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Development of LNG Vaporization Systems Applying Hybrid Ground Source Heat Pumps Combined Ground Heat Exchangers with Air-water Heat Exchangers

Takao Katsura^{a*}, Yutaka Shoji^a, Hitoshi Akai^{a,b}, Katsunori Nagano^a, Jun Shishido^c,
Mitsuhiro Ishikawa^d, Yuichi Yashima^c, Koji Tanifuji^f

^a Hokkaido University, Kita13-Nishi 8, Kita-ku, Sapporo, 060-8628, Japan

^b Fukushima University, Kanayagawa 1, Fukushima, 960-1296, Japan

^c Tohoku Electric Power Co., Inc., 1-7-1 Honcho, Aoba-ku, Sendai, 980-8550, Japan

^d Hokkaido Electric power Co., Inc., Odori-Higashi 1, Chuo-ku, Sapporo 060-8677, Japan

^e NIPPON GAS DEVELOPMENT CO., LTD, 4-2-1 Kyutaromachi, Chuo-ku, Osaka 541-0056, Japan

^f ZENERAL HEATPUMP INDUSTRY CO., LTD., 121 Mishinden Odaka-cho, Midori-ku, Nagoya, 459-8001, Japan

Abstract

In order to reduce the gas consumption in LNG satellite stations, the authors have developed LNG vaporization systems applying hybrid ground source heat pumps (HGSHPs) combined ground heat exchangers (GHEXs) with air-water heat exchangers (AWHEXs). The heat pumps can vaporize the LNG with high efficiency because it is possible to vaporize the LNG by using the low-temperature hot water of around 25°C. The ground source heat pumps (GSHPs) can supply the hot water stably even in the winter season due to no need of defrosting operation. In addition, the HGSHP system with AWHEXs can prevent the decrease of ground temperature due to the excess heat extraction. The authors constructed the field experimental apparatus and carried out the vaporization experiment with a HGSHP. The results indicated that it is possible to vaporize the liquid Nitrogen (Instead of LNG) by using hot water with the temperature of 25°C and the low-temperature hot water supply with GSHP yields the reduction of energy consumption.

Keywords: Hybrid ground source heat pump; LNG vaporization; Ground heat exchanger; Air-water heat exchanger; Field experiment

1. Introduction

Recently, the number of facilities applying LNG satellite station is increasing in the case where the facilities has high gas demand such as factories. In some LNG satellite stations, it is necessary to burn the vaporized natural gas in order to supply the natural gas stably. In this case, 3~5% of the vaporized natural gas is used for burning, therefore, it is required to reduce the gas consumption for energy saving.

It is possible to reduce the energy consumption by applying the heat pump system because the natural gas can be vaporized by using the hot water with lower temperature compared to the usual hot water with the temperature of 60°C. Especially, installation of GSHP systems is effective because of no need of the de-frosting operation. However, if the GSHP systems are applied for LNG vaporization, in which the heating demand is generated through the year, there may be a long-term decrease of ground temperature due to the excess heat extraction.

Therefore, the HGSHP system with AWHEXs is applied to prevent the decrease of ground temperature. Although the solar collectors that can absorb the solar heat are also used in the hybrid GSHP system [1], [2], the efficiency of the solar system drops during cloudy and rainy days. In addition, the solar heat cannot be collected during the night. In comparison, the AWHEXs can extract the heat from air even in the condition of

* Corresponding author. Tel.: +81-11-706-6284; fax: +81-11-706-6284.

E-mail address: katsura@eng.hokudai.ac.jp

cloudy or rainy weather if the air temperature is higher than the temperature of heat carrier fluid. It can recover the ground temperature by injecting heat regardless of the weather condition. In addition, the efficiency of heatpump can be improved compared to the conventional GSHP system if the hybrid GSHP provides heating in summer season. The authors constructed the field experimental apparatus of gas vaporization system with HGSHP and the experimental proof of gas vaporization with HGSHP was carried out. In addition, the energy saving effect of HGSHP was evaluated by using the result of experiment.

2. Outlines and advantage of system

Figure 1 shows a concept diagram of LNG vaporization system applying HGSHP. The system consists of heat pump units, GHEXs, AWHExs, and LNG vaporization heat exchangers. Depending on the outside air temperature conditions, it is possible to select only the GHEXs or a combination of GHEXs and AWHExs as the heat source. Then, the heat pump units supply hot water to the LNG vaporization heat exchangers and the LNG is vaporized. Here, the LNG vaporization heat exchangers are designed so that the hot water does not freeze even in the case where the hot water with lower temperature is supplied.

The following advantages of LNG vaporization system applying HGSHP are mentioned;

- A. It is possible to obtain the heating output to stably vaporize the LNG.
- B. There is no decrease of heating output and heating COP occurred by the de-frosting operation.
- C. In summer season, the outside air with high temperature can be utilized as the heat source. In addition, the ground temperature surrounding GHEX can be recovered by injecting the surplus heat to the ground.
- D. The hot water with temperature of 25°C can be supplied from heat pump units because the LNG is vaporized with the hot water. Therefore, the energy efficiency and energy saving effect are larger than those in the common heating in which the hot water with temperature of 35~45°C is supplied.

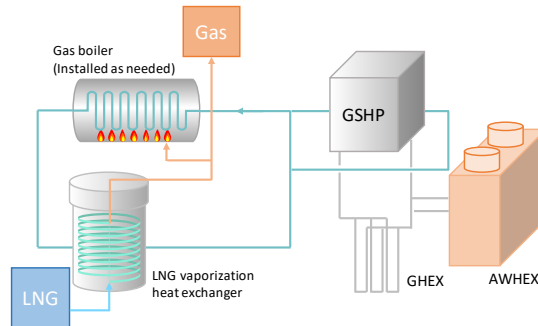


Fig.1 Concept of LNG vaporization system with hybrid GSHP system

3. Field experiment of gas vaporization system with HGSHP

3.1 Outlines of field experimental apparatus

The experimental apparatus of gas vaporization system with HGSHP shown in Figure 2 was constructed in the field of Hokkaido University in Sapporo city. The apparatus is a cut-down version of actual LNG vaporization system. In the experiment, the liquid nitrogen was used instead of LNG. Table 1 indicates the specification of heat pump unit (HP in Figure 2). The heat pump unit has two inverter compressors. The heat pump unit was connected to the two GHEXs with length of 100 m in the primary side and the vaporization heat exchanger in the secondary side, respectively. In addition, the AWHEx was connected between the heat pump unit and GHEXs. Therefore, it is possible to switch only the GHEXs or a combination of GHEXs and an AWHEx as the heat source. Table 2 indicates measurement points in the field experiment. The inlet and outlet temperatures and the flow rates in the primary side and the secondary side of heat pump unit were measured. By using the measured values of temperatures and flow rates, the heating output and the heat extraction rate were calculated. Additionally, the mass flow rate of vaporized nitrogen gas and the temperatures

before and after vaporization were measured, so that the consistency between the heating output from heat pump unit and the amount of heat used for vaporization could be confirmed. The heat pump COP and system COP were also evaluated by measuring the electric powers of a heat pump unit, circulation pumps, and a fan of AWHEXs.

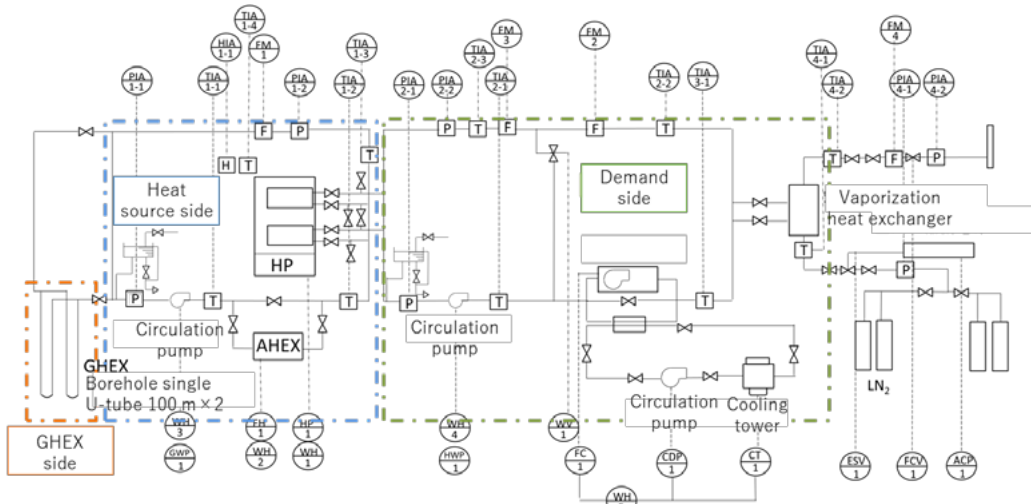


Figure 2 Diagram of field experimental apparatus

Table 1 Specification of heat pump unit

Heat exchanger	Plate heat exchanger
Flow rate	21 L/min
Rated heating output	13.6 kW
Rated electric power	4.2 kW

Table 2 Measurement items

Equipment (Number)	Measuring items	Unit
Pt-100 sensor TIA1-1	Outlet temperature of GHEXs	°C
Pt-100 sensor TIA1-2	Inlet temperature of HP in the primary side	°C
Pt-100 sensor TIA1-3	Inlet temperature of GHEXs	°C
Pt-100 sensor TIA1-4	Outlet temperature of HP in the primary side	°C
Pt-100 sensor TIA1-4	Ambient temperature	°C
Pt-100 sensor TIA2-1	Outlet temperature of HP in the secondary side	°C
Pt-100 sensor TIA2-2	Outlet temperature of vaporization heat exchanger or fan-coil unit	°C
Pt-100 sensor TIA2-3	Inlet temperature of HP in the secondary side	°C
Pt-100 sensor TIA4-1	Liquid nitrogen temperature	°C
Pt-100 sensor TIA4-2	Nitrogen gas temperature	°C
Flow meter FM-1	Flow rate in the primary side of HP	L/min
Flow meter FM-3	Flow rate in the secondary side of HP	L/min
Flow meter FM-4	Flow rate of nitrogen gas	Nm ³ /h
Power meter WH-1	Electric energy of HP	kWh
Power meter WH-2	Electric energy of fan of AWHEX and circulation pump	kWh

3.2 Conditions of field experiment

Table 3 indicates conditions of field experiment. The experiments V1-1~V1-5 were carried out in winter season and only the GHEXs were used as heat source. The supply temperature of hot water and the mass flow rate of nitrogen gas were changed. The experiments V2-1~V2-3 were carried out in summer season and a combination of GHEXs and an AWHEX were used as heat source. The mass flow rate of nitrogen gas was changed.

Table 3 Conditions of field experiment

Test number	Test period	Heat source	Hot water temperature [°C]	Nitrogen flow rate [Nm ³ /h] (Load ratio)
V1-1	19/1/23 10.30-11.00	Ground	45	90 (100%)
V1-2	19/1/23 11.37-12.07		35	90 (100%)
V1-3	19/1/23 14.00-14.30		25	90 (100%)
V1-4	19/1/23 14.30-14.50		25	68(75%)
V1-5	19/1/23 15.06-15.36		25	45(50%)
V2-1	18/8/8 11:20-12:00	Ground + Air	25	90 (100%)
V2-2	18/8/8 12:00-13:00			45(50%)
V2-3	18/8/8 13:00-14:00			30(33%)

3.3 Results and discussions

Figure 3 shows the inlet and outlet temperatures (TIA2-1, TIA2-3) and the flow rates (FM-3) in the secondary side of heat pump unit in the experiments V1-3~V1-5. The variations of nitrogen gas temperature (TIA4-2) and mass flow rate of nitrogen gas (FM-4) are also drawn in Figure 3. The mass flow rate was close to the set value and the gas temperature changed from 10°C to 20°C. The liquid nitrogen temperature was about -170°C, therefore, it was confirmed that the liquid nitrogen was vaporized. Next, the outside air temperature (TIA1-4), the inlet and outlet temperatures (TIA1-2, TIA1-3), and the flow rates (FM-1) in the primary side of heat pump unit in the experiments V1-3~V1-5 were demonstrated in Figure 4. Although the inlet temperature in the primary side decreased, the temperature was higher than the outside air temperature. In addition, Figure 5 indicates the heating output, the heat extraction rate, and the electric power of system (Heat pump unit + Circulation pump in the primary side) in the experiments V1-3~V1-5. In the experiment V1-3, the heating output was approximately 12 kW and the electric power of system was approximately 2.2 kW, respectively. The system COP, which is the ratio of heating output to electric power of system, was approximately 5.5. This result indicated that the high value of system COP was obtained by supplying the hot water with temperature of 25°C even in the winter season.

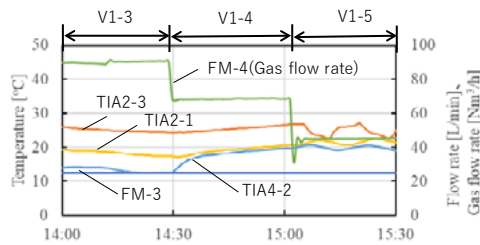


Figure 3 Variation of temperature and flow rate in the secondary side

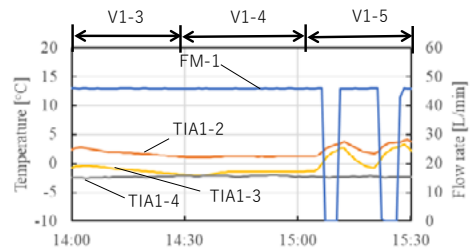


Figure 4 Variation of temperature and flow rate in the primary side

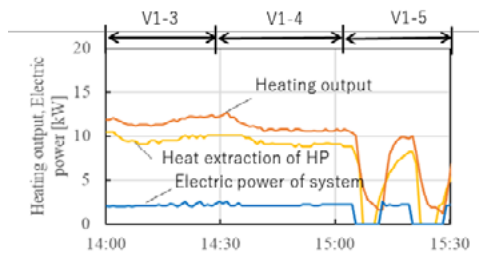


Figure 5 Variation of heating output, heat extraction and electric power

Figure 6 shows the inlet and outlet temperatures (TIA2-1, TIA2-3) and the flow rates (FM-3) in the secondary side of heat pump unit in the experiments V2-1~V2-3. The variations of nitrogen gas temperature (TIA4-2) and mass flow rate of nitrogen gas (FM-4) are also drawn in Figure 6. The mass flow rate was almost kept at the set value and the gas temperature varied from 10°C to 25°C. Therefore, the liquid nitrogen was stably vaporized as well as the experiments V1-3~V1-5. The outside air temperature (TIA1-4), the inlet and outlet temperatures (TIA1-2, TIA1-3), and the flow rates (FM-1) in the primary side of heat pump unit in the experiments V2-1~V2-3 were demonstrated in Figure 7. The inlet temperature was approximately 20°C higher than the temperature in the experiments V1-3~V1-5. This was due to the heat extraction from the AWHEX. In addition, Figure 8 indicates the heating output and the electric power of system (Heat pump unit + Circulation pump in the primary side + Fan of AWHEX) in the experiments V2-1~V2-3. Although the heating output was not constant, the average heating output in the experiment V2-1 was almost as much as the heating output in the experiment V1-3. Figure 9 shows the heat extraction rates of heat pump unit, GHEXs, and AWHEX. The heat extraction rate of AWHEX were much higher than the heat extraction rate of heat pump unit. This result indicated that the surplus heat from AWHEX was injected to the ground via the GHEXs.

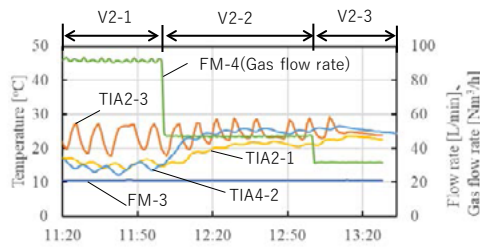


Figure 6 Variation of temperature and flow rate in the secondary side

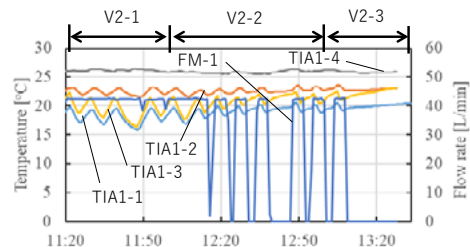


Figure 7 Variation of temperature and flow rate in the primary side

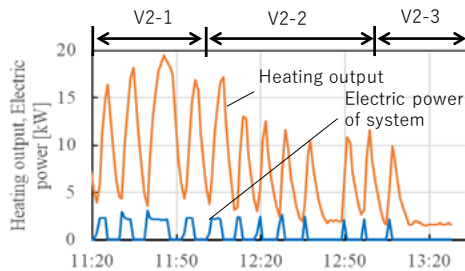


Figure 8 Variation of heating output, and electric power

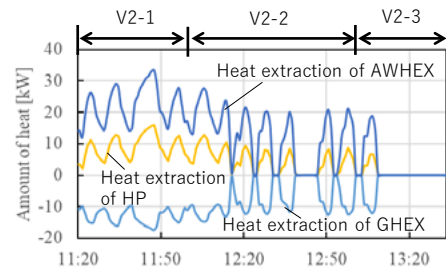


Figure 9 Variation of heat extraction

Table 4 summarizes the heating output from heat pump unit, the heating output for vaporization, the electric power of system, and the system COP(SCOP). The heating output from heat pump unit and the heating output for vaporization were almost equality. Therefore, the heating output from heat pump was used for vaporization. When the SCOPs in the experiments V1-1~V1-3 were compared, the SCOP in V1-3 (Hot water temperature: Approx. 25°C) was approximately 1.3 times of the SCOP in V1-2 (Hot water temperature: Approx. 35°C) and approximately 1.7 times of the SCOP in V1-1 (Hot water temperature: Approx. 45°C). From this result, the improvement of SCOP by supplying the hot water with lower temperature was confirmed. In addition, the SCOPs in the experiments V2-1~V2-3, in which the AWHEX was used in summer season, were more than 10. Basis on these results, the primary energy consumptions in V1-3 and V2-1 were calculated and were compared to the conventional gas boiler system (Boiler efficiency: 0.85). If the primary energy consumption per the electric energy was set as 9.76 MJ/kWh [3], the energy saving effects were approximately 57% in V1-3 and approximately 76% in V2-1, respectively.

Table 4 Summary of field experiment

Test number	Heating output from GSHP [kW]	Heating output for vaporization [kW]	System electric power [kW]	SCOP
V1-1	13.3	13.6	4.2	3.2
V1-2	12.6	13.1	2.9	4.3
V1-3	11.9	12.6	2.2	5.4
V1-4	11.0	10.0	2.4	4.6
V1-5	5.5	6.5	1.1	5.0
V2-1	11.4	12.4	1.1	10.8
V2-2	6.7	6.2	0.5	13.4
V2-3	3.0	3.5	0.2	15.0

4. Summary

- 1) The outlines and advantages of LNG vaporization system with HGSHP were explained.
- 2) By using the field experimental apparatus of vaporization system with HGSHP, the authors tested the vaporization of nitrogen liquid instead of LNG. As the result, it was possible to stably vaporize the liquid nitrogen by supplying the hot water with temperature of 25°C. In addition, when the hot water temperature was kept at around 25°C, the SCOP of HGSHP system was 5.4 in the winter season. This SCOP was approximately 1.7 times of the SCOP in the case where the hot water temperature was around 45°C.
- 3) The SCOPs in the experiments V2-1~V2-3, in which the AWHEX was used in summer season, were more than 10.
- 4) Basis on the field test result, the primary energy consumptions were calculated and were compared to the conventional gas boiler system. When the hot water temperature was around 25°C, the energy saving effects were approximately 57% in winter season (Only GHEX was used) and approximately 76% in summer season (Combination of GHEX and AWHEX was used), respectively.

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