CO_2 Capture Technology of Mitsubishi Heavy Industries

— Results to Date and Application to Onboard Systems for Ships —

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1. INTRODUCTION

In July 2023, the International Maritime Organisation (IMO) extensively revised its GHG Strategy and set the target for 2050 at net zero, strengthened from the previous target of 50% [1]. Shipping is a so-called "hard to abate" sector, i.e., decarbonization is more difficult in the shipping sector than in other sectors. However, GHG emissions from shipping account for about 3% of total GHG emissions and are therefore not negligible. Mitsubishi Heavy Industries, Ltd. (MHI) began the development of technology for CO_2 capture from combustion flue gas with Kansai Electric Power Co., Inc. in 1990, and delivered the first commercial plant to a Malaysian fertilizer company in 1999. As of August 2025, a total of 18 commercial CO_2 capture plants are currently in service around the world. MHI's CO_2 capture plant is applicable to various types of combustion flue gases, including heavy oil, coal, and natural gas, and the recovered CO_2 is used in a variety of applications, such as enhancement of fertilizer and methanol production, general uses such as dry ice, and EOR (Enhanced Oil Recovery) to increase oil production. Most notably, MHI delivered the world's largest CO_2 capture plant (4776 metric tonnes per day) for a coal-fired power plant to Petra Nova Parish Holdings LLC, U.S. at the end of December 2016. MHI continues to promote research and development of CO_2 capture technologies with the aims of improving reliability, reducing the cost of future CO_2 capture plants, and increasing the application of its technology.

2. MHI'S R&D AND COMMERCIAL EXPERIENCE

MHI's CO_2 capture technology was commercialized as the KM CDR Process and uses a proprietary solvent, KS-1™ [2]. This process can capture more than 90% of the CO_2 from a flue gas stream and produce CO_2 with a purity of more than 99.9%. Steam consumption is also lower than that of other conventional technologies. Fig. 1 shows the schematic flow of the KM CDR Process and the process description.

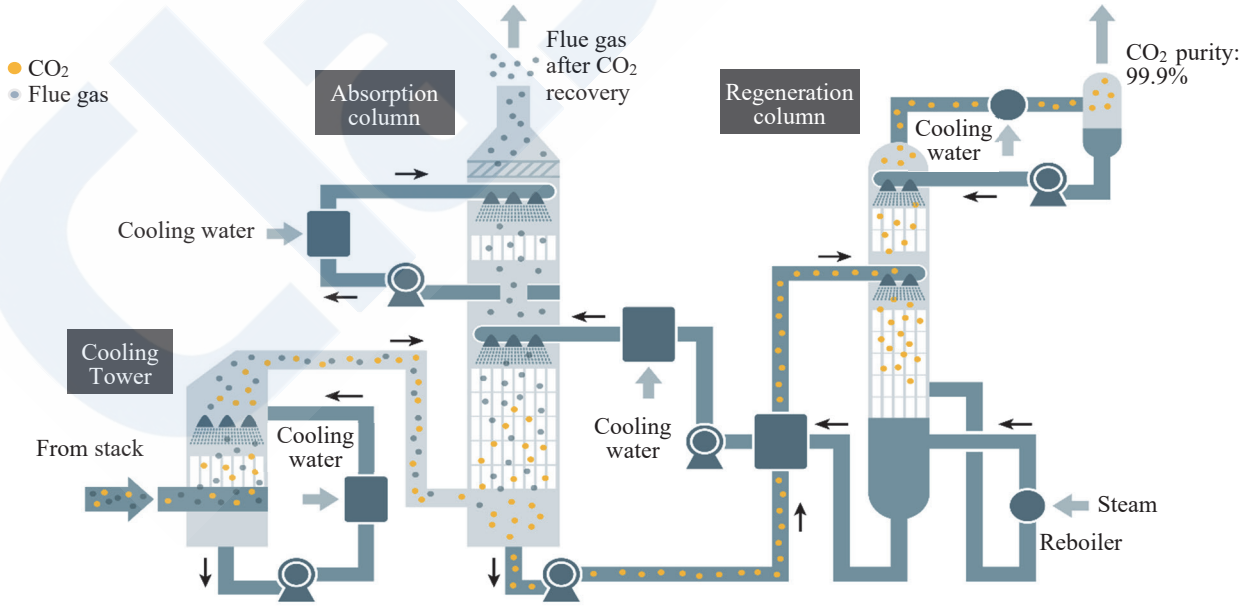

Fig. 1 MHI's CO_2 capture process (KM CDR Process™)

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Flue gas containing CO_2 is introduced into the flue gas quencher, where it is cooled, and is then pressurized by a blower installed downstream of the quencher, and delivered to the CO_2 absorber filled with packing. The flue gas enters the bottom section of the absorber and reacts with the alkaline absorption solvent on the packing surface. The solvent absorbs the CO_2 from the flue gas, and the remaining flue gas is discharged into the atmosphere. The solvent, now rich in CO_2, is transferred to the regenerator, where the CO_2 is separated from it by steam stripping, resulting in regeneration of the solvent (ready for re-use). Use of MHI's latest energy-saving regeneration process can considerably reduce the amount of steam required in this process, reducing operational expenditure (OPEX).

In 2016, MHI successfully delivered a highly-reliable CO_2 capture plant (capacity: 4776 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 Fig. 2 is a photo of the completed plant. The CO_2 captured from a 240MW equivalent slipstream of flue gas is compressed by the CO_2 compressor, transferred through a 130km pipeline, and injected into an oil field. As a result of these efforts, oil production at the oil field was expected to increase significantly from about 300 barrels per day when CO_2 injection began. As of October 2017, oil field production had increased to roughly 4000 barrels per day [3].

Table 1　Overview of plant for EOR project in Texas (USA)

Item	Content
Plant location	Thompsons (Texas, USA)
Gas source	NRG WA Parish power plant 610 MW coal-fired thermal power plant
Process	KM CDR Process™
Solvent (absorbent solution)	Amine-based solvent KS-1™
Plant scale	240 MW equivalent
CO_2 capture rate	90%
CO_2 capture amount	4776 t/d

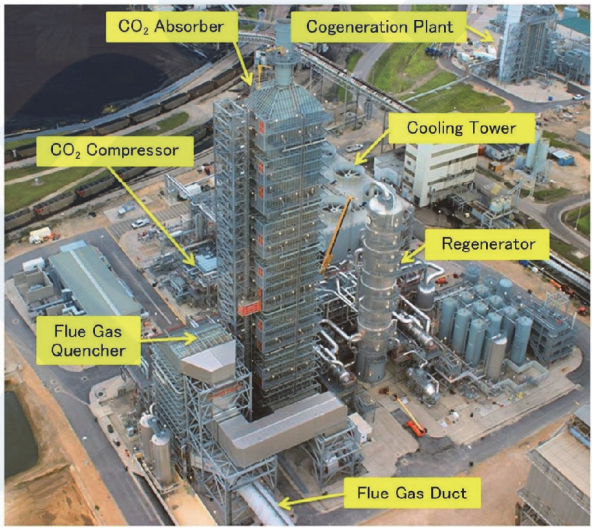

Fig. 2　Appearance of CO_2 capture plant for EOR project in Texas (USA)

Fig. 3 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 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 compression process employs the world's largest eight-stage integrally-geared CO_2 compressor, which was supplied by Mitsubishi Heavy Industries Compressor Corporation. A dehydrator is installed in the CO_2 compression process to meet the moisture specifications of the

CO_2 pipeline.

At a coal-fired power plant, the operational load is adjusted according to daily electric power demand. Boiler operation changes constantly, and with it, flue gas conditions such as the 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. Use of this control system allows operation of the CO_2 plant without constant attention by the CO_2 capture plant operator [4].

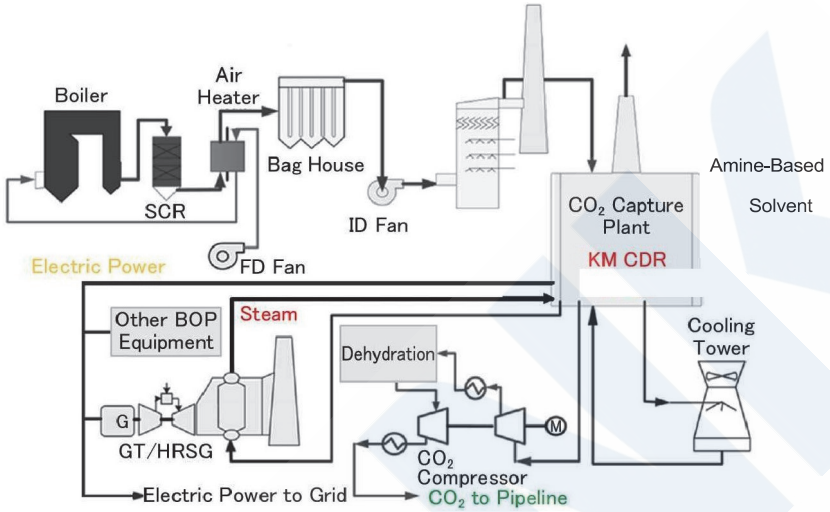

Fig. 3 System configuration of CO_2 capture plant for EOR project in Texas (USA)

3. FEATURES OF SMALL-SCALE CO_2 CAPTURE SYSTEMS

MHI has delivered a proprietary CO_2 capture process, the KM CDR Process™, to coal-fired power plants and chemical plants. The scale of the plants delivered so far is approximately 500t-CO_2/day or larger. Based on this technology, MHI is now developing small-scale CO_2 capture systems to realize concurrent CO_2 reductions while also responding to the reduction needs of small-scale CO_2 emission sources.

Although the basic process of the small-scale CO_2 capture system under development is the same as that of large-scale plants, the following features are required in a small-scale system:

(1) Applicable to many emission sources
(2) Installable in a limited area
(3) Operable without full-time operators

In order to respond to various inquiries, we adopted a standard design for small-scale systems, and not a design tailored to each customer's specifications, like the designs used in conventional large-scale plants. A system with a compact design was realized by modularization to enable installation in a smaller area. Modularization has the advantages of reducing field works and allowing an early start of system operation, and also eliminates the need for storage sites for construction materials, etc. The small-scale system is equipped with an automatic operating and remote monitoring system, allowing operation without a full-time operator.

In addition to MHI's conventional customers, such as thermal power plants and chemical plants, these systems are expected to be applied in various industrial sectors such as biomass power plants, cement factories, steel mills, gas engines, waste incineration facilities, etc. (Fig. 4), where efforts to reduce CO_2 are expected to accelerate in the future [5].

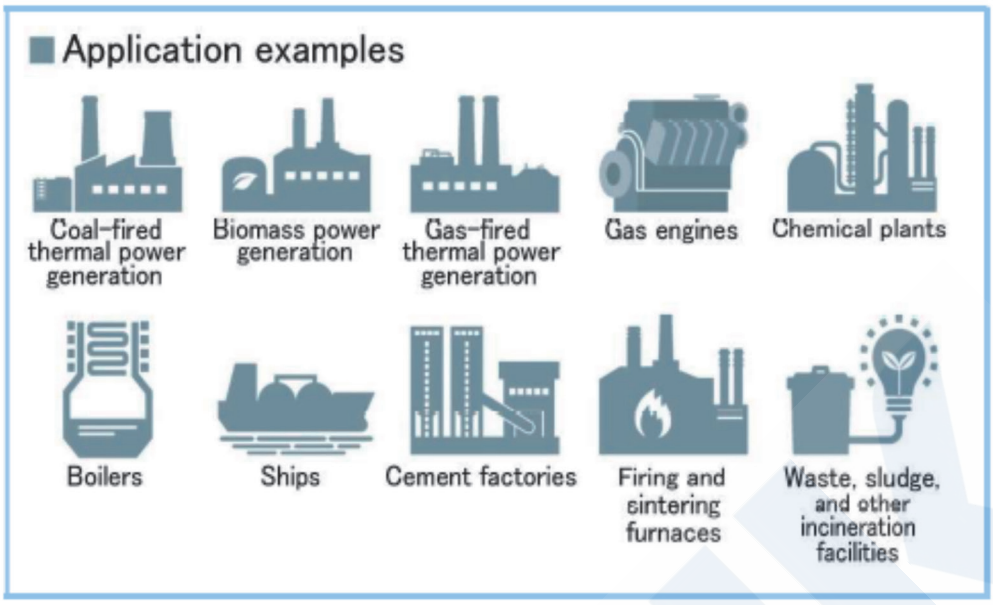

Fig. 4　Examples of applications of small-scale CO_2 capture plants

4.　DEVELOPMENT OF ONBOARD CO_2 CAPTURE SYSTEMS FOR SHIPS

MHI is also developing onboard CO_2 capture systems to reduce CO_2 emissions from ships. This chapter introduces our latest initiative in this area, the onboard CO_2 capture system demonstration project CC-Ocean (Carbon Capture on the Ocean)[*1], which was carried out jointly with Kawasaki Kisen Kaisha, Ltd. and Nippon Kaiji Kyokai [6].

To verify the CO_2 capture technology under offshore conditions and formulate the requirements for onboard use, in this project, a demonstration test of a small-scale CO_2 capture demonstration plant (hereinafter, demo-plant) was conducted under commercial operating conditions by installing the demo-plant on the coal carrier “CORONA UTILITY” operated by Kawasaki Kisen, Ltd. This demonstration under actual commercial conditions was a “world’s first.” The project was conducted over a two-year period. A HAZID evaluation of the demo-plant and a safety evaluation of the equipment and system were conducted by Nippon Kaiji Kyokai (ClassNK), after which the demonstration plant was fabricated, installed on the coal carrier, and operated in an offshore environment for approximately six months to measure and check its performance. The CO_2 capture system of the demo-plant installed on the coal carrier was originally a unit for exhaust gas treatment employing the chemical absorption method at an onshore plant, and was converted for onboard installation (Fig. 5).

Fig. 5　Test ship “CORONA UTILITY” and demo-plant (white container)

In this project, the performance of the demo-plant exceeded the planned values for the CO_2 capture amount, CO_2 capture rate, and captured CO_2 purity, and the equipment could be operated and maintained by the crew of the coal carrier without any problems. The effects of engine load fluctuations and ship motion on CO_2 capture performance and the effects of the ship’s exhaust gas on the CO_2 absorbent were also verified. In addition, guidelines for safety measures associated with ship operation, including measures against leakage of the CO_2 absorbent, ventilation concepts for equipment installation areas, etc., were

established as requirements for operating CO_2 capture systems in an offshore environment.

Based on the knowledge obtained and the technical issues discovered as a result of this demonstration, in the future, we will promote efforts toward commercialization of the onboard CO_2 capture system by establishing the concept of a total system, including onboard CO_2 liquefaction and storage, and optimizing the system as an offshore system, considering unloading the onboard CO_2 to land.

5. CONCLUSION

The IMO has extensively revised its GHG Strategy and set the target for 2050 at net-zero carbon emissions, which was strengthened from the previous target of 50%. Mitsubishi Heavy Industries, Ltd. (MHI) recognizes that reduction of GHG emissions is a major issue, and promotes the development of technologies for this purpose not only by the company itself, but also in cooperation with others companies in the Mitsubishi Heavy Industry Group and external organizations. We will continue developing MHI technologies to contribute to the transition to net-zero emissions in international shipping.

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