ID: 2016-ISFT-254

Experimental Study on Condenser and Steam Flash Tank in a Steam Heat Pump

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Abstract: *In this paper, experimental study on condenser and steam flash tank was conducted for steam heat pump system. The condenser type was plate heat exchanger and its refrigerant was R245fa. Before doing experiment, cycle simulation was carried out to estimate steam production operating conditions and experimental apparatus was setup for measuring heat transfer coefficient. Experiment was conducted at a temperature lower than the temperature of the steam produced and the heat transfer correlation was obtained for the real scale design. The heat transfer coefficient for the water in the test plate heat exchanger with 2 channels was measured through experiment and then the heat transfer coefficient of the R245fa refrigerant in heat exchanging with water was measured. The heat transfer was classified into sensible and latent heat transfer where the correlation of the latent heat transfer coefficient was derived by measuring sensible heat. The latent heat transfer coefficient was from 1,700 to 2,500 under the condition of Reynolds number from 13,000 to 42,000. From these results, the real scale plate heat exchanger for 360kW could be designed with 20 layers for hot side and 40 layers for cold side. The flash tank which was used as steam production component was designed for the steam supplying at 500kg/h, 120℃ during 10 minutes, and its volume was obtained as 120L considering the volume of liquid and vapor.*

Keywords: *steam heat pump, R245fa, heat exchanger, condensation heat transfer, flash tank*

1. INTRODUCTION

Conventional heat pump produces hot water by using the air and geothermal heat source and it is installed for heating in residential and commercial buildings. Heat pumps for steam production, in which the steam can be produced more than 120℃ using a high-temperature waste heat, is developing briskly at home and abroad in order to apply it to the industry field [1-3].

R245fa is used as a refrigerant in the system and it operates at least up to 135 ℃ and 25 bar or more in order to produce steam at high temperature and high pressure. Flash tank is added to the heat pump system and the water converts into steam through condenser and flash tank.

In this paper, the condensation heat transfer coefficient of the plate heat exchanger was experimentally measured for the design of a condenser applied to the production of steam in the heat pump. The experimental procedure is shown in Fig. 1 and cycle simulation study was conducted for determining the operating condition preliminary to the experiment.

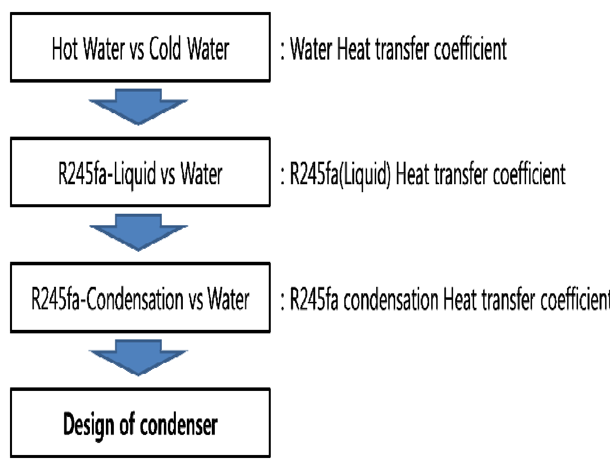


Fig. 1. Experimental procedure

2. SIMULATION STUDY

Fig. 2 shows simulation results by using Aspen HYSYS. It simulated the operation conditions of condenser and flash tank for the steam production, whose conditions were 120℃ and 500 kg/h. As shown in fig.2, the pressurized water flows through condenser where the water is heated from R245fa in condenser, and becomes high temperature and high pressure water. After that it flows into the flash tank and its working pressure goes down to convert into steam. Target steam temperature and mass flow rate were given and pressure drop in heat exchanger and mixer was given as 0.5 bar. Water circulation rate was given as 63,600 kg/h and refrigerant flow rate and temperature at condenser inlet were given as 13,050 kg/h and 135. From these conditions, the results at condenser outlet were obtained as shown in fig. 2 and the capacity in condenser was calculated as 364.8 kW.

For the purpose of design of condenser the condensation heat transfer coefficient was measured in next section and real scale condenser design was proposed based on the above simulation results.

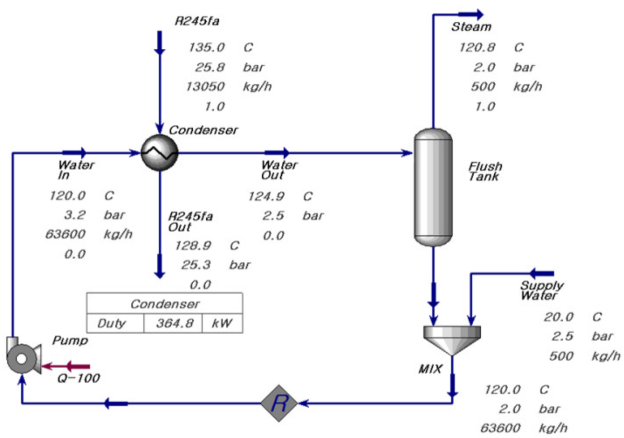


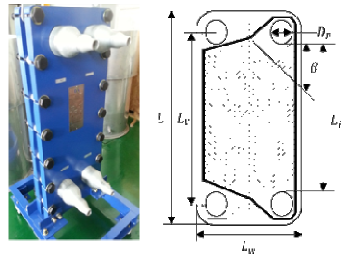
Fig. 2. Simulation condition of condenser for steam generation heat pump

3. EXPERIMENT SETUP AND RESULTS

3.1 HEAT EXCHANGER FOR TEST

The steam generating heat pump operates in the high pressure, above 30 bar. In consideration of this operating condition, the welded type plate heat exchanger was selected as test heat exchanger for condenser. Recently the brazing type plate heat exchanger has been widely used due to compact design and good performance but it needs more experience for high pressure safety [4]. The brazing type heat exchanger is difficult to stack a small number of plates compared with welded type heat exchanger because it should have over 10 plates to fix the ports. This gives rise to the problem that experimental system should be larger.

Fig. 3 represents the geometry of the heat exchanger used in this test. The width and length of plate was 369 mm and 969 mm. The heat exchanger had only a cold layer and a hot layer and it was supported by iron plate 50 mm at both sides for operating in the high pressure.



Chevron angle	β (°)	50
Port diameter	D_p (mm)	114
Plate width	L_w (mm)	369
Plate length	L (mm)	969
Chevron area length	L_v (mm)	855
Port to port length	L_p (mm)	741
Corrugation depth	b (mm)	3.0
Thickness of the plate	t (mm)	0.6
Effective corrugated area	A (m^2)	0.26

Fig. 3. Plate geometry of heat exchanger

3.2 CONVECTIVE HEAT TRANSFER COEFFICIENT OF WATER

To obtain the convective heat transfer coefficient of water that passes through the heat exchanger, the experimental apparatus was configured as fig. 4. Each temperature and pressure was measured at inlet and outlet of hot side and cold side. The test was conducted by increasing same flow rate at both sides. From Equations (1) and (2), the heat transfer coefficient was obtained. Heat transfer coefficients of cold and hot fluids were assumed to be the same. Fig. 4 (2) was plotted by using Equations (3) and (4). Finally, Equation (5) was obtained from the curve fit of fig. 4.

$$Q = UA\Delta T_{lm} \tag{1}$$

$$\frac{1}{U} = \frac{1}{h_C} + \frac{t}{k_{wall}} + \frac{1}{h_H} \quad (h_C \approx h_H) \tag{2}$$

$$Nu = \frac{h \cdot D_h}{k} \tag{3}$$

$$Nu/Pr^{1/3} = A \cdot Re^B \tag{4}$$

$$Nu_w = 0.45601 \cdot Re^{0.6028} Pr^{1/3} \tag{5}$$

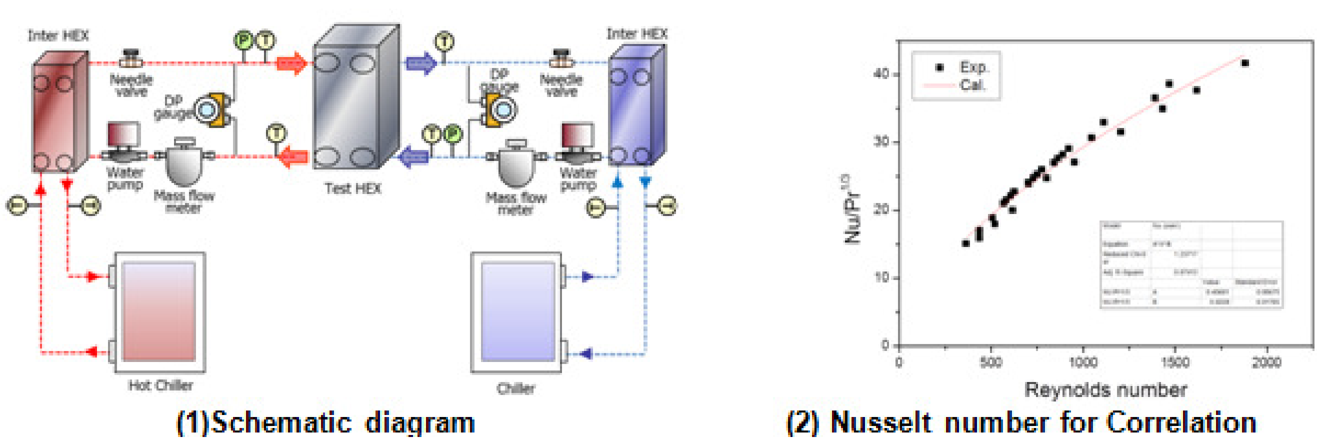


Fig. 4. Schematic diagram of experiment and result for heat transfer coefficient of water

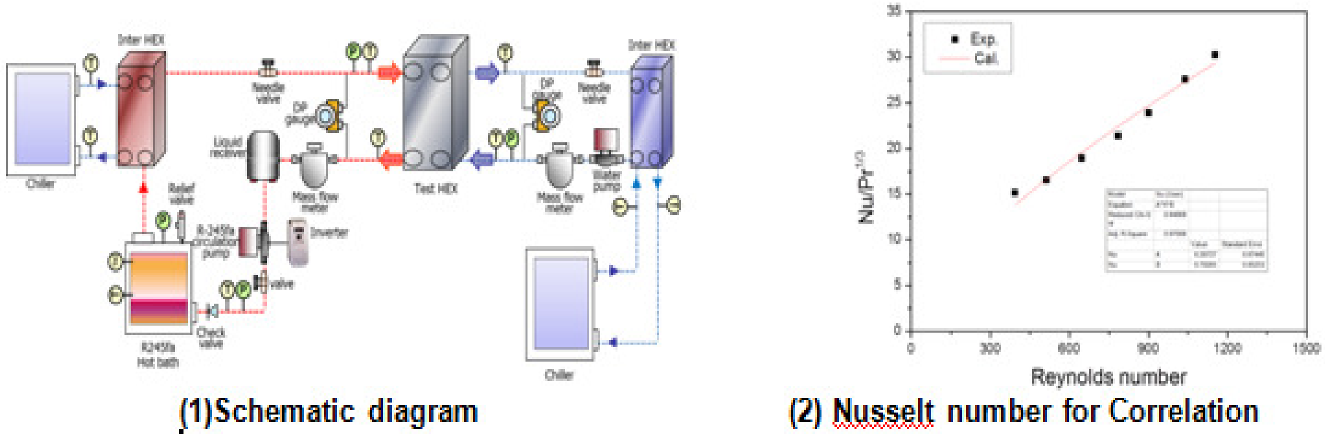


Fig. 5. Schematic diagram of experiment and result for heat transfer coefficient of R245fa liquid

3.3 R245fa LIQUID CONVECTIV HEAT TRANSFER COEFFICIENT

Fig. 5 shows the schematic diagram of test apparatus for determining R245fa liquid fluid heat transfer coefficient. R245fa was evaporated by electric heater inside hot bath and was subcooled in inter HEX by chiller. And this subcooled refrigerant and cold water flowed in hot and cold side respectively. The heat transfer coefficient of liquid R245fa was obtained by applying the same method as mentioned at section 3.2. The obtained heat transfer coefficient was shown in Equation (6). The heat transfer coefficient of water that needed for Equation (6) was calculated by using Equation (5).

$$Nu_R = 0.20727 \cdot Re^{0.70265} Pr^{1/3} \quad (6)$$

3.4 R245fa CONDENSATION HEAT TRANSFER COEFFICIENT

In this experiment, the measurement method was that all condensation region was determined using some assumption. The outlet subcooled temperature of refrigerant was known by using measured temperature and pressure at outlet, and cooled heat capacity was calculated for subcooled region. And then the saturation temperature of water and refrigerant inside heat exchanger was calculated, the condensation area was determined as shown in Fig. 6. This needed the assumptions that pressure loss wasn't generated for subcooled region.

The experimental apparatus to obtain condensation heat transfer of R245fa was shown as fig. 7. The superheated temperature of R245fa at inlet of test heat exchanger was measured approximately to be 0°C and the subcooled temperature at outlet was kept to be in the range 5°C to 7°C. The sensible heat transfer capacity was average 5.8% of the total heat transfer capacity, therefore it was found that the condensation heat transfer was dominated. By same procedure to obtain heat transfer coefficient, fig. 7 was plotted by using Equation (7). And the correlation for condensation heat transfer coefficient of R245fa was finally presented in Equation (8).

$$Nu/Pr^{1/3} = A \cdot Re^{B} + C \cdot Re^{D} \quad (7)$$

$$Nu_L = (0.51977 \cdot Re^{0.68201} + 2.70099E9 \cdot Re^{-1.72271}) Pr^{1/3} \quad (8)$$

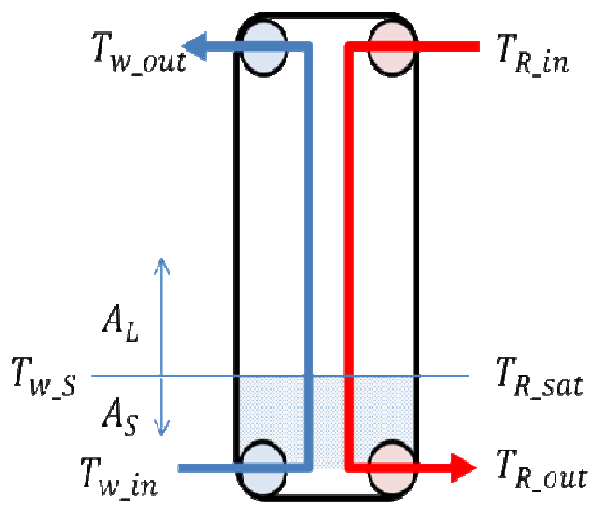


Fig. 6. Division of heat transfer area between latent and sensible

4. HEAT EXCHANGER DESIGN FOR REAL SCALE

The design of real scale condenser for steam generating heat pump was carried out according to operating condition as shown in Fig. 2 by using developed correlations in this paper. Fig. 8 represented the procedure for the design of heat exchanger. First step is determinant of stacked plates of cold side and hot side by pressure loss condition. However in this paper tests for measurement of pressure loss was not conducted, but the design was focused on heat transfer. The array of stacked layers has generally 1:1 or 1:2 ratio in hot side and cold side. This operating condition was selected 2:1 ratio because the flow rate of R245fa is about 1/5 of water. According to the procedure as shown in the fig. 8, the overall heat transfer coefficients were compared by the temperatures of operating condition and by the calculation of correlations, and the number of stacked plates was fixed where these values corresponded closely. Finally, the condenser could be designed to have 26 layers of R245fa side and 52 layers of water side considering 20% margin which was widely adopted in a commercial heat exchanger design. The total heat transfer area was 13.5 m^2 and the condensation heat transfer coefficient of R245fa was calculated 4454 $W/m^2 \cdot K$.

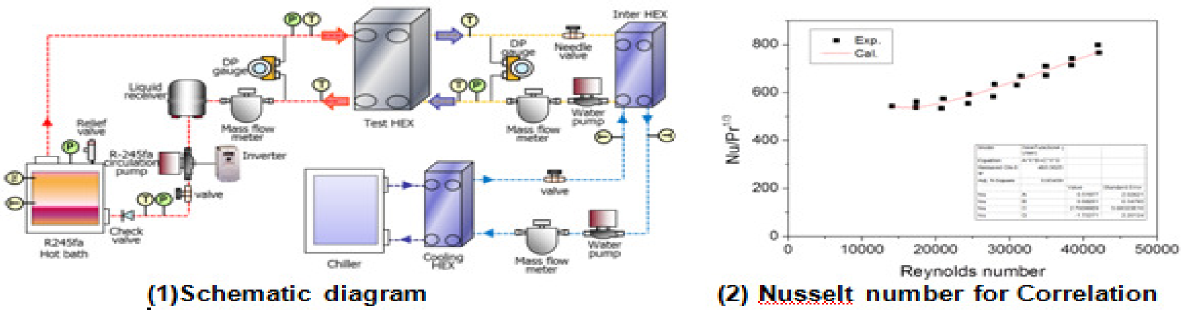


Fig. 7. Schematic diagram of experiment and result for condensation heat transfer coefficient of R245fa

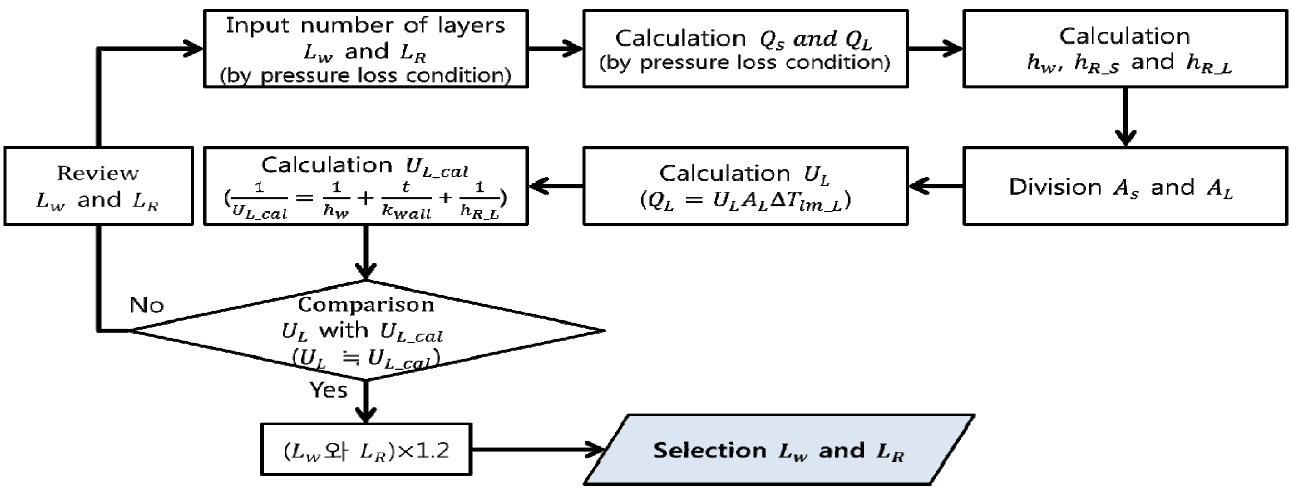


Fig. 8. Design procedure of heat exchanger

5. CONCLUSIONS

In this paper, the experimental study on condenser was conducted and the design of flash tank was proposed for steam heat pump system. R245fa was used as refrigerant and simulation was conducted for the real scale design. In order to derive the heat transfer correlation of condenser, convection and condensation heat transfer coefficient was measured for R245fa refrigerant. With the correlation, real scale condenser which uses R245fa was designed with R245fa side 26 layers and water side 52 layers considering 20% margin. Through this study, the heat exchanger design in R245fa condenser was established and in the future the real scale heat exchanger will be tested and analyzed for the application to the industry.

ACKNOWLEDGEMENT

This research was supported by “Development of Unit systems Applied to Thermal Energy Network for Building/Industrial Application (Grant No. 20132010101780)” by Ministry of Trade, Industry & Energy.

REFERENCES

[1] Kim, J. S.; Lee, G. B.; Na, H. S.; Kim, M. S. Research on the reliability test of compressor for high temperature heat pump, Proceeding of SAREK, 2014, 308- 311.

[2] Iizuka, K. High efficiency steam supply systems using heat pump cycle, JSRAE, Reito. 2014, 89, 1039, 305-310.

[3] Shim, Y. B.; Park, K. J.; Jung, D. S.; Kim, J. S. Condensation heat transfer coefficients of R245fa on a plain tube, Journal of Air-conditioning and Refrigeration Engineering, 2007, 19, 555-562.

[4] Gulenoglu, C.; Akturk, F.; Aradag, S.; Uzol, N. S.; Kakc, S. Experimetal comparison of performances of three different plates for gasketed plate heat exchangers, Int. Journal of Thermal Sciences, 2014, 75, 249-256.