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Experimental Setup and Test of a Desalination System Using a Heat Pump

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Abstract

This study aimed to analyze the mechanism and the basic performances of a heat pump desalination system. As a kind of evaporation method, a heat pump system using cascade cycles of R410A and R134a generates 80℃ of heat to the heat pump condenser and transfers it the plate type heat exchanger. Heat generated by the heat pump is transferred through the plate type heat exchanger and the fin tube type exchanger. Through the 3-way valve installed in the seawater supply system to reduce the heating time, water below set temperature 60℃ is recycled and water above the set temperature is discharged to the storage tank. The hot water discharged into the storage tank is evaporated and passed through the cyclone and the bag filter to the fin tube type heat exchanger by using the vacuum pump, which condenses into fresh water by heat exchange with the low temperature air of the heat pump evaporator. The amount of hot water that can be produced is about 20ℓ/min and the power consumption used for the entire system is estimated to be 9.3 kWh/㎥.

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Keywords: Desalination; Heat Pump; Evaporation; 3-Way Valve

1. Introduction

Currently, more than 40% of the world's population suffers from water shortages. In addition, due to global warming and deepening climate change, uncertainties in water resource use and management are increasing. Korea, which is relatively rich in water resources, is also concerned about the lack of water in mountainous and coastal areas due to climate change [1]. Along with these problems, various measurements are needed for the independence of the building facilities in the island area. While the development of alternative water resources is needed, seawater desalination technology is receiving the most attention, and the reverse osmosis method, which consumes less energy than the conventional evaporation method, is increasing. According to Kim et al. [2], the reverse osmosis system occupies about 90% in the overseas seawater desalination plant market, and 87.5% of seawater desalination facilities in Korea use reverse osmosis. Kesieme at al. analyzed desalination technologies in the context of carbon pricing and found that the cost of desalination schemes increased by introduction of a price for carbon, but RO still remain the lowest cost [3]. However, reverse osmosis also has a limitation in that a pretreatment facility is essential, energy recovery cannot be more than 50%, and maintenance costs are high due to membrane replacement [4]. In addition to maintenance costs and energy aspects, existing seawater desalination systems are difficult to apply to island areas due to their large size. This study aimed to analyze the mechanism for the optimal design of seawater desalination system using heat pump that is a compact facility and can be applied as an independent water supply system for island buildings.

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2. Experiment apparatus and method

To study the performance of heat pump desalination system, the experimental apparatus is setup, which consists of a heat pump system, cyclone, bag filter and seawater supply system. The heat pump system is a commercial product of LG Electronics and refrigerant cycle uses R410a and R134a cascade cycles. The seawater supply system consists of a seawater tank, a circulation pump, 3-way valve and check valve, as shown in Fig.1. Heat generated by the heat pump is transferred through the plate type heat exchanger and the fin tube type exchanger. A vacuum pump was installed to adjust the evaporation pressure, and a demister was installed to capture the uncondensed vapors being discharged through the vacuum pump. The blowout air temperature of the heat pump evaporator and the water temperature in seawater tank were measured using a thermocouple wire (T type). The inlet and outlet water temperatures between the heat pump condenser and the plate type heat exchanger and water temperature at 3-way valve were measured by automatic temperature sensor.

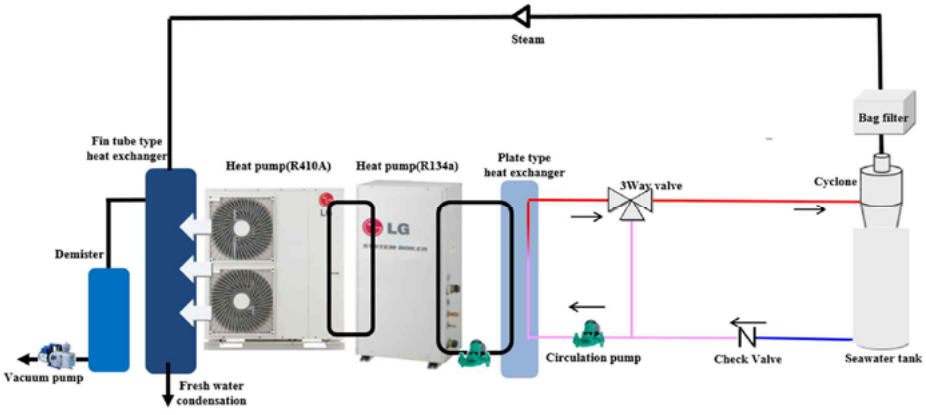

Fig. 1. Schematic diagram of heat pump desalination system

Fig. 2. Photo of the experimental apparatus

3. Results

3.1. Experiment apparatus analysis

Schematic diagram of the heat pump desalination system is shown in Fig.1. A heat pump system using cascade cycles of R410A and R134a generates 80℃ of heat to the heat pump condenser and transfers it the plate type heat exchanger. The seawater circulated in the seawater supply system receives heat from the plate type heat exchanger and is heated to the storage tank. Through the 3-way valve installed in the seawater supply system to reduce the heating time, water below set temperature 60℃ is recycled and water above the set temperature is discharged to the storage tank. The hot water discharged into the storage tank is evaporated and passed through the cyclone and the bag filter to the fin tube type heat exchanger by using the vacuum pump, which condenses into fresh water by heat exchange with the low temperature air of the heat pump evaporator.

3.2. Fluid state inside system

The inlet and outlet water temperature variations between the heat pump condenser and the plate type heat exchanger and water temperature variations at 3-way valve are shown in Fig.2. After the heat pump starts up, the temperature is continuously increased, and 70℃ hot water is passed through the 3-way valve to produce a storage tank.

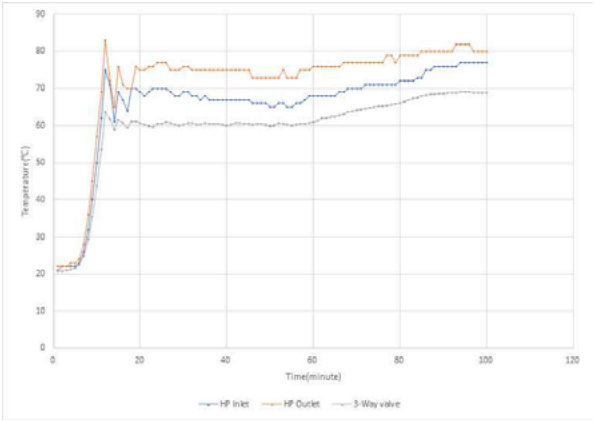

Fig. 2. Temperature variations in each point

3.3. Productivity and Energy consumption

After 90 minutes of a heat pump operation, the amount of hot water produced is about 20ℓ/min and the power consumption used for the entire system is estimated to be 9.3 kWh/㎥. The conditions of the produced hot water are shown in Table 1.

Table 1. Condition of produced hot water

Temperature	Water flow rate	vacuum pressure	Energy consumption
70℃	20ℓ/min(1.2 ㎥/h)	0.3077 atm	9.3 kWh/㎥

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4. Conclusions

This study aimed to develop a high-efficiency seawater desalination system using heat pump. The heat pump condenser heats seawater and generated steam condenses through heat exchange with the heat pump evaperator. Heat pump cycles were constructed using refrigerants R410A and R134a. The vapor is condensed by removing impurities as it passes through the cyclone and bag filter. The mechanism analysis results are as follows.

1. A heat pump system using cascade cycles of R410A and R134a generates 80℃ of heat to the heat pump condenser and transfers it the plate type heat exchanger. The hot water discharged into the storage tank is evaporated and passed through the cyclone and the bag filter to the fin tube type heat exchanger by using the vacuum pump, which condenses into fresh water by heat exchange with the low temperature air of the heat pump evaporator.
2. By installing 3-way valve, hot water can be produced quickly and it can produce hot water of 70 ℃ continuously.
3. After 90 minutes of a heat pump operation, the amount of hot water produced is about 20ℓ/min and the power consumption used for the entire system is estimated to be 9.3 kWh/㎥.

Experimental results show that energy consumtion of heat pump desalination system for fresh water production is 9.3kW/㎥, which requires more energy than reverse osmosis and large-scale evaporaton plants. But it will increase the efficiency by expanding the scale of heat exchanger and heat storage tank. The price of production water during the short term is expected to be least considering the construction cost, pertreatment cost and facility maintenance cost.

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