MHI's Commercial Experiences with CO_2 Capture and Recent R&D Activities

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Mitsubishi Heavy Industries, Ltd. (MHI) started developing technology for CO_2 capture from combustion flue gas with Kansai Electric Power Co., Inc. in 1990. The first commercial plant was delivered in 1999 for a Malaysian fertilizer company, and as of January 2018, a total of 13 commercial CO_2 capture plants are currently in service around the world. MHI's CO_2 capture plant is applied to various combustion flue gases including heavy oil, coal, and natural gas, and the recovered CO_2 is used for a variety of applications including the enhancement of fertilizer/methanol production, general use such as for dry ice, and EOR (Enhanced Oil Recovery) for the purpose of increasing oil production. Most notably, MHI delivered the world's largest CO_2 capture plant (4,776 metric tonnes per day) on a coal fired power plant to Petra Nova Parish Holdings LLC, U.S. at the end of December 2016. The project has been recognized by well-known publications including Power Engineering, Power Magazine, and Engineering News Record (ENR). MHI continues to promote research and development of CO_2 capture technology to improve the reliability, reduce the cost of future CO_2 capture plants, and increase the application of its technology.

1. Introduction to the CO_2 Opportunity

CO_2 emissions have become a widely discussed subject in recent years because of the effect on the global climate. Understanding the global effort that would be necessary to combat climate change, the Paris Agreement, a new international framework aiming to reduce greenhouse gas (GHG) emissions, was adopted at the Conference of the Parties to United Nations Framework Convention on Climate Change (COP) in December 2015, and it entered into force in November 2016.

Among the options available to reduce GHG emissions is CO_2 Capture and Storage (CCS). CCS projects capture CO_2 emitted from the combustion of fossil fuels and stores it in the ground. A report issued in November 2016 by the International Energy Agency (IEA) titled 20 Years for Carbon Capture and Storage described the importance of CCS. In particular, the power generation sector, which produces the majority of CO_2 emissions, will require CCS to meet the emissions goals set out by the Paris Agreement.

CO_2 can be used for a variety of economic purposes. CO_2 is widely used for general purposes such as carbonated beverages, dry ice for cooling, shielding gas for welding, and other miscellaneous uses. In the chemical industry, it is used as a raw material for the production of fertilizer, methanol, and other chemicals. In the oil industry, CO_2 can be used to increase oil production of mature oil fields while storing a large amount of CO_2.

Recently, studies on CO_2 Capture, Utilization, and Storage (CCUS) have been actively undertaken by several companies and organizations. Regardless of how the CO_2 is ultimately used, MHI understands that the cost of CO_2 capture and the reliability of the technology must continue to be improved to support its wide deployment. Some of these cost reductions will come with experience, while the technology improvements will be engineered through R&D.

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2. MHI's R&D and Commercial Experiences and Application of Recovered CO_2

MHI's CO_2 capture technology is known as the KM CDR Process™ and uses a proprietary solvent known as the KS-1™ solvent.[1] This process can capture more than 90% of the CO_2 from a flue gas stream and produce CO_2 that is more than 99.9% pure. MHI's technology uses less steam than other conventional technologies. **Figure 1** shows a schematic flow of the KM CDR Process™ and the process description.

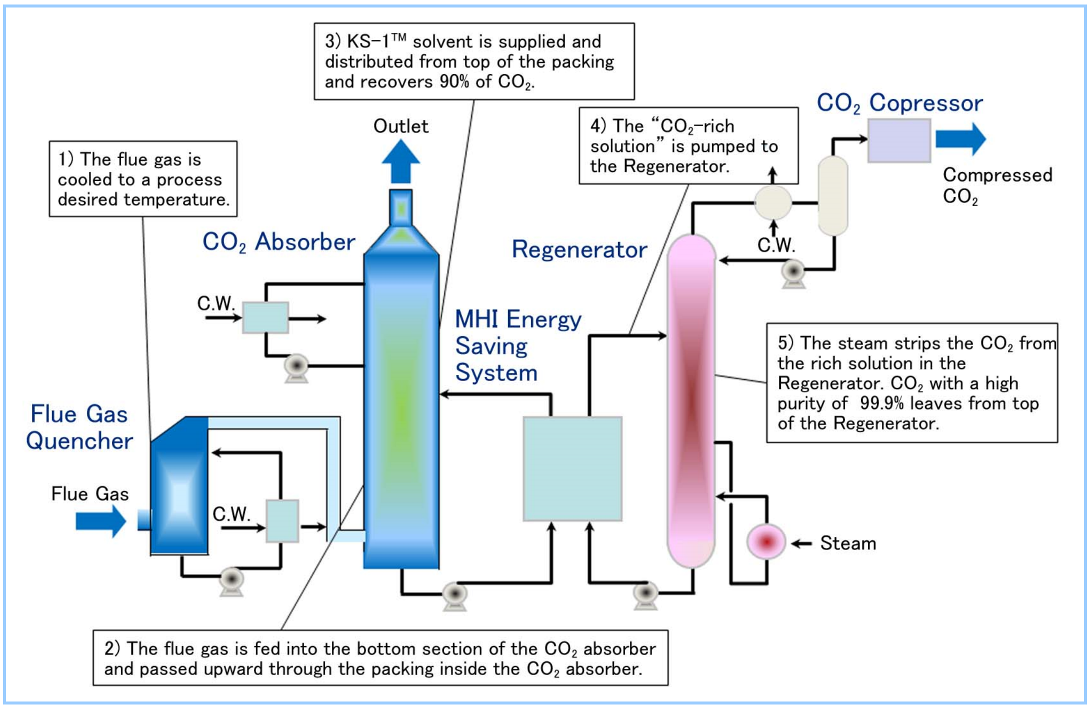

Figure 1 Flow of MHI's CO_2 capture process (KM CDR Process™)

In 1991, MHI built its first CO_2 capture pilot plant at Kansai Electric Power Co., Inc.'s Nanko Power Plant which burns natural gas. The Nanko Pilot Plant helped MHI to develop the KM CDR Process™. To this day, MHI continues to use the 2 metric tonnes per day (tpd) pilot plant to improve the KM CDR Process™ and test new solvents.

Through the pilot plant testing, MHI delivered its first commercial plant (with a capacity of 210 tpd) for a Malaysian fertilizer company in 1999. The captured CO_2 from a natural gas furnace increases urea production at the fertilizer plant, and the plant has been continuously operating for nearly 20 years. Since then, MHI has delivered an additional eleven (11) projects capturing CO_2 from natural gas sources. Most recently, the CO_2 capture plant for NIPPON EKITAN Corporation started commercial operation in November 2017.

Just as important as capturing CO_2 from natural gas combustion, MHI has tailored the technology to capture CO_2 from coal fired flue gas. Coal fired flue gases have more impurities than natural gas-fired flue gases so separate pilot plant tests were necessary to enhance the KM CDR Process™ for coal fired power plants. These testing facilities include:

- The R&D Pilot Plant (with a capacity of 1 tpd) at the MHI Research & Innovation Center
- The Matsushima Pilot Plant (with a capacity of 10 tpd) at the Matsushima Thermal Power Station of Electric Power Development Co., Ltd.

To commercialize the technology for coal fired power plants, MHI had to demonstrate the KM CDR Process™ on a larger scale, so in 2011, MHI started a long-term KM CDR Process™ demonstration at the James M. Barry Electric Generating Plant, owned by Alabama Power (a subsidiary of Southern Company). The demonstration facility was constructed with Southern Company, a major electric power company in the U.S., and the U.S. Electric Power Research Institute (EPRI). With a capacity of 500 tpd, this facility was the first large-scale demonstration on coal fired flue gas in the world.

Following the demonstration, MHI was confident in its ability to deliver a commercial-scale CO_2 capture plant for the Petra Nova Project. Given all of MHI's experiences (shown in **Figure 2**), it is believed that MHI is the leading provider of commercial-scale CO_2 capture plants.

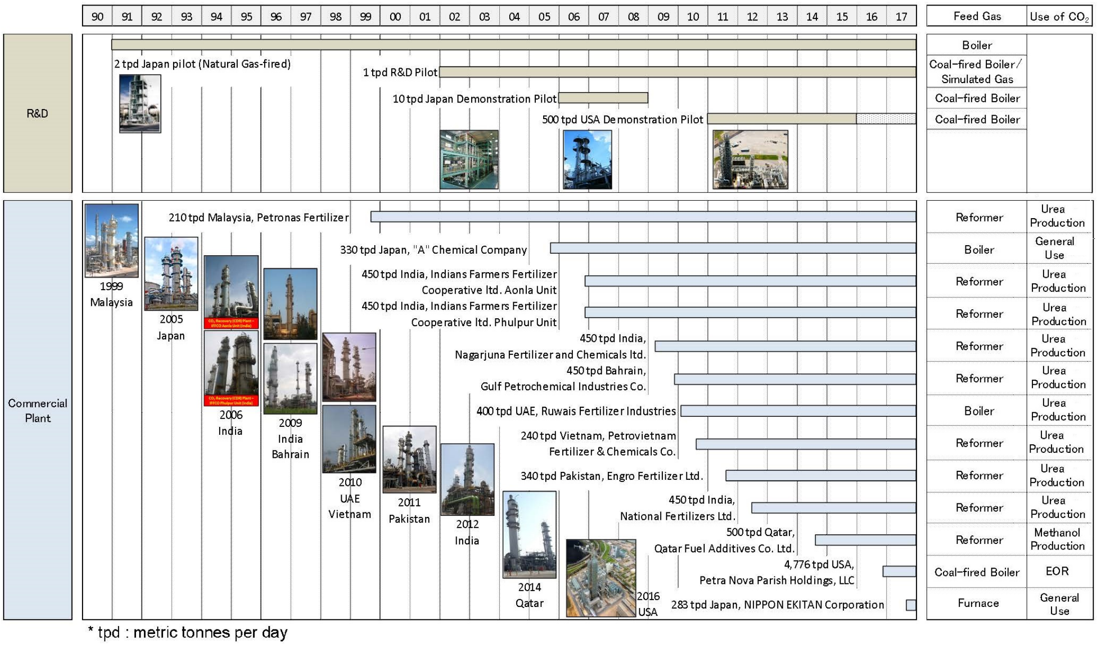

Figure 2 MHI's experiences of R&D facilities and commercial plants

3. Completion of the world's largest CO_2 capture plant

In 2016, MHI successfully delivered a highly-reliable CO_2 capture plant (with a capacity of 4,776 tpd) for the Petra Nova Project. The Petra Nova Project is jointly owned by NRG Energy Inc., a U.S. Independent Power Producer, and JX Nippon Oil & Gas Exploration Corporation. The plant started commercial operation at the end of December 2016. **Table 1** details the plant specifications and **Figure 3** is a photo of the completed plant. The CO_2 captured from a 240 MW equivalent slipstream of flue gas is compressed by the CO_2 compressor, transferred through a 130-km pipeline, and injected into an oil field. Through these efforts, it is expected that the oil production at the oil field will increase significantly from about 300 barrels per day when CO_2 injection began. As of October 2017, the oil field production has increased to roughly 4,000 barrels per day.[2]

Table 1 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 610MW (Net) coal-fired power generation facility
Process	KM CDR Process™
Absorption liquid	KS-1™ solvent
Plant scale	Corresponding to 240MW
CO_2 recovery rate	90 percent
CO_2 capture amount	4,776 metric tonnes per day

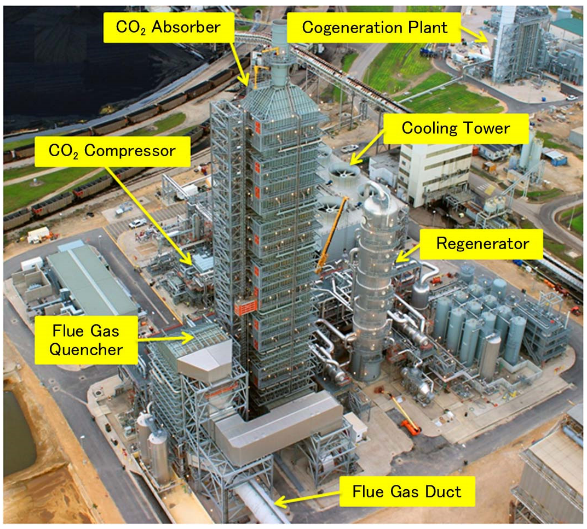

Figure 3 Completed CO_2 capture plant for EOR project in Texas, U.S.A

Figure 4 shows the facility configuration of this CO_2 capture plant and other related facilities. The CO_2 capture plant is located downstream of existing air quality control systems (AQCS) to limit the impurities in the flue gas. The electricity and steam required for the CO_2 capture plant are supplied from a cogeneration unit consisting of a gas combustion turbine connected to an electrical generator and a heat recovery steam generator. As a result, CO_2 can be recovered without decreasing the existing power generation output from the host unit or affecting how its power is dispatched to the power market. The world's largest eight-stage integrally-geared CO_2 compressor supplied by Mitsubishi Heavy Industries Compressor Corporation is employed, and in the CO_2 compression process, a dehydrator is installed to meet the moisture specifications in the CO_2 pipeline.

One major feature is that MHI designed the flue gas quencher and CO_2 absorber as rectangular towers. With rectangular shaped towers, MHI improved the efficiency of the construction work and shortened the construction time. MHI also implemented new systems into the KM CDR Process™ to further improve the technology. Three of the major improvements are:

(1) Automatic load adjustment control system
(2) Improved amine emission reduction system
(3) Improved energy saving system

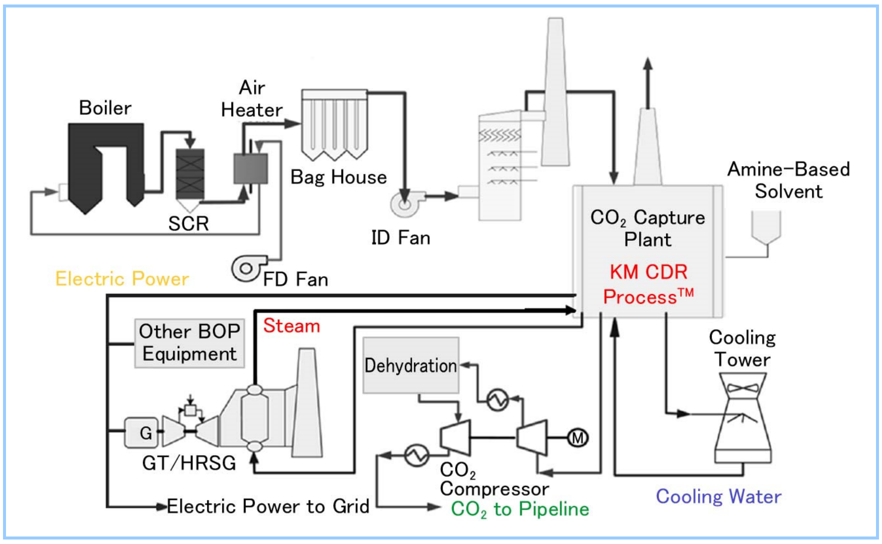

Figure 4 Facility configuration of CO_2 capture plant and related facilities for EOR project in Texas, U.S.A

3.1 Automatic load adjustment control system

At a coal fired power plant, the operational load is adjusted according to the daily electric power demand. The boiler operation changes all the time, and with it, flue gas conditions such as flow rate and CO_2 concentration also change. MHI developed an automatic load adjustment control system for the CO_2 capture plant to maintain optimized operation following the dynamic flue gas condition of the host coal fired plant. This control system allows the CO_2 capture plant operator not to pay continuous attention to the CO_2 capture plant operation. **Figures 5**, **6**, **7** and **8** show the operation trend using the automatic load adjustment control system. Even if the CO_2 concentration in the flue gas changes significantly, the desired CO_2 recovery ratio, capture amount, and steam consumption rate can be maintained.

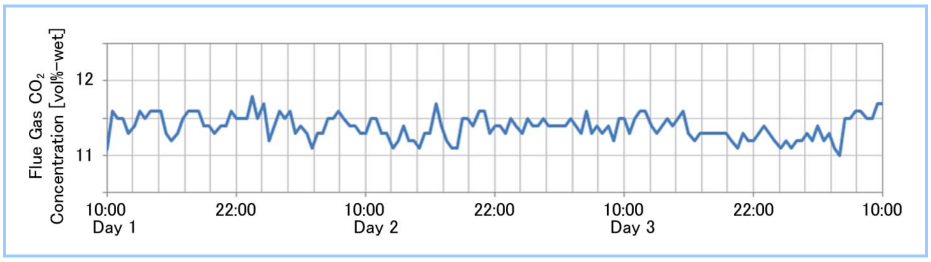

Figure 5 Trend of flue gas CO_2 concentration for EOR project in Texas, U.S.A

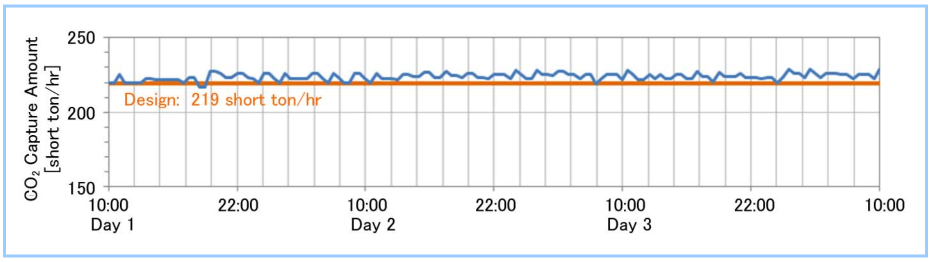

Figure 6 Trend of CO_2 capture amount for EOR project in Texas, U.S.A

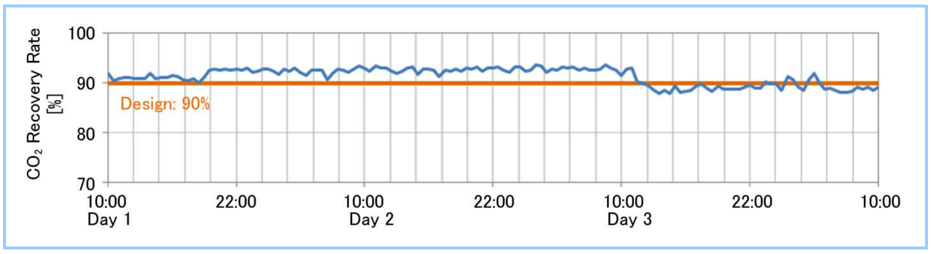

Figure 7 Trend of CO_2 recovery rate for EOR project in Texas, U.S.A

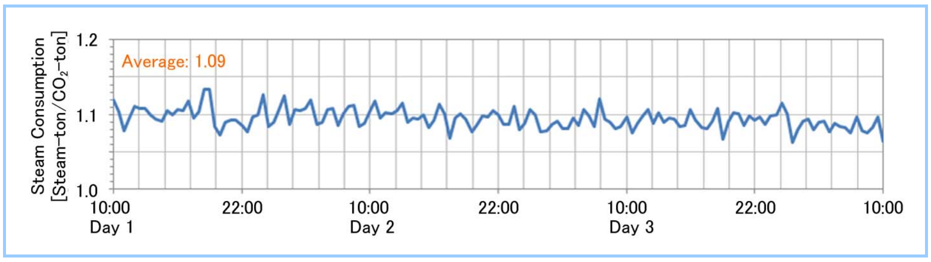

Figure 8 Trend of steam consumption for EOR project in Texas, U.S.A

3.2 Improved amine emission reduction system

The treated flue gas from the CO_2 absorber contains a small amount of amine, which is the main component of the absorption solvent. Coal fired flue gas contains many impurities. In particular, it is known that SO_3 among them increases amine emissions significantly even in low concentration according to MHI's experience at one of its commercial plants, the pilot plant test at the R&D center and the 500 tpd demonstration facility for coal fired flue gas. Therefore, MHI developed the improved amine emission reduction system to prevent the loss of solvent due to amine emissions. As can be seen from **Figure 9**, which shows the results at the 500 tpd demonstration facility, the improved system reduced amine emissions by over 90% compared with the conventional system.

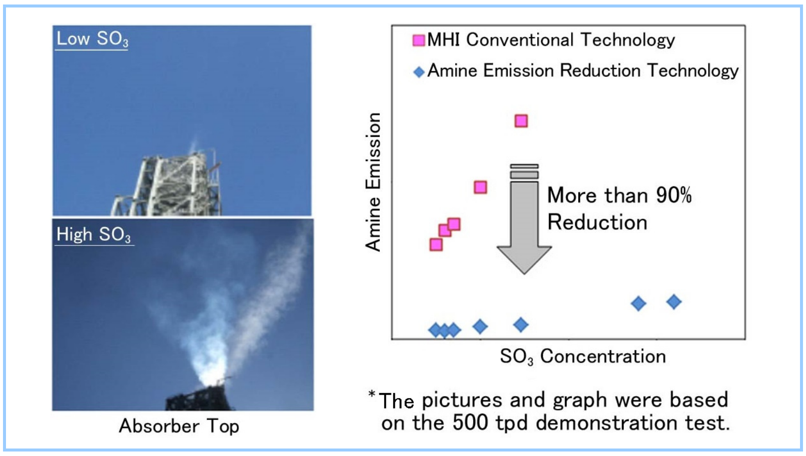

Figure 9 Relationship between SO_3 concentration and amine emission

3.3 Improved energy saving system

MHI applied the improved energy saving system to reduce steam consumption by 5% compared with MHI's previous energy saving system. Among the CO_2 capture plants delivered by MHI, the improved energy saving system provides the best energy efficiency.

4. Latest R&D Updates

4.1 Development of new absorption solvent and process optimization

In recent years, MHI has made efforts to develop a new absorption solvent which has the following attributes compared with KS-1™; (1) similar steam consumption, (2) lower degradation and lower solvent consumption, and (3) lower amine emissions. Evaluation tests have been conducted at the Nanko Pilot Plant using new solvents. MHI confirmed that the steam consumption and amine emissions are within the desired range. The next step is to optimize the entire process, including the peripheral systems, and commercialize the new solvent in the near future.

4.2 Fully-automatic operational system

Using the lessons learned from the development of the automatic load adjustment control system and the vast amount of operating data gathered from actual plants, MHI has been making efforts to develop a fully-automatic operational system. The objective is to reduce operating failures and operator work load during unstable conditions such as during startup or shutdown of the facility. This new system can be applied to both new and existing plants.

4.3 Cost reduction

MHI is currently working on reducing capital and operating costs to help improve the economic viability of CO_2 capture projects for widespread deployment. By analyzing actual operating data and evaluating construction methods, MHI plans to identify areas for capital cost reduction. This could include optimizing equipment and facility design, evaluating equipment layouts to reduce the footprint of the facility, and modularizing the facility. In addition, MHI is evaluating further cost reduction by optimizing how the auxiliary facilities such as utility supply units are integrated with the CO_2 capture plant.

4.4 Deployment in other industrial fields

Another area of interest for MHI is the use of its KM CDR Process™ for other applications. The gas conditions and compositions for these new uses will likely be different from those of fossil fuel-fired flue gas. Therefore, MHI needs to study and adjust the plant operating parameters to optimize performance before commercialization.

5. Conclusion

MHI is the world leader in the deployment of CO_2 capture systems due to its consistent commitment to continual improvement. As a result of MHI's R&D efforts, the KM CDR Process™ is much more energy efficient and easier to operate than other conventional technologies. MHI has delivered 13 commercial CO_2 capture plants for the production of fertilizer, methanol, and oil, as well as for other general uses. Of particular note, MHI delivered the world's largest CO_2 capture plant on a coal fired power plant for the Petra Nova Project. MHI continues to research new ways to increase the reliability and economic efficiency of the technology so that it can support wide deployment, while helping to solve one of the world's greatest challenges.

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