Effect of Intake Air Temperature on Performance and Emissions of Diesel Fueled Engine

Project Team

Samer Al-Takrouri Saif Shabaneh

Supervisor

Dr. Zuhdi Salhab

Submitted to the College of Engineering

in partial fulfillment of the requirements for the

Bachelor degree in Automotive Engineering

Palestine Polytechnic University

December 2018.

Palestine Polytechnic University

Hebron – Palestine

Mechanical Engineering

Effect of Intake Air Temperature on Performance and Emissions of Diesel Fueled Engine

By the guidance of our supervisor, and by the acceptance of all members in the testing committee, this project is delivered to Mechanical Engineering Department in the college of engineering and technology, to be as fulfillment of the requirement of the department for the Bachelor's degree of Mechanical Eng. / Automotive Engineering.

Supervisor signature

....

20 . 1 . 19

Testing committee signature

Diya Arafah ....

.... 20/1/2019

The head of department signature

....

Dedication (Arabic)

إلى السنبلة الذهبيّة في بِلادي وبيّارات البرتقال... إلى كرومِ العِنَب وغصن الزيتون... ودَم الشهداء ودَمعة الأطفال .... إلى رغيف الطابون وريح الزَعتر ...... إلى (فِلسطين) تِلك التي صَنعتني كَي أكونَ هُنا.

إلى الشموع التي احترقت لتصنع لنا غدا أفضل (شهداء الحرية).

إلى القابعين خلف القضبان لننعم بطعم الحرية (أسرانا البواسل).

إلى ملاكي في الحياة..... إلى معنى الحب والى معنى الحنان والتفاني .... إلى بسمة الحياة وسر الوجود ... إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي إلى أغلي الحبايب (امي الحبيبة).

إلى من كلله الله بالهيبة والوقار .... إلى من علمني العطاء بدون انتظار .... إلى من احمل اسمه بكل افتخار , ارجو من الله أن يمد في عمرك لترى ثمارا قد حان قطافها بعد طول انتظار وستبقى كلماتك نجوم اهتدي بها اليوم وفي الغد إلى الابد (والدي العزيز).

إلى من تحلو بالإخاء وتميزوا بالوفاء والعطاء إلى ينابيع الصدق الصافي (أصدقائي).

إلى الذين أجدهم معي في السراء والضراء (أقاربي الأعزاء) .

إلى من سرنا سويا ونحن نشق الطريق معا نحو النجاح والإبداع إلى..(زملائي).

إلى أولئك الذين يحملون على كاهلهم بناء جيل المستقبل (أساتذتنا الكرام)

Acknowledgment

We would like to express our gratitude for everyone who helps us during the graduation project, starting with endless thanks for our supervisor Dr. Zuhdi Salhab who did not keep any effort in encouraging us to do a great job, providing us with valuable information and advice to be better each time. Thanks for the continuous support and kind communication which great effect regarding to feel interesting about what we are working on. Finally, thanks to the “Mechanical Engineering Department” for the beneficial lectures provided.

Abstract

To determine the effect of intake air temperature on emissions of a diesel engine, a study consists of intake air at variable temperature. The Experiment was conducted on direct injection fuel, four cylinders, Experimental engine connected to gas analyzer. The experimental results show that there was a significant relation of the intake air temperature with performance of the engine. Increasing the intake air temperature HC, CO, NO_X and CO_2, are increase. Impact of intake air is noticeable when temperature of air is high such as 77ºc.

لتحديد تأثير درجة حرارة الهواء المدخل على انبعاثات محرك الديزل ، تتكون الدراسة من هواء السحب عند درجة حرارة متغيرة. أجريت التجربة على وقود الحقن المباشر ، أربع أسطوانات ، محرك تجريبي متصل بمحلل الغازات العادمة . تُظهر النتائج التجريبية وجود علاقة معنوية لدرجات حرارة هواء السحب مع أداء المحرك. زيادة درجة حرارة الهواء الداخل يودي الى زيادة HC , CO NO_X , CO2 . يمكن ملاحظة تأثير درجة حرارة الهواء الداخل على المحرك عندما تكون درجة حرارة الهواء مرتفعة مثل 77 درجة مئوية.

Table of Contents

List of Figures

List of Tables

1

CHAPTER ONE

INTRODUCTION

1.1. Introduction

1.2. Importance of the project

1.3. Motivation

1.4. Budget

1.5. Time Plan

Effect of Intake Air Temperature on Performance and Emissions of Diesel Fueled Engine

1.1 Introduction

Nowadays, the studies and technology that are used in the automotive world revolve around the setting of emission parameters where, it exports strict and calibrated laws that restrict the percentage of emissions in vehicles such as: European emission standards (Euro). The effect of changing in ambient temperature has an important role to the performance of machine and equipment. Therefore increasing of surrounding temperature in the world nowadays will affect the performance and the quality of air especially related to internal combustion engine. Internal combustion engine also known as heat engine depends so much on the changes in temperature. The experimental study results on the emissions and performance of internal combustion engine Volkswagen (2 liter diesel engine) as shown in the figure (1.1) at different intake temperatures. While the exhaust emissions are of CO, NO_2, VOC and NO that were measured by using gas analyzer. The data were taken at different intake temperatures (5°C, 10 °C, 20 °C, 30 °C, 35°C, 45°C, 55 °C, 65°C, 70°C and 77°C). Increases in the intake temperature result to small improvement in the engine performance. The lower intake temperature the lower emission was produced.

Figure (1.1): Volkswagen (2 liter diesel engine).

The experiment was conducted with a commercially four cylinder, turbocharged, direct injection engine. Engine efficiency decreased and exhausts gas temperature increased with increasing in intake air temperature. The fuel consumption increased with an increase in intake air temperature.

1.2 Importance of the project

The project aims to measure the best intake temperature and pressure to obtain the lowest emissions of exhaust gases and obtain the highest performance of the engine where it also aims to refrigerate and heat the intake air of the engine through two stages are ,the simple refrigeration cycle and the air is heated by electric heater coils where the project aims to change the density of the air inside the engine by refrigeration and heating it and changing the density of the volume efficiency which is one of the most important methods in controlling the state of part load on the engine. So we made a range of temperatures to show their effects.

1.3 Motivation

Diesel powered engines will be used more extensively due to its higher thermal efficiency and high fuel economy compared to gasoline engines. It is perceptible that the air intake mass flow rate shrinks when the engine power decreases. In diesel engine, supercharger or turbocharger is widely used to increase air flow rate to the engines and enhance the volumetric efficiency. At higher temperature, charge density can suffer and combustion temperatures can become too high. This can limit engine output. If temperatures are too low, starting the engine at low temperatures can be problematic.

1.4 Budget

In our project, the total cost for the project is 1744 NIS for built and design depending on figure (1.2).

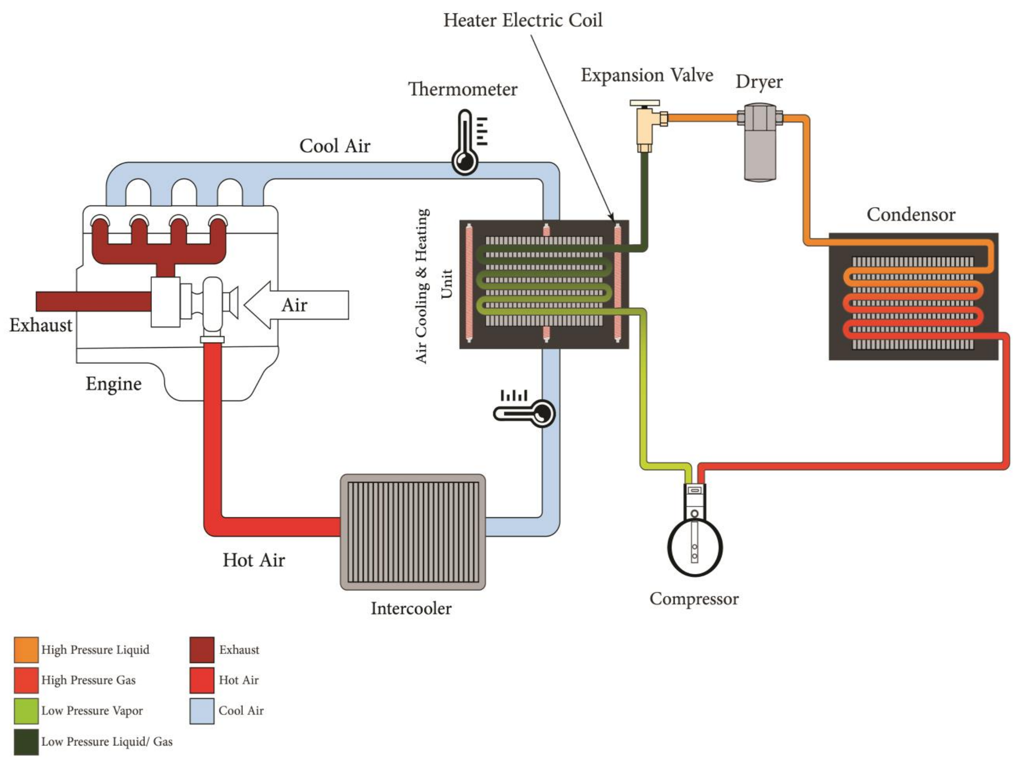


Figure (1.2): Diagram of the system.

Table (1.1): Total cost.

Tools & Device	No.	Piece price	Price (NIS)
condenser	1	120	120
Temperature sensor	2	30	60
Heater electric coil	3	10	30
button	9	4	36
Metal box	1	135	135
Plastic box	1	40	40
Compressor	1	600	600
Gas R-134a	1	150	150
Dryer	1	50	50
Copper tubes	7	17.5	123
Electrical motor	1	400	400
Total			1744

1.5 Time Plan

Table (1.2) shows the schedule time for first semester.

Table (1.2): Schedule time-first semester.

NO. of Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Identifying the Project ide																
Project requirement and collecting data																
Writing and Documentation for chapters																
Calculations																

Table (1.3) shows the schedule time second for semester.

Table (1.3): Schedule time-second semester.

Task \ **NO. of Week**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Making animation for cooling and heating cycle with engine test.	■	■	■													
The required designs.			■	■	■	■	■									
Project Building						■	■	■	■	■	■	■	■	■		
Testing and experimental result															■	■
Writing and documentation of chapters			■	■	■	■	■	■	■	■	■	■	■	■	■	■

2

CHAPTER TWO

INLETAIR TEMPERATURE AND LITERATURE REVIEW

2.1. Inlet Air Temperature

The temperature is a degree of hotness or coldness that can be measured using a thermometer. It's also a measure of how fast the atoms and molecules of a substance are moving. The temperature is measured in Fahrenheit, Celsius, and Kelvin scales. In the Internal combustion engine, the temperature is a major component to combust the fuel and run the engine, so it is necessary to keep the temperature at a controllable level in order to operate the engine safely. Once the temperature in the engine has reached intolerable values, the engine blocks and components may suffer damage.

One of the important parameters to determine the overall efficiency of an engine is its volumetric efficiency. It is the ratio of breathable air available to the engine to its swept volume. Maximizing volumetric efficiency ensures that the entire capacity of the cylinder is used to create torque. Hence, to increase engine efficiency, volumetric efficiency is always maximized. When intake air gets warm, its density decreases which means the mass of air entering the engine is lower for the same volume. This decreases the volumetric efficiency of the engine as there is lower air for complete combustion. This also directly decreases engine efficiency.

Ambient temperature is the temperature of the surrounding environment. The performance of an engine is influenced by the ambient conditions. The most important ambient conditions influence internal combustion engine performance is air humidity and inlet air temperature. Air humidity has an influence on the combustion since an increase in humidity is slowing down the combustion speed as well as reducing the maximum combustion temperature. On the one hand this will influence the knock margin and the NO_X emissions in a positive way, but on the other hand the efficiency of the engine is affected negatively. Inlet air temperature will take into account as a subject to been discussed regarding the performance of internal combustion engine. But there are different definitions for the ambient air temperature and air inlet temperature. The ambient air temperature also described as the temperature that is measured outside of the engine compartment and air inlet temperature is the temperature measured at the inlet of the turbocharger.

The ambient temperature does not directly influencing the engine performance at all, but in most cases the ambient temperature will have an influence on the air inlet temperature before enter combustion chamber or turbocharger and the engine cooling system. Turbochargers are commonly used on truck, car, train, aircraft and construction equipment engines to boost engine efficiency and power by forcing extra air to combustion chamber. They are often used at spark ignition engine and compression ignition Engine.

2.2. Literature Review

"Alam et al" (2005) did study on “Effects of Inlet air Temperature on Performance and Emissions of a Direct Injection Diesel Engine Operated with Ultra Low Sulfur Diesel Fuel”, experiments were conducted with a commercially six cylinder, water cooled, turbocharged, direct injection engine. Engine efficiency decreased and exhausts gas temperature increased with increase in inlet air temperature. The authors also confirmed that the fuel consumption increased with an increase in inlet air temperature [1]. "Mamat et al" (2010) did study on “Effect of Boost Temperature on the Performance and Emissions of a Common Rail Diesel Engine Operating with Rapeseed Methyl Ester (RME)” His experimental result was that the increase of inlet temperature lead to the reduction of in-cylinder entrap mass and therefore reduced the Oxygen and heat capacity of the charged air. This has resulted in enlarge of BSFC at low load but slightly lower the BSFC at part load when the charge air temperature is increased [2]. Pan et al.(2015) did experiment on “The impact of intake air temperature on performance and exhaust emissions of a diesel Methanol dual fuel engine” An experimental research was conducted to observe the mutual effect of intake air temperature and methanol substitution ratio on performance and emission characteristics of a diesel methanol dual fuel engine. The authors conclude that Decreasing of intake air temperature also prolonged the ignition delay, which caused a later combustion phasing and smaller peak cylinder pressure. For the majority testing points, the indicated thermal efficiency increased with increasing intake air temperature. Supplementary increase of intake air temperature would reduce the indicated thermal efficiency [3].

"Arpan Rana", "Prof. Gaurav Rathod" and "Dr.Tushar Patel" did a study on "Effect of Intake Air Temperature on Performance of CI Engine Fueled with Diesel", the experiment was conducted on Multi fuel, single cylinder and four strokes, experimental engine connected to eddy current type of dynamometer for load arrangement. The experimental results as following [4]:

- **Specific Fuel Consumption (SFC)**

Figure (2.1) represent specific fuel consumption (SFC) for diesel with increase in intake air temperature.

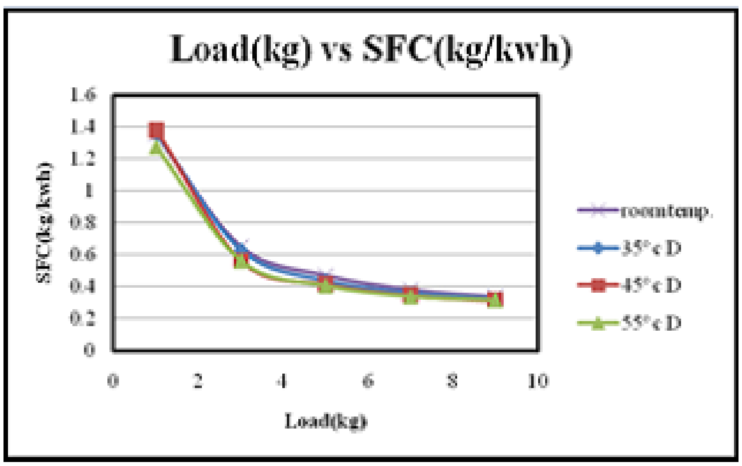


Figure (2 .1): Load vs. Specific Fuel Consumption [4].

It is seen that with increase in intake air temperature, specific fuel consumption is decrease at lower load range but when engine load increase specific fuel consumption for all temperature remain almost constant.

- **Brake thermal efficiency (BTHE)**

Figure (2.2) shows relation between the load and Brake thermal efficiency. Brake thermal efficiency is inversely proportional to specific fuel consumption so break thermal efficiency increase with increase in intake air temperature because specific fuel consumption is decrease with increase in intake air temperature. Brake thermal efficiency is increases with increase in load and temperature.

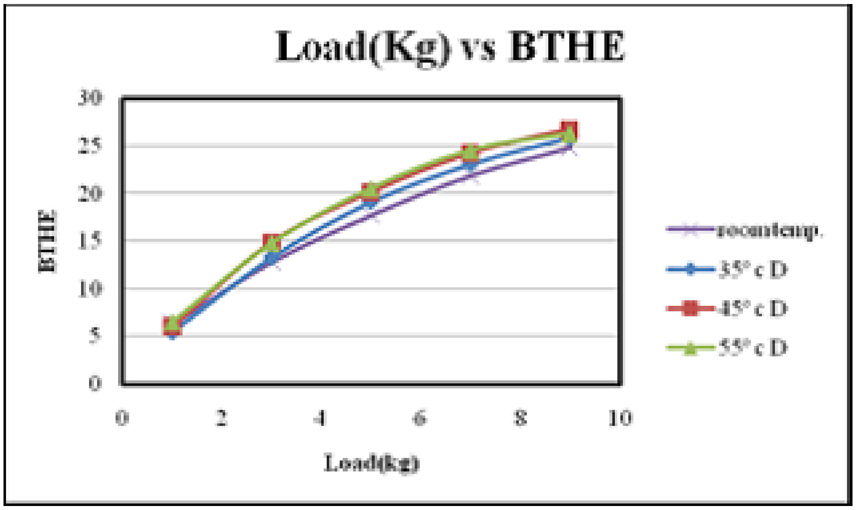


Figure (2. 2): Load vs. Brake Thermal Efficiency [4].

- **Indicated Thermal Efficiency (ITHE)**

Figure (2.3) represent relationship between loads and indicated thermal efficiency for diesel. it is seen that indicated thermal efficiency at 45ºc inlet air temperature. Indicated thermal efficiency is directly proportional to indicated power so with increase in intake air temperature such as 55ºc indicated thermal efficiency of diesel is decrease due to decrease in indicated power.

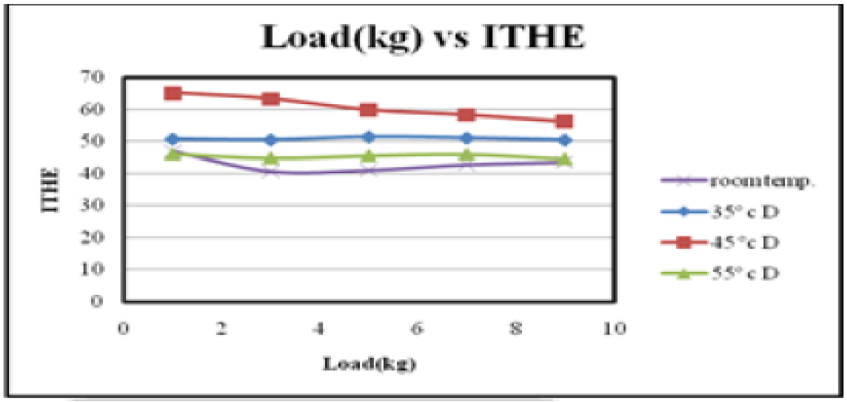


Figure (2 .3): Load vs. ITHE for diesel mechanical efficiency [4].

- **Mechanical Efficiency**

It is clear from figure (2.4) that with boost in intake air temperature and load mechanical efficiency initially at lower intake air temperature it is decrease but when temperature of intake air is increase (e.g 55 ºc) mechanical efficiency is further increase. At 55ºc mechanical efficiency of system is highest because with increase in intake air temperature indicated power of the engine is decrease at 55 º c inlet air temperatures.

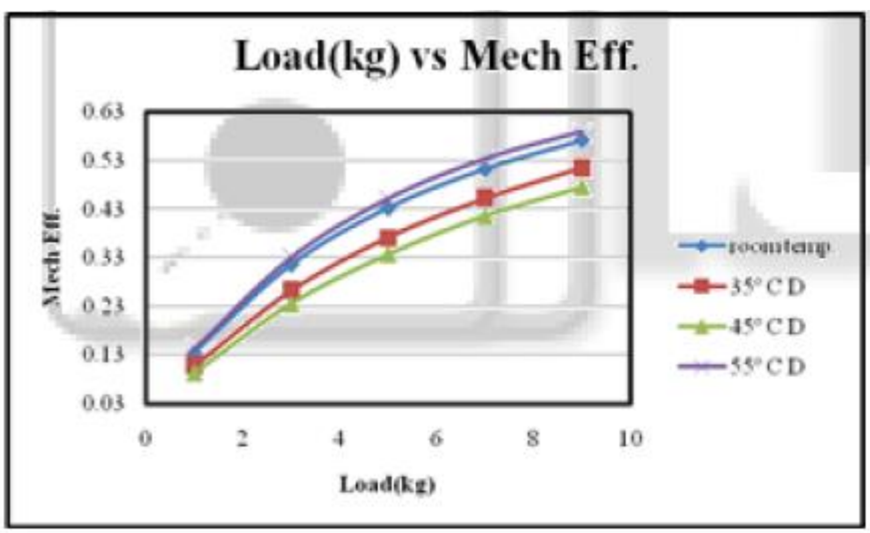
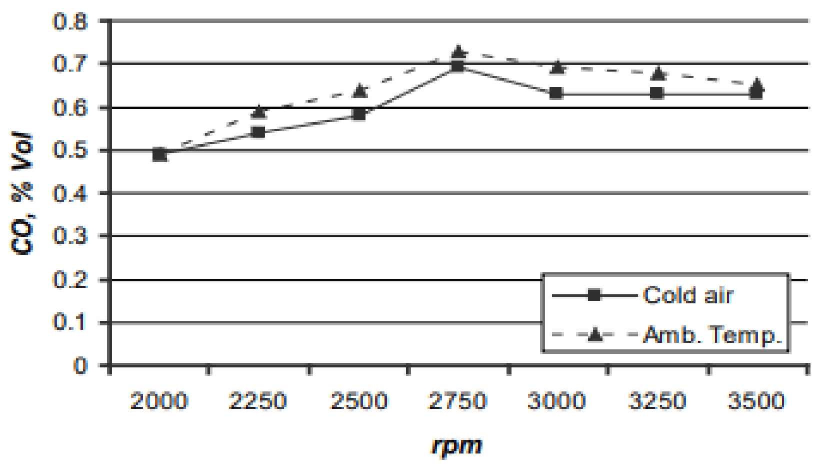


Figure (2. 4): Load vs. Mechanical efficiency [4].

"James Brunton", "David Kennedy" and "John` Kelleher" did a study on" Air Intake Cooling Motor Vehicle Performance Enhancement" , the Experiment was on The Safrane engine capacity is 1995cm3 with a compression ratio of (9.2:1) . This car employs a Renix multipoint sequential injection system. The experimental results as following [5]:

- The emission readings were all extracted from the exhaust pipe before the gasses entered the catalytic converter. In Figures (2.5), (2.6) and (2.7) the values of CO, CO_2 and HC are shown for different rpm values at cold air around 10 °C and ambient temperature conditions.



Figure(2 .5): Exhaust gas co vs. rpm [5].

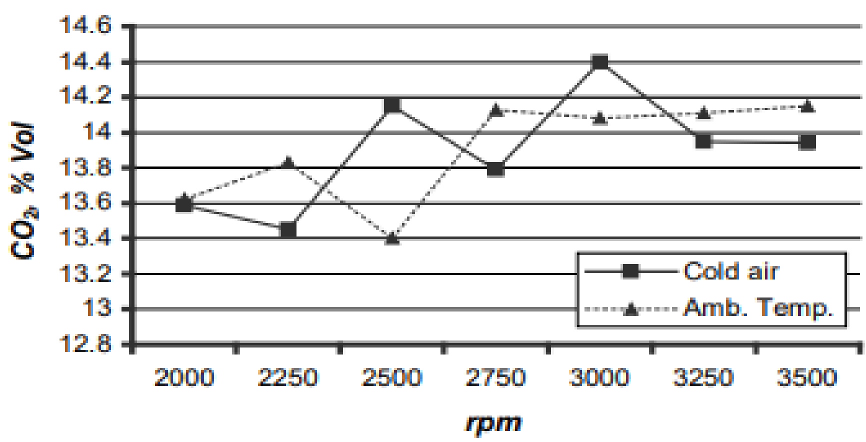


Figure (2 .6): Exhaust gas co_2 vs. rpm [5].

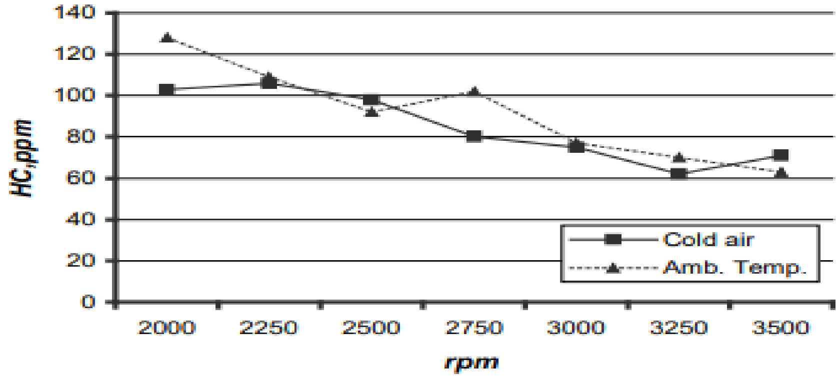


Figure (2. 7): Exhaust gas HC vs. rpm [5].

- The specific fuel consumption is related to the power and this is evident from the results obtained by the fuel consumption meter during the testing. Results are presented in figure (2.8).

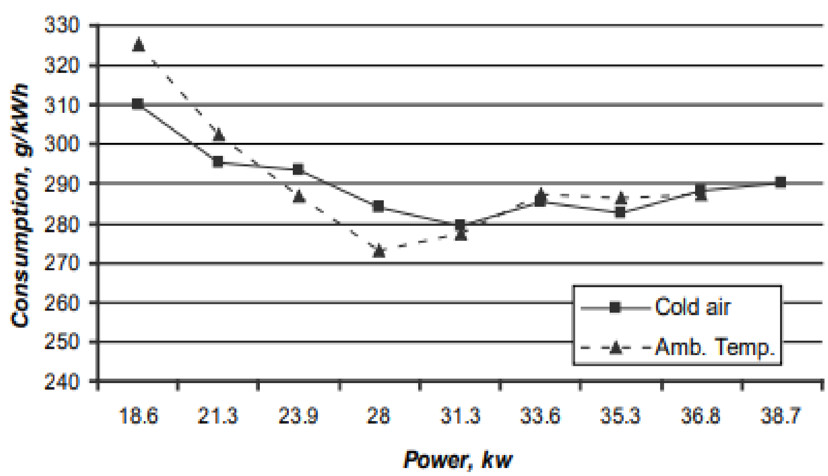


Figure (2 .8): Consumption / Power values for Cold Air and Ambient Temperature [5].

3

CHAPTER THREE
Design and building of the project

3.1. Design of the project

- **3.1.1. Introduction**
- **3.1.2. p-h diagram analysis**
- **3.1.3. Calculations and design**
  - **3.1.3.1. Design the heat exchanger**
  - **3.1.3.2. Design of fins**
  - **3.1.3.3. Design results**

3.2. Project building

3.3. Experimental setup

3.1. Design of the project

3.1.1. Introduction

Engine refrigeration and the heating cycle was designed for an inlet air temperature for a diesel engine. The evaporator and the electric heater coils were used to cool and heat the inlet air respectively. The simple refrigeration cycle consists of a compressor, condenser, expansion valve and evaporator. To achieve the goals, the evaporator was covered by the insulated cover by using rock wool. The evaporator was designed with calculated dimensions (design chapter), the evaporator case includes the input and output ports for inlet air in addition to the entrance and exit of refrigerating gas to avoid a thermal heat transfer between the inlet air and the refrigerating gas inside the tubes. We used thermal sensors to measure the temperature before and after the evaporator. The used refrigerating gas in the cooling cycle is R-134a. Measuring the amount of the exhaust gases produced after the cooling and heating of the inlet air is required.

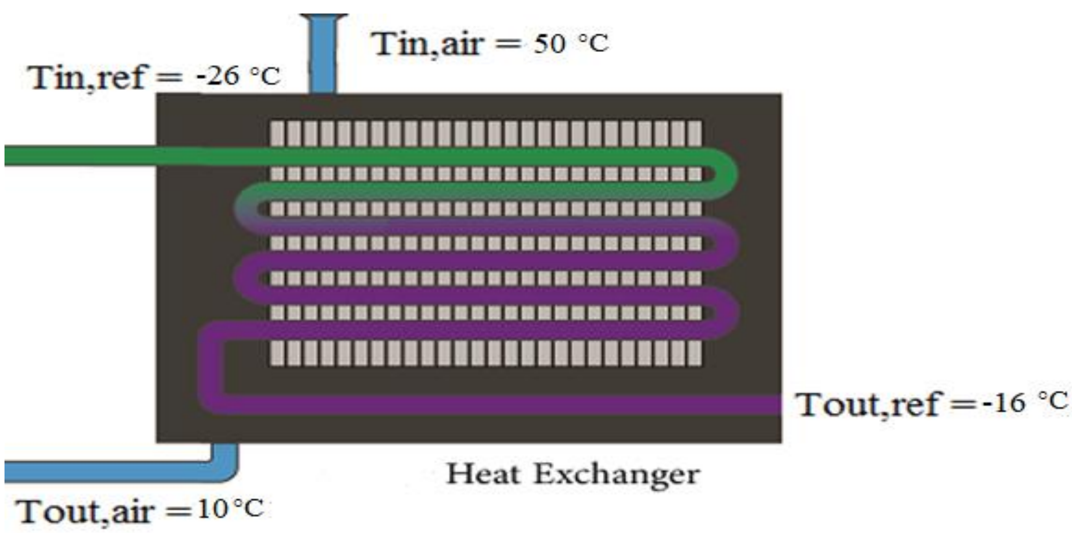


Figure (3. 1): Simple form for heat exchanger.

The gas R-134a has been chosen for many reasons:

1) Environmental friendly.

2) Cheap.

3) Available.

4) Compressor compatible with R-134a.

5) $P_c/P_L < 9$.

3.1.2. p-h diagram analysis

The load in compressor (W_{in}) that need to cool the high inlet air temperature (50 ℃) to the low temperature (10℃) inlet air and the maximum mass air flow rate (120 kg/s), the figure (3.2) was drawn by using COOLPACK program to get the enthalpy value at each state to determine the amount of heat transfer.

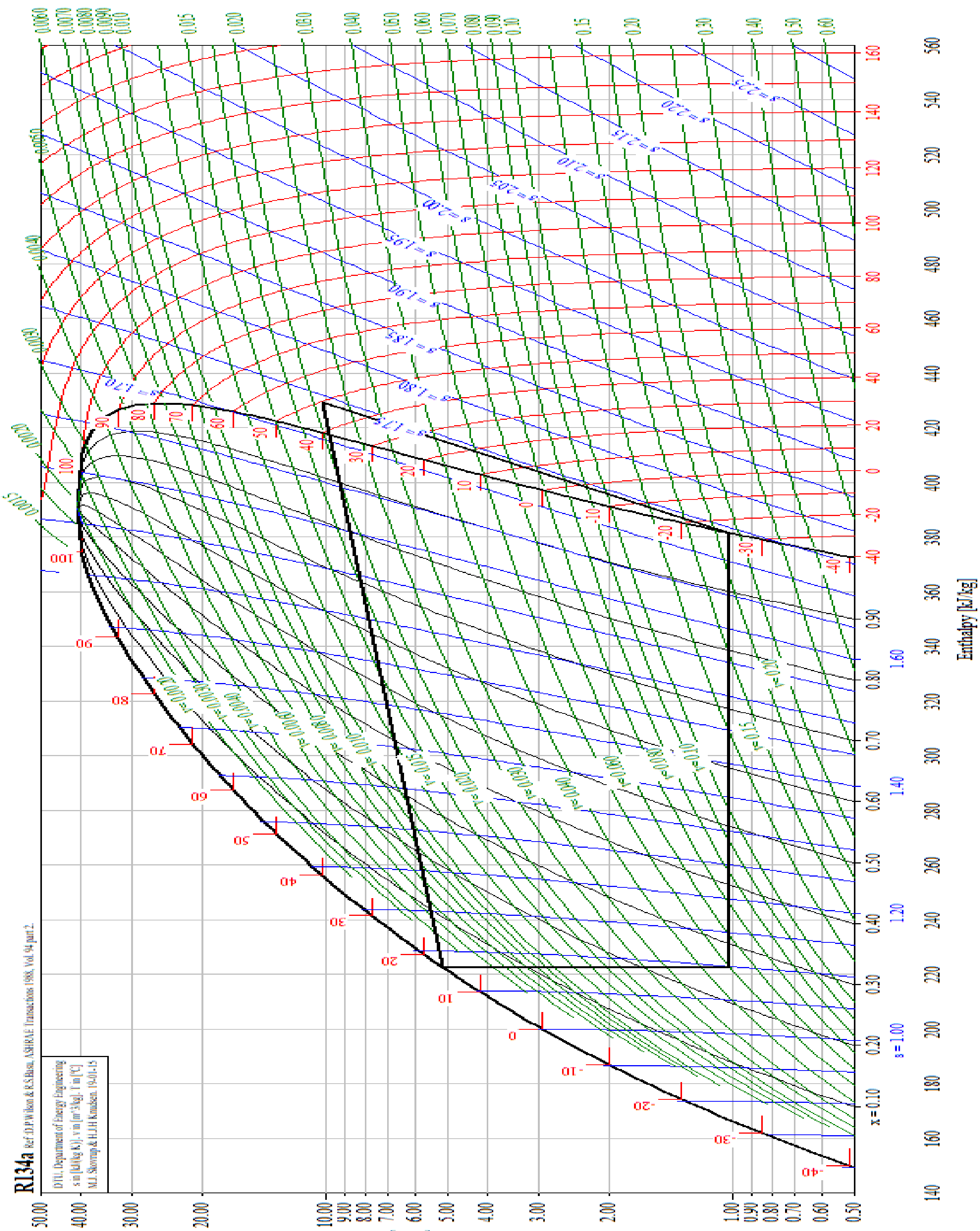


Figure (3. 2): p-h diagram of refrigerant R-134a

The values of temperature, pressure and enthalpy of each stage depends on p-h diagram of R134a as shown in table (3.1).

Table (3. 1): properties for R-134a for each stage

Properties / Each stages	Enthalpy [kJ/kg]	Pressure [bar]	Temperature [°C]
At point 1 before compressor.	382	1	-26
At point 2 after compressor.	430	5	40
At point 3 after condenser.	247	5	32
At point 4 before heat exchanger.	247	1	-16

3.1.3. Calculations and design

$\dot{m}_{air}$**= 120 kg/s =0.0120 g/s. (Has been measured)**

$C_{p,air}$**=1.01 kJ/kg·K.**

$T_{air,out}$ **= 10 °C.** , $T_{air,in}$**= 50°C.**

$$q_{evp,in} = h_1 - h_4 \tag{3.1}$$

= 382 – 247 = 135 kJ/kg.

$$q_{cond,out} = h_2 - h_3 \tag{3.2}$$

= 430 - 247 = 183 kJ/kg.

$$w_{cond,in} = h_2 - h_1 \quad (3.3)$$

$= 430 - 382 = 48$ kJ/kg.

$$COP_R = \frac{ql}{w_{in}} = \frac{h_1 - h_4}{h_2 - h_1} \quad (3.4)$$

$= \frac{135}{48} = 2.8125.$

$$COP_{carnot} = \frac{TL}{TH - TL} \quad (3.5)$$

$= \frac{(273+-16)}{(273+40)-(273+-16)} = 4.5893.$

$$Q_{air} = \dot{m}_{air} * C_{p,air} * (T_{air,out} - T_{air,in}) \quad (3.6)$$

$= 0.0120 \times 1.01 \times (50 - 10) = 0.4848$ kW $= 0.64992$ hp

$$Q_{evp} = \dot{m}_r * (h_1 - h_4) \quad (3.7)$$

$$Q_{evp} = Q_{air}$$

$$\dot{m}_r = \frac{Q_{air}}{(h_1 - h_4)}$$

$= \frac{0.4848}{(382-247)} = 0.00359$ kg/s.

$$\boldsymbol{W_{in} = \dot{m}_r * (h_2 - h_1)} \tag{3.8}$$

$$= \mathbf{0.00359 \times (430\text{-}382) = 0.17232\ kW = 0.231085\ hp.}$$

$$\boldsymbol{Q_{cond} = \dot{m}_r * (h_2 - h_3)} \tag{3.9}$$

$$= \mathbf{0.00359 \times (430\text{-}247) = 0.65697\ kW = 0.8810\ hp.}$$

$$\boldsymbol{Q_{evap} = \dot{m}_r * (h_1 - h_4)} \tag{3.10}$$

$$= \mathbf{0.00359 \times (382\text{-}247) = 0.48465\ kW = 0.64992\ hp.}$$

Where:

q_{evp} :heat transfer in evaporator .

Q_{evp}. : Heat Transfer Flow Rate in Evaporator.

h_1: enthalpy before compressor.

h_2: enthalpy before condenser.

h_3: enthalpy before throttle.

h_4: Enthalpy before Evaporator.

$\dot{m}_{air}$: mass flow rate of the inlet air.

$\dot{m}_r$: mass flow rate of refrigerant R134a.

Cp_{air}: Specific Heat of air.

w_{in}: Compressor work.

W_{in}: Compressor Power.

Q_{air}: : Heat Transfer Flow Rate of the air.

COP_r: coefficient of performance for cooling.

3.1.3.1. Design the heat exchanger

By using logarithmic mean temperature difference method (LMTD), the amount of heat transfer in heat exchanger at high accuracy was calculated:

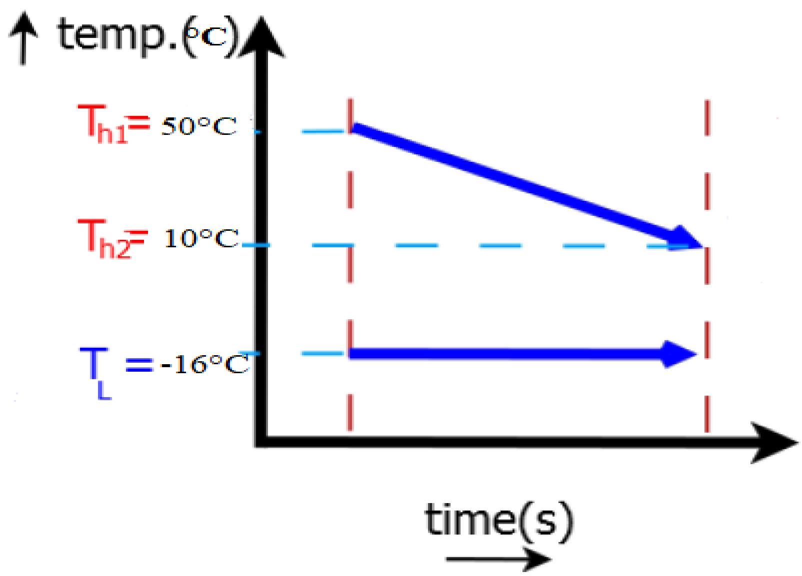


Figure (3. 3): Temperature profile for parallel flow heat exchanger

$$LMTD = \frac{(Th_1 - TL_1) - (Th_2 - TL_2)}{\ln \frac{(Th_1 - TL_1)}{(Th_2 - TL_2)}} \quad \textbf{(3.11)}$$

$$= \frac{(15 - -16) - (10 - -16)}{ln \frac{(50 - -16)}{10 - -16)}} = \frac{40}{0.9316} = 42.94°C$$

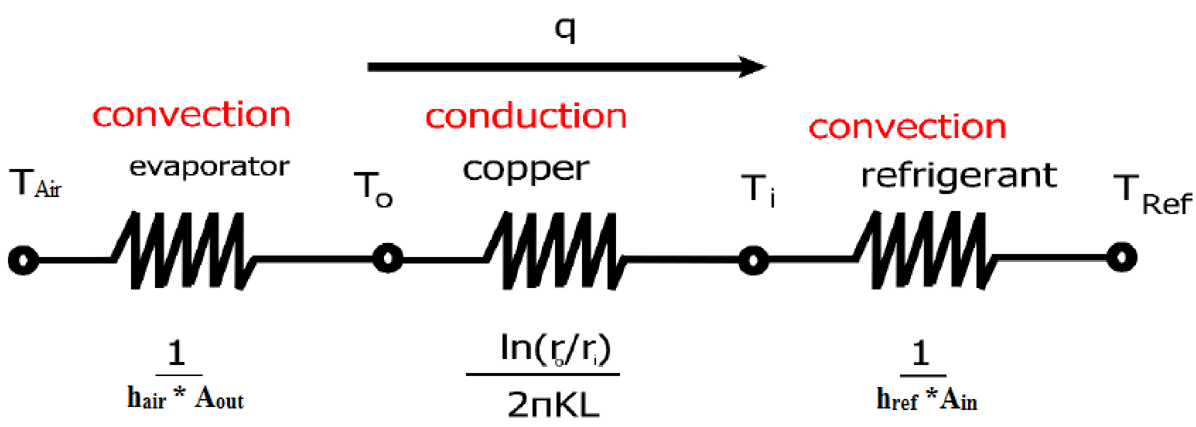


Figure (3. 4): Thermal-resistance network for overall heat transfer.

Where r_{in}, r_{out} are standard selection of the copper tube diameter 10mm at thickness **t**=1mm.

$$\mathbf{A_{out} = 2 * \pi * r_{out} * L = 2 * \pi \times (5 * 10^{-3}) * L = 0.0314\, L}$$

$$\boldsymbol{A_{in} = 2 * \pi * r_{in} * L = 2 * \pi * (4.5 * 10^{-3}) * L = 0.0282\, L}$$

$$\boldsymbol{K_{copper} = 204\, W/m.K}$$

$$\boldsymbol{U = \frac{1}{\frac{1}{h_{air} * A_{out}} * \frac{ln^{r_{out}}/r_{in}}{2 * \pi * 204 * L}}} \tag{3.12}$$

$$= \frac{1}{\frac{1}{350 * 0.0314 * L} * \frac{ln\, ^5/_{4.5}}{2 * \pi * 204 * L}} = 396.502\, W/m^2.K$$

$$Q_{H.E} = Q_{evap} = 4846.5\ W.$$

.

$$Q_{H.E} = U * A * LMTD \qquad (3.13)$$

4848 = 396.502 * L * 0.0314 * 42.94

L=9.0683m≈ 9m.

Assume Length of turn = 0.41 m.

Number of turns = 9/0.41 = 22 turns.

Where:

$Q_{H.E}$: Heat Transfer in Heat Exchanger.

U: Overall Heat-Transfer Coefficient.

A: Surface Area for Refrigerant Tube.

LMTD: Logarithmic Mean Temperature Difference.

Th_1: Temperature of Exhaust Gas That Inlet Heat Exchanger.

Th_2: Temperature of Exhaust Gas That Outlet Heat Exchanger.

TL_1: Temperature of Refrigerant Gas That Inlet Heat Exchanger.

TL_2: Temperature of Refrigerant Gas That Outlet Heat Exchanger.

h_{evp}: convection heat transfer coefficient of R-134a.

A_{evp}: Area of Evaporator.

h_{air}: Convection Heat Transfer Coefficient of air.

A_{ref}: Area of Refrigerant Tube.

r_{out}: outer radius of refrigerant tube.

r_{in}: inner radius of refrigerant tube.

k_{coop}: thermal conductivity of copper.

L: length of refrigerant tube (cooper tube).

So, the length that needed for refrigerant tube **10m** at **diameter 10 mm** and **thickness 1.0mm,** and the dimensions of evaporator is (30*20*10) cm**.**

3.1.3.2. Design of fins

The fin is extended surface that are designed to increase the heat transfer that's operating against insulators , the design of fins is very important to measure the rate of heat transfer and the temperature at the end of the fins as shown in figure (3.5) .

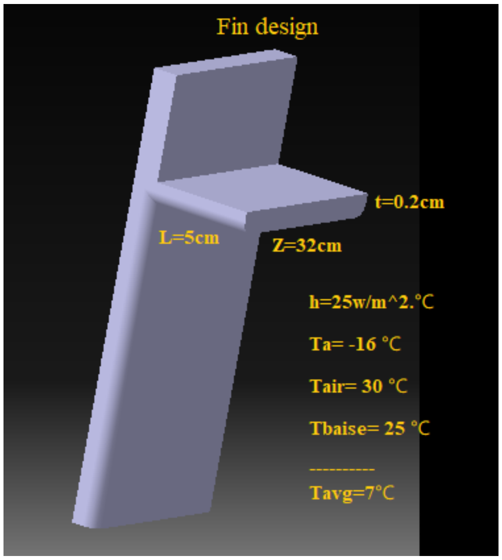


Figure (3. 5): illustration for fin.

$$Area\ of\ the\ fin = Z * t \tag{3.14}$$

$$= 0.2*32*10^{-4} = 6.4*10^{-4}\ m^2.$$

P for square fin = (2*Z)*(2*t) **(3.15)**

$$=0.644\ m.$$

$$m = \sqrt{\frac{h * P}{K * A}} = \sqrt{\left(\frac{25 * 0.644}{204 * 6.4 * 10^{-4}}\right)} = 11.10473\ m^{-1}. \tag{3.16}$$

$$m * L = 0.55524.$$

$$\frac{h}{m * K} = 0.01104\ m.$$

$$\theta = T_B - T_{\infty} = 25 - 7 = 18℃.$$

$$q = \sqrt{P * K * A} * \theta * \frac{\sinh(m * L) + \frac{h}{m * K} * \cosh(m * L)}{\cosh(m * L) + \frac{h}{m * k} * \sinh(m * L)} = 13.1074\ watt. \tag{3.17}$$

The temperature at the end of the fin is equal:

$$\frac{\theta}{\theta_0} = \frac{T - T_\infty}{T_0 - T_\infty} = \frac{cosh[m * (L - X)] + \frac{h}{(m * K)} * sinh[m * (L - X)]}{cosh(m * L) + \frac{h}{(m * K)} * sinh(m * L)} \tag{3.18}$$

At X=L , T=22.456 ℃

Where:

q: rate of heat transfer.

h: convection heat transfer coefficient.

P: surrounding of the rectangular.

A: area of the rectangular.

K: conduction heat transfer coefficient.

t: thickness.

T_b: base temperature.

T_∞: fluid temperature.

θ: temperature difference.

sinh: sinusoidal hyperbolic.

cosh: cosine hyperbolic.

T: required temperature.

L: length of the fin.

Z: width of the fin.

By depending on the results of the fins design (heat transfer rate and the value of temperature at the end of the fin with the dimension of evaporator) the number of fins is 200 fins and the distance between the fins is 1 mm.

3.1.3.3. Design results

Design results Summary of heat exchanger properties as shown in the table (3.2).

Table (3. 2): Design Result.

#	Name	Value	Unit
1	Refrigerant gas type	R-134a	-
2	Refrigerant tube diameter	10	mm
3	Refrigerant tube thickness	1	mm
4	Refrigerant tube material type	Copper	-
5	Refrigerant tube length	10	m
6	Compressor Power	2.31085	hp
7	Number of turns	22	Turn.

3.2. Project building

After finishing all of the calculaions and equations that required to design the project, the parts of the structure has been accomulated as follows :

- The container of the air unit that shown in figure (3.6) used to fix electric heater coils and evaporator inside it ,the dimensions of the box is (40,30,20) cm .

Figure (3. 6):The container of the air unit.

- The box was drilled from a hole with diameter 4.5 cm, then welding the metal cylinder with diameter 5 cm above the hole to serve as inlet and outlet as shown in figure (3.7).

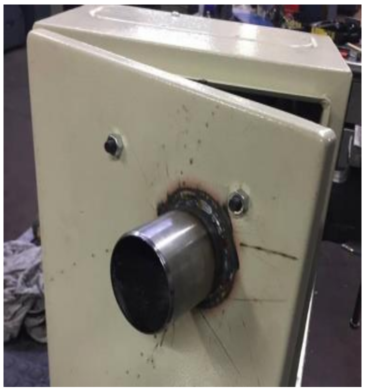


Figure (3. 7): The container after welding the ports.

- The electric heater coils were fixed inside the box by fitting them onto a metal piece and then attaaching it as shown in figure (3.8) to avoid a short circuit.

Figure (3. 8): Electric Heater Coils.

- In order to fix the evaporator, two holes were opened to insert the pipes of the evaporator through 2 cm above electric heater coils, as shown in figure (3.9).

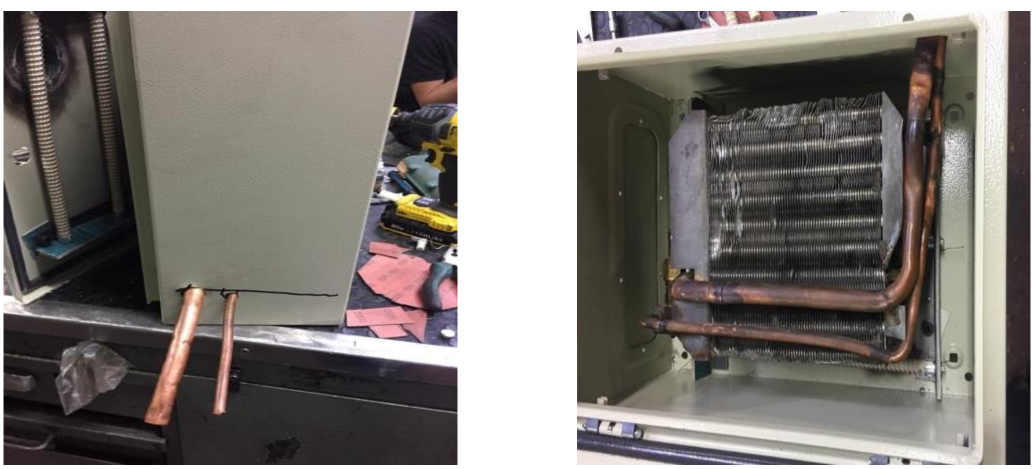


Figure (3. 9): The Evaporator.

- The work of the electric heater coils was checked and tested as shown in figure (3.10), to ensure the safety of the connections.

Figure (3.10): Testing the electric heater coils.

- The box is completely covered with thermal insulation (rock wool) and metal cover as shown in figure (3.11).

Figure (3. 11): Rock wool and metal cover insulators.

- Figure (3.12) shows the plastic box with electric connections buttons (high speed fan , low speed fan, compressor and electric heater coils) and it has two screens to display the temperature of the engine inlet air.

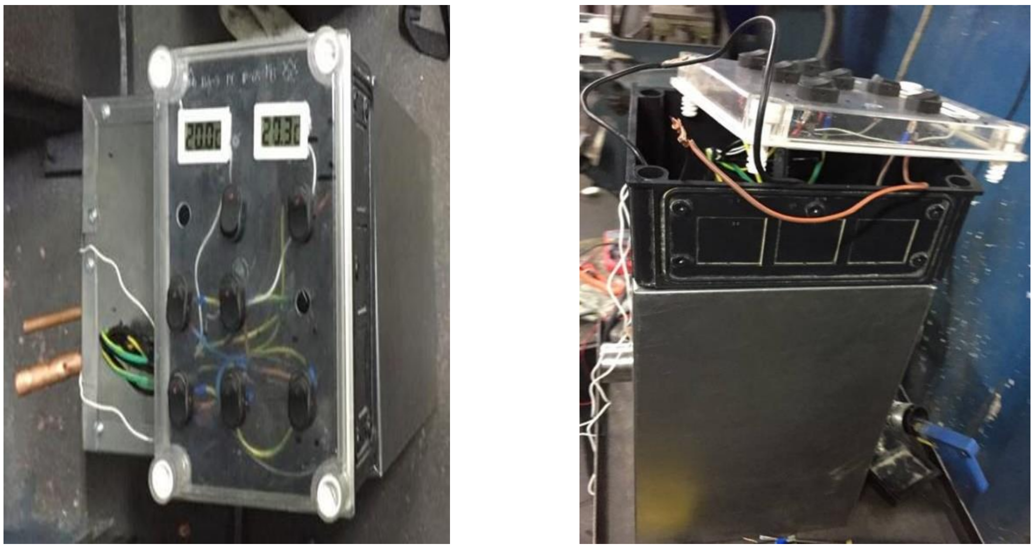


Figure (3. 12): Plastic box with electric connections.

- The compressor was connected to an electric motor by using a belt, also an external air conditioning cycle was built because the engine stand has a limit space. Pipes were welded to the cycle as shown in figure (3.13), and leakage test was done to ensure that the cycle is ready to fill the gas and run it .

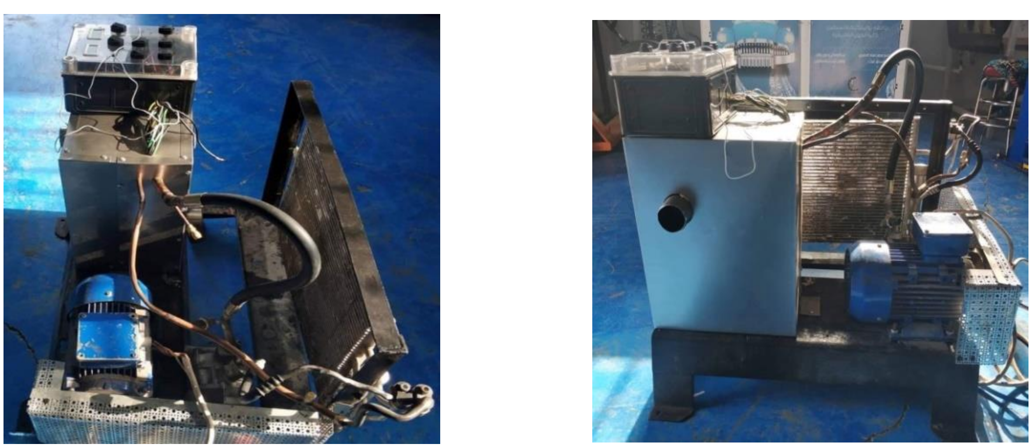


Figure (3. 13): The general view of refrigeration and heating systems.

- After ensuring that there is no leakage in the connections, vacuum test was done to be sure that there is no air in the cycle. In order to charge the cycle, a gas cylinder was connected to the cycle by a gas filling line that carrying R-134a as shown in figure (3.14). After opening the gas cylinder, the compressor and fan were turned on until the pressure reached 35 psi and the required cooling obtained.

Figure (3. 14): Filling the cycle by the gas.

- In order to get a good appearance and protection from corrosion, there was a necessary to paint everything that is metal as shown in figure (3.15).

Figure (3. 15): The heating and refrigeration unit after painting.

- Connecting the heating and cooling unit between the engine and intercooler then put temperatures sensors on the unit inlet and outlet ports as shown in figure (3.16).

Figure (3. 16): Engine with Heating and refrigeration unit.

3.3. Experimental Setup

Experiments were carried out on direct injection fuel, four cylinders, and research engine connected to gas analyzer. The engine disclaimer is listed in table (3.3) [5], intake air temperature is increased by electric heater coils and decreased by air conditioning cycle which was placed inside air unit as shown in figure (3.17). Preferred intake air temperature was achieved by using evaporator and electric heater coils which have temperature range from 10 ºc to 77 ºc. Intake air temperature was also measured by thermo sensors which were attached after air insulator box of experimental engine for continues monitoring the temperature of intake air.

Table (3. 3): 2.0 Liter TDI Technical Data.

Design	4-Cylinder In-Line Engine
Displacement	120 in3 (1968 cm3)
Bore	3.189 in. (81 mm)
Stroke	3.760 in. (95.5 mm)
Valves per Cylinder	4valves
Compression Ratio	16.5:1
Maximum Output	140 hp (103 kW) at 4000 rpm
Maximum Torque	236 lb-ft (320 Nm) at 1750 rpm up to 2500 rpm
Engine Management	Bosch EDC 17 (Common Rail Control Unit)

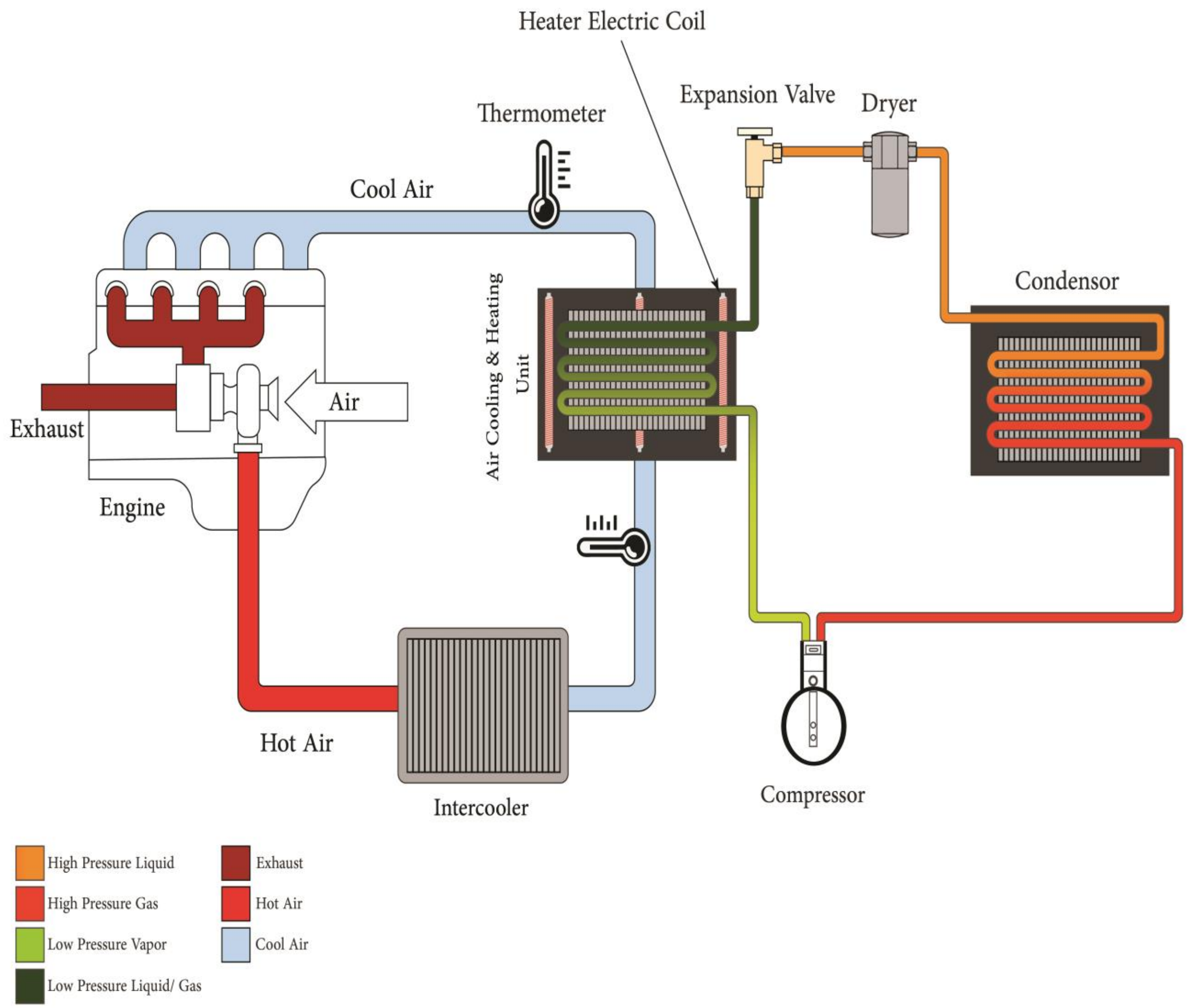


Figure (3. 17): Diagram of the system.

4

CHAPTER FOUR

Experimental Results and Performance

4.1 Engine performance calculations

One of the project objectives is to investigate the effect of intake air temperature on engine performance besides emissions investigation.

Usually, engine performance is studied and investigated using so- called Dynamometer device. Because of the unavailability of this device at University, we had to use software instead of the measurements.

The thermodynamic and emissions parameters of spark-ignition engines powered by gaseous fuels study was used as a reference as appropriate for compression ignition engines .

An Encrypted Excel- Pressure Program was used to calculate the temperature and pressure of in cylinder charge taken into consideration engine actual working cycle and all actual engine specifications [7]. Temperatures and pressures of engine working cycle were calculated with different values of intake air temperature at constant engine speed (2000 rpm), excess – air ratio (l = 1.3), and boost pressure of 172 kPa.

Table (4.1) shows the calculated temperature and pressure values as a result of intake air temperature different values.

Table (4. 1): Performance table with variation at intake air temperatures.

Intake air temperature [K]	Max. combustion temperature (Tmax) [K]	Max. combustion pressure (Pmax) [MPa]
290	1918	6.99
300	1945	6.95
320	2026	6.86
340	2097	6.79
360	2168	6.72
370	2203	6.69

Figures bellow illustrate the engine working cycles (diagrams) of temperature and pressure, and p– V diagram as a function of crank angle degrees showing the effect of intake air temperature on these processes (cycles).

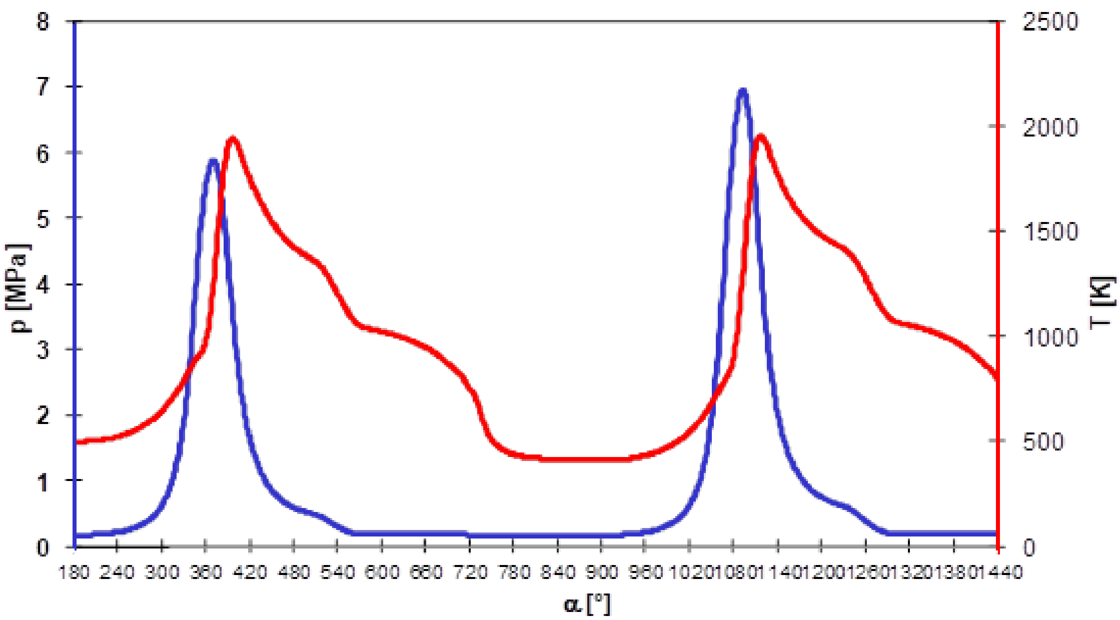


Figure (4. 1): T –α and p – α diagrams versus crank angle degree ($T_{intake} = 300K$)

This curve indicates the relationship between where the red color illustrates the relationship between the temperature and crank angle , the curve in blue illustrates the relationship between the pressure and crank angle.

When temperature of intake air decrease, the ignition delay period becomes longer that's means more probability accumulate the diesel drops before burning in the compression stroke , where the temperature rises. Fear lies about the arrival of the accumulated diesel droplets to the degree of self-ignition before the ignition of injected fuel, if the amount of diesel droplets accumulated large an early explosion and this increases the probability of the knock phenomenon.

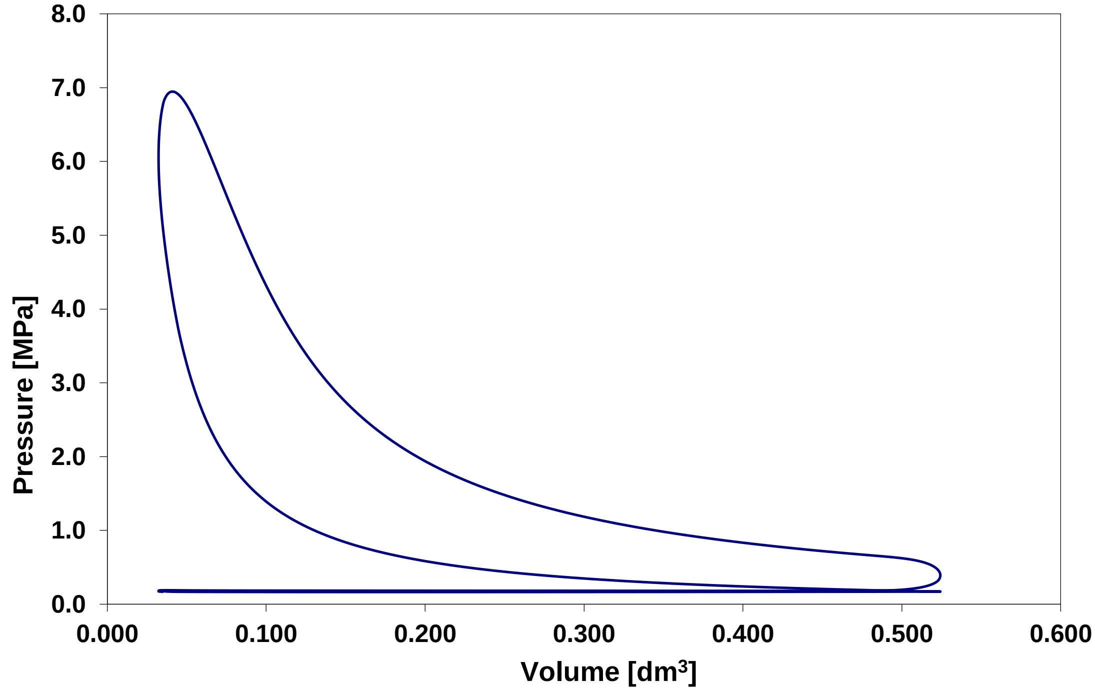


Figure (4. 2): P – V diagram versus crank angle degree ($T_{intake} = 300K$)

At the beginning, the intake is happen on low pressure, then the compression stroke makes the pressure increases and the volume decreases, and then the injection comes before the top dead center in a few degrees and the ignition phase comes and when ignition occurs then the pressure decreases as a result expansion stroke and then the exhaust stroke to reject the exhaust gases and the value to the pressure reached 6.99 MPa at 300 K temperature for intake air compared to the 370 K temperature where it reached 6.8 MPa as shown in figure (4.4) .

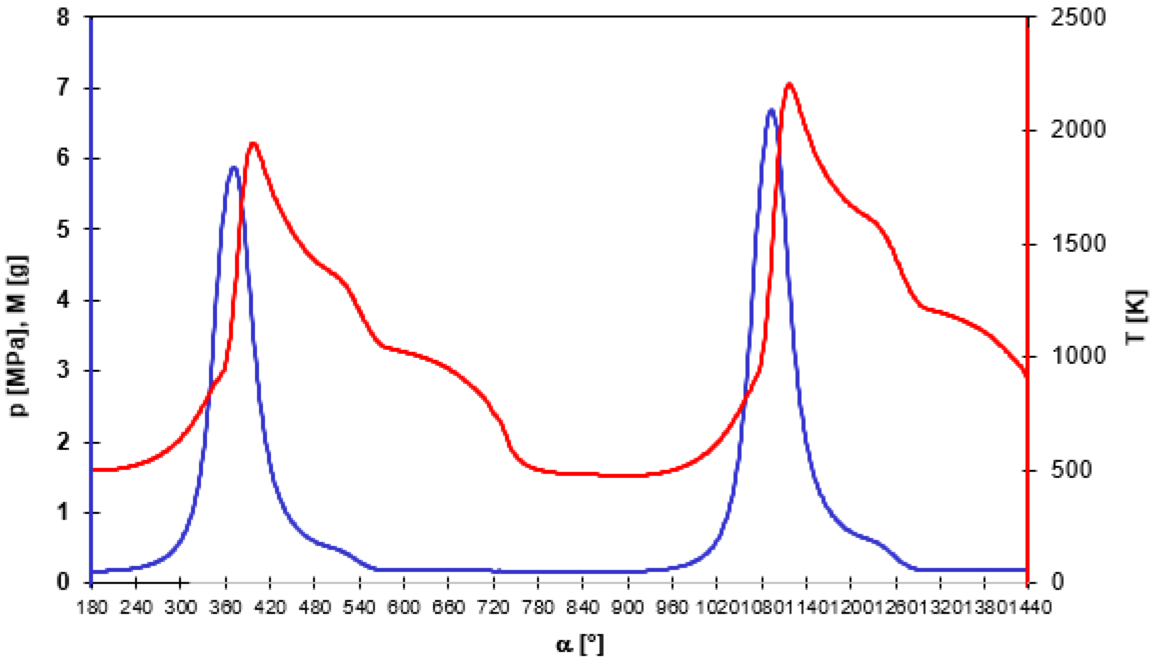


Figure (4. 3): T – α and p – α diagrams versus crank angle degree ($T_{intake} = 370K$)

As the intake temperature was higher, the surface of combustion chamber became hot. The impingement of fuel spray on hot surface affected the fuel evaporation and mixing processes. Similar effects were reported that with an increase in wall temperatures, ignition delays decreased. The reason for a decrease in ignition delays with higher intake temperature may be due to the fast mixing rate resulting from faster fuel evaporation in higher temperature. The high temperature in the chamber indicated rapid evaporation to the injected fuels and shortened ignition delay.

When intake air gets warm, its density decreases, meaning that mass of air entering the engine is lesser for the same volume. This decreases the volumetric efficiency of the engine as there is lesser air for complete combustion. This also directly decreases engine efficiency. An increase in the inlet temperature of the mixture increases the temperature at the end of compression, which in turn increases the temperature of the last part of the charge to burn, thus shortening the delay period and greatly increasing the knock.

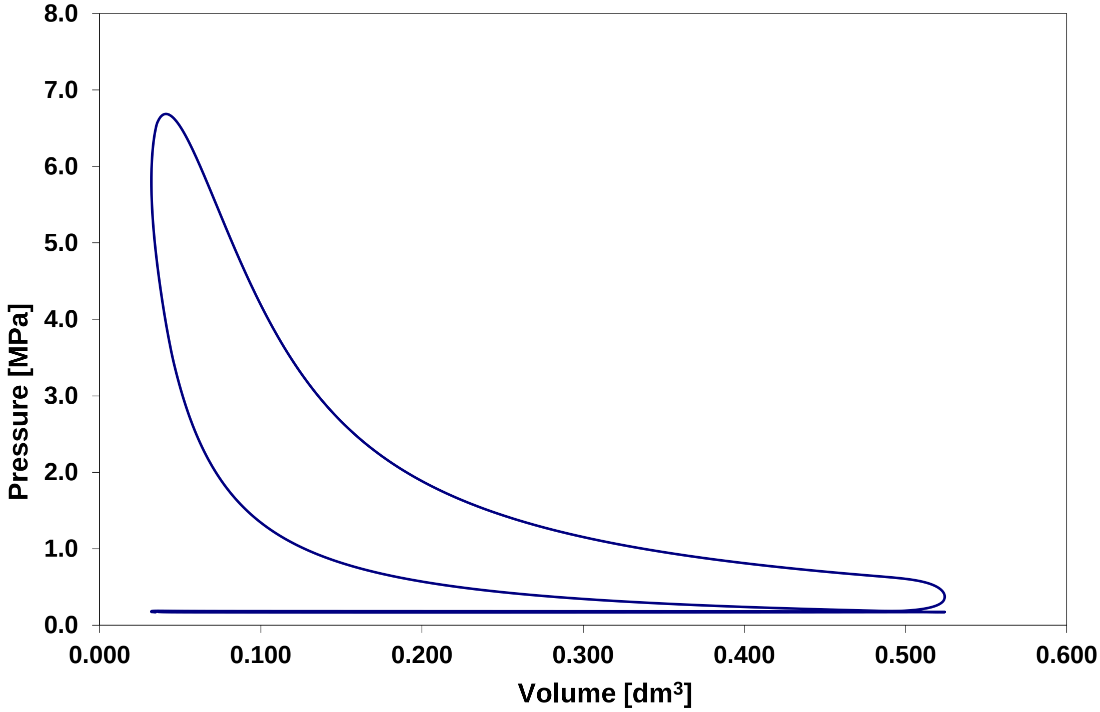


Figure (4. 4): P - V diagram versus crank angle degree ($T_{intake} = 370K$)

4.2 Experimental results

The “MultiRAE” Lite gas analyzer as shown in figure (4.5) was used to get the values of (CO, NO, NO_2 and VOC) results and the data sheet for this device were attached after references .The experimental results are shown in table (4.2).

Figure (4. 5): The “MultiRAE” gas analyzer.

Table (4. 2): Experimental results.

Temperature (°C)	Normal load value (%)	Engine torque (N.m)	Fuel consumption (L/h)	VOC (ppm)	NO (ppm)	CO (ppm)	NO_2 (ppm)
5	36.2	64.9	2.41	9	63	500	19.9
10	37.5	67.2	2.52	10	85	470	19.9
20	40.7	69.3	2.33	11	117	410	19.9
30	42.1	74	2.53	14	135	318	19.9
35	45.9	68.5	2..54	16	119	263	19
45	45.9	66.5	2.31	16	124.5	132	5.7
55	36.5	79	2.53	16	125.5	81	4.9
65	44.5	62.7	2.38	18	130	66	5.3
70	42	67.1	2.33	18	108	58	7
77	42.3	66	2.32	20	87	50	9.7

Intake air temperature and values of (NO, CO, VOC and NO_2) were measured with different values of intake air temperature at constant engine speed (2000 RPM) was plotted as show in figures (4.6),(4.7),(4.8),(4.9) and (4.10).

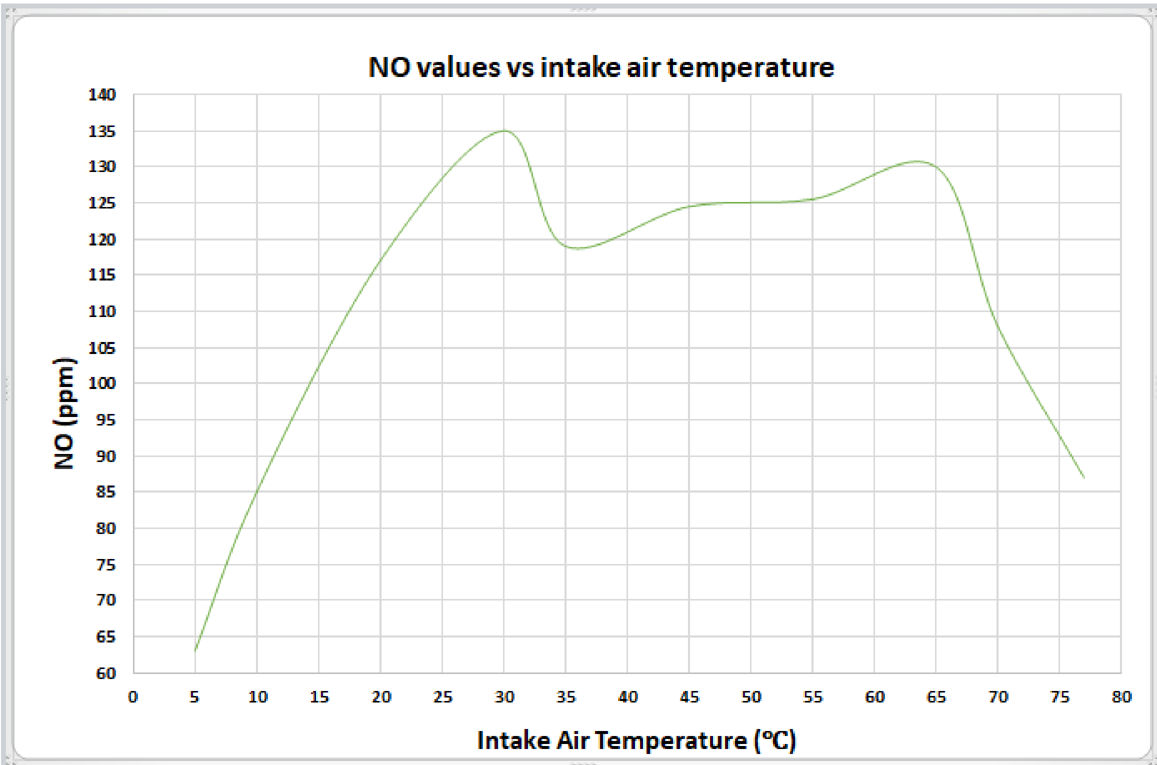


Figure (4. 6): The relationship between the intake air temperature and values of NO.

When the intake air temperature decreases the NO decreases. When the intake air temperature increase that's leads to increase the temperature inside the combustion chamber and therefore will increase the value of NO. And then a slight fluctuation for NO value due to the lack of precision and instability of the engine from 120 - 135 ppm. The density of air decrease and this reduce Oxygen inside the combustion chamber and this leads to reduce the amount of NO.

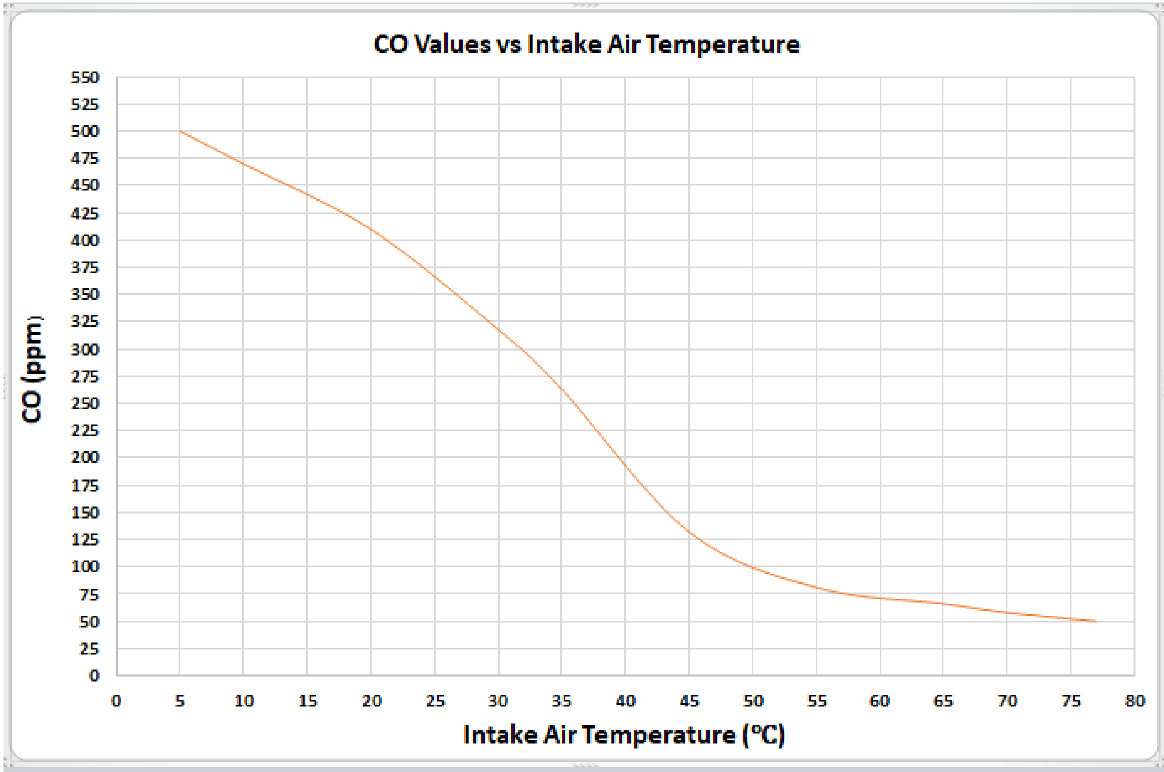


Figure (4. 7): The relationship between the intake air temperature and values of CO.

At the beginning, the intake air temperature at the combustion chamber is low and there is incomplete combustion and high density for air, so the volumetric efficiency is high and the ratio of CO increases because the amount of injected fuel and when the intake air temperature to the combustion chamber increases that's means decreases the volumetric efficiency and therefore the ratio of CO will decrease. CO reacts with Oxygen to give CO_2 if there is not enough air, the value of the CO will remain high.

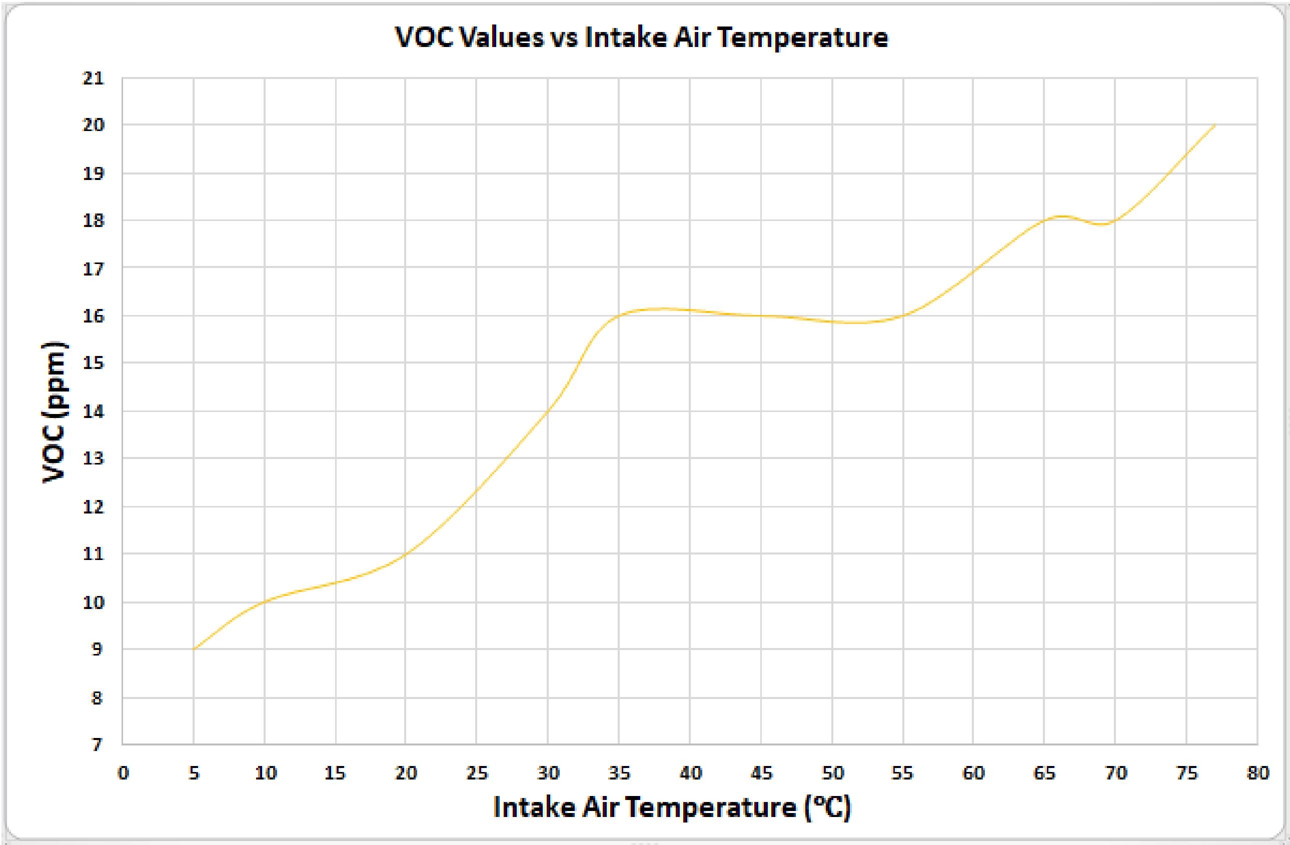


Figure (4. 8): The relationship between the intake air temperature and values of VOC.

At the beginning, the value of VOC be few, but when increases the intake air temperature inside the combustion chamber, the fuel is decrease, so the combustion is incomplete and this increase VOC. The amount of air inside combustion chamber is decrease, so it will extinguish the flame.

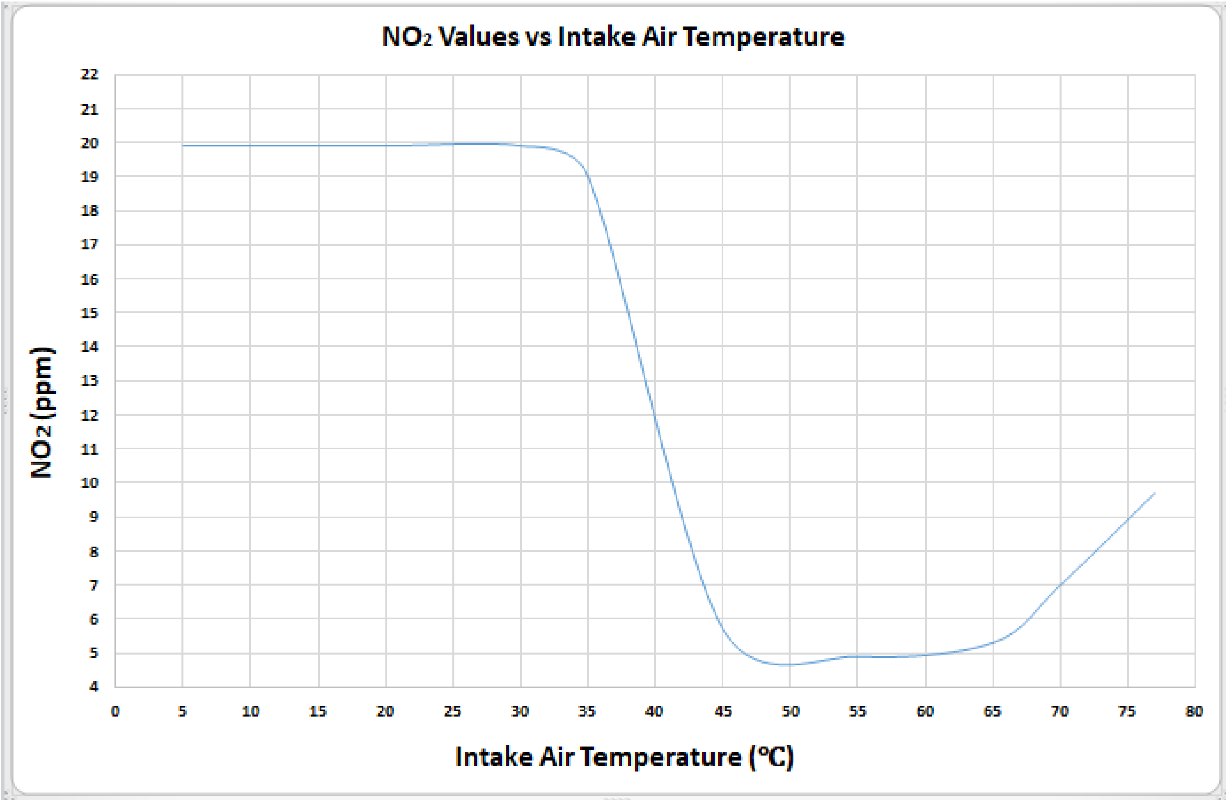


Figure (4. 9): The relationship between the intake air temperature and values of NO_2.

At the beginning, we do not take the reading because the gas analyzer has an over limit that cannot be shown on the device screen. Formation for NO_2 we need the reaction of NO and Oxygen. When the intake air temperature inside the combustion chamber increases, the Oxygen is reduced to NO_2 because there are not enough Oxygen atoms to form NO_2.

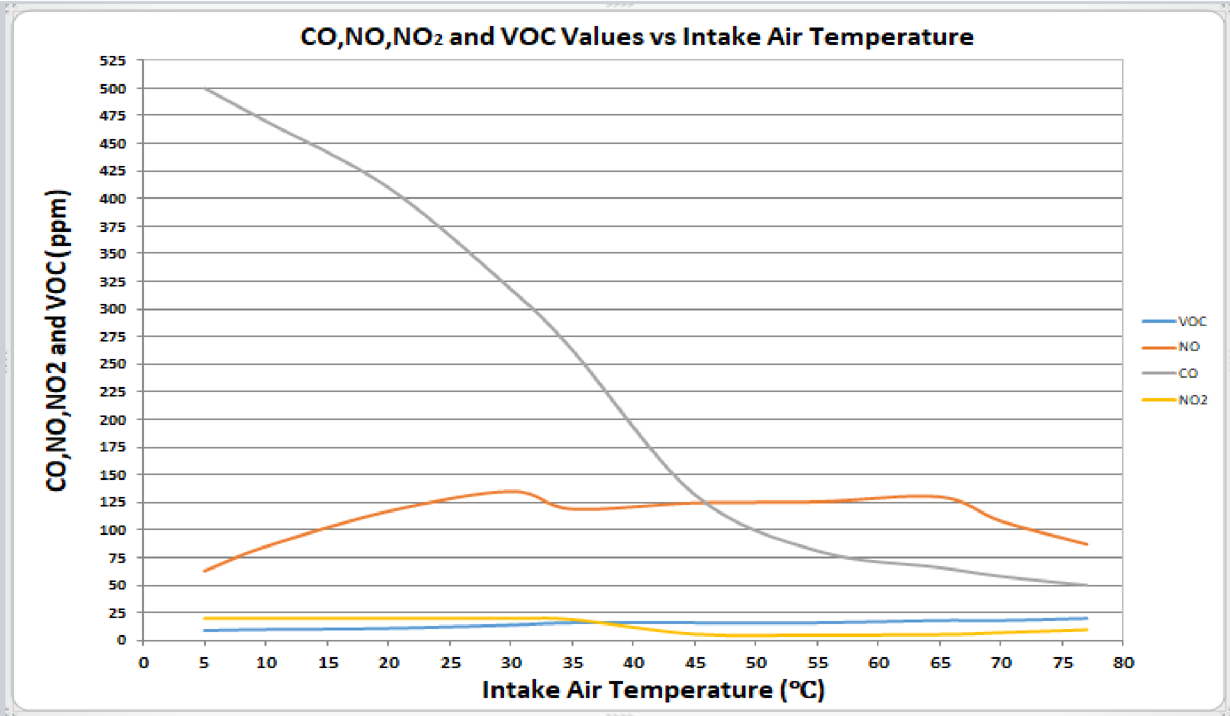


Figure (4. 10): The relationship between the intake air temperature and values of (NO , CO ,VOC and NO_2).

4.3 Conclusion

The variation for intake air temperature has a positive advantage when refrigerate intake air temperature for unburned hydrocarbons and NO this decreases the value for these emissions and one disadvantage that increases the CO value because the incomplete combustion is occur , but increase the intake air temperature that's include decrease of CO value. When temperature of air increases, its density decreases. So for the same displacement of piston in suction stroke or in other words, same volume of intake air less mass enters the combustion chamber. Decreasing of intake air temperature also prolonged the ignition delay, which caused a later combustion phasing and smaller peak cylinder pressure.

References:

[1] Alam, M., Song, K. H., & Boehman, A. (2005). Effects of inlet air temperature on performance and emissions of a direct injection diesel engine operated with ultra-low sulfur diesel fuel. In Proceedings of the International Conference on Mechanical Engineering (ICME2005)

[2] Mamat, Nik Rosli Abdullah, Hongming Xu, Miroslaw L. Wyszynski, A. Tsolakis" Effect of Boost Temperature on the Performance and Emissions of a Common Rail Diesel Engine Operating with Rapeseed Methyl Ester (RME)" Proceedings of the World Congress on Engineering 2010 Vol II WCE 2010, June 30 - July 2, 2010, London, U.K

[3] Pan, W., Yao, C., Han, G., Wei, H., & Wang, Q. (2015). The impact of intake air temperature on performance and exhaust emissions of a diesel methanol dual fuel engine. Fuel, 162, 101-110.

[4] www.scribd.com/document/338853078/Effect-of-Intake-Air-Temperature-On-Performance-of-CI-Engine-Fueled-with-Diesel.

[5] Brunton, J., Kennedy, D., & Kelleher, J., Air Intake Cooling Motor Vehicle Performance Enhancement. International Journal for Scientific Research & Development. Dublin Institute of Technology.

[6] www.auto-data.net/en/volkswagen-jetta-vi-2.0-tdi-140hp-18483.

[7] Zuhdi Salhab "thermodynamic and emissions parameters of spark-ignition engines powered by gaseous fuels." Technical university of Liberec. Faculty of mechanical engineering, 2001".