Impact of the electric compressor for automotive air conditioning system on fuel consumption and performance analysis

A A Zulkifli¹, A A Dahlan¹, A H Zulkifli¹, H Nasution², A A Aziz¹, M R M. Perang¹, H. M. Jamil¹ and M N Misseri¹
¹Automotive Development Centre, Universiti Teknologi Malaysia, Skudai, 81310 Johor Bahru, Johor, Malaysia
²Department of Mechanical Engineering, Faculty of Industrial Technology, Universitas Bung Hatta, Padang 25132, Sumatera Barat, Indonesia

Email: henry@fkm.utm.my

Abstract. Air conditioning system is the biggest auxiliary load in a vehicle where the compressor consumed the largest. Problem with conventional compressor is the cooling capacity cannot be control directly to fulfill the demand of thermal load inside vehicle cabin. This study is conducted experimentally to analyze the difference of fuel usage and air conditioning performance between conventional compressor and electric compressor of the air conditioning system in automobile. The electric compressor is powered by the car battery in non-electric vehicle which the alternator will recharge the battery. The car is setup on a roller dynamometer and the vehicle speed is varied at 0, 30, 60, 90 and 110 km/h at cabin temperature of 25°C and internal heat load of 100 and 400 Watt. The results shows electric compressor has better fuel consumption and coefficient of performance compared to the conventional compressor.

1. Introduction
The belt-driven compressor is the mechanical type of the compressor and this is a concept of the conventional air conditioning (AC) system in automobile. The compressor is connected to the engine crankshaft through belting system. The compressor works by using the energy from the engine. Therefore workload is applied to the engine due to the use of this type of compressor in AC system [1-13]. This might reduce the performance of the engine. To overcome such problem, changing the power source for the AC system to the electrically driven will greatly benefit in reducing the fuel consumption and also increases the performance of the engine [1, 2, 5-8].

Fuel consumption of a vehicle can be affected by up to 20% for AC system [1]. This number can be reduced by lowering the energy consumed by the compressor. This study proposed to retrofit an electric compressor to the current conventional AC system in conventional vehicle.

This system is proposed so that the compressor speed is independent to the engine crankshaft speed, thus better energy efficiency and temperature control inside vehicle cabin [2]. The electric compressor is powered by direct current (dc) so that it does not need a power inverter that alternate current compressor would require. Electric compressor is easy to maintain and install to a compact system and offers low energy consumption [2]. Previous study of such as the compressor that creates a mobile heating, ventilation and air conditioning (HVAC) system for operation with the engine off. It is a solution to disable idle stop to reduce fuel consumption by temporarily switching off the engine into
a sleep mode when the vehicle is at a stop [4]. Another study developed small, lightweight and high-efficiency electric compressors. The performance of the dc compressor for automobile AC system shows that the electric compressor gives better performance than that the conventional compressors despite the cabin temperature distribution and cooling effect are a letdown by the dc compressor [6]. Guyonvarch et al. [8] carried out fuel consumption for conventional and electrically driven AC compressor. However, the comparison is only possible to a limited extent. This is due to the AC system was not specifically designed for the 12V onboard voltage system from the conventional system. The research studied 42V electric AC system for low emission, architecture, comfort and safety of the next-generation vehicles.

The objective of this paper is to investigate the coefficient of performance (COP), cabin temperature fuel usage of electric compressor retrofitted into conventional vehicle air conditioning system. The results are compared to belt-driven compressor.

2. Experimental Set Up

Experimental approach is used for this study. A compact hatchback vehicle with 1.3 liter gasoline engine is retrofitted with the electric compressor. The electric compressor is powered by the car battery which is charged by the alternator. Variable parameters are shown in table 1 and the schematic diagram for electric compressor is shown in figure 1.

![Figure 1. Schematic diagram for electric compressor vehicle air conditioning system.](image)

| Parameter                  | Range of variation |
|----------------------------|--------------------|
| Engine speed (km/h)        | 0, 30, 60, 90, 110 |
| Internal Load (Watt)       | 100, 400           |

The temperature, pressure and mass flow rate of the system is taken at the points shown in figure 1. The temperature is taken using thermocouples connected to the temperature data logger. The pressure and mass flow rate of the air conditioning system is taken manually using pressure gauge and flow meter, respectively.

The vehicle is setup on roller dynamometer to emulate the flat road condition. The internal heat load is to represent the heat coming from passengers inside vehicle cabin which is one passenger emits 100 W of heat. The refrigerant used is HFC-R134a. Figure 2 shows the vehicle on the roller dynamometer and the air conditioning control setting.
The electric compressor is working at maximum speed 2500 rpm. The control system for both electric compressor and conventional compressor is on/off controller placed in the evaporator. All tests are started at 30°C. Fuel flow meter is used to measure the usage of fuel through the one hour test period.

3. Mathematical Modelling
An efficient AC system is the one that manage to remove heat greatly with less energy needed. The performance of AC system can be expressed in term of coefficient of performance, COP. In term of the refrigerating effect, $Q_e$ and work input, $W_{net,in}$, the COP can be expressed as:

$$\text{COP} = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_e}{W_{net,in}} = \frac{h_1 - h_4}{h_2 - h_1}$$

(1)

where $h_1$, $h_2$ (kJ/kg) are the enthalpy at the compressor inlet and outlet respectively, $h_4$ (kJ/kg) is the enthalpy at the evaporator inlet.

The formula used to find the percentage of fuel consumption reduction is:

$$\% \text{ Fuel Consumption Reduction} = \frac{\text{Fuel}_{DC} - \text{Fuel}_{Conventional}}{\text{Fuel}_{Conventional}} \times 100$$

(2)

4. Results and Discussion
Figure 3 (a) and (b) show the fuel consumption against vehicle speed of conventional compressor and electric compressor. The electric compressor consumes less fuel compared to conventional compressor up to 18%. This is because there is fewer loads to the vehicle come from the compressor and better energy efficiency. Increase internal heat load would cause fuel increment to both of the system.
Figure 3. Fuel consumption against vehicle speed; (a) 100 W internal heat load and (b) 400 W internal heat load.

Figure 4 (a) and (b) show the temperature responses against vehicle speed. The temperature of electric compressor is always at the temperature setting nevertheless the vehicle speed. This is because the electric compressor is independent from the engine speed. Conventional compressor on the other hand is dependent to the vehicle speed causing the compressor to work at higher speed and hence, the temperature cannot be controlled efficiently. This causes waste of energy and hence higher energy consumption.

Figure 5 (a) and (b) show the COP of the systems against vehicle speed. Electric compressor shows better COP because of less energy needed to compress the refrigerant of the system. The COP for 400 W of internal heat is higher compared to 100 W. COP for conventional compressor decreasing as the vehicle speed increasing because the compressor consumes higher energy as the compressor speed also increasing.
5. Conclusions
This research presents the cabin temperature responses by the electrically driven compressor is more accurate to the temperature set point even though the belt-driven compressor temperature distribution is lower. The compressor performance of electrically driven compressor is higher than the belt-driven compressor about 15 to 54%. The experiment shown that the fuel reduction percentage by the electrically driven compressor to the belt-driven compressor about 5 to 14%.

We can conclude that using the direct current compressor has high possibility in reducing the load of engine system and will result in the higher coefficient of performance and lowering the fuel consumption. This can help in fuel saving of the vehicle.

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