1. INTRODUCTION

In recent years, deregulation has been promoted in the Japanese electric power market. In December 1995, the Electric Utility Industry Law was revised, allowing wholesale supply of electricity for the purpose of stimulating competition in the field of power generation. In April 1997, a self-wheeling system was introduced in order to make power transmission lines available for use by more companies. In March 2000, it became possible for extra-high-voltage users (20 kV or higher) to engage in retail power supply business.

In order to launch into the electric power business according to these deregulation measures, Osaka Gas Co., Ltd. installed a power plant with a capacity of 18 MW at Senboku LNG Terminal I, and began electric power wholesale in July 2002. We plan to construct a 50-MW-class power plant at our Himeji LNG Terminal. Commercial operation date of this facility is scheduled in June 2004.

This paper describes a power generation project at the Osaka Gas Himeji LNG Terminal that aims to enhance competitiveness through maximum use of the infrastructure on the premises; for example, by using LNG cryogenic energy for gas turbine inlet air cooling.

2. LNG REGASIFICATION PROCESSES AT LNG TERMINALS

The LNG regasification processes conducted at Osaka Gas LNG terminals is shown in Fig.1. LNG is transported to the LNG terminal by LNG tankers at the extremely low temperature of -160°C, and temporarily stored in LNG tanks. Inside the LNG tank, BOG is continuously produced due to external heat input. To maintain the internal pressure of the LNG tank at a constant level, the generated BOG must be processed. For this purpose, a BOG compressor is used to pressurize BOG and send it to a calorific value adjustment facility.

LNG is then sent from the LNG tank to the LNG vaporizers by feed pumps. The LNG vaporizer uses the heat energy of sea water to vaporize the LNG, and supplies the gas to customers.

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**Fig. 1** LNG regasification processes
3. OUTLINE OF THE POWER PLANT AT HIMEJI TERMINAL

3.1 Outline of the power plant

The power plant being constructed at the Himeji LNG Terminal features a variable heat/power ratio gas turbine combined cycle system. By using an aero-derivative gas turbine with the world's top class of efficiency, this plant is capable of attaining a power generating efficiency of 50.2%, which is almost as high as that of a large thermal power plant.

The project plant adopts a DSS (Daily Start and Stop) operation mode, and the electric power output from the generator and the steam obtained by using exhaust heat will be consumed inside the LNG terminal for the purpose of reducing the LNG processing costs. Surplus power exceeding the demand of the plant (approx. 47 MW max.) will be provided wholesale to other companies based on a grid-connected supply system.

The plant features a combined cycle generating facility that is comprised of a gas turbine, a generator, a steam turbine, a heat recovery steam generator and other peripheral equipments. The system flow of the project power plant is shown in Fig.2. The area inside the dotted line in the diagram indicates the existing LNG processing infrastructure at the LNG terminal.

The gas turbine uses BOG (boil-off gas) generated in the LNG tank as fuel. The heat recovery steam generator utilizes the heat energy of the exhaust gas from the gas turbine to produce steam, part of which is used as process steam in the LNG terminal, and the rest is supplied to the steam turbine for the generation of electric power, then condensed by the condenser and recirculated to boiler.

The condenser uses sea water for cooling, and the sea water heated by the condenser is supplied to the existing LNG vaporizer, where it is used to vaporize LNG. To prevent the gas turbine output from decreasing during summer, the existing LNG vaporizer is utilized to cool gas turbine inlet air. (See Table 1.)

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generating system</td>
<td>Variable heat/power ratio gas turbine combined cycle system</td>
</tr>
<tr>
<td>Generated power output</td>
<td>52,450 kW</td>
</tr>
<tr>
<td>Fuel</td>
<td>Natural gas (BOG)</td>
</tr>
<tr>
<td>Exhaust heat recovery</td>
<td>Steam supply volume: 0 to 5 t/h</td>
</tr>
<tr>
<td>Cooling system</td>
<td>Sea water cooling system</td>
</tr>
<tr>
<td>NOx emission control</td>
<td>Dry low-NOx combustor and ammonia denitration equipment</td>
</tr>
</tbody>
</table>

Fig. 2  Generation system flow
Table 2 describes the effects achieved through the maximum use of the LNG terminal infrastructure. Use of the existing LNG facilities and utilities allows a reduction in construction costs and the running cost of the power generation plant. It also provides a synergetic effect and lowers the running cost of the LNG regasification facilities.

<table>
<thead>
<tr>
<th>Infrastructure utilization method</th>
<th>LNG regasification process</th>
<th>Power generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling of condensate by sea water used for LNG vaporizer</td>
<td>Reduced use of sea water by LNG vaporizer</td>
<td>Elimination of cooling tower construction cost. Reduced running cost.</td>
</tr>
<tr>
<td>Cooling of intake air for gas turbine by existing LNG vaporizer</td>
<td></td>
<td>Reduced cost for inlet air cooling system. Reduced running cost. Improved power output and generating efficiency.</td>
</tr>
<tr>
<td>Generated steam used by plant</td>
<td>Reduced load for existing boiler</td>
<td>Reduced fuel cost.</td>
</tr>
<tr>
<td>BOG fuel</td>
<td>Reduced cost of processing BOG</td>
<td>Effective use of operators and maintenance personnel.</td>
</tr>
<tr>
<td>Personnel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2 Construction location

The location of the power plant on the premises of the LNG terminal is shown in Fig. 3. The plant is built next to the LNG vaporizers and sea water pumps area to enable the maximum use of LNG cryogenic energy and sea water for cooling.

4. BENEFITS OF CONSTRUCTING POWER PLANTS AT LNG TERMINALS

4.1 Cooling of condenser by sea water used as a heat source for LNG vaporizer

At the LNG terminals, Osaka Gas uses sea water for vaporizing LNG supplied at a temperature of -160°C. This sea water receives cryogenic energy from LNG in the process of vaporizing the LNG, then it is returned to the sea.

At the project power plant, sea water used as a heat source by the LNG vaporizer is also utilized as cooling water for the condensation of steam discharged from the steam turbine. Sea water
used for cooling the condenser is drawn from the main sea water pipe. After it undergoes the heat exchange process in the condenser, it is returned to the main sea water pipe that leads to the LNG vaporizer. Only the amount of sea water required by the condenser is drawn from the main pipe and pressurized by the booster pump.

The project power plant not only eliminates the need for certain facilities required by the circulation-type cooling water system, such as cooling towers, but also reduces the equipment installation area, accessory drive power and industrial water consumption. Since sea water heated through the steam condensation process provides heating energy for the vaporization of LNG, the amount of sea water required by the LNG vaporizer is also reduced. In the project power plant, the calorific value of sea water provided by the condenser balances with the quantity of cryogenic energy supplied by the LNG vaporizer; therefore, the temperature of sea water discharged to the sea remains at the temperature of intake sea water to cause minimal environmental impact.

As described above, by utilizing sea water for cooling steam, the project power plant reduces the equipment cost by approximately 3%, and the running cost by approximately 2%.

4.2 Utilization of LNG cryogenic energy for gas turbine inlet air cooling

4.2.1 Outline

Since increased intake air temperature cause a decrease in the gas turbine output, installation of an inlet air cooling equipment is necessary for maintaining high power output. As shown in Fig. 5, when a gas turbine inlet air cooling system is used to reduce gas turbine inlet temperature from 35°C to 15°C during the warm months, it is possible to improve combined cycle output of approximately 15%.
The project power plant cools inlet air by using water cooled by the existing LNG vaporizer in the process of vaporizing LNG. Chillers are generally used for inlet air cooling, but they have major drawbacks, such as an increase in facility costs and a decrease in net power due to power consumed by accessory power drives.

In the past, LNG cryogenic energy has been utilized by air liquefaction facilities, liquefied carbon dioxide manufacturing facilities, cryogenic power generation systems and the like, but the project plant is the first power generation facility to use LNG cryogenic energy for gas turbine inlet air cooling. At the power plant, approximately 27 t/h of LNG will be used for cooling inlet air.

4.2.2 Inlet air cooling system

Because LNG is extremely cold, providing its cryogenic energy to water used for cooling intake air can result in freezing of the water. For the project plant, Osaka Gas uses a TRI-EX LNG vaporizer since it eliminates the possibility of water freezing when used as an inlet air cooling unit.

The TRI-EX LNG vaporizer uses an intermediary heat medium and consists of three shell-and-tube heat exchangers (thus, it is called a TRI-EX). This vaporizer was originally developed by Osaka Gas. By using an intermediary heat medium for the exchange of heat energy between LNG and sea water, the vaporizer prevents icing on the heat transfer surfaces.

Sea water provides heat to natural gas at the E3 heater in the TRI-EX LNG vaporizer, and gives off the latent heat of evaporation to the intermediate heat medium at the E1 evaporator before it is discharged. Meanwhile, the intermediate heat medium is condensed and dripped through a heat exchange process with low-temperature LNG at the E2 condenser, then it undergoes another heat exchange process with sea water at the E1 evaporator, and evaporates again. This cycle is repeated.

To use the TRI-EX LNG vaporizer for the continuous and stable supply of LNG cryogenic energy for gas turbine inlet air cooling, the existing sea water pipe is branched out and a new pipe is installed for the industrial water circulation.

![Diagram of Gas turbine inlet air cooling system](image_url)
Air (35°C, 55%RH) entering the intake air filter is cooled to approximately 15°C through the heat exchange with the circulating water produced by the vaporizer. This system provides the following control functions.

1) LNG vaporization rate is controlled for the regulation of cold water outlet temperature. When the temperature of the circulating water at the vaporizer outlet decreases to 7°C or lower, the LNG control valve operates and reduces the LNG flow rate.
2) In order to keep the LNG vaporizer in a cool-down condition while the power system is shut down at night, the LNG control valve is controlled to the closed position to minimize the amount of LNG. Steam keeps the circulating water warm.

Since intake air needs to be about 15°C, there is no need to cool air during winter. Therefore, during winter when the gas demand is high, the LNG vaporizer uses sea water as a heat source, thus allowing unrestricted use of LNG for gas supply.

By using the existing LNG vaporizer as an inlet air cooling device, the construction cost and the running cost can be reduced by approximately 2% and 0.5%, respectively. At the same time, annual generated electric power can increase by about 5%.

4.3 On-site use of produced steam
The process supply steam can be controlled in accordance with the demand in the LNG terminal. This can reduce the load on the existing boilers in the LNG terminal by an average of 2 t/h.

4.4 BOG
Because BOG has a low calorific value, it requires a larger amount of LPG for use as city gas supply. By using BOG as fuel for the gas turbine, however, the processing cost can be reduced.

5. SCHEDULE
Osaka Gas began equipment design and production in June 2002, and will start on-site construction in March 2003. The plant is scheduled for completion of installation in December 2003. Then, after commissioning, commercial operation is slated to commence in June 2004.

6. CONCLUSION
Osaka Gas has recently entered the electric power business. This paper has introduced the company's plan for reducing the costs of power generation by using the infrastructure of LNG terminals and LNG cryogenic energy.

As energy supply systems are expected to progress increasingly toward a multi-energy model that includes both gas and electricity, it is important for the company to ensure a low-cost, stable supply of electric power. To respond to the demand for electricity, Osaka Gas plans to construct another large power plant at its Senboku Terminal.