DEVELOPMENT OF RIVERBANK FILTRATION WATER SUPPLY AND RETURN SYSTEM FOR SUSTAINABLE GREEN HOUSE HEATING AND COOLING

Yong Cho[1], Dae Geun Kim[1], Jisook Seo[1], Jong-Pil Moon[2], and Hyoung-Soo Kim[3]

[1]Green Technology Research Center, K-water Institute, Daejeon, Korea

[2] Department of Agricultural Engineering, National Academy of Agricultural Science, Suwon, Korea

[3] Engineering of Energy and Resources, Jungwon University, Choongbuk, Korea

ycho@kwater.or.kr

Keywords: *Riverbank Filtration, Alluvium Aquifer, Temperature Difference Energy, Water-Source Heat Pump, Green House, Heat Source*

ABSTRACT

The green house on the waterfront is air-conditioned by a water-source heat pump system with riverbank filtration water. In order to supply riverbank filtration water in alluvium aquifer, the riverbank filtration facility for water intake and injection, two pumping wells and one recharge well, has been constructed. The research site in Jinju, Korea was chosen as a good site for riverbank filtration water supply among four preliminary sites by the surface geological survey, electrical resistivity soundings, and borehole surveys. In the results of two boreholes drilling at the site, it was revealed that the groundwater table is about 3 m under the ground, and that the sandy gravel aquifer layer in the thickness of 6.5 m and 3.5 m occurs at 5 m and 7 m in depth below the ground level respectively. To prevent the recharge water from affecting the pumped water which might be used as heat source or sink, the distance between pumping and recharge wells is designed at least 70 m with a quarter of recharged flow rate. It is predicted that the transfer term, the recharge water affects the pumping well, is over 6 months of heating season. Hydrogeological simulation and underground water temperature measurement have been carried out for the pumping and recharge well positions.

1. INTRODUCTION

The area of protected cultivation in Korea 2008 reaches to 53,408ha, and heating system for winter is operated to cultivate horticultural crops in 13,329ha which occupy about 25% of that. In the end of the 2008, it is estimated that about 60% of supply quantity of tax-free oil for agriculture is used for heating of protected cultivation. A sudden rise of oil price recently caused weight of heating cost among protected cultivation production costs to sharply go up and added a large difficulty to agricultural management. In response to it, development of energy saving technology is essential and the geothermal heat pump is very excellent in terms of efficiency and applicability. However, the geothermal heat pump has limit of heat source volume, and sea water and ground filtration water may be used as substitute heat source to settle insufficient heat source.

Since most agricultural facilities in Korea is far away from sea, it is very realistic to use ground filtration water heat source from river/dam-reservoir water. Riverbank Filtration water is typically used as ground filtration water from river/dam-reservoir. This method has been used in America, Europe and other regions before about 150 years but feasibility survey for riverbank filtration water including 5 rivers in Korea; Han River, Nagdong River, Keum River, Youngsan River and Sumjin River has been started from the 1990s to use riverbank filtration water. In Changwon located at the downstream of Nagdong River, domestic water is currently supplied by the riverbank filtration method. As the result of analyzing water pumping rate of the water purification station at Daesan-myon in Changwon, water pumping rate shows difference of approximate 2,000 m^3/day and it showed a tendency that water pumping volume is increased especially in a high water season (June, July and August).

Water-source heat pump is generally used for heating and cooling of a building, and riverbank filtration water, ground water, and raw water is used for the heat sources of the system. Hwang et al.(2006) developed the cooling and heating system with bank-filtration water which is transferred to the water treatment works for drinking water. Water volume for heat source is less than 400 m^3, while the filtration water of 60,000 m^3 is pumped a day. Therefore the pumping well didn't need to be considered in the well design. It was confirmed that the system with the temperature of filtration water is 17~19℃ in February could be practical in only 6 days test. Nam and Ooka(2010) investigated the performance of a ground water source heat pump. The system depends on the temperature and depth of the water, and its efficiency is much higher than that of an air source heat pump. In another study, Nam et al.(2010) developed the dual-source hybrid heat pump system using groundwater and air. In spring and autumn, the ground water heat pump system is not more efficient than an air source heat pump based on the temperature comparison between the groundwater and the ambient temperature. According to their experiments, the developed hybrid system showed an improvement of 2~7% compared to a water cooling system, and 4~18% compared to an air source heat pump. Cho and Yun(2011) studied the heat pump system using raw water which is taken from a reservoir and supplied to a water treatment works. It was showed that the cooling and heating load ratio and water temperature affect the performance of the system.

In this study, pumping well and recharging well are developed for sustainable heating and cooling of a green house. The wells are designed and tested to have an appropriate riverbank filtration water pumping rate for the heat pump capacity.

2. MATERIALS AND METHODS

To use filtration water heat source, we selected the optimum region through survey a greenhouse away 300m from the river bank, and performed a site application test to

the paprika cultivation greenhouse of about 3,300 m^2 through optimum design of the heating system using ground filtration water source heat.

2.1 Experimental region

We performed electrical resistivity and boring survey to select the optimum application region for taking filtration water from a river, and performed a feasibility study for thickness of the water aquifer and heating of the experimental greenhouse and the optimum pumping water volume of 1,000 m^3/day for the Gumi and the Jinju region. It was found that the Jinju region is optimal place for pumping water volume, and as the result of the static water level pumping test that was performed in course of a boring survey at the Jinju region, the hydraulic transmission degree of the sand/gravel layer which is main aquifer was good as about 1×10^{-3} cm/sec and the BH-1 hole forms the sand/gravel layer of 3.5m, the BH-1 forms the sand/gravel layer of 6.5m, and it was found that collectable water volume of 1,000 m^3/day could be developed.

2.2 Basic design of heating system for ground filtration water source heat pump.

A concept drawing of the heating system using ground filtration water is as Fig. 1 and the initial facility expenses are very low since depth of pumping and recharging well is not deep and heat source flux is sufficient as a heat pump system using ground filtration water which is underground water not subject to pressure around a river or lake. Water temperature of ground filtration water has very similar characteristics to underground water but operation and management of the system is required considering that change of flowrate is affected by the river. The system developed in this study was designed to reduce water resources and achieve a sustainable circulation to ensure that recovery to the underground aquifer are achieved and that exceeding flux can return to the river through the surface discharge by installing both recharging water and surface discharge pipe, and so that heat exchange efficiency can be improved by installing a filter and removing iron and manganese.

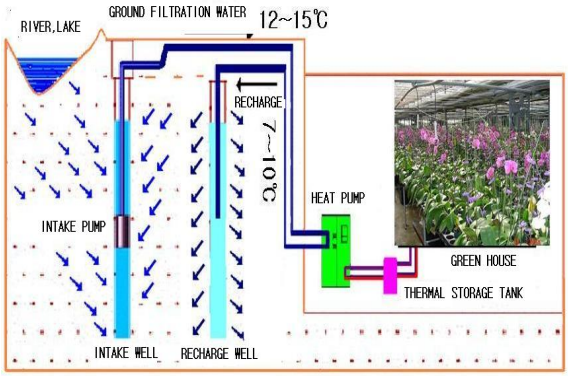

Fig .1 Conceptual Scheme of Ground Filtration Water Source Heat Pump.

2.3 Development of thermal storage tank using a separation plate

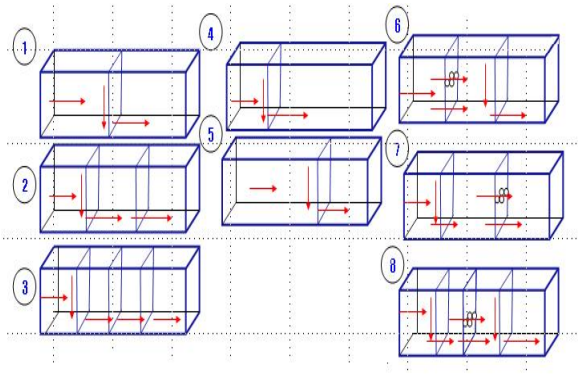

Fig. 2 Temperature separation phenomena experiment of thermal tank through separation plate.

We developed a temperature separation type of thermal storage tank for improving performance of the heat pump using a separation plate and tested temperature separation by a heat insulation separation plate by manufacturing an experimental tank by using an acryl plate as in Fig. 2. In addition, we tested temperature separation effect of both high temperature part and low temperature part by increasing the quantity and made a hole at the bottom part of the separation plate for heat storage tank to pass the separation plate within the experiment tank.

As the result of experiment, the more number of separation plate increase, the better temperature separation, and larger temperature difference. It was found that installing the separation plate in front side as shown in ④ was effective and that temperature separation was achieved better if lengthening a flow line by boring the top and bottom part of the separation plate. Flowrate was designed so that it is same as circulation flowrate or is somewhat larger than it.

2.4 Device for removing iron or manganese

The most efficient method to treat iron and manganese containing a lot of flow is a method to use oxidation sand. We also designed a device to remove foreign material from filtration water by using the method. Design conditions were provided to treat ground filtration water of maximum 500 m^3 per day to ensure that the filtration efficiency is calculated. In addition, the system was composed to compare difference by placing a heat pump passing through the filter and a heat pump not passing through it.

The oxidation sand is remnant material for water treatment developed in Japan and the oxidation sand contacting with manganese covering. It was selected since the material was suitable for the filtration water heat source type of heating system since its use was simple, and treatment speed and efficiency were good. Design was done to ensure that Ferox oxidation power would be distributed by aeration with treatment capacity of 1.5g Fe/l. A cyclone type of sand filter was installed as pre-treatment device.

2.5 Site application test

2.5.1 Development of pumping and recharging well

We developed a recharging well to supply ground filtration water as heat source of the heat pump of 60RT for supplying heating for the experimental greenhouse. We also firstly selected position of a recharging well through the electric resistivity and boring survey, and performed a

hydraulic geological simulation on underground water by using a 3D FEFLOW model to verify it.

We finally selected position of both water pumping hole and recharging hole on the base of the simulation result and theological formula for well hydraulic of the aquifer, and performed the design against remnant material and screen, and finally completed development of water pumping holes at 2 places and recharging hole at a place as in Figure.3

We contracted water collection holes and lifting holes at the site on the final design drawing but partial modification was performed depending on geological status at the site and results of the final construction are same as in Table 1.

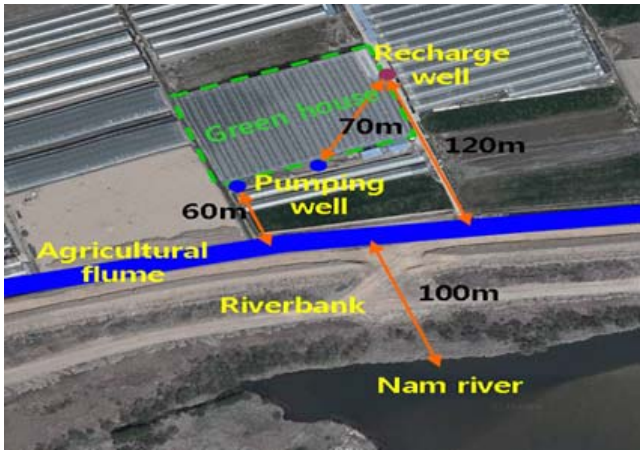

Fig. 3 Research site and its surrounding

Classification	Water pumping hole 1 (m)	Water pumping hole 2 (m)	Recharging hole (m)
Vertical depth	20.0	22.0	22.
D500 section	0.0 ~ 13.0	0.0 ~ 11.5	0.0 ~ 11.5
D400 section	13.0 ~ 20.0	11.5 ~ 22.0	11.5 ~ 22.0
Installation section of outside casing	0.0 ~ 6.0	0.0 ~ 7.0	0.0 ~ 6.5
Processing section of outside casing groove	-	-	6.5 ~ 11.5
Screen installation section	5.0 ~ 15.0	6.0 ~ 16.0	-

Table.1 Construction result of water pumping and recharging holes

2.5.2 Determination of maximum heating load

We determined the maximum heating load by using calculation formula of the maximum heating load of a greenhouse suggested in a guide book for facility horticulture energy saving, and used standard weathering data and temperature in the ground which was measured from the recent 5 years.

- Location: Jung Myung-whan's farm at Daegok, Jinju, Gyeongsangnam-do, Korea (paprika)
- Type of greenhouse: 1-2W type, continuous 7 span plastic greenhouses
- Size of greenhouse: Width 7m x Side height 4m x height 6m x Length 65m, 0.3ha
- Insulation: Single vinyle cover and double aluminum screen
- Design temperature: Lowest outdoor temperature: -8.4°C, Temperature in the ground: 1.3°C,
- Heating setup temperature: 20°C
- Calculation formula of maximum heating load:

$$
\begin{aligned}
Q_{ht} &= (q_i + q_v + q_g) f_w \\
&= \left[A_i \{h_i(1 - f_r) + h_v\}(T_i - T_o) + A_b h_b (T_i - T_g)\right] f_w \\
&= \left[5{,}067 \times \{3.1 \times (1 - 0.45) + 0.2\} \times \{20.0 - (-8.4)\}\right. \\
&\quad \left. + 3{,}185 \times 0.244 \times (20.0 - 1.3)\right] \times 1.1 \\
&= 320{,}000 kcal/h = 372 kW
\end{aligned}
$$

※ Maximum heating load: 372kW, Applicable heating load: 260KW(70% of maximum load)

We determined 70% of maximum heating load as heat pump capacity to save energy by using thermal storage tank and prevent excessive design of heat pump capacity, and substituted the remaining 30% with capacity of a thermal storage tank in order to respond to the maximum heating load. We also installed 2 separation plates inside and installed with classification into high, middle and low temperature parts.

2.5.3 Capacity determination of heat storage tank

- Possible time of heat storage: 09:00~16:30 5.0 h/day (heat storage for 5 hours a day)
- Capacity of heat pump: 266.0 kW = 228Mcal/h
- Temperature of heat storage water use; 50.0°C → 40°C, 10.0 °C
- Storage heat quantity of heat storage tank: Capacity of heat pump× Heat storage time for a day
  = 228.8 Mcal/h × 5.0h/day
  = 1,144 Mcal/day
- Capacity of heat storage tank: Storage capacity of heat storage tank/ Use temperature
  = 1,144 Mcal/day/ 10.0 °C ≈ 110 m^3

※ (320-229) Mcal/h×13hr (heating time at night)
≈ 229Mcal/h×5hr(heat storage time in daytime)

2.5.4 Proper design of heat pump system

We selected a heat pump as in Table 2 using R407 refrigerant that satisfied design capacity while coefficient of performance is beyond 4.0 and that was environment-friendly. We also determined circulation flow in the ground side and the load side depending on capacity of heat pump and design temperature of cold/warm temperature as in Table 3. We finally installed the filtration water heat source type of heating system at the site as in Fig. 4, performed a heating test in the paprika greenhouse at Waryong-ri, Daegok-myon, Jinju city from February 2011 to April 2011, and measured and analyzed coefficient of performance for heat pump, coefficient of performance for system and change of temperature within greenhouse, etc.

Table 2 Capacity of heat pump and coefficient of performance

Model (refrigerant)	Quantity	Capacity of heat pump (kW)		Power consumption (kW)		COP	
		Heating	Cooling	Heating	Cooling	Heating	Cooling
HP0300WW (R407)	2	133.0	105.0	33.0	21.5	4.03	4.88
Total	2	266.0	210.0	66.0	43.0	4.03	4.88

Table 3 Design flow in the ground side and the load side depending on performance of heat pump, Design Temperature of cold/warm water

Design item		Ground side			Load side		
		EWT (℃)	LWT (℃)	Flow (lpm)	EWT (℃)	LWT (℃)	Flow (lpm)
HP-0300WW	Heating	15.0	9.3	250	45.0	50.0	770
	Cooling	18.0	25.3	250	10.9	7.0	770

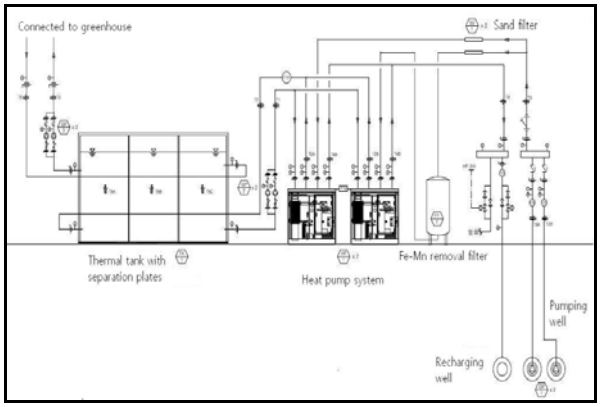

Fig. 4 Design drawing for site application of ground filtration water heat source heat pump

2.6 Riverside filtration water recharging test

The purpose of this study, an important factor to prevent the depletion of riverside filtration water farmers need the people always meet the water requirements, to protect the natural environment nature and compulsion recharging were tested.

Natural recharging experiments are summarized in Table 4, and the recharge well for the test is shown in Fig. 5. For natural recharging test at atmospheric pressure, 63% of intake water from a pumping well can be recharged in the busy season for farmers, while the recharging rate falls down to 19% in the leisure season for farmers.

Table 4 Natural recharging test results

Period	Intaking water volume (l/min)	Recharging volume (l/min)	Recharging rate (%)	Note
March-May	388	244	63	Busy season for farmers
June	399	74	19	Leisure season for farmers



Fig. 5 Natural recharging test at atmospheric pressure

Table 5 Artificial recharging test results

Period	Recharging volume (l/min)	Recharging pressure	Recharging rate (%)	Note
March-May	350	0.7	100	Require prolonged test (one pump)

June	568	1.6	100	Surge around a tube well (two pumps)



Fig. 6 Artificial recharging test and its monitoring

Compulsion recharging test results, recharging rate increased amount, but recharging well dent and underground geological change can be seen that concern.

* Compulsion recharging test : In the state seal with the compulsion pressure test.

Therefore, in order to increase recharging volume the following improvements seem necessary.

◦ Recharging well addition development

(large tube well development, small tube well many development)

◦ According to water demand recharging time control

(Busy season for farmers recharging, Leisure season for farmers bleeding)

◦ Control for intake water volume improve recharging rate

2.7 Effect analysis of soil temperature

For a long time, ground water level variation of heating-cooling energy supply site and ground temperature variation prediction have been carried out using heat source of Riverbank filtration water for controlled horticulture cultivation.

Consequently, Hydrogeological simulation test have been carried out for best management practices for the future and withdrawal well and injection well are redesign of expanded facilities.

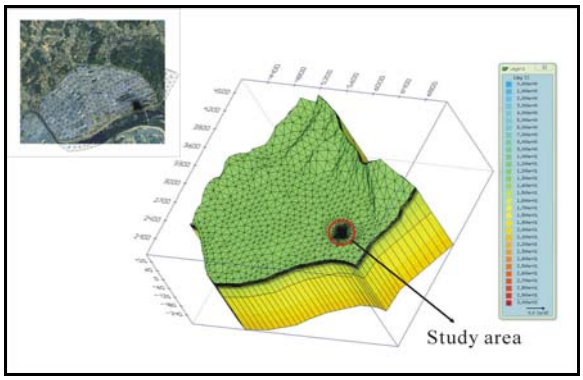

Fig .7 Study area and 3-D finite elements mesh

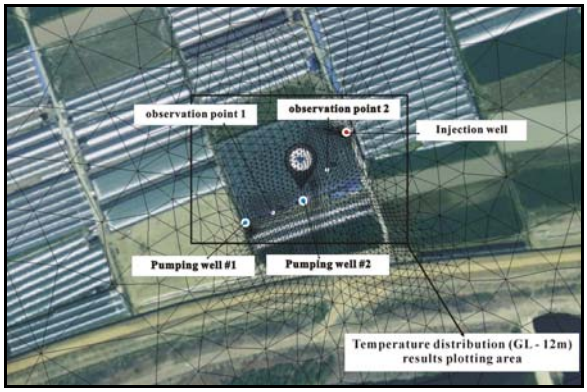

Fig. 8 Detailed map of study area with wells and observation points

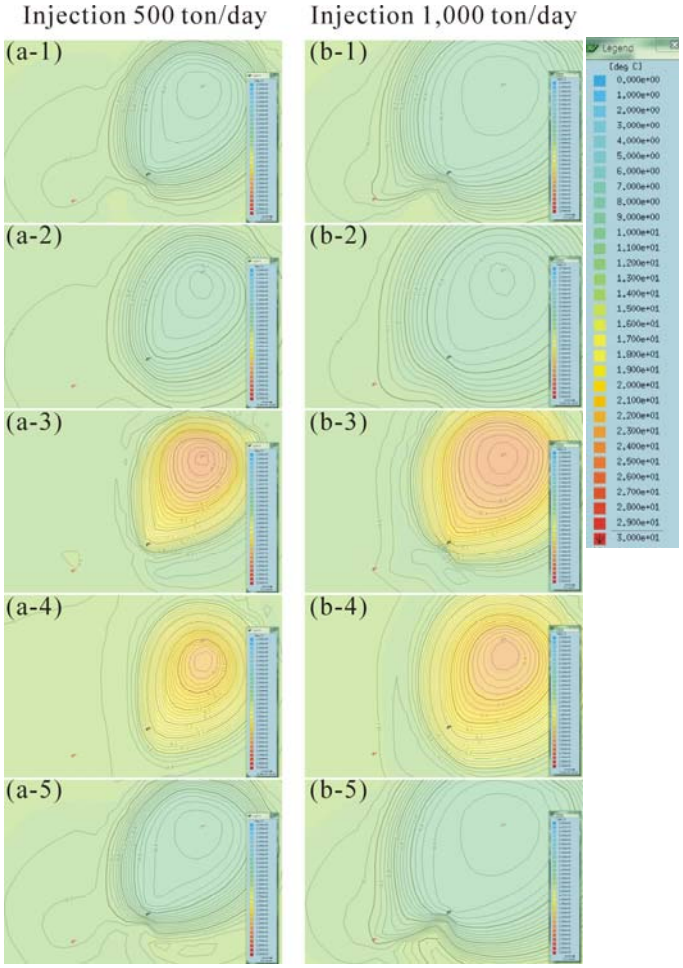

Fig. 9 Results of temperature modeling in aquifer (z = GL -12m) according to injection and time

(a-1) 119 days (b-1) 117days

(a-2) 177 days (b-2) 177days

(a-3) 242 days (b-4) 239days

(a-4) 301 days (b-4) 301days

(a-5) 481 days (b-5) 481days

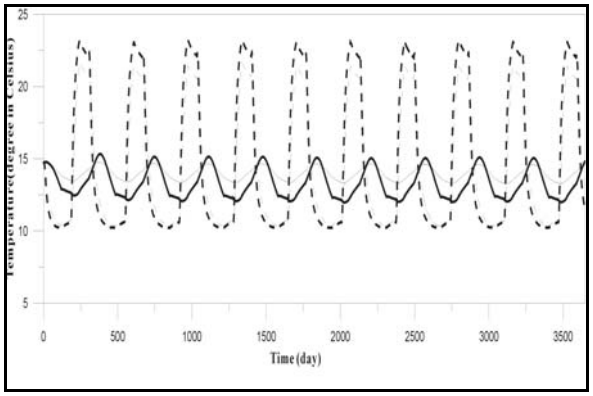

Fig. 10 Temperature changes in observation points 1 (solid lines) and 2 (dashed lines). Thick line represents the case of injection 1,000 ton/day and thin line 500 ton/day

Hydrogeological simulation results are as follows :

1. At the time of 1000 ton injection, second gauging well is after the start of heating 60 days (Injection of cold water) being influenced, At the time of 500 ton injection, this effect is somewhat delayed, but it is affected.

2. Gauging well in the first case, not directly affected by the injected water (10-degree), but heating the water is pumped 1,000 tons at the end of injection, 2-degree inside and outside, injection of 500 tons, could fall to about 1-degree.

3. When stops heating and cooling, injection water is under the influence of groundwater flow Some in the direction of the river flows. but when you start re-conditioning cooling or heating is the amniotic fluid again.

4. After stopping work, the temperature conditions during the initial heating, before heating under the influence of cold water injected, During heating of hot water previously injected under the influence when cooling is relatively economical heating and cooling will help.

5. Overall, a relatively long period of heating, so Slowly in aquifers, the water temperature gradually falling (reference for 2 observational stations of Figure 4) but the phenomena observed, Falling temperatures after 10 years it is estimated that not more than 1 degree.

6. Multiple wells injection rather than independent well injection is recommended.

   It is advantageous in terms of effectiveness and efficiency of heating and cooling.

7. Injected first gauging well at a long distance injection well annual intake of the water temperature is around 2-degree. however, near second gauging well is 8-degree. therefore, second gauging well as initial, relatively economical operation is possible, but increasingly in the latter may be an adverse operating conditions. Reviewed by heating up to stop a second gauging well, first gauging well good to drive economically.

3. RESULTS AND DISCUSSION

We installed the ground filtration water heat source Heat pump in the paprika greenhouse at Waryong-ri, Daegok-myon, Jinju city and performed a heating test. Average heating performance coefficient of performance for heat pump and system measured by month is suggested as in Table 4. It was found that temperature of ground filtration water was lowest in April and the coefficient of performance was reduced as water temperature became low. The results showed that the average coefficient of performance for heat pump range within 4.0-4.5, and the total system coefficient of performance were within 2.9-3.3, which indicated that the efficiency of the heat pump was good. In addition, as the analysis of heat test result, temperature difference between high temperature part and low temperature part showed 5.5℃, when heat supply is performed in a greenhouse due to separation of partition plate and temperature separation phenomena of the thermal storage tank. But temperature difference of 3.0℃ and coefficient of performance for heat pump was improved as Fig. 5 when no heat supply is performed in a greenhouse and when temperature separation phenomena of the heat storage tank were distinct by heat supply.

Table 6 Performance coefficient of heat pump and system heating by month

Month	Temperature of filtration water in river (℃)	Performance coefficient of heat pump (COP_{unit})	Performance coefficient of system (COP_{sys})
Feb.	14.4	4.5	3.3
Mar.	13.8	4.2	3.1
Apr.	11.8	4.0	2.9

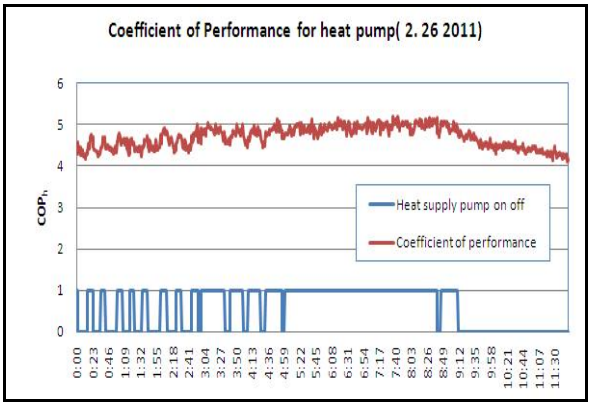

Fig. 11 Improvement effect of coefficient of performance by temperature separation of the thermal storage tank

4. CONCLUSION

We developed a heating system for protected cultivation greenhouse over the middle size using ground filtration water heat source in this study, and the system may be called as a system to maximize energy use efficiency by using a heat pump. In addition, we could construct a continual and stable system through a thermal storage tank using a separation plate, a device to remove sand, iron and manganese, optimum design of both water pumping well and recharging well, and selection of well installation position, etc.

We performed a site application test by selecting the paprika cultivation greenhouse located at downstream of Nam River, Daegok-myon, Jinju city, Korea for verification of this system. The greenhouse area was 3,300m^2. It was designed with a single fold of vinyl cover and 2 layers of horizontal thermal curtain were installed so that 320,000kcal/h can be supplied.

A greenhouse heating test was performed from Feb. 1, 2011 to Apr. 30, 2011. As the result, COP_{unit} of the heat pump was measured in the range of 3.7~4.7, while COP_{sys} of the system was represented as 2.9 ~ 3.3. The coefficient of performance (COP) measured of this system was very good. It was found that coefficient of performance of the heat pump was improved by 20%~30% due to the separation phenomena of a thermal storage tank

ACKNOWLEDGEMENTS

This study was carried out with the support of "Cooperative Research Program for Agricultural Science & Technology Development (PJ006508)", Rural Development Administration, Republic of Korea.

REFERENCES

Cho, Y. and Yun, R.: A raw water source heat pump air-conditioning system, *Energy and Buildings*, Vol. 43, Issue 11, pp. 3068-3073. (2011)

Hwang, K.S., Jung, W.S., and Ahn, Y.S.: The field test of bankfiltration(including alluvial and riverbed deposits) source heat pump cooling & heating system, *Proc. SAREK 2006 Summer Annual Conference*, Pyeongchang, Korea, pp. 1186-1190. (2006).

Nam, Y. and Ooka, R.: Numerical simulation of ground heat and water transfer for groundwater heat pump system based on real-scale experiment, *Energy and Buildings*, Vol. 42, Issue 1, pp. 69-75. (2010).

Nam, Y., Ooka, R., and Shiba, Y.: Development of dual-source hybrid heat pump system using groundwater and air, *Energy and Buildings*, Vol. 42, Issue 6, pp. 909-916. (2010).