Development of vapor compression system using natural refrigerant

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Abstract

Recently, as the life quality has been improved, the demand for the refrigeration system has been increased rapidly. Also, the interest in low GWP chiller is increasing, due to the important environmental problem. Here, we have developed a refrigeration system using R-718 refrigerant, water. Considering the large specific volume and surface tension of the water, we have designed heat exchangers and the compressors. We introduce the performance of the new system with the manufacturing process of the system. Moreover, we show the preparation procedures of the test that are necessary for the system operation.

Keywords: Natural refrigerant; R-718; Turbo compressor; Evaporator; Condenser

1. Introduction

As the quality of life improves, the demand for cooling systems is increasing rapidly. However, since the increase in the manufacture of cooling devices is generally accompanied by an increase in the amount of chemically synthesized refrigerants, a global environmental pollution problem is greatly emerging at the same time. Through the regulation of refrigerants, the use of HFC refrigerants following synthetic refrigerants CFC and HCFC will be greatly reduced. Accordingly, interest in refrigeration and cooling systems using eco-friendly refrigerants with low Global Warming Potential (GWP) is increasing. Korea is the 5th largest producer of refrigeration/air conditioning machinery in the world, showing some technological superiority in the market. In response to the eco-friendly trend of the refrigeration market, research on refrigeration/air conditioning machines that use low GWP and natural refrigerants instead of existing refrigerants is needed. In this study, we would like to introduce the (R-718) cooling system that uses water with zero GWP as a refrigerant. A study on the water refrigerant chiller have not been conducted in Korea, although it has been carried out several times in developed countries such as Germany and Japan.[(1-2)] In this presentation, water refrigerant chillers developed with domestic technology are introduced. In addition, we would like to disclose the manufacturing method and operating performance.

2. Cycle and components of chiller

This refrigerator is a two-stage compression system, an intercooler is used between the first and second stage compressors, and is manufactured according to the following cycle diagram.

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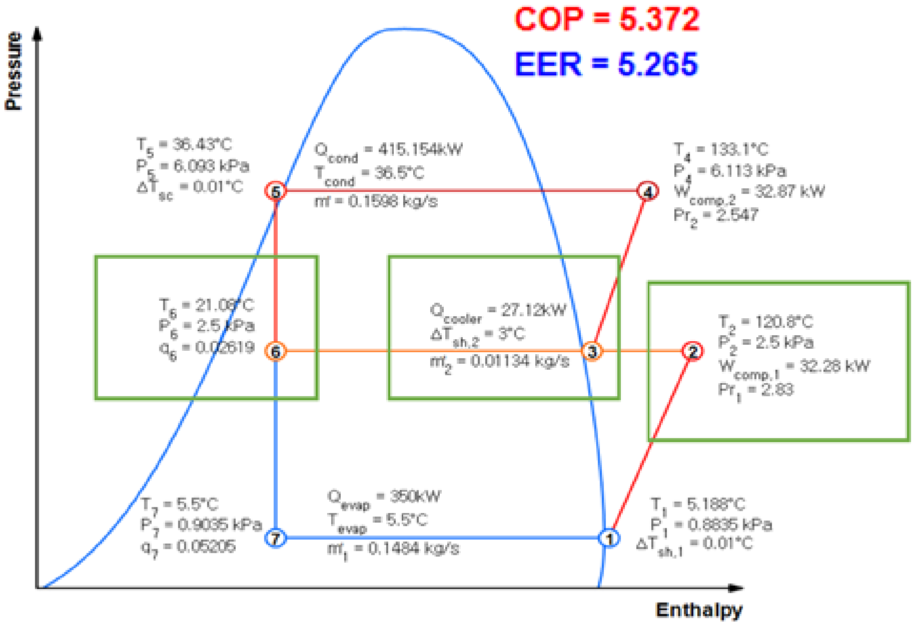

Fig. 1. Cycle of the system

3. Evaporator

Like other turbo chillers, the heat exchanger is designed and manufactured as a shell-and-tube type. Since the pressure difference from outside is not large, the shell is manufactured in an angular shape like an absorption chiller. The evaporator, classified as a falling film evaporator, is driven using a pump and a distributor. Liquid refrigerant is collected at the bottom of the shell, and a pump is installed at the bottom to move the liquid to the top of the evaporator. The liquid, which passes through the distributor, is fallen on the heat transfer tube. The internal pressure is set to 0.9 kpa as a design value, and the internal saturation temperature is set to about 5.4 °C. The inlet temperature of the cold water is 12°C. Since it is higher than the saturation temperature, the droplets, supplied on the heat transfer tube, is immediately evaporated and turned into steam, which is supplied to the first stage compressor. Here, to prevent moisture from entering, an eliminator is installed, as shown in Fig. 2.

Fig. 2. Image of the eliminator installed at the outlet of the evaporator

In order to decide the type and number of tubes, evaporator experiments in lab scale test are performed prior to manufacturing the prototype. A 10 kW evaporator is prepared as shown in the photo, and four (Notched corrugated, Notched floral, Low fin, End cross tubes) different heat transfer tubes are tested. The internal pressure is set to 0.9 kpa, similar to the design pressure. The cold water supply temperature is 12 degrees. As for the evaporator, Notched corrugated tube showed the best performance, but Notched floral tube was the best in terms of low flow stability. So, we decided to use a combination of them. When designing the prototype, at least 130 heat transfer tubes (based on 3 meters) were required in consideration of the cooling capacity. But for stable operation, we installed about additional 50% more, and 204 tubes were installed.

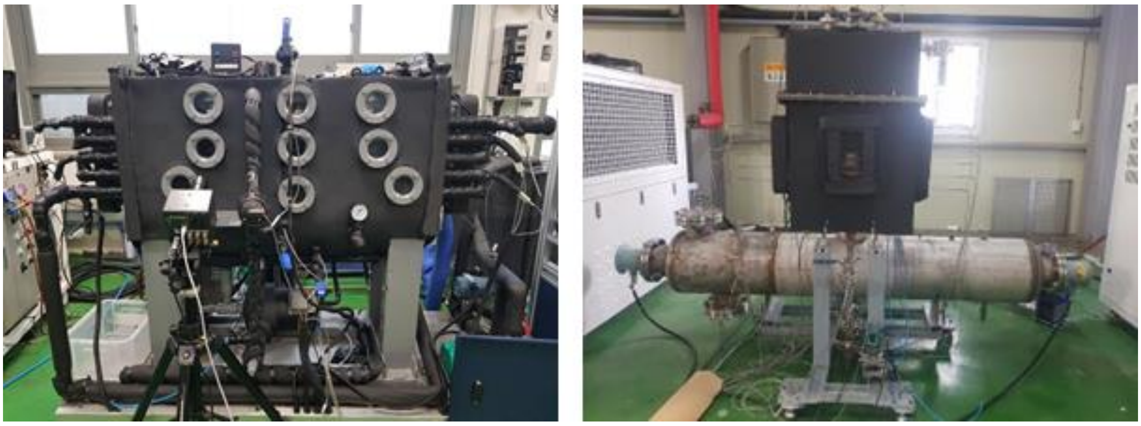

Fig. 3. Images of the 10kW evaporator(left) and condenser(right)

4. Condenser

The internal pressure of the condenser shell is 6.11 kpa, and the saturation temperature is about 36.5 degrees. In the design, the inlet temperature of the cooling water is about 30 degrees, so the refrigerant vapor supplied from the compressor is turned into liquid droplets. The droplets, formed on the upper tubes, fall to the lower ones and are collected at the shell bottom. The liquid moves to the evaporator or intercooler by gravity. Like the evaporator, in order to decide the type and number of heat transfer tubes, lab scale condensation experiments were performed. A 10 kW condenser was prepared as shown in the picture, and 6 different heat tubes (Bare, Corrugated, Floral, Low fin, Notched corrugated, and Notched floral tubes) were employed. The internal pressure is set to 6.1 kpa, similar to the design pressure. The cooling water supply temperature is 30 degrees. Even though the Notched corrugated tubes show the best performance, we decide to use the corrugated, since there was no significant performance difference. Unlike the evaporator which is mainly related to the phase change, the condenser includes the condensing section but also the superheated section, as can be seen in the ph diagram in the figure. Thus, a larger number of heat transfer tubes than for the condensation only are required. Since single-phase heat transfer under vacuum conditions requires a larger heat transfer area, about 4 times more heat transfer tubes were used for cooling the superheated section. Totally, 630 heat transfer tubes are installed. In the overall structure, the condenser should be located at the rear end of the two-stage compressor. But if the connecting parts are arranged in a line, there is a problem that the size becomes excessively large. We also note that the space for the distribution of steam must be added to the front of the condenser, which greatly increases the length of the device. In order to resolve this problem, we erected the condenser, where the refrigerant is supplied vertically to the upper part of the condenser.

5. Intermediate cooler

Since the chiller of this project is a two-stage compression system, an intermediate cooler that cools the vapor that has passed through the first-stage compressor is required. There are two types of intercoolers: an indirect intercooled type and a flash tank type. In this study, the latter is selected to reduce the overall size and the amount of pressure drop. A nozzle is installed on the top of the intercooler and used to change the refrigerant delivered from the condenser into mist. A small reservoir is installed at the bottom of the intercooler and an additional pump is installed to circulate the refrigerant. The refrigerant vapor passing through the first stage compressor (Lp) meets this mist to exchange heat and mass, and the generated vapor enters the second stage compressor (Hp). At this time, the direction of nozzle injection must be carefully determined so that the droplets do not enter the compressor. (Hp) As shown in the design, the temperature of the refrigerant entering the intercooler is approximately 120 ℃, and the temperature of the refrigerant entering the two-stage compressor approximately 24 ℃, but the exact temperature could not be measured in this experiment.

The liquid refrigerant collected at the bottom of the condenser moves through a pipe. Part of the refrigerant goes into the reservoir of the intercooler, and the rest moves to the evaporator shell. At this time, using the U-trap, (U shaped pipe) the liquid are collected at the lower end of the pipe. Due to the pressure difference, a liquid column is formed in the U-trap, and the column separates the condenser and the other sides, the evaporator and the intercooler. Because of this device, the evaporator and intercooler can maintain a different pressure environment than the condenser. The column height is determined by the pressure difference between both ends and the hydrostatic pressure due to gravity.

6. Compressor

This prototype is a two-stage compression system, and both compressors are of centrifugal type. Since water vapor has a large specific volume and the compressed environment is in a vacuum state, considerably large impellers are required. The diameter of LP is about 970 mm, and the diameter of Hp is about 650 mm. All of the impellers were made of aluminum, and were manufactured with a 5-axis processing machine as shown in Fig. 4. The two compressors are arranged side by side and operated independently. The compression ratio of LP is about 2.8, and the compression ratio of Hp is 2.6. The compressor efficiencies are 76% and 75%, respectively. Bearings are ball bearings and roller bearings. A cooling fan is installed at the rear end, and a cooling line using water connected to the outside is installed to cool the motor. (See Fig. 5)

Fig. 4. Lp(left) and Hp(right) impellers

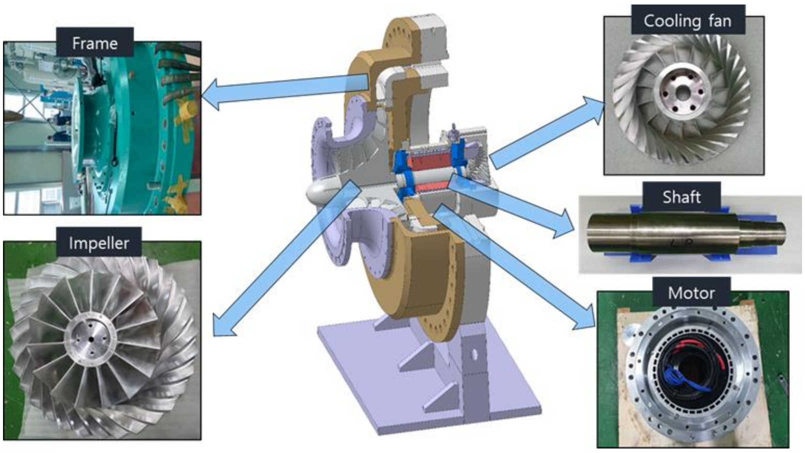

Fig. 5. Structure of the compressor (Lp)

Fig. 6. Image of the prototype

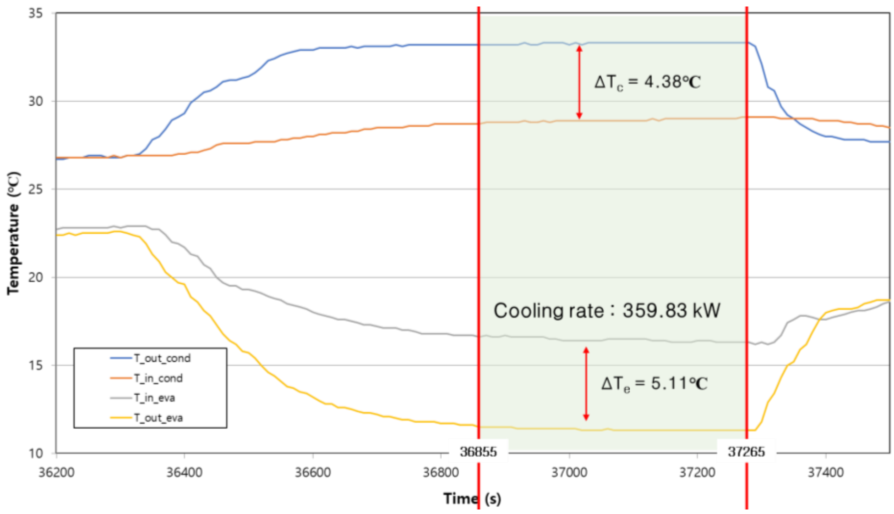

Fig. 7. Temperature change during the operation

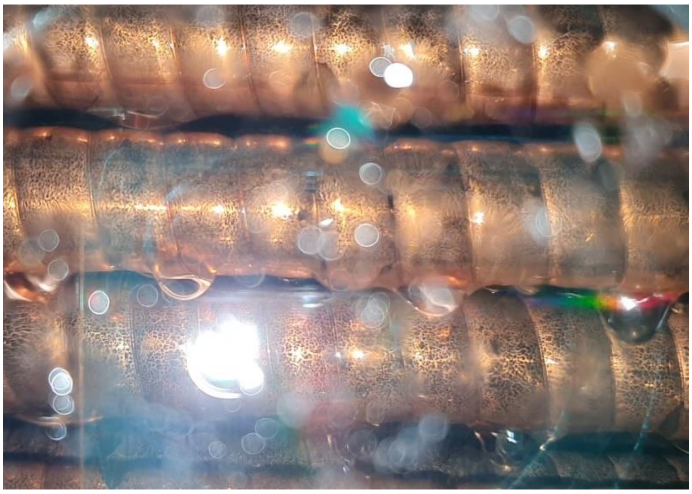

Fig. 8. Image of the condensation

7. Performance of the system

Prior to operating the prototype,(See Fig. 6) we created a vacuum environment and injected water into the evaporator, condenser, and the intercooler. Cold water and cooling water were set to flow at 1,000 lpm and 1,200 lpm. It was operated while increasing the number of revolutions of LP (primary compressor) and HP (secondary compressor) step by step. If the vibration increases or the internal bearing temperature increases while increasing the number of revolutions, we immediately stop the operation. Finally, it was driven up to LP: 10,000 rpm and HP: 16,300 rpm.

As the phase change occurred in the evaporator, the temperature of the cold water was dropped, resulting in a temperature difference of about 5.11 °C at the inlet and outlet.(See Fig. 7) In the condenser, as shown in Fig. 8, condensation actively occurred on the surface of the heat transfer tubes, and the temperature of the cooling water was increased by about 4.38 °C. The total heat capacity was measured as 359.83 kW and 366.60 kW for the evaporator and condenser, respectively. Considering that the total power used by the compressor is 50.48 kW, the calculated heat capacity of the condenser should be about 410.31 kW, but condensation on the inner wall due to conduction occurs together (the amount of condensation on the inner wall was not calculated), resulting in low performance of the condenser.

Upon reaching equilibrium, the average cooling water inlet/outlet temperatures are 16.48 °C and 11.36 °C, and the average cooling water inlet/outlet temperatures are 28.90 °C and 33.27 °C, as shown in Fig. 7. The temperature change is shown in the graph in the figure. The COP considering power consumption and cooling heat was calculated as 6.80, and the overall heat transfer coefficient of the evaporator at this time was calculated as 5,596 W/m^2°C. In the case of the condenser, considering the condensing part includes the single phase heat exchange in the superheated and supercooled sections, we derived the overall heat transfer coefficient, 4,596 W/m^2°C.

8. Conclusions

In this study, the evaporator, condenser, and compressor were studied in detail to develop the specifications to be applied to the R-718 refrigerator, and the entire system was manufactured by applying them to the prototype. In addition, performance evaluation and analysis were performed by connecting and operating electric devices. For actual product development, several factors, including a huge size, have to be improved, through additional research. We believe that this study has a significant meaning in that it the development direction of the R-718 refrigerant system was investigated through this study.

Acknowledgements

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