ABSTRACT

An LNG carrier “LNG JAMAL” equipped with 5 Moss-type spherical tanks (capacity : abt.135,000m³) is built for the Oman LNG Project involving Osaka Gas Co., Ltd., which is scheduled to start operating in November 2000. In order to establish the superiority of natural gas in the market among energy sources, there is strong demand for reducing LNG transportation costs. The new LNG carrier employs various new technologies, including the world's first on-board BOG reliquefaction plant, to realize low-cost, safe LNG transportation.

This paper focuses on the reliquefaction plant onboard the LNG carrier. The report introduces the cost-effective features of the reliquefaction plant, based on which the installation was decided. For the reliquefaction process to be used, the Brayton cycle with N₂ coolant was selected by comparing several cycles for their initial investment and running costs. The paper also describes the design concept, such as the system redundancy, related to the reliability of the reliquefaction plant as the BOG processing equipment that controls the tank pressure.

By demonstrating that the reliquefaction plant can process all BOG generated during the voyage, it will help to find application in new propulsion systems for LNG carriers, such as diesel engines and other plants. The LNG JAMAL is a new generation LNG carrier that points to a new direction for future LNG carriers for the energy industry, in which competition is expected to intensify in the 21st century.
RESUME

Un transporteur de GNL “JAMAL GNL” équipé de cinq citernes sphériques de type Moss (capacité: 135 000 m³) est en cours de construction pour un projet Oman GNL impliquant Osaka Gas Co., Ltd. prévu pour commencer à fonctionner en Novembre 2000. Afin d’établir la supériorité du gaz naturel sur les autres sources d’énergie du marché, la demande de réduction des coûts de transport du GNL est importante. Le nouveau transporteur de GNL utilise diverses nouvelles technologies, entre autres, la première usine de reliquéfaction embarquée au monde, pour réaliser un transport de GNL à bas prix et sûr.

Cette étude met l’accent sur l’usine de liquéfaction embarquée à bord du transporteur de GNL. Le rapport présente les caractéristiques de rentabilité de l’usine de reliquéfaction, sur la base desquelles l’installation a été décidée. Afin de pouvoir utiliser le processus de reliquéfaction, le cycle Brayton avec le fluide frigorifique N2 a été sélectionné en comparant l’investissement de départ et les coûts de fonctionnement de plusieurs cycles. L’étude décrit également les concepts de création, tels que la redondance des systèmes en fonction de la fiabilité de l’usine de reliquéfaction comme équipement de traitement de GB contrôlant la pression de la citéne.

La démonstration que l’usine de reliquéfaction peut traiter tout le GB généré pendant le voyage aidera à trouver des applications pour de nouveaux systèmes de propulsion des transporteurs de GNL tels que les moteurs diesel et autres groupes de propulsion.
1. BASIC PLAN FOR LNG JAMAL

1.1 Description of the Oman LNG Project

Osaka Gas has agreed to purchase nearly 660,000 tons of LNG from Oman LNG L.L.C. (OLNG) over a 25-year period from November 2000 to 2024. The loading terminal in Qalhat began supplying LNG to Korea Gas in April 2000 and to Osaka Gas in November 2000. Details of the project are shown in Table.1. The following are the high points of the contract between Osaka Gas and OLNG.

1) The entire contracted quantity is transported by a single LNG carrier over the long route between Japan and Oman.
2) Osaka Gas is the only buyer.
3) The contract is FOB (Free On Board) with the purchaser providing transportation from the port of loading.

![Fig.1 Oman LNG Pj. Scheme](image-url)
1.2 LNG Carrier Design Concepts

The following design concepts were applied in the construction of the “LNG JAMAL”.

1) Achieving maximum reliability
Since a single carrier is used here, any problem with the carrier have tremendous repercussions on the entire project. That is why the highest standards of reliability as well as optimum specifications drawn from comparative studies on conventional carriers were used in the design of the carrier.

2) Achieving ship-to-shore compatibility at multiple terminals
In recent years, demand has been growing among buyers for flexible LNG carrier operations to meet the need for spot LNG purchases to cope with fluctuating natural gas demand and to achieve economical management of LNG carriers by using them for other LNG projects between scheduled operations and improving their operation rates. Because the project is an FOB contract with Osaka Gas as sole buyer, there is built-in flexibility that makes loading and unloading relatively easy at terminals other than that for the Oman Project. With that in mind, the carrier was built for ship-to-shore compatibility at loading terminals like Bontang, Karratha, Bintulu, Lumut and Ras Laffan as well as the terminals in the Oman Project like Qalhat, Senboku, Himeji.

3) Aggressively adopting new technologies
New, even unproven technologies capable of cutting cost and improving reliability were applied in the design with the appropriate technical evaluation. This paper focuses on Boil Off Gas (BOG) reliquefaction plant among these innovative technologies.

1.3 Schedule for the Oman Project

Fig.2 shows the entire schedule for the project.

<table>
<thead>
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<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
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<tbody>
<tr>
<td>LNG JAMAL</td>
<td>🍀</td>
<td>🌹</td>
<td>🌹</td>
<td>🌹</td>
</tr>
<tr>
<td>Ship Building</td>
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Table.2 Major Specifications

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<th>Present Carrier</th>
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<tr>
<td>Type</td>
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<tr>
<td>Tank Capacity</td>
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<td>Number of Tanks</td>
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<tr>
<td>Overall Length</td>
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<tr>
<td>Moulded Breadth</td>
<td>46 m</td>
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<tr>
<td>Moulded Depth</td>
<td>25.5 m</td>
</tr>
<tr>
<td>Design Draught</td>
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<tr>
<td>Normal Output</td>
<td>24,120 kW</td>
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<tr>
<td>Boil Off Rate</td>
<td>0.14%/day</td>
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<tr>
<td>Ship Speed</td>
<td>19.5 kn</td>
</tr>
<tr>
<td>Days per round</td>
<td>abt.30 days</td>
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</tbody>
</table>

Fig.2 Master Schedule for Oman LNG Project
2. ECONOMIC EVALUATION OF THE BOG RELIQUEFACTION PLANT

2.1 Transportation Cost of an LNG Carrier with BOG Reliquefaction Plant

The BOG that results from injecting heat into the cargo tank on an LNG carrier while the carrier is underway is usually used as fuel for propulsion. The amount of BOG is a relatively large percentage of the amount loaded LNG when used for long-distance travel such as this project between Oman and Japan. Since consumption of costly LNG by the carrier as fuel during LNG transport decreases the amount of LNG transported and leads to an increase in transportation costs, the installation of a BOG reliquefaction plant on the carrier was studied.

1) Evaluation indicators

The following equation is used to determine the base price per heat quantity of transported LNG.

\[
\text{LNG Base Price} = \frac{C_{\text{FOB}} \times V_L + \text{Capital Cost} + \text{Expenses for the Carrier} + \text{Operating Cost}}{V_L - V_{\text{BOG}}} \]

\[
= C_{\text{FOB}} + \frac{V_{\text{BOG}} \times \text{Capital Cost} + \text{Expenses for the Carrier} + \text{Operating Cost}}{V_L - V_{\text{BOG}}} \]

This suggests that the transportation cost (T/C), the section with underline in the equation above minus the price of loaded LNG per amount of heat quantity, is an indicator for evaluating economics of the system.

On conventional LNG carriers, fuel oil (FO) mixed with BOG is burned in the boiler for propulsion. On a carrier equipped with a reliquefaction plant, BOG reliquefaction increases the amount of LNG unloaded and it increases the amount of FO consumed because the boiler burns FO only and the fuel used to drive the reliquefaction plant is added to the fuel used for propulsion. This means that the results of the evaluation on economics varies radically with fluctuations in LNG and FO price. The FO price ratio was defined in the present study as shown below, and varying parameters were evaluated to calculate the economics.

\[
\text{FO price ratio} = \frac{\text{FO price per heat quantity}}{\text{BOG price per heat quantity}}
\]
Table 3 shows the conditions for calculating the economics.

2) Evaluation results

Fig. 3 shows a graph comparing T/C in instances with or without a reliquefaction plant with the FO price ratio plotted on the horizontal axis. T/C on the vertical axis is expressed as a ratio. Here T/C is 1.0 when the FO price ratio is 0.9.

It is clear from Fig. 3 that a FO price ratio of 1.05 is a branch point, and that instances with reliquefaction plants are advantageous when FO is cheaper, but is not when FO is more expensive. In this project, the economics were evaluated at a FO price ratio of 0.9, and the reliquefaction plant was added when the transportation cost was low.

If the propulsion system combines a diesel engine that is more thermal efficient than a steam turbine to the reliquefaction plant, the results should show that the carrier equipped with the reliquefaction plant is more advantageous than the results of this study show. The reasons that the reliquefaction plant, which has yet to prove to be economical, was installed are as follows because the agreement in this project is an FOB contract. The cost of BOG generated during the trip is relatively high compared to that of ex-ship contracts where the seller is responsible for transporting the LNG.

2.2 Boil Off Rate Optimization

This section focuses on BOR (Boil Off Rate) optimization for an LNG carrier equipped with a reliquefaction plant. Fig. 4 shows how the transportation cost varies using changes in BOR as a parameter. The dotted line in the graph represents the cost of transportation by an LNG carrier not equipped with a reliquefaction plant, while the solid line indicates the cost of transportation with a reliquefaction-plant-equipped LNG carrier. With a carrier without reliquefaction plant, reducing BOR achieves a lower transportation cost. When an LNG carrier is equipped with a reliquefaction system, the higher the amount of BOG to be liquefied is — that is, the higher the BOR — the larger the cost benefit of the reliquefaction plant. Therefore, the transportation cost by a reliquefaction-plant-equipped LNG carrier indicates a curved line, which is represented by the solid line in the graph.
As the graph clearly shows, the optimum BOR point is at 0.10% without a reliquefaction system. However, with a reliquefaction plant, the optimum point shifts toward a higher BOR value.

3. DESIGN CONCEPTS OF THE RELIQUEFACTION PLANT

Osaka Gas Co., Ltd. has designed, manufactured and test operated the reliquefaction plant in collaboration with NYK Line, Mitsubishi Heavy Industries, Ltd., Chiyoda Corporation and Osaka Gas International Transport Inc.

3.1 BOG Processing

The following criterion was established as the first design concept of the reliquefaction equipment.

Preventing fatal effects to the LNG carrier operation caused by reliquefaction plant malfunctioning.

In order to burn BOG in the boilers, conventional LNG carriers use turbine plants as a propulsion system, although they are inferior to diesel engines in efficiency. Successful establishment of a method of processing BOG with a reliquefaction plant will therefore pave the way toward the use of new and more efficient propulsion systems in LNG carriers. However, due to a lack of proven track records in BOG reliquefaction equipment for LNG carriers at the present, we decided to install a conventional boiler for processing BOG on the LNG JAMAL. Therefore, study was focused on the installation of a reliquefaction plant on an LNG carrier with turbine propulsion plant.

On the LNG JAMAL, BOG generated in the cargo tank is pressurized by BOG Compressors. The generated BOG can be processed by either the main boiler or the reliquefaction plant. In normal operation, only the reliquefaction plant processes all BOG.
In the event that a problem occurs in the reliquefaction equipment, the BOG line is switched to the boiler system, and the interrupted BOG Compressor operation is restarted for BOG processing by the boiler. This ensures the smooth operation of the LNG carrier.

Fig. 5 BOG Processing of “LNG JAMAL”

3.2 Selection of the Liquefaction Cycle

The second design concept of the liquefaction equipment was as follows.

*Preventing the need for an increased number of operators resulting from the use of the reliquefaction plant.*

The liquefaction cycle of a mixed-refrigerant system offers high liquefaction efficiency. This system, however, complicates refrigerant management procedures, such as making-up and adjusting composition. In view of this, the Brayton cycle, which uses nitrogen as a refrigerant, was selected to achieve the above design target. The N2 Brayton cycle is simple and requires only a few devices, thus meeting the following requirements of the onboard reliquefaction system.

- Minimum installation space due to the limited onboard space
- High equipment reliability to withstand hull motion and vibration
- Low initial investment

The third design concept was as follows.

*Keeping maintenance of reliquefaction equipment during conventional periodic dry-docking (in intervals of 2 to 2.5 years).*

The rotating machine used for the N2 Brayton cycle was made by a manufacturer with a proven record for marine use. A plate-fin type heat exchanger was selected for the heat transfer between the nitrogen refrigerant and the BOG because of its high heat transfer performance and compact size. Since the nitrogen and BOG that flow inside the
heat exchanger are not corrosive, the heat exchanger does not require open inspection. Only hydrostatic and leak tests shall be conducted during periodic dry-dock inspections.

3.3 Redundancy

Since the BOG processing and cargo tank pressure control can be provided either by the boiler or the reliquefaction plant, a redundant design concept was not adopted for the reliquefaction plant. However, since the BOG Compressors operate for BOG processing regardless of whether the boiler or reliquefaction plant is used, two compressor units were installed for redundancy. Each compressor unit is fully capable of processing BOG at the designed BOR of 0.14% per day. The boiler, which uses dedicated Fuel Oil burners to generate steam for the propulsion turbine, also features the same redundancy as those of conventional LNG carriers.

When only a reliquefaction plant is used for BOG processing in the future, there will be a need for redundancy in the reliquefaction equipment. To do so, the rotating machines — the N2 compressor, N2 Booster / Expander and LNG return pump — may need backup units. We will verify the reliability of these equipments during the plant operation. Since the plate-fin type heat exchanger is maintenance-free, a backup heat exchanger is not required.

![Fig.6 Flow Diagram of Reliquefaction Plant](image)
4. OUTLINE OF THE DESIGN

4.1 Major Specifications

The main specifications of the reliquefaction system are listed in the Table.4. The rated liquefaction capacity is approximately 3 t/h, which was determined by subtracting the design margin of BOR calculated from the operating data of conventional LNG carriers from the cargo tank heat insulation design value (BOR = 0.14%/day). The cryogenic energy produced by the expansion of N2, with its pressure reducing from 3.5 MPaA to approximately 0.65 MPaA, is used to liquefy the BOG. The turn-down performance was set to 1 t/h, which is equivalent to approximately 30% of the control capacity of the control valve and other devices. The cooling water flow rate in the intermediate cooler is 300 m³/h.

The design conditions are shown in the Table.5. The maximum N2 component in BOG was estimated to be 6% based on the composition of LNG supplied by the Oman Project. During a laden voyage, the BOG temperature is expected to rise to -120°C due to the heat inleak into the pipe between the tank and reliquefaction equipment.

4.2 Composite Devices

The two electric centrifugal single-stage compressors feed BOG to the reliquefaction plant or boiler. When feeding BOG to the reliquefaction plant, the two units are connected in series and operate in the Tandem Mode to increase the BOG pressure to 450 kPaA, or in the Single Mode in which only one unit operates. The rated liquefaction capacity of 3 t/h is achieved in the Tandem Mode, in which the BOG liquefaction pressure is higher. When feeding BOG to the boiler, the Single Mode is used, as is done on conventional LNG carriers.

The brazed-aluminum plate-fin type heat exchanger consists of three units: the N2 Cooler that precools the N2, the BOG Condenser that liquefies the BOG, and the LNG Subcooler that supercools LNG prior to returning it to the tank. This three-part heat exchanger and expander are contained in a cold box measuring 3.6 m in width, 2.0 m in depth, and 6.8 m in height.

<table>
<thead>
<tr>
<th>Table.4 Major Specification</th>
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<tr>
<td>Design Capacity</td>
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<td>Min. Capacity</td>
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<tr>
<td>Power Consumption</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table.5 Design Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOG Composition</td>
</tr>
<tr>
<td>CH4</td>
</tr>
<tr>
<td>N2</td>
</tr>
<tr>
<td>BOG Temperature (Laden Voyage)</td>
</tr>
<tr>
<td>BOG Temperature (Ballast Voyage)</td>
</tr>
<tr>
<td>Atmospheric Temperature</td>
</tr>
<tr>
<td>Cooling Water Temperature</td>
</tr>
</tbody>
</table>

Fig.7 Cold Box
The recycle N2 compressor is a steam-turbine-driven centrifugal 2-stage compression unit. Since steam is generated for the propulsion steam turbine on the LNG JAMAL, it was decided to use a steam-turbine-driven recycle N2 compressor to effectively utilize the generated steam.

4.3 Compact Layout

The first technical topic in the development of the onboard BOG reliquefaction plant was to achieve a compact layout of devices to maximize use of the limited onboard space. The BOG and LNG processing devices were installed in the Cargo Machinery Room (see Fig. 8), which is a gas zone on a conventional LNG carrier where the BOG Compressors would be installed. Since the N2 compressor is driven by the steam turbine, it was installed near the boiler in the Engine Room and connected to the N2 Booster / Expander in the Cargo Machinery Room with N2 pipes.

- Although increasing the liquefaction pressure improves the liquefaction efficiency, it was decided to use BOG Compressors capable of providing boiler service similar to those used on conventional LNG carriers on account of space restrictions, and they are shared with the reliquefaction plant.

- A plate-fin type heat exchanger with the largest heat transfer area capable of being installed in the limited onboard space was selected to achieve high liquefaction efficiency. The N2 Cooler and BOG Condenser were separated due to the height restriction of the room and were installed in the Cold Box with LNG Subcooler.

Consequently, all of the liquefaction devices were successfully installed in the Engine Room and Cargo Machinery Room, both of which measure the same as those on a conventional LNG carrier.

4.4 Adaptation to Marine Conditions (Measures against Hull Motion)

The following design considerations were taken for the equipment to offset the effects of hull motions.

To ensure equipment reliability under moving conditions, higher priorities were placed on the selection of devices that were made by manufacturers whose products had proven track records in marine use. The plate-fin type heat exchanger has a high natural frequency, which will not cause resonance with hull vibrations.

- The N2 refrigerant, which is a gas and is not subject to phase change, is not susceptible to the effects of tilting.

- The BOG Condenser that produces liquid LNG is a vertical type, and the substance at the heat exchanger inlet is in a gaseous state; therefore, liquid drifts are unlikely to occur.

<table>
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<tr>
<th>Athwartship</th>
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<th>Dynamic 22.5°</th>
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<td>Dynamic 7.5°</td>
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<tr>
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<tr>
<td>Vibration</td>
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</table>

Table 6 Considered Hull Motions
Fig. 8 General Arrangement of Reliquefaction Plant

Fig. 9 Reliquefaction Plant Layout
5. CONTROL SYSTEM

5.1 Reliquestion Load Control

The reliquefaction load is controlled by regulating the liquefaction pressure. The reliquefaction equipment load is regulated by the Cargo Tank Pressure Control and BOG Compressor Flow Control.

In the Cargo Tank Pressure Control Mode, the BOG Compressors' BOG processing demand volume relative to the tank pressure fluctuation is determined, and the BOG Compressors supply BOG to the reliquefaction device at a rate corresponding to the demand volume. In the BOG Compressor Flow Control Mode, the BOG Compressors feed BOG to the reliquefaction plant at the preset processing rate. These two control modes are also provided in the BOG Compressors of conventional LNG carriers for processing BOG in the boilers. Therefore, the reliquefaction plant on the LNG JAMAL has the same control modes to allow the operators to use familiar control functions.

5.2 Automation

To avoid the need for an increase in the number of operators due to the installation of the reliquefaction plant, automation control system was incorporated. Startup and shutdown of the reliquefaction plant are performed by two operators, but an automatic control system adjusts BOG load fluctuations once the equipment starts operation. Startup of the reliquefaction plant requires manual operation of the switches on the machine for activating the BOG Compressors. Once the BOG Compressors start operating, the control panel in the Cargo Control Room can be used to start reliquefaction plant operation.

The reliquefaction plant is designed for unattended operation during nighttime. The operator can set the tank pressure value to be maintained at night by using the Tank Pressure Control Mode, or he can set an optimum BOG processing flow value determined according to the tank pressure and oceanographic/climatic conditions by using the BOG Flow Control Mode.

5.3 Operating Modes

There are three BOG Compressor operating modes: Tandem, Single and Parallel. The Tandem Mode is selected when the BOG flow rate is in the range of 1 to 3 t/h. In this mode, the two BOG Compressors operating in a series connection provide high liquefaction pressure for enhanced liquefaction capacity and efficiency. The Single Mode can be selected when the BOG flow rate is in the range of 1 to 2.4 t/h. This mode is used when one of the BOG Compressors is inoperable or when the amount of generated BOG remains low for an extended period of time. The Parallel Mode is selected when the amount of generated BOG exceeds 3 t/h. In this mode, one BOG Compressor feeds BOG to the reliquefaction plant, while the other BOG Compressor supplies surplus BOG exceeding the liquefaction capacity to the boiler.

The operating mode for the return of liquefied LNG to the tank can be selected from two types. The Pump Return Mode uses the LNG Return Pump, while the Direct Return Mode sends liquefied LNG directly to the tank. When the BOG Compressors are operating in the Tandem Mode, the liquefaction pressure is high enough to send LNG to the tank, thus eliminating the need for operating the pump. In the BOG Compressor Single Mode, the Pump Return Mode is used. LNG can be returned to the tank in two methods, either to the tank bottom or by the tank spray.
5.4 Operation

Fig. 11 shows a typical navigation pattern. After leaving a loading terminal on a laden voyage, the reliquefaction plant is started. Since the amount of generated BOG is higher on a laden voyage than on a ballast voyage, the BOG Compressors operate in Tandem Mode to maintain the reliquefaction capacity within a range of approximately 2 t/h to the designed value of about 3 t/h. In this operation, liquefied LNG is returned to the tank bottom. When approaching an unloading terminal, the LNG and BOG pipes used for unloading operation are cooled, and this process generates BOG at a rate of more than 3 t/h. While the lines are being cooled, the BOG Compressors are operated in the Parallel Mode for the processing of BOG by the reliquefaction plant and boiler. Prior to unloading, the reliquefaction plant is shut down, and it is not operated during the unloading operation.

On a ballast voyage after unloading, the amount of generated BOG is as low as 1 to 2.5 t/h; thus, the reliquefaction plant can be operated with the BOG Compressors in either Tandem or Single Mode. On conventional LNG carriers, spray operations are conducted during a ballast voyage to reduce the tank temperature. On the LNG JAMAL, liquefied BOG can be sprayed. During the line cooling operation prior to arriving at a loading terminal, the BOG Compressors are operated in Parallel Mode. While docked at a loading terminal, the reliquefaction plant is in non-operation.
Since the LNG JAMAL is equipped with the boiler that serves as a BOG processing device, it is possible to conduct a tank pressure management operation using the boiler in the same way as on a conventional LNG carrier. As such, a malfunction in the reliquefaction equipment would not interrupt the operation of the LNG JAMAL.
6. TEST OPERATION RESULTS

A test operation of the liquefaction plant was conducted from October 15 to 30, 2000. The following introduces the results of this test operation. The reliquefaction plant will be subjected to another test operation during an actual LNG JAMAL voyage to evaluate the designed BOG liquefaction capacity and system controllability.

6.1 Liquefying Performance

The equipment provided stable liquefying performance at a maximum liquefaction rate of 3 t/h and a minimum rate of 1 t/h. This confirmed that the reliquefaction plant is capable of automatic operation in accordance with BOG loads in the liquefaction rate range of 1 to 3 t/h.

6.2 Load Control

Fig.12 shows a trend graph of tank pressure in the reliquefaction plant operating in the Tank Pressure Control Mode. The data confirmed the proper tracing performance of the tank pressure control for the reliquefaction plant when the tank pressure setting was lowered linearly. The tank pressure control started at the timing shown in the graph. The tank pressure moved toward the set point, and then followed the change in the process value.

![Tank Pressure Control Graph]

Fig.12 Tank Pressure Control

Fig.13 shows a trend graph of the BOG flow and LNG return pressure in the reliquefaction plant operating in the BOG Compressor Flow Control Mode. As indicated in the graph, the reliquefaction equipment provided stable processing of BOG at the set BOG Flow value.
7. CONCLUSION

LNG carriers must transport as much LNG as possible on single voyages to meet the demand of the cargo owners. For this purpose, various studies have been carried out to improve the loading capacities of LNG carriers. For the LNG JAMAL, a high transportation capacity was achieved with the installation of a BOG reliquefaction plant that reliquefies the generated BOG during a voyage. The reliquefaction plant described in this paper provided the following results.

- In a project in which the value of BOG is high in relation to the fuel oil, the economic benefit of a reliquefaction plant becomes large, thus making its installation on the LNG carrier practical.

- Installation of a reliquefaction plant shifts the optimum BOR point upward.

- The use of the N2 Brayton cycle enables the installation of a compact reliquefaction system on a conventional LNG carrier without requiring additional space.

- A reliquefaction system can operate automatically with the BOG processing volume in the range of 1 to 3 t/h.

- System automation eliminates the need for additional operators for the reliquefaction plant.

- A reliquefaction plant used as BOG processing equipment can serve to control the tank pressure for the LNG carrier during the voyage.

Since the LNG JAMAL has demonstrated the effectiveness of the reliquefaction plant as BOG processing equipment, it paved the way toward adopting new propulsion systems for LNG carriers that are more efficient than a steam turbine. The use of a diesel engine or electric propulsion system will most likely be examined in the construction of new LNG carriers.

The LNG JAMAL incorporates various innovative technologies, such as a BOG reliquefaction plant, to reduce costs and improve safety in LNG transportation. The LNG JAMAL is a new-generation LNG carrier that points to a new direction for future LNG carriers for the energy industry, in which competition is expected to intensify in the 21st century.
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