78000m^3/83000m^3 LPG Carriers Combining Versatility and Economic Efficiency

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Today, with the expansion of the distribution of liquefied petroleum gas (LPG), there is a worldwide boom in constructing large LPG carriers. Mitsubishi Heavy Industries, Ltd. (MHI) LPG carriers are highly regarded in terms of reliability, good performance and wide versatility based on extensive construction experience since the Bridgestone Maru was constructed in 1962. The 78,000 m^3 LPG carrier (78LPG carrier below) series has been a long-term popular product and we have recently developed an 83,000 m^3 LPG carrier (83LPG carrier below) to respond to the needs for larger carriers, which has already been handed over to BP Shipping Limited. At present, our sales activities are conducted with the 78 and 83LPG carrier lineup and we will continue working on further improvements toward gaining constant orders through responding to the various needs of our customers.

1. Introduction

The commercial marine transportation of LPG, which started in the 1960s and has expanded year by year since then, amounted to about 50 million tons worldwide in 2005, and today approximately 110 large LPG carriers are engaged in its transportation. MHI has built approximately sixty LPG carriers since 1962 including multi purpose vessels which can carry LPG and also ammonia, etc. and have established a good track record, having constructed the largest number of LPG carriers in the world.

In particular, the company's basic concept with regard to 78LPG carriers has been widely accepted since the delivery of the Nichiyuh Maru in 1989 and more than thirty 78LPG carriers have been built to date. Today, having added the 83LPG carriers its lineup, MHI is engaged in sales activities to meet its customers' needs.

This paper introduces the features of MHI's newest 78/83LPG carriers such as good performance, wide versatility, and structural integrity which realize excellent reliability, and their rational specifications for LPG carriers, and touches on their future aspects.

2. Characteristics of MHI 78,000 m^3/83,000 m^3 LPGC

As shown in **Table 1**, the construction of MHI's LPG carriers started with the Bridgestone Maru in 1962 (constructed by Yokohama Dockyard and Machinery Works) and has continued to this day, including the transfer to Nagasaki Shipyard and Machinery Works in 1980. In particular, a total of thirty-three 78LPG carriers, which originated with the Nichiyuh Maru of 1989, have been constructed to date, including one model change, and they are now regarded as the de facto standard size in the large LPG carrier market. As a result, this model has become the standard for ship-shore compatibility, which has created more demand for the 78,000 m^3 type, and thus this model has been continuously constructed till the present day. Further, the continuous construction of the same model has contributed not only to accumulating experience in design and manufacturing but to quality improvements.

The 83LPG carriers which joined the lineup from 2006 inherited the design concepts of the 78LPG carriers.

The characteristics of MHI's 78/83LPG carriers are described below.

Table 1 LPG carriers constructed by MHI

Year of delivery	Vessel name	Cargo capacity	Remarks
January 1962	Bridgestone Maru	28 837m^3	World's first fully refrigerated large LPG carrier
April 1970	Kanayama Maru	70 238m^3	
March 1980	Gas Libra	77 327m^3	The last LPG carrier built at Yokohama Dockyard & Machinery Works. A total of fourteen LPG carriers were built there.
February 1982	Tenryu Maru	77 290m^3	The first LPG carrier built at Nagasaki Shipyard & Machinery Works.
September 1989	Nichiyuh Maru	78 508m^3	The first first-generation 78LPG carrier. A total of twenty-two first-generation 78LPG carriers were built.
June 2000	Gas Diana	78 888m^3	The first second-generation 78LPG carrier
March 2006	British Confidence	83 270m^3	The first 83LPG carrier

As of June 2007, a total of eleven second-generation 78LPG carriers (order backlog 5 vessels) had been built with a total of three 83LPG carriers (order backlog 6 vessels).

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2.1 Basic concept

MHI's 78/83LPG carriers were designed based on the following concepts:

(1) To adopt a highly versatile basic design by giving consideration to various trade patterns.
(2) To be outstanding in voyage profit with good propulsive performance (fuel consumption).
(3) To secure a highly reliable hull structure.
(4) To be highly usable in actual operation based on simple and rational specifications.

2.2 Basic design

While the vessels used for transportation of LNG (liquefied natural gas) are most often designed as a special vessel for each specific project, LPG carriers are often used with unspecified buyers or shipping points and are often subject to multiple port unloading, thus requiring high flexibility.

Considering this flexibility and major trading routes, between the Middle East and Japan, we have made it possible for the 78LPG carrier to enter the major terminals for large LPG carriers by adopting an overall length of not more than 230 m, a shallow draught of 10.6 m, and an air draught of less than 40 m. (**Table 2** shows the principal specifications.)

The 83LPG carrier has been designed based on the 78LPG carrier's hull form having outstanding performance, and has the same length and width but with a greater depth and draught.

As shown in **Fig. 1**, it is equipped with four independent prismatic cargo tanks, adopting thermal insulation of polyurethane foam which covers the cargo tanks. For the tank configuration, minimizing the clearance between the hull and the tank and keeping good manufacturability were taken into consideration in order to achieve good volumetric efficiency and fit the high performance hull form. Also, the tank dome has been placed in the center of the tank on account of structural rationality and in-tank accessibility.

Table 2 Principal specifications

	78LPG carrier	83LPG carrier
Loa (m)	230.0	230.0
Lpp (m)	219.0	219.0
B (m)	36.6	36.6
D (m)	20.8	21.65
d (m)	10.6	11.15
Deadweight (t)	abt. 48 500	abt. 51 000
Cargo capacity (m^3)	78 500	83 000
Main engine output MR (kW) NR (kW)	 12 360 11 120	 13 700 12 330
Service speed (kt)	16.7	17.0
Endurance (sm)	18 000	18 000

All the fuel tanks have been placed at the aft part considering the ease of maintenance. Also, as an environmental measure, the LPG carriers built in recent years have a double-sided structure for the fuel oil tanks, ahead of the enforcement of the regulation.

2.3 Propulsive performance and fuel consumption

The hull form of 78/83LPG carriers was decided in consideration of the following points:

- To contain independent prismatic tanks.
- To secure sufficient parallel body length considering ship-shore compatibility.
- To maintain good performance both at loaded and ballast condition.

The hull form was designed based on extensive accumulated data considering the above points and optimized by CFD and model experiments.

Further, the carrier is equipped with a Mitsubishi Reaction Fin as an energy-saving device as well as a highly efficient skewed propeller.

As a result, as shown in Table 1, the service speed of 16.7 kts (17.0 kts for the 83LPG carrier) is assured at loaded condition and good performance is also secured at ballast condition.

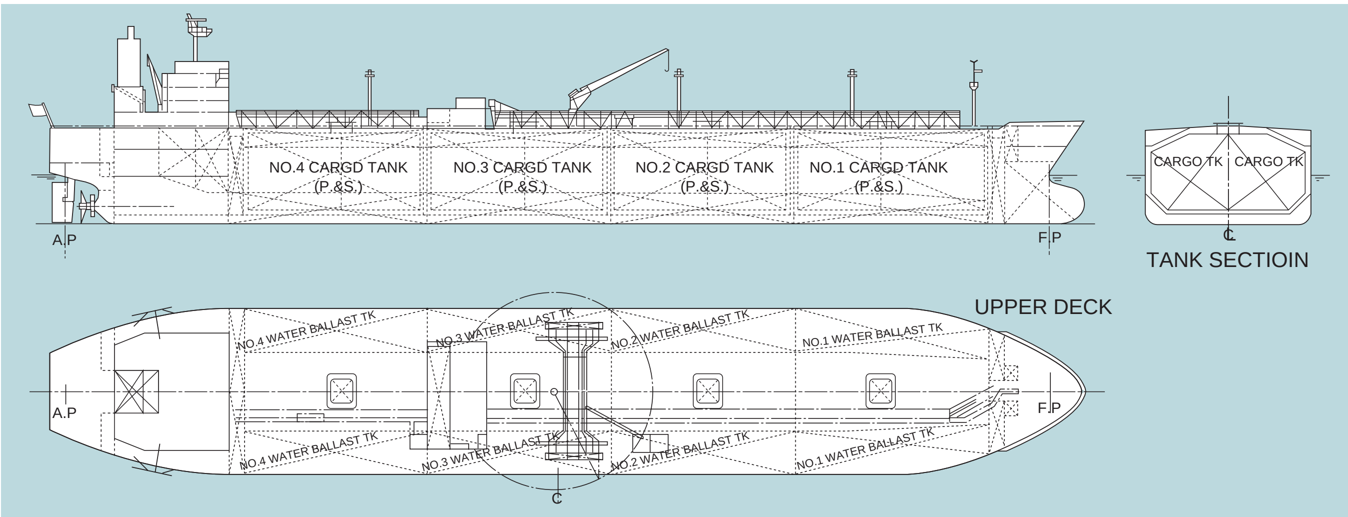

Fig. 1 General arrangement plan

2.4 Structure design

The structural characteristics of the 78LPG carrier are shown in **Fig. 2**. The independent prismatic tanks are contained in a cargo hold of a shape similar to a bulk carrier and are supported by a structure called a bearing seat. The anchors are mounted on the bottom and top faces of the tank, and prevent the tank from being moved by pitching and rolling. Further, to maintain versatility, the cargo tanks have sufficient strength so that cargo can be loaded without a liquid level limitation.

The structure of the present second generation 78LPG carriers have been decided considering the following to be a robust structure based on extensive feedback from the first generation.

- The dimensions and configuration of the hopper structure which supports the loads at the cargo tank side were determined by FEM analysis.
- Layout of bearing seat: The seat structure and layout were determined in accordance with the results of reaction force calculations based on FEM analysis.
- The layout of the pitching anchor was determined in consideration of the movement of the cargo tank at sea.

Also, for the carriers built in recent years, FEM strength analysis by LR ShipRight was implemented and structural notations, SDA and FDA, have been acquired. In addition, the fatigue strength was evaluated with high precision by a simulation of the stress response in ocean waves based on the spectrum analysis method (DILAM: direct loading analysis method) (**Fig. 3**). The results have been incorporated into the design.

With regard to vibration, based on a theoretical design using a proven numerical propeller calculation method called UQCM (unsteady quasi-continuous method), we developed a highly efficient propeller with outstanding cavitation performance, which successfully reduced the propeller excitation force. At the same time, the structure was designed to avoid resonant vibration by a whole vessel FEM analysis. In connection with the above, we carried out a cavitation test using MHI's cavitation tunnel to check the cavitation pattern and pressure fluctuation, which confirmed the performance. (**Figure 4** shows an example of a cavitation test.) Further, we adopted a 7 cylinder main engine which has advantageous vibration characteristics.

As a result of these measures, a sufficiently low vibration level has been verified.

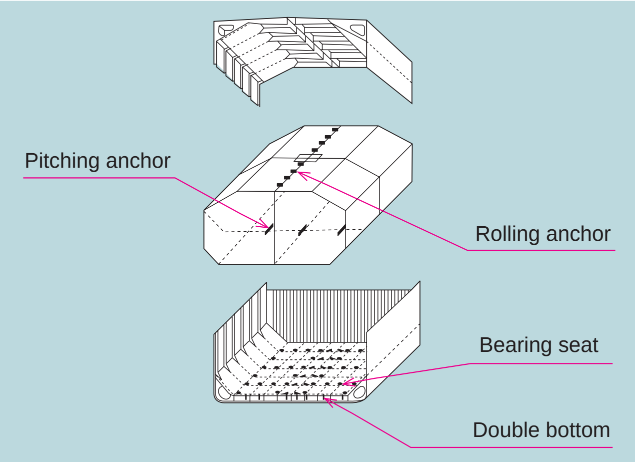

Fig. 2 Tank structure

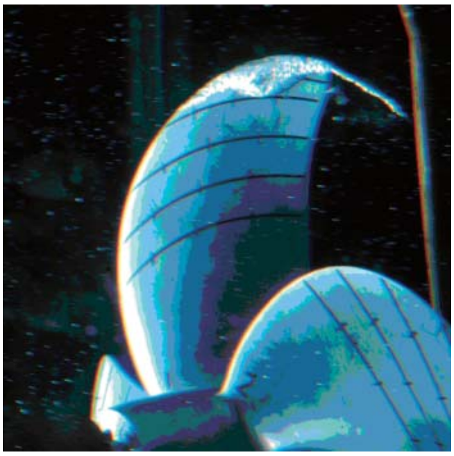

Fig. 4 Cavitation test

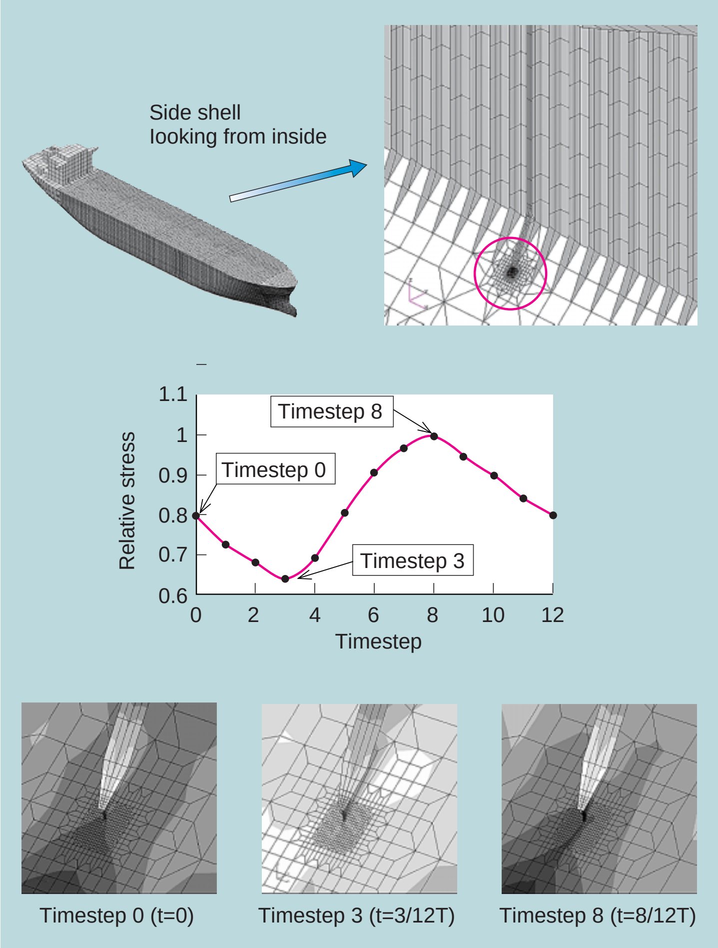

Fig. 3 Simulation of stress response in oceanic waves concerning local stress conducted by DILAM, a sophisticated analysis method

Table 3 Particulars of cargo section

Kind of cargo	Propane, butane
Cargo tank Type Number of tanks	Independent prismatic tank Type A 4
Cargo Pump	Electric motor driven submerged pump 8 sets
Reliquefaction plant	4 sets
Thermal insulation	Polyurethane foam
Booster Pump	1 set
LPG Heater	1 set
Inert Gas Generator	1 set

2.5 Specifications of cargo section

Table 3 shows the principal specifications of the cargo section of MHI's 78/83LPG carriers. The features of the cargo section are described below.

- Simple equipment configuration with easy maintenance

  There are many multi purpose LPG carriers which can carry cargo other than LPG such as ammonia. On the other hand, in MHI's 78/83LPG carriers, by limiting the cargo only to propane and butane, the cargo handling equipment has been optimized for these cargoes, which enables simplicity and good maintainability. For example, as there are no restrictions concerning the use of copper for propane and butane, submerged cargo pumps which are compact and safe have been adopted.

- Compatibility with shore terminals

  The manifold layout and specifications of the cargo handling equipment were chosen considering compatibility with existing shore terminals, thus assuring a versatile design.

- Flexibility of cargo allocation

  The cargo piping was designed to enable the loading of propane and butane in tanks in any combination. Also, the piping was installed to facilitate changing the number of reliquefaction plants in operation according to the volume of boil-off gas. Thus flexibility of cargo operations is taken into consideration.

3. Future trends of LPG carriers

With regard to the future trends of LPG carriers, below is a brief outlook regarding vessel size and environmental measures.

3.1 Size

From the perspective of reducing transportation costs per unit, the size of LNG carriers is increasing. While the standard size was 135,000 m^3 just a decade ago, a carrier exceeding 200,000 m^3 is being built in 2007.

On the other hand, although there is a possibility that some large LPG carriers will be built for specific projects, it is generally presumed that demand for highly versatile vessels for worldwide trade will continue as is the case today.

3.2 Environmental measures

Under the circumstances where each nation is tightening up its environmental restrictions, the need for environmental measures is expected to increase in LPG carrier industry where versatility is considered important.

(1) Measures against main engine exhaust emission

While NOx emissions have already been restricted by international regulations, restrictions on SOx emissions are also being tightened on a regional basis such as in the Baltic Sea and the North Sea. As the environmental restrictions are expected to become even tighter, the fuel oil tanks are subdivided as a measure for the sulfur control of fuel oil.

Also to reduce CO_2 emissions, requests for low fuel consumption will also increase.

(2) Ballast water treatment

With regard to the treatment of ballast water, it is scheduled that the installation of treatment equipment will be made obligatory after 2012. Prior to that, pilot equipment is planned to be installed on the 78LPG carrier which is scheduled to be completed in March 2008.

4. Conclusion

MHI has been building LPG carriers since 1962. In the field of 78/83 LPG carriers, making the most of the experience accumulated over many years and improvements in the course of technological evolution, MHI's vessels have long been regarded as the standard in the LPG carrier market.

With the expectation that demands for LPG will further increase in the future, we will continue to supply high-quality LPG carriers by making good use of our shipbuilding experience and we would like to meet our customer's needs by proactively improving economic efficiency and environmental measures.


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