Development of LNG Vaporization System with Ground Source Heat Pump Part 5 Study on optimal operation method of Hybrid Ground Source Heat Pump System with Air-Water Heat Exchangers

地中熱ヒートポンプを用いた LNG 気化システムの開発に関する研究 (第 5 報) ハイブリッド地中熱ヒートポンプシステムの運用方法の検討

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Abstract: In order to clarify the optimal operation method of the hybrid ground source heat pump (GSHP) system, this paper discusses the performance of ground source heat pump (GSHP) at different operation condition. The operating conditions of the Air-Water Heat Exchangers (AWHEX) when the ambient temperature reaches what degree, and how to operate the AWHEX when there is no heat load is investigated. Therefore, by using simulation calculations, the hybrid GSHP system were performed at different AWHEX operating temperatures (above 5 ° C, 7 ° C, 9 ° C, 11 ° C), and different AWHEX operating methods (no operation, operation at half flow, operation at full flow) when there is no heat load, the optimal operation method of Hybrid GSHP System with AWHEX is studied. It is recommended to operate AWHEX when the ambient temperature reaches 5 °C, and operate it at the full flow rate when there is no heat load.

1. Introduction

In the previous report (part4), the method of determining the scale of ground heat exchangers (GHEX) and air-water heat exchangers (AWHEX) was clarified, and the design method of the hybrid ground source heat pump (GSHP) with AWHEX was studied. This report establishes a hybrid GSHP operating method by operating AWHEX under different operating conditions.

As explained in Part 4 of the previous report, it was found that there was a relationship between heat extraction of AWHEX and ambient temperature, heat load, flow rate. Therefore, in this report, what ambient temperature should be to operate AWHEX, and whether to operate AWHEX when there is no heat load are discussed. The performance of the hybrid GSHP is studied under the AWHEX operating method by using simulation tool[1)].

2. Hybrid GSHP performance at different AWHEX operating temperatures

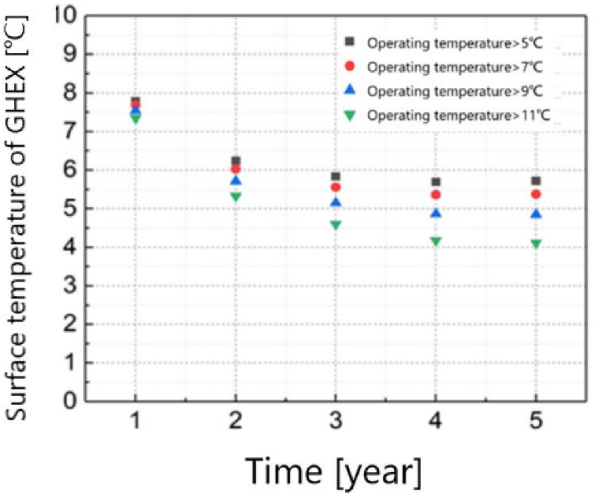
2.1 AWHEX operating temperature setting

The performance of AWHEX is shown in Fig3 in the previous report (part4), it was found that there was a relationship between the heat extraction of AWHEX and the ambient temperature. Therefore, it is set to operate AWHEX at each operation temperature of AWHEX, and the surface temperature of GHEX, heat extraction of GHEX, and annual SCOP are obtained through simulation calculation. Specifically, the AWHEX operating method is importing the conditions such as the number of GHEX and AWHEX, vaporization heat load, ambient temperature, and underground temperature into the simulation tool, and set the operating temperature of AWHEX. When the ambient temperature is lower than the outlet temperature of GHEX in the primary side and when the ambient temperature is lower than the set operating temperature (5 °C, 7 °C, 9 °C, 11 °C), the entire flow is bypassed without passing through AWHEX. However, in order to recover the underground temperature and ground heat, AWHEX is set to started when the ambient temperature is higher than the outlet temperature of GHEX in the primary side, and the ambient temperature is higher than the set operation temperature (5 °C, 7 °C, 9 °C, 11 °C) even when no evaporation heat load occurs.

2.2 Results for each AWHEX operating temperature

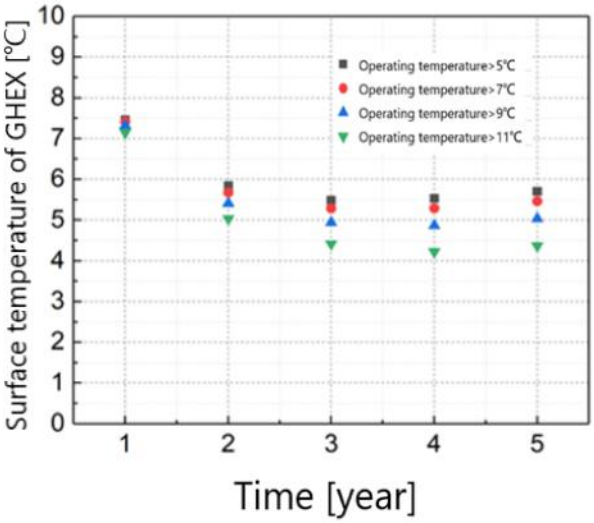
Simulation calculation was performed under the conditions of each set operating temperature (5 ℃, 7 ℃, 9 ℃, and 11 ℃), and the results of the surface temperature of GHEX, heat extraction of GHEX, and annual variation of SCOP at different AWHEX operating temperatures were obtained.

Fig1~Fig3 show the variation of surface temperature of GHEX at different the number of GHEX and AWHEX. From Fig1~Fig3, the discrimination of the surface temperature of GHEX became smaller at different AWHEX operation temperatures due to the increase in scale, but the surface temperature of GHEX was the highest when the AWHEX operation temperature was 5 ℃ or higher. Fig4~Fig6 show the variation of heat extraction of GHEX at different the number of GHEX and AWHEX. It was verified that the amount of heat extraction increases when the scale of GSHP is bigger. Moreover, when the AWHEX operating temperature reaches 5℃, it can be said that the amount of heat extraction of GHEX is the smallest and the effect of injecting heat into the underground is the best. Fig7~Fig9 show the variation of annual SCOP at different the number of GHEX and AWHEX. According to the results in Fig7~Fig9, the annual SCOP are almost the same at any AWHEX operating temperature (5 ℃, 7 ℃, 9 ℃, 11 ℃). However, When the AWHEX operating temperature is above 5 ℃, it is indicated that surface temperature of GHEX is the highest (Fig1~Fig3), and the amount of heat injection of GHEX is the most (Fig4~Fig6). Therefore, it is recommended that AWHEX be operated when the outside air temperature reaches 5 ℃.



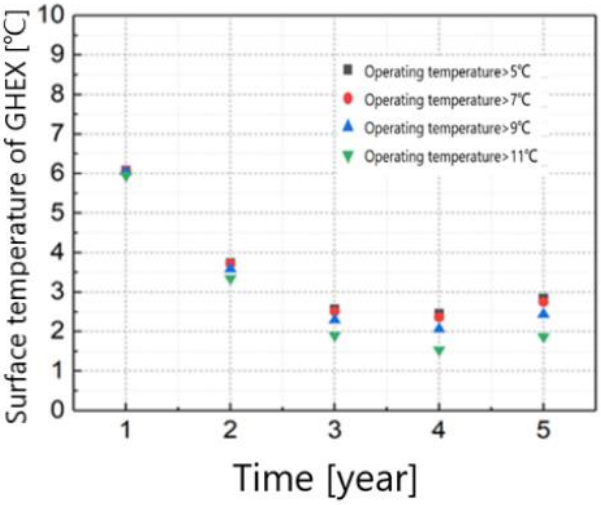
GHEX=19、AWHEX=10

Fig1 Variation in surface temperature of GHEX



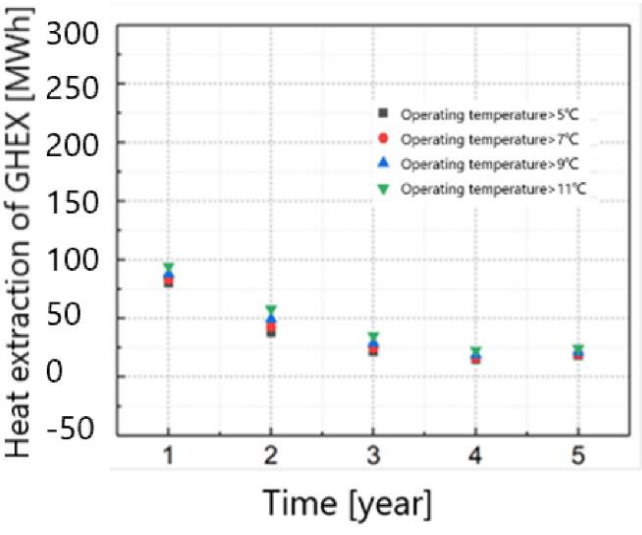
GHEX=36、AWHEX=20

Fig2 Variation in surface temperature of GHEX



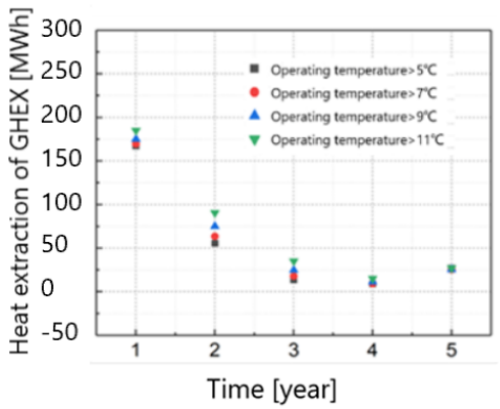
GHEX=74、AWHEX=24

Fig3 Variation in surface temperature of GHEX



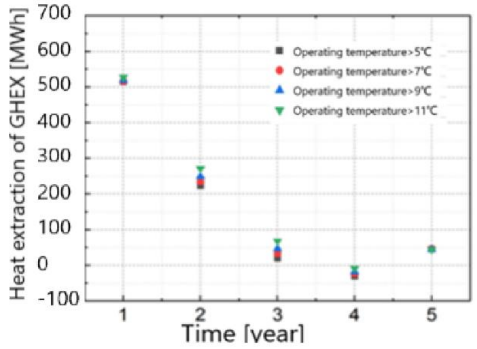
GHEX=19、AWHEX=10

Fig4 Variation in heat extraction of GHEX



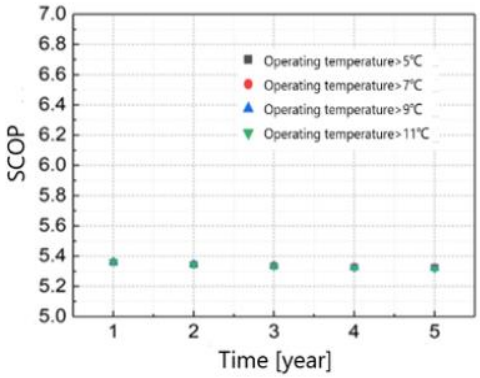
GHEX=36、AWHEX=20

Fig5 Variation in heat extraction of GHEX



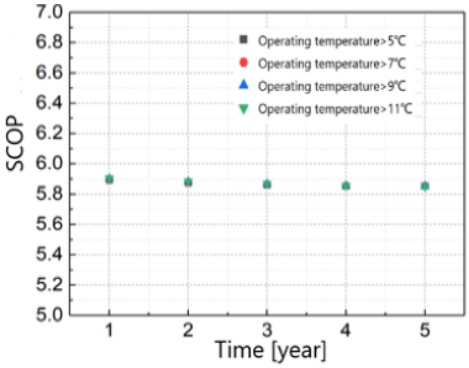
GHEX=74、AWHEX=24

Fig6 Variation in heat extraction of GHEX



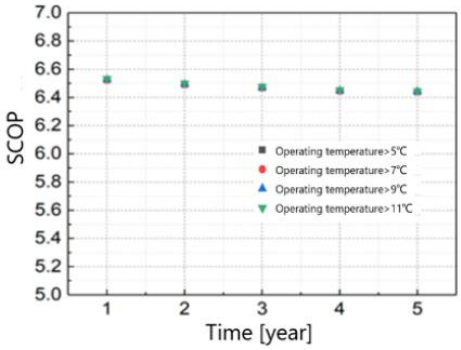
GHEX=19、AWHEX=10

Fig7 Variation in SCOP



GHEX=36、AWHEX=20

Fig8 Variation in SCOP



GHEX=74、AWHEX=24

Fig9 Variation in SCOP

3. Hybrid GSHP performance under each AWHEX operating condition in the case of no heat load

3.1 AWHEX operating condition setting

When there is no heat load, flow rate of AWHEX is 0 (AWHEX is not operated), runs at half flow rate (flow rate of AWHEX is half of primary side), and runs at full flow rate (flow rate of AWHEX is equal to primary side) of different condition is set. Under the three conditions, through the simulation calculation, the surface temperature of GHEX, the heat extraction of GHEX, and the annual SCOP are obtained. The performance of the hybrid GSHP with different AWHEX operation flow rates are examined when there is no heat load.

The first operating condition is that AWHEX is not operated when there is no heat load, so the power consumption and heat extraction of AWHEX is 0. Secondly, when AWHEX is run at half flow rate without heat load, the power consumption of AWHEX and HP are set to one-fourth of the power consumption of AWHEX and heat pump in the case of full flow rate, and the heat extraction of AWHEX is set to one-quarter of the heat extraction in the case of full flow rate. Finally, AWHEX is run at full flow rate when there is no heat load.

The setting of each AWHEX operating condition is shown as follows when there is no heat load:

① Do not run AWHEX

$Q_{hp} = 0$ kW and $T_{pout} < T_{aout}$ and $T_{aout} > 5$℃

$E_{fan} = 0$

$Q_{AWHEX} = 0$kW

② AWHEX runs at half flow rate

$Q_{hp} = 0$kW and $T_{pout} < T_{aout}$ and $T_{aout} > 5$℃

$LV_{fl} = 0.5rLV_{fl}$

$E_{p1} = 0.25rE_{p1}$

$E_{fan} = 0.25rE_{fan}$

$Q_{AWHEX} = 0.75\ (0.2417LV_{fl} + 0.517) \cdot (T_{aout} - T_{pout})$

③ AWHWX runs at full flow rate

Q_{hp}=0kW and T_{pout}<T_{aout} and T_{aout}>5°C:

LV_{fl}= rLV_{fl}

E_{pl}=rE_{pl}

E_{fan} = rE_{fan}

Q_{AWHEX}=(0.2417・ LV_{fl} +0.517)・(T_{aout}-T_{pout})

3.2 Results with different AWHEX operating conditions

The results are shown the surface temperature of GHEX, heat extraction of GHEX, and annual SCOP in Fig10~12 (GHEX=86, AWHEX=20). The surface temperature of GHEX is the lowest when the AWHEX does not operate, and the surface temperature of GHEX is found to be the highest when the AWHEX operates at full flow rate from Fig10. Therefore, when there is no heat load, it can be said that the operation of AWHEX is effective for the recovery of the underground temperature. According to the Fig11, when the AWHEX does not operate, the heat extraction of GHEX is the highest, and the heat extraction of the GHEX becomes the lowest when the AWHEX operates at full flow. Then, it was found that the operation of AWHEX increases the amount of heat injection of GHEX when there is no heat load. In addition, the amount of heat extraction of GHEX in the first to fourth years has decreased. It can be said that the operation of AWHEX is effective in recovering underground heat. The result of annual SCOP is shown in Fig12. If the AWHEX does not operate, because the power consumption of the AWHEX is the lowest, and it was found that the annual SCOP at this time was the highest compared to other operating conditions. On the other hand, when the AWHEX operates at full flow, the annual SCOP is the lowest because the power consumption of the system is the largest. However, as shown in Fig12, indicating that the discrimination of the annual SCOP was small under the three AWHEX operating conditions. As for the optimal operating conditions of AWHEX, considering the recovery of the underground temperature and the underground heat, the operating condition that the AWHEX operates at the full flow rate is recommended when there is no heat load.

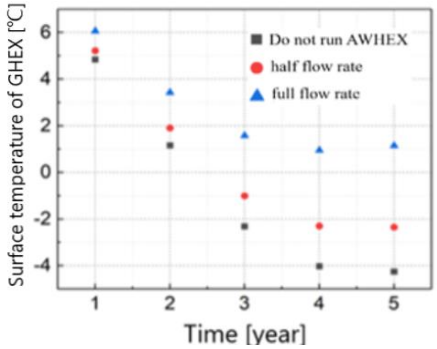


Fig10 Variation in surface temperature of GHEX

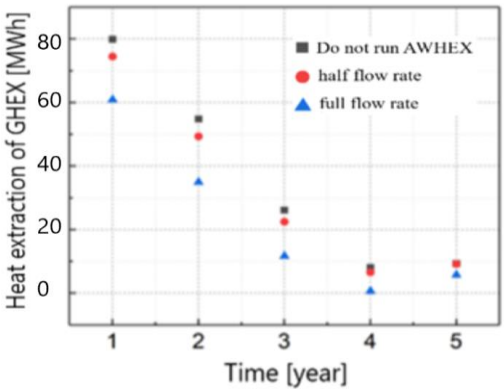


Fig11 Variation in heat extraction of GHEX

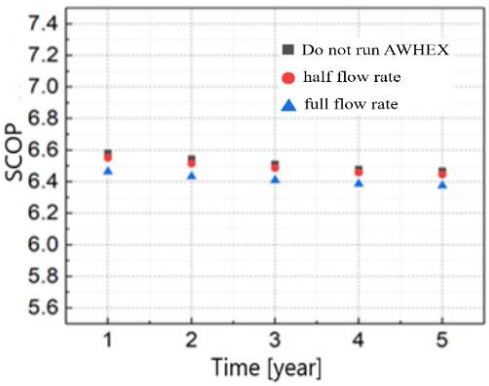


Fig12 Variation in SCOP

4. Conclusion

1) Simulation calculations of the hybrid GSHP system at each AWHEX operating temperature (5 ° C, 7 ° C, 9 ° C, 11 ° C) were performed. It is recommended to operate AWHEX when the ambient temperature reaches 5 °C.

2) In case of no heat load, simulation calculations of the hybrid GSHP system were performed using different AWHEX operating methods Considering the recovery of the underground temperature and underground heat, the AWHEX operates at the full flow rate is recommended when there is no heat load.

References

1) 葛 隆生 ほか. 土壌熱源ヒートポンプシステム設計・性能予測ツールに関する研究: 第 1-3 報 空気調和・衛生工学会 論文集. 2008;33:1-10.

Subscript

E_{fan}: power consumption of fan [kW]

rE_{fan}: rated power consumption of fan [kW]

E_{pl} : power consumption of pump [kW]

rE_{pl} : rated power consumption of pump [kW]

LV_{fl} : circulation flow rate in the primary side[L/min]

Q_{AWHEX}: heat extraction of AWHEX