

Experimental study on performance characteristics of the inner condenser in air-sourced heat pump

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Abstract- In this study, experiment to analyze heating performance characteristics of the inner condenser with air heat source has been done with various operating conditions, which are likely to match the air-sourced heat pump system test conditions under cold ambient conditions, such as variation of compressor speed. As the ambient temperature was decreased from 5°C to -10°C, the heat capacity of the inner condenser decreased by 54% due to the reduction of the refrigerant flow rate with the decrease of the refrigerant density of 45%. The heating capacity of the inner condenser increased by 40% due to higher refrigerant mass flow rate with the increase of the compressor speed from 2,000 RPM to 3,500 RPM. However, the COP of heat pump system decreased by 26% due to the additional compressor power.

Keywords- Air-sourced heat pump, Battery electric vehicle, COP, Heating performance, Inner condenser

1. Introduction

Many automotive companies are developing green cars without an internal combustion engine, because international regulations on the use of fossil fuel resources have become strict with increases in global warming and glacier melting. Since conventional vehicles use fossil fuels for driving, many automotive makers are developing green cars that do not use fossil fuels to protect environment. Although the classifications of green cars have not been officially defined internationally, we generally classify electrically driven vehicles as electric vehicles, fuel cell electric vehicles and hybrid vehicles [1]. Among them, electric vehicles (EVs) including plug-in hybrid have been particularly developed to deal with environmental regulations [2]. Electric vehicles are eco-friendly and emit no air-pollutants, but their short driving range is a critical problem. The maximum driving range of recent-developed electric vehicles is approximately 200 km, but it decreases by about over 40% with the operation of the heating and cooling units [3-5]. Therefore, efficient heating and cooling units for the cabin should be developed to increase the driving range of electric vehicles. However, previous studies on heat pumps focused on internal combustion engines in the field of the vehicle and residential building. However, since heat pump system is deemed to be more appropriate for the electric vehicle lack of heating source, the application and sufficient heating performance of the heat pump for the vehicle is required to be developed [6, 7]. In this study, since one of the additional components

for the vehicle's heat pump is the inner condenser compared to residential heat pump system due to different operating conditions, such as dehumidifying with heating, inner condenser's performance characteristics were investigated under real driving conditions, such as ambient temperature and compressor rotational speed. The heating performance of the inner condenser and power consumption of the heat pump system was measured and COP was calculated to find out tested heat pump efficiency.

2. Experimental Setup

Fig. 1 presents a schematic diagram of the test setup. The experimental setup was composed of a scroll type electric compressor, an exterior heat exchanger, an inner condenser, an evaporator, electric air-heaters, an electric expansion valve (EEV), a temperature-controlled expansion valve (TXV), and an accumulator. The scroll electric compressor had a displacement volume of 34.0 cm³ rev⁻¹. The exterior was a parallel-flow type, louvered-fin brazed-aluminum heat exchanger of 21 mm in depth, 370 mm in height, and 400 mm in width. The inner condenser was a parallel-flow type, louvered-fin brazed-aluminum heat exchanger of 37 mm in depth, 156 mm in height, and 232 mm in width. The evaporator was a laminated aluminum heat exchanger of 58 mm in depth, 260 mm in height, and 250 mm in width. The rated capacity of electric air-heaters was 6.0 kW. The EEV, which were used as expansion devices, had an orifice diameter of 1.6 mm. The experimental setup was operated as follows. The condensed liquid refrigerant in the inner condenser flew into the exterior heat exchanger through electrical expansion valve. The refrigerant evaporated in the exterior heat exchanger enters the compressor. The indoor air is heated through the inner condenser.

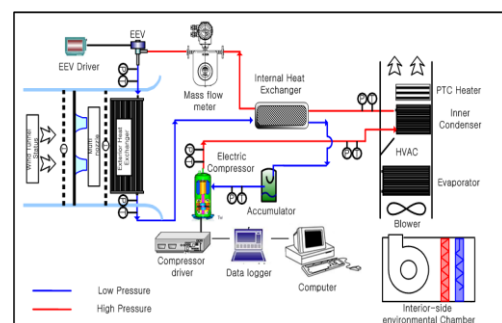


Fig. 1. Schematic diagram of the experimental setup of air-sourced mobile heat pump system

Table 1 shows the test conditions. The indoor air dry bulb temperature was varied at the range of -10~5°C and indoor air relative humidity was fixed at 50.0%. In the tested modes, the operating characteristics of the heat pump were measured by varying the exterior air temperature from -10°C to 5°C, the indoor air flow rate was fixed at 300 m³ min⁻¹.

Table 1. Test conditions

Components		Conditions
Compressor speed (rev/min)		2,000, 3,500
Inner condenser	Inlet air flow velocity (m ³ /min)	300
	Inlet air temperature (°C)	5, 0, -5, -10
Exterior heat exchanger	Inlet air flow rate (m/s)	1.2, 2.2
	Inlet air temperature (°C)	5, 0, -5, -10
	Relative humidity (%)	50%

The refrigerant-side heat transfer rate was calculated by the refrigerant enthalpy method (ASHRAE Standard 116, 1983) [8]. Equation (1) was used to calculate the refrigerant-side heat transfer rate. The air-side heat transfer rate was calculated by utilizing both the air flow rate and enthalpy difference, which were calculated by equation (2). Equation (2) was used to calculate the air-side heat transfer rate. Both results showed a good agreement within 5%. The heating COP (coefficient of performance) of the mobile air-source heat pump system was calculated by equation (3).

$$\dot{Q}_r = \dot{m}_r \Delta h_r \quad (1)$$

$$\dot{Q}_a = \dot{m}_a C_{p,a} (T_{a,i} - T_{a,o}) \quad (2)$$

$$COP = \frac{\dot{Q}_a}{W_{electricdrivencompressor}} \quad (3)$$

3. Results and Discussion

Fig. 2 shows the heating performance characteristics with the variation of ambient temperature. The heating performance analysis of the inner condenser was performed. As ambient temperature lowers, the refrigerant density on suction lowers and therefore the refrigerant flow rate is decreased. As a result, the inner condenser's heating capacity is decreased with ambient temperature. In case of the COP, the increment trend shown along decreasing ambient temperature because of the higher compressor work change. The refrigerant mass flow rate lowered due to the density change on compressor suction.

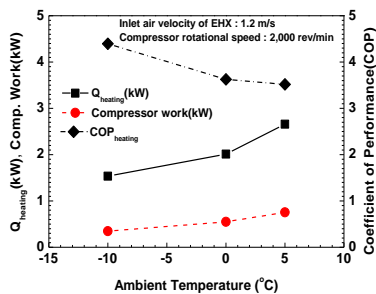


Fig. 2. Heating performance characteristics with the variation of ambient temperature

As shown in Fig. 3, the compressor suction pressure decreased with the decrease of the ambient temperature.

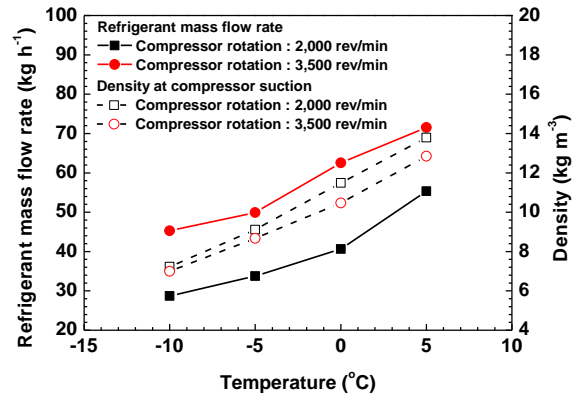


Fig. 3. Refrigerant mass flow rate characteristics

Also, the refrigerant density decreased by about 45.0% as the ambient temperature ranging from 5.0°C to -10°C and density change ranging from 45.0% to 48.0%. Fig. 4 shows the heating performance characteristics with the variations of compressor speed. As the compressor speed increased, the heating capacity increased by 67.0% and the compressor work increased by 133.0%. Therefore, the COP decreased by 29.0%. In addition, the heating capacity is required to have over 5.0kW to achieve the comfort level at ambient temperature -10°C under the given operating conditions such as the compressor rotational speed, the air inlet temperature for the exterior heat exchanger.

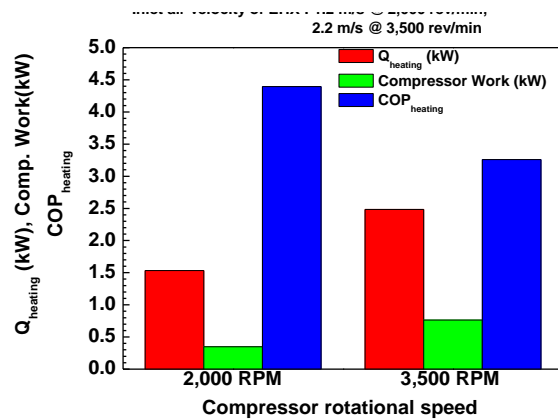


Fig. 4. Heating performance characteristics with the variations of compressor speed

4. Conclusions

This paper presented test results of the air-sourced heat pump system with the variation of operating conditions. The experimental devices to evaluate the heating performances of the proposed system was built. Experimental results showed that the heating capacity decreased due to the decreasing heat source with the inlet air temperature for exterior heat exchanger. And the heating capacity is decreased with the

decrease of the ambient temperature. In addition, the heating capacity characteristic was evaluated with the ambient compressor rotational speed and heat capacity to reach comfort level in this system was additionally required at the conditions of the compressor speed of 3,500 RPM and ambient temperature of -10 °C.

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