Liquefied CO_2 Carrier "EXCOOL"

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As an effective means to realize a carbon-neutral society, CCUS (Carbon dioxide Capture, Utilization and Storage) is attracting attention. In order to realize a CCUS value chain, a means of transporting the captured CO_2 to the storage site is necessary. Liquefied CO_2 carriers are considered to be a safe and low-cost means of transportation and their demand is predicted to increase in the future, so there are high expectations for the technology to be established.

EXCOOL (hereinafter referred to as "the vessel") is a liquefied CO_2 (LCO_2) and liquefied petroleum gas carrier built at Shimonoseki Shipyard & Machinery Works of Mitsubishi Heavy Industries, Ltd. for the purpose of being offered to the New Energy and Industrial Technology Development Organization (NEDO) project "Research, Development and Demonstration of CCUS Technology/Large-scale CCUS demonstration testing at Tomakomai/Demonstration testing on CO_2 Transportation". The vessel was delivered in November 2023 and will be utilized for the aforementioned NEDO demonstration testing.

1. Features of the vessel

1.1 Specifications and general arrangement

Table 1 and **Figure 1** shows the specifications and general arrangement of the vessel, respectively. The vessel is a pressurized liquefied gas carrier with a forecastle and a poop. The main hull has a single-bottom structure with two cargo holds, each of which is equipped with one horizontal cylindrical cargo tank. The propulsion system is a single-engine, single-shaft, controllable pitch propeller, and a bow side thruster is provided for berthing and unberthing. The vessel's navigation area is classified as the greater coasting area (non-international), so there are less restrictions on the navigation area where demonstration testing can be conducted. In addition, since the main route is between Maizuru and Tomakomai, cold weather protection measures are also provided.

Table 1 Specifications of EXCOOL

Length overall	(m)	Abt. 71.99
Breadth	(m)	12.50
Depth	(m)	5.50
draft	(m)	4.60
Gross tonnage (Japanese)		996
Complement	(persons)	10
Total cargo tank capacity	(m^3)	Abt. 1,450
Speed	(kn)	12.0
Maximum output of main engine	(kW)	1,471

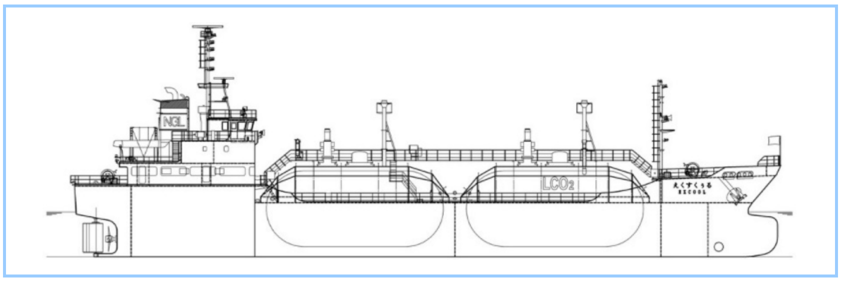

Figure 1 General arrangement

1.2 CO_2 characteristics and requirements for liquefied CO_2 carrier

At room temperature and atmospheric pressure, CO_2 is a colorless, odorless gas that is heavier than air. When transporting CO_2 by ship, it is desirable to liquefy it to reduce its volume, but as shown in the phase diagram in **Figure 2**, keeping CO_2 in a liquid state requires maintaining low temperatures and high pressures. For this reason, the temperature and pressure of liquefied CO_2 to be transported by sea needs to be in the range of approximately -55 to -20°C and just below 1.0 MPaA to 2.0 MPaA, respectively, thus the tank to contain the CO_2 needs to be a pressure vessel made of a material with high strength and excellent low-temperature characteristics.

In addition, if the pressure and temperature of CO_2 fall below the triple point during marine transportation or cargo handling, solidification may occur, i.e., dry ice may be formed. Therefore, in designing cargo tanks and cargo handling equipment of the liquefied CO_2 carrier, these factors need to be taken into consideration.

Generally, to reduce the risk of dry ice formation during operation, it is desirable to maintain a relatively high pressure and a sufficient margin with respect to the triple point shown in Figure 2. In this case, however, the cargo tank needs to withstand a relatively high pressure, thus its size is limited from the viewpoint of structural strength. On the other hand, to improve transportation efficiency, it is desirable to keep pressure conditions as low as possible and increase the volume of the cargo tank. In this way, these two conflicting factors need to be carefully taken into consideration in designing cargo tank structures and cargo handling equipment and setting cargo handling conditions is an important technological point for the realization of safe and efficient marine transportation by the liquefied CO_2 carrier.

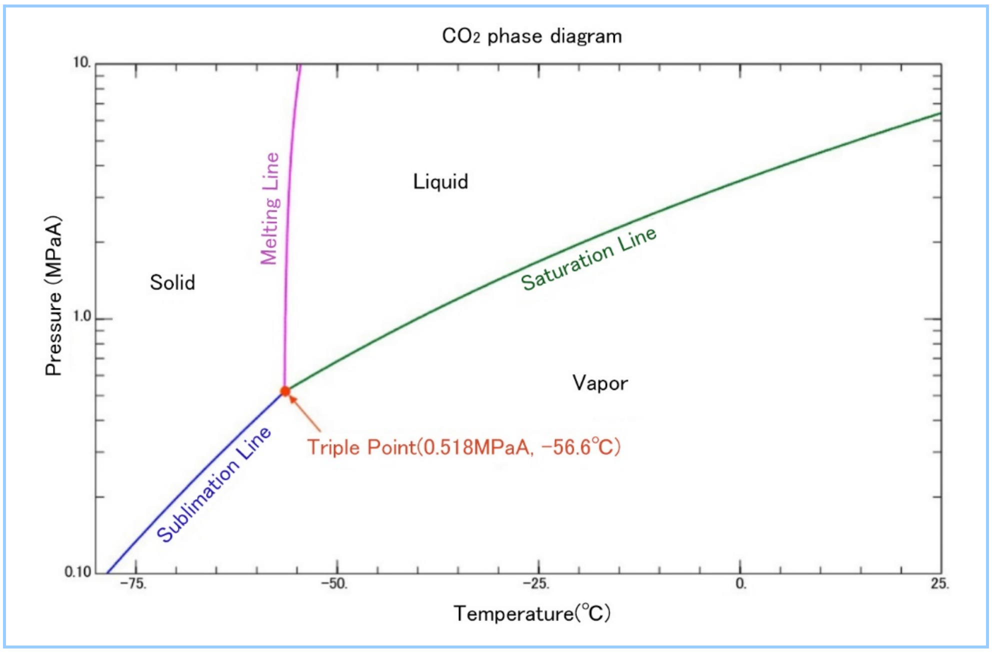

Figure 2 CO_2 phase diagram

1.3 Cargo tank

The vessel is equipped with two horizontal cylindrical cargo tanks, which are the independent tank type C as specified in the regulations of the International Maritime Organization (IMO) on the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk

(IGC Code). In order to satisfy the requirements of the IGC Code and the rules of the Classification Society, appropriate structural design and material selection for the cargo tanks were made as an LCO_2/LPG carrier. In addition, necessary countermeasures are taken against sloshing phenomena, which occur when the period of ship motion and the natural period of the liquid free surface in the tank are in sync, by calculating the detailed fluid loads using computational fluid dynamics (CFD) calculations and evaluating the strength of the tank structure using finite element analysis (FEA). **Figure 3** shows an example of the flow of liquefied CO_2 in the tank based on CFD analysis.

The cargo hold is divided into two sections, the front section and the rear section, and the tank covers are placed independently on the No. 1 and No. 2 cargo tanks. To minimize the clearance between the cargo tanks and the tank covers and maximize the tank volume at the same time, the structural reinforcement members of the tank covers are placed outside the hold. This measure allows the 996-gross tonnage vessel to secure a total volume of approximately 1,450 m^3 for the two tanks.

Furthermore, since low-temperature liquefied CO_2 is stored in the cargo tanks, their outer surfaces are covered with urethane foam insulating materials to suppress heat gain from the outside. **Figure 4** shows the external appearance of the cargo tank.

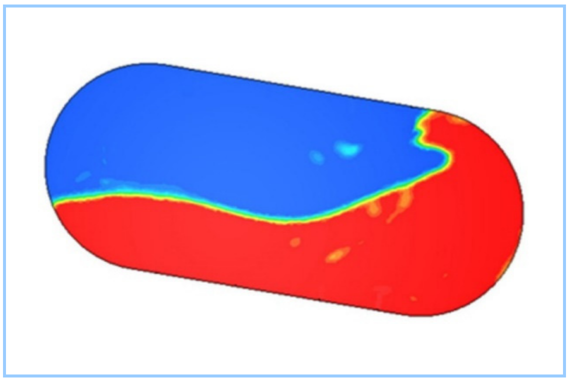

Figure 3 CFD sloshing simulation of liquefied CO_2 cargo tank

Figure 4 Cargo tank

1.4 Cargo handling equipment

The vessel's cargo handling equipment consists of shore manifolds located in the middle of the vessel between the two tanks on both sides of the hull, and two cargo tanks equipped with cargo pump, piping, instrumentation, and tank dome with access manhole. Two cargo gas compressors for cargo handling are installed in the cargo gas compressor room under the forecastle deck.

For these cargo handling equipment, equipment selection and piping design as LCO_2/LPG carriers were conducted considering various temperatures and densities due to cargo conditions, as well as changes in the state of liquefied CO_2 due to pressure and temperature changes during operation.

Furthermore, to ensure safe handling of CO_2 on board, experts from within the MHI Group have conducted repeated risk assessments in order to take the necessary safety measures. Prior to the delivery of the vessel, the gas trial (testing with cargo liquids) required by the IGC Code was conducted to confirm the performance of the cargo tanks and cargo handling equipment.

2. Future prospect

In order to achieve carbon neutrality by 2050, which is the reduction target of the Japanese government, it is considered important to implement CCUS in society, so liquefied CO_2 carriers are expected to be in greater demand in the future as a means of safe and economical mass transport of CO_2 separated and captured at the source to storage sites.

Mitsubishi Shipbuilding Co., Ltd. Is working to “Realizing Decarbonization of the Maritime Economy" in its "Marine Future Stream" development strategy, and as part of this, we are actively promoting the commercialization of the "LCO_2 handling system”, which consists of cargo tanks and cargo handling equipment for liquefied CO_2 carriers. Through such approaches, we will continue to contribute to the realization of a decarbonized society as a marine system integrator.