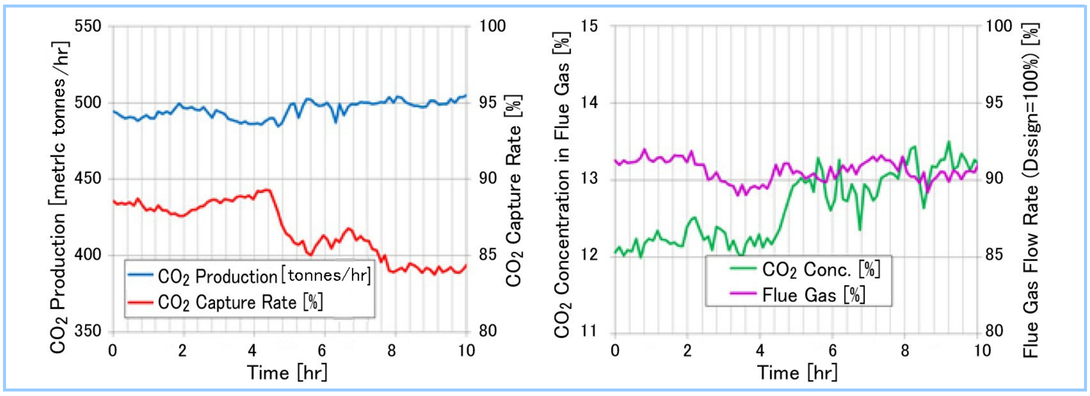

Figure 5 Operation trend (with load-following control system turned off)

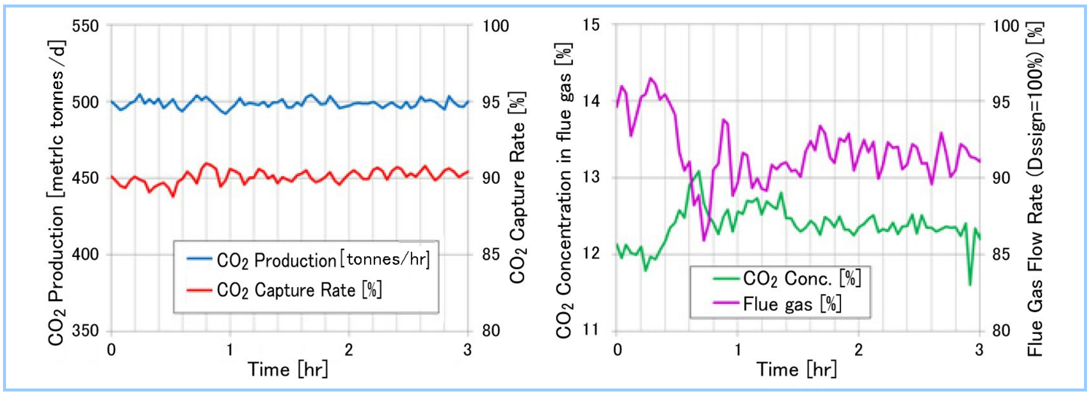

Figure 6 Operation trend (with load-following control system turned on)

(5) Future efforts

Before attaining a CO_2 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 CO_2 capture plants and the practical application of this to large CO_2 capture plants, used for the flue gas of coal-fired plants, was obtained. Today the CO_2 capture demonstration facility in the U.S. is used to develop and verify new technologies. Currently (2014-2015) the CO_2 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 CO_2 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 CO_2 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 CO_2 in flue gas is captured. In addition, the introduction of HES enables further elimination of impurities such as SO_3 from flue gas, resulting in the reduction of the load on the CO_2 capture plant.

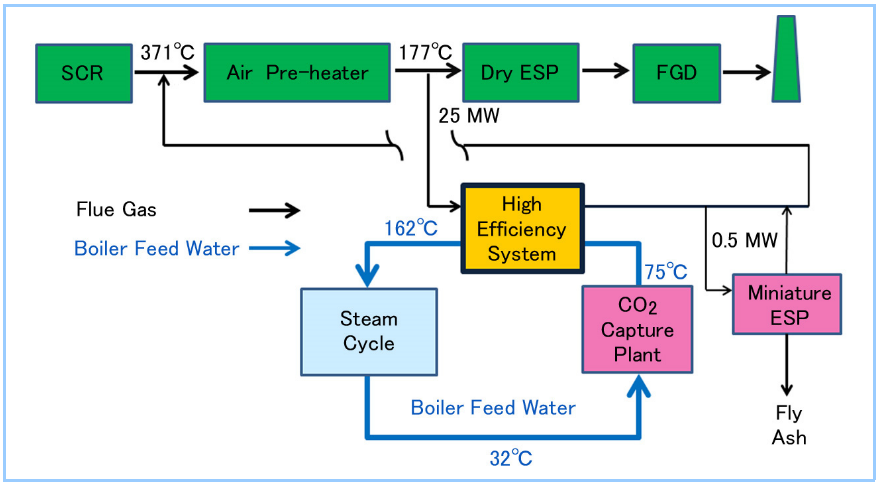

Figure 7 Block flow of integrated project

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.

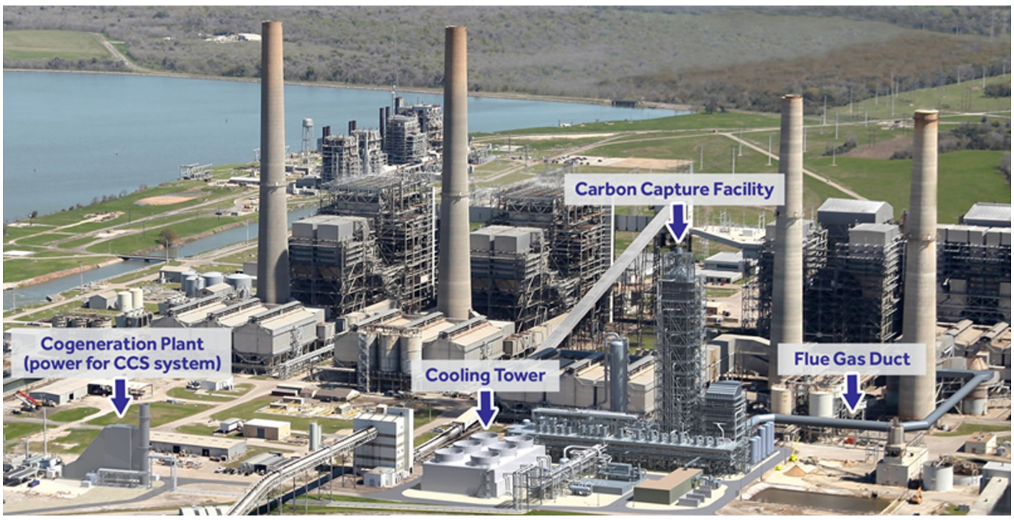

Figure 8 Conceptual drawing of completed CO_2 capture plant for EOR project in Texas, U.S.A

Table 2 Outline of CO_2 capture plant for EOR project in Texas, U.S.A

Item	Description
Plant location	Thompsons (Texas, U.S.A.)
Plant owner	Petra Nova (joint venture between NRG Energy Inc. and JX Nippon Oil & Gas Exploration Corporation)
Gas source	NRG WA Parish power generation plant 610 MW(Net) coal-fired power generation facility
Process	KM CDR Process®
Absorption liquid	KS-1™ solvent
Plant scale	Corresponding to 240 MW
CO_2 capture ratio	90 percent
CO_2 capture amount	4,776 tonnes/day

Figure 9 shows the process structure of this CO_2 capture plant and the related facilities.[4] The steam and electricity required for the operation of the CO_2 capture plant are supplied from the auxiliary gas turbine and exhaust heat recovery boiler, and therefore CO_2 can be recovered without decreasing the power generation output from existing power generation facilities.

It is expected that CO_2 EOR, which is a combination of EOR and CO_2 capture from a power generation plant or a chemical plant, will be widely used and the market for utilizing CO_2 capture plants will grow. MHI continues to improve the technologies for CO_2 capture plants and promotes the commercialization of large CO_2 capture plants that are suitable for the CO_2 EOR and CCS markets.

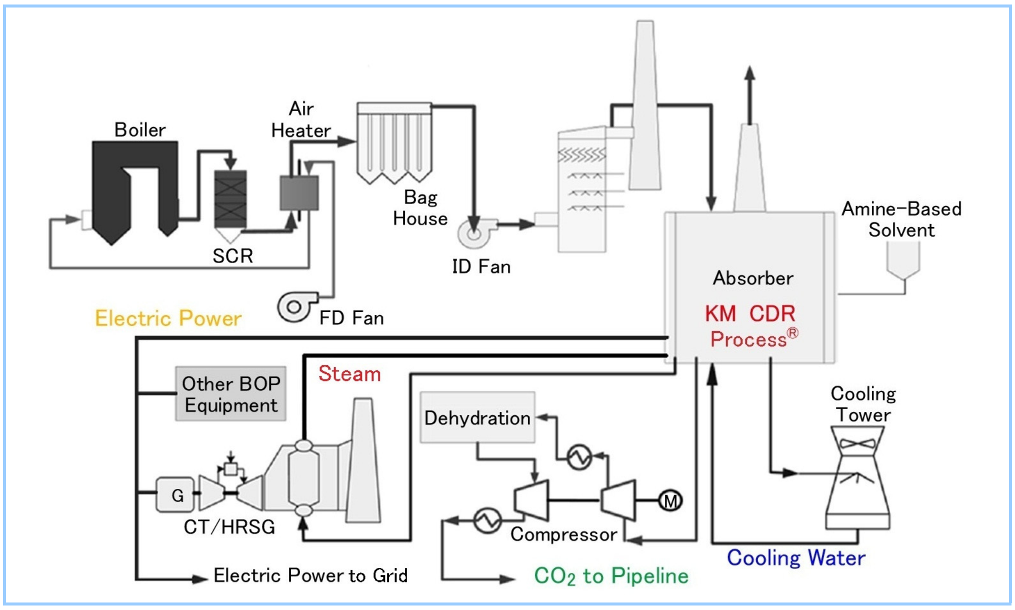

Figure 9 Process structure of CO_2 capture plant for EOR project in Texas, U.S.A

4. Conclusion

MHI, together with Southern Company, operated a CO_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_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_2 capture plants, enhancing their reliability. MHI continues technological development for the deployment of the large scale CO_2 capture plants.

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