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The study of secondary loop system with efficient and flammable refrigerants in MAC

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Abstract

In EV market, two key factors are driving range and cost. The conventional heat pump system can extend driving range in cold season, but it has lots of components and has complicated structures. The cost of heat pump is also more expensive than normal air-condition system with air PTC heater.
To solve these challenges, secondary loop system has been considered for EV thermal management system based on coolant system. However, it has weak point in regard to fast cool down, warm up and maximum performance due to heat loss. To solve those problems, some refrigerant is in study, and we did drop in test with efficient & flammable refrigerants (R1234yf, R152a, R290). Test result shows the possibility of secondary loop system & challenges.

Keywords: Secondary loop; Heat Pump; Flammble refrigerant; R152a; R290

1. Introduction

In the EV market, which is growing in size over time, EVs are valued as mileage and price. Among them, many electric vehicles use heat pump system to increase the mileage, but the heat pump system has a large number of parts and a complicated system configuration, which makes it less competitive in terms of price. On the other hand, electric heaters are often used in general A / C systems to solve electric car cooling / heating at low prices. In winter, the use of electric heaters is the biggest factor in reducing the mileage of electric cars.

After all, in order to increase the competitiveness of electric vehicles, a simple configuration and a low-cost heat pump system are required. As a solution, a secondary loop heat pump system is attracting attention these days. However, the secondary loop heat pump system has a heat transfer process of refrigerant-cooling water-air, and in this process, heat exchange efficiency is reduced, and performance is lower than that of a direct system for refrigerant-air heat exchange.

In this study, the refrigerant was studied as a method to improve the performance of the secondary loop heat pump system. Drop-in evaluation was performed on three refrigerants R1234yf, R152a, and R290 with different characteristics, and the cooling / heating performance of each refrigerant was compared.

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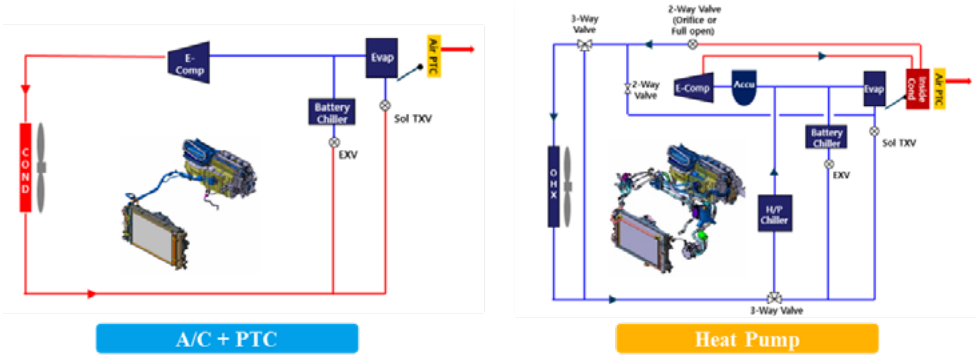

Fig. 1. A/C+PTC System / Heat Pump System

2. Body

2.1. *Secondary Loop System Definition*

Comparing current direct heat pump systems with secondary loop systems shows a number of differences in component count and pipe connections. The current heat pump system has a large number of heat exchangers for cooling and heating, and includes a plurality of refrigerant valves for changing the direction of the refrigerant, and the increase in the number of components increases the price of the heat pump system. Secondary loop systems can reduce the number of components because there is no need to switch the refrigerant direction, which leads to a lower price.

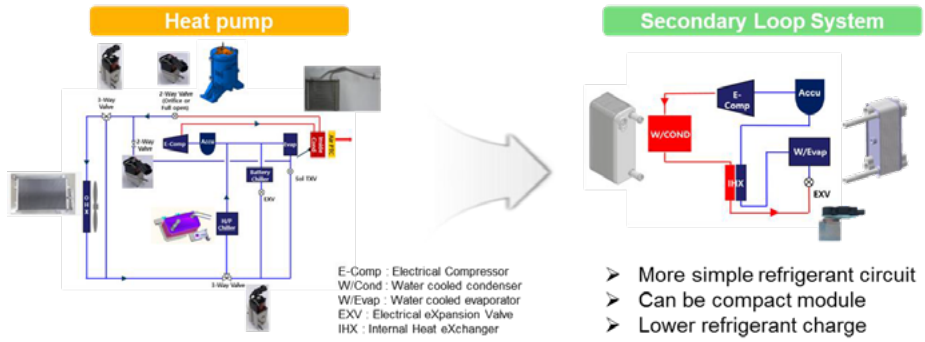

Fig. 2. Direct heat pump system / Secondary loop system

In a secondary loop system, cooling and heating are operated by circulation of the coolant. When cooling, the coolant heat exchanged from the evaporator is drawn to the heat exchanger in the HVAC, and when heating, the coolant heat exchanged from the condenser is drawn. Figure 3 shows the coolant circuit at A/C mode and H/P mode.

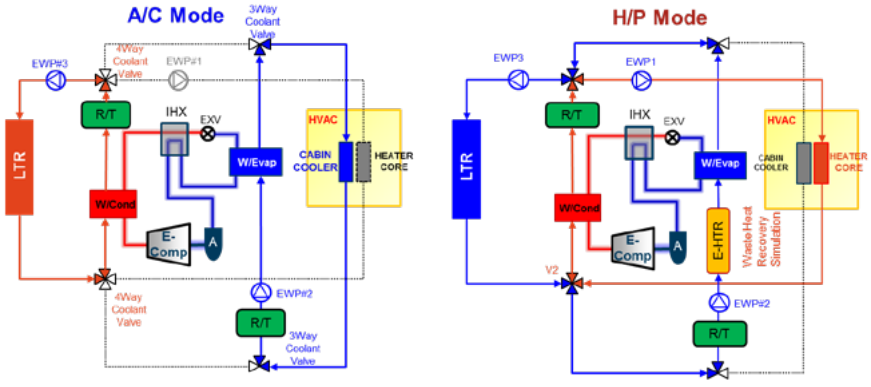

Fig. 3. Cooling mode and heating mode in secondary loop system

The advantage of the secondary loop is that the system is simpler in construction, and the disadvantage of the secondary loop is that the performance is degraded due to the heat exchange process. In fact, when R1234yf refrigerant used in the current heat pump is used in the secondary loop, cooling performance is reduced by about 22% and heating performance is reduced by about 15%.

2.2. Refrigerant Characteristics Comparison

With R1234yf refrigerant, it is difficult to satisfy the performance in the secondary loop system. There are limitations in refrigerant characteristics. In this study, we applied the refrigerant of R152a and R290 to check whether the performance can be satisfied in the secondary loop. R152 and R290 are low-GWP eco-friendly refrigerants and low cost. In addition, the heat of vaporization is large relatively, which can lead to higher performance.

Table 1 Refrigerant characteristic comparison

	Market Application	Environmental Regulation (GWP)	Safety Regulation	Estimated Cost ($/kg)	Heat of vaporization (kJ/kg) at 0°C	Heat of vaporization (kJ/kg) at 60°C	System Matching
R134a	Current (will Phase down)	1430	A1	3.4	198.6	139.1	Direct
R1234yf	Launched (Global)	3	A2L	66.8	163.3	110.4	Direct
R152a	TBD	124	A2	-	307.1	229.3	Indirect
R290	TBD	3	A3	3.1	374.9	259.2	Indirect

The p-h diagram (Fig. 4) shows that the heat of vaporization of these two refrigerants is large, and in particular, R290 has a relatively lower saturation temperature at the same pressure, which improves the cooling performance and heating performance.

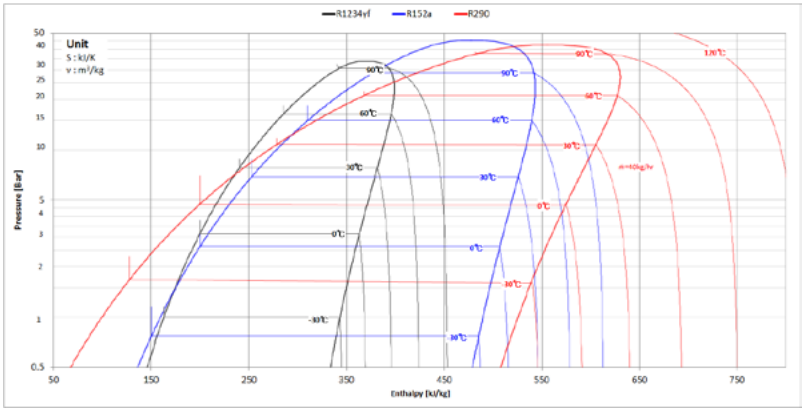

Fig. 4. p-h Diagram of Refrigerants

2.3. Bench Rig Test Result

Figure 5 shows the results of the refrigerant charge amount determination test. The test was on A/C high load condition, 35°C ambient temperature and 50% relative humidity. The refrigerant charge amount is reduced by 45% in the secondary loop system compared to the direct heat pump system. Where R152a and R290 are further reduced by 27% and 58%, respectively. If 1000g of refrigerant is charged in the R1234yf direct heat pump system, the refrigerant charge amount of the R290 secondary loop system is about 230g. This is half of the IEC standard 500g (self-contained).

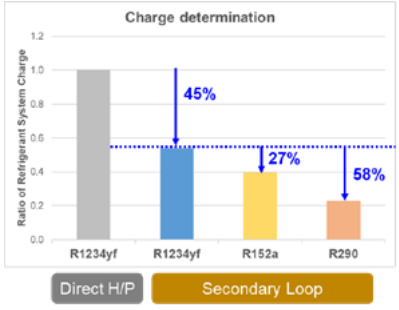

Fig. 5. Results of refrigerant charge determination test

Cooling performance test was performed under an ambient temperature of 35°C, humidity 40% RH conditions. The air flow rate on the HVAC side was 450cmh, and the air flow rate on the air cooled condenser and radiator side was 2.5 m/s. The compressor is a 33cc electric scroll type compressor and was operating 7000rpm.

Figure 6 and 7 show the results of the A/C test. The secondary loop system based on the R1234yf reduces 22% performance over the direct system. The air discharge temperature at the evaporator shows that the direct system is 8.5°C, while the secondary loop system is 11.8°C, because coolant is in between the refrigerant and the air. In more detail, the refrigerant temperature of the evaporator under the above conditions is about 5°C, and in heat exchanger refrigerant cools the air to 8.5°C. On the other hand, in the second loop, when the refrigerant temperature of the evaporator reaches 5°C, and it makes the coolant temperature about 8.5°C, and the 8.5°C coolant makes the air 11.8°C.

In this case, when R152a refrigerant is used, the heat of vaporization is large, and a cycle is formed at a lower pressure and a temperature in the evaporator, thereby improving cooling performance by about 4%. At

the same pressure, the saturation temperature is slightly higher than R1234yf, but the heat of vaporization is relatively large, so performance can be secured at a small flow rate.

When using R290 refrigerant, the effect of the refrigerant characteristics is very huge. Cooling performance is improved by 30%, which is equivalent to a direct system using R1234yf. R290 has a high heat of vaporization and a low saturation temperature at the same pressure. So it is possible to make refrigerant at lower temperature, coolant at lower temperature, and discharge air at lower temperature. However, Pd is formed relatively high, so the compressor power is consumed more, and the COP is lowered, but this COP is similar to the secondary loop system of the R1234yf, which is not a disadvantage of the R290.

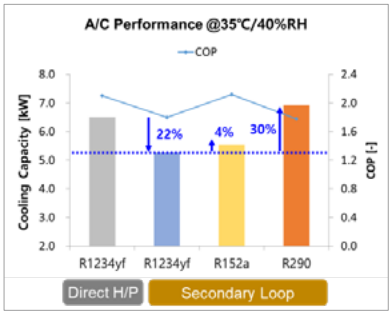

Fig. 6. Results of A/C performance test

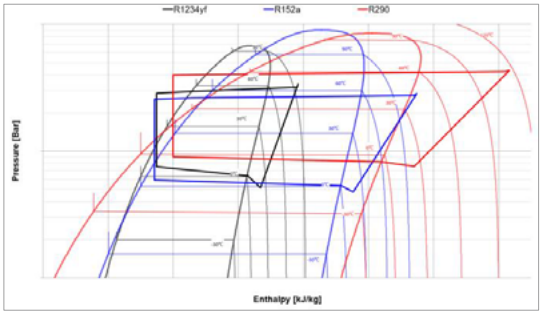

Fig. 7. p-h diagram comparison in A/C mode

Figure 8 and 9 show the results of the H/P test. Heating performance test was performed under an ambient temperature of -20°C. The air flow rate on the HVAC side was 300cmh, and the compressor was operating 5000rpm. The waste heat of the electrical equipment was simulated, and 2 kW of energy was supplied to the evaporator. Since the same heat absorption amount of waste heat was applied, the performance difference was not large. However, the low pressure side refrigerant state at this time can confirm the performance impact of the refrigerant characteristics. R1234yf and R152a have a refrigerant temperature of -20°C or -19°C based on compressor suction side, whereas R290 has refrigerant temperature of -30°C.

What the refrigerant temperature is lower than outside air means that additional heat absorption from outside air is possible. Because the refrigerant temperature on low pressure side of R1234yf and R152a is similar to outside air, heat absorption from outside air is not possible, it makes limited heating performance. However, R290 is lower than outside air by 10°C, so additional heat absorption from outside air is possible, which can improve heating performance.

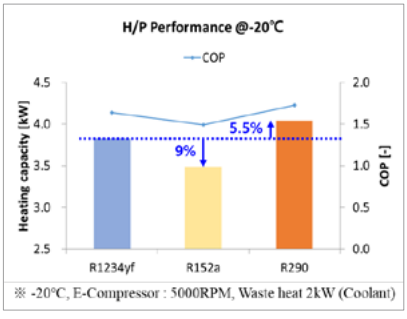

Fig. 8. Results of H/P performance test

Fig. 9. p-h diagram comparison in H/P mode

Figure 10 shows the comparison of heating performance with only outside air heat absorption of R1234yf direct system and R290 secondary loop system. In -20°C condition, the air flow rate on the HVAC side was 300cmh, and the air flow rate on the air cooled condenser and radiator was 2.5m/s. The compressor was operating 5000rpm. Even though R290 is a secondary loop system, the heating performance is about 17%

higher than the R1234yf of the direct system. Because of the temperature and pressure characteristics of R290 described above, it is possible to absorb more outside heat sources than when operating a heat pump with R1234yf.

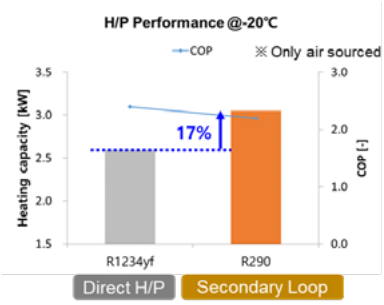

Fig. 10. Results of H/P performance test with only outside heat source

3. Summary/Conclusions

In order to improve the performance of the secondary loop heat pump system, the study was done about the refrigerants. Drop-in test was performed on three refrigerants R1234yf, R152a, and R290 with different characteristics, and the cooling / heating performance for each refrigerant was compared. Changing from direct heat pump system to secondary loop heat pump system based on R1234yf reduces cooling performance by about 22% and heating performance by about 15%. However, using R290 refrigerant improves cooling performance by 30%, equivalent to the direct system of R1234yf. The heating performance is above the direct system of R1234yf due to the increase of outside air heat absorption. The R290 refrigerant can overcome the performance shortcomings of the secondary loop system, which can help reduce the cost of electric vehicles through the application of the secondary loop system.

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