International Gas Union Research Conference 2011

LNG COLD ENERGY SUPPLY FOR CO2 REDUCTION AND ENERGY CONSERVATION IN MITSUI CHEMICALS ETHYLENE PLANT

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1. ABSTRACT

Cryogenic energy of LNG (LNG cold energy) can be used for a number of facilities including air separation/liquefaction and cryogenic power generation. Osaka Gas, through its 30-year experience in utilizing LNG cold energy, has developed and introduced various processes for practical uses which realized energy conservation and reduced CO2 emissions. As part of the company's efforts in enhancing efficient energy utilization, a new process has been developed to utilize LNG cold energy in an ethylene plant at an adjacent chemical plant of an LNG receiving terminal of Osaka Gas.

The new process was employed at a manufacturing plant where ethylene and propylene had been manufactured from naphtha or off-gas in petrochemical works and purified by a low temperature separation process in the ethylene plant. Unlike the conventional process in which cold energy for the separation is generated by driving the refrigeration compressor with steam turbine fuelled by fuel oil and off-gas, LNG cold energy was used to partially replace the cold energy required for the low temperature separation process. As a result, the amount of fuel oil consumption for the steam boiler was reduced considerably. Also, use of the LNG cold energy enabled the plant to keep the load of the refrigeration compressors at a lower level and it reduced the fuel consumption for the steam boiler.

The new LNG cold energy utilization process installed in the ethylene plant has contributed to broaden the scope of LNG cold energy utilization both in quality and quantity, making the rate of LNG cold energy utilization at Senboku Terminal 1 reach 100%. In economic and environmental terms, the new process has enabled the plant to reduce fuel oil consumption by 13,000 kiloliters/year and reduction of CO2 emission by approximately 30,000 tons/year.

The current paper reports the development of the new process with a focus on engineering and design.

TABLE OF CONTENTS

2. BODY OF PAPER

2.1. INTRODUCTION

2.1.1. LNG cold energy

Increasing attention has been given to utilization of cryogenic energy of LNG (LNG cold energy) as an effective means for achieving greater energy conservation and reducing CO2 emission. In the background of this trend is a rising demand for LNG on a global level amid concerns over addressing the issues of climate change and achieving efficient energy utilization.

LNG cold energy has two elements in its utilization; 'temperature energy' and 'expansion energy.' The former is derived from temperature difference between LNG and the atmosphere. The latter is obtained from the expansion process of LNG when it expands 600 times in volume upon evaporation. Without having effective facilities for its recovery and utilization, LNG cold energy is lost into the sea when LNG is evaporated at LNG receiving terminals.

The maximum potential work by these energies is calculated by the following formulae.

The temperature energy: $E=H-H_0-T_0(S-S_0)$ The expansion energy: $E=R'T_0 \ln (P/P_0)$

(H: enthalpy, T: temperature, S: entropy, R': gas constant, P: pressure; the subscript "0" indicates the ambient condition)

In LNG receiving terminals, LNG exists under a variety of conditions, and the ratio between temperature and expansion energies depends on its temperature, pressure and composition (Table 1). Under the same composition and temperature, the greater the expansion energy of LNG is, the lower its temperature energy becomes.

Temperature [deg.C]	Pressure [MPaG]	Temperature Energy [kWh/t]	Expansion Energy [kWh/t]
-160	0	240	0
-160	4.4	110	130
-160	8.0	90	150

Table 1 LNG's cold energies under different conditions

2.1.2. New LNG Cold Energy Utilization Facility

Osaka Gas, since its start of LNG import in 1972, has been engaged in developing various LNG cold energy utilization facilities. Those developed and employed for practical use are shown in Fig. 1. Among these facilities and processes, the company became the first in the world to develop cryogenic power generation and BOG re-liquefaction facilities. Utilizable LNG cold energy is fluctuated by seasonal and hourly fluctuation of Osaka Gas's gas supply, and the base-load LNG cold energy can be used by these facilities which are difficult to change load of cold energy. As a result of the company's efforts in furthering the advancement of LNG cold energy utilization, the base-load LNG cold energy has already been almost fully utilized (Fig.2). Under these circumstances, therefore, development of a new LNG cold energy utilization process can be justified by greater energy conservation effects as LNG cold energy supply to the existing facilities needs to be reduced.

1970s	1977: **Air separation** (Cold Air Products No.1) at Senboku Terminal 1 1979: **Cryogenic power generation** (1,450 kW: Rankine cycle) at Senboku Terminal 2
1980s	1980: **Liquefied carbon dioxide** (Kinki Ekitan Co., Ltd.) at Senboku Terminal 1 1982: **Cryogenic power generation** (6,000 kW: Rankine cycle + direct Expansion) at Senboku Terminal 2 1983: **Air separation** (Second cold air products) at Senboku Terminal 2 1987: **Cryogenic power generation** (2,800 kW: Rankine cycle) at Himeji Terminal 1987: **Neighboring chemical plant** (Energy supply for cold water or for cooling medium) at Senboku Terminal 1 1989: **Cryogenic power generation** (2,400 kW – by direct expansion) at Senboku Terminal 1
1990s	1993: **Air separation** (Cryo Air) at Senboku Terminal 1 1997: **Boiloff gas reliquefaction** (BOG: 15 t/h) at Senboku Terminal 2
2000s	2000: **Cryogenic power generation** (1,520 kW – by direct expanding) at Himeji Terminal 2004: **Cooling of intake air** (50,000 kW – G/T) at Himeji Terminal 2004: **RING** (by cooperation with neighboring plants) at Senboku Plant 1 2005: **Neighboring chemical plants** (Cold energy supply business for low-temperature distillation processes) at Senboku Terminal 1
2010s	2010: **Neighboring ethylene plant** (Cold energy supply for chemical product manufacturing processes) at Senboku Terminal 1

Fig.1 LNG cold energy facilities

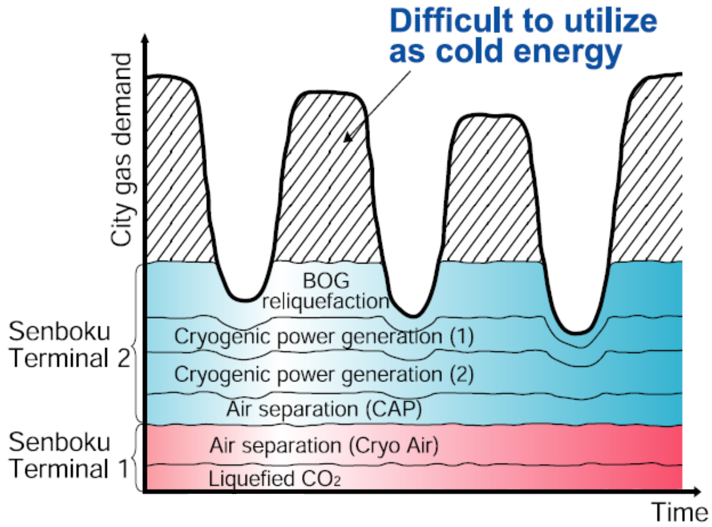

Fig.2 Limit to LNG cold energy utilization

In developing a new process, a focus was made on an ethylene plant at Mitsui Chemical's Osaka Works located adjacent to Senboku 1 LNG Terminal of Osaka Gas. Requiring cryogenic energy at an extremely low temperature, the ethylene plant of Mitsui used a conventional refrigeration equipment. Attention was given to the low temperature range where COP rate is lowered to which LNG cold energy was to be applied. LNG cold energy when it replaces the conventional refrigeration equipment has an advantage of lower electricity consumption, because LNG cold energy requires only electricity for driving a pump for transferring LNG regardless of temperature range, resulting in considerable saving of power requirement (FIg.3). At the plant, ethylene and propylene are manufactured through low-temperature distillation after cracking of naphtha and off-gas (Fig. 4). In the conventional process, the cold energy is generated by refrigeration compressor driven by steam turbine and the required steam is generated by steam boiler using fuel oil or off-gas. In the new process, its cold energy requirement is partially replaced by LNG cold energy, and it results in reduced power consumption for compression as well as lower fuel consumption for steam generation.

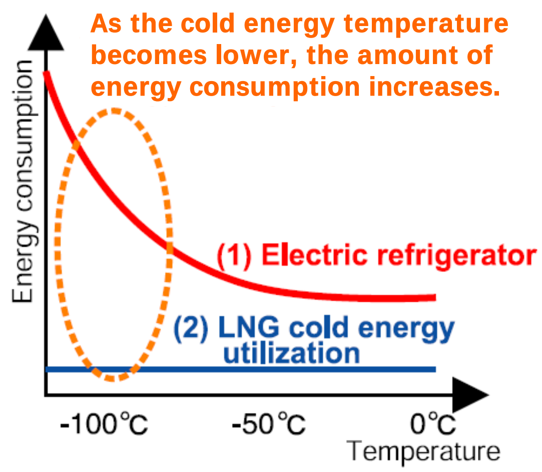

Fig.3 Advantage of LNG cold energy utilization

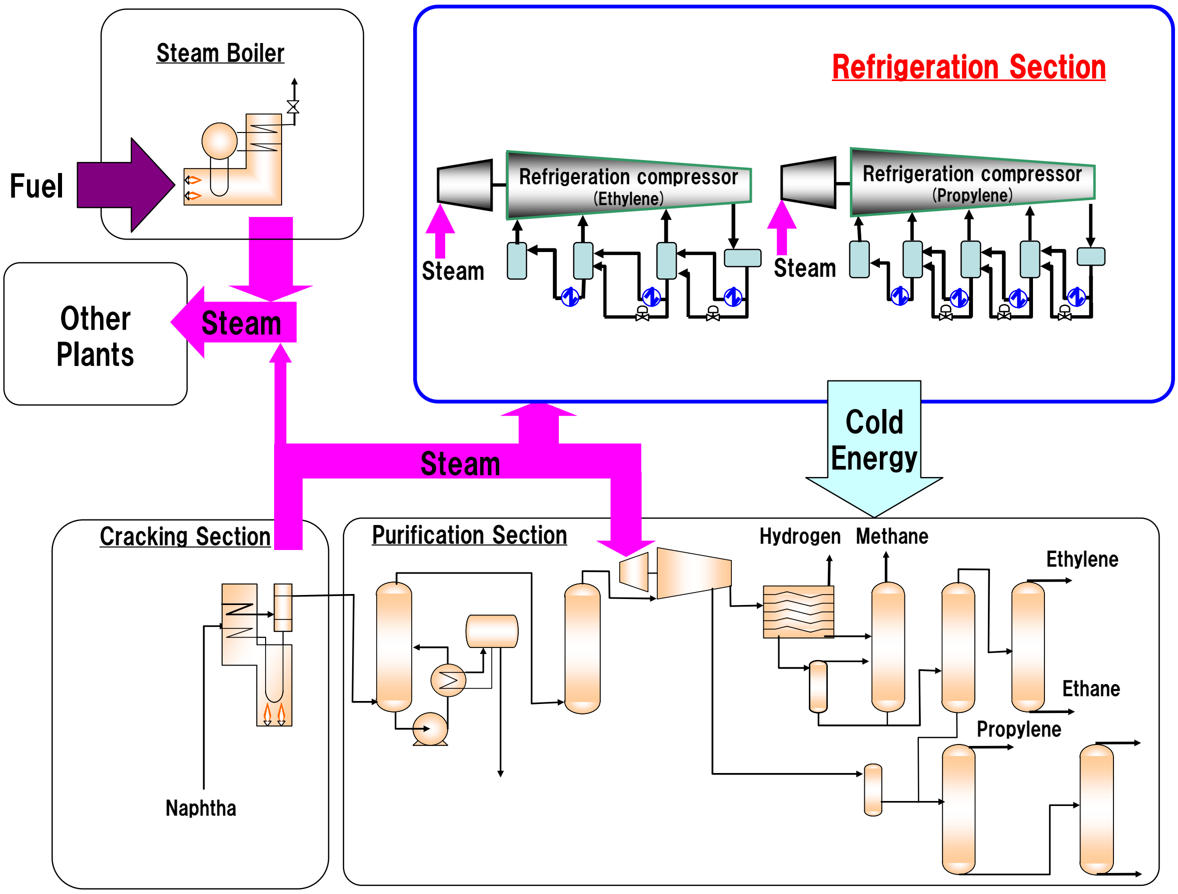

Fig.4 Conventional refrigeration system in ethylene plant

2.2. CHALLENGES AND MEASURES OF LNG COLD ENERGY UTILIZATION IN ETHYLENE PLANT

2.2.1. Developing a New Process: challenges

Major challenges in developing a new process utilizing LNG cold energy included the following;

(1) Due to high utilization of LNG cold energy already made at Senboku I LNG Terminal and seasonal and hourly fluctuation of Osaka Gas's gas supply (70-200 tons/hour), amount of LNG to be supplied from the terminal could be in shorted (fig.5).

(2) The volume of LNG for the new process had to be matched with seasonal and hourly fluctuation of Osaka Gas's gas supply.

With these challenges in the background, a new process needed to realize a high level of stability not affected by gas supply operations because the plant is a key plant for Mitsui Chemicals and to maximize energy conservation to achieve a high utilization of LNG cold energy.

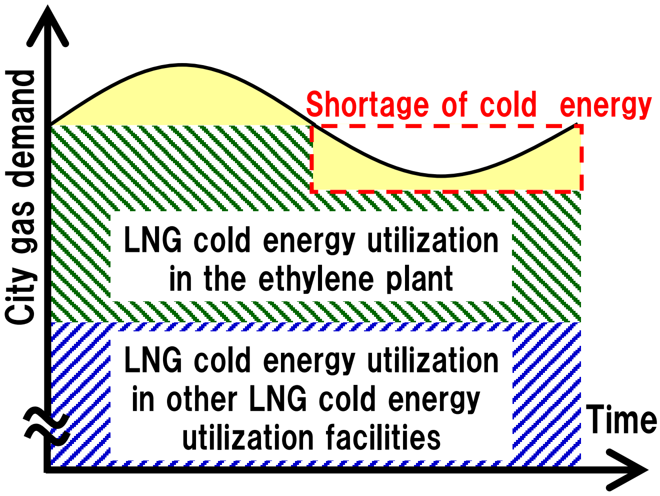

Fig.5 Shortage of cold energy in the ethylene plant

2.2.2. Developing a New Process: achieving operational stability

In order for the process to achieve its operational stability, it was understood that LNG cold energy could be used in combination with the cold energy derived from the existing refrigeration compressor. By this means, the cold energy could be supplemented in case of LNG supply shortage for the ethylene plant. Furthermore, the process could be operated by having the compressor alone in case of the shutdown of LNG supply due to periodic repair or power outage etc. When the process was operated with the combined supply of cold energy, there were no major capital cost additions for the new compressor because of use of the existing compressor.

2.2.3. Developing a New Process: achieving energy conservation

Some issues were identified in examining the process's energy conservation effects;

(1) When LNG is the single source of cold energy in the new process, a maximum energy saving can be achieved due to total removal of power load for compressor (Fig.6). From the operational perspective, however, ethylene plant operation needs to be adjusted when meeting LNG supply shortage.

(2) When LNG cold energy is combined with refrigeration compressor, the lowered power portion for the compressor replaced by LNG cold energy translates into the saved steam turbine power. Due to the risks of surging of pressure and flow rate of the centrifugal compressor caused by excessively lower load, the minimum operational load of the compressor was about 70% of the rated load, i.e. the remaining 30% of the cold energy requirement to be supplied by LNG.

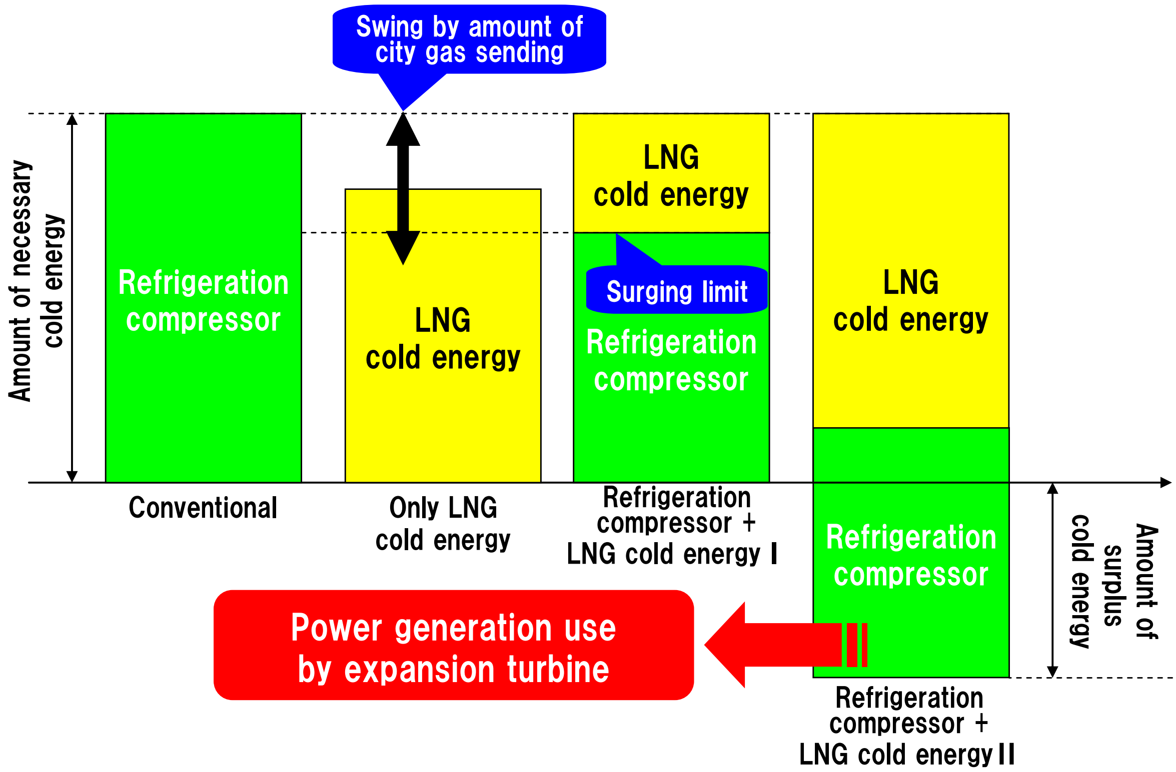

Fig.6 Cold energy balance of ethylene plant

To address the above issues, an examination of the process was made to maximize the use of LNG for meeting without restricting the LNG cold energy supply to the needed cold energy requirement at the ethylene plant. As a result, a process was successfully developed in which LNG volume could be increased to a maximum. This was made possibly by employing an expansion turbine which removed surging limit restrictions of the compressor (Fig. 7). Advantages of the process include efficient utilization of LNG cold energy through phases along the broad temperature ranges of the ethylene plant (-100 C to 20 C) (Fig. 8) [1]. With the use of LNG cold energy in the process, significant energy saving is being expected equivalent to 13,000kl of crude oil and CO_2 emission reduction of 30,000 tons annually.

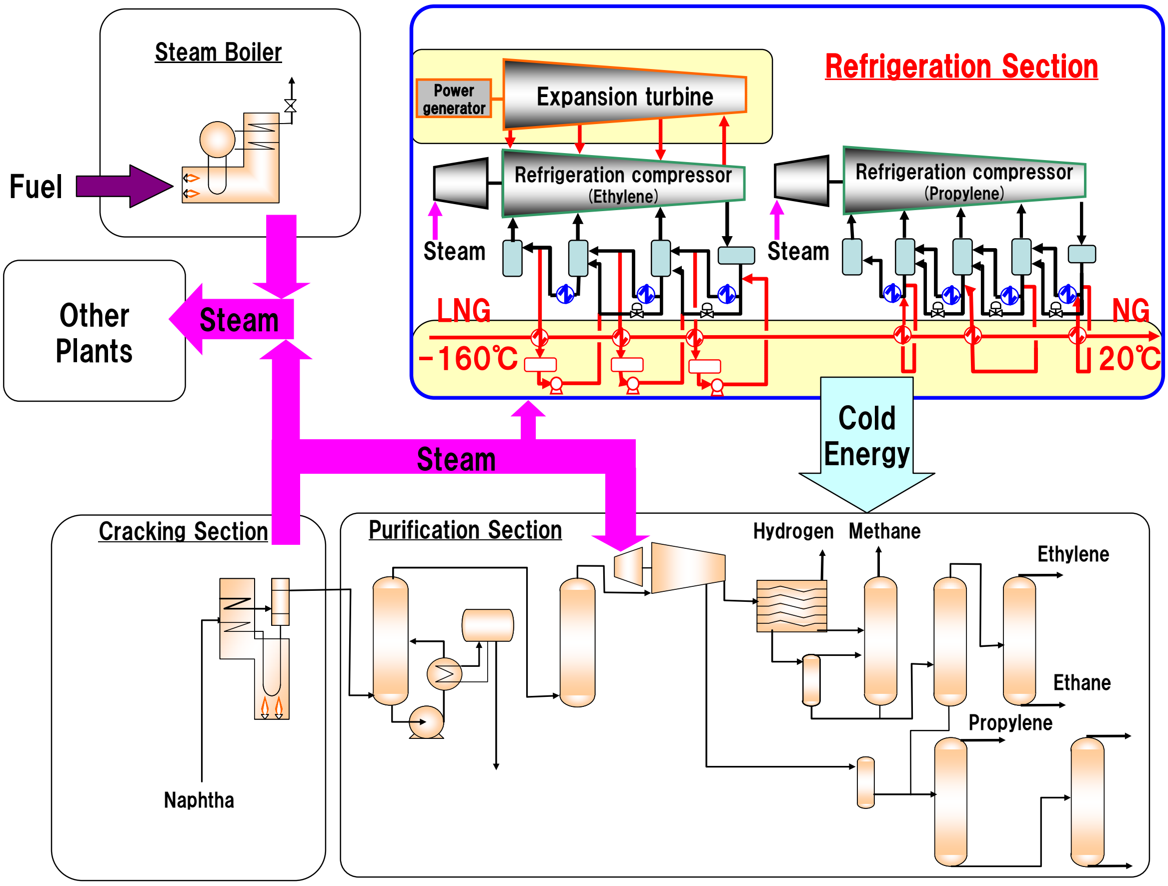

Fig.7 New refrigeration system in ethylene plant

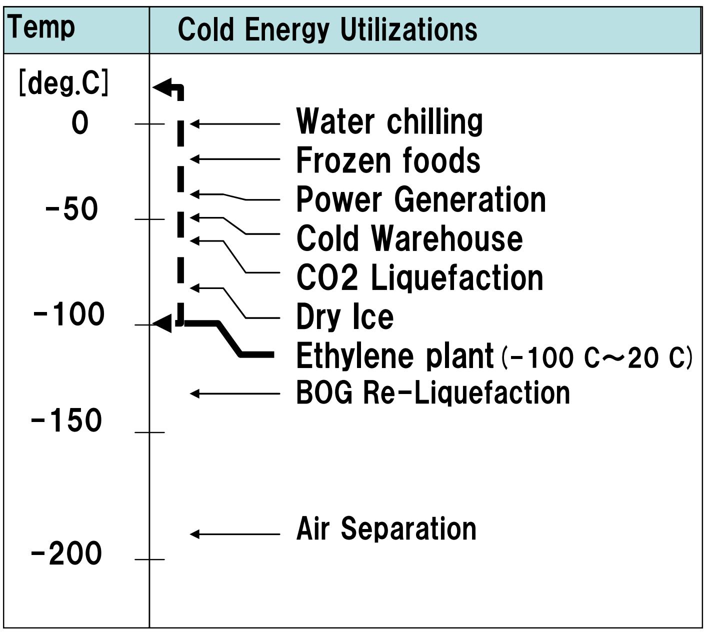

Fig.8 LNG cold energy utilization facilities and required temperature ranges

2.3. DESIGN AND CONSTRUCTION OF LNG SUPPLY AND RECEIVING FACILITY

2.3.1. Construction Organization and Schedule

As shown in Fig. 9, a joint undertaking by the three companies involved, namely Mitsui Chemicals, Osaka Petrochemical Industries (a wholly owned subsidiary of Mitsui), and Osaka Gas, was conducted to build a facility to supply LNG from Senboku 1 Terminal of Osaka Gas and to receive natural gas utilized in the ethylene plant. Prior to the construction work, the facility had been made to the New Energy and Industrial Technology Development Organization (NEDO) for a grant as part of the government's plans for promoting energy conservation. With the support of the government's grant, the facility construction was launched in 2008 and completed in September 2010. After smooth commissioning, a full-scale operation was commenced in January 2011.

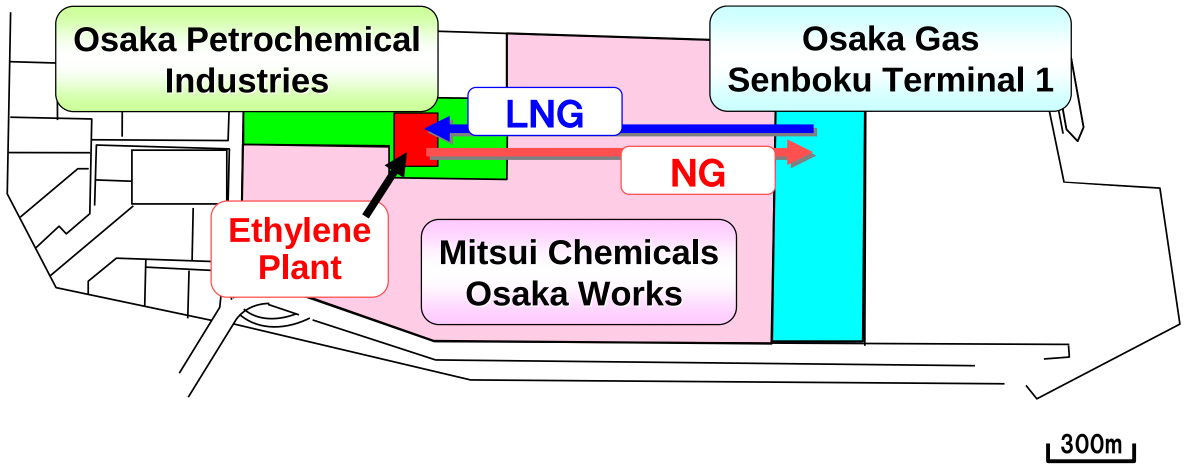

Fig.9 Plant layout

2.3.2. Key Points of Engineering and Design

Key points in engineering and design of the plant include the following;

(1) The use of a coriolis meter helped to reduce costs associated with gas property and composition analysis, unlike the conventional method of using flow meters which require flow-rate calibration (Fig.10). The high accuracy of the meter also proved its reliability for transaction.

(2) A calorimeter was installed to monitor the quality of vaporized natural gas upon its return to Osaka Gas. It is required that LNG after its cold energy utilization does not affect the utility's gas supply, particularly at the plant's start-up and at change of LNG supply volume for any variation in gas calorific value. In order to meet an emergency case of a major fluctuation in calorific value and to ensure quality of gas for utility business, the plant was designed to be able to isolate the supply of utility gas from Senboku 1.

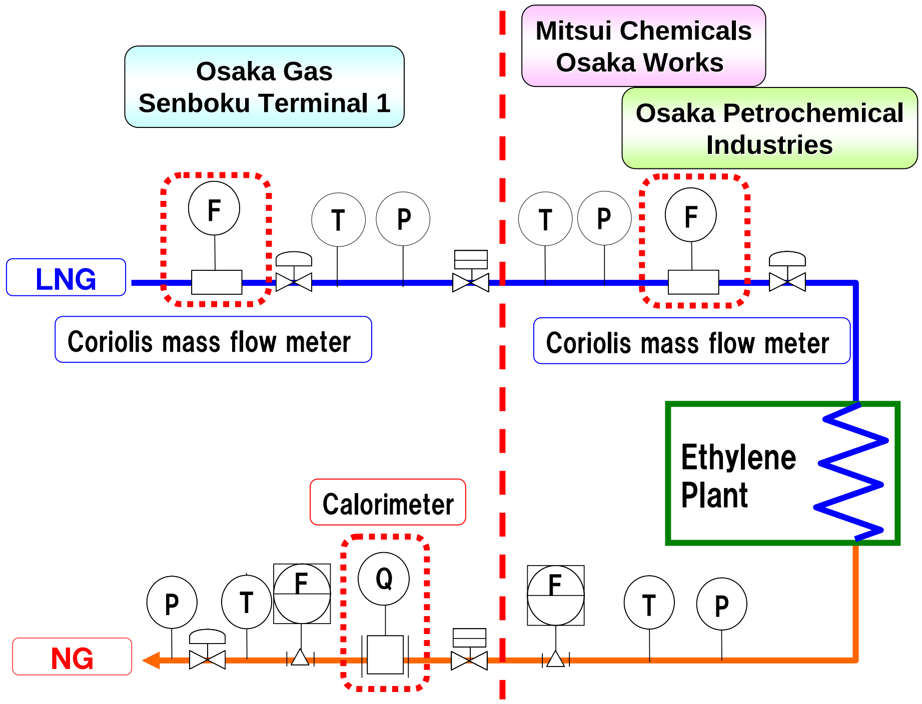

Fig.10 Process flow of the LNG supply and receiving plant

2.3.3. Operation Results

2.3.3.1. Energy Conservation Effect

Since its commissioning in September 2010, the plant has been operated in a stable manner. It has been verified that no change in pressure of LNG and natural gas and calorific value of natural gas has occurred at change of LNG flow rate (Fig. 11). Moreover, the expected effect of energy conservation and CO2 reduction was confirmed through the operation results of the process at the ethylene plant.

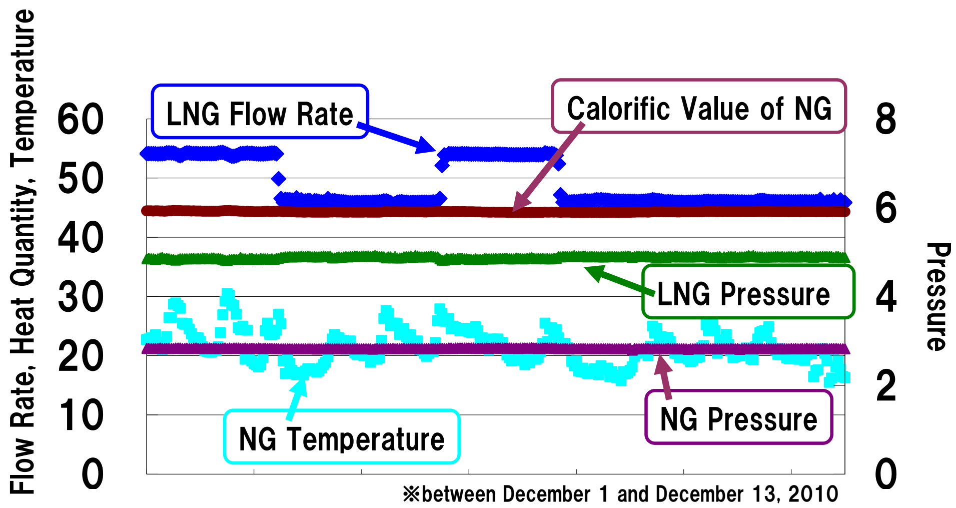

Fig.11 Operation results of the LNG supply and receiving plant

2.3.3.2. Increase of Quantity of LNG Cold Energy Utilization

With the start of the new LNG cold energy utilization process, the entire LNG at Senboku 1 is supplied to the network through LNG vaporization at LNG cold energy utilization facilities. Unlike the conventional vaporization process of using seawater in which LNG cold energy is wasted into seawater, send-out of natural gas is made without the use of vaporizers (Fig.12) [2].

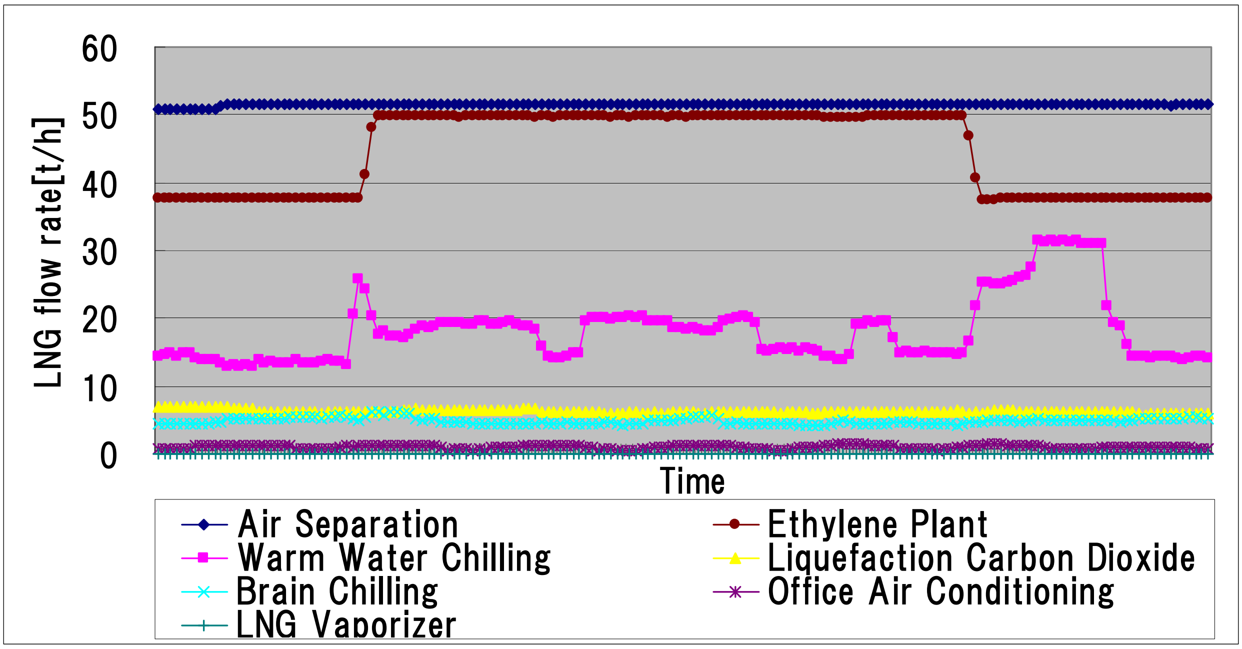

Fig.12 Flow rate of LNG cold energy utilization facilities

2.3.3.3. Improvement of Quality of LNG Cold Energy Utilization

The efficiency of LNG cold energy utilization facilities is evaluated by the following formula (Fig.13); It has been valued that LNG cold energy utilized considerably efficiently in the ethylene plant.

(The efficiency of LNG cold energy utilization) [%]

= (Amount of power reduction by LNG cold energy utilization) [kWh/t-LNG]

/ (LNG cold energy) [kWh/t-LNG]

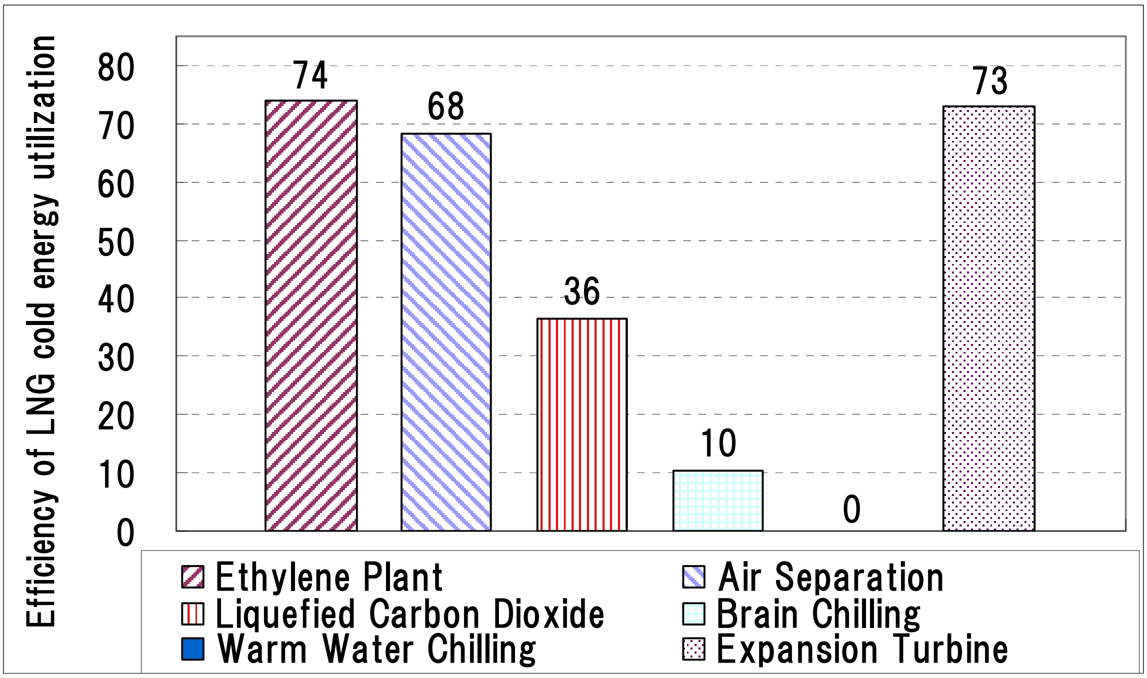

Fig.13 Efficinecy of LNG cold energy utilization facilities

The quality of the LNG cold energy utilization in Senboku Terminal 1 is evaluated by the following formula;

LNG cold energy utilization in the ethylene plant improves the quality of the LNG cold energy at the terminal (Fig.14).

(The efficiency of LNG cold energy utilization) [%]

=∑ ((The efficiency of LNG cold energy utilization facility) [%]*(LNG flow rate of LNG cold energy utilization facility) [t/h])/∑ (LNG flow rate of LNG cold energy utilization facility) [t/h]

LNG cold energy utilization facilities and LNG vaporizer	The efficiency of LNG cold energy utilization facility	Total LNG mass of each facilities for one week [t]	
		LNG cold energy utilization in Ethylene Plant	
		before	after
Ethylene Plant	74	0	7491
Air Separation	68	8316	8662
Liquefied Carbon Dioxide	36	1349	1050
Brain Chilling	10	848	818
Warm Water Chilling	0	6916	3051
LNG Vaporizer	0	0	0
Expansion Turbine	73	10756	10273
The efficiency of LNG cold energy utilization in Senboku Terminal 1[%]		38	52

Fig.14 Improvement of the efficiency of LNG cold energy utilization in Senboku Terminal 1

2.4. CONCLUSION

Mitsui Chemicals, Osaka Petrochemical Industries, and Osaka Gas jointly worked with a focus on the ethylene plant which had significant potential for reducing energy consumption by utilizing LNG cold energy in the Mitsui Chemicals Osaka Works.

By combining LNG cold energy with the compressors and the expansion turbine, it became possible to develop the new process with high operational stability and large energy conservation effects. It was decided to employ LNG cold energy in the ethylene plant, the key plant in the petrochemical works.

The construction and commissioning of the LNG supply and receiving plant was completed in 2010 through close cooperation of the three companies without any accidents and troubles, and the plant has been operated in a stable manner.

The process became the world's first successful case in introducing a large amount of LNG cold energy in the ethylene plant. As the result, the process realized effective energy conservation and reduced emission for as much as approximately 13,000 kiloliter/year of crude oil and approximately 30,000 tons/year of CO_2, respectively.

The new LNG cold energy utilization facility in the ethylene plant has improved the rate and the quality of LNG cold energy utilization in Senboku Terminal 1. Osaka Gas intends to continue its efforts toward advancement in the utilization of LNG cold energy for further energy conservation and CO_2 reduction in the future.

3. REFERENCES

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4. LIST TABLES

5. LIST OF FIGURES