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Performance Analysis of Water-Water Heat Pump System of 100 kW Scale for Cooling Agricultural Facilities

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Abstract

Purpose: In this study, the performance of cooling system with the water-water heat pump system of 100kW scale made for cooling agricultural facilities, especially for horticultural facilities, was analyzed. It was intended to suggest performance criteria and performance improvement for the effective cooling system. **Methods:** The measuring instruments consisted of two flow meters, a power meter and thermocouples. An ultrasonic and a magnetic flow meter measured the flow rate of the water, which was equivalent to heat transfer fluid. The power meter measured electric power in kW consumed by the heat pump system. T-type thermocouples measured the temperature of each part of the heat pump system. All of measuring instruments were connected to the recorder to store all the data. **Results:** When the water temperature supplied into the evaporator of the heat pump system was over 20°C, the cooling Coefficient Of Performance(COP) of the system was higher than 3.0. As the water temperature supplied into the evaporator, gradually, lowered, the cooling COP, also, decreased, linearly. Especially, when the water temperature supplied into the evaporator was lower than 15°C, the cooling COP was lower below 2.5. **Conclusions:** In order to maintain the cooling COP higher than 3.0, we suggest that the water temperature supplied into evaporator from the thermal storage tank should be maintained above 20°C. Also, stratification in the thermal storage tank should be formed well and the circulating pumps and the pipe lines should be arranged in order for the relative low-temperature water to be stored in the lower part of the thermal storage tank.

Keywords: Agricultural facilities, Coefficient of performance, Heat pump, Thermal storage tank

Introduction

The heat pump system is a Heating, Ventilation, Air Conditioning (HVAC) equipment. The system is useful for cooling in summer and heating in winter. It has excellent performance compare to the amount of energy it consumes. Thus, usage of the system as a HVAC equipment is, recently, significantly increasing for cooling and heating in the agricultural facilities and many buildings. It is evaluated by the U. S. Environmental Protection Agency (EPA). The EPA states, “It is low-energy consumption, eco-friendly and the most cost effective system among the current cooling and heating systems for buildings over the world.”

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The heat pump system is divided into compression and absorption types. The compression type heat pump system is mainly used, now. The reasons are (1) it is relatively simple to operate and maintain, (2) it has excellent performance. The compression type heat pump system cools and heats by using a compressor, a condenser, expansion valves, an evaporator and a four-way valve, etc. The compression type heat pump system has same components. However, only the heat exchanger type is different due to the different kind of heat source and heat sink. Since the control and operation methods could be different based on the load characteristics of the targeted facilities, it is important to establish the optimum method of operation reflecting the load characteristics. By establishing the optimum method of operation, we can save the power consumption of the heat pump system and improve the coefficient of performance. Totally, we can save the heating and cooling cost.

In order to utilize the heat pump system effectively for cooling and heating agricultural facilities, it is necessary to establish design criteria for the load and systemic control must by analyzing the cooling/heating load characteristics of targeted agricultural facilities. After the heat pump system with such design criteria above is made completely, the overall problems should be analyzed with enough trial running. Also, the effective control method of operation should be made.

Usually, PE (Polyethylene) or Glass-coated protected cultivation facilities had an adverse effect on plant growth because the indoor temperature of the facilities in summer rises up to 35～40°C (Kim et al., 2011). Regarding the climate circumstances in Korea, the indoor temperature of a greenhouse rises incredibly in summer. Therefore, it is impossible for crops to grow, normally. As a result, many farmers often stop cultivating during summer. The annual utilization rates of the facilities fell down (Nam, 2000).

The representative cooling methods used in Korea might include cooling using a refrigerator, evaporation, geothermal heat, ventilation and light shading, etc. The cooling method using refrigerator costs a lot because it spends much energy (Kim et al., 2006).

There are studies about promoting growth, increasing the merchandising rates and the number of products by cooling the greenhouses starting with some kinds of higher value-added crops (Yu et al., 2006; Nam et al., 2000; Ryu et al., 1999; Moon, 1999, Lee, 1994; Kim et al., 2011). There are studies about analyses of the cooling effect, the seedling production effect, the power consumption and energy balance of a closed transplant production system (Lee et al., 2006; Kim et al., 2003, 2002). Considering the aspects of the effective usage and the profitability of agricultural facilities, achieving year-round cultivation through the optimization of environment (ex, cooling) inside of greenhouses during summer is a confront subject (Nam, 2000).

In this study, the performance of cooling system with the water-water heat pump system of 100 kW scale made for cooling agricultural facilities, especially for horticultural facilities, was analyzed. It was intended to suggest performance criteria and performance improvement for the effective cooling system.

Materials and Methods

Experiment equipments

The water-water heat pump system of 100 kW scale used in this study was made for both cooling and heating. The condenser and evaporator were made as a plate type heat exchanger for exchanging heat between refrigerant and water as heat transfer fluids. Refrigerant condenses in the condenser while high-temperature gas phase refrigerant made contacts with water. The water temperature rises while the water penetrates through the condenser. The water is transferred into the PE pipe type heat exchanger as shown in Figure 1. The water gets cooled. Then, the water gets transferred into the condenser again. The water in the thermal storage tank is supplied into the evaporator. The water in the thermal storage tank cools

Figure 1. Photo of the PE pipe type heat exchanger.

Figure 2. Photo of the water-water heat pump system of 100 kW scale for cooling performance test.

gradually while the refrigerant evaporates in the evaporator.

Ryu et al. (2012) suggested the design criteria for the PE pipe type heat exchanger. It has excellent corrosion resistance and low installation costs. In this study, a PE pipe type heat exchanger was, also, made based on the criteria mentioned above. The heat pump system is shown in Figure 2.

Experiment methods

In order to increase the accuracy of the measurement, the heat pump system was operated longer than 60 minutes to get stabilized. While it was operated continuously for 480 minutes, the data was collected every 10 minutes to analyze the cooling performance.

As shown in Table 1, the measuring instruments consisted of two flow meters, a power meter and thermocouples. An ultrasonic and a magnetic flow meter measured the flow rate of the water as heat transfer fluid. The water exchanged heat with refrigerant in the condenser and the evaporator. A power meter measured electric power in kW consumed by the heat pump system. T type thermocouples measured the temperature of each part of the heat pump system. All of measuring instruments were connected to the recorder to store all the data.

Results and Discussion

Temperature changes of the water as heat transfer fluid at the entrances and the exits of condenser and evaporator

Figure 3 displays the temperature changes of the water at the entrances and the exits of the condenser and the evaporator for 480 minutes. While conducting the cooling performance test, the water temperature at the entrances and the exits of the evaporator became, gradually, lower. The water temperature at the entrances and the exits of the condenser became, gradually, higher.

As shown in Figure 3, the water temperature supplied into the condenser (at the entrance of the condenser) was 27.4°C at the beginning of the experiment. After passing through the condenser (at the exits of the condenser), the temperature was 40.2°C, which increased by 12.8°C. Later, the water temperature supplied into the condenser tends to rise, gradually. It was because the water supplied into the condenser by the pipe was heated up by sunlight. The experiment was conducted during the daytime in summer. After 480 minutes, the water temperature supplied into the condenser was 33.5°C. Moreover, after passing through the condenser, it rose up to 44.0°C, which is increased by 10.5°C. Comparing with the beginning period of the experiment, the difference between the temperatures before and after the water passing through the condenser was lower by 2.3°C. The reason was because the water temperature supplied into the evaporator (at entrance of the evaporator) became lower. That is, it was because as the less amount of heat was absorbed from the evaporator, the less amount of heat was discharged to the condenser.

The cooling performance test was conducted after the water temperature in the thermal storage tank was maintained at a constant level. It was designed to form the stratification naturally while the water flows in the

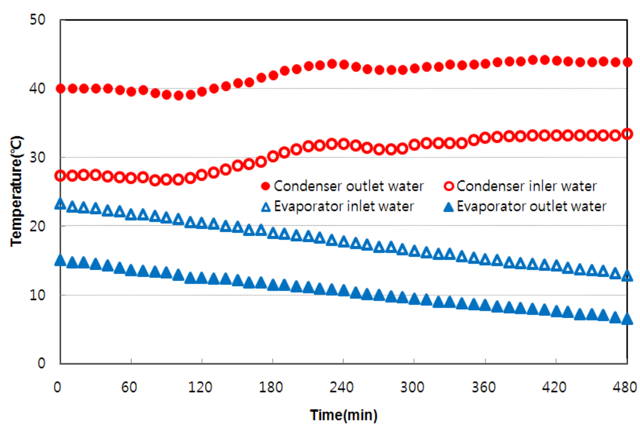

Figure 3. Variation of the water temperature passing through evaporator and condenser.

Table 1. Specifications of the measuring instruments for performance test

Measuring instruments	Specifications
Ultrasonic flow meter	PT868, Panametrics, Norway
Electromagnetic flow meter	EF-501, Seoyong Engineering Co., Korea
Recorder	MV-200, Yokogawa, Japan
Temperature sensors	T type, Daehyeon Tech, Korea
Power meter	CW-240, Yokogawa, Japan

lower part of the thermal storage tank again after the water flows out from the upper part of the thermal storage tank was cooled by passing through the evaporator.

At the beginning of the experiment, the water temperature in the thermal storage tank was 23.4°C. Then, it was cooled down to 15.1°C while passing through the evaporator. The difference of the temperatures was 8.3°C. Later, the water temperature in the thermal storage tank became lower, gradually. In 480minutes, it fell down to 12.9°C. At that time, the water temperature flowed in the tank after passing through the evaporator was 6.6°C. The difference between the temperatures of the entrance and the exit was 6.6°C.

As analyzed above, the temperature difference between the water at the side of the condenser and at the side of the evaporator tended to decrease gradually as time passed by. As the lower the water temperature inside the thermal storage tank, the smaller the temperature difference between the water passing through the evaporator and the condenser at the entrances and the exits.

Power consumption, amount of heat absorbed/discharged and cooling COP

The power consumption, the amount of heat absorbed from the evaporator, discharged out of condenser and the cooling COP sequentially during the cooling performance test are shown in Figure 4. During the cooling performance experiment, the power consumption was 35.43 kW at the beginning of the experiment. It tended to increase more or less up to 38.31 kW, later. It was judged that the reason was because the water temperature supplied into the condenser (at the entrance of the condenser) rose. It tended that the amount of heat discharged out of the condenser decreased from 150.33 kW to 123.31 kW, linearly. The amount of heat absorbed from the evaporator, also, decreased from 115.81 kW at the beginning to 87.91 kW in 480 minutes, linearly. The amount of heat absorbed from evaporator and discharged out of condenser decrease in similar forms almost in parallel lines

The cooling COP was 3.27 at the beginning, but it decreased down to 2.29 in 480 minutes. The reason was because the water temperature supplied into condenser rose and the water temperature supplied into the evaporator fell (See Figure 3).

Cooling COP based on variation of the water temperature at the entrance of the evaporator

The cooling COP of the heat pump system is affected significantly by the water temperature supplied into the evaporator from the thermal storage tank. As shown in Figure 5, in case of the water temperature supplied into the evaporator from the tank was higher than 20°C, the COP exceeded 3.0. However, as the water temperature became lower, the cooling COP became lower, gradually. Therefore, in case of the water temperature was lower than 15°C, it decreased to the level lower than 2.5.

Based on the results above, in order to maintain the COP at the level above 3.0, the water temperature supplied into the evaporator from the thermal storage tank should be adjusted to be maintained at the level above 20°C. Thus, if possible, the stratification in the thermal storage tank should be formed well. Also, after the relative high-temperature water in the upper part of the thermal storage tank was cooled in the evaporator, the circulating pumps and the pipe lines should be arranged in order for the water to be stored in the lower part of the thermal storage tank.

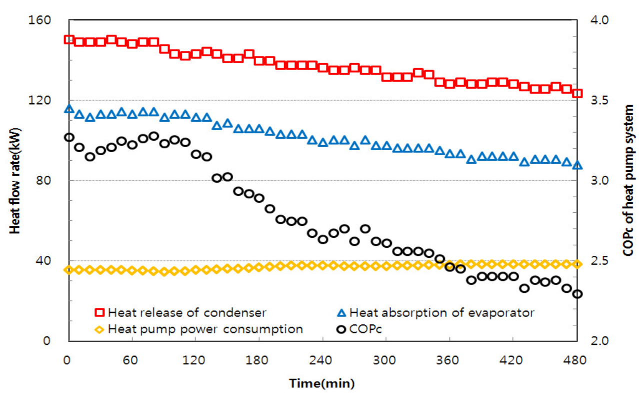

Figure 4. Variation of power consumption, amount of heat absorbed from evaporator and discharged out of condenser and COP.

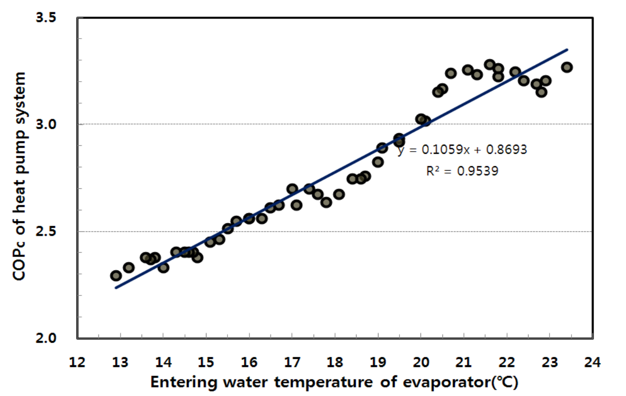

Figure 5. COP variation of the heat pump system according to water temperature entering into evaporator in cooing test.

Conclusions

In this study, we analyze the performance of the water-water heat pump system for cooling agricultural facilities during the high-temperature period in summer. In case that the water temperature supplied into the evaporator was higher than 20°C, the cooling COP was more than 3.0. In case that the water temperature supplied into the evaporator was lower than 15°C, the cooling COP fell down at the level below 2.5. As the water temperature supplied into evaporator of the heat storage tank became lower gradually, the cooling COP falls down linearly. Therefore, we suggest that in order to maintain the COP at a high level while cooling operation, the water temperature supplied into the evaporator from thermal storage tank should be maintained higher, stratification in the thermal storage tank should be formed well and the circulating pumps and the pipe lines should be arranged in order for the relative low-temperature water to be stored in the lower part of the thermal storage tank and the relative high-temperature water to be stored in the upper part of the thermal storage tank.

Conflict of Interest

The authors have no conflicting financial or other interests.

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