PERFORMANCE EVALUTION OF PROTON WAJA CAR AIR CONDITIONING SYSTEM

MOHAMAD NADZIF B. ZAHIRUDIN

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature: ....

Supervisor: MR. MOHD YUSOF BIN TAIB

Position: Lecturer

Date:

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature: ....

Name: MOHAMAD NADZIF B. ZAHIRUDIN

ID Number: MH 07003

Date:

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All praises and thanks be to Allah S.W.T, who had guided us to this, never could we have found guidance, were it not that Allah had guided us! (Q7 : 43)

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Lastly, I want to thank to all my friends who shared and giving me their ideas and advise in completing this project. Thank you very much and may Allah bless all of you.

ABSTRACT

Air conditioning is a process by which air is cooled or heated, cleaned or filtered, and circulated or recirculated. Air conditioning had become a standard option on most vehicle for enhancing comfort and safety. Regarding to this situation, an experiment and analysis need to be done to analyze the coefficient of performance (COP) of Proton Waja car during variable compressor speed and variable refrigerant weight. There are four locations of temperature measurement were selected in order to analyze the system. These locations are at the inlet and outlet of the compressor, the outlet of the condenser, and the inlet of the evaporator, respectively. The pressure was measured at the low pressure side and high pressure side which are at the outlet of the evaporator and inlet of the condenser, respectively. Before experimenting, a Statistica Software was used to reduce the error of experiment, and this software can design the experiment order. Besides that, the result from manual calculation can be validate with the result from Statistica Software. All of the parameters are measured during the cycle and were analyzed by using the properties table for refrigerant-134a and the *p-h* diagram for refrigerant-134a in order to determine the heat rejection, cooling effect, work of compressor and the coefficient of performance (COP) of the air conditioning system. The heat rejection, cooling effect, work of compressor, and the COP of the air conditioning system were investigated at variable speed of compressor and variable weight of refrigerant. The COP of the system was decreasing as the increasing of time and the compressor speed. It is also similar to COP of the system during the increasing of refrigerant weight and time in other experiment.

ABSTRAK

Penyaman udara adalah satu proses di mana udara disejukan atau dipanaskan, dan dibersihkan atau ditapiskan. Penyaman udara telah menjadi satu keperluan pada kebanyakan kenderaan untuk meningkatkan keselesaan dan keselamatan. Kebanyakan sistem penyaman udara automotif, pemampat adalah dipacu oleh enjin dengan menggunakan tali sawat. Sesuai dengan situasi ini, percubaan dan analisis perlu dilakukan untuk menganalisis pekali prestasi sistem (COP) Proton Waja pada masa kelajuan pemampat dimanipulasikan dan pada masa berat gas pendingin dimanipulasikan. Ada empat lokasi pengukuran suhu dipilih untuk menganalisis sistem. Lokasi ini berada di saluran masuk dan keluar pemampat, saluran keluar pada alat kondensasi, dan saluran masuk alat pengewapan. Tekanan dalaman sistem telah diukur pada bahagian tekanan rendah dan bahagian tekanan tinggi yang mana masing-masing adalah di saluran keluar pada alat pengewapan dan di saluran masuk alat kondensasi. Sebelum percubaan, sebuah Perisian Statistik digunakan untuk mengurangkan kesalahan uji kaji, dan perisian ini boleh merancang tatanan uji kaji. Di samping itu, keputusan daripada pengiraan manual boleh disahkan dengan keputusan daripada Perisian Statistik. Semua perimeter telah diukur sepanjang kitaran pada dan telah dianalisis dengan menggunakan jadual harta untuk bahan pendingin R-134a dan carta *p-h* untuk bahan pendingin R-134a dalam menentukan jumlah penyingkiran haba, kesan penyejukan, kerja yang dilakukan oleh pemampat dan pekali prestasi sistem (COP). Penyingkiran haba, kesan penyejukan, kerja yang dilakukan oleh pemampat, dan COP sistem telah diselidik pada kelajuan pemampat yang berbeza dan pada perbezaan berat gas pendingin yang berbeza. COP sistem menurun apabila sukatan waktu dan kelajuan pemampat meningkat. Hal ini juga mirip dengan COP sistem selama peningkatan berat gas pendingin dan waktu pada uji kaji lain.

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LIST OF SYMBOLS

P	Pressure
T	Temperature
H	Enthalpy
Q_{high}	Heat Rejection
Q_{low}	Cooling Effect
W_c	Work of Compressor
P	Density
V_c	Compressor Displacement Volume
W_c	Speed of Compressor
17_c	Compressor Volumetric Efficiency
R	Gas Constant
M	Mass Flow Rate
V_c	Compressor Volumetric Rate
Kg	Kilogram
°C	Degree Celcius
kJ	Kilojoule
Pa	Pascal
M	Meter

LIST OF ABBREVIATIONS

COP	Coefficient of Performance
TXV	Thermostatic Expansion Valve
FOV	Fixed Orifice Tube
VCRC	Vapor Compression Refrigeration Cycle

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Air conditioning system is defined as the simultaneous mechanical control of temperature, humidity, and air motion [8]. Air conditioning also is the process which air is cooled or heated, cleaned or filtered, and circulated [4]. Figure 1.1 shows operation of the air conditioning system. Majority of the air conditioning in automotive used vapor compression refrigeration system in its cycle [4]. The schematics diagram in Figure 1.2 shows the schematics diagram of automotive air conditioning system.

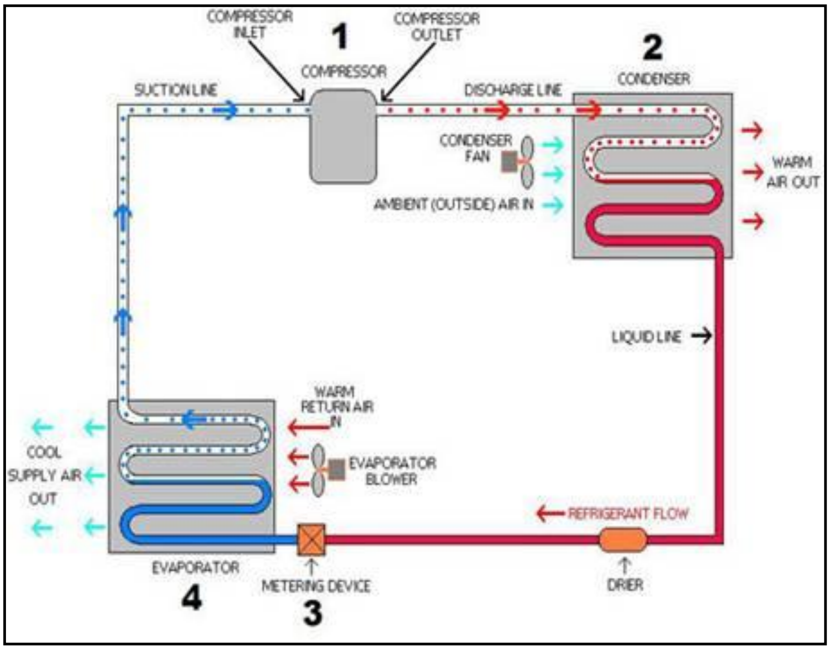


Figure 1.1: Schematics diagram of air conditioning circuit and cycle diagram

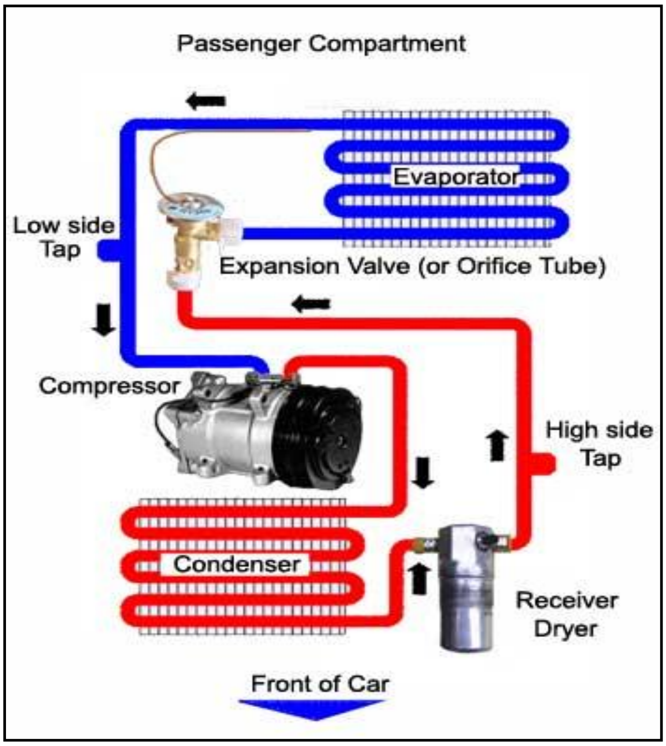


Figure 1.2: Schematics Diagram of Automotive Air Conditioning System

The basic components that used in automotive air conditioning system are compressor, condenser, evaporator, expansion valve or orifice tube, and accumulator or receiver drier. The main component that acts like a heart in this system is compressor. The compressor continuously cycles on and off to meet the cooling requirements of the passenger compartment and is mounted to the engine and is belt driven and its cycling rate is directly related to the automobile vehicle speed. At the front of the compressor is the magnetic clutch which when given power engages the compressor. The condenser is usually in front of the radiator. The expansion valve controls the flow of refrigerant into the evaporator. The expansion valve has a capillary tube with a thermal bulb that controls how far open or closed it is. The thermal bulb and the internal pressure of the refrigerant balance to control just the exact amount of refrigerant needed. The thermal bulb is clamped to the output of the evaporator. If not enough refrigerant is flowing to cool the evaporator, this bulb is sense it and open more or vice versa. The evaporator is the heat exchanger that removes heat from the inside of the vehicle. It is located in or adjacent to the passenger compartment, usually mounted on the fire wall. As the refrigerant-134a passes through the evaporator, heat transfer from the air flowing across results in the vaporization of the refrigerant. Vapor refrigerant leaving the evaporator is compressed to a relatively high pressure and temperature by the compressor. Next, the refrigerant passes through the condenser, where the refrigerant condenses and there is heat transfer from the refrigerant to the air flow across the condenser. Finally, the refrigerant enters the expansion valve and expands to the evaporator pressure. The refrigerant exits the valve as a two-phase liquid-vapor mixture and gets in to the evaporator to begin the cycle again. The airflow across the evaporator is either re-circulated air from the passenger compartment or fresh air drawn from the outside, or some combination of the two.

The refrigerant system reaches to a steady-state operating condition when the mass flow rate through the compressor is equal to the amount of vapor generated in the evaporator [4]. The automotive air conditioning system is designed to operate under a wide range of heat conditions, and as such the capacity of the fixed volume compressor is larger than needed under most operating conditions. To allow the system to function across a wide range of environmental conditions, the compressor is cycled on and off based on the low-side refrigerant pressure. The compressor is shut off when the pressure in the evaporator falls below the preset value which is chosen to assure that condensate does not freeze on the evaporator. Even after the compressor shuts off, there will still persist a pressure imbalance across the expansion valve that will force refrigerant to flow from condenser to the evaporator. As the evaporator fills with the refrigerant, its pressure will increase. Once the low side refrigerant pressure reaches the preset level, the compressor will restart. The compressor is continuously turned on and off in this manner. Since the compressor is belt driven device coupled to the engine, when the engine speed changes so does the compressor speed, which results in a fluctuation of the refrigerant mass flow rate. Turning the compressor on and off position is provided by an electro-magnetic clutch.

There are several different types of automotive air conditioning systems which are the Receiver Drier (Filter Drier) – Expansion Valve System which uses the valve to control refrigerant flow and cycles the compressor clutch to control evaporator temperature and the Accumulator – Orifice Tube System which uses a fixed orifice and an accumulator to control refrigerant flow and cycles the compressor clutch to control evaporator temperature, and Suction Throttling Valve System which uses an expansion valve to control refrigerant flow into the evaporator and a suction throttling valve to control refrigerant flow out of the evaporator. The last system does not cycles the compressor clutch, rather it cycles the compressor suction to the evaporator**.**

1.2 PROBLEM STATEMENT

Nowadays as we known, to service vehicle air condition, ordinary services will be done by mechanic at the workshop. The basic services include gas leak test, charging, change compressor oil, clean magnetic clutch [4]. The main problem occurred in the most of services is when charging process. The amount of refrigerant that will be refill is not professionally in accurate number of amount. This is why sometimes, after we service our air condition, the cooling of the air is worst than before service. In this thesis, we set that by different weight of the amount of the refrigerant different cooling rate will be produce. Pressure and temperature is parameters that should be known when analyzing.

1.3 PROJECT OBJECTIVES

There are three objectives that have been determined as below:

a. To analyze the performance of car air conditioning system at variable of refrigerant weight during charging process.

b. To analyze the performance of car air conditioning system by determining coefficient of performance, COP at different speed of compressor.

c. Validate both result in Statistica.

1.4 PROJECT SCOPES

a. Review, find and gather all about literature of automotive air conditioning system on previous journals and reference books.

b. Study parameters, calculation and Statistica Software that will be involve in analysis.

c. Run the experimental in the system of air condition in Waja car

d. Analysis the performance of air conditioning system in manipulating compressor speed and manipulating refrigerant weight.

e. Documentation.

1.5 FLOW CHART

Figure below shows the flowchart of this project:

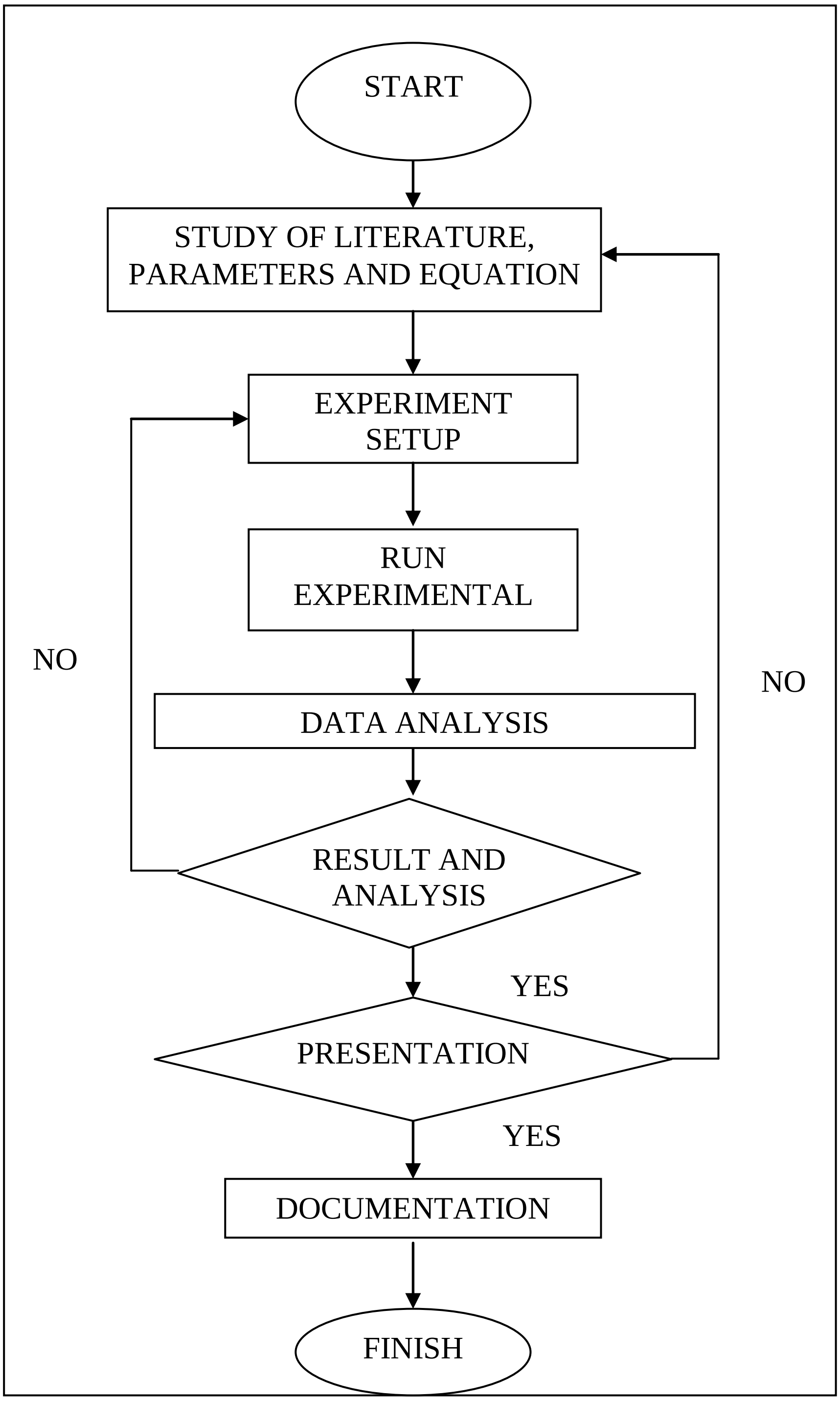


Figure 1.3: Final Year Project Flow Chart

CHAPTER 2

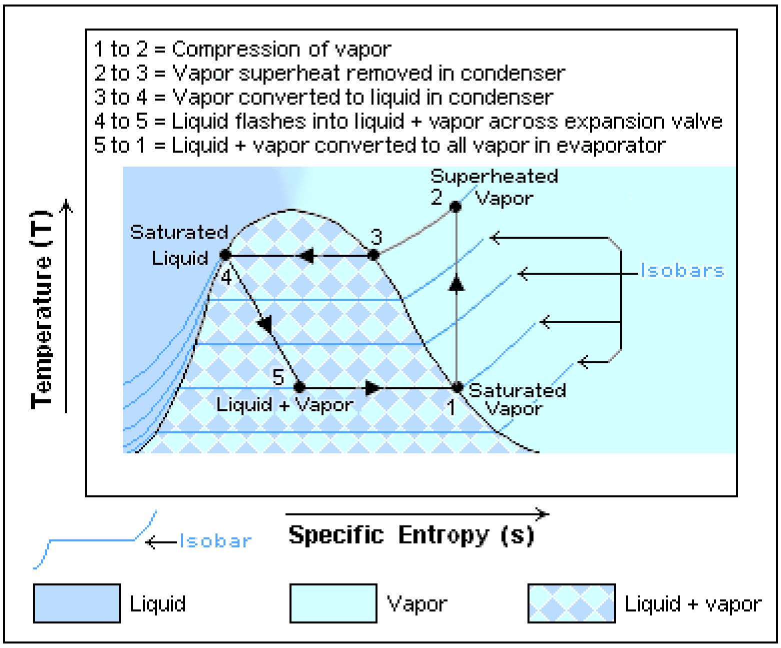
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will be discussing about literature review of air conditioning system. The literature review including on the theory of air conditioning system and the function of each basics component of air condition. Now more than ever, air conditioning starts since 1940’s. The improvement of air conditioning system begins with Computerized Automatic Temperature Control known as CATC. This CATC allow setting the desired temperature and having the system adjust automatically. Before this, used Refrigerant R-12, known as Freon. Then change with refrigerant R – 134 a because of damaging effect to ozone layer [8].

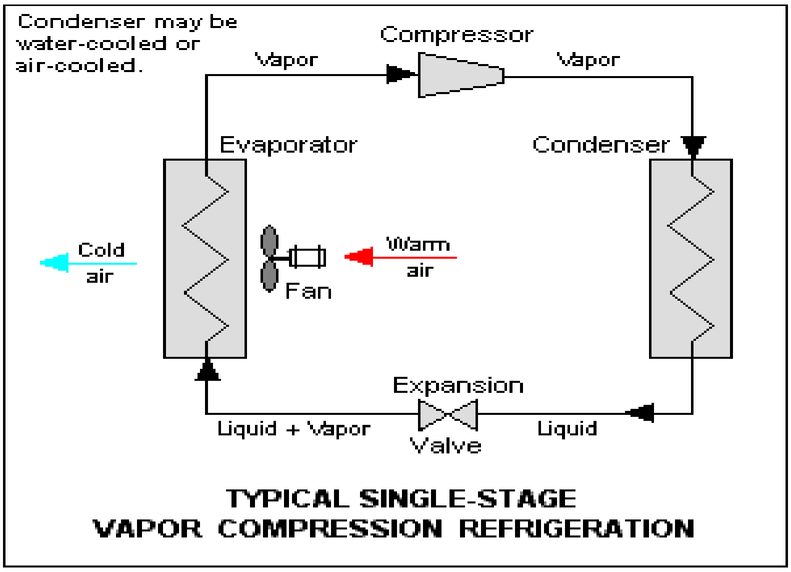
2.2 THEORY OF AIR CONDITIONING SYSTEM

Most of the automotive air conditioning system is using the vapor compression refrigeration cycle. The ideal vapor- compressed refrigeration cycle is the result of eliminating the impracticalities associated with the reversed Carnot cycle by vaporizing the refrigerant completely before it is compressed and by replacing the turbine with a throttle device [1]. As had been mentioned before, it consists of a compressor, a condenser, an expansion device for throttling, and an evaporator. The cycle operates at two (2) pressures, P_{high} and P_{low}, and consists of four (4) thermodynamic process involving the working fluid, traversing four (4) fluids states at T_{low} and T_{high} [2].



(GNU) Image: Milton Beychok and Henry Padleckas

Figure 2.1: Diagram of the thermodynamic cycle for vapor-compression refrigeration [1]



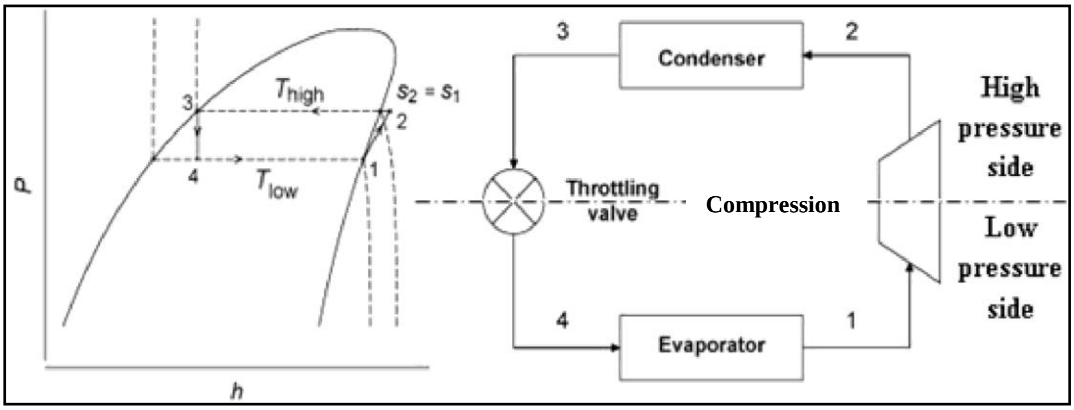
(GNU) Image: Milton Beychok

Figure 2.2: Schematic diagram of vapor-compression refrigeration system

The ideal vapor- compression refrigeration cycle is illustrated in the diagram on *T-s* diagram in Figure 2.1. It consists of five (5) processes [1].

1-2	Isentropic compression of vapor
2-3	Vapor superheated remove in condenser
3-4	Vapor converted to liquid in condenser
4-5	Liquid flashes into liquid with vapor, across expansion valve
5-1	Liquid with vapor converted to all vapor in evaporator

The cycle also can be illustrated on *p-h* diagram as shown in Figure 2.2 that had been successfully discussed by S. Figueroa-Gerstenmaier, M. Francova, M. Kowalski, M. Lisal, I. Nezbeda, and W.R. Smith [2]. The *P-h* diagram is widely used for analyzing the performance of the cycle.



(a) (b)

Figure 2.3: A simplified ideal vapor compression refrigeration cycle operating between temperatures T_{low} and T_{high}.

Figure 2.3 (a) show the process path on *p–h* diagram corresponding to the schematic diagram of the process equipment as illustrated in Figure 2.3 (b) where *p* is the pressure and *h* is the molar enthalpy. The isotherms are indicated by dashed lines. The processes involved are as follows, with the numbers denoting the states indicated in Figure 2.3.

1. An equilibrium liquid–vapor mixture at point 4 that is at T_{low} and the corresponding vapor pressure P_{low}, (P_1=P_4) evaporates to a saturated vapor at point 1. The process is indicated by the line (4 → 1) in Figure 2.3 (a). This provides a means for heat absorption by the working fluid in an amount of cooling effect, Q_{low} at T_{low}. The heat absorbed per mole of working fluid is

$$Q_{low} = h_1 - h_4$$

2. The saturated vapor in point 1 is compressed isentropically to a vapor at P_{high} and T_{high} in point 2, where Phigh , (P_2=P_3) is the vapor pressure at T_{high}, indicated by the line (1→2) in Figure 2.3 (a). The work done by the compressor per mole of working fluid is

$$W_C = h_2 - h_1$$

3. The compressed fluid enters a condenser, producing saturated liquid at (P_{high}, T_{high}) in point 3, as indicated by the line (2→3). The heat rejection in the condenser is

$$Q_{high} = h_2 - h_3$$

4. The saturated liquid enters the throttling valve expansion device, exiting as a vapor–liquid mixture as the original at point 4, indicated by the line (3 →4). The pressure drop in this irreversible process occurs at constant enthalpy.

All four component associated with the ideal vapor-compression refrigeration cycle are steady-flow devices, and thus all four processes that make up the cycle can be analyzed as steady-flow processes. The efficiency of a Vapor Compression Refrigeration Cycle is measured by its coefficient of performance (COP), defined as

$$COP = \frac{Q_{low}}{W_c}$$

2.3 COMPONENTS OF AIR CONDITIONING SYSTEM

There are four major components in air conditioning system as discussed earlier in chapter 1. There are compressor, condenser, expansion device, and evaporator. In automotive application, one component must be added to the air conditioning system which is receiver drier to make sure the refrigerant that flow to the expansion device fully in vapor phase. Each component in the automotive air conditioning system will be discussed in next section of this chapter.

2.3.1 Compressor

The function of the compressor is to compress and circulate superheated refrigerant vapor around a closed loop system (any liquid or dirt will damage the compressor) [3]. Compressor varies in design, size, weight, rotational speed and direction, and displacement. Some compressors are variable displacement and some are fixed. The compressor uses about 80% of the energy required to operate an air conditioning system [3]. This means that the compressor used in the system will determined the overall efficiency of the system.

Figure 2.4: Automotive Air Conditioning Compressor

Operation

In automotive air conditioning, the compressor as shown in Figure 2.3 is driven by an engine driven pulley system. At the front of the compressor is a magnetic clutch which when given power engages the compressor. The compressor draws in refrigerant vapor from the suction side which is the outlet of the accumulator (fixed orifice valve system) or the outlet of the evaporator (expansion valve system) [3].

Types of Compressor

As had been stated by Steven Daly [3], there are three main categories of compressor:

(i) Reciprocating – crank and axial piston
(ii) Rotary – vane
(iii) Oscillating – scroll compressor

2.3.2 Condenser

The function of the condenser is to act as a heat exchanger to dispel the heat energy contained in the refrigerant [3]. Superheated vapor enters the condenser at the top and subcooled liquid leaves the condenser at the bottom.

The pressure and temperature has been raised by the compressor. There is a need to lower the temperature to change it back into liquid enabling it to act as a cooler again in the system. To accomplish this, the refrigerant flows into the condenser as a vapor and gives off to the surrounding area and most of the refrigerant (depending on system load) condenses back into liquid which then flows into the receiver/drier.

In automotive application, the condenser as shown in Figure 2.4 is located at the front of the vehicle (in front of the radiator) where strong air flow through its core can be achieved when the vehicle is in motion. To aid the removal of heat when the vehicle is stationary or at low speed, the condenser is fitted with a single or double fan system.

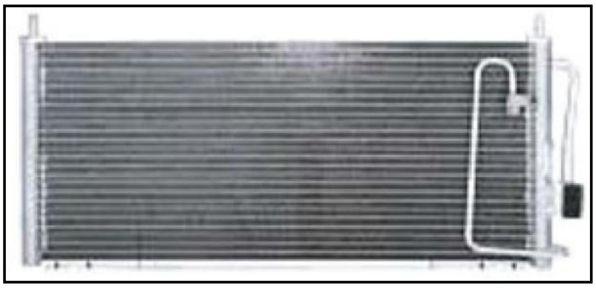


Figure 2.5: Automotive Air Conditioning Condenser

2.3.3 Receiver Drier

A receiver-drier as shown in Figure 2.6 is used when the thermostatic expansion valve metering device is used and is positioned between the condenser and the thermostatic expansion valve.

As had been stated by Steven Daly [3], the function of the receiver-drier is as follow:

(i) To ensure the system is free from dirt preventing any excessive wear or premature failure of components.

(ii) To remove moisture from the refrigerant ensuring no ice can form on any components within the system which may cause a blockage and to ensure no internal corrosion can form.

(iii) To act as a temporary reservoir to supply the system under varying load conditions.

(iv) To allow only liquid refrigerant to flow to the expansion valve.

(v) To act as a point for diagnostics (sight glass sometimes fitted)

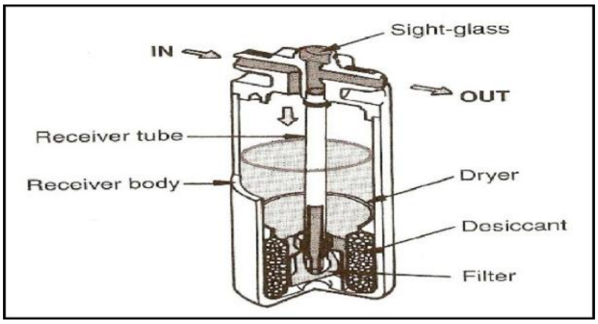


Figure 2.6: Automotive Air Conditioning Receiver-Drier

Operation

Refrigerant entering the receiver-drier in an ideal system will be in a liquid state. If the system is under heavy load, the condenser may have not been enough efficient to this means a small amount of vapor may be present. Liquid and vapor can enter the receiver through the inlet it will separate. Liquid will fall to the bottom of the receiver while vapor will rise to the top. The outlet is connected to a receiver tube internally which has a pickup point at the bottom of the receiver where the filter is positioned.

The refrigerant flows through the desiccant and filter to get to the outlet pickup tube. This ensures that only liquid refrigerant flows to the expansion device.

2.3.4 Expansion Device / Metering device

To control the amount of refrigerant volume flowing through the evaporator, a metering device as shown in Figure 2.7 must be used. As had been stated by Steven Daly [3], the function of metering device is as follows:

(i) To separate the high pressure and low pressure side of the system.

(ii) To meter the volume of refrigerant and hence the cooling capacity of the evaporator.

(iii) To ensure that the superheated refrigerant exiting the evaporator.

Currently there are two main categories of metering devices used :

(i) Thermostatic Expansion Valve (TXV)

(ii) Fixed Orifice Valve (FOV)

Figure 2.7: Automotive Air Conditioning Thermostatic Expansion Valve

2.3.5 Evaporator

The evaporator as shown in Figure 2.8 is very similar in construction to a condenser. The function of an evaporator is to provide a large surface area to allow the warm often humid air to flow through it releasing its heat energy to the refrigerant inside [3].

The ideal temperature of the evaporator is 32° Fahrenheit or 0° Celsius. The refrigerant by this time will have a large pressure and temperature drop coming through the expansion/fixed orifice tube valve causing it to want to boil and just requiring the heat energy to do so. The evaporator absorbs the heat energy from the air flowing over its surface. The energy is transferred and the refrigerant reaches saturation point. At this point the refrigerant can still absorb a small amount of heat energy. The refrigerant will do so and become superheated. The superheated refrigerant will then flow to the compressor (TXV system) or accumulator (FOV system).

In automotive application, evaporator is located inside the heater box in the vehicle. The benefit of the evaporator is dehumidification. As warmer air travels through the aluminum fins of the cooler evaporator coil, the moisture contained in the air condenses on its surface. Dust and pollen passing through stick to its wet surfaces and drain off to the outside. On humid days you may have seen this as water dripping from the bottom of your vehicle. Rest assured this is perfectly normal.

Figure 2.8: Automotive Air Conditioning Evaporator

2.4 EXPERIMENTAL SETUP IN PROTON WAJA ENGINE COMPARTMENT

The important part in the experimenting the system by doing setup in engine compartment of the Proton Waja car is the location of the pressure and temperature measurement,it is to ensure the correct data will be produced. Several technical paper related to the study were referred in order to develop a reliable air conditioning compartment test.

2.4.1 Temperature Measurement

Previously, O. Kaynakli and I. Horuz [4], and Eric. B. Ratts and J. Steven Brown [5] were discussed about temperature measurement points on a car air conditioning. In the experiment that had been done by [4], there are six points for refrigerant temperature measurement, each at the inlet and outlet of condenser, expansion valve, and compressor. They also had chosen four points of air temperature measurement, each at the inlet and outlet of evaporator (dry bulb temperature and wet bulb temperature) [4] as shown in Figure 2.9.

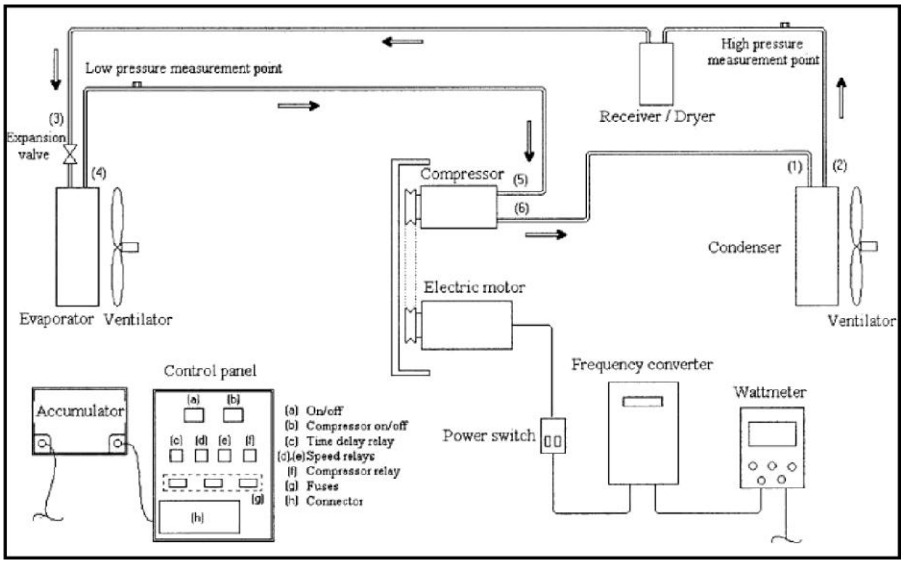


Figure 2.9: Schematic Diagram for air conditioning system compartment done by O. Kaynakli and I. Horuz Eric. B.

Ratts and J. Steven Brown [5] were chosen five locations for temperature measurement. There are at the inlet and outlet of the compressor, outlet of condenser, and inlet and outlet of the evaporator, respectively as shown in Figure 2.10.

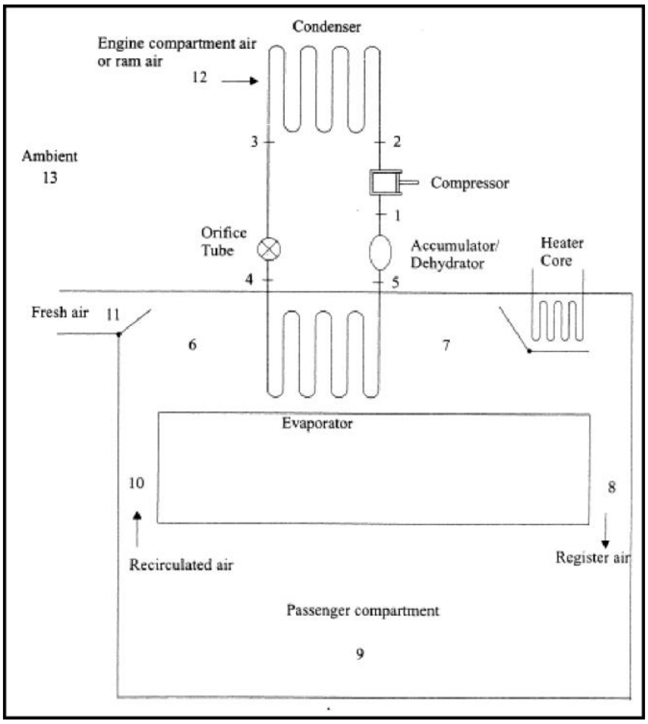


Figure 2.10: Schematic Diagram for air conditioning system compartment done byEric. B. Rattsand J. Steven Brown

O. Kaynakli and I. Horuz [4] were used thermocouple wire to measure the temperature of refrigerant and air at each point decided by them. Eric. B. Ratts and J. Steven Brown [5] were used T-type thermocouples in stainless steel thermowell*s* in order to measure the refrigerant temperature at each point that has been decided.

2.4.2 Pressure Measurement

O. Kaynakli and I. Horuz [4] and M. Hosoz and H. M. Ertunc [6] were discussed about pressure measurement points on a car air conditioning. There are two points of pressure measurement for the refrigerant. It is at high pressure side and the other one is at low pressure side. According to [4], each point of pressure measurement is at the inlet of condenser and at the inlet of evaporator as shown in Figure 2.9.

M. Hosoz and H. M. Ertunc [6] were measure the pressure at the inlet and outlet of compressor as shown in Figure 2.10. It was assumed that the evaporating and condensing pressure were equal to the suction and discharge pressure of compressor, respectively.

O. Kaynakli and I. Horuz [4] used Bourdon pressure gauges, measurement scale of 0-100 kg/cm^2 at the high pressure side and Bourdon pressure gauges, measurement scale of 0-6 kg/cm^2 at the low pressure side in their experiment.

M. Hosoz and H. M. Ertunc [6] used the bourdon gauge, range of 0/3000 kPa at the high pressure side and bourdon gauge, range of -100/1000 kPa at low pressure side in their experiment.

2.5 SUMMARY

The literature review is very important as a guide to make sure that the understanding about the concept was achieved. In this paper, the literature study about the basic concept of air conditioning had been discussed clearly and this literature review will help to continue the next step in completing the research. The next chapter will discuss the methodology to carry on the work.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discusses about the methodology of the experiment and how the experiment will be setting up. The experiment is used to generate base data by measuring pressure and temperature at appropriate points. By using these data, the performance of the air conditioning system can be evaluated. Statistica software also will be use in analyzing the data. All of them were handled properly in order to produce the desired results.

This chapter also discusses the testing procedure of air conditioning such as purging, evacuation, charging process, and data collection. The development of the experiment compartment was referred to several journals and technical paper.

Step by step how to carry on this project from the beginning until the end was shown in Figure 3.1 in order to successfully complete the project.

3.2 METHODOLOGY FLOWCHART

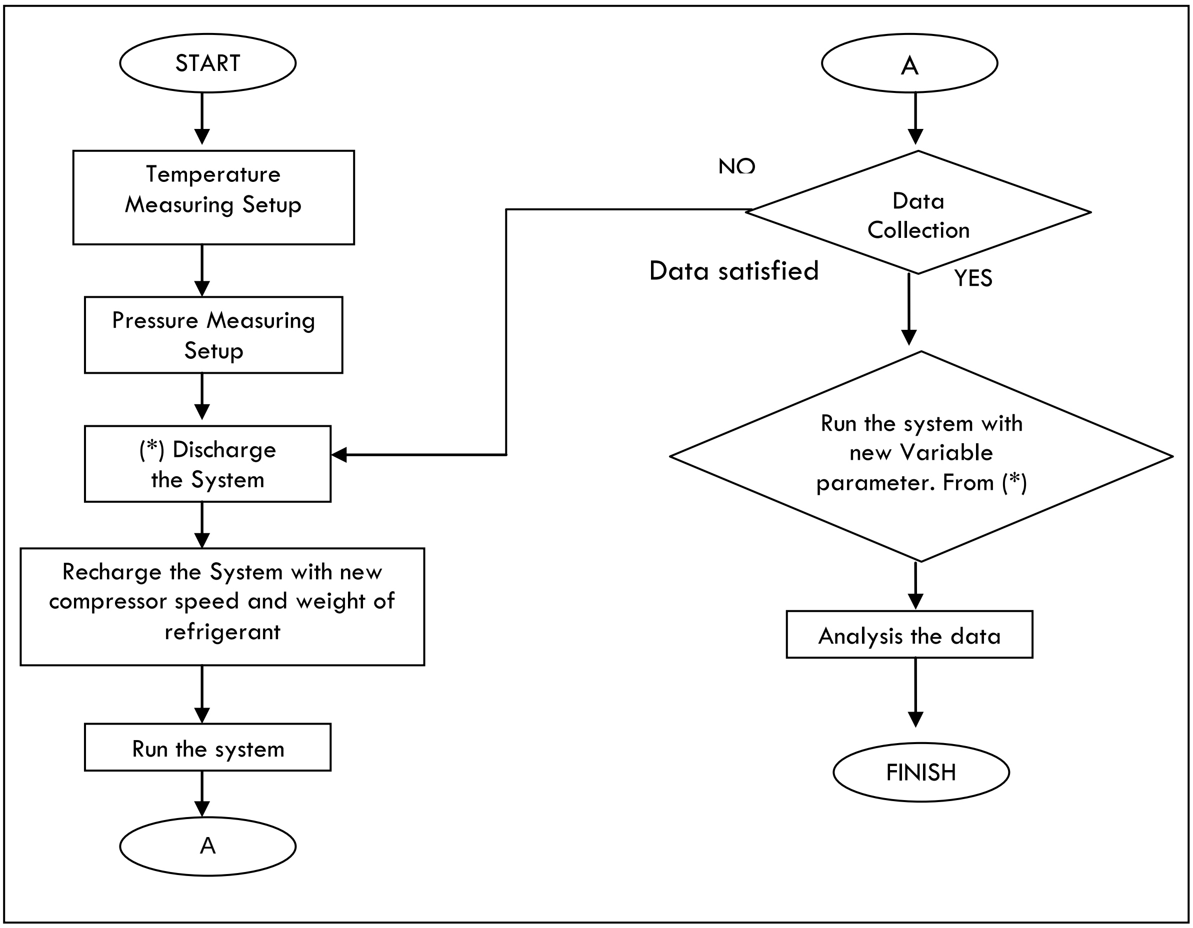


Figure 3.1: Methodology chart.

3.3 EXPERIMENTAL COMPARTMENT SETTING

3.3.1 Step 1: Method to measure temperature.

In order to get the Coefficient of Performance, COP of the air conditioning system, value of 'h' enthalpy is needed. The value of 'h', enthalpy will be get at four (4) points on the air conditioning system by determining temperature and pressure. Each point is at the inlet and outlet of compressor and expansion valve.

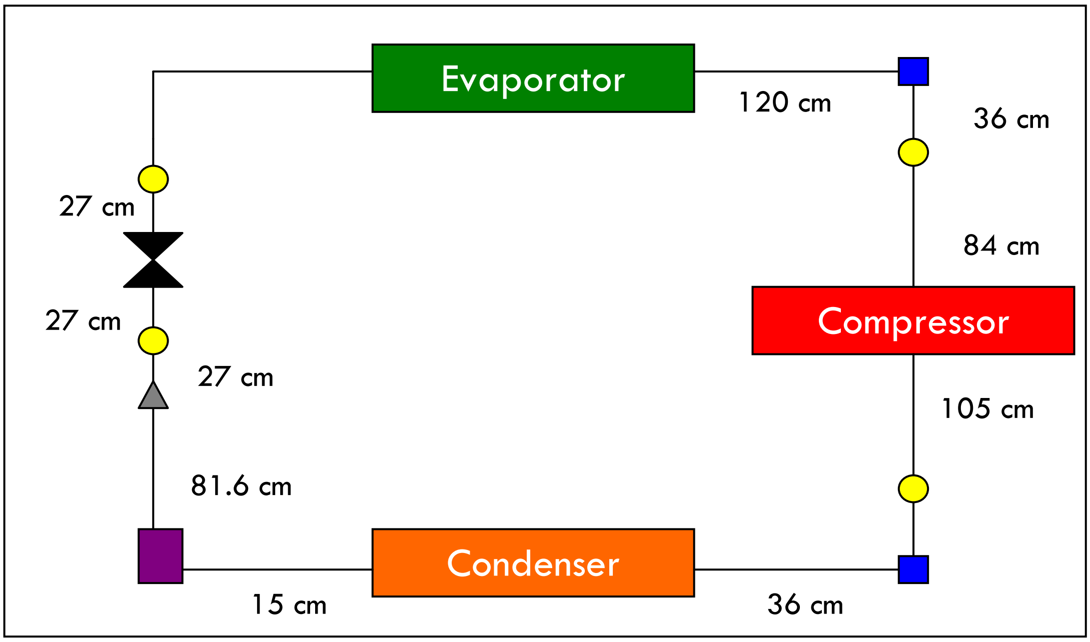


Figure 3.2 : Schematic diagram of air conditioning circuit with point to plug in thermocouple and its dimension.

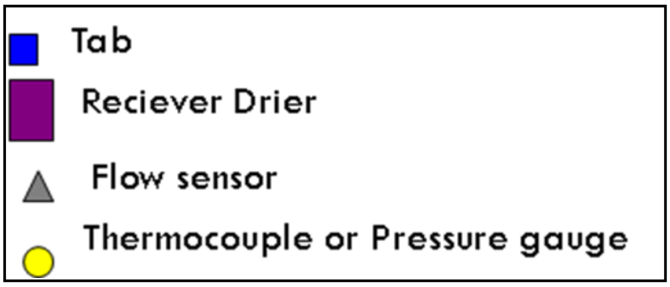


Figure 3.3 : Figure show the notation for the schematic diagram above and below that shown in Figure 3.1 and Figure 3.3.

3.3.2 Step : Method to measure pressure.

To get the value of four (4) point of pressure, two (2) Bourdon pressure gauges will be use. According to [8], each point of pressure measurement is at the inlet of condenser and at the inlet of evaporator. Use measurement scale of 0-100 kg/cm2 at the high pressure side and measurement scale of 0-6 kg/cm2 at the low pressure side in this experiment. [9]. Only two (2) will be use because in other two (2) point, the pressure value will be the same. It was assumed that the evaporating and condensing pressure were equal to the suction and discharge pressure of compressor, respectively. [9]

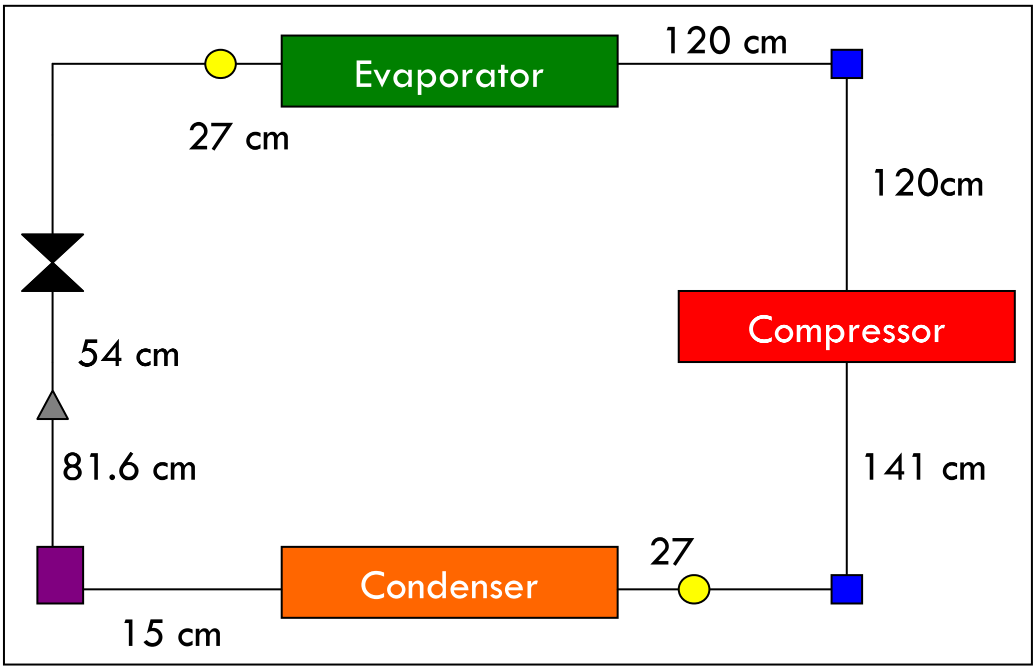


Figure 3.4: Schematic diagram of air conditioning circuit with point to plug in Bourdon gauge and its dimension.

3.3.3 Step : Manipulating parameters.

By manipulating the amount of R 134-a in the system, the system will be discharge and charge again. When charging the system, the weight or the amount of R 134-a will be decide by myself and according to standard charging process.

3.3.4 Step : Manipulating second parameters.

By manipulating the speed of compressor that will be use in the system, the system will be discharge and charge again. Before run the system with new charging condition, the speed of compressor can be set with new speed that we want to be manipulate.

3.4 OVERALL EXPERIMENT SETTING - UP

Each pair of thermocouple wires were connected to the thermocouple scanner. Thermocouple scanner is a device that use to read the measured temperature. There are four thermocouple scanners that were used to measure the temperature of refrigerant at four points as discussed in previous section and all the thermocouple scanners were fitted on a acrylic panel. Two pressure gauges were used and were respectively installed at low pressure side and high pressure side as discussed in previous section. All of these pressure gauges were fitted on a same acrylic panel with the thermocouple scanners. The temperature and pressure measurements of each point were read manually through visualization and all the data were collected after twenty minutes the system was running to make sure the system were going stable.

3.5 PURGING

Purging can be defined as a process of removing the solid contaminants such as excess oil, sludge, metallic debris from a failed compressor, etc, which could cause poor cooling or even component failure in the system [7]. Only the condenser, evaporator, and system pipeline should be purged. Purging on the other component will damage the component.

The refrigerant was removed from the system since the process of constructing test rig and therefore the refrigerant tube was exposed to the air and moisture from surrounding. In addition, the brazing process during the construction of test rig had caused the existence of foreign substance in the refrigerant tube.

The Oxygen-Free-Nitrogen (OFN) was used for purging by blowing it into the system since this will avoid the introduction of air and hence moisture into the system.

3.6 EVACUATION

Evacuation is a process to remove all traces of moisture before recharging the system with refrigerant [7]. Any moisture is very harmful to the air conditioning system since the moisture can freeze in the system, restricting the flow of refrigerant, and moisture also reacts with the refrigerant to produce acids, which damage the internal component of the system. Moisture in the system also leads to excessive system pressure. Evacuating the system also act as a leak check. If the system does not hold the vacuum, there must be a leak in the system.

Figure 3.5: Vacuum Pump

Figure 3.6: Manifold Gauge

The most common used equipment for evacuation process is vacuum pump and manifold gauge as shown in figure 3.4 and figure 3.5, respectively. The evacuation process was carried out according to the following procedures:

a) The manifold gauge low side hose (blue) was connected to the low pressure port, high pressure hose (red) was connected to the high pressure port, and service hose (yellow) was connected to the inlet port of the vacuum pump.

b) The manifold gauge high and low pressure side hand valves were opened as far as possible.

c) The vacuum pump was switched on.

d) After approximately 10 minutes, the high and low pressure hand valves were closed and the vacuum pump was switched off. The reading on the low side manifold gauge should be approaching 760 mm Hg (30 in Hg).

e) The system was leaved for about 5 minutes and the reading on the low side manifold gauge was checked. The reading should not change, indicating the system was holding vacuum and if the gauge reading moves back towards zero, this indicates there are leak in the system.

3.7 CHARGING

Charging is a process that fills the system with refrigerant. There are two basic alternatives methods of charging the system which are the vapor charging or liquid charging. There are several methods in determining the ideal amount of refrigerant to be charged into the refrigerator such as charging by weight, by observing the sight glass and pressure, and by monitoring the current load. In the present work, the method of vapor charging by observing the sight glass and pressure was selected.

The manifold gauge as shown in Figure 3.4 was used in the charging process and the system was charging by refrigerant-134a. The charging process was carried out according to the following procedures:

a. When the evacuation process was completed, the manifold gauge service hose (yellow) was disconnected from the vacuum pump and reconnected to the refrigerant-134a cylinder valve.
b. Open the valve of the refrigerant cylinder for several seconds so that the gauge should indicate the pressure of about 3.5 bars and then close it back.
c. Open the low pressure valve on the left hand side of the manifold gauge.
d. Run the air conditioning so that the compressor will engage the magnetic clutch. If the compressor does not engage, add the refrigerant until the compressor engages the magnetic clutch
e. Add the refrigerant into the system until the pressure gauge indicate the pressure of about 3.5 bar.
f. Close back the low pressure valve on the manifold gauge.

3.8 PROCEDURES FOR USING STATISTICA SOFTWARE

In order to validate my coefficient of performance, COP that i get from the manual calculation, and the base data that ern from the actual experiment. Statistica software need to be use.

3.8.1 Design of Experiment

First of all, before running the actual experiment, the experiment should be designed by Design of Experiment, DOE one of application that includes in the Statistica software. Doe help to design our experiment regarding to our parameters that want to be use. Due to my experiment, i used 2 (two) parameters versus 2 (two) parameters. Thats means 2 parameters independent and 2 parameters dependent occurs in this experiment. The factorial design that give by DOE are stated below:

a. *2k* Factorial Design.

To complete replication of such a design 2x2x.....x2 = *2k* particularly useful in early stage of experimental work when many factors are likely to be investigated. The Residual Analysis as below:

$$\gamma = \beta_0 + \beta_1 \chi_1 + \beta_2 \chi_2 \ldots\ldots$$

b. *2k* Design Factor for k ≥ 3 factors.

The Residual analysis is as below:

$$\gamma = \beta_0 + \beta_1 \chi_1 + \beta_2 \chi_2 + \beta_{12} \chi_1 \chi_2 \ \ldots$$

where : χ_1 = factor A

χ_2 = factor B

$\chi_1\ \chi_2$ = AB interaction

c. Regression coefficient.

β_1, β_2, and β_{12} = estimated by one- half the corresponding effect estimates

β_0 = grand average

Using 2_k Factorial Design, we must select the function bar in Doe application and key in the parameters that stated before. Doe will design the order of our experiment due to replication number that we can state from beginning of the design.

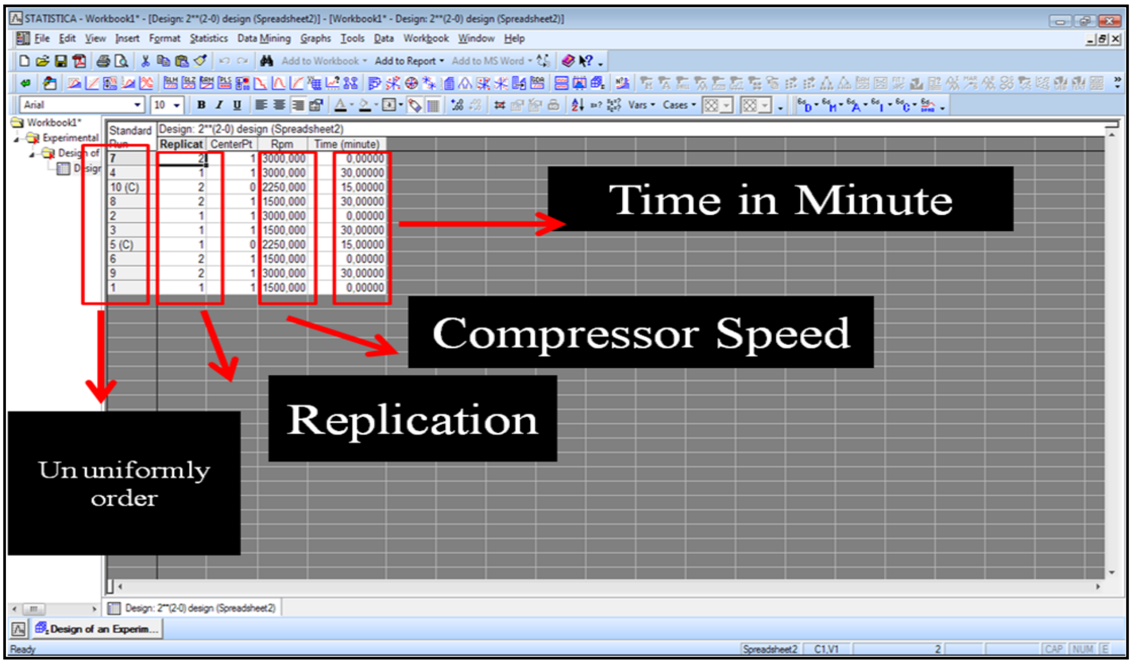


Figure 3.7: Picture of experiment order that designed by DOE in Statistica

3.9 SUMMARY

The methodology is very important as a guide to carry on the experimental work to ensure that the invention is successfully done. The next chapter will discuss and analyze the results obtained from the actual experiment and Statistica analyzing work that had been done.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter will be displayed the result from the experiment that had been conducted. Three set of experiment were done in this project. The first one is the experiment when manipulating compressor speed, the second one is experiment by manipulating refrigerant gas weight, and the third one is analyzing both COP result from both experiments in a Statistica. The results from both type experiments was analyzed and summarized in order to relate the coefficient of performance of air conditioning system in Proton Waja car with the parameters that manipulated and get an algorithm which show the very of the experiment according to actual and software experimenting besides analyzing.

4.2 DESIGN OF EXPERIMENT BY DOE APPLICATION

The experiment was designed by DOE application and the step is shown in Figure 4.1 below.

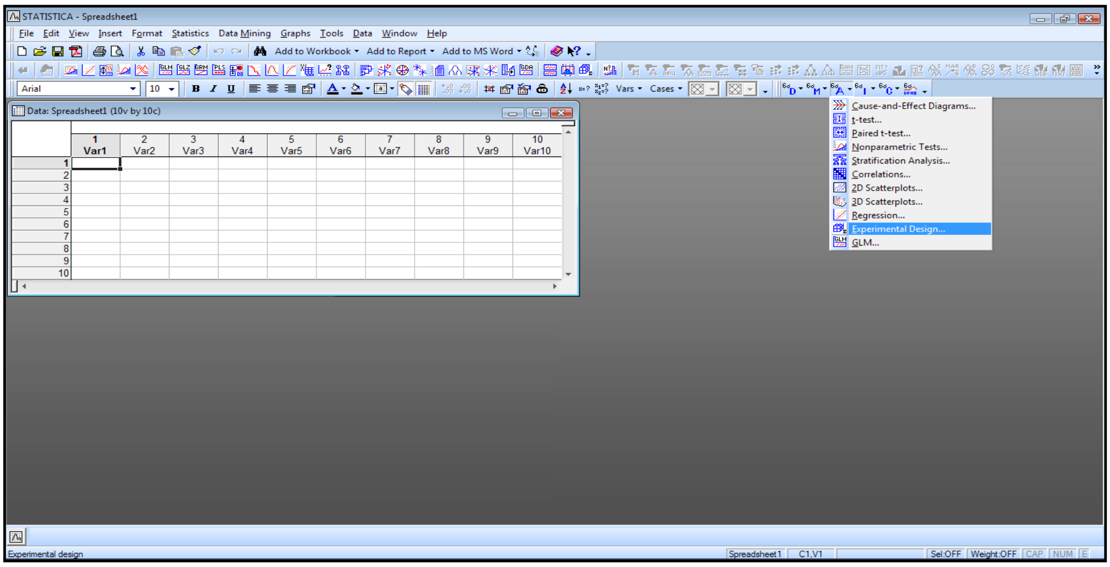


Figure 4.1: First step of work book for DOE (Design of Experiment)

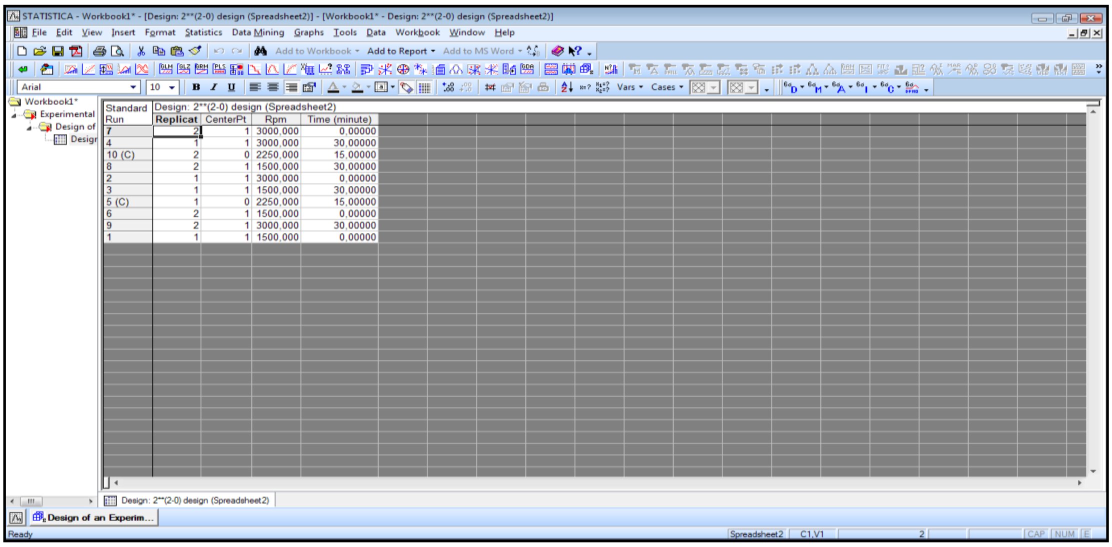


Figure 4.2: Second step of work book for DOE (Design of Experiment)

Regarding to the figure above, by using Statistica, there are a lot of application in that software. One of the application is DOE, Design of Experiment. First step of using this application is, as a need to open new spread sheet and view for toolbar Six Sigma Analysis. Then choose Experiment Design as shown in Figure 4.1. This is the result for designing the experiment as shown in Figure 4.2. DOE (Design of Experiment) application helps to design our experiment so that our experiment that want to run did not running in uniformly. DOE will rearrange our two factors that is compressor speed in round per minute (rpm) against time in minute . This design also will be same acting to other experiment that during manipulating refrigerant gas weight and vice versa. The order schedule shown in table below.

4.3 DATA COLLECTION FOR EXPERIMENTAL ORDER DUE TO DOE APPLICATION BY MANIPULATING COMPRESSOR SPEED

The experiment was testing by following procedures or order that designed by DOE as discussed in section three. The pressure and temperature at each points as discussed in previous section was measured at fix value 1.6 kg weight of refrigerant gas with container and was collected due to time ordered by DOE. The compressor speed was manipulated from 1500 rpm till 3000 rpm.The experimental was running smoothly while observing session also important to ensure the system was going stable and all the data was recorded in the table below **:**

Table 4.1 : First order of Manipulating Compressor Speed at 3000 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
0	0	0	27	35	43	43

Table 4.2 : Second order of Manipulating Compressor Speed at 3000 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
30	229.19	1482.03	22	69	58	58

Table 4.3 : Third order of Manipulating Compressor Speed at 2250 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
15	245.79	1374.85	24	64	55	55

Table 4.4 : Fourth order of Manipulating Compressor Speed at 1500 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
30	269.56	1175.12	25	57	44	44

Table 4.5 : Fifth order of Manipulating Compressor Speed at Replication 3000 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
0	0	0	26	34	43	43

Table 4.6 : Sixth order of Manipulating Compressor Speed at Replication 1500 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
30	266.49	1173.12	25	57	44	43

Table 4.7 : Seventh order of Manipulating Compressor Speed at Replication 2250 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
15	259,9	1272,43	25	60	47	47

Table 4.8 : Eighth order of Manipulating Compressor Speed at 1500 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
0	0	0	27	35	33	33

Table 4.9 Ninth order of Manipulating Compressor Speed at Replication 3000 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
30	229,02	1488,05	22	69	60	58

Table 4.10 : Tenth order of Manipulating Compressor Speed at Replication 1500 rpm

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
0	0	0	26	36	44	43

4.3.1 Data Analysis

There are two methods to analysis the data in order to determine the thermodynamic properties of the refrigerant-134a. The first one is by using *p-h* diagram for the refrigerant-134a as shown in Appendix D and the second one is by using thermodynamics properties table for the refrigerant-134a as shown in Appendix C. The two methods above can be choose either one in order to determine the properties of the refrigerant but cannot be used both at the same time.

In this analysis, the thermodynamics properties table for refrigerant-134a was used to determine the enthalpy of the refrigerant by interpolation at each point in order to find the heat rejection, cooling effect, work of compressor, and coefficient of performance of the system as well. The *p-h* diagram for refrigerant-134a was also used to show the vapor compression refrigeration cycle of the air conditioning system.

In this analysis, the theory of ideal vapor compression refrigeration cycle was reffered in order to determine the enthalpy at three and point four. Based on the theory, the enthalpy at point three was in saturated liquid region and enthalpy at point four was equal to the enthalpy at point three as shown in Figure 2.1. The enthalpy of the refrigerant at each point, heat rejection, cooling effect, work of compressor, and the coefficient of performance of the system was shown in example of calculation below.

4.3.2 Example of Calculation

Example for 2nd order.

P_1 = 229.19 kPa P_2 = 1480.03 kPa P_3 = 229.19

T_1 = 22˚C T_2 = 69˚C T_3= 58˚C

From Table A-13 at T_1= 22˚C at saturated vapor (*hg*). Getting value of enthalpy (*h*) by using interpolation:

$$\frac{22 - 20}{30 - 20} = \frac{h_1 - 270.18}{278.89 - 270.18} \qquad h_1 = 271.92 \text{ kJ/kg}$$

From Table A-13 at T_2= 69˚C at saturated vapor (*hg*). Getting value of enthalpy (h) by using interpolation:

$$\frac{69 - 60}{70 - 60} = \frac{h_2 - 285.47}{297.10 - 285.47} \qquad h_2 = 286.63 \text{ kJ/kg}$$

From Table A-11 at T_3= 58˚C at saturated fluid (*hf*). Getting value of enthalpy (*h*) by using interpolation:

$$\frac{58 - 56}{60 - 56} = \frac{h_3 - 132.91}{139.36 - 132.91} \qquad h_3 = 136.135 \text{ kJ/kg}$$

Cooling Effect, Q_{low}

$$Q_{low} = 271.92 - 136.135$$

$$= 135.78 \text{ kJ/kg}$$

Compressor Work in, W_{in}

$$W_{in} = 286.63 - 271.92$$

$$= 14.71 \text{ kJ/kg}$$

Coefficient of Performance, *COP*

$$COP = \frac{135.78 \text{ kJ/kg}}{14.71 \text{ kJ/kg}}$$

$$= 9.23$$

Table 4.11: Table overall data collection and COP value from manual calculation

Comp. Speed (rpm)	Time (minute)	h1 (kJ/kg)	h2 (kJ/kg)	h3 (kJ/kg)	Q_L (kJ/kg)	W_{in} (kJ/kg)	COP
1500	0	265.18	269.03	97.94	167.74	3.85	43.56
1500	0	264.68	269.49	114.28	150.4	4.81	31.26
1500	30	273.76	290.188	114.28	159.48	16.428	9.707
1500	30	273.76	290.188	114.28	159.48	16.428	9.707
2250	15	272.88	294.028	131.33	141.55	21.428	6.693
2250	15	273.76	289.64	118.07	155.69	15.88	9.804
3000	0	152.41	269.03	112.77	152.41	3.85	39.58
3000	0	264.65	268.57	112.77	151.91	3.89	39.05
3000	30	271.92	286.63	136.135	135.78	14.71	9.23
3000	30	271.92	286.63	139.36	132.56	14.71	9.011

4.3.3 Effect of Compressor Speed

From the Table 4.11 above, three graphs cofficient of performance versus time regarding to varying of compressor speed and increment of time was plotted and shown below.

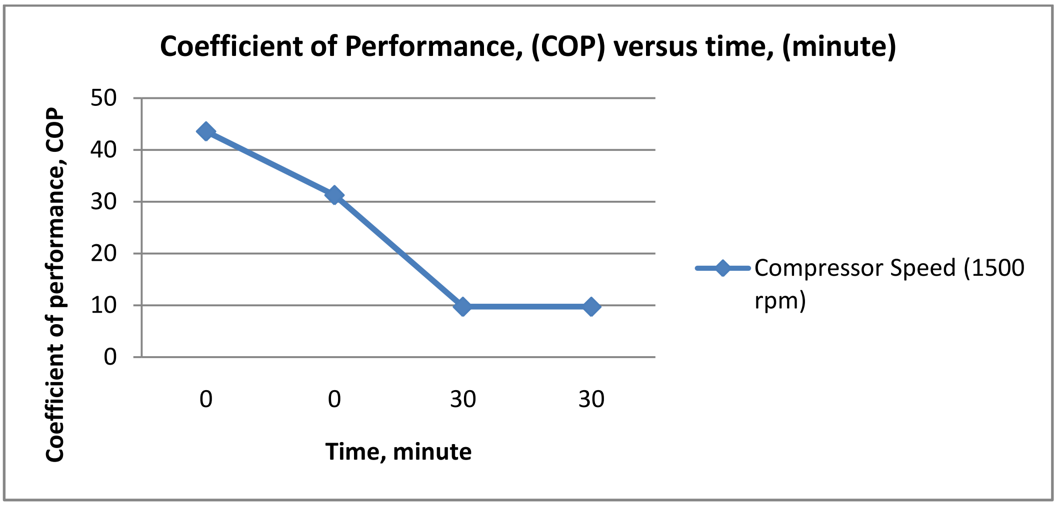


Figure 4.3: Graph Coefficient of Performance, (COP) versus Time, (minute) at compressor speed 1500 rpm.

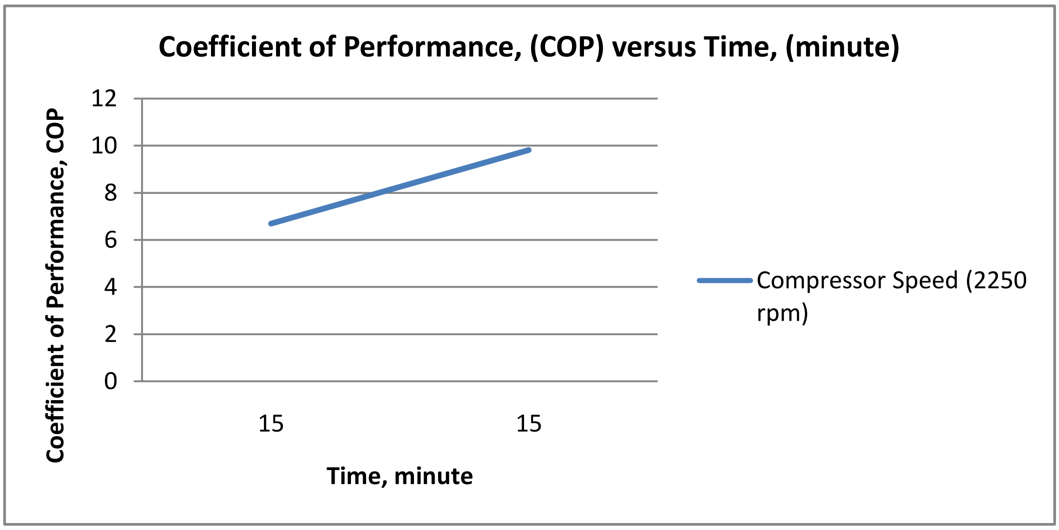


Figure 4.4: Graph Coefficient of Performance, (COP) versus Time, (minute) at compressor speed 2250 rpm.

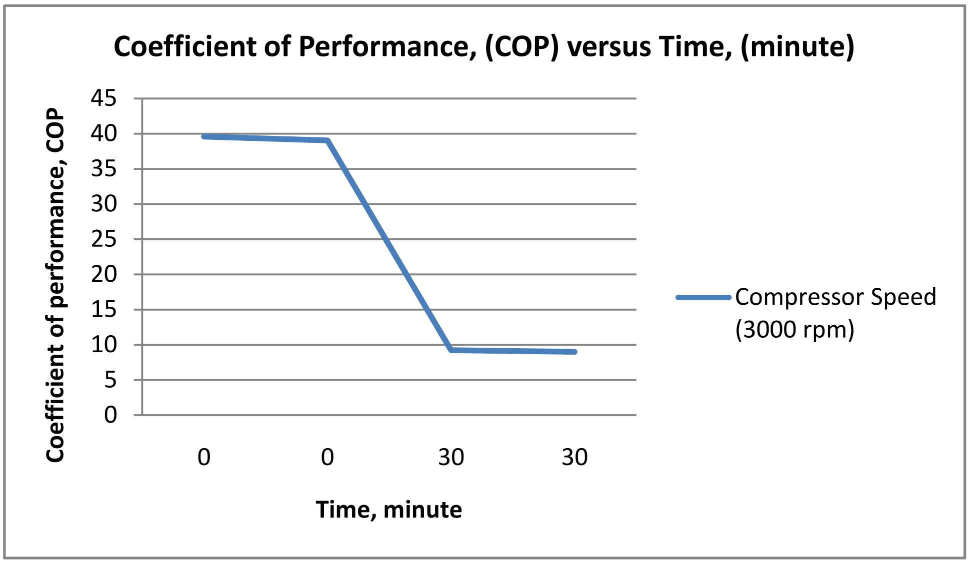


Figure 4.5: Graph Coefficient of Performance, (COP) versus Time, (minute) at compressor speed 3000 rpm.

Performance of the system means the system is better but the coefficient of performance of the air conditioning system that was determined so higher and the percentage error is about 329% to 543%. This is impossible to get the value.

The higher value of the coefficient of performance of the Proton Waja air conditioning system that had been got is actually because of the several factors. The major factor was shown in Figure 4.6 below. When the data that had been got from the experiment was plotted on the P-h diagram for refrigerant-134a as shown in figure below, the entropy of point two had been got less than the entropy at point one.

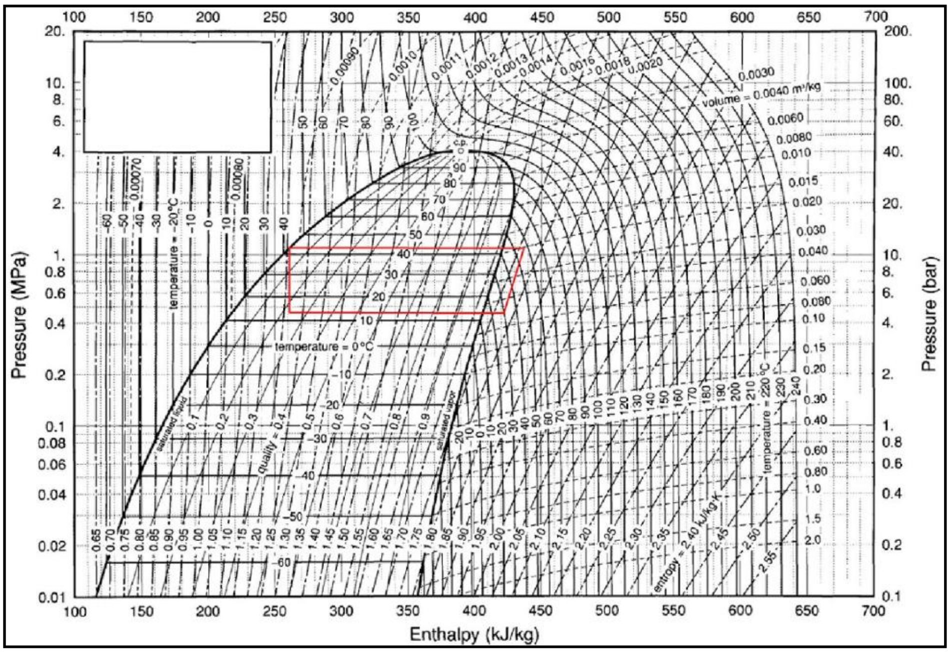


Figure 4.6: *p-h* Diagram for Vapor Compression Refrigeration Cycle of The Proton Waja Car Air Contioning system.

Based on the ideal vapor compression refrigeration theory, the process one to two is an isentropic process as shown in Figure 4.7 below means that the entropy at point two should be equal to the entropy at point one and entropy at point two cannot be less than the entropy at point one.

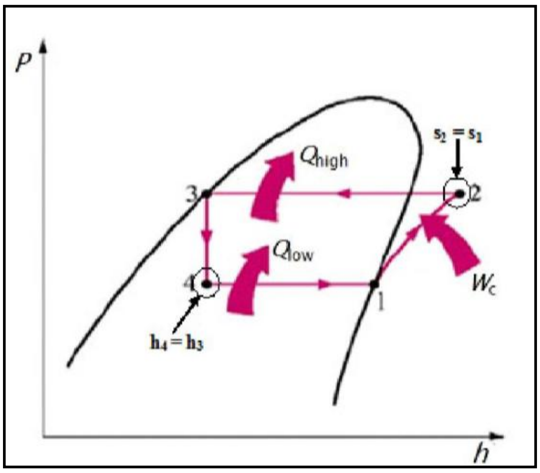


Figure 4.7: p-h Diagram for Ideal Vapor Compression Refrigeration Cycle System

The process was not follow the isentropic process because the temperature measurement at point two was done at distance quite far from the discharged valve. To get the exact value of temperature at point two, the temperature should be measured exactly at discharge valve in the compressor.

Based on the theory, enthalpy at point one should be at saturated vapor region. In this experiment, the enthalpy at point one was in the superheated region. This phenomena also same in actual application to ensure the refrigerant that enters the compressor fully in vapor phase and to prevent compressor damage. If there have liquid enters the compressor, it will damage the compressor.

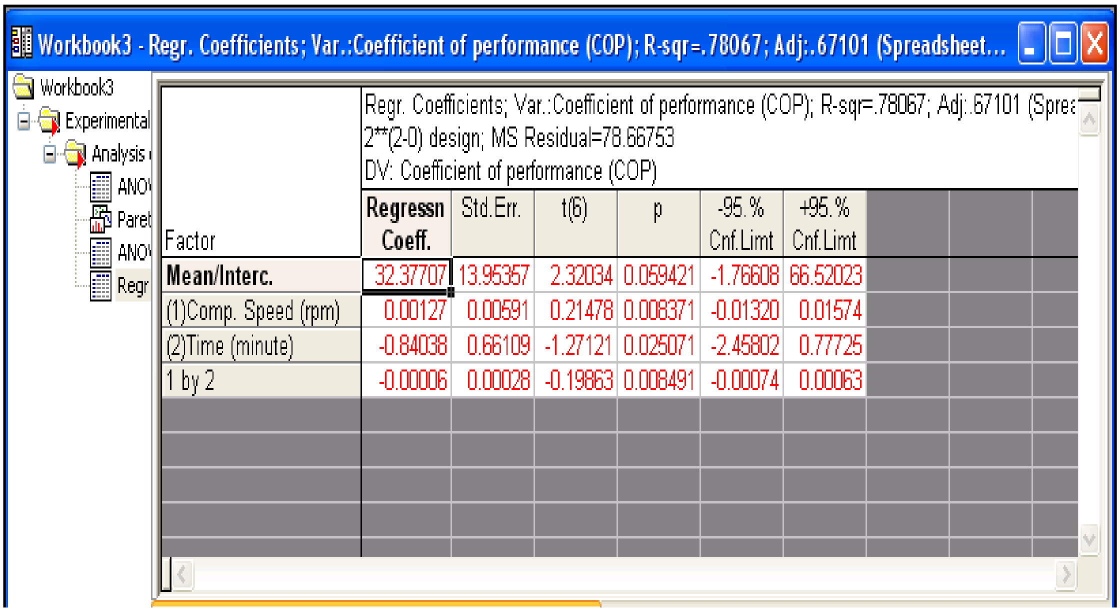
4.3.4 Result Analysis from Statistica

After all the COP for all independent parameters were get, all the COP value were transfer into the Statistica software back to analyze the data. The data that Statistica will analyze was not about the cofficient of performance of the system, but it analyze the error of the experiment, the parameters that brings most effect, the probability in experiment and analysis of the variance. Figure 4.8 below show the data sreadsheet,all the result that get from Statistica also shown.

Data: Spreadsheet13* (3v by 10c)

	1 Comp. Speed (rpm)	2 Time (minute)	3 Coefficient of performance (COP)
1	3000	0	39.58
2	3000	30	9.23
3	2250	15	6.693
4	1500	30	9.707
5	3000	0	39.05
6	1500	30	9.707
7	2250	15	9.804
8	1500	0	43.56
9	3000	30	9.011
10	1500	0	31.26

Figure 4.8 : Data Spreadsheet from manual calculation transfered into Statistica



Workbook3 - Regr. Coefficients; Var.:Coefficient of performance (COP); R-sqr=.78067; Adj:.67101 (Spreadsheet...

Regr. Coefficients; Var.:Coefficient of performance (COP); R-sqr=.78067; Adj:.67101 (Sprea
2**(2-0) design; MS Residual=78.66753
DV: Coefficient of performance (COP)

Factor	Regressn Coeff.	Std.Err.	t(6)	p	-95.% Cnf.Limt	+95.% Cnf.Limt
Mean/Interc.	32.37707	13.95357	2.32034	0.059421	-1.76608	66.52023
(1)Comp. Speed (rpm)	0.00127	0.00591	0.21478	0.008371	-0.01320	0.01574
(2)Time (minute)	-0.84038	0.66109	-1.27121	0.025071	-2.45802	0.77725
1 by 2	-0.00006	0.00028	-0.19863	0.008491	-0.00074	0.00063

Figure 4.9 : Data Spreadsheet of Regression Coefficient

In Figure 4.9 above show all data in red color, those mean the data is significant [14]. P column showed P- Value for this analysis and those data in the column in range of $0 < P < 0.05$ [14]. Beside, value of Mean over Interception in Regression Coefficient column will be substitute in β_0. Value of Compressor speed in Regression Coefficient column is substitute in β_1. Value of Time in Regression Coefficient column is substitute in β_2.

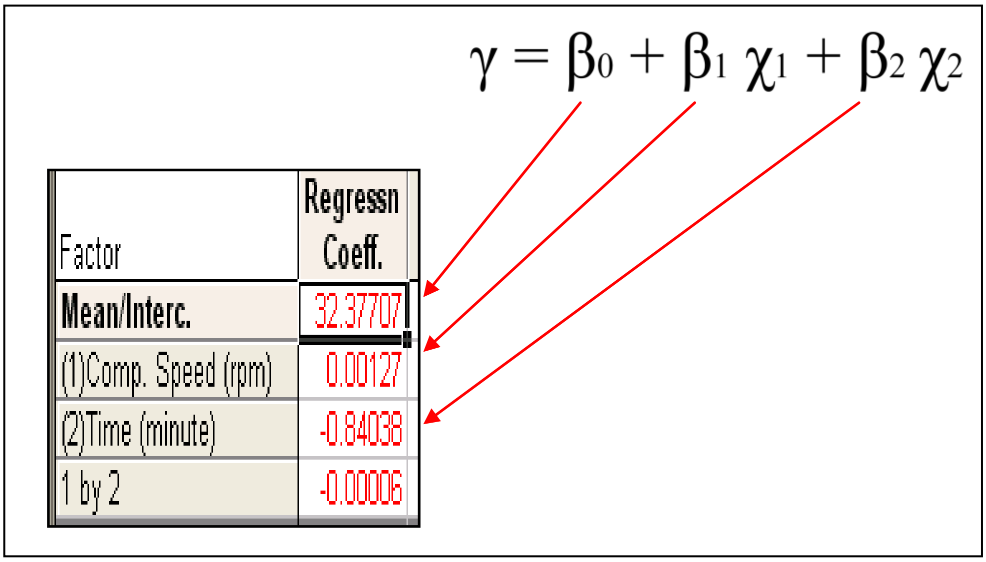


Figure 4.10 : Regression Coefficient collumn that should subtitude with value of β

From the Regression Coefficient Table, value of Mean over Interception, value of Compressor Speed (rpm), value of Time (minute) will be substituted in the algorithm that given by Statistica and the final algorithm is shown below.

$$\gamma = 32.37707 + 0.00127\chi_1 + -0.84038\chi_2$$

4.3.5 Example of calculation

This figure below shows the same table of Figure 4.8 that shown in page 42.

Data: Spreadsheet13* (3v by 10c)

	1 Comp. Speed (rpm)	2 Time (minute)	3 Coefficient of performance (COP)
1	3000	0	39.58
2	3000	30	9.23
3	2250	15	6.693
4	1500	30	9.707
5	3000	0	39.05
6	1500	30	9.707
7	2250	15	9.804
8	1500	0	43.56
9	3000	30	9.011
10	1500	0	31.26

Figure 4.8 : Data Spreadsheet from manual calculation transfered into Statistica

For example:

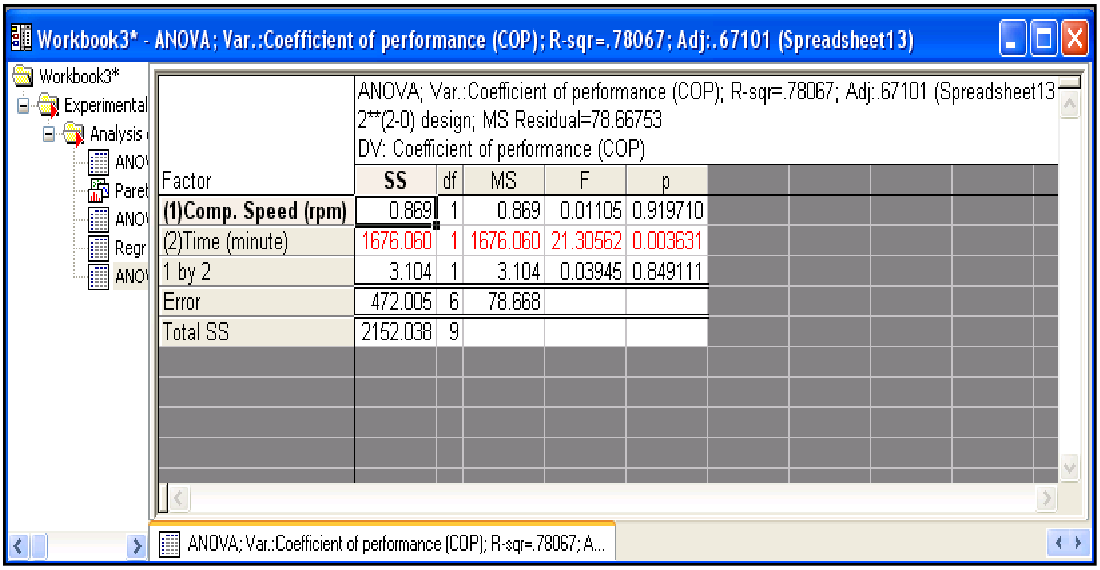
Take at time 0 during compressor speed at 3000 rpm.

$$\gamma = 32.37707 + 0.00127(3000) + -0.84038(0) = 36.18707$$

Take at time 30 during compressor speed at 3000 rpm.

$$\gamma = 32.37707 + 0.00127(3000) + -0.84038(30) = 10.97567$$

4.3.6 Analysis of Variance



Workbook3* - ANOVA; Var.:Coefficient of performance (COP); R-sqr=.78067; Adj:.67101 (Spreadsheet13)

ANOVA; Var.:Coefficient of performance (COP); R-sqr=.78067; Adj:.67101 (Spreadsheet13
2**(2-0) design; MS Residual=78.66753
DV: Coefficient of performance (COP)

Factor	SS	df	MS	F	p
(1)Comp. Speed (rpm)	0.869	1	0.869	0.01105	0.919710
(2)Time (minute)	1676.060	1	1676.060	21.30562	0.003631
1 by 2	3.104	1	3.104	0.03945	0.849111
Error	472.005	6	78.668		
Total SS	2152.038	9			

Figure 4.11: ANOVA Table.

Figure 4.11 show Anova table by meaning analysis of variance. This table shows the results that have been analyze the variance in this analysis. The red colors value in the straight row show that the most bring effect to the analysis [14]. From this Anova table, we know that the most bring effect to the analysis is time (minute) also shown below in Figure 4.12.

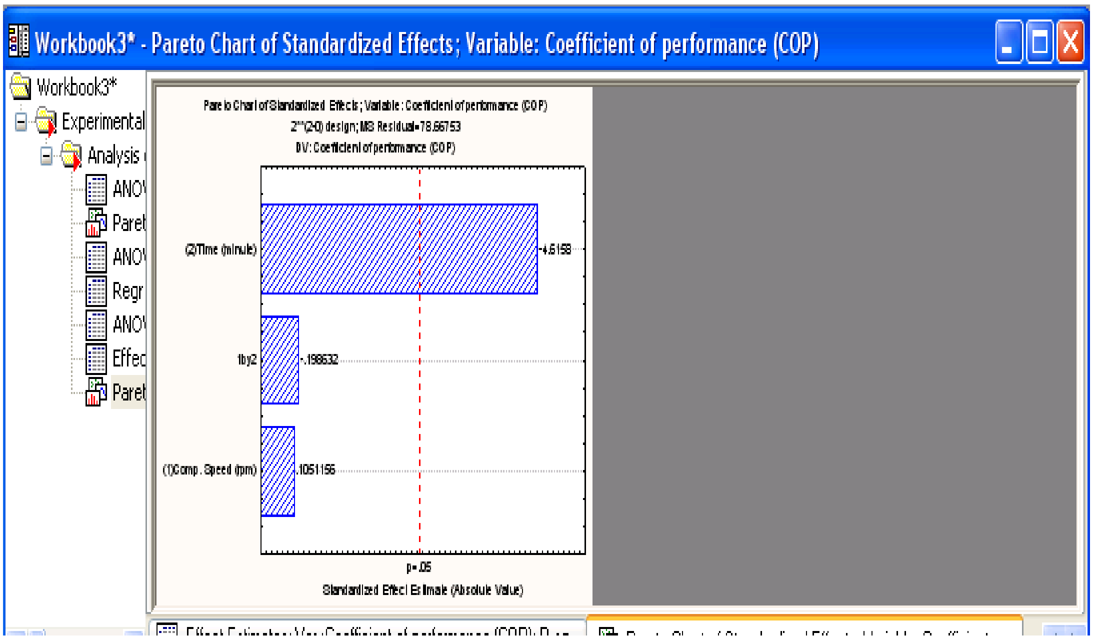


Figure 4.12: Pareto Chart of Standardized Effects.

4.4 DATA COLLECTION FOR EXPERIMENTAL ORDER DUE TO DOE APPLICATION BY MANIPULATING REFRIGERANT GAS WEIGHT

The experiment was testing by following order that designed by DOE as did in privious experiment. The pressure and temperature at each points as discussed in previous section was measured at fix value 1500 rpm compressor speed and was collected due to time ordered by DOE. The refrigerant gas with container weight was manipulated from 1.2kg till 1.6kg. All the data was recorded in the table below **:**

Table 4.12 : First order of Manipulating Refrigerant Gas Weight at 1.2kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
0	0	0	28	35	32	32

Table 4.13 : Second order of Manipulating Refrigerant Gas Weight at 1.6kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
0	0	0	27	36	33	33

Table 4.14 : Third order of Manipulating Refrigerant Gas Weight at 1.2kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
30	244.63	1314.85	25	54	50	50

Table 4.15 : Fourth order of Manipulating Refrigerant Gas Weight at 1.6kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
30	268.49	1177.63	24	57	44	43

Table 4.16 : Fifth order of Manipulating Refrigerant Gas Weight at 1.4kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
15	252.17	1421.77	25	54	48	48

Table 4.17 : Sixth order of Manipulating Refrigerant Gas Weight Replication at 1.2kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
0	0	0	28	36	34	34

Table 4.18 : Seventh order of Manipulating Refrigerant Gas Weight Replication at 1.6kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
0	0	0	27	35	33	33

Table 4.19: Eighth order of Manipulating Refrigerant Gas Weight Replication at 1.2kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
30	244.86	1307.95	26	53	49	49

Table 4.20 Ninth order of Manipulating Refrigerant Gas Weight Replication at 1.6kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
30	270.16	1180.13	25	57	44	44

Table 4.21 : Tenth order of Manipulating Refrigerant Gas Weight Replication at 1.4kg

Time (m)	Pressure, P1 (kPa)	Pressure, P2 (kPa)	Temperature, T1 (°C)	Temperature, T2 (°C)	Temperature, T3 (°C)	Temperature, T4 (°C)
15	251.17	1417.86	26	55	48	48

4.4.1 Data Analysis

As previous experiment too, there are two methods to analysis the data in order to determine the thermodynamic properties of the refrigerant-134a. The first one is by using *p-h* diagram for the refrigerant-134a as shown in Appendix D and the second one is by using thermodynamics properties table for the refrigerant-134a as shown in Appendix C. The two methods above can be choose either one in order to determine the properties of the refrigerant but cannot be used both at the same time.

In this analysis, the thermodynamics properties table for refrigerant-134a was used to determine the enthalpy of the refrigerant by interpolation at each point in order to find the heat rejection, cooling effect, work of compressor, and coefficient of performance of the system as well. The *p*-*h* diagram for refrigerant-134a was also used to show the vapor compression refrigeration cycle of the air conditioning system.

In this analysis, the theory of ideal vapor compression refrigeration cycle was followed in order to determine the enthalpy at three and point four. Based on the theory, the enthalpy at point three was in saturated liquid region and enthalpy at point four is equal to the enthalpy at point three as shown below. The enthalpy of the refrigerant at each point, heat rejection, cooling effect, work of compressor, and the coefficient of performance of the system was shown in example of calculation below.

4.4.2 Example of Calculation

Example for 3rd order.

P_1 = 244.63 kPa P_2 = 1314.85 kPa P_3 = 244.63 kPa

T_1 = 25˚C T_2 = 54˚C T_3= 50˚C

From Table A-13 at T_1= 25˚C at saturated vapor (*hg*). Getting value of enthalpy (*h*) by using interpolation:

$$\frac{25 - 20}{30 - 20} = \frac{h_1 - 269.36}{278.16 - 269.36} \qquad h_1 = 273.76 \text{ kJ/kg}$$

From Table A-13 at T_2= 54˚C at saturated vapor (*hg*). Getting value of enthalpy (h) by using interpolation:

$$\frac{54 - 50}{60 - 50} = \frac{h_2 - 278.27}{289.64 - 278.27} \qquad h_2 = 282.82 \text{ kJ/kg}$$

From Table A-11 at T_3= 50˚C at saturated fluid (*hf*). Getting value of enthalpy (*h*) by using interpolation:

$$\frac{50 - 48}{52 - 48} = \frac{h_3 - 120.39}{126.59 - 120.39} \qquad h_3 = 123.49 \text{kJ/kg}$$

Cooling Effect, Q_{low}

$$Q_{low} = 273.76 - 123.49$$

$$= 150.27 \text{ kJ/kg}$$

Compressor Work in, W_{in}

$$W_{in} = 282.82 - 273.76$$

$$= 9.06\ kJ/kg$$

Coefficient of Performance, *COP*

$$COP = \frac{150.27\ \text{kJ/kg}}{9.06\ \text{kJ/kg}}$$

$$= 16.586$$

Table 4.22: Table overall data collection and COP value from manual calculation

Refrigerant weight (kg)	Time (minute)	h1 (kJ/kg)	h2 (kJ/kg)	h3 (kJ/kg)	Q_L (kJ/kg)	W_{in} (kJ/kg)	COP
1.2	0	265.68	269.03	96.48	169.2	3.35	50.5
1.2	0	265.68	269.49	99.40	166.28	3.81	43.64
1.2	30	273.76	282.82	123.49	150.27	16.586	9.06
1.2	30	272.88	281.68	121.94	150.94	8.8	17.15
1.4	15	273.73	276.12	120.39	153.37	2.36	64.98
1.4	15	272.88	276.12	120.39	152.49	3.24	47.06
1.6	0	265.18	269.49	97.76	167.42	4.31	37.68
1.6	0	265.18	269.03	97.94	167.74	3.85	43.56
1.6	30	271.88	290.188	114.28	158.6	17.308	9.163
1.6	30	273.76	290.188	114.28	159.48	16.928	9.707

4.4.3 Effect of Refrigerant Weight

From the Table 4.12, three graphs cofficient of performance versus time regarding to varying of refrigerant gas weight and increment of time was plotted and shown below.

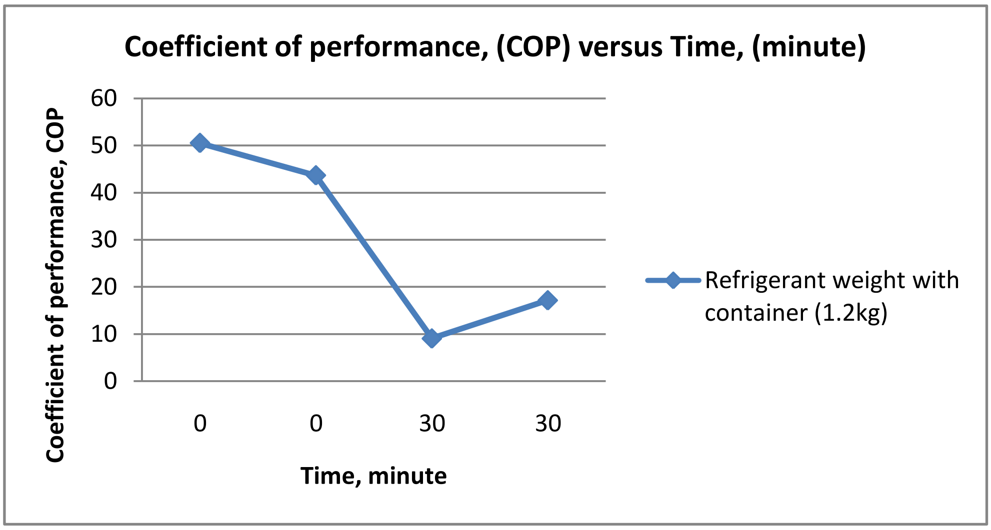


Figure 4.13: Graph Coefficient of Performance, (COP) versus Time, (minute) at refrigerant gas weight with container 1.2kg.

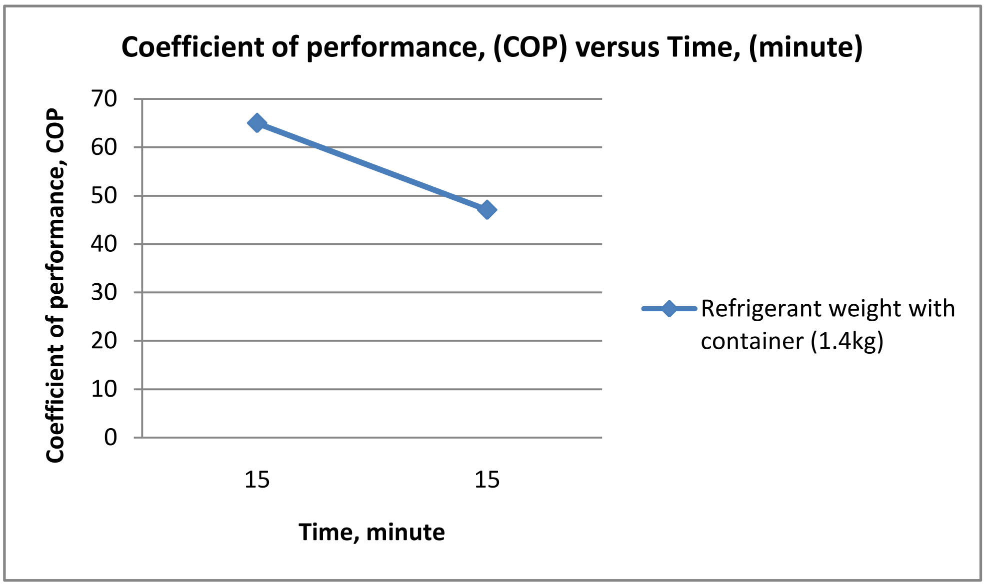


Figure 4.14: Graph Coefficient of Performance, (COP) versus Time, (minute) at refrigerant gas weight with container 1.4kg.

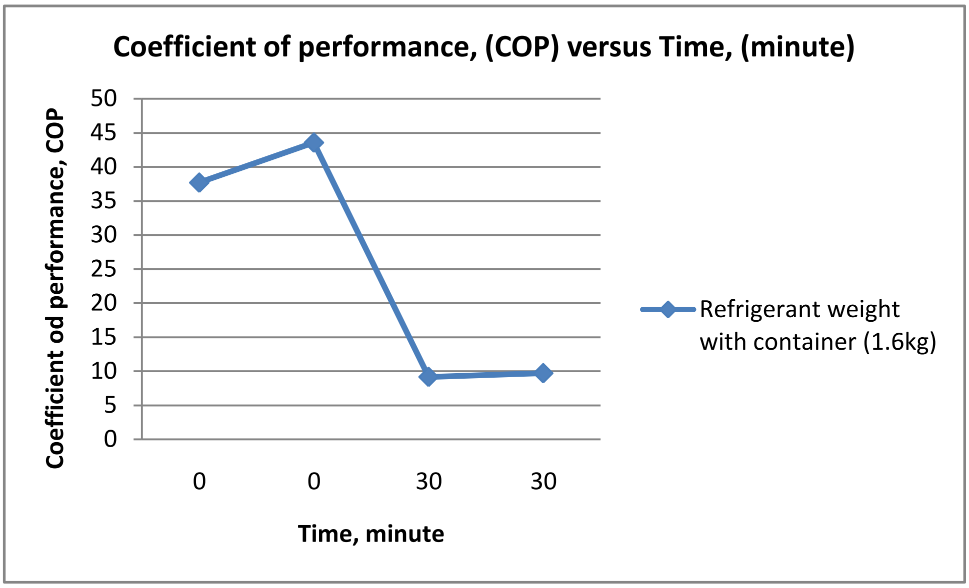


Figure 4.15: Graph Coefficient of Performance, (COP) versus Time, (minute) at refrigerant gas weight with container 1.6kg.

The higher value of the coefficient of performance of the Proton Waja air conditioning system that had been got is actually because of the several factors. The major factor was shown in Figure 4.6 below. When the data that had been got from the experiment was plotted on the P-h diagram for refrigerant-134a as shown in figure below, the entropy of point two had been got less than the entropy at point one.

4.4.4 Analysis result from Statistica

After all the COP for all independent parameters were get, all the COP value were transfer into the Statistica software back to analyze the data. The data that Statistica will analyze was not about the cofficient of performance of the system, but it analyze the error of the experiment, the parameters that brings most effect, the probability in experiment and analysis of the variance. Figure 4.16 below show the data sreadsheet,all the result that get from Statistica also shown.

Data: Spreadsheet (gas vs cop)* (10v by 10c)

	1 Weight (kg)	2 Time (minute)	3 Coefficient of Performance ,COP
1	1.2	30	9.06
2	1.2	30	17.15
3	1.4	15	64.98
4	1.6	0	37.68
5	1.6	30	9.163
6	1.6	30	9.707
7	1.6	0	43.56
8	1.2	0	50.5
9	1.2	0	43.64
10	1.4	15	47.06

Figure 4.16 : Data Spreadsheet from manual calculation transfered into Statistica

Workbook1* - Regr. Coefficients; Var.:Coefficient of Performance,COP; R-sqr=.58724...

Workbook1
Experimental
Design of
Desig
Desig
Experimental
Analysis
Regr

Regr. Coefficients; Var.:Coefficient of Performance,COP; R-sqr=.58
2**(2-0) design; MS Residual=255.0724
DV: Coefficient of Performance,COP

Factor	Regressn Coeff.	Std.Err.	t(6)	p	-95.% Cnf.Limt	+95.% Cnf.Limt
Mean/Interc.	72.1125	56.40947	1.278376	0.024834	-65.917	210.1415
(1)Weight (kg)	-16.1250	39.92747	-0.403857	0.047003	-113.824	81.5740
(2)Time (minute)	-1.4102	2.66183	-0.529773	0.036153	-7.923	5.1031
1 by 2	0.2317	1.88220	0.123083	0.019061	-4.374	4.8372

Regr. Coefficients; Var.:Coefficient of Performance,COP; R-sq...

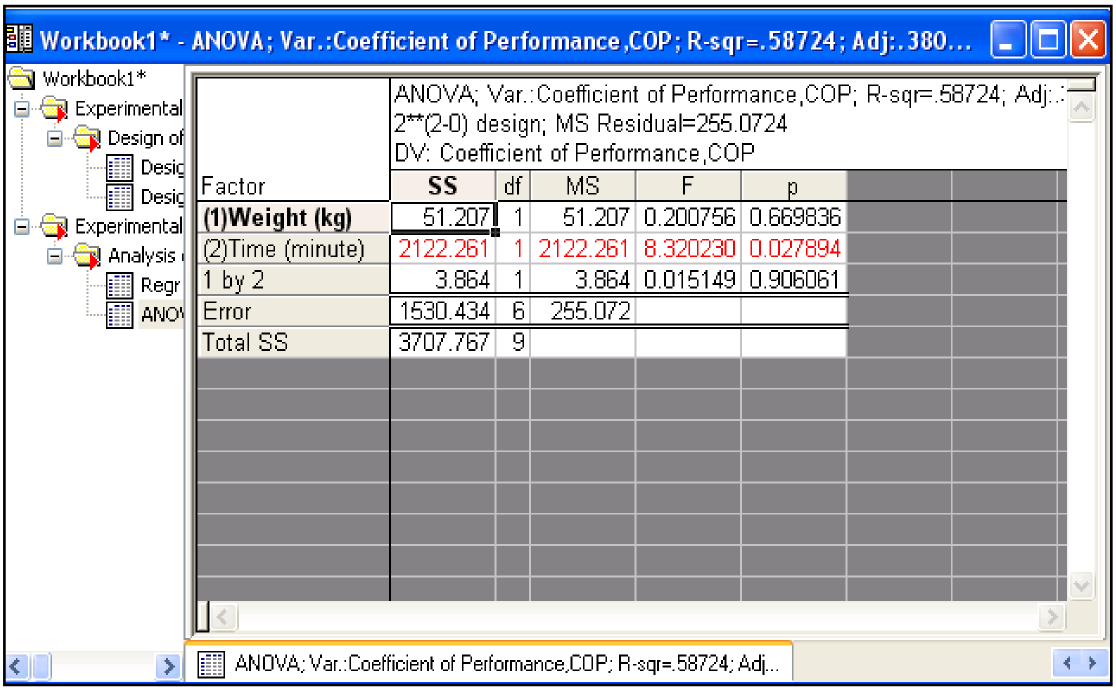
Figure 4.17 : Data Spreadsheet of Regression Coefficient

In Figure 4.17 above show all data in red color, those mean the data is significant [14]. P column showed P- Value for this analysis and those data in the column in range of $0 < P < 0.05$ [14]. Beside, value of Mean over Interception in Regression Coefficient column will be substitute in β_0. Value of Compressor speed in Regression Coefficient column is substitute in β_1. Value of Time in Regression Coefficient column is substitute in β_2.

From the Regression Coefficient Table, value of Mean over Interception, value of Compressor Speed (rpm), value of Time (minute) will be substituted in the algorithm that given by Statistica and the final algorithm is shown below.

$$\gamma = 72.1125 + (-16.1250)\chi 1 + (-1.4102)\chi 2$$

4.4.5 Analysis of Variance



ANOVA; Var.:Coefficient of Performance,COP; R-sqr=.58724; Adj:.:
2**(2-0) design; MS Residual=255.0724
DV: Coefficient of Performance,COP

Factor	SS	df	MS	F	p
(1)Weight (kg)	51.207	1	51.207	0.200756	0.669836
(2)Time (minute)	2122.261	1	2122.261	8.320230	0.027894
1 by 2	3.864	1	3.864	0.015149	0.906061
Error	1530.434	6	255.072		
Total SS	3707.767	9			

Figure 4.18: ANOVA Table.

Figure 4.11 show Anova table by meaning analysis of variance. This table shows the results that have been analyze the variance in this analysis. The red colors value in the straight row show that the most bring effect to the analysis [14]. From this Anova table, we know that the most bring effect to the analysis is time (minute) also shown below in Figure 4.12.

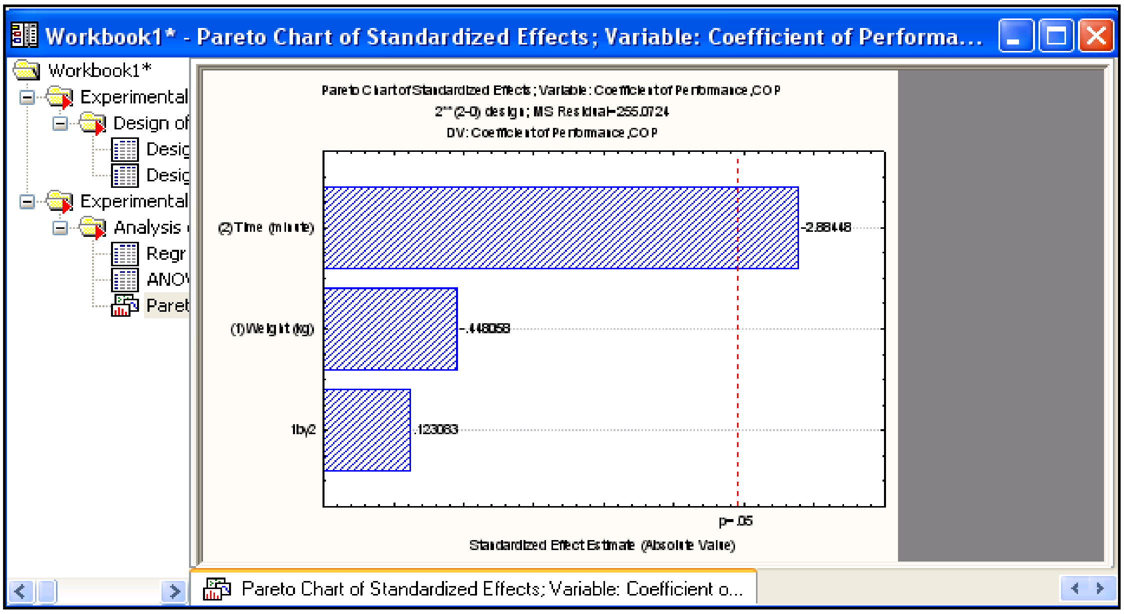


Figure 4.19: Pareto Chart of Standardized Effects.

When the speed of compressor was increased, the work of compressor will increased as well. This is because of the refrigerant that will compressed to the higher pressure and will give result in the increasing the refrigerant temperature at point two. The enthalpy of the refrigerant at point two also increased as the increasing of pressure and temperature at that point.

The coefficient of performance of the air conditioning system also decreased as the increasing of the compressor speed. This is because of the decreased of the cooling effect and the increasing of the compressor work. This also because of the fluctuation of the refrigerant mass flow rate that will be produced the system losses especially in the compressor losses.

4.5 SUMMARY

The results were shown that the increasing of the speed of compressor will give the result on the decreasing of the coefficient of performance of the system. From the result, the factors that influence in the performance of the system had been got and can be as a guide in improvement of Proton Waja car air conditioning system for better performance. The next chapter is the conclusions and recommendation to improve the experiment method in order to get more efficient result in analysis either with actual experiment or using software.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Those all above, in Final Year Project 2, all the objective had achieved. COP of Air Conditioning System in Proton Waja Car already get. The result from manual calculation show that by manipulating parameters, the COP will decrease while the result from Statistica software show that by manipulating parameters does not give much effect to the COP of the system. By the way, increasing of time that give more effect for the COP.

By using Statistica software, the error in experiment can be reduce and the result given by Statistica shown that increasing of time most effected parameter that give the result for dependent parameter that is COP. From Statistica, the manual calculation result can be validate between statistic experiment. Beside, Statistica can give an algorithm for the experiment. The equation have been prove and the result not too far different with the result by actual experiment.

For manipulating Compressor Speed, $\gamma = 32.37707 + 0.00127\chi_1 + -0.84038\chi_2$

For manipulating Refrigerant Weight, $\gamma = 72.1125 + (-16.1250)\chi_1 + (-1.4102)\chi_2$

But, not all the COP data that can be proved with this equation. It is because in Statistica, using application DOE, the replication that been applied is only one time. The algorithm need to improved to get more accurate.

The understanding about the Vapor Compression Refrigeration Cycle that had been used in the cycle of air conditioning system was understood clearly when experimental was tested and analyzed. So, it can be the aid in the air conditioning study for automotive application and also as a tool in the study of Vapor Compression Refrigeration Cycle.

The paper also discussed the relation between the speed of compressor, weight of refrigerant gas and the coefficient of performance of the Proton Waja car air conditioning system for automotive application. The analysis that had been done on the effect of the speed of compressor to the coefficient of performance of the system was result in the decreasing of the system performance as the increasing of the speed of compressor.This also be the same as vice versa by manipulating refrigerant weight.

This is because of the increasing of the losses in the system, decreasing of the cooling effect, and the increasing of compressor work as the increasing of the compressor speed. As had been mentioned in the previous chapter, the compressor is the heart of the air conditioning system and it uses about 80% of the energy required to operate an air conditioning system. This means that the compressor used in the system will determined the overall efficiency of the system. Last but not least, this analysis is successful and recommendation should be suggest for more effective in analyzing.

5.2 RECOMMENDATIONS

Recommendations are need to improve the experiment in order to get more effective result and more suitable in the air conditioning analysis for automotive application and for further research in this project. The recommendations for the experiment improvement are stated as below:-

a) More replication stated before experimenting by applying many replication during DOE, Design of Experiment.

b) The electric motor that had been used to rotate the compressor should be changed with the higher speed motor so that the compressor can be rotate at variable speed.

c) The temperature measurement should be in the pipe to get the accurate reading of refrigerant temperature. So, several holes should be made on the pipe so that the thermocouple wire can be fitted into the pipe.

d) The temperature measurement at point 2 should be exactly at the discharged valve in the compressor to get the accurate reading at that point. So the compressor needs to be modified so that the thermocouple wire can be fitted at that point.

e) The pressure measurement should be exactly at the inlet and outlet of the compressor since 80% of energy in the air conditioning system was used by the compressor. So the accurate value for the compressor work needs to be determining so that the accurate value of COP can be got.

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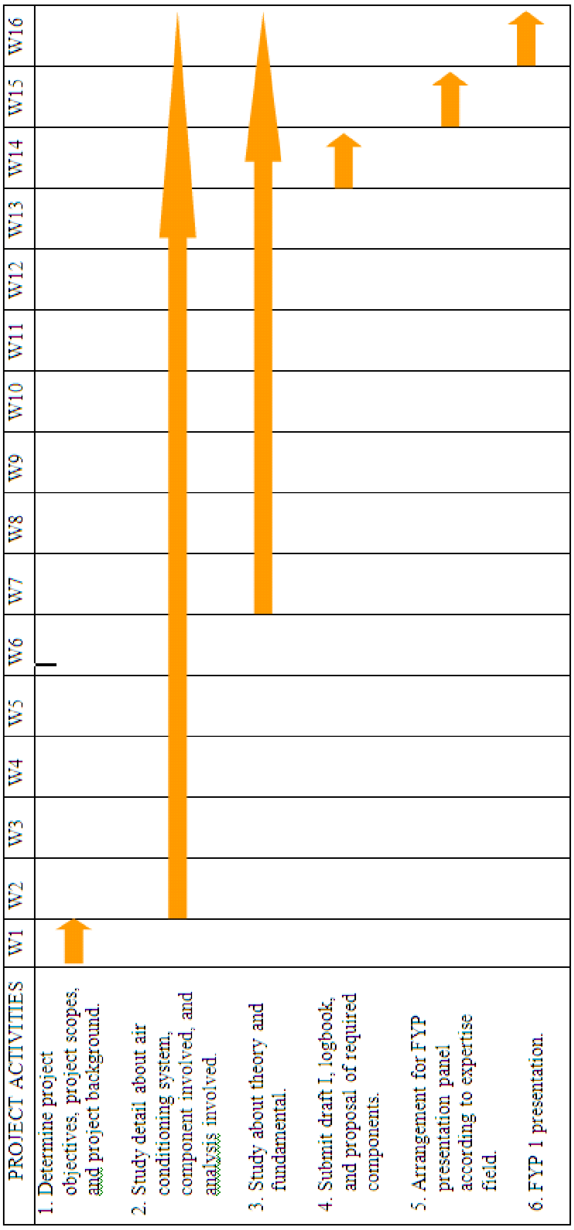
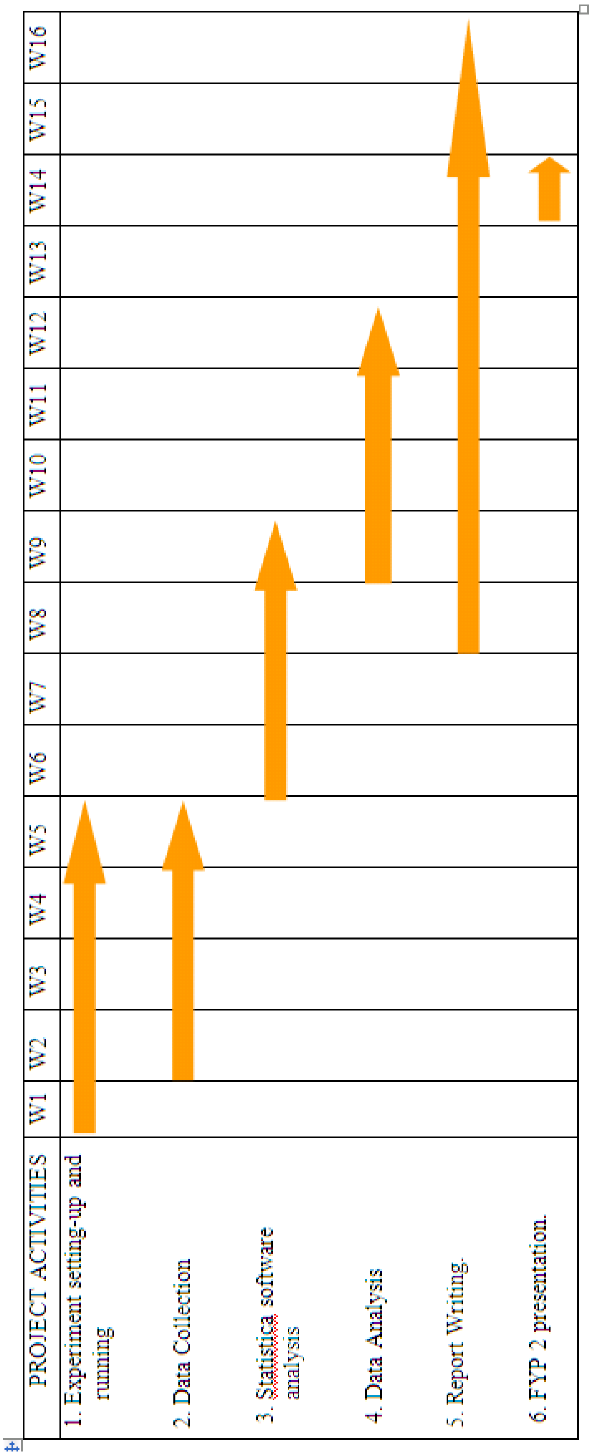
APPPENDIX A

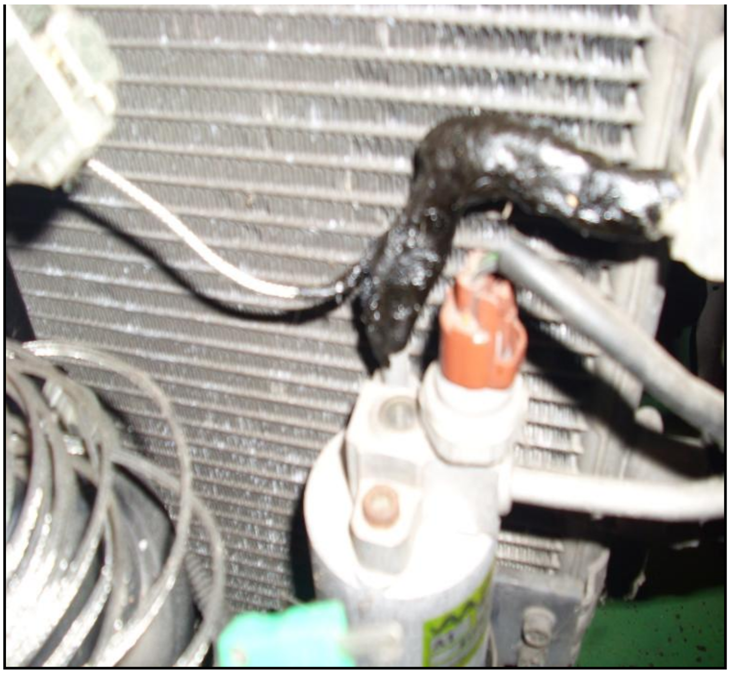


FYP 1 Gantt Chart



FYP 2 Gantt Chart

APPENDIX B



Thermocouple installation in engine compartment

Thermocouple Reader Front View

Thermocouple Reader Back View

Thermocouple

APPENDIX C

TABLE A–11

Saturated refrigerant-134a—Temperature table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
−40	51.25	0.0007054	0.36081	−0.036	207.40	207.37	0.000	225.86	225.86	0.00000	0.96866	0.96866
−38	56.86	0.0007083	0.32732	2.475	206.04	208.51	2.515	224.61	227.12	0.01072	0.95511	0.96584
−36	62.95	0.0007112	0.29751	4.992	204.67	209.66	5.037	223.35	228.39	0.02138	0.94176	0.96315
−34	69.56	0.0007142	0.27090	7.517	203.29	210.81	7.566	222.09	229.65	0.03199	0.92859	0.96058
−32	76.71	0.0007172	0.24711	10.05	201.91	211.96	10.10	220.81	230.91	0.04253	0.91560	0.95813
−30	84.43	0.0007203	0.22580	12.59	200.52	213.11	12.65	219.52	232.17	0.05301	0.90278	0.95579
−28	92.76	0.0007234	0.20666	15.13	199.12	214.25	15.20	218.22	233.43	0.06344	0.89012	0.95356
−26	101.73	0.0007265	0.18946	17.69	197.72	215.40	17.76	216.92	234.68	0.07382	0.87762	0.95144
−24	111.37	0.0007297	0.17395	20.25	196.30	216.55	20.33	215.59	235.92	0.08414	0.86527	0.94941
−22	121.72	0.0007329	0.15995	22.82	194.88	217.70	22.91	214.26	s237.17	0.09441	0.85307	0.94748
−20	132.82	0.0007362	0.14729	25.39	193.45	218.84	25.49	212.91	238.41	0.10463	0.84101	0.94564
−18	144.69	0.0007396	0.13583	27.98	192.01	219.98	28.09	211.55	239.64	0.11481	0.82908	0.94389
−16	157.38	0.0007430	0.12542	30.57	190.56	221.13	30.69	210.18	240.87	0.12493	0.81729	0.94222
−14	170.93	0.0007464	0.11597	33.17	189.09	222.27	33.30	208.79	242.09	0.13501	0.80561	0.94063
−12	185.37	0.0007499	0.10736	35.78	187.62	223.40	35.92	207.38	243.30	0.14504	0.79406	0.93911
−10	200.74	0.0007535	0.099516	38.40	186.14	224.54	38.55	205.96	244.51	0.15504	0.78263	0.93766
−8	217.08	0.0007571	0.092352	41.03	184.64	225.67	41.19	204.52	245.72	0.16498	0.77130	0.93629
−6	234.44	0.0007608	0.085802	43.66	183.13	226.80	43.84	203.07	246.91	0.17489	0.76008	0.93497
−4	252.85	0.0007646	0.079804	46.31	181.61	227.92	46.50	201.60	248.10	0.18476	0.74896	0.93372
−2	272.36	0.0007684	0.074304	48.96	180.08	229.04	49.17	200.11	249.28	0.19459	0.73794	0.93253
0	293.01	0.0007723	0.069255	51.63	178.53	230.16	51.86	198.60	250.45	0.20439	0.72701	0.93139
2	314.84	0.0007763	0.064612	54.30	176.97	231.27	54.55	197.07	251.61	0.21415	0.71616	0.93031
4	337.90	0.0007804	0.060338	56.99	175.39	232.38	57.25	195.51	252.77	0.22387	0.70540	0.92927
6	362.23	0.0007845	0.056398	59.68	173.80	233.48	59.97	193.94	253.91	0.23356	0.69471	0.92828
8	387.88	0.0007887	0.052762	62.39	172.19	234.58	62.69	192.35	255.04	0.24323	0.68410	0.92733
10	414.89	0.0007930	0.049403	65.10	170.56	235.67	65.43	190.73	256.16	0.25286	0.67356	0.92641
12	443.31	0.0007975	0.046295	67.83	168.92	236.75	68.18	189.09	257.27	0.26246	0.66308	0.92554
14	473.19	0.0008020	0.043417	70.57	167.26	237.83	70.95	187.42	258.37	0.27204	0.65266	0.92470
16	504.58	0.0008066	0.040748	73.32	165.58	238.90	73.73	185.73	259.46	0.28159	0.64230	0.92389
18	537.52	0.0008113	0.038271	76.08	163.88	239.96	76.52	184.01	260.53	0.29112	0.63198	0.92310

TABLE A–11

Saturated refrigerant-134a—Temperature table (*Continued*)

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
20	572.07	0.0008161	0.035969	78.86	162.16	241.02	79.32	182.27	261.59	0.30063	0.62172	0.92234
22	608.27	0.0008210	0.033828	81.64	160.42	242.06	82.14	180.49	262.64	0.31011	0.61149	0.92160
24	646.18	0.0008261	0.031834	84.44	158.65	243.10	84.98	178.69	263.67	0.31958	0.60130	0.92088
26	685.84	0.0008313	0.029976	87.26	156.87	244.12	87.83	176.85	264.68	0.32903	0.59115	0.92018
28	727.31	0.0008366	0.028242	90.09	155.05	245.14	90.69	174.99	265.68	0.33846	0.58102	0.91948
30	770.64	0.0008421	0.026622	92.93	153.22	246.14	93.58	173.08	266.66	0.34789	0.57091	0.91879
32	815.89	0.0008478	0.025108	95.79	151.35	247.14	96.48	171.14	267.62	0.35730	0.56082	0.91811
34	863.11	0.0008536	0.023691	98.66	149.46	248.12	99.40	169.17	268.57	0.36670	0.55074	0.91743
36	912.35	0.0008595	0.022364	101.55	147.54	249.08	102.33	167.16	269.49	0.37609	0.54066	0.91675
38	963.68	0.0008657	0.021119	104.45	145.58	250.04	105.29	165.10	270.39	0.38548	0.53058	0.91606
40	1017.1	0.0008720	0.019952	107.38	143.60	250.97	108.26	163.00	271.27	0.39486	0.52049	0.91536
42	1072.8	0.0008786	0.018855	110.32	141.58	251.89	111.26	160.86	272.12	0.40425	0.51039	0.91464
44	1130.7	0.0008854	0.017824	113.28	139.52	252.80	114.28	158.67	272.95	0.41363	0.50027	0.91391
46	1191.0	0.0008924	0.016853	116.26	137.42	253.68	117.32	156.43	273.75	0.42302	0.49012	0.91315
48	1253.6	0.0008996	0.015939	119.26	135.29	254.55	120.39	154.14	274.53	0.43242	0.47993	0.91236
52	1386.2	0.0009150	0.014265	125.33	130.88	256.21	126.59	149.39	275.98	0.45126	0.45941	0.91067
56	1529.1	0.0009317	0.012771	131.49	126.28	257.77	132.91	144.38	277.30	0.47018	0.43863	0.90880
60	1682.8	0.0009498	0.011434	137.76	121.46	259.22	139.36	139.10	278.46	0.48920	0.41749	0.90669
65	1891.0	0.0009750	0.009950	145.77	115.05	260.82	147.62	132.02	279.64	0.51320	0.39039	0.90359
70	2118.2	0.0010037	0.008642	154.01	108.14	262.15	156.13	124.32	280.46	0.53755	0.36227	0.89982
75	2365.8	0.0010372	0.007480	162.53	100.60	263.13	164.98	115.85	280.82	0.56241	0.33272	0.89512
80	2635.3	0.0010772	0.006436	171.40	92.23	263.63	174.24	106.35	280.59	0.58800	0.30111	0.88912
85	2928.2	0.0011270	0.005486	180.77	82.67	263.44	184.07	95.44	279.51	0.61473	0.26644	0.88117
90	3246.9	0.0011932	0.004599	190.89	71.29	262.18	194.76	82.35	277.11	0.64336	0.22674	0.87010
95	3594.1	0.0012933	0.003726	202.40	56.47	258.87	207.05	65.21	272.26	0.67578	0.17711	0.85289
100	3975.1	0.0015269	0.002630	218.72	29.19	247.91	224.79	33.58	258.37	0.72217	0.08999	0.81215

Source: Tables A–11 through A–13 are generated using the Engineering Equation Solver (EES) software developed by S. A. Klein and F. L. Alvarado. The routine used in calculations is the R134a, which is based on the fundamental equation of state developed by R. Tillner-Roth and H.D. Baehr, "An International Standard Formulation for the Thermodynamic Properties of 1,1,1,2-Tetrafluoroethane (HFC-134a) for temperatures from 170 K to 455 K and Pressures up to 70 MPa," *J. Phys. Chem, Ref. Data*, Vol. 23, No. 5, 1994. The enthalpy and entropy values of saturated liquid are set to zero at −40°C (and −40°F).

TABLE A–12

Saturated refrigerant-134a—Pressure table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
60	−36.95	0.0007098	0.31121	3.798	205.32	209.12	3.841	223.95	227.79	0.01634	0.94807	0.964
70	−33.87	0.0007144	0.26929	7.680	203.20	210.88	7.730	222.00	229.73	0.03267	0.92775	0.960
80	−31.13	0.0007185	0.23753	11.15	201.30	212.46	11.21	220.25	231.46	0.04711	0.90999	0.957
90	−28.65	0.0007223	0.21263	14.31	199.57	213.88	14.37	218.65	233.02	0.06008	0.89419	0.954
100	−26.37	0.0007259	0.19254	17.21	197.98	215.19	17.28	217.16	234.44	0.07188	0.87995	0.951
120	−22.32	0.0007324	0.16212	22.40	195.11	217.51	22.49	214.48	236.97	0.09275	0.85503	0.947
140	−18.77	0.0007383	0.14014	26.98	192.57	219.54	27.08	212.08	239.16	0.11087	0.83368	0.944
160	−15.60	0.0007437	0.12348	31.09	190.27	221.35	31.21	209.90	241.11	0.12693	0.81496	0.941
180	−12.73	0.0007487	0.11041	34.83	188.16	222.99	34.97	207.90	242.86	0.14139	0.79826	0.939
200	−10.09	0.0007533	0.099867	38.28	186.21	224.48	38.43	206.03	244.46	0.15457	0.78316	0.937
240	−5.38	0.0007620	0.083897	44.48	182.67	227.14	44.66	202.62	247.28	0.17794	0.75664	0.934
280	−1.25	0.0007699	0.072352	49.97	179.50	229.46	50.18	199.54	249.72	0.19829	0.73381	0.932
320	2.46	0.0007772	0.063604	54.92	176.61	231.52	55.16	196.71	251.88	0.21637	0.71369	0.930
360	5.82	0.0007841	0.056738	59.44	173.94	233.38	59.72	194.08	253.81	0.23270	0.69566	0.928
400	8.91	0.0007907	0.051201	63.62	171.45	235.07	63.94	191.62	255.55	0.24761	0.67929	0.926
450	12.46	0.0007985	0.045619	68.45	168.54	237.00	68.81	188.71	257.53	0.26465	0.66069	0.925
500	15.71	0.0008059	0.041118	72.93	165.82	238.75	73.33	185.98	259.30	0.28023	0.64377	0.924
550	18.73	0.0008130	0.037408	77.10	163.25	240.35	77.54	183.38	260.92	0.29461	0.62821	0.922
600	21.55	0.0008199	0.034295	81.02	160.81	241.83	81.51	180.90	262.40	0.30799	0.61378	0.921
650	24.20	0.0008266	0.031646	84.72	158.48	243.20	85.26	178.51	263.77	0.32051	0.60030	0.920
700	26.69	0.0008331	0.029361	88.24	156.24	244.48	88.82	176.21	265.03	0.33230	0.58763	0.919
750	29.06	0.0008395	0.027371	91.59	154.08	245.67	92.22	173.98	266.20	0.34345	0.57567	0.919
800	31.31	0.0008458	0.025621	94.79	152.00	246.79	95.47	171.82	267.29	0.35404	0.56431	0.918
850	33.45	0.0008520	0.024069	97.87	149.98	247.85	98.60	169.71	268.31	0.36413	0.55349	0.917
900	35.51	0.0008580	0.022683	100.83	148.01	248.85	101.61	167.66	269.26	0.37377	0.54315	0.916
950	37.48	0.0008641	0.021438	103.69	146.10	249.79	104.51	165.64	270.15	0.38301	0.53323	0.916
1000	39.37	0.0008700	0.020313	106.45	144.23	250.68	107.32	163.67	270.99	0.39189	0.52368	0.915
1200	46.29	0.0008934	0.016715	116.70	137.11	253.81	117.77	156.10	273.87	0.42441	0.48863	0.913
1400	52.40	0.0009166	0.014107	125.94	130.43	256.37	127.22	148.90	276.12	0.45315	0.45734	0.910
1600	57.88	0.0009400	0.012123	134.43	124.04	258.47	135.93	141.93	277.86	0.47911	0.42873	0.907
1800	62.87	0.0009639	0.010559	142.33	117.83	260.17	144.07	135.11	279.17	0.50294	0.40204	0.904
2000	67.45	0.0009886	0.009288	149.78	111.73	261.51	151.76	128.33	280.09	0.52509	0.37675	0.901
2500	77.54	0.0010566	0.006936	166.99	96.47	263.45	169.63	111.16	280.79	0.57531	0.31695	0.892
3000	86.16	0.0011406	0.005275	183.04	80.22	263.26	186.46	92.63	279.09	0.62118	0.25776	0.878

TABLE A–13

Superheated refrigerant-134a

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	P = 0.06 MPa (T_{sat} = −36.95°C)				P = 0.10 MPa (T_{sat} = −26.37°C)				P = 0.14 MPa (T_{sat} = −18.77°C)			
Sat.	0.31121	209.12	227.79	0.9644	0.19254	215.19	234.44	0.9518	0.14014	219.54	239.16	0.9446
−20	0.33608	220.60	240.76	1.0174	0.19841	219.66	239.50	0.9721				
−10	0.35048	227.55	248.58	1.0477	0.20743	226.75	247.49	1.0030	0.14605	225.91	246.36	0.9724
0	0.36476	234.66	256.54	1.0774	0.21630	233.95	255.58	1.0332	0.15263	233.23	254.60	1.0031
10	0.37893	241.92	264.66	1.1066	0.22506	241.30	263.81	1.0628	0.15908	240.66	262.93	1.0331
20	0.39302	249.35	272.94	1.1353	0.23373	248.79	272.17	1.0918	0.16544	248.22	271.38	1.0624
30	0.40705	256.95	281.37	1.1636	0.24233	256.44	280.68	1.1203	0.17172	255.93	279.97	1.0912
40	0.42102	264.71	289.97	1.1915	0.25088	264.25	289.34	1.1484	0.17794	263.79	288.70	1.1195
50	0.43495	272.64	298.74	1.2191	0.25937	272.22	298.16	1.1762	0.18412	271.79	297.57	1.1474
60	0.44883	280.73	307.66	1.2463	0.26783	280.35	307.13	1.2035	0.19025	279.96	306.59	1.1749
70	0.46269	288.99	316.75	1.2732	0.27626	288.64	316.26	1.2305	0.19635	288.28	315.77	1.2020
80	0.47651	297.41	326.00	1.2997	0.28465	297.08	325.55	1.2572	0.20242	296.75	325.09	1.2288
90	0.49032	306.00	335.42	1.3260	0.29303	305.69	334.99	1.2836	0.20847	305.38	334.57	1.2553
100	0.50410	314.74	344.99	1.3520	0.30138	314.46	344.60	1.3096	0.21449	314.17	344.20	1.2814
	P = 0.18 MPa (T_{sat} = −12.73°C)				P = 0.20 MPa (T_{sat} = −10.09°C)				P = 0.24 MPa (T_{sat} = −5.38°C)			
Sat.	0.11041	222.99	242.86	0.9397	0.09987	224.48	244.46	0.9377	0.08390	227.14	247.28	0.9346
−10	0.11189	225.02	245.16	0.9484	0.09991	224.55	244.54	0.9380				
0	0.11722	232.48	253.58	0.9798	0.10481	232.09	253.05	0.9698	0.08617	231.29	251.97	0.9519
10	0.12240	240.00	262.04	1.0102	0.10955	239.67	261.58	1.0004	0.09026	238.98	260.65	0.9831
20	0.12748	247.64	270.59	1.0399	0.11418	247.35	270.18	1.0303	0.09423	246.74	269.36	1.0134
30	0.13248	255.41	279.25	1.0690	0.11874	255.14	278.89	1.0595	0.09812	254.61	278.16	1.0429
40	0.13741	263.31	288.05	1.0975	0.12322	263.08	287.72	1.0882	0.10193	262.59	287.06	1.0718
50	0.14230	271.36	296.98	1.1256	0.12766	271.15	296.68	1.1163	0.10570	270.71	296.08	1.1001
60	0.14715	279.56	306.05	1.1532	0.13206	279.37	305.78	1.1441	0.10942	278.97	305.23	1.1280
70	0.15196	287.91	315.27	1.1805	0.13641	287.73	315.01	1.1714	0.11310	287.36	314.51	1.1554
80	0.15673	296.42	324.63	1.2074	0.14074	296.25	324.40	1.1983	0.11675	295.91	323.93	1.1825
90	0.16149	305.07	334.14	1.2339	0.14504	304.92	333.93	1.2249	0.12038	304.60	333.49	1.2092
100	0.16622	313.88	343.80	1.2602	0.14933	313.74	343.60	1.2512	0.12398	313.44	343.20	1.2356
	P = 0.28 MPa (T_{sat} = −1.25°C)				P = 0.32 MPa (T_{sat} = 2.46°C)				P = 0.40 MPa (T_{sat} = 8.91°C)			
Sat.	0.07235	229.46	249.72	0.9321	0.06360	231.52	251.88	0.9301	0.051201	235.07	255.55	0.9269
0	0.07282	230.44	250.83	0.9362								
10	0.07646	238.27	259.68	0.9680	0.06609	237.54	258.69	0.9544	0.051506	235.97	256.58	0.9305
20	0.07997	246.13	268.52	0.9987	0.06925	245.50	267.66	0.9856	0.054213	244.18	265.86	0.9628
30	0.08338	254.06	277.41	1.0285	0.07231	253.50	276.65	1.0157	0.056796	252.36	275.07	0.9937
40	0.08672	262.10	286.38	1.0576	0.07530	261.60	285.70	1.0451	0.059292	260.58	284.30	1.0236
50	0.09000	270.27	295.47	1.0862	0.07823	269.82	294.85	1.0739	0.061724	268.90	293.59	1.0528
60	0.09324	278.56	304.67	1.1142	0.08111	278.15	304.11	1.1021	0.064104	277.32	302.96	1.0814
70	0.09644	286.99	314.00	1.1418	0.08395	286.62	313.48	1.1298	0.066443	285.86	312.44	1.1094
80	0.09961	295.57	323.46	1.1690	0.08675	295.22	322.98	1.1571	0.068747	294.53	322.02	1.1369
90	0.10275	304.29	333.06	1.1958	0.08953	303.97	332.62	1.1840	0.071023	303.32	331.73	1.1640
100	0.10587	313.15	342.80	1.2222	0.09229	312.86	342.39	1.2105	0.073274	312.26	341.57	1.1907
110	0.10897	322.16	352.68	1.2483	0.09503	321.89	352.30	1.2367	0.075504	321.33	351.53	1.2171
120	0.11205	331.32	362.70	1.2742	0.09775	331.07	362.35	1.2626	0.077717	330.55	361.63	1.2431
130	0.11512	340.63	372.87	1.2997	0.10045	340.39	372.54	1.2882	0.079913	339.90	371.87	1.2688
140	0.11818	350.09	383.18	1.3250	0.10314	349.86	382.87	1.3135	0.082096	349.41	382.24	1.2942

TABLE A–13

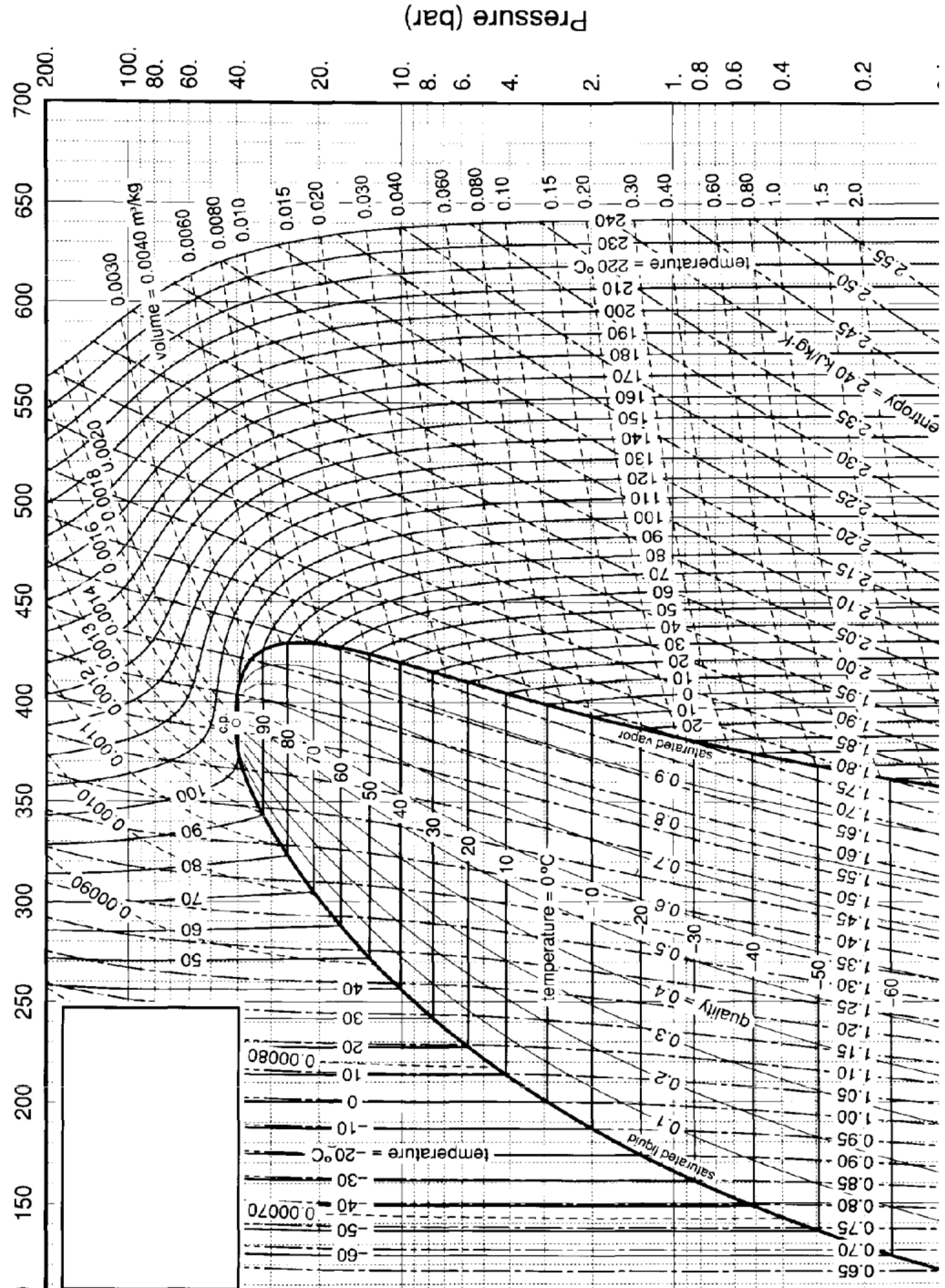
Superheated refrigerant-134a (*Continued*)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg ·
	P = 0.50 MPa (T_{sat} = 15.71°C)				P = 0.60 MPa (T_{sat} = 21.55°C)				P = 0.70 MPa (T_{sat} = 26.69°C)			
Sat.	0.041118	238.75	259.30	0.9240	0.034295	241.83	262.40	0.9218	0.029361	244.48	265.03	0.919
20	0.042115	242.40	263.46	0.9383								
30	0.044338	250.84	273.01	0.9703	0.035984	249.22	270.81	0.9499	0.029966	247.48	268.45	0.931
40	0.046456	259.26	282.48	1.0011	0.037865	257.86	280.58	0.9816	0.031696	256.39	278.57	0.964
50	0.048499	267.72	291.96	1.0309	0.039659	266.48	290.28	1.0121	0.033322	265.20	288.53	0.995
60	0.050485	276.25	301.50	1.0599	0.041389	275.15	299.98	1.0417	0.034875	274.01	298.42	1.025
70	0.052427	284.89	311.10	1.0883	0.043069	283.89	309.73	1.0705	0.036373	282.87	308.33	1.054
80	0.054331	293.64	320.80	1.1162	0.044710	292.73	319.55	1.0987	0.037829	291.80	318.28	1.083
90	0.056205	302.51	330.61	1.1436	0.046318	301.67	329.46	1.1264	0.039250	300.82	328.29	1.111
100	0.058053	311.50	340.53	1.1705	0.047900	310.73	339.47	1.1536	0.040642	309.95	338.40	1.138
110	0.059880	320.63	350.57	1.1971	0.049458	319.91	349.59	1.1803	0.042010	319.19	348.60	1.165
120	0.061687	329.89	360.73	1.2233	0.050997	329.23	359.82	1.2067	0.043358	328.55	358.90	1.192
130	0.063479	339.29	371.03	1.2491	0.052519	338.67	370.18	1.2327	0.044688	338.04	369.32	1.218
140	0.065256	348.83	381.46	1.2747	0.054027	348.25	380.66	1.2584	0.046004	347.66	379.86	1.244
150	0.067021	358.51	392.02	1.2999	0.055522	357.96	391.27	1.2838	0.047306	357.41	390.52	1.269
160	0.068775	368.33	402.72	1.3249	0.057006	367.81	402.01	1.3088	0.048597	367.29	401.31	1.295

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg ·
	P = 0.80 MPa (T_{sat} = 31.31°C)				P = 0.90 MPa (T_{sat} = 35.51°C)				P = 1.00 MPa (T_{sat} = 39.37°C)			
Sat.	0.025621	246.79	267.29	0.9183	0.022683	248.85	269.26	0.9169	0.020313	250.68	270.99	0.915
40	0.027035	254.82	276.45	0.9480	0.023375	253.13	274.17	0.9327	0.020406	251.30	271.71	0.917
50	0.028547	263.86	286.69	0.9802	0.024809	262.44	284.77	0.9660	0.021796	260.94	282.74	0.952
60	0.029973	272.83	296.81	1.0110	0.026146	271.60	295.13	0.9976	0.023068	270.32	293.38	0.985
70	0.031340	281.81	306.88	1.0408	0.027413	280.72	305.39	1.0280	0.024261	279.59	303.85	1.016
80	0.032659	290.84	316.97	1.0698	0.028630	289.86	315.63	1.0574	0.025398	288.86	314.25	1.045
90	0.033941	299.95	327.10	1.0981	0.029806	299.06	325.89	1.0860	0.026492	298.15	324.64	1.074
100	0.035193	309.15	337.30	1.1258	0.030951	308.34	336.19	1.1140	0.027552	307.51	335.06	1.103
110	0.036420	318.45	347.59	1.1530	0.032068	317.70	346.56	1.1414	0.028584	316.94	345.53	1.130
120	0.037625	327.87	357.97	1.1798	0.033164	327.18	357.02	1.1684	0.029592	326.47	356.06	1.158
130	0.038813	337.40	368.45	1.2061	0.034241	336.76	367.58	1.1949	0.030581	336.11	366.69	1.184
140	0.039985	347.06	379.05	1.2321	0.035302	346.46	378.23	1.2210	0.031554	345.85	377.40	1.210
150	0.041143	356.85	389.76	1.2577	0.036349	356.28	389.00	1.2467	0.032512	355.71	388.22	1.236
160	0.042290	366.76	400.59	1.2830	0.037384	366.23	399.88	1.2721	0.033457	365.70	399.15	1.262
170	0.043427	376.81	411.55	1.3080	0.038408	376.31	410.88	1.2972	0.034392	375.81	410.20	1.287
180	0.044554	386.99	422.64	1.3327	0.039423	386.52	422.00	1.3221	0.035317	386.04	421.36	1.312

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg ·
	P = 1.20 MPa (T_{sat} = 46.29°C)				P = 1.40 MPa (T_{sat} = 52.40°C)				P = 1.60 MPa (T_{sat} = 57.88°C)			
Sat.	0.016715	253.81	273.87	0.9130	0.014107	256.37	276.12	0.9105	0.012123	258.47	277.86	0.907
50	0.017201	257.63	278.27	0.9267								
60	0.018404	267.56	289.64	0.9614	0.015005	264.46	285.47	0.9389	0.012372	260.89	280.69	0.916
70	0.019502	277.21	300.61	0.9938	0.016060	274.62	297.10	0.9733	0.013430	271.76	293.25	0.953
80	0.020529	286.75	311.39	1.0248	0.017023	284.51	308.34	1.0056	0.014362	282.09	305.07	0.987
90	0.021506	296.26	322.07	1.0546	0.017923	294.28	319.37	1.0364	0.015215	292.17	316.52	1.019
100	0.022442	305.80	332.73	1.0836	0.018778	304.01	330.30	1.0661	0.016014	302.14	327.76	1.050
110	0.023348	315.38	343.40	1.1118	0.019597	313.76	341.19	1.0949	0.016773	312.07	338.91	1.079
120	0.024228	325.03	354.11	1.1394	0.020388	323.55	352.09	1.1230	0.017500	322.02	350.02	1.108
130	0.025086	334.77	364.88	1.1664	0.021155	333.41	363.02	1.1504	0.018201	332.00	361.12	1.136
140	0.025927	344.61	375.72	1.1930	0.021904	343.34	374.01	1.1773	0.018882	342.05	372.26	1.163
150	0.026753	354.56	386.66	1.2192	0.022636	353.37	385.07	1.2038	0.019545	352.17	383.44	1.190
160	0.027566	364.61	397.69	1.2449	0.023355	363.51	396.20	1.2298	0.020194	362.38	394.69	1.216
170	0.028367	374.78	408.82	1.2703	0.024061	373.75	407.43	1.2554	0.020830	372.69	406.02	1.242
180	0.029158	385.08	420.07	1.2954	0.024757	384.10	418.76	1.2807	0.021456	383.11	417.44	1.267

APPENDIX D



Pressure-Enthalpy Diagram for HFC-134a Units