ABSTRACT

As increase in the use of cold energy for air separation, cold storage, and food processing, re-gasified gas is also increased at Liquefied Natural Gas (LNG) receiving terminals. The summed rate of both the re-gasified gas and normal Boil-Off Gas (BOG) from storage tanks often exceeds the gas send-out rate of the terminal. From safety and economic points of view, treatment of both BOG and re-gasified gas resulting from the cold energy supply is a troublesome matter at a LNG receiving terminal. To overcome this problem effectively, a gas re-liquefaction system has been designed and operated at the Pyeong-Taek LNG receiving terminal, South Korea.

This paper presents the design concepts and features of the gas re-liquefaction process installed at the Pyeong-Taek LNG terminal. It also presents the methodology developed to obtain the optimum gas re-liquefaction system based on the total economics as well as system reliability. Integrated approaches considering high operational system reliability and cost effective design are also discussed. The results are proven with the system reliability as well as economic operation through a three-year case history of the Pyeong-Taek LNG receiving terminal. The methodology discussed in this paper can be applied directly to any LNG terminal considering expansion of the practical use of cold energy from LNG.
Introduction

Cold energy in Liquefied Natural Gas (LNG), which may be dissipated and wasted to heat media (generally seawater) during re-gasifying process, is a very valuable energy. LNG is a cryogenic temperature liquid with a boiling point of about —160°C and its amount of cold energy is approximately 840 KJ/Kg. Most LNG receiving terminals operate cold energy utilization plants to use this LNG cold energy. Pyeong-Taek LNG receiving terminal, which is owned and operated by the Korea Gas Corporation (KOGAS), supplies LNG for using cold energy to the near air separation plant, Seoul Cold Air Plant (SCAP). The KOGAS also has the future plans to maximize the utilization of LNG cold energy. As increase in the use of cold energy for air separation, cold storage, and food processing, re-gasified gas is also increased at LNG terminals.

The total vapor of natural gas (NG) can be divided into two categories. One is re-gasified gas from cold energy utilization plants and the other is Boil-Off gas (BOG) from LNG storage tanks and equipment with relevant piping system. The handling NG vapor had been solved easily by sending the gas as fuel to the adjacent thermal power plant after compression of vapor at the Pyeong-Taek terminal. This solution was no more acceptable because the thermal power plant switched the main fuel from NG to bunker-C oil due to cost differences between them. As a result the terminal had to change fundamentally the way of its operation. To resolve this problem, the KOGAS decided to install gas re-liquefaction system using supersaturated LNG. The purpose of the gas re-liquefaction system is to provide a new economical way of handling the inevitable BOG at LNG terminal and re-gasified gas from the cold energy utilization plants. This paper describes the outline of the system and the features of its process for gas re-liquefaction system installed at the Pyeong-Taek LNG terminal. This paper also presents system reliability and economic operation based on a three-year case history of the Pyeong-Taek LNG receiving terminal.

Description of Gas Delivery System

The role of Pyeong-Taek terminal is base-load LNG terminal in KOGAS. Presently, 10 units of storage tanks are under operation with a total capacity of 100,000 kiloliter. The terminal handled about 7.5 million-ton of LNG in 1999. Figure 1 shows the conceptual schematic of LNG process at the Pyeong-Taek terminal. There are two or three low-pressure (LP) LNG pumps per storage tank. The nominal capacity of the LP pumps is 310 m³/h with the range of discharge gage pressures from 14 to 16 kg/cm². These submerged in-column centrifugal pumps provide the first stage of send-out pressurization.

The pressurized LNG from primary pumps is re-gasified through LP vaporizers. The re-gasified gas from LP vaporizers is mixed with the vapor of NG consists of both BOG mainly from LNG storage tanks and re-gasified gas returning from cold energy utilization plants. The operating pressure of the LP send-out system is controlled to meet the pressure requirement of the downstream thermal power plant. In order to maintain the LP send-out pipeline pressure, the number of operating LP vaporizers at the terminal and the amount of LNG to be supplied to SCAP are controlled to meet downstream pressure requirement.

The barrel mounted multi-stage centrifugal pumps (secondary pumps) boost the pressure up to 76 kg/cm², which enables to drive the pressurized LNG through re-gasifiers. There are two types of re-gasifiers: one is seawater open racked type vaporizer (ORV) and the other is internal submerged combustion vaporizer (SMV). ORVs are used for the base load re-gasifiers and SMVs are used for the back up and peak shaving facilities. The vaporized NG is injected into the HP trunk lines. As the send-out pressure increases, a secondary pump is stopped and the operation number of re-gasifiers and primary pumps are adjusted, if required.

Vapor in LNG Terminal

The BOG in LNG receiving terminal under normal operation is the result of heat being added to the LNG by heat fluxes through the walls from the surroundings of LNG tanks, equipment, and associate piping system. Pump efficiency also contributes in generation of BOG. The BOG is mainly composed of
methane (over 99 %). The major portion of BOG comes out from storage tank. BOG rate increases when LNG is unloaded from LNG cargo to storage tank due to the difference of saturation pressure and temperature between LNG cargo and storage tanks. The accumulated latent heat during LNG cargo voyage also increases BOG during unloading LNG, which is called a flashing phenomenon.

The amount of BOG was precisely estimated using a computer system, developed by Dae-Woo Engineering Company, under normal and unloading conditions. The summary of vapor gas is presented in Table 1. The rate of evaporation of LNG from a storage tank is essentially controlled by the amount of supersaturated pressure of the stored LNG and surface area of the vapor-liquid interface. The following Hashemi et al. model was used to estimate the BOG rate, $m_{BOG}$:

$$m_{BOG} = 0.04\Delta P_{s}^{3/4} \left[ \frac{Kg}{hr - m^{2}} \right]$$  

(1)

where, $\Delta P_{s}$ is supersaturated pressure. It is a function of the average rate of change in the saturation temperature of the liquid with pressure, $dT/dP$, and the total temperature difference between the bulk of the liquid and the surface, $\Delta T_s$:

$$\Delta P_{s} = \frac{-dT}{dP} \sqrt[3]{\Delta T_s}$$  

(2)

Additional vapor can be generated when certain conditions arise. Two conditions often observed and considered in this estimation were:

1. tank pressure drop when barometer reading falls or the vapor withdrawal increases, and
2. supersaturated liquid reaching the surface from the bulk beneath or from the wall ascending boundary layer.

The total BOG rate depends on the terminal operating mode, the season, temperature, the day/night etc. It varies from 8 to 30 t/h. The main reason for this large fluctuation is due to LNG unloading operation. The BOG was mixed with the LP re-gasified gas after compression by five sets of two stages reciprocating, Labyrinth non-contacted type, BOG compressors. The design capacity of each compressor is 10 t/h of BOG with a maximum discharge gauge pressure of 11 kg/cm² and discharge temperature ranges from 14 to 47 °C. The vapor of the compressed BOG and returned re-gasified gas from cold energy utilization plant were used as fuel gas for the tank vacuum breaker, internal consumption (gas firing absorbed type heating/chilling unit), neighboring KIA Motors and the adjacent thermal power plant.

**Design Conditions**

LNG from —157 to —150 °C with 14 to 16 kg/cm² is supplied to cold energy utilization plant. This LNG passes through LP heat exchangers and returns to the terminal at 5 to 25 °C of vapor with minimum 9 kg/cm². The amount of 16 to 28 t/h of re-gasified gas is generated by the cold energy heat exchanger in SCAP. In case of limited LNG volume, a minimum feed rate of 18 t/h is required to allow a continuous operation of the SCAP.

In order to analyze the possibility of re-liquefaction using supersaturated LNG, gas supply pattern was investigated. Figure 2 shows the monthly gas send-out patterns. In this study, the amount of LP gas send-out was excluded because the adjacent thermal power plant planned to switch the main fuel to bunker-C oil. The LNG flow rate varies with gas demand, seasons, and ambient temperature. Gas supply in June was recorded as the lowest gas send-out. In order to secure the design of the system, the hourly gas supply patterns were also investigated. This study showed that gas demand was significantly dropped early in the morning (02:00 — 05:00 am). The lowest hourly gas supply was observed in June as shown in Fig. 3. BOG rate is also decreased with decrease in temperature in early morning.

However, the LNG flow rate in the early morning in summer is predicted to be below the designed flow. The following four possible cases were considered in the conceptual design:

1. Control the amount of LNG, which supplies cold energy to SCAP, in order to minimize the re-gasified gas. The exceeded vapor, which can not be re-liquefied by the LNG flow rate with the minimum re-gasified gas from cold energy utilization plant (called critical case), is to be sent to the adjacent thermal power plant with the same price of Bunker-C oil.
(2) Minimize sending LNG to cold energy utilization plant and re-circulation of mixed LNG with re-liquefied gas to LNG storage tanks.

(3) Install a cold energy storage system using phase change material, which allows to store cold energy during daytime and to use it when LNG flow is insufficient to re-condense the vapor.

(4) Construction of re-liquefaction system using expander and compressor of re-gasified gas with cold energy exchange with LNG. All vapor generated in the terminal is compressed after cooling by heat exchange with LNG being supplied to HP vaporizers.

Extensive studies were done to investigate each case to see there was no conflict against company’s policy, which is the safe operation of the terminal. Especially, when the LNG flow is lower than the required LNG flow to re-liquefy the vapor of natural gas (summed BOG and re-gasified gas from cold energy utilization plant), the special system analysis was done to establish the scenario in order to get a secure operation. From the gas demand forecasting, the critical case is rare and it will be solved in one or two years of operation with increase in gas demand. Moreover the gas demand during summer time was anticipated to increase because of increase in gas demand for the electricity generation from combined cycle thermal power plants located in Seoul metropolitan area and for building cooling by gas fired absorbed type chillers. Four cases were carefully evaluated in view of system reliability and workability as well as total economics including operating costs. For both cases the minimum supply of LNG to cold energy utilization plant did not affect the terminal operation as well as SCAP operation except the production rate was decreased for couple of hours. The required LNG for the minimum operation of SCAP is about 16 t/h of LP LNG. The production rate of SCAP is then reduced to almost half. From this study, Case 1 was chosen for vapor handling at the Pyeong-Taek terminal. Comparison of the economic analysis for different type of re-liquefaction system under different operating modes is presented in Table 3.

The expected minimum NG vapor flow rate is 22 t/h (8 t/h from BOG plus 16 t/h from cold energy recovery and deduct 2 t/h for the domestic consumption). The required LNG to re-liquefy 22 t/h vapor as a critical case is 213 t/h. From the hourly gas supply pattern in Fig. 3 shows that the minimum gas send-out is 200 t/h at very early morning (3:00 — 4:00 am). The surplus 13 t/h of warmed LNG should be re-stored in the LNG tanks or the exceeded vapor (about 1 t/h), which cannot be re-liquefied by 200 t/h of LNG, should be sent to the adjacent thermal power plant.

The additional BOG rate due to the re-stored 13 t/h of the mixed (warmed) LNG into LNG tank, which is assumed that LNG is filled with 50 % of its capacity, is shown in Fig. 4. It presents the effects of re-stored the mixed LNG on BOG rate. Since the amount of the re-stored LNG is very tiny in view of total LNG volume stored, increase in BOG rate is not significant during the period of storage of LNG for re-liquefaction. The LNG flow rate then increases over the required LNG for full re-liquefaction from 5:00 am. This design concept was considered in the conceptual design stage but it required a special care to avoid the sudden vaporization (roll-over) due to the accumulation of latent heat inside the tank. For the safe operation of the terminal Case 2 was excluded in the design possibilities and Case 1 was chosen for this project.

Design of Re-Condenser

The basic principle of the re-liquefaction system is to cool, re-liquefy and send-out the excess vapor of natural gas by mixing with supersaturated low pressure LNG taken from the LP LNG header line. LNG stored in storage tank is slightly above or at its saturation point at the operating pressure of the tank (Point A, Fig. 5). After pressurization by the primary pumps, the LNG is supersaturated (Point D, Fig. 5). It is, therefore, capable of absorbing a certain quantity of heat whilst remaining liquid. The following design principles and operating conditions are described based on the manual and calculation notes submitted by the Dae-Woo Engineering Company (as local detail design company) and the Tractebel Engineering International (contractor for design and manufacturing the re-liquefaction system).

In particular, it can absorb the heat required for the condensation of the BOG up to the saturated point (Point E, Fig. 5). In order to improve the heat and mass transfer of gas and liquid phases, the
condensation takes place in a packed tower where gas and liquid enter the top of the re-condenser and flow co-currently through the bed of metal rings, where both phases come in close contact. The re-condenser operating level is carefully monitored and maintained at half height. If re-condensing heat exchanger level rises, the stepwise overfilling protection system will be initiated. Figures 6 and 7 show the required supersaturated LNG flow with the amount of vapor to be re-liquefied with the different inlet temperatures of vapor. When the heat and mass transfer occurs, the heat required for vapor cooling and condensation will result in a liquid temperature rise.

If the liquid inlet flow rate and temperature are kept constant, the re-liquefaction system can be operated at low pressure when the gas flow rate and temperature are low. When the amount of vapor is high, the re-liquefaction system should be operated at high pressure. Practically, the re-liquefaction system having normal operating range 2 to 8.0 Kg/cm² can liquefy all vapor up to 60 t/h if LNG liquid flow is over 450 t/h. In this case, the LNG should be supersaturated under —155°C and 8.5 Kg/cm². The mixing ambient temperature gas with cold LNG in re-condensing heat exchanger will increase in temperature of LNG at the secondary pump suction to —130°C. Therefore, increase in temperature of mixed LNG decreases liquid density from 445 to 417 Kg/m³. The temperature and density of mixed LNG depends on the temperature and flow coming to re-condenser of both LNG and vapor of natural gas. Figure 8 shows the process flow diagram for gas re-liquefaction system.

**Operation and Control Scheme**

At low vapor flow, the cooling requirements are low. If the liquid flow rate remains constant, the recondensing heat exchanger operates at low pressure (2 to 4 Kg/cm²). On the other hand, the recondensing heat exchanger operates at high pressure (6 to 8 Kg/cm²) because the cooling requirements are high at high vapor flow rate. The operation mode to re-condense more vapor of natural gas is either to increase the operating pressure with the same liquid inlet flow or to increase LNG inlet flow with the same operating pressure. When LNG inlet flow rates are lower than the required LNG to re-liquefy all vapor flowing into the re-condensing heat exchanger, it is required either to adjust the amount of vapor or increase LNG flow, which is re-circulated to storage tanks.

Since the operating pressure of re-condensing heat exchanger is a key parameter of the re-liquefaction system, it is required to monitor continuously. With any situation modifying the LNG and vapor inlet conditions, such as LNG unloading begins, additional BOG compressor starts, and increase in LNG supplying cold energy to SCAP. Real time operation parameters are important to control and keep the re-condenser pressure within the normal operating pressure ranges. This is achieved by Distributed Control System (DCS) and monitored at the Central Control Center (CCC) automatically.

The operating pressure in the recondensing heat exchanger will vary from 0.5 to 8.5 Kg/cm² (as a design basis) depending on the operating conditions such as flow, temperature and compositions of re-gasified gas and enthalpy available in supersaturated inlet LNG streams. The mixture is, then, sent to the boosting pumps which discharge the warmer and lighter LNG under flow control into the suction headers of HP pumps. One or two boosting pumps are running according to the send-out demand. The first role of boosting pump is to compensate the low suction pressure of secondary pumps due to the operating pressure of re-liquefaction system. The design suction pressure of secondary pump is 14 Kg/cm². However, the operating pressure of re-liquefaction system is limited as 8 Kg/cm² owing to the vapor pressure (from BOG compressors and from cold energy utilization plant). In addition, the boosting pumps also compensate the barometric head of secondary pump, which requires relatively higher head than design case. This caused a revision in the actual operating philosophy of the terminal.

The density of the mixed LNG at the secondary pump suction header is different from the density initially used in design of the HP pumps. The density depends on the ratio of vapor re-liquefied with its temperature and LNG flow fed to re-condensing heat exchanger. Consequently, the changes in liquid density affect pump performance. The performance of a pump depends on its performance curve, which gives the barometric head (h) as a function of the volumetric rate (v). In order to pressurize LNG up to the design point (76 Kg/cm²), barometric head should be increased from h₁ to h₂ when the liquid density is...
decreased. Then, the pumping volume is reduced from $V_1$ to $V_2$ as shown in Fig. 9. Effects of LNG density variation on pump operating conditions are presented in Table 2.

**Operation Reliability**

Primary control station for the operation of the re-liquefaction system is the local control panel, which is designed to ensure the monitoring, the control and the safe operation of the system. The local panel is connected to the distributed control system (DCS). All operating information and alarms related to the re-liquefaction system are reported to local control panel. Important operation information and warning signals are sent to CCC through DCS. In addition, some warning alarms directly affected on operation of the system are also reported on local control panel as well as CCC such as Emergency Shut Down (ESD) signals from BOG compressors, LP pumps, and HP pumps.

As the re-liquefaction system is a key facility installed in both LP and HP delivery systems, all operation conditions and alarms related to the system are reported to the CCC. A staged shutdown system has been developed in order to get safe and high reliable operation for both vapor re-liquefaction system and gas send-out system. The following concerns, sorted from the highest priority to the lowest, are taken into consideration in designing operation modes.7,8

1. Safety of people and environment
2. Equipment safety
3. Continuous HP gas delivery
4. Continuous vapor re-liquefaction

The process shutdown of the re-liquefaction system has a vital role to ensure the safety in the case of some unexpected event, which may have an adverse effect on safe operation. The safety sequence shall stop the running boosting pumps, isolate the LNG inventory of the buffer compartment and close the main inlet and outlet headers when abnormal operation conditions are detected. Figure 10 shows the re-liquefaction system installed at the Pyeong-Taek terminal.

**Economic Analysis**

If the amount of exceeded vapor is low, the most simple and economical way is to flare or vent through flare stack or vent stack. Considering increase in the amount of re-gasified gas from cold energy utilization plants due to extensive use of cold energy in future, the installation of gas-liquefaction system can get high reliability and economic operation of LNG terminal in view of long term basis of terminal operation. One of the most important issues affecting economical analysis is construction cost as well as operating cost. Operating cost varies due to electricity cost and labor cost. Construction costs of each system described in the Design Conditions section are obtained from lump sum basis with the capacity of maximum 60 t/h vapor treatment. However, the real construction costs are used for Case 1.

In order to compare economical efficiency of each system, discounted net present value (NPV) concept was used. The following are the NPV calculation basis:

- Operation period: 10 years
- Maximum LNG handling volume: 7 million-ton per year
- Annual maintenance cost: 4% of equipment cost
- Electricity cost: $5.6\,\text{c}/\text{Kwh}$
- Interest rate: 8%
- Capital cost and taxes: excluded

The summary of economic analysis is presented in Table 3. The most economical way was the re-condensing type vapor re-liquefaction system.

**Conclusions**
(1) Gas re-liquefaction system using re-condensing heat exchanger installed at the Pyeong-Taek terminal has proven its reliable operation over three years.

(2) Re-condensing type of vapor re-liquefaction system has a high operational reliability. The reliable operation has been achieved without re-circulation of mixed LNG by controlling the LNG supply to cold energy utilization plant.

(3) The consideration of vapor treatment system in LNG terminal and the initial plan of cold energy utilization can provide a more reliable system operation as well as higher economical benefits.

(4) The liquid phase of LNG returning from cold energy utilization plants is more preferable in view of handling re-gasified gas in terminal.

**Recommendations**

After operation of the 3rd terminal, Tong-Young LNG receiving terminal, in KOGAS, the role of the Pyeong-Taek LNG terminal will be changed from base load to load control terminal. The expected LNG handling volume at the Pyeong-Taek terminal will decrease from 55 % in 2000 to 31 % in 2010. The supply of supersaturated LNG will then be dropped below 200 t/h in summer season. The cooling vapor dramatically reduces the requirement of supersaturated LNG. The pressurized LNG from secondary pumps (up to 76 Kg/cm²) can be used for cooling the vapor because it is still supersaturated. Therefore, the possible solution in this case is to install high-pressure heat exchanger to cool vapor using LPG as heat exchange media.

**Nomenclature and Abbreviation**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>BOG</td>
<td>boil-off gas</td>
</tr>
<tr>
<td>DCS</td>
<td>distributed control system</td>
</tr>
<tr>
<td>(\Delta P_s)</td>
<td>super saturated pressure</td>
</tr>
<tr>
<td>(dT/dP)</td>
<td>average rate of change in saturation temperature in liquid with pressure</td>
</tr>
<tr>
<td>(\Delta T_s)</td>
<td>total temperature difference between liquid and surface</td>
</tr>
<tr>
<td>HP</td>
<td>high pressure</td>
</tr>
<tr>
<td>LP</td>
<td>low pressure</td>
</tr>
<tr>
<td>(m_{BOG})</td>
<td>BOG rate</td>
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<tr>
<td>NG</td>
<td>natural gas</td>
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</table>

**Acknowledgement**

The authors wish to thank Korea Gas Corporation (KOGAS) for permission to present this paper and extend their sincere thanks to Tractebel Engineering International (TEI) and Dae-Woo Engineering Company for their permission to reproduce data included in this paper. The authors also express their appreciation to the Well Construction Technology Center (WCTC) of the Mewbourne School of Petroleum and Geological Engineering at the University of Oklahoma for the financial support and encouragement. Special thanks are extended, particularly to S.W. Kang and H.B. Lee of KOGAS for their kind assistance and useful discussion.

**References**

6. Analysis of Natural Gas Supply Patterns  Gas Main Control Center of Korea Gas Corporation, May 1997.
Table 1 — Vaporized gas flow for BOG and re-gasified NG

<table>
<thead>
<tr>
<th>Description</th>
<th>BOG</th>
<th>Re-gasified gas from SCAP</th>
<th>Design condition</th>
</tr>
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<tbody>
<tr>
<td>Pressure (Kg/cm²)</td>
<td>10</td>
<td>9</td>
<td>8.5</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>14 — 47</td>
<td>5 — 25</td>
<td>36</td>
</tr>
<tr>
<td>Flow (T/h)</td>
<td>8 — 30</td>
<td>16 — 28</td>
<td>60</td>
</tr>
<tr>
<td>Composition CH₄</td>
<td>99.26</td>
<td>88.97</td>
<td>94.39</td>
</tr>
<tr>
<td>% mole C₂H₆</td>
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<td>8.95</td>
<td>4.43</td>
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<tr>
<td>C₃H₈</td>
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<td>1.51</td>
<td>0.74</td>
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<tr>
<td>i-C₄H₁₀</td>
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<td>0.24</td>
<td>0.11</td>
</tr>
<tr>
<td>n-C₄H₁₀</td>
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<td>0.32</td>
<td>0.15</td>
</tr>
<tr>
<td>N₂</td>
<td>0.34</td>
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Table 2 — Effects of LNG density variation on pump performance

<table>
<thead>
<tr>
<th>Pump characteristics</th>
<th>Unit</th>
<th>Design</th>
<th>Before gas re-liquefaction</th>
<th>After gas re-liquefaction</th>
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<tbody>
<tr>
<td>LNG inlet</td>
<td>°C</td>
<td>-160</td>
<td>-155</td>
<td>-130</td>
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<tr>
<td>LNG inlet density</td>
<td>Kg/m³</td>
<td>455</td>
<td>453</td>
<td>417</td>
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<tr>
<td>Available inlet pressure</td>
<td>Kg/cm²</td>
<td>14</td>
<td>14</td>
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<tr>
<td>Required discharge pressure</td>
<td>Kg/cm²</td>
<td>76</td>
<td>76</td>
<td>76</td>
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<tr>
<td>Required discharge head</td>
<td>m</td>
<td>1363</td>
<td>1368.6</td>
<td>1503</td>
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<tr>
<td>Resulting volumetric flow rate</td>
<td>m³/h</td>
<td>290</td>
<td>287</td>
<td>195</td>
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<tr>
<td>Resulting mass flow rate</td>
<td>t/h</td>
<td>132</td>
<td>130</td>
<td>80.4</td>
</tr>
<tr>
<td>Resulting pump efficiency</td>
<td>%</td>
<td>68</td>
<td>68</td>
<td>63</td>
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</table>

Table 3 - Comparison of the economic analysis (Unit: 1000 US$)

<table>
<thead>
<tr>
<th>Items</th>
<th>Case 1 (Re-condensing)</th>
<th>Case 3 (Cold energy storage)</th>
<th>Case 4 (Cold expander)</th>
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</thead>
<tbody>
<tr>
<td>Equipment cost</td>
<td>4,300</td>
<td>5,800</td>
<td>8,300</td>
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<tr>
<td>Construction cost</td>
<td>5,800</td>
<td>6,200</td>
<td>7,500</td>
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<tr>
<td>Operating cost per year</td>
<td>295</td>
<td>250</td>
<td>940</td>
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<tr>
<td>Maintenance cost per year</td>
<td>172</td>
<td>232</td>
<td>332</td>
</tr>
<tr>
<td>Net Present Value</td>
<td>10,488</td>
<td>12,294</td>
<td>19,183</td>
</tr>
</tbody>
</table>
Fig. 1 — Conceptual schematic of LNG process at the Pyeong-taek terminal

Fig. 2 — Comparison of monthly gas supply pattern

Legend
- LNG Line
- Vapor Line

Gas supply, [1000 ton]

Month

Choice/Supply in 1996
Choice/Supply in 1999

Fig. 2 — Comparison of monthly gas supply pattern
Fig. 3 — Gas hourly supply pattern in June 1996 as a design basis\textsuperscript{6}

Fig. 4 — Effect of re-storage of the mixed LNG on BOG rate\textsuperscript{7}
**Fig. 5** — Pressure vs temperature phase envelope of LNG

- **A**: storage LNG
- **B**: cricondenbar
- **C**: critical point
- **D**: LNG incoming to recondenser
- **E**: LNG outgoing from recondenser
- **T**: cricondentherm

**Fig. 6** — Required LNG flow under different operating pressures of re-condensing heat exchanger at 36 °C of vapor inlet temperature
Fig. 7 — Required LNG flow under different operating pressures of re-condensing heat exchanger at 7.5 °C of vapor inlet temperature

Fig. 8 — Process flow diagram of BOG re-liquefaction system
Fig. 9 — Effect of BOG re-liquefaction on HP pump performance curves

Fig. 10 — BOG re-liquefaction system installed at the Pyeong-Taek LNG terminal