DOMESTIC LNG SUPPLY SYSTEM BY PRESSURE BUILD-UP TYPE LNG CARRIER

SYSTÈME DE FOURNITURE DE GNL À L’INTERIEUR DU PAYS PAR LE MÉTHANIER DU TYPE PRESSURISÉ

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ABSTRACT

Presently, gas suppliers throughout Japan are advancing the replacement of conventional gas materials with natural gas and LNG is supplied to small-scale gas suppliers by tank lorries or railway containers. However, a more efficient means of LNG transportation has been demanded by medium-scale gas suppliers (whose annual consumption is in between approximately 30,000 and 300,000 tons) located far from LNG import terminals.

Recently, Nippon Steel Corporation has realized a LNG secondary transportation system by small-size coastal vessels for the first time in Japan. In this system, pressure build-up type LNG carrier “Shinju Maru No.1” built by Kawasaki Shipbuilding Corporation is utilized for LNG supply to places of consumption that are approximately 200 nautical miles away from LNG receiving terminals for oceangoing LNG carriers. The establishment of this secondary transportation system has enabled the LNG supply to small and medium-scale LNG consumers with more reasonable price than before.

This report describes the outline of the LNG secondary transportation system along with the outline of the pressure build-up type domestic LNG carriers with the following items: (1) System Concept, (2) Cargo operation, and (3) Results of comparison between design estimation and measured data on actual vessel. Expansion of domestic secondary transportation service to many more consumers will be expected in the future, because the system is suitable to the characteristics of LNG consumption in Japan, where places of consumption are mainly located along coastal areas.

RESUME

Actuellement, les fournisseurs de gaz dans tout le Japon sont en train de remplacer les gaz classiques par le gaz naturel, et le GNL est livré aux petits fournisseurs de gaz par des camions-citernes ou des conteneurs ferroviaires. Cependant, les moyens fournisseurs de gaz (dont la consommation annuelle est comprise approximativement entre 30 000 et 300...
000 tonnes), situés loin des terminaux d’importation de GNL, demandent des moyens plus efficaces de transport de GNL.

Nippon Steel Corporation a récemment réalisé, pour la première fois au Japon, un système de transport secondaire de GNL par de petits navires côtiers. Dans ce système, le méthanier du type pressurisé “Shinju Maru No.1”, construit par Kawasaki Shipbuilding Corporation, est utilisé pour la livraison de GNL aux lieux de consommation qui se trouvent à environ 200 miles marins des terminaux de réception de GNL destinés, destinés aux méthaniers océaniques. La mise en place de ce système de transport secondaire a permis la livraison de GNL aux petits et moyens consommateurs de GNL à un prix plus raisonnable qu’avant.

Ce rapport décrit les grandes lignes du système de transport secondaire de GNL avec la description générale des méthaniers du type pressurisé pour le transport intérieur en ce qui concerne les points suivants : (1) Concept du système, (2) Manutention de la cargaison, et (3) Résultats de la comparaison entre l’estimation faite lors de la conception et les données mesurées sur le navire réel. Il est espéré que le service de transport secondaire intérieur s’étendra à beaucoup plus de consommateurs dans l’avenir, car le système est adapté aux caractéristiques de consommation du GNL au Japon, où les lieux principaux de consommation se trouvent le long des zones littorales.

1. PROJECT BACKGROUND

1.1 Present Conditions of LNG Secondary Transportation and Problems Awaiting Solution

Presently, over 20 LNG terminals are in operation in Japan. Most of them are located in places of consumption concentrating in the Pacific coastal zone (See figure 1).

According to the actual results in 2002, approximately 50 million tons of LNG (approximately 15 million tons for gas suppliers and approximately 35 million tons for power generation and other purposes) were imported to Japan by large-size LNG carriers. As far as the LNG imported by the gas suppliers is concerned, it is mainly supplied to consumers close to the LNG import terminals through pipelines.

On the other hand, the LNG secondary transportation of an annual amount of several thousand tons is performed by tank lorries of about 10 tons capacity each or railway containers for places far from the LNG import terminals, where the connection of pipelines is inefficient. The scale of the LNG secondary transportation amounts to approximately 250,000 tons annually throughout Japan. (As of 2002, the number of applicable business establishments was 50 with an annual average consumption of approximately 5,000 tons each.)

The 10-ton-scale transportation of LNG in tank lorries or railway containers, however, has the following problems.

(1) Great quantitative restrictions
   (The means of transportation will be extremely inefficient if a certain scale is exceeded.)

(2) Difficulty in obtaining a scale merit
Therefore, more efficient means of transportation substituting the use of tank lorries or railway containers has been demanded by medium-scale gas suppliers (whose annual consumption is in between approximately 30,000 and 300,000 tons each) located far from the LNG import terminals.

![Figure 1. LNG Terminals in Japan](image)

1.2 Development of LNG Secondary Transportation System by Small LNG Carrier

Under the above backgrounds, gas suppliers having their production facility on the coast of the Seto Inland Sea have been strongly requesting LNG secondary transportation using coastal service vessels. In response to their request, Nippon Steel Corporation has realized LNG secondary transportation by a small coastal vessel for the first time in Japan.

The LNG secondary transportation reported here is intended for the LNG supply business for places of consumption (the Takamatsu terminal of Shikoku Gas Co., Ltd. in Takamatsu city and the Chikko terminal of Okayama Gas Co., Ltd. in Okayama city) approximately 200 nautical miles away from a domestic LNG terminal (Kitakyushu LNG Co., Ltd. in Kitakyushu city*1) by the small-size pressure build-up type LNG carrier built by Kawasaki Shipbuilding Corporation (See figure 2).

The establishment of the secondary transportation system has made it possible to provide LNG more inexpensively than before to medium-scale LNG consumers who had to rely on tank lorries and railway transportation in the past. Furthermore, this system has excellent transportation efficiency in comparison with land transportation. It is also a desirable system from a viewpoint of the reduction of environmental burdens.

*1: Shipments from the Himeji Terminal (in Himeji city) of Osaka Gas Co., Ltd. are expected in and after 2005.
2. PROJECT OUTLINE

2.1 Transportation Plan

The following quantity of LNG will be transported on an annual basis.

Table 1. LNG Transportation quantity and number of voyages

<table>
<thead>
<tr>
<th>Year</th>
<th>2003</th>
<th>2011</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual transportation quantity (ton)</td>
<td>22,000</td>
<td>approx.170,000</td>
<td>approx.200,000</td>
</tr>
<tr>
<td>Number of voyage per year</td>
<td>22</td>
<td>approx. 170</td>
<td>approx. 200</td>
</tr>
<tr>
<td>Required number of vessel</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

2.2 Transportation Route

The following transportation route will be taken.
2.3 Outline of Domestic LNG Transportation System

2.3.1 Operation Pattern

Figure 3. Transportation route

Figure 4. Operation pattern
2.3.2 Required Time

(1) Navigation Time
   (in case of Kitakyushu, Tobata port at a speed of approx. 12 knots)
   • Loading port (Tobata) → Discharging port (Takamatsu): Approx. 17 hours
   • Loading port (Tobata) → Discharging port (Okayama): Approx. 18 hours

(2) Berthing hours (Almost common for loading port and discharging port)
   • Berthing hours: Approx. 6 to 7 hours
     (Breakdown)
     (i) Loading/Discharging: Approx. 2 to 3 hours
     (ii) Others: Approx. 4 hours
        (Berthing/Deberthing, preparations for loading/discharging, preparations for
         departure, other miscellaneous operations)

(3) Required time for one round navigation
   • Approx. 46 to 50 hours (approx. 2 days)

2.4. Cost

Figure 5 shows a rough cost comparison between vessels and tank lorries for domestic secondary transportation. Provided that the transportation distance stays constant, the cost drops with an increase in the quantity of cargo, thus competitiveness increase.

The quantity of cargo on the cost crossover point varies with not only transportation distance but also the amount of investment (i.e., the vessel, facilities at export/import terminals). Therefore, further study on each case is necessary.

![Figure 5. Images of cost vs. means of transportation (for constant distance)](image-url)
### 2.5. Outline of LNG Export/Import Terminals (For Reference)

#### 2.5.1 Export Terminal

**Kitakyushu LNG Co., Ltd.**

<table>
<thead>
<tr>
<th>Location</th>
<th>Tobata-ku, Kitakyushu, Fukuoka Prefecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plottage</td>
<td>Existing 202,048 m²</td>
</tr>
<tr>
<td>LNG storage facilities</td>
<td>Existing LNG storage tank 480,000 kl (60,000 kl x 8 tanks)</td>
</tr>
<tr>
<td>Port facilities</td>
<td>Existing: Oceangoing LNG tanker berth for 125,000m³ vessel × 1 New construction: Domestic LNG tanker berth for 2,500m³ (2,936 gross tons) vessel × 1</td>
</tr>
<tr>
<td>Annual handling quantity</td>
<td>Acceptance quantity: 1,670,000 tons annually (achievement in 2002) Shipment quantity: 21,000 tons in 2003 to approx. 100,000 tons in 2017 (The balance will be shipped from the Himeji Terminal of Osaka Gas)</td>
</tr>
<tr>
<td>Year of construction</td>
<td>Commencement of work for this project in 2002 and start of operation in 2003 (shipping facilities only)</td>
</tr>
</tbody>
</table>

#### 2.5.2 Import Terminal

(1) **The Takamatsu Terminal of Shikoku Gas Co., Ltd.**

<table>
<thead>
<tr>
<th>Location</th>
<th>Port of Takamatsu (on the premises of Shikoku Gas Co., Ltd., Asahimachi, Takamatsu, Kagawa Prefecture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plottage</td>
<td>14,313 m²</td>
</tr>
<tr>
<td>LNG storage facilities</td>
<td>New construction: 10,000 kl × 1</td>
</tr>
<tr>
<td>Port facilities</td>
<td>New construction: Domestic LNG tanker berth for 2,500 m³ (2,936 gross tons) vessel × 1</td>
</tr>
<tr>
<td>Annual handling quantity</td>
<td>Acceptance quantity: 8,000 tons in 2003 to approx. 130,000 tons in 2017 (Total amount of Shikoku Gas Co., Ltd.)</td>
</tr>
<tr>
<td>Year of construction</td>
<td>Commencement of work in 2001 and start of operation in 2003</td>
</tr>
</tbody>
</table>

(2) **The Chikko Terminal of Okayama Gas Co., Ltd.**

<table>
<thead>
<tr>
<th>Location</th>
<th>Port of Okayama (on the premises of Okayama Gas Co., Ltd., Fukushima-chiku, Okayama, Okayama Prefecture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plottage</td>
<td>86,505 m²</td>
</tr>
<tr>
<td>LNG storage facilities</td>
<td>New construction: 7,000 kl × 1</td>
</tr>
<tr>
<td>Port facilities</td>
<td>New construction: Domestic LNG tanker berth for 2,500 m³ (2,936 gross tons) vessel × 1</td>
</tr>
<tr>
<td>Annual handling quantity</td>
<td>Acceptance quantity: 13,000 tons in 2003 to approx. 70,000 tons in 2017</td>
</tr>
<tr>
<td>Year of construction</td>
<td>Commencement of work in 2001 and start of operation in 2003</td>
</tr>
</tbody>
</table>
3. OUTLINE OF PRESSURE BUILD-UP TYPE LNG CARRIER

3.1 Features of Vessel

Different from large-size oceangoing LNG carriers, the cargo tank of this vessel is constructed under a pressure build-up concept (to be further described later). With the adoption of the pressure build-up system, the vessel is not required boil-off gas handling, so the cargo operation during navigation becomes much easier. Furthermore, the system enabled the adoption of an oil-fired diesel engine, which is common for merchant vessels, as the propulsion system. These factors made the operability of this vessel similar to pressurized-type coastal service LPG carriers, which have many experience of coastal service in Japan. Therefore, crews of coastal vessels those have no experience on LNG carriers can operate this vessel comparatively with ease.

Furthermore, each voyage of this vessel is short, and the vessel has to arrive and leave the berth frequently. Therefore, the vessel is provided with a bow thruster, controllable pitch propeller, and high-lift rudder, thus improving the manoeuvrability of the vessel.

From a safety point of view, in preparation of the emergency stop of the main engine at sea as a result of trouble, the vessel is provided with an emergency propulsion motor powered by the generator of the vessel so that the vessel would not fall in an inoperable state. Moreover, the side and bottom of the hull are of double-hull construction to minimize the influence of accidents on the cargo tanks. The vessel navigates in coastal areas, but the hull was constructed on an oceangoing basis and has sufficient structural strength.

Table 2 shows the main particulars of the vessel, and figure 6 shows the general arrangement of the vessel.

<table>
<thead>
<tr>
<th>Items</th>
<th>Particulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification</td>
<td>Coasting service (domestic)</td>
</tr>
<tr>
<td>Principal Dimensions</td>
<td>80.3 m (Lpp) x 15.1 m (B) x 7.0 m (D) x 4.171 m (d)</td>
</tr>
<tr>
<td>Deadweight</td>
<td>1,781 t</td>
</tr>
<tr>
<td>Main Propulsion System</td>
<td>4-cycle marine diesel engine</td>
</tr>
<tr>
<td>Max. Continuous Output</td>
<td>1,912 kW x 270 rpm</td>
</tr>
<tr>
<td>Ship’s speed</td>
<td>abt. 12.4 kts</td>
</tr>
<tr>
<td>Cargo Tank</td>
<td>2 x Independent Cylinder Tank made of aluminum alloy (Type C)</td>
</tr>
<tr>
<td>Volume</td>
<td>2,513 m3 (total)</td>
</tr>
<tr>
<td>Design Temperature</td>
<td>−163 deg.C</td>
</tr>
<tr>
<td>MARVS</td>
<td>300 kPaG</td>
</tr>
<tr>
<td>Tank Insulation</td>
<td>Kawasaki Panel System, B.O.R.: 0.47 %/day</td>
</tr>
</tbody>
</table>
3.2 Concept of Pressure Build-up Type LNG Carrier

3.2.1 Overview

Since LNG is transported at cryogenic temperature, it is impossible to avoid external heat ingress completely. An oceangoing LNG carrier sends boil-off gas due to heat ingress to the boiler in the engine room for utilizing as a propulsion fuel. Therefore, the cargo tank pressure is maintained at almost the same as atmospheric pressure and the cargo temperature is kept almost constant. On the other hand, under the pressure build-up concept, boil-off gas is not discharged outside the tank, and heat ingress is stored in the cargo inside tanks. That is, heat ingress is absorbed as a result of a temperature rise of the LNG in the tanks, and the cargo tank pressure rises gradually while keeping the balance of temperature and pressure inside the tanks.

In this project, the pressure build-up concept was applied for the simplification of the cargo operation of the vessel considering the following aspects:

1) The temperature and pressure rises of the LNG in the cargo tank at sea can be kept low by minimizing heat ingress into the cargo tank due to the application of Kawasaki Panel System as high-performance tank insulation.

2) The design of the tank as a pressure vessel is easy owing to its small capacity.

3.2.2 Cargo Tank Design

The concept of the LNG tank of low-temperature pressure build-up type is found in the IGC code and classification society rules, but there had been no actual experience of building the tank of this type in Japan. Therefore, it was necessary to determine specific design requirements, such as the pressure build-up period to be set, conditions for the calculation of the cargo tank pressure and temperature rises within the period, etc.
Especially, the most important items were the estimation of the cargo tank pressure rise and the setting of the design pressure of the tanks to allow the pressure rise. The tank temperature and pressure rises vary with the situation of the tanks. That is, during navigation, the LNG in the tanks is in a state of agitation at all times due to the ship motion and the temperature rise of the LNG in the tanks may be considered uniform in the tanks.

On the other hand, under conditions where the tanks are left still such as the vessel is at anchor in a still water (though it seems more severe assumption than actual), which is similar to the environment of on-land terminal, there will be a high-temperature stratum on the surface of the LNG, which is seen in LNG tanks of on-land terminals as well. In such cases, a great rise in the cargo tank pressure was anticipated.

From the beginning of the development of this vessel, we discussed with Class NK and set a pressure build-up period to be 7 days from the single voyage duration required for navigation through Japan plus 2 days’ margin. The design pressure of the tank was set to 300 kPaG in consideration of the high-temperature surface stratum phenomena of the LNG.

Furthermore, with consideration to securing the necessary period for countermeasure against marine accidents, such as stranding, an agitation device by LNG showering was installed to extend the pressure build-up period to be maximum 21 days by equalizing the pressure and temperature distribution of the LNG in the tank.

In order to satisfy these design requirements, we adopted the tank system consist of two horizontal cylinder tanks (also with consideration to tank arrangement in a limited space at fore part of the vessel) made of aluminum-alloy and Kawasaki Panel tank insulation system based on our achievement in the construction of Moss type LNG carriers in the past.

The tank support was designed to be saddle-type structure and its shape was suitably decided by detail study on the continuity of the tank with the insulation at the time of the contraction at low temperature. Figure 7 shows the cargo tank.

Figure 7. Cargo tank
3.2.3 Sloshing Analysis

Swash bulkhead, which is usually installed for horizontal cylindrical tanks of small-size pressure type LPG carriers, is not installed for this vessel to avoid damage to the connection parts between the tanks and bulkheads.

Furthermore, pipe tower, which is usually installed for the storage of inner piping and equipment in large-size Moss type LNG carriers, is neither installed due to simplification of structural arrangement.

Consequently it is necessary to investigate the influence of sloshing on the inner tank equipment, 3D sloshing analysis was conducted by the technical institute of Kawasaki Heavy Industries, Ltd. and the load distribution to each part of the equipment according to the calculated flow speed distribution in the position of the equipment was estimated [1]. Then the allocation and support method of the equipment was decided based on the result of analysis.

Figure 8 shows an example of the analysis.

3.3 Cargo Temperature and Pressure Rises During Navigation

3.3.1 Laden Voyage

As described before, heat ingress to the cargo tanks of the vessel is absorbed with a temperature rise in the LNG in the tanks. Figure 9 shows the result of our study of the tank inner pressure rise under the condition that the tank is kept still with a high-temperature surface stratum generated in the LNG.
According to the above graph, the cargo tank pressure after the pressure build-up period of 7 days will be approximately 280kPaG with high-temperature surface stratum generation, which was below the design tank pressure of 300kPaG. In the case of maintaining the uniformity of LNG in the tanks with the LNG shower system used, the pressure rise after the pressure build-up period of 21 days in emergency situations will be approximately 170kPaG, which is also less than 300kPaG according to Figure 9.

Figure 10 shows the tank inner temperature rise and the surface temperature of LNG after 7 days will be around minus 140°C.

### 3.3.2 Verification of Shower System

The vessel is provided with the LNG shower system for the purpose of extending the pressure build-up period by maintaining the uniformity of LNG temperature in the tanks. For the purpose of verifying the effectiveness of LNG shower system, a stratification extinction test was conducted at design stage [1].
Figure 11 shows the system diagram of the test equipment.

![Test equipment system diagram](image)

**Figure 11. Test equipment system diagram**

At the test, liquid nitrogen, which has close property to LNG, was filled into the inner tank and was sealed to reproduce the pressure build-up state. Then liquid nitrogen was showered through a nozzle installed at the upper part onto the liquid surface to check the extinction of the stratum.

Figure 12 shows the changes of the liquid and gas temperatures and the inner pressure of the tank. The stratum and bulk liquid at a pressure of 300kPaG were mixed by showering the liquid nitrogen onto the liquid surface.

As a result, the surface temperature of the liquid dropped and the liquid temperature distribution became almost uniform. Then it is confirmed that the pressure dropped to approximately 100kPaG, which is correspond to the saturated pressure at the liquid temperature.

![Changes of liquid and gas temperatures and pressure](image)

**Figure 12. Changes of liquid and gas temperatures and pressure**
3.3.3 Ballast Voyage

Different from laden voyage, most of heat ingress during navigation is absorbed by a temperature rise of the gas in tanks at ballast voyage because there is little residual LNG in the tanks. Furthermore, the residual LNG is evaporated into gas due to the heat ingress and the tank inner pressure rises within a short period in comparison with the pressure rise at laden voyage.

Figures 13 and 14 show the results of the study on tank inner temperature and pressure rises in case that the residual LNG was 2 m$^3$ per tank. From these graphs, the tank inner pressure after pressure build-up period of 21 days is approximately 270kPaG, which is still within the design tank pressure (300kPaG).

The cargo tank pressure is influenced not only by the gas temperature and pressure in the tank immediately after the discharge of cargo, but also by the amount of residual LNG. Therefore, it is important to reduce the residual LNG as much as possible at ballast voyage.

![Figure 13. Pressure rise at ballast voyage](image1)

![Figure 14. Gas temperature rise at ballast voyage](image2)
3.3.4 Comparison with Actual Data

The vessel came into actual operation in early August 2003. As of the end of August 2003, the vessel finished six voyages. Figure 15 shows the comparison of the design assumption of the LNG temperature rise in the tanks and the actual data measured at laden voyage.

The actual data varied more or less with each voyage, but it is confirmed the temperature rises were almost according to the design assumption and the vessel satisfies the specified performance.

![Figure 15. Actual LNG temperature rises in tanks](image)

3.4 Cargo Tank Insulation

High reliability is required to the cargo tank insulation because it is an important element related to the pressure build-up concept. That is the reason why Kawasaki Panel System tank insulation, which was developed of Kawasaki’s own and achieved good results on many large-size Moss type LNG carriers, was adopted with the following specifications.

3.4.1 Tank Surface Part

Like large-size Moss type LNG carriers, insulation panel is consist of double layer construction with phenolic resin foam in the low-temperature side and polyurethane foam in the normal-temperature side. The panel was mounted to each tank with stud bolts.

However, the tank curvature become larger than the large-size vessel, so we determined the optimum positions and number of fixed bolts according to the analysis on the load on mounting parts of insulation panel.
3.4.2 Tank Supporting Saddle Part

At the saddle part, insulation liner consists of laminated phenolic resin is applied and connected to the insulation structure of the cargo tank with foamed-in-place polyurethane foam.

Furthermore, waterproof coating is applied to the surface of the panel joint part of the polyurethane foam to prevent the water ingress into the insulation structure.

3.5 Summary

The vessel was delivered at the end of July 2003 after the cargo handling test using LNG and engaged in the LNG transportation from Tobata terminal of Kitakyushu LNG Co. Ltd. to Takamatsu terminal of Shikoku Gas Co. Ltd. and Chikko terminal of Okayama Gas Co. Ltd.

For the cargo tank and cargo handling equipment, it is confirmed that they have sufficient quality also by cold test using liquid nitrogen prior to the above cargo handling test.

The pressure build-up type LNG carrier is expected to contribute to the small-scale LNG secondary transportation project not only in Japan but also in foreign countries in the near future.

4. DEVELOPMENT OF DOMESTIC SECONDARY TRANSPORTATION IN FUTURE

The secondary transportation system by coastal vessels has been developed as an optimum means of transportation covering a capacity of approximately 30,000 tons to 300,000 tons of LNG (See table 3).

Japan has industrial areas consuming the above range of capacity in the coastal areas. The further application of the system for many more gas suppliers and consumers for industrial use is prospected in the future, so the contribution of the system to expansion of LNG applications is expected.

Table 3. Means of transportation according to demand scale

<table>
<thead>
<tr>
<th>Scale of LNG demand</th>
<th>Means of transportation</th>
<th>Time of introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large More than 300,000 ton per year</td>
<td>LNG imports by oceangoing large LNG carriers</td>
<td>1969-</td>
</tr>
<tr>
<td>Between approx. 30,000 and 300,000 ton per year</td>
<td>Secondary transportation by domestic LNG carriers</td>
<td>2003-</td>
</tr>
<tr>
<td>Small Less than 30,000 ton per year</td>
<td>Land transportation by LNG tank lorries</td>
<td>1970-</td>
</tr>
</tbody>
</table>
ACKNOWLEDGMENT

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REFERENCES CITED