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A Study on the Performance Characteristics and Design of a High-Temperature Condenser for a Steam Heat Pump with R245fa

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Abstract: *This paper presents a design of high temperature condenser for heat pump using zero ODP refrigerants for 120 ℃steam production. Refrigerant considered R245fa because heat pump cycle was analyzed to present the highest thermal efficiency (COP) for each refrigerant when the evaporation temperature and the isentropic efficiency of the compressor were fixed at 60 ℃and 0.84. R-245fa was found to be suitable taking COP and the operating pressures into account. In addition, effects of isentropic efficiency of the compressor and the effectiveness of the internal heat exchanger on the COP of the heat pump adopting R245fa as working fluid were examined.*

The present study has been conducted the design of high temperature condenser for steam heat pump. The capacity load of steam heat pump is about 300 kW;the steam has 120 ℃, 0.422kg/h. Therefore saturated temperature and pressure of refrigerant in condenser are 128 ℃and 2.256 MPa. And the pressure drop of refrigerant in condenser is below 65 kPa.

For high temperature condenser we selected a Plate and Shell Heat Exchanger (PSHE). PSHE is combined by characteristics of Shell and Tube Heat Exchanger and Plate Heat Exchanger. So PSHE is able to endure the high temperature and pressure. Also, it is possible to make compact design.

This experimental loop capacity is 10 kW. We will obtain the many experimental results for PSHE and then be applied 300 kW high temperature condenser of steam generation heat pump. In this paper, experimental study of the R245fa condensation heat transfer was conducted in steam generation heat pump system. PSHE was designed based on real size for the condenser of the heat pump through a simulation and experimental system was setup in order to measure heat transfer coefficient. The convection heat transfer coefficient was obtained through sensible heat transfer of water and refrigerant.

Keywords: *R245fa, PSHE*

1. INTRODUCTION

Steam is a highly efficient medium of heat transfer and has a wide variety of applications in industrial processes. The conventional central supply-based method of steam generation involves large energy losses during steam transport, making this method inadequate for the industrial processes that require distributed control. In contrast, a heat pump system capable of generating steam using low-temperature industrial waste heat (≤70°C) as a heat source (Fig. 1) enables the distributed control of individual industrial processes and acts as green technology by helping reduce energy consumption.

The development of such a steam-generating heat pump system should be preceded by the R&D of a high-temperature condenser that enables efficient heat exchange between the working fluid (R245fa) and water (steam) to ensure optimal steam generation [1].

We conducted a preliminary study toward the development of a high-temperature condenser, which is capable of producing steam with a capacity of 300 kW, and an optimal steam generation system. We then constructed a prototype with 10kW capacity and tested its performance.

2. DESIGN AND PRELIMINARY ANALYSIS OF A HIGH-TEMPERATURE CONDENSER

The condenser selection criteria are as follows: compact architecture, efficient heat exchange, efficient temperature level (≥128°C), and resistance to the high-pressure load (≥2.5 MPa) of operation range. Heat exchange occurs between the hot-side with the refrigerant (R245fa) and the cold-side with water, and optimal steam generation is possible only when the fluid achieves 2-phase to 2-phase or the water side reaches the state of superheated pressurized water. Furthermore, repair and maintenance of the heat exchanger should be easy and economical. We compared various heat exchangers based on these criteria and selected the plate-and-shell heat exchanger (PSHE) that combines

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the best features of the plate-type and shell-and-tube type exchangers [2].

For developing the steam-generating high-temperature condenser, we conducted a preliminary analysis, varying the system operation conditions. Fig. 2 presents the basic analysis conditions and results.

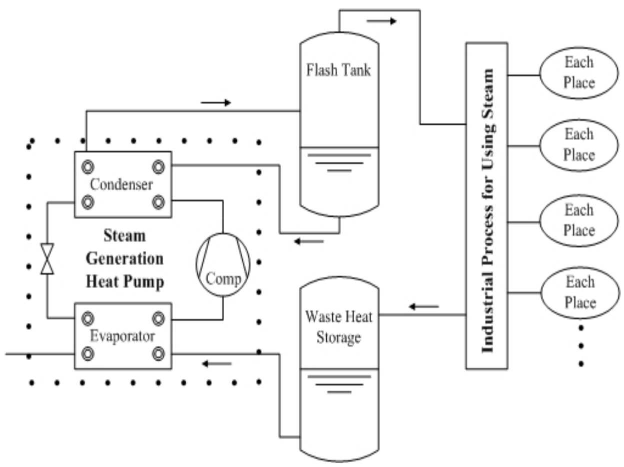

Fig. 1.Schematic diagram of steam generation heat pump [3]

Given that the total heat varies depending on the temperature of make-up water at a fixed heat capacity for steam generation, we set the capacity of the condenser at 300 kW, the saturation temperature of water at 123°C, the condensation temperature of the refrigerant at 128°C (5°C higher than the saturation temperature of water), and superheat and sub-cooling at 5°C and 4°C, respectively, in consideration of the condenser exit conditions.

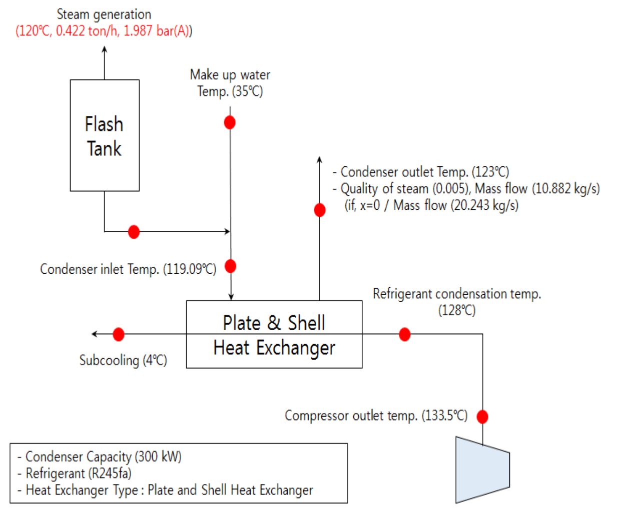

Fig. 2. Design of high temperature condenser [4]

The temperature of the make-up water, whose amount is equal to that of the generated steam, was calculated as 35°C. The steam production rate and average refrigerant flow were 0.422 ton/h and 2.497 kg/s, respectively, in this configuration.

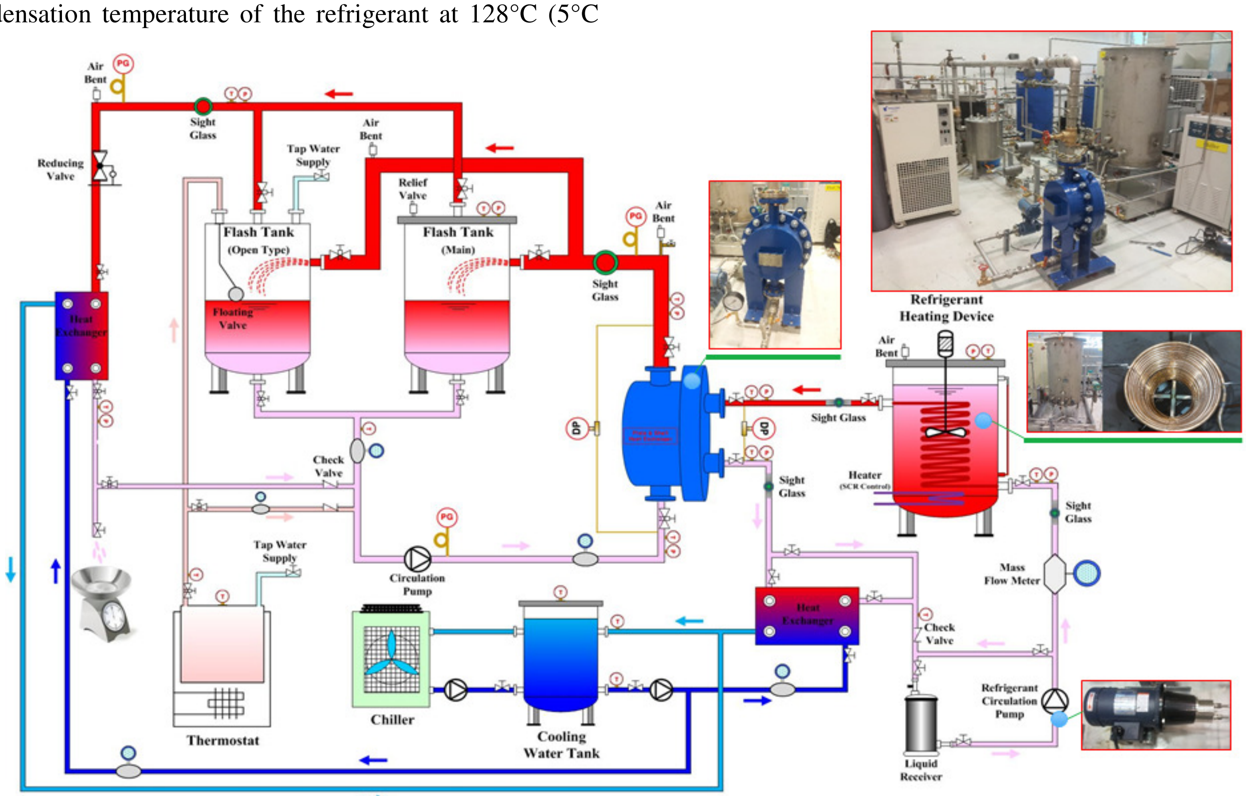

Fig. 3. Schematic diagram of experimental system for high temperature condenser [5]

TABLE 1: Specific volume and flow rate according to steam dry quality in condenser

Sat. Temp. (℃)	Sat. Pressure (MPa)	Dry Quality	Specific Volume (m^3/kg)	Mass Flow Rate (kg/s)	Volume Flow Rate (m^3/h)
123	0.218	0	0.00106	20.243	77.5
		0.001	0.00188	17.272	116.7
		0.005	0.00514	10.882	201.3
		0.01	0.00921	7.441	246.8
		0.02	0.01736	4.559	284.9
		0.03	0.02551	3.286	301.8
		0.04	0.03366	2.568	311.1
		0.05	0.04181	2.108	317.3

Table 1 presents the results of comparison of the dryness-dependent volumetric flow rate and specific mass flow rate in the 2-phase condition of the condenser's cold-side exit. The design dryness of the condenser was set at 0.05%.

3. HIGH-TEMPERATURE CONDENSERTEST DEVICE CONSTRUCTION

For the configuration mentioned above, we constructed a heat exchanger with 10kW capacity (Fig. 3). To control the temperature and pressure of the refrigerant, we opted for a refrigerant-heating system without a heat pump. This was implemented by designing and fabricating a helical coil heat exchanger, thereby using oil as the heating medium (Seriora 2120) for heat exchange with the refrigerant. We chose a magnet-driven refrigerant pump to circulate the refrigerant under constant pressure. A stable supply of refrigerant fluid was realized by means of a liquid receiver.

Additionally, the system was configured to enable the parallel connection of various flash tanks to ensure efficient steam generation test runs.

4. PRELIMINARY TEST AND PLAN FOR FUTURE TEST

In the preliminary test of the proposed high-temperature condenser, we tested its safety, adequacy of water, pressure, and flow control on the refrigerant side and water side. The temperature control of the refrigerant side was performed using PID control logic in the refrigerant heater and auxiliary heater. Constant pressure was maintained using a regulator while heating. Inverter control was applied to the flow rate. For the water side, we tested an open system first, and confirmed the adequate generation of high-temperature water (≥90°C).

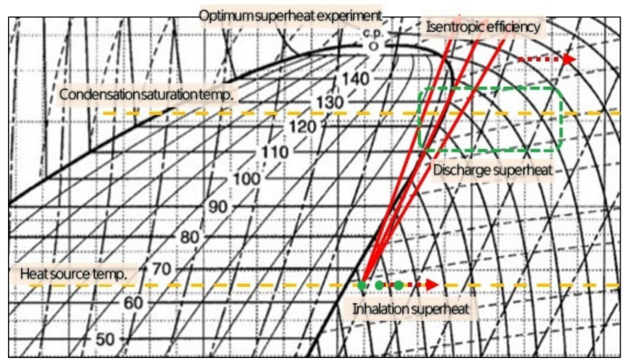

Fig. 4. Optimum superheat experiment (R245fa) [6]

The saturation curve of R245fa, which was used as refrigerant for the steam-generating heat pump, was skewed to the right compared with other refrigerant saturation curves. This should be dealt with by fixing the superheat at an optimal level. Otherwise, the fluid can enter the compressor, damage it, and cause the degradation of the entire system.

As shown in Fig. 4, a preliminary test will be conducted on the optimal superheats when generating high-temperature water (≥90°C) and steam (≥120°C), respectively. We also intend to design a high-temperature condenser optimized for steam generation by conducting a basic test of a basic-form heat exchanger.

5. CONCLUSIONS

In this study, we conducted a system analysis and designed a high-temperature condenser to enable future development of a steam generator/high-temperature condenser with 300kW capacity and to enable the optimization of a steam-generating system.

Additionally, we conducted a preliminary study toward the construction of a test device with 10kW capacity.

ACKNOWLEDGMENT

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