Development of onboard CO_2 Capture System

— “CC-Ocean Project” for verification testing of onboard CO_2 capture system —

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1. INTRODUCTION

With the increasing global momentum of decarbonization, the IMO adopted a “GHG reduction strategy” aimed at halving GHG emissions from the international shipping sector by 2050 and reducing those emissions to zero at an early period within this century, and even faster reduction has also been discussed in many quarters. As measures to reduce GHG, conversion from fossil fuels to alternative fuels such as synfuels, hydrogen and ammonium has been studied. On the other hand, utilization of the captured CO_2 or semi-permanent storage in CO_2 storage sites, are also regarded as one candidate for GHG reduction.

As part of Mitsubishi Heavy Industries (MHI) Group’s energy transition strategy, Mitsubishi Shipbuilding Co., Ltd. is also engaged in the development of onboard CO_2 capture system with the aim of reducing CO_2 emissions from ships. This paper introduces “Carbon Capture on the Ocean” (CC-Ocean) project for verification testing of onboard CO_2 capture system, which was conducted in cooperation with Kawasaki Kisen Kaisha, Ltd. (“K” Line) and Nippon Kaiji Kyokai (ClassNK), with support from Japan’s Ministry of Land, Infrastructure, Transport and Tourism (MLIT), as the most recent of this company’s efforts.

2. OUTLINE OF CC-OCEAN PROJECT

In this project, a small-scale CO_2 capture demonstration plant (hereinafter, “demo plant”) was installed on a coal carrier “CORONA UTILITY” (hereinafter, “the ship”) operated by “K” Line, and the world’s first demonstration test under commercial operation conditions was carried out in order to verify the CO_2 capture technology on the ocean and organize marinization requirements.

The project was carried out over a period of two years. After HAZID (HAZard IDentification: identification of inherent hazards and assumed accidents) of the demo plant by ClassNK, the demo plant was fabricated and installed on the ship, and the demonstration test started in August 2021, and measurements to confirm performance of the demo plant on the ocean were conducted for approximately six months.

The demo plant installed on the ship was fabricated with measures against ship motion/vibration, which are unique to ships, based on a CO_2 capture system designed for onshore plants which use the chemical absorption method. Fig. 1 shows an illustration of the demo plant.

Fig. 1 Illustration of demo plant

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3. OUTLINE OF CO_2 CAPTURE SYSTEM

Fig. 2 shows the process flow of CO_2 capture from the exhaust gas of a marine engine. The demo plant consists mainly of four towers: exhaust gas quencher, absorption tower, exhaust gas cleaning tower and regeneration tower. The exhaust gas discharged from the marine engine is absorbed by a blower from a pipe branching partly from the exhaust gas pipe installed at the outlet of the funnel and is supplied to the demo plant. The exhaust gas supplied to the demo plant is first delivered to the exhaust gas quencher and cooled to almost normal temperature with fresh water spayed from above in the tower. The fresh water circulates in the system and removes heat from the exhaust gas by heat exchange with seawater.

The exhaust gas discharged from the exhaust gas quencher is delivered to the absorption tower, where it comes into contact with an absorbent sprayed from above in the tower, and the CO_2 in the exhaust gas is absorbed by the absorbent.

Next, the exhaust gas discharged from the absorption tower is delivered to the exhaust gas cleaning tower, and the CO_2 absorbing liquid contained in the exhaust gas is washed away by fresh water sprayed from above in the cleaning tower.

The clean exhaust gas discharged from the exhaust gas cleaning tower is then vented to atmosphere through a pipe leading to the area of the funnel.

The absorbent which has absorbed the CO_2 is delivered to the regeneration tower from the bottom of the absorption tower, and is heated with steam to release CO_2, after which the regenerated absorbent returns to the absorption tower and is reused.

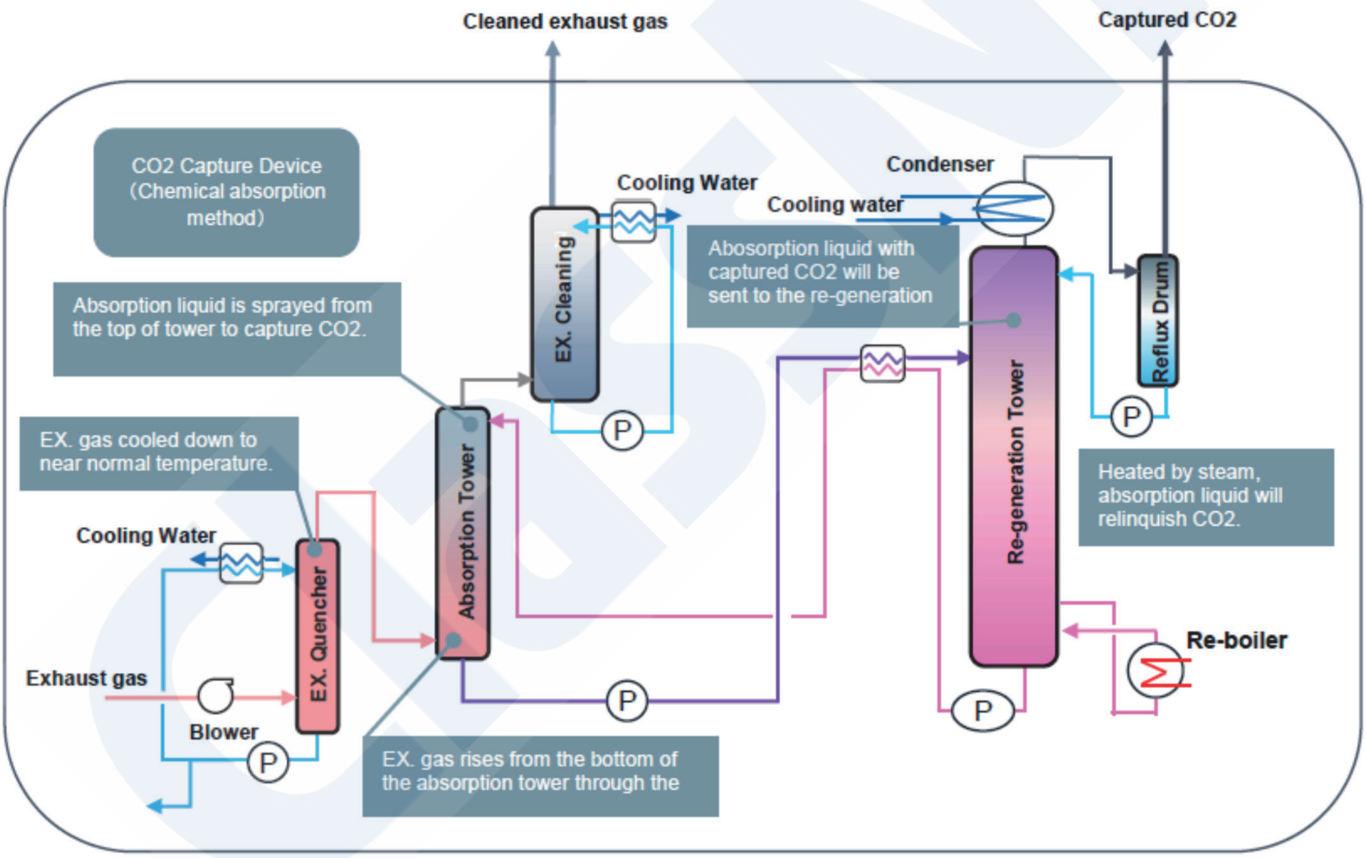

Fig. 2 Process flow of CO_2 capture

Because the purpose of this project was to verify the CO_2 capture technology on the ocean, as mentioned above, CO_2 liquefaction system or CO_2 storage tank were not equipped. The CO_2 captured in the regeneration tower was released into the atmosphere after analysis of its properties.

4. HAZID OF DEMO PLANT

4.1 Procedure for HAZID

The following shows the procedure of the HAZID conducted with the demo plant.

①In order to identify risks, ClassNK mainly conducts a review of the safety of the CO_2 capture system, and “K” Line mainly reviews the operation of the demo plant.

②For the risks identified in ①, the system failure modes and causes and the influence from failures (local influence, consequential influence on entire system) are analyzed.

③The risks are evaluated by quantifying, as indexes, the severe influence and failure frequency of effect on human beings and ships in the event that the risks actually occur.

④Measures to reduce the risks are formulated and reflected in the design/manufacture and operation manual of the demo plant and the instruction manual for CO_2 absorbing liquid.

⑤The risks after risk reduction measures are implemented are reevaluated to confirm whether the risks are on an acceptable level.

4.2 Risks and Risk Reduction Measures

Table 1 shows the major risks identified in the HAZID and measures to reduce those risks.

Table 1 Major risks and risk reduction measures

Risk	Risk reduction measures
Leakage of CO_2 absorbing liquid	• Take measures to prevent scattering at pipe joints of the CO_2 absorbing liquid. • Visually check that no leakage of the CO_2 absorbing liquid is observed before the startup of the demo plant, during operation and after shutdown. • Provide a caution plate (“Check that there is no chemical leaks or other abnormalities when entering the room”) at the entrance of the demo plant room. • Take measures to prevent the CO_2 absorbing liquid from leaking outside the ship in case of leakage from the demo plant. • In the operation manual, add procedures for checking for leakage of the CO_2 absorbing liquid when entering the room and the action to be taken in the event of leakage.
Erroneous handling of CO_2 absorbing liquid	• Wear protective equipment when handling the CO_2 absorbing liquid. • While replenishing the CO_2 absorbing liquid, visually check the liquid level of the makeup tank. • If it is difficult to replenish the CO_2 absorbing liquid due to vibration caused by the emergency generator located under the demo plant or ship motion, do not replenish the liquid.
Leakage of exhaust gas or CO_2	• When entering the demo plant room and before starting the demo plant, run the exhaust fan. • The exhaust fan start/stop switch must be installed outside the demo plant room. • Provide a caution plate (“Run the exhaust fan when entering the demo plant room and before starting the demo plant”) at the entrance of the demo plant room. • In the operation manual, add procedures for operating the exhaust fan.

5. INSTALLATION WORK

5.1 Outline of Demo Plant Ship

The following is an outline of the ship on which the demo plant was installed.

Ship name: CORONA UTILITY

Ship type: 88 000-ton coal carrier

Dimensions of ship: Length 229.98 m, Breadth 38 m, Depth 19.9 m

Completion: January 2016

Ship registration: Japan

5.2 Outline of Installation Work

The installation work was conducted at the quay of Yokohama Dockyard & Machinery Woks of MHI. Fig. 3 shows the image of the installation work. An additional overhanging deck was installed beside the engine casing, and the demo plant was installed in an independent room (hereinafter, “demo plant room”) built on the deck.

Since the ship is engaged in transportation of coal for electric power generation, it was necessary to carry out the installation work at a point on the route to the loading port after unloading. Therefore, the timing for the work was determined while checking the vacancy of the quay of the Yokohama Dockyard & Machinery Works and carefully adjusting the ship operation schedule.

To shorten the work period, the following preparations were made before the installation work at Yokohama Dockyard & Machinery Works, and the installation work was completed in a short period as planned.

- Work such as piping and wiring to the demo plant and hull reinforcement associated with the installation of the demo plant room were conducted at this company’s dock in China.
- The demo plant room, including the internal fittings, was fabricated onshore in advance, and the entire room was installed as a unit after the ship was docked.
- Inspections such as resurveying due to revisions of the classification certificate and JG certificate, which were required when the demo plant room was installed, were conducted onshore before the installation of the room.

Figs. 4 to 6 show the condition of demo plant room installation.

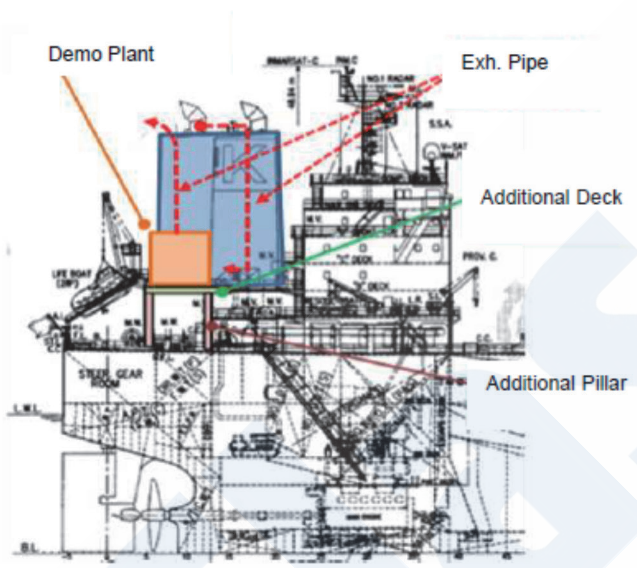

Fig. 3　Image of installation work

Fig. 4　Condition of demo plant room installation

Fig. 5　Condition of demo plant room installation

Fig. 6　Demo plant room after completion of installation on the ship

6. DEMONSTRATION TEST

6.1 Outline of Test

The demonstration test was conducted on the ship's route between Japan, Australia, Canada and Russia. After the demo plant was installed on the ship, engineers of Mitsubishi Shipbuilding were on board the ship for approximately one month to perform tasks such as plant operation and maintenance, instructions on the plant operation to crew and measurement of the exhaust gas and the separated/captured CO_2.

After the completion of the test by the engineers of Mitsubishi Shipbuilding, the crew continued tasks such as plant operation, measurement and maintenance for approximately five months. During this demonstration test, the operation manual for the demo plant continued to be updated by the crew and was optimized as a valuable manual filled with field know-how, becoming a “bible” for reliable operation of the plant. In this way, the world's first attempt in which a ship's crew captured CO_2 during commercial ship operation was successfully completed.

The measurements in the demonstration test were started after operation of the demo plant had reached a steady state, and the composition of the inlet exhaust gas, outlet exhaust gas and captured CO_2 gas were measured. For items that could not be analyzed on the ship, only sampling of the substances was conducted, and the sampled substances were brought back ashore and analyzed.

During the test, the operational data acquired on the ship were promptly transferred to an onshore facility and various analyses were conducted by Mitsubishi Shipbuilding, which then provided advice to the ship on adjustment of the demo plant and additional replenishment of the CO_2 absorbing liquid in order to support the demonstration test. The fact that procedures for this kind of communication between the ship and the onshore facility, confirmation of the operational data and the crew support were established between “K” Line and the ship before the demonstration test began is also considered one important factor in the success of the demonstration test.

Figs. 7 to 10 show the condition of the demonstration test.

Fig. 7 Condition of demo plant operation

Fig. 8 Instructions on demo plant operation to ship's crew

Fig. 9 Measurement of exhaust gas discharged from the marine engine

Fig. 10 Operation of demo plant by ship's crew

6.2 Verification Items

The following were the major verification items in the demonstration test. The results for each are summarized below in section 6.3.

①CO_2 capture performance of demo plant

②Effect of fluctuations in engine load and ship motion on CO_2 capture performance

6.3 Test Results

6.3.1 CO_2 Capture Performance of Demo Plant

In the demonstration test, Mitsubishi Shipbuilding confirmed the amount of captured CO_2, CO_2 capture rate and purity of the captured CO_2 were achieved as planned and verified the proven onshore CO_2 capture technology could be also applied to marine use. The purity of the captured CO_2 was more than 99.9%. When an onshore plant captures CO_2 with a purity of more than 99.9%, the captured CO_2 can be used in a wide range of applications, including chemical processes to enhance production of fertilizer or methanol, general use such as dry ice for cooling, and enhanced oil recovery (EOR) to increase crude oil production. In this demonstration test, CO_2 with comparable high purity was also successfully captured.

6.3.2 Effect of Fluctuations in Engine Load and Ship Motion on CO_2 Capture Performance

During the demonstration test, the load on the main engine fluctuated between approximately 40% and 70% and since there was no change in the CO_2 concentration in the exhaust gas at the demo plant inlet, these fluctuations had no significant effect on CO_2 capture performance. Similarly, almost no effect of ship motion during the demonstration test period on CO_2 capture performance was observed.

7. CONCLUSION AND FUTURE PROSPECT

This paper introduced an outline of the CC-Ocean Project as a technological approach to the capture of CO_2 from ships, the verification items and the result of the demonstration test.

Based on the knowledge and technological issues obtained thorough the demonstration test, in the future, Mitsubishi Shipbuilding intend to proceed with the development of a total system including CO_2 liquefication and onboard CO_2 storage, which have not been considered in the demonstration test, and pursue efforts to commercialize the system by achieving marinization, downsizing and cost reduction.

As described above, MHI Group is pursuing a range of strategic measures to strengthen businesses related to energy transition, and establishing a CO_2 ecosystem is a key part of this effort. Carbon dioxide capture, utilization, and storage (CCUS) is attracting attention as an effective means to achieve a carbon neutral society. Mitsubishi Shipbuilding, in response to these demands, is continuing its efforts to reduce greenhouse gas (GHG) emissions from ships and other types of marine equipment, in order to contribute to environmental conservation, and the realization of a carbon neutral society on a global scale.

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