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Liquefied CO_2 Carriers and Ammonia as Fuel

Capital Link Decarbonization in Shipping Forum

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MITSUBISHI HEAVY INDUSTRIES

Characteristic of CO_2

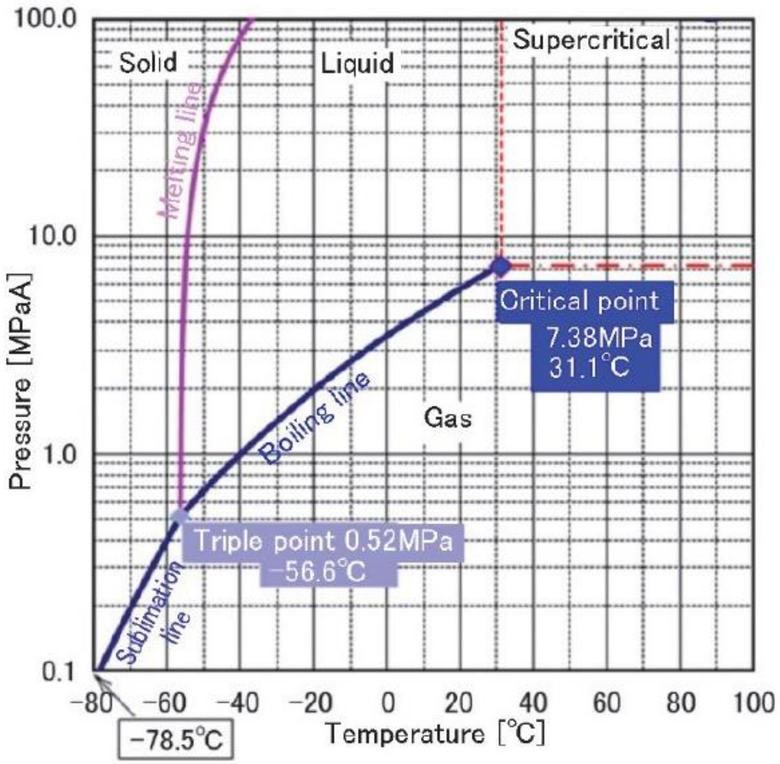

Figure: CO2 phase diagram

- CO_2 is a colorless and odorless gas that is slightly heavier than air at room temperature and atmospheric pressure.

- If the pressure and temperature of liquefied CO_2 fall to the triple point, dry ice may be generated, which may cause operational problems such as blockage of piping.

- To reduce the risk of dry ice generation during operations, it is generally desirable to transport liquefied CO_2 with the pressure kept as high as possible to provide a sufficient margin against the triple point. However, in such cases, the cargo tank needs to be able to withstand relatively high pressure and its size is limited from a structural strength standpoint.

Technological development status of liquefied CO_2 carrier

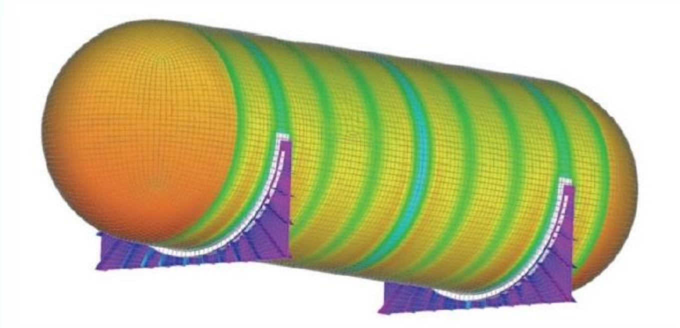

Figure: Example of structural strength analysis of liquefied CO_2 cargo tank

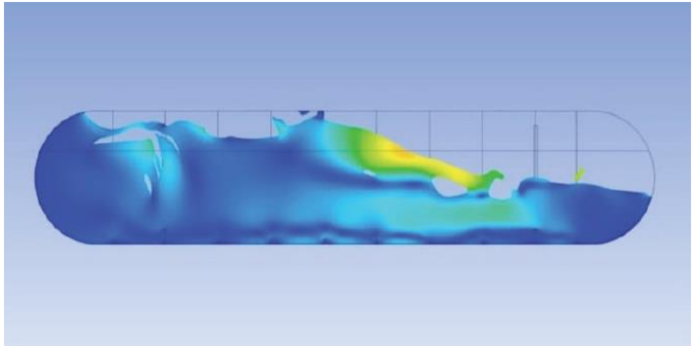

Figure: CFD sloshing simulation of liquefied CO_2 cargo tank

- In order to keep CO_2 in a low-temperature and high-pressure state, suitable cargo containment system is applied.
- Type-C (IGC code) tank generally adopted for cargo tanks of small liquefied gas carriers is well proven however appropriate consideration of greater specific gravity of liquid CO_2 (> 2 x LPG) is required.
- Mitsubishi Shipbuilding ensure the reliability of the cargo containment system by conducting detailed numerical analysis and numerical simulation by using CFD calculation.
- Mitsubishi Shipbuilding conducted comprehensive technical verifications and our cargo containment system for liquefied CO_2 carrier has obtained Approval in Principle (AIP) from Bureau Veritas.

Initiatives in liquefied CO2 transportation demonstration project for NEDO

Table: Principal particulars of liquefied CO_2 demonstration ship for NEDO

Registration	Japan
Length overall	72.0 m
Beam	12.5 m
Draft	4.55 m
Tank capacity	1,450 m^3

Figure: Conceptual image of the liquefied CO_2 demonstration ship for NEDO

- Mitsubishi Shipbuilding have signed a contract with Sanyu Kisen K.K. to build a demonstration ship for liquefied CO_2 transportation to be used in Research and Development of CCUS Technology in Tomakomai by New Energy and Industrial Technology Development Organization (NEDO).

- The demonstration ship will be delivered in the second half of fiscal 2023 prior to a liquefied CO_2 carrier built for the Norwegian "Northern Lights Project", one of the world's leading CCS projects, and is expected to be the world's first liquefied CO2 carrier for CCUS.

- Mitsubishi Shipbuilding is responsible for the entire design and construction of the demonstration ship, including the cargo tank system installed thereon, utilizing the knowledge cultivated so far in the construction of liquefied gas carriers.

Development of onboard CO_2 capture system

Marine-based CO_2 Capture System installed on board the CORONA UTILITY

https://www.mhi.com/news/21080501.html

- As MHI Group's aim of building a CO_2 ecosystem, Mitsubishi Shipbuilding is also working on the development of onboard CO_2 capture systems.

- In the project "CC-Ocean" which was jointly implemented with Kawasaki Kisen Kaisha, Ltd. and Nippon Kaiji Kyokai, Mitsubishi Shipbuilding conducted a demonstration test of a small-scale CO_2 capture demonstration plant under commercial operating conditions of ship, which was the first time in the world.

- The project was conducted over two years. A HAZID evaluation of the plant and a safety evaluation of the equipment and system were conducted, and then the demonstration plant was fabricated, installed on the coal carrier, and operated in an offshore environment for approximately six months for measurement and checking of the performance.

Ammonia as Fuel

Table: Characteristics of each ship's fuel

Ship's fuel (CO_2 emissions per calorific value)	Carbon-free, carbon-neutral fuel that allows diversion of infrastructure	Fuel liquefaction conditions	Fuel volume per calorific value	Suitability for mass transportation, long-term navigation
Heavy oil (1.0)	Biodiesel	Atmospheric pressure, room temperature	Base	Suitable
LNG (0.74)	Carbon recycled methane, biomethane	Atmospheric pressure, -162℃	x 1.7	Suitable
Methanol (0.90)	Carbon recycled methanol, biomethanol	Atmospheric pressure, room temperature	x 2.4	Suitable
Ammonia (0)	Green ammonia, blue ammonia	Atmospheric pressure, -33℃ or 1.8 MPaA, room temperature	x 2.7	Suitable
Hydrogen (0)	Green hydrogen, blue hydrogen	Atmospheric pressure, -253℃	x 4.5	Possible

- In recent years, increasing the sense of crisis over the global environment and climate change, it has been required to take measures for GHG reduction and carbon neutrality.
- LNG fuel has already been recognized as a bridging solution before carbon neutral fuels.
- The conditions and backgrounds for energy supply are different by ship type and operation pattern, and it is expected that ship's fuels in a variety of segments will coexist in the future.
- As shown in Table, differently from other candidate fuels, ammonia does not emit CO_2 and it has suitable characteristics for mass transportation and long-term navigation. Therefore, ammonia is recognized as a promising option.

Expectations for ammonia fuel

Figure: 87,000m3-type LPG-fueled large LPG/ammonia carrier

Figure: Image of large ammonia carrier

- Public-Private Fuel Ammonia Promotion Council under the Ministry of Economy, Trade and Industry of Japan has set the target of achieving the annual ammonia transportation volume to Japan of about 3 million tons by 2030 and about 30 million tons by 2050.

- Aug. 2021, Mitsubishi Shipbuilding has concluded a technical cooperation agreement with Namura Shipbuilding relating to LPG powered VLGCs which are capable of transporting both LPG and ammonia. Based on this agreement, Namura Shipbuilding is constructing LPG powered VLGCs on order from MOL Group.

- Nov. 2021, Mitsubishi Shipbuilding has reached an agreement with MOL and Namura Shipbuilding on joint development of large-size ammonia carrier fueled by ammonia.

Ammonia fuel supply system packages

Example of ammonia fuel supply system package	Example of LNG fuel supply system package
Ammonia fuel tank	LNG fuel tank
Ammonia boil-off gas treatment device/re-liquefaction device	LNG boil-ff gas compressor
Instrumentation equipment for ammonia fuel tank	Instrumentation equipment for LNG fuel tank
Emergency shutdown device for ammonia fuel tank/ bunkering	Emergency shutdown device for LNG fuel tank/bunkering
Ammonia fuel supply equipment	LNG fuel supply equipment
Ammonia fuel pump	LNG fuel pump
Instrumentation equipment for ammonia fuel supply	Instrumentation equipment for LNG fuel supply
Ammonia abatement device	-

Example of requirements for ammonia abatement equipment
Treatment of boil-off gas from ammonia tank
Treatment of purge gas in fuel piping
Treatment of leaked ammonia gas
Treatment of gas ammonia fuel tank at the time of regular inspection

- Ammonia fuel supply systems is better to be provided as a reliable package, as same as the LNG-fueled ship.
- To consider the large-scale use of ammonia as marine fuel, it is also necessary to quickly set up ammonia related rules and training for crews.
- So, development based on the same tech. from LNG is better for ammonia-fueled ships, equipment and crews.

Transition from LNG as fuel to Ammonia as fuel

80k DWT Bulk Carrier (Ammonia fuel)

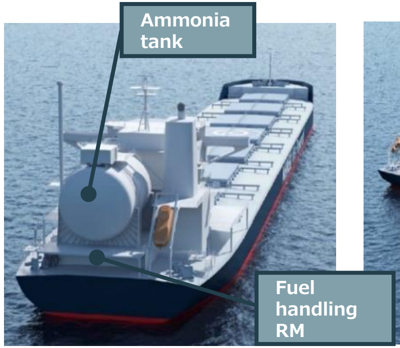

Table: Points on planning of ammonia-fuel-ready LNG-fueled ships

Points on planning of ammonia-fuel-ready LNG-fueled ships	
Fuel tank	Use of materials suitable for both LNG fuel and ammonia fuel
Main engine, auxiliary engine	Suitability of materials, difference in combustibility/calorific value, availability of partial modification, post treatment of exhaust gas
Fuel supply system	Differences between LNG fuel and ammonia fuel, know-how about handling of gaseous fuel
Compartments/arrangement	Arrangement of tanks, engines and a fuel supply system, fire protection structure, consideration of flammability/toxicity hazardous areas
Corrosiveness	Selection of materials in consideration of corrosiveness of ammonia and stress corrosion cracking
Abatement device	Planning on installation of an ammonia abatement device

- One of our prime concerns is when the use of carbon neutral fuels will get in largescale stage.
- It is difficult to forecast the time because there are various elements to be considered.
- Therefore, to secure flexibility in ship operation, ammonia-fuel-ready LNG-fueled ships have emerged as a new option.
- To operate ammonia-fueled ships, it is also important to secure capable crews beforehand, familiar with handling of gas fuel, that is well-experienced crews in LNG fuel.

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