Experimental Investigation of Innovative Thermal Mechanical Refrigeration System

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Abstract

The current electrical refrigeration and air condition systems are considered as one of the major sources for ozone depletion and global warming problems. Furthermore, the consume a large percent of the worldwide gross production of electricity (around 17%). Therefore, developing new refrigeration systems that able to work using renewable sources (solar, geothermal, etc) and or waste heat sources is necessary to address these problems. In this poster, the experimental investigation of an innovative thermal-mechanical refrigeration (TMR) system is presented. The TMR system replaces the electric compressor of the conventional refrigeration systems with an innovative expander-compressor unit (two connected double-acting cylinders). The proposed ECU can be driven by ultra-low heat temperature sources, has simple configuration, and high flexibility for the operating conditions. A hybrid electric-compressor and ECU refrigeration setup was developed to investigate the performance of the ECU and compare it to that of an electric compressor. The experiment was conducted using R134a as a working fluid at different masses. The results shows that a maximum COP of 0.57 is obtained at refrigerant mass of 30g (in electric mode) and a maximum COP of 0.41 and is obtained at refrigerant mass of 60g (in ECU mode).

Introduction

- Traditional refrigeration systems use HFO/HFC refrigerant blends which have negative impacts on environment such as ozone depletion and global warming [1-4,12-13].
- Furthermore, refrigeration and air-conditioning systems consume around 17% of the world-wide electricity [5].
- Therefore, developing new refrigeration systems that work by sustainable energy sources and use eco-friendly refrigerant are urgent need to address these issues [14-16].
- Recently, refrigeration systems that use thermal energy as a power source (such as absorption and ejector-based systems) have gained much interest by researchers in the field.
- However, most of the proposed thermal refrigerating systems have complex configurations, low COP at low temperature source, and comparatively high capital costs [6-8].
- Recently, Sleiti et al. [9] have proposed a new thermal mechanical refrigeration (TMR) system that efficiently works with ultra-low temperature source (as low as 70 °C) with efficiency higher than 9%.
- Thus, the proposed TMR system can efficiently works by versatile sources of energy such as solar, geothermal, and waste heat sources. Also, the proposed TMR system use eco-friendly refrigerant with zero ozone depletion potential [10].
- Moreover, the new TMR system has simple configuration and competitive capital cost compared to the conventional refrigeration systems [11].
- This poster describes the proposed TMR system, and the results obtained by experimental testing for a hybrid electric-TMR setup which is built by the authors in Qatar University.

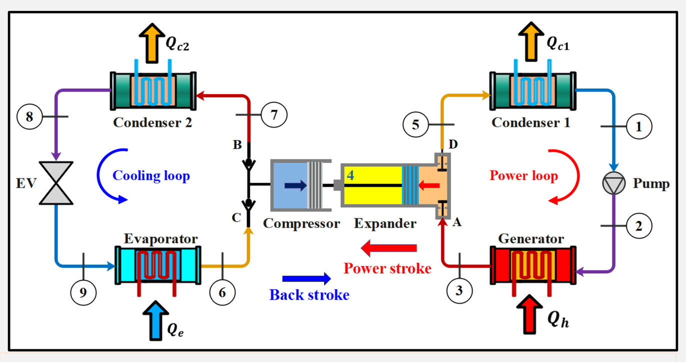


Figure 1. The configuration of the thermo-mechanical refrigeration system.

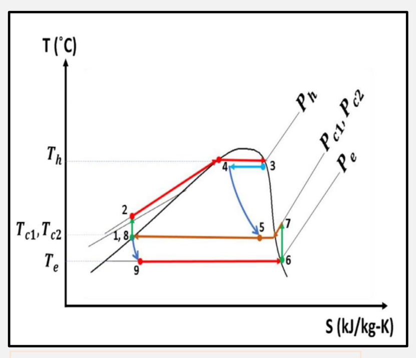
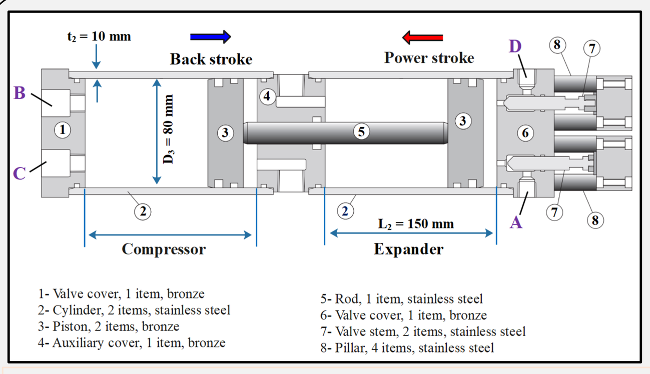


Figure 2. T-S diagram of the TMR system.



- $COP_{elect.} = \frac{Q_{ev}}{\dot{W}_{comp}}$ (1)
- $COP_{ECU} = \frac{Q_{ev}}{\dot{W}_{exp}}$ (2)

Q_{ev} is the cooling load, $\dot{W}_{comp}$ is the input power of the electric compressor, $\dot{W}_{exp}$ is the power produced by the expander of the ECU.

Figure 3. Design of the ECU with performance indicator of the hybrid electric-ECU refrigeration system.

Description

- The proposed TMR system composed of integrated power and cooling loops as shown in Figure 1.
- Instead of electric compressor, the TMR system use an innovative expander-compressor unit (ECU) to compress the refrigerant of the cooling loop to the condenser pressure (states 6-7 in Figure 2).
- The ECU consists of double acting pistons with internal diameter of 80mm and stroke length of 150mm for each piston as presented in Figure 3.
- To test the performance of the ECU and compared it to that of an electric compressor, a hybrid electric-pneumatic-mechanical (HEPM) setup is built as shown in Figure 4 and Figure 5.
- The HEPM setup exactly simulate the working mechanism of the theoretical TMR system shown in Figure 1.
- The power loop is replaced with high-pressure cylinder in the HEPM setup to provide the required pressure to drive the expander of the ECU.

Experiment setup

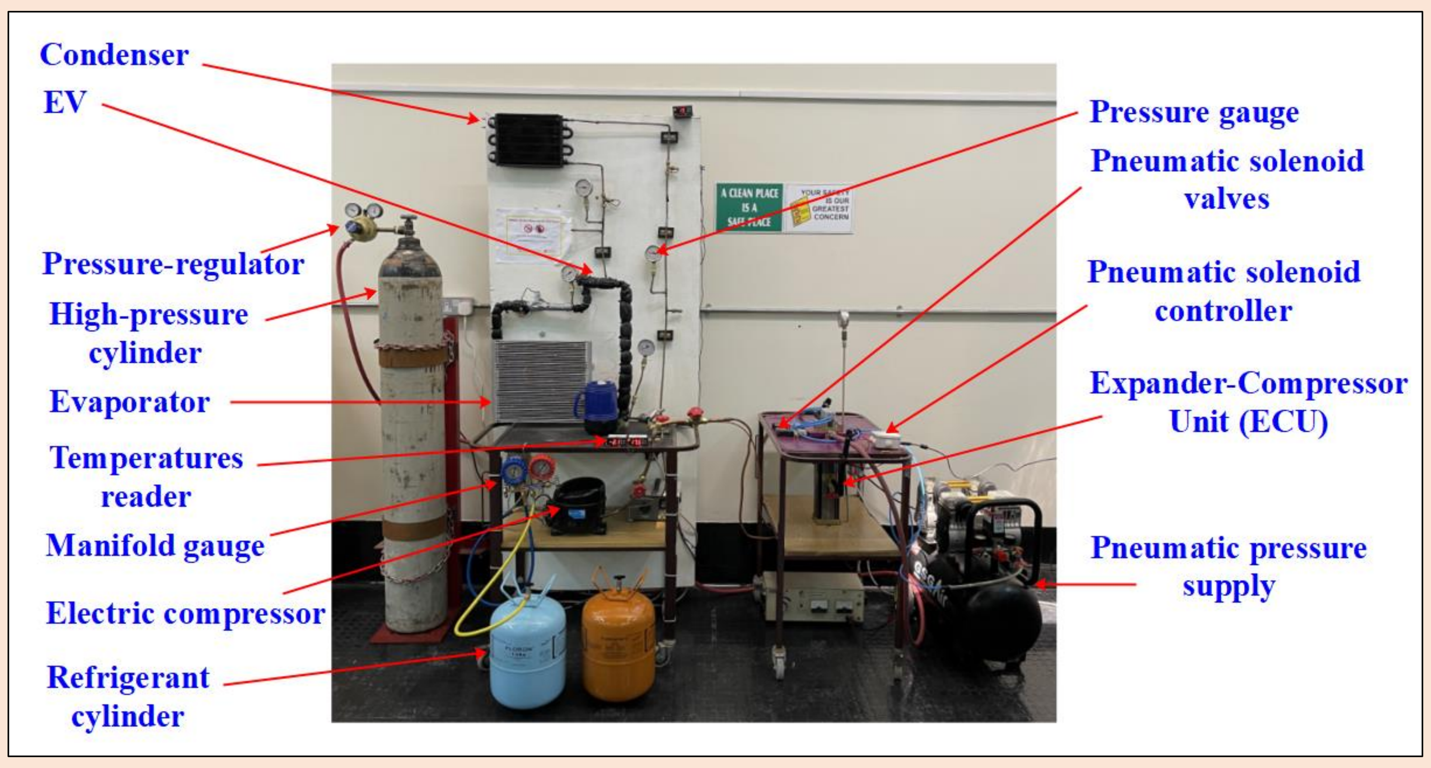


Figure 4. View of the actual setup in the research lab.

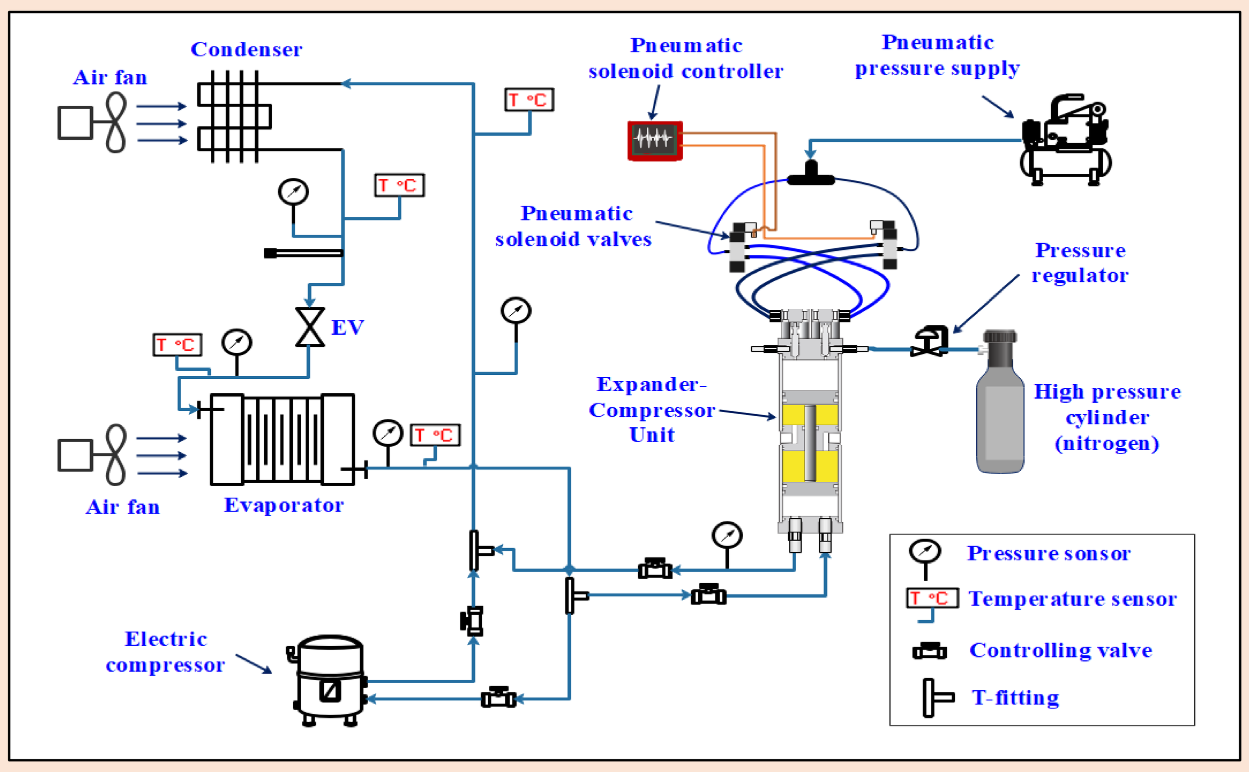


Figure 5. Schematic diagram of the hybrid electric and ECU experimental setup.

Results and discussion

- Figure 6 shows the testing procedures which are applied to test and measure the performance of the refrigeration system in both electric-compressor and ECU operational modes.
- The experiment was carried out using R134a as a refrigerant at different mass in each test with high-pressure of 90psi being supplied to the ECU at ambient temperature of 18°C.
- The measured experimental results were validated by comparing them against the theoretical simulated results as shown in Figure 7 (a) and (b) for electric and ECU, respectively.
- In electric-compressor mode, the error of the measured values compared to the theoretical values ranges from 0.73% to 1.85% while in ECU mode range from 4.50% to 4.80% which is acceptable since the theoretical model neglects the pressure drops across the setup components.
- Figure 9 and Figure 10 show the calculated COP and Q_{ev} of the electric-compressor mode and ECU mode, respectively, under the real measured temperatures and pressures at the terminals of the condenser and evaporator of the cooling loop. Figure 8 compares the electric-compressor and ECU modes under the conditions shown figures 9 and 10 (b and c).
- In electric-compressor mode, a maximum COP of 0.57 and Q_{ev} of 0.68 kW are obtained at refrigerant mass of 30g. While in ECU mode, a maximum COP of 0.41 and Q_{ev} of 0.26 kW are obtained at refrigerant mass of 60g.
- The maximum COP and Q_{ev} of the electric-compressor mode are higher than of the ECU mode by 1.39 and 2.61 times, respectively. However, the frequency of the ECU is only 18rpm which is ultra-low frequency compared to that of the electric compressor (>2000 rpm).

Testing procedures

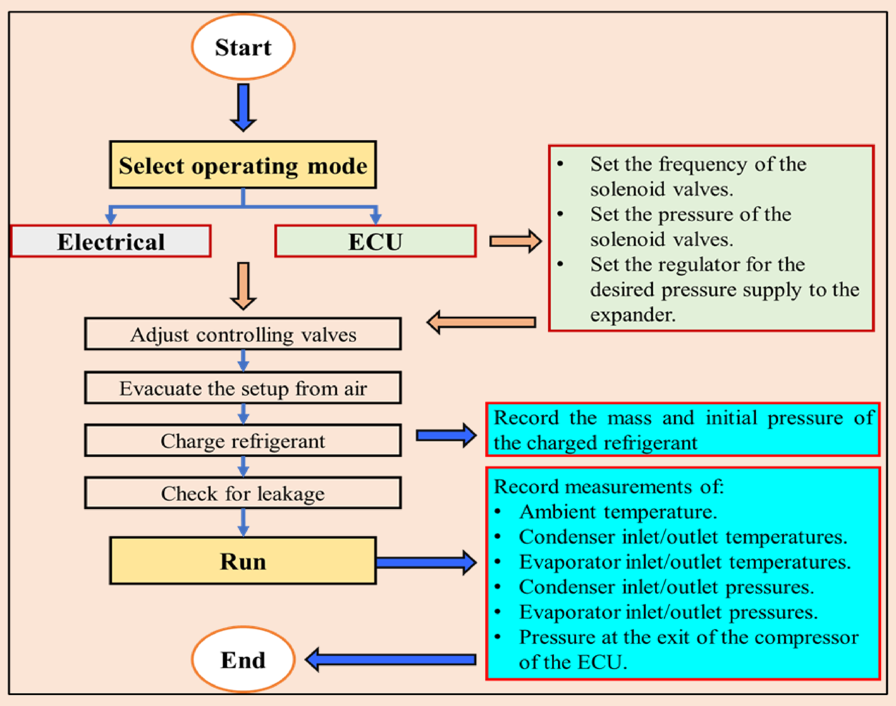


Figure 6. Testing procedures of the hybrid ECU and electrical setup.

Validation

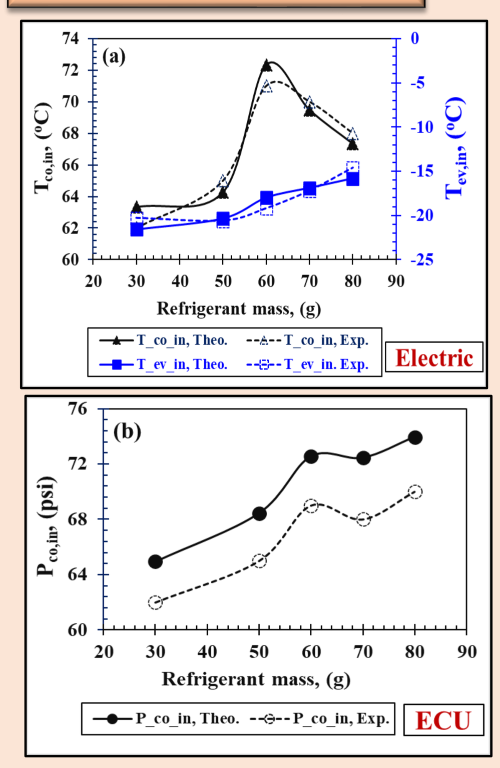


Figure 7. Validation of (a) electric, and (b) ECU operational modes.

Comparison

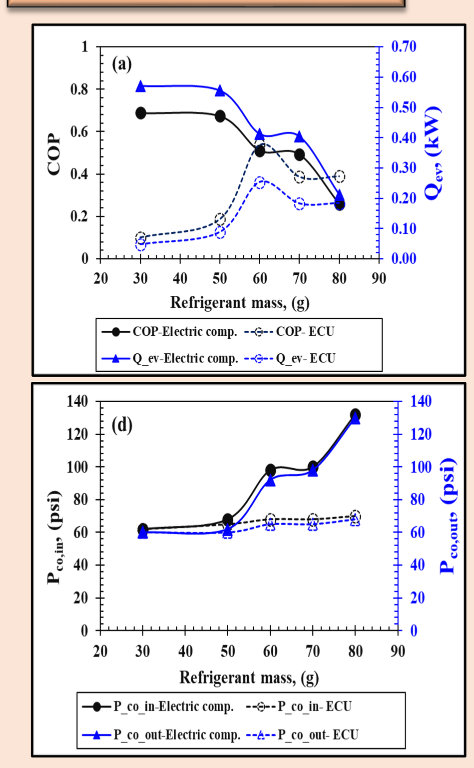


Figure 8. Comparison between the electrical and ECU operational modes.

Results of electric operational mode

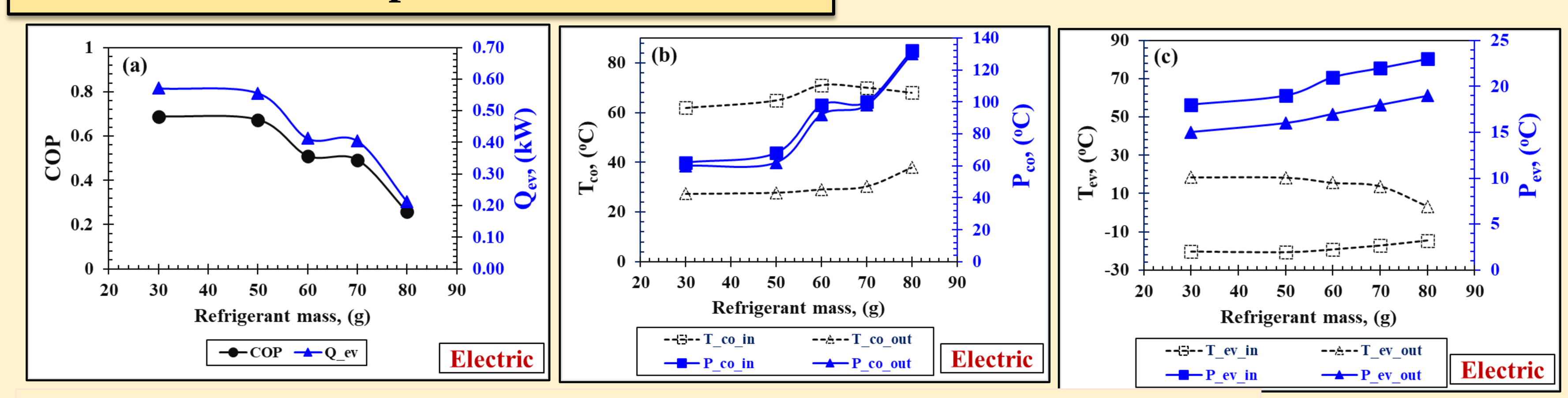


Figure 9. Experimental results of the electric operational mode.

Results of ECU operational mode

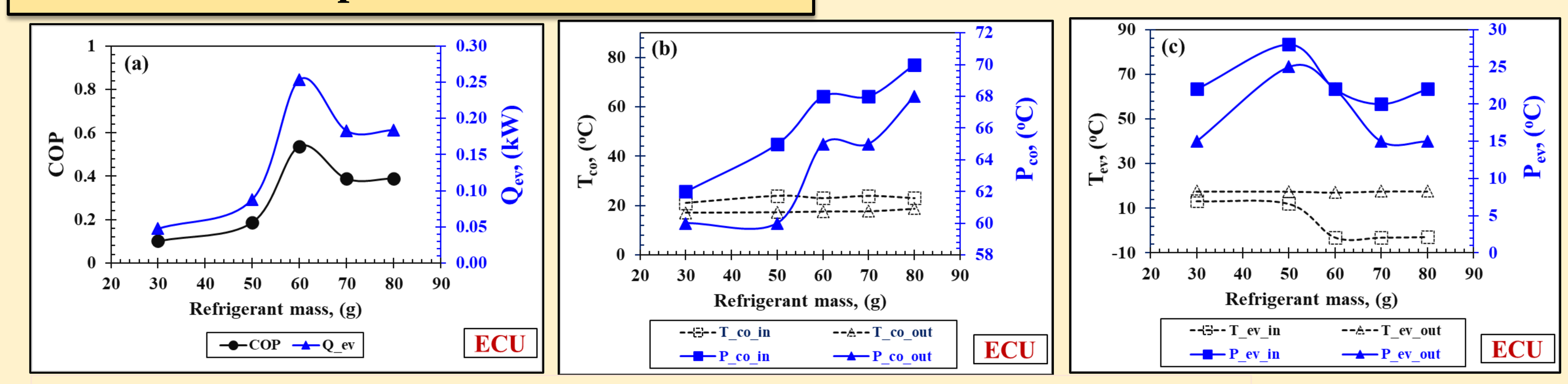


Figure 10. Experimental results of the ECU operational mode.

Conclusions

- An innovative TMR that works with ultra-low temperature sources (as low as 70 oC) using refrigerants with zero ozone depletion potential was introduced.
- A hybrid electric-pneumatic-mechanical (HEPM) refrigeration setup was built to experimentally testing and investigating the proposed TMR system and compared it to conventional electrical refrigeration system.
- The experiment was performed using an ECU with diameter of 80mm and stroke length of 150mm for each piston., R134a as a refrigerant, supply pressure of 90psi, ECU frequency of 18rpm, and QD Series R134a Refrigeration Compressor (220V/50Hz).
- The results show that the COP and Q_{ev} of the electric-compressor mode is 1.39 and 2.61 times higher than of the ECU mode.
- As a future work, to enhance the performance of the ECU compared to the electric operational, higher frequency must be applied, and the refrigerant should be changed to that works efficiently with the ECU such as (R1234yf).

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