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DEVELOPMENT AND EVALUATION OF AN AUTOMOTIVE AIR-CONDITIONING TEST RIG

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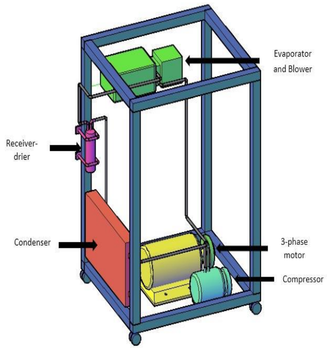
Graphical abstract



Abstract

To evaluate an air-conditioning system performance on board of a car is quite cumbersome and tedious process due to the limitation of space in the engine compartment. This paper presents the process of designing and the result from the automotive refrigeration system simulation that have been integrated into the test rig. To perform the test on automotive refrigeration simulator the location for the temperature measurement selected and thermocouples were installed. The locations of the temperature probes are at the inlet and outlet of compressor, condenser outlet and the inlet of the evaporator. The gas pressure was measured at low and high pressure sides located at evaporator outlet and receiver-drier respectively. The test results were analyzed using the properties table of the refrigerant used. The coefficient of performance (COP), cooling load of the system and compressor power consumption were determined. The variable parameters used are the evaporator blower speed and the air velocity passes through the condenser. The experimental results obtained show that increasing the blower speed will reduce the COP of the refrigeration system. The maximum COP of the system is 4.3 at the lowest evaporator blower speed. The power consumption will be reduced when the air flow velocity through the condenser is varied from 0 to 70 km/hr respectively.

Keywords: Automotive refrigeration, test rig, variable evaporator blower speed

1.0 INTRODUCTION

Automotive air conditioning is a cooling system that is widely use in modern car today. The cooling system is not intended for the engine but to impart cooling effect to the occupants inside the vehicle in the hot weather. According to ASHRAE [1], the air conditioning is a mechanical process for simultaneous control of temperature, humidity, and air motion. Automotive air conditioning system is a looping process of heat transfer which is consist the process of evaporation and condensation. During the evaporation the refrigerant absorbing heat and changing from liquid to vapour meanwhile for the condensation the process is vice versa [2]. There are many ways to do the study on the automotive refrigeration system which is through the experimental and the computer simulation software [3]. For the experimental, the performance test can be done through the real car experiment and through the test rig experiment. The test rig is a rig which the automotive air conditioning system are installed outside from the vehicle itself. This method is developed due to the small space from the real car air conditioning system thus it help and easy to do the experiment. The automotive refrigeration test rig usually consist basic air conditioning from the vehicle like compressor, condenser, evaporator, and motor that belt driven the compressor. Since most of the automotive refrigeration test rig use motor, therefore the electrical energy consumption is used instead of the fuel.

The experimental and analysis of automotive air conditioning system is complicated than the stationary air conditioning because the different condition that affect the air conditioning system performance. As for the automotive air conditioning system, the vehicle speed directly affecting the compressor rotating speed when the vehicle moving. The velocity, volume, temperature and the direction of air flow from the air conditioning panel or evaporator should be adjustable due to the driving and climatic condition. Besides, the vehicle received more sun load pass through the windshield and window compared to the load that passes through the building. Therefore, the air conditioning system in a vehicle should able to cooling down the cabin temperature quickly and quiet during operating [4, 5].

To evaluating the performance an automotive refrigeration system, an off board bench have been develop. The two major variables that have been investigated to perform the testing is the variable speed of compressor and the speed of evaporator fan. The correlation of the compressor and the COP of the system have been developed. Typically the COP are affected by both variable meanwhile the refrigerant flow rate influence mainly by the compressor speed [6].

From Rat and Brown (2000), they have analysed the automotive refrigeration performance, COP using the experimental method. Their experimental analysis was focusing on the relationship COP of the cycle, compressor rotation speed and also vehicle speed. Besides experimenting with the compressor rotation speed variables, the analysing the automotive refrigeration system performance, COP is also relate to the different type of refrigerant mixture, R12, R124 and R152 [7]. The experimental analysis on the compressor capacity relationship to the automotive refrigeration performance was also conducted by Jabardo (2002). There is also a study on the refrigerant flow inside automotive air conditioning accumulator that is critical to compressor safety, system COP and lubrication [10].

The experimenting on the building air conditioning performance was also performed by the F. Yu and K. Chan [11]. They have carried out experimentation on the performance of a home air conditioning. They show how the COP of the refrigeration system can be improved by modulating heat rejection through variable speed condenser fan. By using the algorithm that have been develop by these researchers, in which they use set point of condensing temperature to determine the suitable number and condenser fan speed, appropriate and controlled heat rejection can be achieved.

The computer simulation study on the automotive air conditioning system also has been conducted. It is the parametric study using CARSIM computer simulation program. It is to study the effect of variable volume flow rate of supply air ,number of occupant in passenger cabin, vehicle speed and fractional outside air intake (XOA), on dry bulb temperature and specific humidity of the cabin's air and the evaporator coil cooling load of the automotive air conditioning system of a *Proton Wira* model. The results of the simulation indicate that the flow rate has affected the cabin temperature, in which the increase in humidity will increase the evaporator cooling coil temperature [12].

2.0 METHODOLOGY

This test rig was designed based on the input of actual parameters normally utilised for an automotive refrigeration system evaluation. The components in the rig are compressor, condenser, evaporator, thermal expansion valve, and receiver drier [13 - 15]. Figure 1 shows the illustration of the automotive refrigeration test rig.

The fabricated automotive refrigeration test rig consist of several components which comprised of motor, compressor, condenser, evaporator, receiver-drier, alternator, flow meter, belting, battery, tubes and connectors.

Before attaching the component, the measurement must be taken for each component such the length, height, and width. Besides, another aspect taken into account is the mechanical properties of the component such the direction of rotation of motor and air flow direction for the condenser and evaporator.

For the motor pulley, the pulley was fabricated to follow the parameter relationship between motor and crankshaft from actual vehicle. The parameters that have been measured are the pulley diameter and pulley rotation speed of crankshaft and compressor respectively. The calculations as follows are used to compute the ration between the compressor and the crankshaft.

The calculations performed are as follow:

$$DC/Dm = Nm/Nc \qquad (1)$$

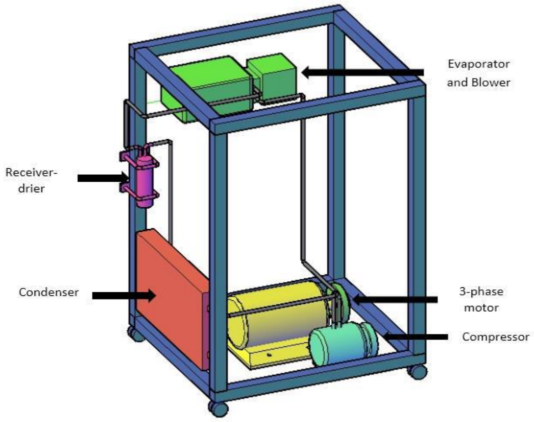


Figure 1 Automotive refrigeration test rig design

where,

DC = compressor/alternator pulley diameter

Dm = crankshaft/motor pulley diameter

Nm = crankshaft/motor rotation speed

Nc = compressor/alternator rotation speed.

The pulley ratio from the vehicle that integrates into the test rig system is 1.

The next installation is the electrical wiring to the system. Most automobiles use 12V circuit including the air conditioning system. In the automotive refrigeration test rig, compressor, condenser fan, and blower fan used the power directly from the battery. To avoid the battery voltage depletion during operation, the battery was recharged with the alternator. In this automotive refrigeration test rig, the electrical circuit for the system is divided into three sections i.e. air conditioning clutch circuit, blower motor circuit and, alternator circuit.

2.1 Experimental Apparatus and Procedures

The instrumentation uses in this experiment are to measure the parameter such the pressure, temperature, air flow and air velocity so that the air conditioning performance can be calculated. Thermocouple wires are connected to the miniature thermocouple connector. In this experiment the T-type of thermocouple was used as it has suitable range of temperature. The thermocouple were placed at the inlet and outlet of evaporator and condenser and it represent by symbol T1, T2, T3, and T4.The junction of thermocouple were soldered and placed at the tube surface. The data of measurement was show through the thermocouple scanner. To measure the pressure on high side and low side of the air conditioning, the pressure gauge was used. The high side pressure will be measured at the outlet of the condenser while the low side pressure will be measured at the evaporator outlet. The pressure range for the high side gauge is -30-500 psi and for the low side gauge is range from -30- 250 psi. The pressure gauge is used when to filled the gas into the system. The gas was filled through the low side hose which is at the evaporator outlet. The gas filled until the gauge at the low side show the reading about 30 psi which is the standard pressure for the automotive refrigeration system. Flow meter is used to measure the refrigerant flow rate in air conditioning system. The flow meter placed at the filter-drier outlet of the system. The measurement of refrigerant flow rate occur when the pressure in system change. The anemometer in the experiment is turbine anemometer and hot wire anemometer SD card logger. Turbine anemometer was used to measure velocity of the air and air flow on condenser and evaporator. The hot wire was used to measure the air temperature in and out from the evaporator. The measurement was taken by placed the anemometer at four different point of inlet and outlet of evaporator and condenser. The averages of reading are taken for the analysis. The air flow measurement must be taken by calculate the area of air flow.

The experiments were performed under variable parameter in which the evaporator blower speed were varied in steps and the air velocity that passed through the condenser was regulated. The experimental set up is shown in the Figure 2.

2.2 Mathematical Formulation

The mathematical formulas are based on the first law of thermodynamic applied to the system.

Work compressor,

$$\dot{W}_{12} = \dot{m}\,(h_2 - h_1) \tag{2}$$

Cooling load at evaporator,

$$\dot{Q}_{14} = \dot{m}\,(h1 - h4) \tag{3}$$

Cooling load of the system system,

$$\dot{Q}_{system} = \dot{Q}_{14} \tag{4}$$

Coefficient of performance (COP) of the system is define as,

$$\begin{aligned} \text{COP} &= (\text{Desired output/Required input}) \\ &= \dot{Q}_{14} \,/\, \dot{W}_{12} \end{aligned} \tag{5}$$

where,

$\dot{Q}_{14}$ = Cooling load (kW)
$\dot{W}_{12}$ = Compressor work (kW)
$\dot{m}$ = Mass flow rate (kg/s)
h = Enthalpy (kJ/kg)

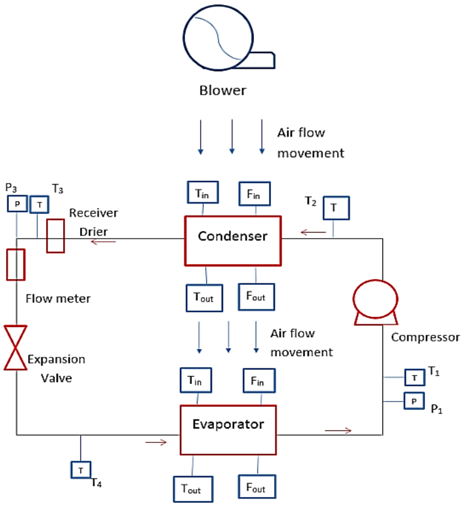


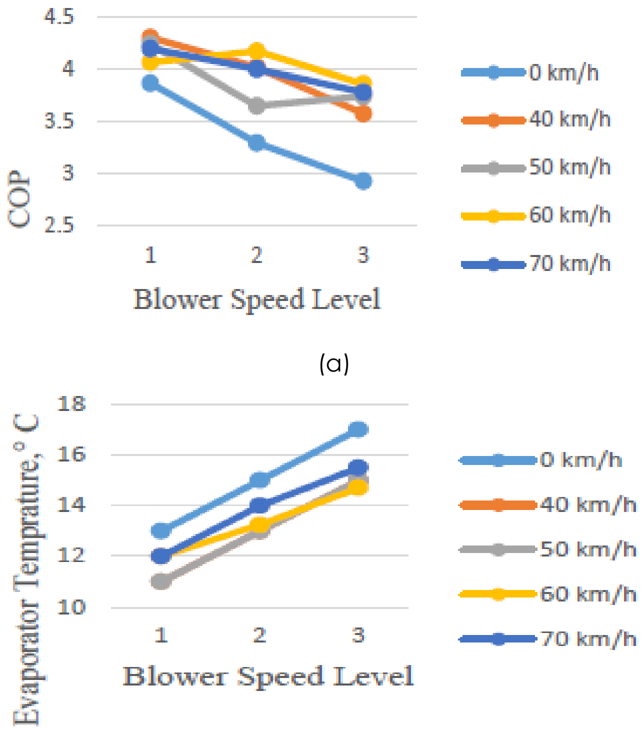
Figure 2 Experimental setup diagram

3.0 RESULTS AND DISCUSSIONS

The experiment was carried out by varying the evaporator blower speed and the air velocity through the condenser. The results of the analysis are presented in graphical forms which shows the coefficient of performance, COP, cooling load of system and compressor power consumption respectively

3.1 Effect of Variable Evaporator Blower Speed

Figure 3 (a) and (b) show the coefficient of performance of the refrigeration test rig against the evaporator blower speed when the condenser received the air velocity at 0, 40, 50, 60 and 70 respectively. From the graph, it shows that COP refrigeration is the higher when the blower speed is the lowest meanwhile the smaller COP refrigerant recorded when the blower speed functioning to the maximum speed. This shows that the air conditioning performance is at best when the blower speed reduced lowest speed. The graphs shows that the evaporator temperature is the higher when the blower turns up to the maximum speed and colder at lowest blower speed. However the evaporator temperature decreasing when the air velocity that hit the condenser increase. This results shows that the heat from the cooling system of evaporator is also directly affected by the velocity of the air to remove the heat from the system thus increasing the cooling effect of evaporator.



(a)

(b)

Figure 3 Graphs of COP and evaporator temperature against blower speed level

Figure 4 shows the evaporator cooling capacity, Q (kW) against the evaporator blower speed. The cooling capacity is reduced when the blower speed increased from 1 (slow) to 3 (fast). The reduction of cooling capacity shows that the evaporator is starving and it will reduce the heat transfer coefficient in evaporator since the refrigerant flow is not sufficient enough to cool the heat load.

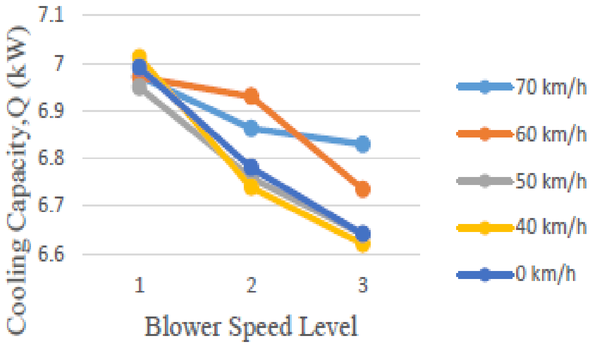
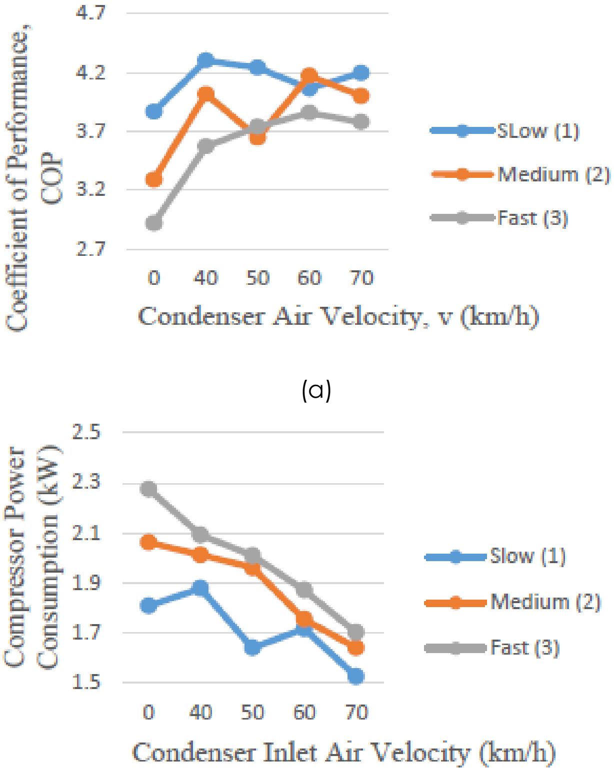


Figure 4 Graph cooling capacity (kW) against blower speed level



(a)

(b)

Figure 5 Graph COP and compressor power consumption (kW) against air velocity (km/h)

3.2 Effect of Variable Air Velocity to the Condenser Inlet

Figure 5 (a) and (b) show the graphs of coefficient of performance against the condenser air velocity for the various speed of evaporator blower. The graph shows the COP of the cycle for the blower speed at medium and high are increasing when the condenser air velocity increase. These finding shows that the increasing f air velocity will increase condenser heat rejection thus increase the COP of the cycle. The COP refrigeration is higher when the evaporator blower speed is set up to the lowest speed. They show the graphs of compressor power consumption against the air flow through the condenser inlet. The graph shows the compressor power consumption to electrical demand has decreasing due to the increasing in heat rejection air flow. The increasing air flow also effect at every speed of evaporator blower. This finding indicate that the compressor power consumption is depending on how much heat rejected by the condenser fan at given cooling capacity.

Figure 6 shows the cooling capacity (kW) trend against the condenser inlet air velocity (km/h). As an overall, the graph shows that cooling capacity increasing due to the increasing in air flow and velocity through the condenser. The cooling capacity at the evaporator was affected by the reduction of condenser temperature. This reduction in condenser temperature is caused by the increasing in heat rejection since the compressor running with constant speed. The increased in the cooling capacity is about 1%.

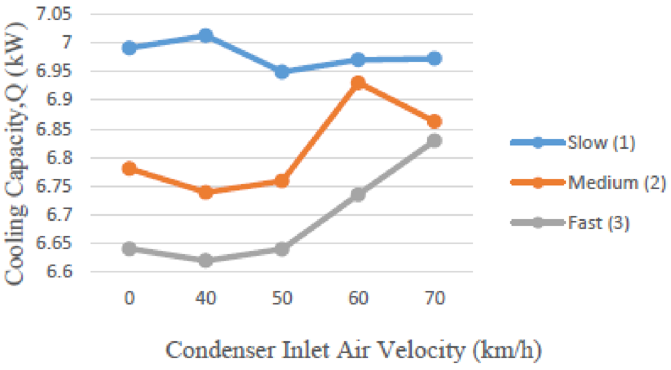


Figure 6 Cooling capacity, Q (kW) against condenser inlet air flow velocity (km/h)

4.0 CONCLUSION

From the test rig design and the development work of the automotive refrigeration system, it can be concluded that to design a similar test rig, the knowledge of the complete system must be clearly understood, especially the components, operating parameters, the expected characteristics as well as the design safety factor. Upon completion of the fabrication work, the test rig is to be tested to make sure that the test rig is in accordance to the desired specifications. From the experiments that have been carried out, it can be concluded that the COP of the refrigerator will decrease when the evaporator blower speed is raised. The maximum and minimum COP of the system is observed to be 4.3 and 2.9 respectively. This is because the evaporator inlet temperature rise has caused the power consumption to increase thus reduces the cycle of the COP refrigerant. The maximum power consumed by the compressor is 2.3 kW when no air is forced through condenser and use evaporator blower speed at level 3. The lowest compressor power consumption calculated is 1.5 kW. Besides, the increasing of air flow to the condenser inlet has reduced the compressor power consumption and this finding shows that more heat will be rejected from the condenser, and subsequently the COP refrigeration unit will be increased.

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