Experimental Study Combining Electric Powered Compressor in Automobile Air Conditioning System

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Abstract: Converting automobile air conditioning systems from internal combustion engine-based to electric-based vehicles is challenging due to different power sources and limited parts available in the market. The present study aimed to evaluate the performance of an electricity-driven compressor integrated into an automobile air conditioning system. This preliminary test was conducted experimentally on a lab scale testbed and has not been implemented in an actual automobile cabin. The ½ horsepower capacity of the electric compressor was used in the system along with the instrument to measure the system's performance (i.e., COP). The fan speed in the evaporator is variated to identify their impact on the system's performance.

1 INTRODUCTION

Due to the popularity of electric vehicles recently and global attention to environmentally friendly energy sources, converting internal combustion engine-based vehicles (ICEVs) to electric-based vehicles (EVs) is a promising option apart from manufacturing new electric vehicles. A successful story of converting ICEVs to EVs has been reported by several researchers (Pedrosa, 2014), (Kaleg, 2015), (Silva, 2019). However, previous studies of converting ICEVs to EVs have not dealt with the heating, ventilation, and air conditioning (HVAC) system. Whereas the HVAC system is one of the components that significantly underwent this change in this conversion process.

The compressor is the main component used in most automobile air conditioning (AAC) systems, and it takes the most significant percentage of total power consumption in AAC systems (i.e., 50-80%) (Westphalen, 2001). In the case of ICEVs compressors, the prime mover is coupled with the engine, which must turn on whenever the HVAC system is operated. The compressor speeds also depend on the engine speed, which may mismatch with cooling capacity demands. On the contrary, the compressor used in the HVAC system for EVs is independent due to an electricity-driven compressor (Zhang, 2018), so energy consumption can be managed efficiently.

Several concepts and strategies have been proposed and tested to produce more energy efficient in term of compressor in AAC system. Aurich (2018) has tested four different compressor: scroll compressor, rotary piston compressor, and double-rotary piston. The study summarize that scroll compressor has an overall very good performance with a good coefficient of performance as well as low pressure pulsation followed the rotary piston compressor, The double-rotary piston compressor, and the axial piston compressor. Baumgart (2015) has been suggested a new powertrain concept of compressor which equipped with electric motor dan mechanical coupling to the gearbox and the main motor. From the viewpoint of refrigerant, a low-

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Global Warming Potential refrigerants (i.e. R134a) has been tested in accordance with the compressor of AAC and it is proven to have better performance in saving the energy consumed compare to conventional one (Essa, 2021), (Wu, 2020). Lee (2013) found that cooling capacity increased with the increase of the compressor frequency in electric bus.

The performance of air conditioning using various refrigerants has been tabulated by several studies in a few last decades; among them is Kiatsiriroat (1997), who revealed that R22 has COP between 2.5 to 4.8.

In this study, an electricity-driven compressor is combined in conjunction with another part of vapor pressure HVAC system in conventional ICE-based vehicles. The tests were carried out experimentally in a laboratory scale. The performance of the systems is evaluated using several variations of speed and temperature on the condenser and evaporator sides.

2 METHODOLOGY

2.1 Experimental Setup

he experimental setup of testbed is basically a vapor pressure system that contain of compressor, condenser, expansion valve, and evaporator which can be found in Fig. 1. Three pressure gauge installed in the system, i.e., at line 1, 2, and 3 to identify low and high pressure in the system (rated from 0 – 16 kg/cm^2). Whereas the thermocouple and sight glass installed in line 1-4, and line 1-2 respectively.

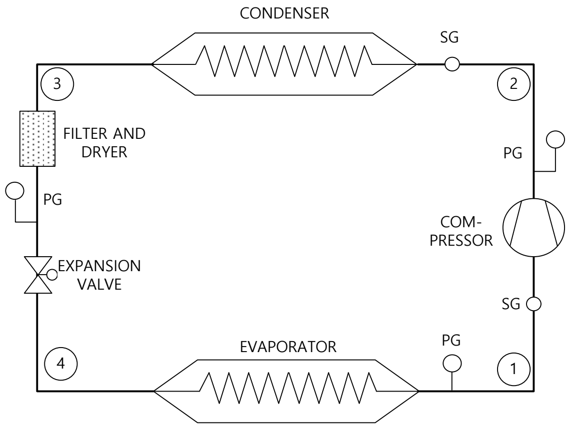

Figure 1: Schematic diagram of experimental setup.

We used a hematic compressor with a ½ horsepower rating capacity (340 watts) dismantled from a ½ HP split air conditioner manufactured by LG. The motor's input voltage is 220 V at 50Hz with no inverter mode. We apply R22 refrigerant to the system as recommended by the compressor manufacturer. The car condenser was installed in the testbed with nominal dimensions of 450 x 350 x 25,6 mm with a thermal capacity of 900 J/kg.K, according to the manufacturer (Pokka). The primary material is aluminium, with the inlet and outlet connection is ½" and 3/8" respectively. Induced draft axial fan installed on the condenser with a diameter of 30 cm and capacity of 0,178 m3/s, and 72-watt rating power (or 12 VDC and 6 A).

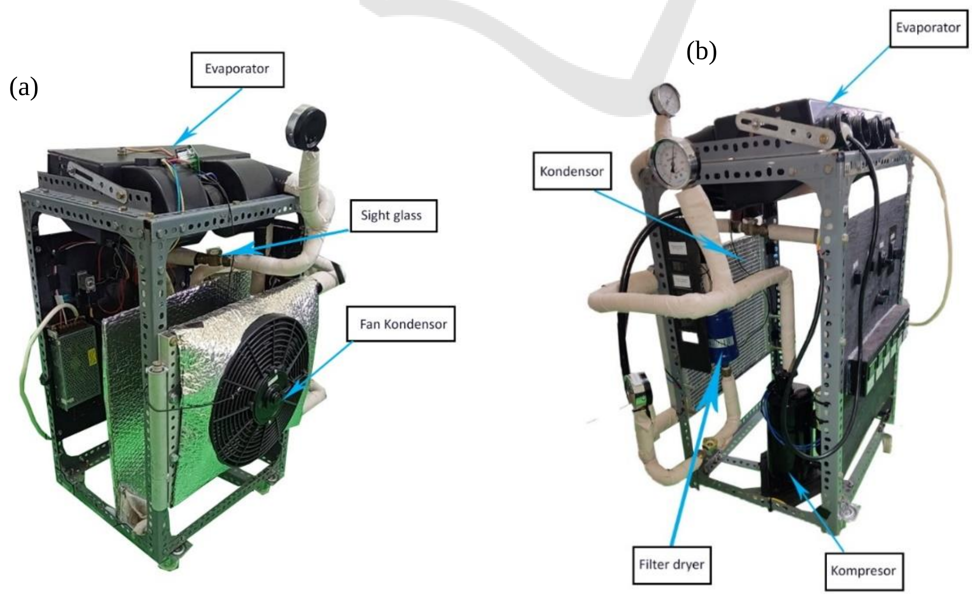

Figure 2: The experimental setup of testbed, (a) front view, (b) back view.

The evaporator installed in the system has a rated thermal capacity of 900 J/kg.K with ten coiled loops compacted in a 400 x 165 x 135 mm plastic enclosure. The fin and the coil are aluminium-based materials with inlet and outlet connector is 3/8 inch and ½ inch, respectively. This evaporator is equipped with two embedded radial fans at the capacity of 72 Watt. The thermal expansion valve is installed in the system. Finally, we installed the power meter to measure the compressor's power. The complete package of an experimental setup can be seen in Fig. 2.

2.2 Testing Schemes

Three variations of air flow rate out from the evaporator are controlled by the fan speed. We measure the velocity and air flow rate using an airflow meter at the evaporator grill. The set of velocity (v) and airflow rate (q) variations can be seen in Table 1.

Table 1: Variation of air flow rate out from the evaporator.

Test number	v (m/s)	q (Lps)
1	2.0	15.7
2	3.0	23.6
3	4.0	31.4

The ambiance temperature during the test is between 28-31°C. The performance of the system is calculated using the coefficient of performance (COP), as shown in the following equation:

$$COP = \frac{Q_c}{W_c},$$

where Q_c is the heat absorbed in the evaporator and W_c is work done by the compressor. The heat absorbed in the evaporator is the different of enthalpy of refrigerant entering (h_4) and leaving (h_1) the evaporator as formulated below:

$$Q_c = h_1 - h_4.$$

Meanwhile, the work of the compressor is the difference between of enthalpy of refrigerant entering (h_4) and leaving (h_1) the compressor as formulated below:

$$W_c = h_2 - h_1.$$

3 RESULT AND DISCUSSION

We have measured the air temperature from the outlet grill evaporator of various airflow rates as shown in Fig. 3. The error bar shows the lowest and highest air temperature measured within nine samples. Those measured air temperatures are acceptable compared to the air temperature from most of the exit grill of an automobile air conditioning system (i.e., 15-18°C).

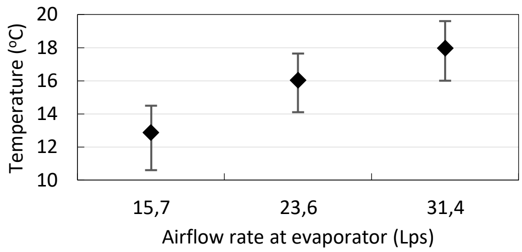

Figure 3: Temperature at outlet grill of evaporator.

Figure 4 shows the plot P-h diagram of the measured pressure and temperature of the present system. A slight difference in the enthalpy of work done by the compressor can be found compared to the heat absorbed by the evaporator.

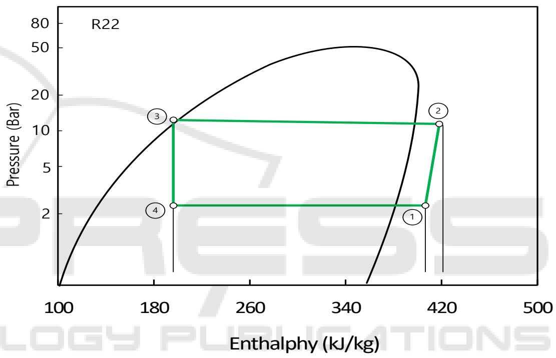

Figure 4: P-h diagram of the system.

The effect of various airflow rates in the evaporator against the refrigerant temperature can be seen in Table 2. From the table, it shows that the temperature difference of refrigerant entering and leaving the evaporator ($\Delta T_{1\text{-}4}$) has about similar value at various fan speed. It means that the air flow rate in the evaporator does not affect much on the refrigerant temperature.

Table 2: The temperature of refrigerant as an effect of various fan speed in evaporator.

v (m/s)	Refrigerant temperature (°C)				
	T_1	T_2	T_3	T_4	$\Delta T_{1\text{-}4}$
2.0	26.5	58.5	33.4	-2.4	28.9
3.0	28.3	59.1	34.0	-0.7	29.0
4.0	29.0	56.6	34.0	0.4	28.6

The effect of refrigeration (Qc) and work done by the compressor (Wc) of various evaporator fan speeds can be seen in Fig. 5. The enthalpy of Qc and Wc in the system is calculated from the P-h diagram shows about similar when the fan speed is increased. The power consumed by the compressor also does not significantly affect due to the fan speed. The average power consumption by the compressor is 228,1 ±1,16 watts.

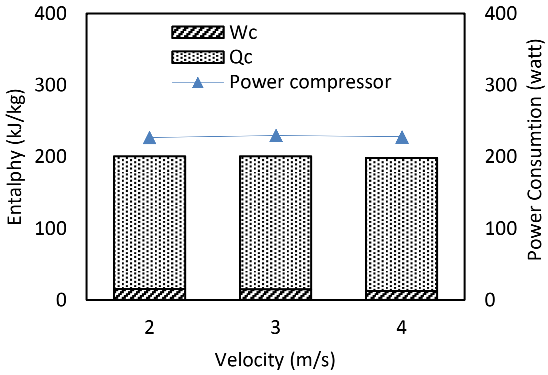

Figure 5: The effect of refrigeration and work done by the compressor of various evaporator fan speeds.

The performance of the system is measured by COP which can be seen in Fig. 6. The figure shows the COP even much greater than 4 where most of air conditioners in automobile with R22 refrigerant has.

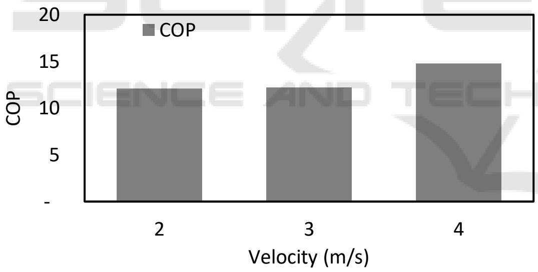

Figure 6: The COP of three variation fan speed.

4 CONCLUSIONS

Combining electric powered compressor in automobile air conditioning system has been successfully implemented. The air temperature leaving the evaporator unit has an acceptable range proportional to their volume flow. It also found that the COP of the system does not significantly influence by the fan speed of the evaporator.

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REFERENCES

Aurich, J., Baumgart, R., (2018). *Comparison and evaluation of different A/C compressor concepts for electric vehicles, International Compressor Engineering Compressor, Perdue e-Pubs.*

Baumgart, R., Aurich, J., Ackermann, J., Danzer, C., (2015). *Comparison and evaluation of a new innovative drive concept for the air conditioning compressor of electric vehicles, Symposium on International Automotive Technology. SAE International.*

Essa, D., Spickler, B., Depcik, C., Shiflett, M.B., (2021). *Air conditioning cycle simulations using a ultrahigh-speed centrifugal compressor for electric vehicle applications, International Journal of Refrigeration*, Vol. 131, 803-816.

Kaleg, S., Hapid, A., Kurnia, M.R., (2015). *Electric vehicle conversion based on distance, speed and cost requirements, Energy Procedia*, Vol. 68, 446 – 454.

Kiatsiriroat, T., Euakitt, T., (1997). *Performance analyses of an automobile air-conditioning system with R22/R124/R152A refrigerant, Applied Themal Engineering*, Vol. 17, (I) 1, pp. 1085-1097.

Lee, D.Y., Cho, C.W., Won, J.P., Park, Y.C., Lee, M.Y., (2013). *Performance characteristics of mobile heat pump for a large passenger electric vehicle, Applied Thermal Engineering*, Vol. 50 (1), 660-669.

Pedrosa, D., Monteiro, V., Gonçalves, H., Martins, J.S., Afonso, J.L., (2014). *A Case Study on the Conversion of an Internal Combustion Engine Vehicle into an Electric Vehicle, IEEE Vehicle Power, and Propulsion Conference*, 1-5.

Silva, J.E., Junior, J.U., (2019). Converting a conventional vehicle into an electric vehicle (EV), Brazilian Archives of Biology and Technology. Vol. 62.

Westphalen, D., Koszalinski S., (2001)., *Energy Consumption Characteristics of Commercial Building HVAC Systems*, Vol. 1, U.S. Department of Energy.

Wu, J., Zhou, G., Wang, M., (2020). *A comprehensive assessment of refrigerants for cabin heating and cooling on electric vehicles, Applied Thermal Engineering*, Vol.174, 115258.

Zhang, Z. Wang, J., Feng, X., Chang, L., Chen, Y., Wang, X., (2018). *The solutions to electric vehicle air conditioning systems: A review, Renewable and Sustainable Energy Reviews*, Vol. 91, 443–463.