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Development of AHP, the Integrated Climate System Module for EV

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Abstract

This paper presents the results of AHP (Air-controlled Heat Pump), a new concept of climate system for electric vehicle developed in order to overcome the disadvantages of conventional heat pump system to be applied to an electric vehicle for better efficiency. Unlike conventional heat pump system gets cooling and heating by change the refrigerant flow, AHP changes only the air flow path by door control to get cooling and heating functionality. The cooling performance of AHP at 45°C ambient temperature was a little better at high speed driving mode and much better at idle condition than current EV heat pump systems in spite of less power consumption. Also, heating performance at -20°C ambient was satisfied with reduction of power consumption which can achieve 15~27% EV driving range extension compared to electric heater system.

Keywords: Air-controlled Heat Pump System; Air Cooled Condenser; Water Cooled Condenser; Electric Vehicle;

1. Introduction

In recent years, market trends in automotive industry are changing to eco-friendly vehicles due to the lack of fossil fuel energy and global warming issues. The eco-friendly vehicles (Hybrid Vehicle, Plug-In-Hybrid and Battery Electric Vehicle) are being actively developed and rapidly spread out. Despite those wide spread trends, the EV(Electric Vehicle) has still remained technical issues - driving range, high cost and electric charging infra issues.[1] Among these issues, the driving range decrease caused by operating cooling and heating system in the EV cabin is the most pessimistic point to invigorate market.

The EV does not have a heating heat source from engine, unlike conventional internal combustion engine vehicles. It is common to solve the problem using a high voltage PTC electric heater. In this way, while minimizing changes in the existing air conditioning system, due to low efficiency, it has a big problem of reducing the driving range up to 50% in cold weather.[2]

Many vehicle makers and researchers on various types of heat pump system applied in a direction that compensates this non-efficiency with concept of heat recovery from ambient air or using vapor injection compression.[3-4] While the heat pump system is currently applied in vehicle products, the performance is significantly reduced in very cold (-10℃ or less) ambient conditions due to the characteristics of the R134a/R1234yf refrigerant, so it is common to correspond to the heating load with an additional high voltage PTC electric heater. Also heat pump system has frosting problem that happens in heating mode occurring system performance and driving distance decreases due to block of exterior heat exchanger. Some experimental study was conducted to solve the outside condenser frosting problem with various heat exchanger design.[5]

Another case of the heat pump system applied to vehicle products is as following; it is possible to operate the heat pump cycle at -20°C by applying a technology of utilizing the waste heat from vehicle power devices such as driving motors, inverters and so on. This technology can achieve a power reduction of

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battery more than 20% to 25% compared to the high voltage PTC heater only system. Despite the good efficiency of this heat recovery concept, system layout have to have a complex configuration of valves and piping to control the refrigerant path including additional high voltage electric heater and still have the problems caused by outside heat exchanger frosting.

In this study, we proposed an air-controlled heat pump system (AHP) concept to solve the complexity of conventional heat pump systems and improve heating performance with the feasible performance evaluation including vehicle test.

2. AHP System overview

2.1. Basic concept of AHP

There are various types of air conditioning systems for currently EV application which are shown in Fig.1. The first one, applying a high voltage PTC heater only system, has a simple configuration similar to the existing internal combustion engine vehicles. The general heat pump system, the second one, and heat recovery system from vehicle power system consist of a complex piping and a number of refrigerant path switching valves for getting advantages of heating power saving with the heat recovery from ambient air and sometimes waste heat from electric driving power system such as driving motor(s), inverter, etc.

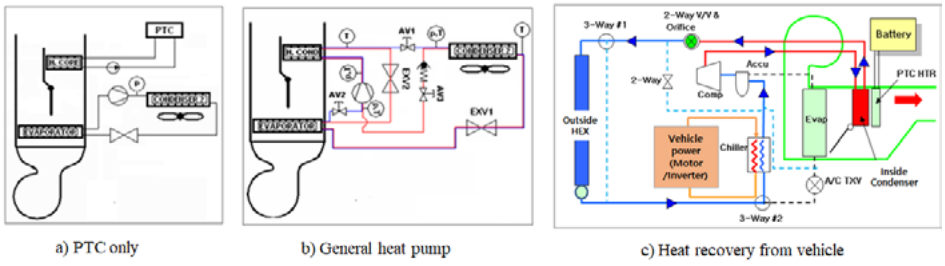


Fig. 1. Various type of electric vehicle air conditioning system

For more efficient and popular market trend, new concept of air conditioning systems for electric vehicles that can achieve weight savings by reducing the number of parts through simplifying the system configuration is required. The basic concept of the integrated air conditioning system "AHP (Air controlled Heat Pump)" developed for EV is the same as the concept of the air conditioning system since it uses hot air through the condenser as a heating heat source. Unlike the existing heat pump system changes the refrigerant flow path to implement the cooling and heating function, the refrigerant flow of AHP is always the same, while keeping the air flow into the cabin room according to the passenger's needs to implement the comfort of the cabin inside.

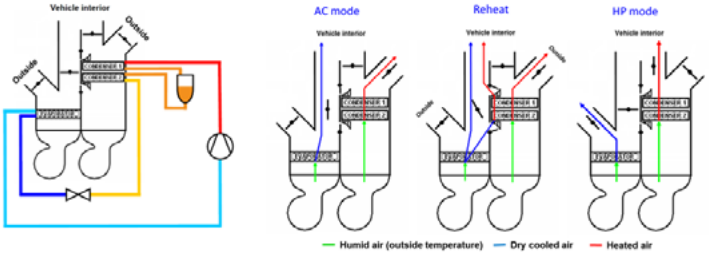


Fig. 2. Schematics and airflow path of AHP system

Fig.2 shows a schematics of AHP system and how it works. Unlike the conventional Heat Pump system as mentioned before, the refrigerant flow path is always in the same direction in cooling or heating mode. Only the airflow is changed depending on which mode user chooses. In A/C mode, cold air through evaporator goes in to the cabin room by control of door opening/closing and the warm air through the condenser is exhausted out to ambient. Vice versa in heating mode of cabin. Every valve is controlled in a HVAC system. For other mode as like dehumidifying function, it can be realized with another reheat door system.

The other word, AHP is an integrated air conditioning system by placing the condenser in one HVAC and make every function in cabin air conditioning with 1-directional and simple refrigerant system; So it can be called the integrated climate system module and is also referred to as the "Air controlled Heat Pump, AHP".

2.2. AHP system construction

For final target of this study, vehicle level performance and driving range extension evaluating, we try to apply the basic concepts of AHP system to electric vehicle. With this goal, the vehicle package and component capacity evaluating study with various type was done.

For better condensing performance and COP in A/C mode, the compact AHP model has a water-cooled condenser, while the air-cooled condenser is installed in HVAC for heating function for cabin. Fig.3 is a comparison of the AHP system in vehicle layout, and it shows the configuration of the actual system application. Depending on the location, the compressor may vary, but the overall refrigerant piping length is shorter and simpler configuration is possible.

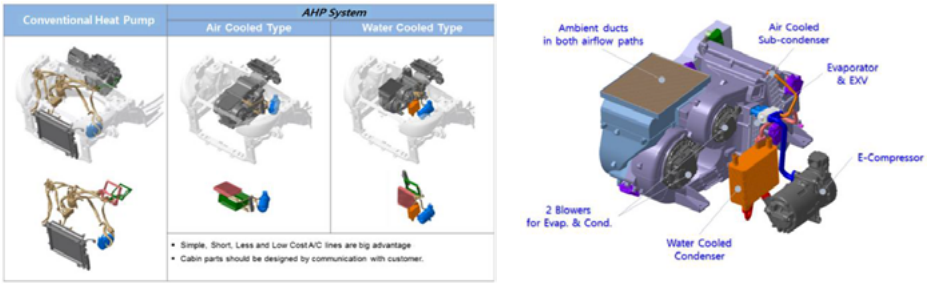


Fig. 3. AHP system construction and vehicle layout

3. Performance evaluation

3.1. Bench rig test

We did bench rig test with previously mentioned water-cooled type AHP prototype sample and evaluated it with conventional heat pump system's performance. The performance-related goals of this research were aimed at the same level of A/C performance and compressor power consumption compared to the conventional EV. The heating performance reached the same as conventional type (Cabin room average temperature 20 °C after 20minutes driving @ ambient -20°C) but the power consumption reduced as details shown in Table 1.

Table 1 Performance target of bench rig test

		Target (@-20°C Ambient)	Conventional system		AHP system
			PTC only	Heat Pump	
Average cabin room temp. (°C)		20	26.2	23.1	**Over 20**
Power consumption (kWh)	PTC heater	-	3.93	1.99	**Improve 20%**
	e-Compressor	-	0	1.07	
	Total	-	3.93	3.06	

Fig.4. shows the comparison of the test results from the bench performance evaluation at ambient temperature 45°C conditions in the cooling mode of the AHP and conventional heat pump systems. The initial

two simulated driving conditions, 50KPH and 100KPH vehicle speed, are judged to have similar cooling performance and COP. The third case, idle simulated conditions, relatively shows 15% higher cooling capacity and 30% better COP.

These evaluating results are the advantages of the system having a dual condensing, secondary air-cooled condenser of the water-cooled condenser with better sub-cool region due to characteristic configuration of AHP. In the other words, the AHP system configuration can have the advantage of being able to introduce the external air directly into the condenser not affecting heat pick-up in vehicle in-front located condenser.

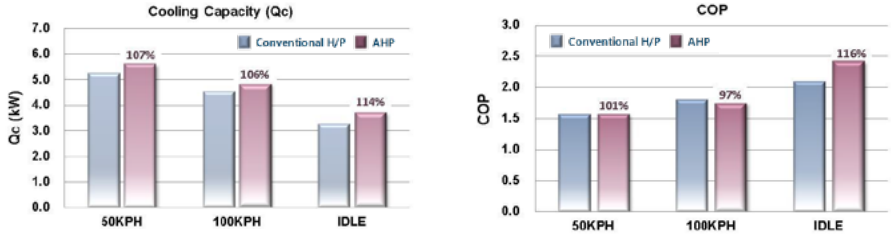


Fig. 4. Comparison of bench rig performance test

With regards to special design and construction of AHP system, this system can have the other advantage of a chance to get more heat recovery from cabin room exhausted waste heat. As is in conventional vehicle air conditioning system, there is some waste heat by extracting air process which can be recovered by recirculation to evaporator inside HVAC in heat pump mode as shown in Fig.7. The case a) conventional system already has partial recirculation logic for better heating performance, such as a certain portion of the air is recirculated to heater (or inside condenser) with fresh air from cabin outside and the remaining is extracted out to ambient. While in case of b) AHP system, some portion of extract air induced to evaporator located in HVAC and makes it possible to recover the waste heat so that refrigerant cycle works in low ambient temperature.

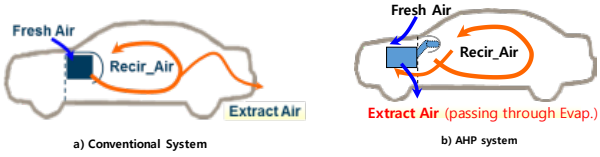


Fig. 5. Outdoor discharge air waste heat recovery in heating mode

Fig.6. shows the bench performance evaluation results of EHR (Exhaust air Heat Recovery) effect on AHP system compared to conventional heat pump system. Although conventional system has heat recovery from electric driving power system, EHR concept has better performance up to 32% and same level of COP. This effect would be more increased in low ambient temperature condition with increasing refrigerant flowrate in system.

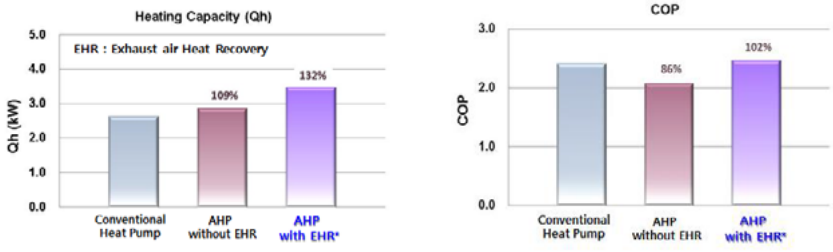


Fig. 6. Effect of EHR in bench rig heating performance test

3.2. Vehicle performance test in climate chamber

In previous section, we got the results of better performance level of AHP system in bench rig test to evaluate the effect of power consumption in real vehicle application. AHP concept sample was equipped to EV product and tested in climate chamber. Table 2. shows detailed test condition of cabin heating and cooling including performance target.

Table 2. Test condition and performance target of vehicle chamber test

	Test condition	Driving mode / Check time	Target performance ; (Cabin interior temperature)
Max cool-down	Ambient temperature : 45℃	50 KPH / 5 min.	Under 38 ℃
	Relative humidity : 40%	50 KPH / 30 min	25 ℃
	Sun load : 1,000 W/m^2	100 KPH / 60 min	22 ℃
	Vehicle full soaking	IDLE / 90min	29 ℃
Max heat-up	Ambient temperature : -20℃	50 KPH / 20 min.	Over 20 ℃
	No sun load	IDLE / 25 min	-
	Vehicle full soaking	100 KPH / 40 min	29 ℃

Fig.7. shows the results of the actual vehicle max cool-down test evaluation. In the case of AHP each temperature is satisfied with the target performance in the entire driving mode, 0.3℃ ~ 0.7℃ difference compared to the conventional system, and especially in the IDLE mode it has a dominant performance of more than 4℃. This can be seen as the advantages of the dual condensing system with water-cooled and auxiliary air-cooled condenser. Also we can consider IDLE performance is much better with less heat pick-up effect which is AHP system characteristics of no front-end located condenser. Despite this better A/C performance, its power consumption was confirmed to be 97% compared to conventional system.

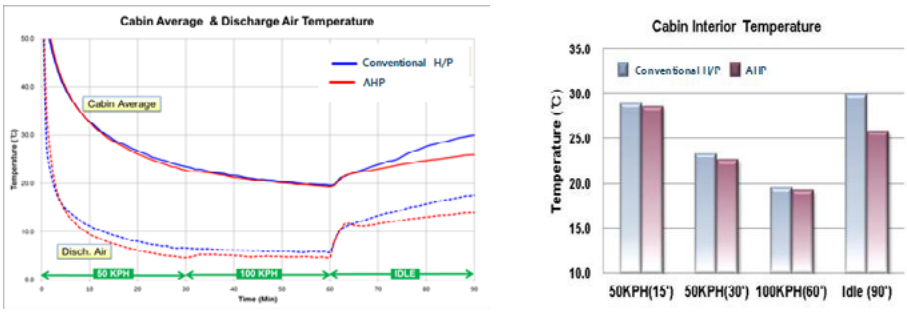


Fig. 7. Comparison of climate chamber vehicle cool-down test

As discussed, it is very serious issue that EV cabin heating requirement makes driving range decreased. For this reason, AHP system development is focused on heat pump efficiency and how to control the electric heater in initial driving mode. With EHR concept and optimized control logic of electric PTC heater operation, AHP system can get more efficiency with same cabin heating performance as shown in Fig. 8. The heating performance of AHP system meets target of average cabin temperature in driving modes and shows somewhat better discharge temperature compared to conventional H/P. In addition, the total power consumption of AHP is 2.39kWh for all the vehicle test modes which is 15% reduction from conventional H/P system power consumption of 2.8kWh. Those results can be achieved with EHR system's characteristic concept for more heat recovery that cause more refrigerant flow in low ambient temperature condition. And another contributor can be electric heater operation control that optimized usage portion in initial mode right-after vehicle start with soaking status. Fig 9. shows power consumption of e-compressor and electric heater (high voltage PTC heater) of different operation logics with regards to test time flow and driving modes.

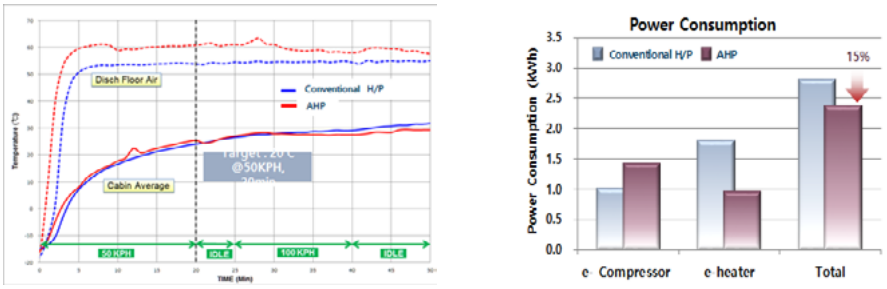


Fig. 8. Comparison of climate chamber vehicle heat-up test

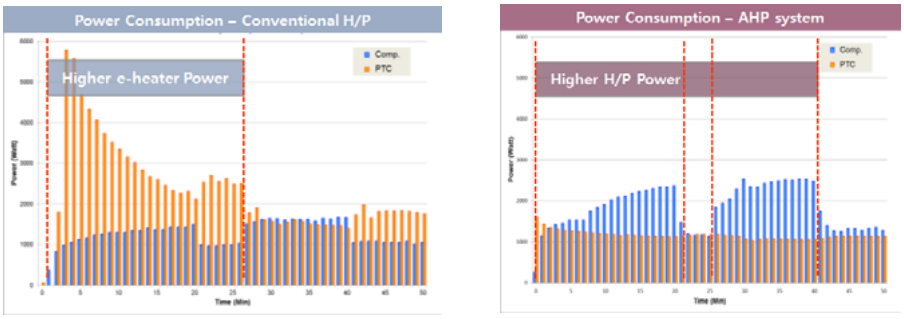


Fig. 9. Comparison of power consumption in vehicle heat-up test

3.3. Vehicle fleet test for driving range evaluation

The main target of this study is EV driving range extension effect with more efficient air conditioning system. With this purpose, we did vehicle fleet test with 3 type of air conditioning system; PTC heater only system, conventional heat pump system and AHP system. The fleet test was conducted at the same time with auto temperature setting for 3 different vehicles with each air condition system and driving range was evaluated with vehicle battery SOC measurement and power consumption calculation. Fig. 10 shows the fleet test course, ambient condition of early winter season and test vehicle status.

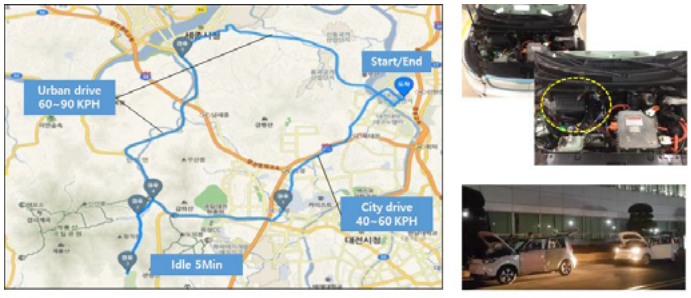
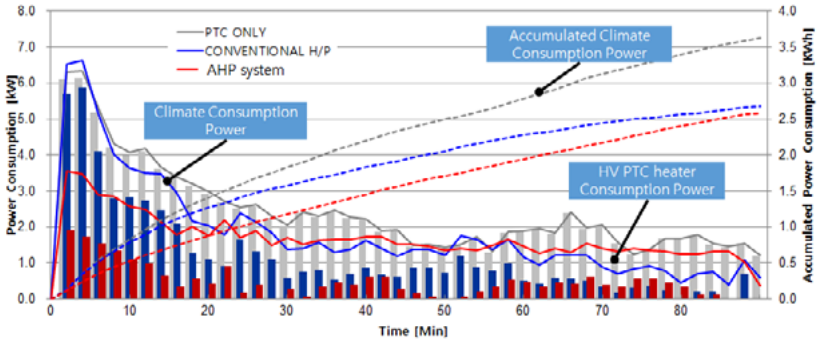


Fig. 10. Vehicle fleet test course and condition

We conducted vehicle power consumption and driving range calculation with real time battery SOC and air conditioning power measurement as shown in Fig. 11. The AHP system has 30.5% less power consumption and 27% driving range extension compared to PTC heater only system. When compared to conventional heat pump system, driving range extension effect is not much higher but this effect may become better in lower ambient condition test. Of course, cabin heating performance is at the same level in all type of vehicles but AHP system shows best performance.



Model	Accumulated Power Consumption			
	Comp.(kWh)	PTC (kWh)	Blower(kWh)	Total (kWh)
PTC ONLY	-	3.65	0.07	3.72
Conventional H/P	0.96	1.68	0.07	2.71 (-27.2%)
AHP system	1.67	0.75	0.17	2.59 (-30.5%)

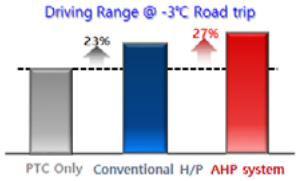


Fig. 11. Power consumption and driving range extension in vehicle fleet test

We may get more improvement in driving range extension after engine room thermal insulation, optimizing cabin room temperature control logic and fast-activated refrigerant cycle through EXV control improvement.

4. Conclusion

A new concept air conditioning system for electric vehicles is evaluated with air controlled heat pump system. In the bench rig, climate chamber vehicle and real road vehicle performance test, AHP system has better efficiency in cool-down and heat-up performance which can be a positive effect on driving range extension. Followings are the detailed conclusions.

- Through the bench rig and vehicle climate chamber test, AHP system cooling performance is better than the current heat pump system, particularly in idle performance.
- The heating performance in bench rig and vehicle test are almost same and efficiency is 3~15% higher, especially in lower ambient temperature condition. This higher efficiency of AHP system affect positively on driving range with the extension of 15~27% compared to electric heater only system.
- The improvement with more efficient component control logic and vehicle package study will be followed for future application in electric vehicle industry.

Acknowledgements

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