Palestine Polytechnic University

College of Engineering and Technology

Mechanical Engineering Department

Graduation Project

Water Consumption Diagnostic Tool for Gasoline and Diesel Engines

By

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Dedication (إهداء)

إلى السنبلة الذهبيّة في بِلادي و بيّارات البرتقال ...إلى كرومِ العِنَب و غصن الزيتون ...و دَم الشهداء و دَمعة الأطفال..... إلى رغيف الطابون و ريح 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), ونخُصّ إخوانَنا الأسرى من أبناءِ جامعتنا العَريقة.

إلى ملاكي في الحياة...الى معنى الحب و الى معنى الحنان و التفاني....الى بسمة الحياة و سر الوجود...الى من كان دعائها سر نجاحي و حنانها بلسم جراحي الى اغلى الحبايب...(امي الحبيبة).

إلى من كلّله الله بالهيبة و الوقار....الى من علمني العطاء بدون انتظار....الى من احمل اسمه بكل افتخار..ارجو من الله ان يمد في عمرك لترى ثمارا قد حان قطافها بعد طول انتظار و ستبقى كلماتك نجوم اهتدي بها اليوم و في الغد و الى 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 سوياً ونحن نشق الطريق معاً نحو النجاح والإبداع إلى... (زميلاتي وزملائي).

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

Abstract:

The project is aimed to determine the source of water leakage in vehicles, in which the source of lack may be from engine or not, and that by the determination of the percentage of water which goes out with exhaust gases and compare it with the theoretical percentage of water. Therefore, by determining the problem of water leakage in the engine can saving time and effort is utilized.

The result of this project is a device that changes the physical state of water vapor in exhaust gases to water by condensation, also it work to calculate the theoretical amount of water that emerged from burning fuel, then compare these values to determine if there is leaking in the engine or not.

It found that the water condensation efficiency in gasoline engines higher than in diesel engines, where the efficiency in gasoline engines reached 94% and in diesel engines reached 85% because of many reasons that discussed in the project.

يهدف المشروع بشكل اساسي الى تحديد مصدر نقص المياه في المركبات, بحيث ان النقص يمكن ان يكون في المحرك او من مصادر اخرى, وذلك من خلال تحديد نسبة المياه التي تخرج مع غازات العادم ومقارنتها بالنسبة الطبيعية بحيث اذا كانت النسبة كبيرة فانه يمكن التاكد ان سبب المشكلة من المحرك, وذلك يؤدي الى توفير الوقت والجهد في حل المشكلة بدلا من البحث في جميع المصادر التي يمكن ان تؤدي للمشكلة.

وفي هذا المشروع سيتم عمل جهاز يعمل على تغيير الحالة الفيزيائية لبخار الماء الى ماء بالتكثيف, وبالمقابل يتم حساب الكمية النظرية للماء الناتج من حرق الوقود والعمل على مقارنة هذه القيم لتحديد فيما إذا كان يوجد تسريب في المحرك.

حيث وجدنا بأن كفاءة تكثيف الماء في محركات البنزين اعلى من كفاءة تكثيف الماء في محركات السولار , حيث وصلت كفاءة التكثيف في البنزين 94% و كفاءة التكثيف في السولار وصلت 85% وذلك يعود لأسباب عدة قمنا بتوضيحها في المشروع .

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

The high reliance on vehicles in various forms, kinds, weights and sizes in many uses has led to increased demand for vehicles that led to an increase in their count dramatically and significantly around the world, In view of this fact, progress in manufacturing and vehicle development has become unavoidable, so there is a lot of science research conducted for the development of vehicles and their systems to make them more powerful, efficient and smarter at the same time lower cost and less fuel consumption as they are at the present time.

This transfer of automotive and automotive systems from the simple form to more complicated form, which led to make the diagnosis and process of maintenance more difficult. This may need to be diagnosed with advanced devices which can be expensive or difficult to obtain.

There are many problems that may be exposed to vehicle and that may be the result of the wrong use or for not performing procedures of periodic maintenance of the vehicle. "*Vehicle owners have reported 78,567 engine and engine cooling related problems since 1996. The most common is the engine and engine cooling problems. The number one most common problem is related to the engine and engine cooling (14,493 problems "28 %"). The second most common problem is related to the car stall (8,567 problems "17 %")*." [1], Figure (1.1) with Table (1.1) shows statistics about the most malfunctions facing the vehicle owners around the world.

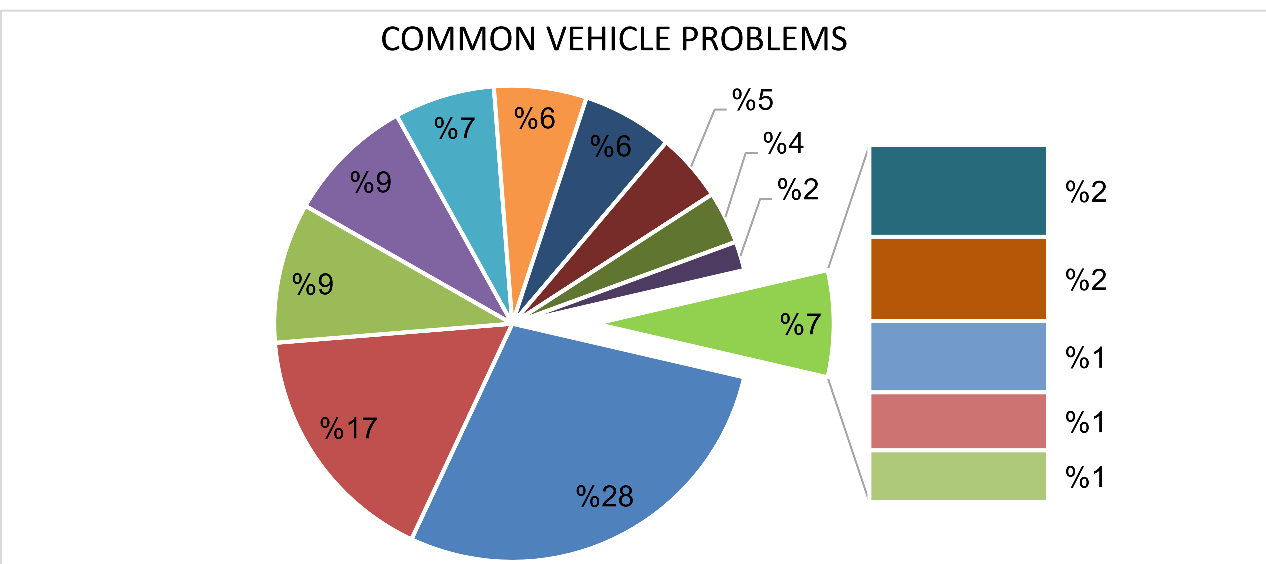

Figure1.1: The Common Vehicle Problem around the World [1].

Table 1.1: The Common Vehicle Problem around the World.

28%	Engine And Engine Cooling problems	4%	Engine Oil system problems
17%	Car Stall problems	2%	Engine Burning Oil problems
9%	Engine Cooling System problems	**Other (7%)**	
9%	Manifold/header/muffler/tail Pipe problems	2%	Catalytic Convertor problems
7%	Engine Belts And Pulleys problems	2%	Engine Head Gasket Failure problems
6%	Electrical problems	1%	Engine Knocking Noise problems
6%	Engine Exhaust System problems	1%	Engine Noise problems
5%	vehicle power train systems	1%	Engine Head Gasket Leaking problems

1.2 Background

Internal combustion engines operate through the principle of conversion of chemical energy in the fuel to heat energy during the combustion process and then into mechanical kinetic energy, the typical 4 cylinder vehicle cruising along the highway at around 80 Km/h, will produce 4000 controlled combustion stroke per minute inside the engine [2] . Obviously, these explosions produce an enormous amount of heat and, if not controlled, will destroy an engine in a matter of minutes.

The cooling system in vehicles is designed to keep the engine running in a certain range of temperatures in order to preserves and reduce the thermal stress on the engine parts to protect this part from corrosion and frailer by transferring heat by Radiation, Convection and Conduction respectively from the combustion chamber (cylinder wall) to coolant medium (water) [3] .

One of the most common problems facing the vehicles is the increase in water consumption or a lack of water level in the radiator, since the problem of coolant water shortages are not as easily recognized by visual inspection of the radiator and hose ,it may cause a lot of problems that can lead to a sharp rise in engine temperature, which could cause damage to the engine due to leakage somewhere in the coolant medium of the cooling system, often it is difficult to locate the leakage which may likely be in the external parts of the cooling system or inside the engine, Figure (1.1) shows the parts of the cooling system which may be possible places where the external leakage occurs specially on radiator pipes, water pump and heater hoses connection which are usually easy to detect with the naked eye.

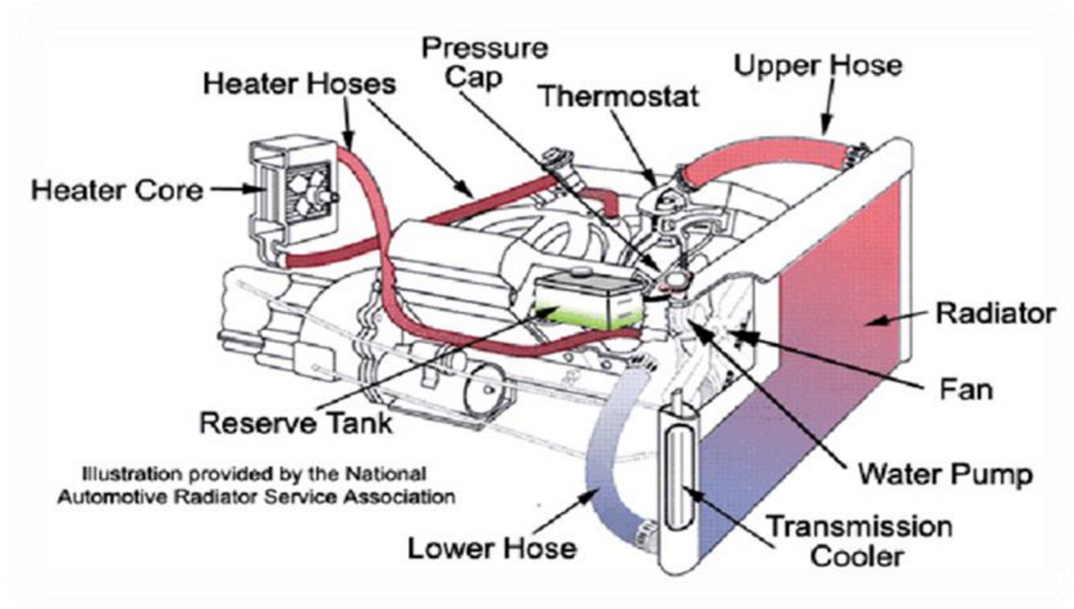

Figure 1.2: Vehicle Cooling System [4].

1.3 Problem Definition

A leakage that occurs inside the engine; results in water mixing with air- fuel mixture in the combustion chamber which causes general weakness in the performance, efficiency and increase in fuel consumption of the engine, often this kind of leakage is difficult to detect because it is caused by an internal defect or crack on a cylinder head, gasket, cooling water streams or cylinders block.

Figure (1.3) shows a side section for CI-engine Figure (1.3a) and SI-engine Figure (1.3b), the figures shows where the cooling medium passes in the cylinder head and engine block. The red arrows describe how and where it can leak, whether it is leaking from the water stream to the combustion chamber as a result of some defect or specific crack in cylinder head of or engine block Figure(1.3 a) and (1.3b) or gasket as shown in Figure (1.3 c), on the other case when water leaks directly from its streams to the exhaust manifold (Fig 1.2 b), all of the above causes a large amount of water coming out with exhaust gases.

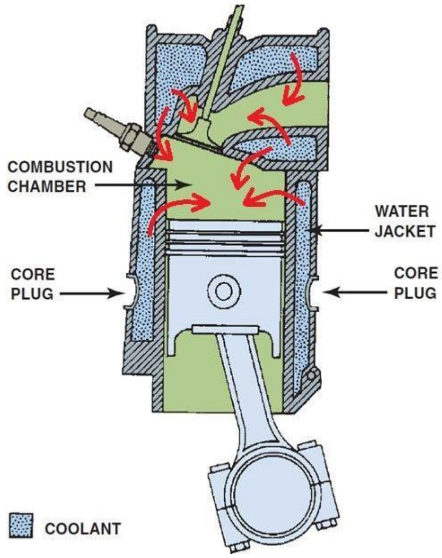

Fig1.3 (a)

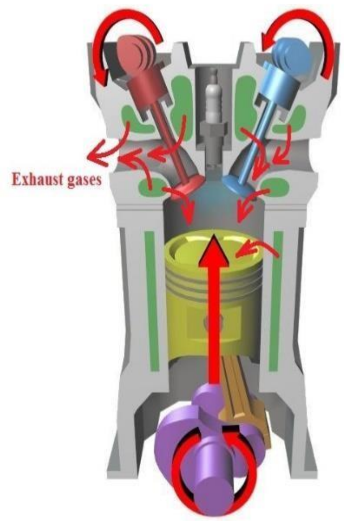

Fig1.3 (b)

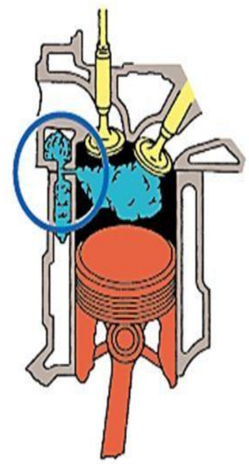

Fig1.3 (c)

Figures 1.3: Places of the water leakage to the combustion chamber and exhaust manifold [5].

In general, leakage of the cooling medium into the combustion chamber often results in a white and gray exhaust gases, but you cannot always say that there is a crack or defect on the gasket from the given color of the exhaust gas, because it can be produced if the engine does not reach the worming up temperature such as diesel engines, the following figure 1.4 shows of some possible colors of the exhaust gases and possible reason of each one.

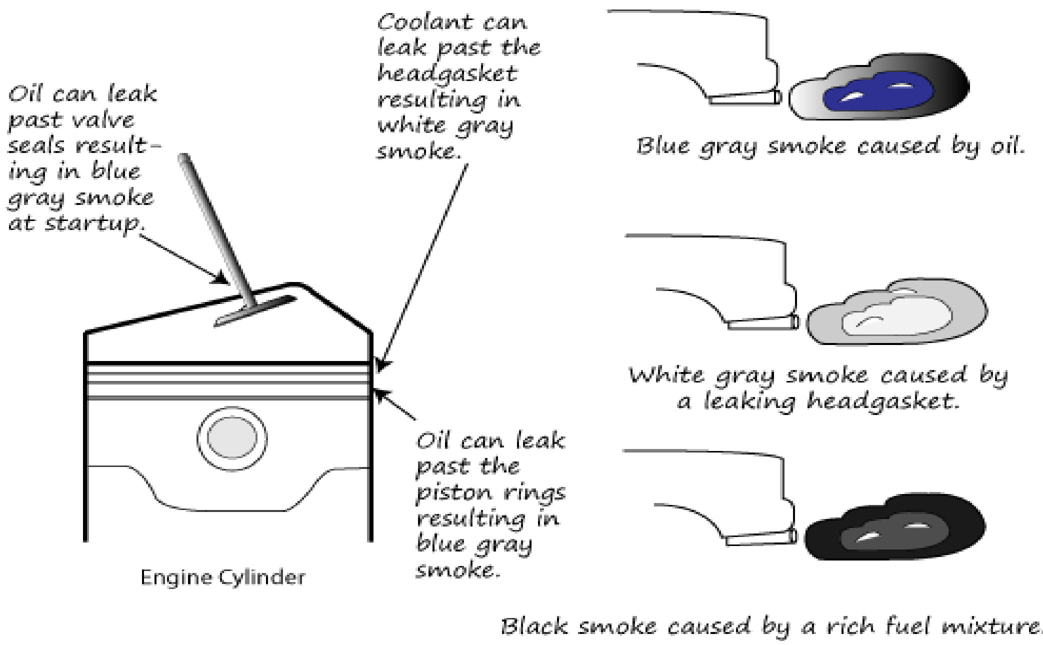

Figure 1.4: Emerging Exhaust Gases Possible Colors [6].

Therefore, some of the technicians in the domestic market adopt the principle of trial and error to troubleshoot this problem , also the process of exploration this king of leakage takes time and considerable effort in additional to the high costs which makes the possibility of fault higher, Therefore that our project aims to design a diagnostic tool that detect the internal leakage of water to the combustion chamber or exhaust system with less time, effort and cost as possible and more accurately by determine the amount of the water coming out from exhaust gases and compare it with the amount of water emerging from an ideal engine.

1.4 Project Objective

The main objective of the project is to design a diagnostic tool to detection an excessive water consumption in vehicle engines and predict the internal water leakage into the combustion chamber or exhaust system through the measurement of the amount of water coming out with an exhaust gases for both diesel and gasoline engines.

In addition, the project targets the following specific objective:

1) The ability to know the reasons for increasing in water consumption in the vehicle.
2) Save time at diagnosis, especially if the problem is related to the internal engine components.
3) Save effort and diagnostic cast, in addition to the rapid diagnosis with more accuracy in measurement, detect and diagnosis.

1.5 Project Sub Problems

After identifying the problems in the visual diagnostic process adapted in local automotive workshops, there are challenges that face the project:

1) Accuracy and speed, diagnosing this problem is required high accuracy and speed to get a good result to Judge the engine condition.
2) Data transfer process, the challenge here is the process of transferring current data from the vehicle and processing it to make it an input to the controller of the diagnostic device.
3) Engine capacity limits, the proposed diagnostic tool can deal with the different engine capacities, in addition to the difference air charging methods such as a turbo charger.

1.6 Principle of Operation

The principle of operation mainly depends on condensation of water and extract it from exhaust gases resulting from the combustion process by using a refrigeration cycle also we have to design a suitable condenser to perform this operation, in addition to using a dryer for emerging gases from condenser to confine a larger amount of water emerging and increase the accuracy of reading, the whole diagnosing process does not start before that the engine reach warm up temperature.

Air is required for the completion of the combustion process, which enter the combustion chamber from outside, air may to be dry or wet air, humidity sensor is used to measure the percentage of humidity in the entering air and send it as a signal to the control unit, this is important to subtract its value from the final result to obtain high accuracy.

Fuel consumption, air mass flow and oxygen sensor (lambda sensor) information's are required as a parameter for the combustion equation to determine the theoretical amount of water generated from the current combustion process, also the outlet exhaust gases temperature sensor is used as a feedback for the refrigeration cycle operation, to ensure full extraction of the water coming out with the exhaust system.

There are some parameters that should be inserted to device by a Keyboard such as the engine capacity and type of fuel system which is important for the diagnostic tool control unit in order to decide on which chemical equilibrium equation will work on.

After a water condensate, the emerging exhaust gases from heat exchanger (condenser) will pass on the humidity sensor which used to measure the amount of water that has not condensed into the condenser, this signal has to be sent to the control unit to be added to the final result to improve the project accuracy.

The following diagram Figure 1.5 describes a general idea about how the project works and how the signals transfer from different sensors to the control unit and then analyzed to displaying the final result.

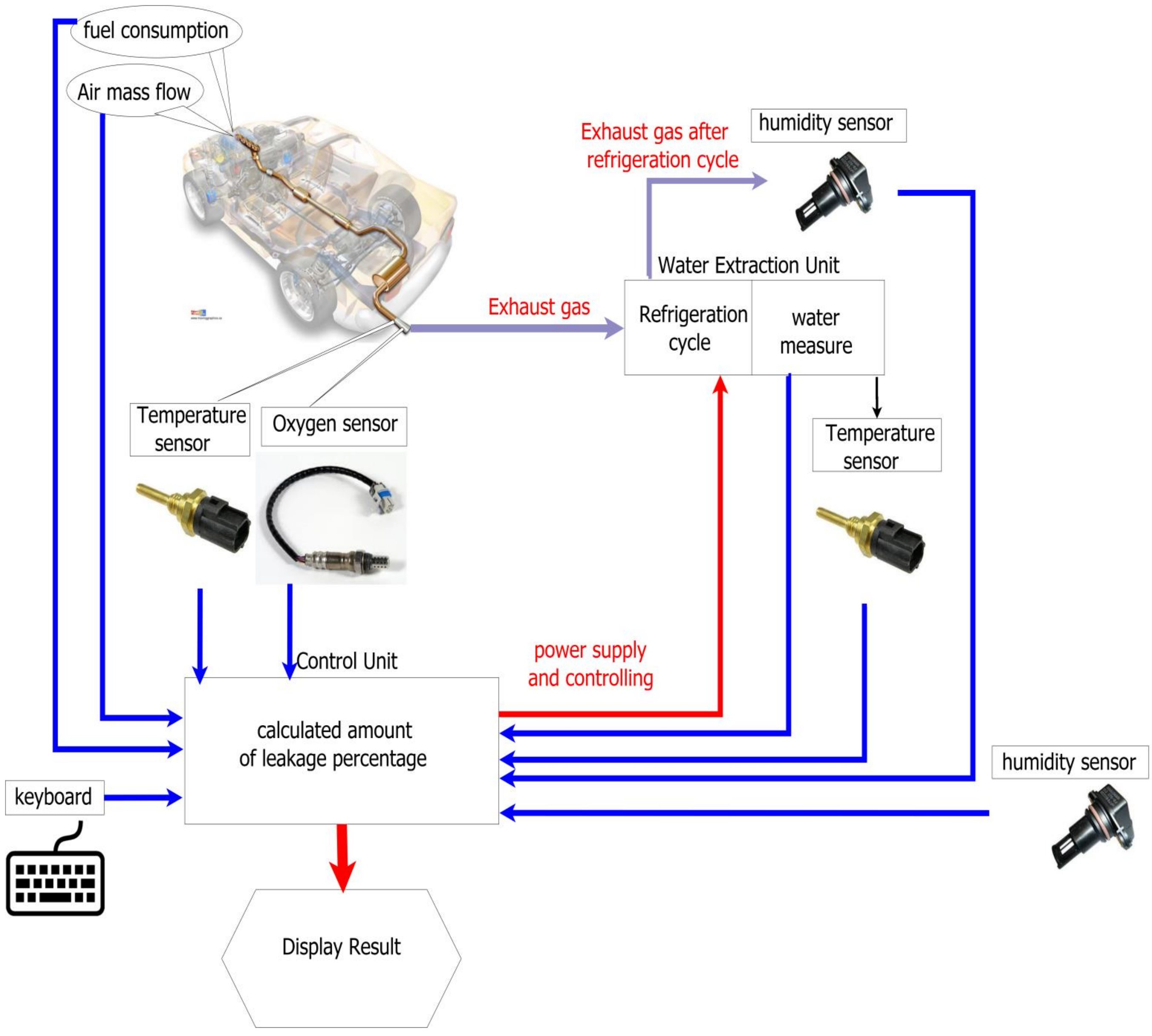

Figure 1.5: Project Block Diagram.

1.6.1 Features expected (Specifications)

There are several feature have been taken into consideration during the designing stage of the diagnostic device:

1) The device is portable and can be easily transported.

2) Suitable weight and dimensions.

3) Receiving data from the vehicle through cable.

4) Resistance to environment influences such as moisture.

5) Control unit must be able to work for an appropriate period without need for charging the batteries.

6) Providing screen to display the result and keypad to specify the vehicle under test.

7) Beautiful exterior with good finishing.

1.7 Project Methodology

The project will pass several steps, every step includes check and test, and on the other hand we will work theoretical and practical together.

Stage one: Identifying the project idea.

Stage two: Project requirement and collecting data.

Stage three: Modeling and calculation.

Stage four: Writing and documentation.

Stage five: Design of a mechanical and electronic component, simulation, and implementation.

Stage six: Testing the experimental result.

1.8 Schedule Time

Table 1.2: Schedule Time-First Semester

Task\Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Identifying the project idea.	■	■	■													
project requirement and collecting data			■	■	■											
Modeling and calculation				■	■	■	■	■	■							
Writing and documentation.				■	■	■	■	■	■	■	■	■	■	■	■	■
Design of a mechanical component and simulation										■	■	■	■			

Table 1.3: Schedule Time -Second Semester.

Task\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Modifying the project idea.																
project requirement and collecting data																
Modeling and calculation																
Writing and documentation.																
Design of a mechanical component and simulation																
Testing and experimental result																

1.9 Total Cost for the Project

The cast of each mechanical and electrical component are shown in the following table (1.4).

Table 1.4: Total Cost Table.

Tools and device	#	Piece price	Price
Humidity sensor	2	10	20
Temperature sensor	1	15	30
Reservoir	1	50	50
Copper tube	5	70	20
Arduino Mega	1	60	60
Cables ,wires	1	30	30
Compressor	1	150	150
Expansion valve	1	10	10
stand	1	50	50
wheels	4	6	24
Electrical parts		30	30
Screen	1	40	40
Refrigerant		70	70
Elbow	5	15	75
USA $			659
NIS			2500

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CHAPTER TWO

MODELING AND CALCULATIONS

2.1 Introduction

In this chapter we show the calculations that we need to complete theoretical part that related to chemistry and physics in our project, such as density of fuel, mass of water emerged in diesel and gasoline engines.

2.2 Combustion Overview

Stoichiometric combustion of hydrocarbon with Oxygen forms water from the Hydrogen and Carbon Dioxide from all of the carbon. The chemical equation for stoichiometric combustion of a hydrocarbon in oxygen is [7]:

$$C_aH_b + xO_2 \rightarrow aCO_2 + \frac{b}{2}H_2O \tag{2.1}$$

Where $x = a + \frac{b}{4}$

Air contains Nitrogen, but when the products are at low temperatures the Nitrogen is neglected. Consider the complete combustion of hydrocarbon fuel of average molecular composition C_aH_b with air. The general equation of complete combustion is [5]

$$C_aH_b + (a+\frac{b}{4})(O_2 + 3.76\ N_2) \rightarrow \frac{b}{4}H_2O + a\ CO_2 + 3.76\ (a+\frac{b}{4})N_2 \tag{2.2}$$

The incomplete combustion of a hydrocarbon with Oxygen produces a gas mixture containing H_2O, CO_2, CO and O_2. The general reaction equation for incomplete combustion of a hydrocarbon in oxygen is:

$$C_aH_b + z(O_2 + 3.76\ N_2) \rightarrow x\ H_2O + y\ CO_2 + d\ CO + f\ O_2 + z\ 3.76\ N_2 \tag{2.3}$$

where

$z = \lambda \times a_{th}$

λ is the excessive air ratio

a_{th} is the theoretical air

2.3 Gasoline Density Calculation

This method is used to obtain fuel density which best fits a set of measured data points. It is called linear regression where the best fitting straight line representing measured data is to be found, so the purpose here is that of choosing a best line based on minimizing the squares of the deviation of the data points from the line.

The equation of straight line:

$$y = b + mx \qquad (2.4)$$

Where m is the slope and b is the X intercept. The regression equation is [6]

$$m = \frac{\sum_{i=1}^{n} xy - \frac{\sum x \sum y}{N}}{\sum x^2 - \frac{(\sum x)^2}{N}} \qquad (2.5)$$

In this project , x represent sample volume V[ml] , y represent the fuel sample mass M[gr], m represent the slope of the line , which is the fuel density ρ [gr/ml] and N represent the number of samples.

i.e. the above equation can be written as ;

$$\rho = \frac{\sum_{i=1}^{n} V \times M - \frac{\sum V \sum M}{N}}{\sum V^2 - \frac{(\sum V)^2}{N}} \qquad (2.6)$$

We made six trials in laboratory to compute the real value of Gasoline density, which shown below in the Table (2.1).

Table 2.1: Measurement Data of Gasoline Samples

Trial	X	Y
1	100	72
2	150	105
3	300	217
4	450	330
5	500	360
6	600	441

Applying equation (2.6) to the above data samples gives ρ = 0.737 gr/ml which is the gasoline density that will be used in this project.

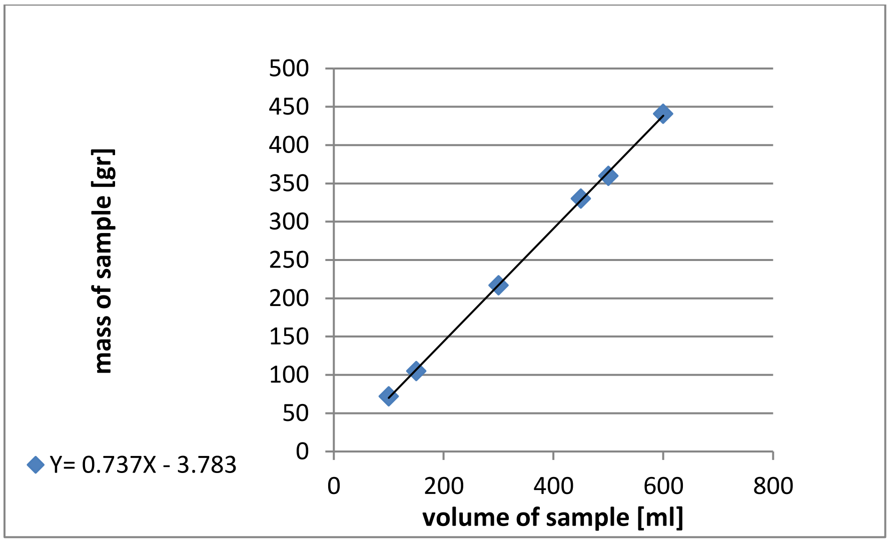


Figure 2.1: Calculation Density of Gasoline

2.4 Gasoline Combustion Calculation

We need to calculate the mass of water that produced from burned one liter of gasoline completely where this value will be compare with the value that will come out from the exhaust gases.

To calculate the mass of gasoline we need to use the combustion equation, so we need the actual chemical formula of gasoline which is [$C_{7.93}H_{14.9291}$] [8].

Here, we worked to balance the gasoline stoichiometric combustion equation, we get that the theoretical air is 11.6372 [gr air / gr gasoline]

$$C_{7.93}H_{14.9291} + a_{th}(O_2 + 3.76\,N_2) \rightarrow (x)\,H_2O + (y)\,CO_2 + (z)\,N_2 \qquad (2.7a)$$

C balance: $\boxed{y=7.93}$

H balance: $2\times x=14.9291 \rightarrow \boxed{x=7.4145}$

O balance: $2\times a_{th}= x + 2\times y \rightarrow \boxed{a_{th}=11.6372}$

N balance: $2\times 3.76\times a_{th}=2\times z \rightarrow \boxed{z=43.75}$

So the following equation represents the net equation of stoichiometric combustion of gasoline ($\lambda=1$):

$$C_{7.93}H_{14.9291} + 11.6372(O_2 + 3.76\,N_2) \rightarrow 7.4145\,H_2O + 7.93CO_2 + 43.75N_2 \qquad (2.7b)$$

But in the actual combustion λ variable (lean or rich) so we multiply the theoretical air by factor represent the excessive air ratio

$$C_{7.93}H_{14.9291}+\lambda\times 11.6372(O_2+3.76N_2)\rightarrow xH_2O+yCO_2+\lambda\times 43.75N_2$$
(2.7c)

From the result of experiment we get the density ρ = 0.737 gr/ml

Depending on equation (2.7b) we calculated the mass of water produced by burning a liter of gasoline.

Mass = number of moles × molar mass (2.8)

$\text{Mass}_{gasoline}$ = number of moles × molar mass

= 1[mole]×110.089 [gr/mole]=110.0891 gr = 0.1100891 kg

Mass_{H2O} = 7.4145[mole] × 18[gr/mole] = 133.461 gr =0.133461 kg

Mass for 1 liter of gasoline:

M= ρ × 1 liter = 0.737 × 1 = 0.737 kg

1 mole gasoline ⟹ 0.1100891 kg gasoline

x mole gasoline ⟹ 0.737 kg gasoline

x = 0.737/0.1100891 = 6.6945774 moles of gasoline in 1 liter.

After we calculate the number of moles gasoline in 1 liter, we can calculate the number of water moles produced from burning this amount of gasoline at stoichiometric condition:

1 mole gasoline ⟹ 7.4145 moles H_2O

6.6945774 mole gasoline ⟹ *x* moles H_2O

x = 7.4145 × 6.6945774 = 49.63695 moles H_2O

to get the mass of water use Eq. (2.8) :

Mass = number of moles × molar mass

= 49.63695 × 18 = 893.465 gr

= 0.893465 kg

Mass ratio = $\frac{mass\ \text{H2O}}{mass\ gasoline} = \frac{893.465}{737}$ = 1.2123

The mass of H_2O (0.893) produced from stoichiometric combustion equation but in actual the combustion will not be at stoichiometry, so this result given us vision about actual value that will be emerged.

This result fit with previous result that we read in precedent research, and tell us the amount of water greater than the amount of gasoline which burnt. This help us to choose the suitable equipment to collect water in our project.

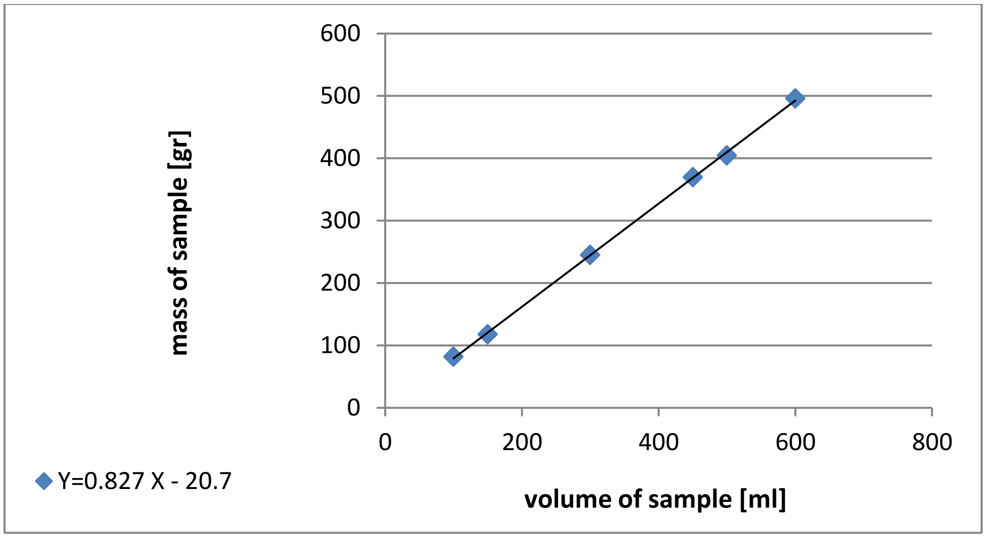
2.5 Diesel Density Calculation

We made six trials in laboratory to compute the real value of Diesel density, which as shown below in the table:

Table 2.2: Measurement Data Of Diesel Samples

Trial	x	y
1	100	82
2	150	118
3	300	245
4	450	370
5	500	405
6	600	496

By using regression method, apply equation (2.3) to the above data samples gives ρ = 0.827 gr/ml which is the diesel density that will be used in this project.



Figurer 2.2: Calculation Density of Diesel

2.6 Diesel Combustion Calculation

We need to calculate the mass of water that produced from burned one liter of Diesel where this value will be compare with the actual value that will come out from the exhaust gases.

To calculate the mass of Diesel we need to use equation (2.6), so we need the actual chemical formula of Diesel which it $C_{12.381}H_{22.1739}$ [6].

Here, we worked to balance the gasoline stoichiometric combustion equation, we get that the theoretical air is 17.9241 [gr air / gr diesel]

$$C_{12.381}H_{22.1739} + a_{th}(O_2 + 3.76\,N_2) \rightarrow x\,H_2O + y\,CO_2 + z\,N_2 \qquad (2.9a)$$

C balance: $\boxed{y=12.381}$

H balance: $2\times x=22.1739 \rightarrow \boxed{x=11.086}$

O balance: $2\times a_{th}= x + 2\times y \rightarrow \boxed{a_{th}=17.9241}$

N balance: $2\times 3.76\times a_{th}=2\times z \rightarrow \boxed{z=67.394}$

So the following equation represents the net equation of stoichiometric combustion of diesel (λ=1):

$$C_{12.381}\,H_{22.1739} + 17.9241(O_2 + 3.76\,N_2) \rightarrow 11.086\,H_2O + 12.38CO_2 + 67.394N_2 \quad (2.9b)$$

But in the actual combustion λ variable (lean or rich) so we multiply the theoretical air by factor represent the excessive air ratio

$$C_{12.381}H_{22.1739}+\lambda\times17.9241(O_2+3.76N_2) \rightarrow 11.086H_2O+12.38CO_2+\lambda\times67.394N_2 \quad (2.9c)$$

From the result of experiment we get the density ρ = 0.827 gr/ml

Depending on equation (2.9b) we calculated the mass of water produced by burning a liter of diesel, use equation (2.8):

$Mass_{diesel}$ = number of moles×molar mass

=1[mole] × 170.7459 [gr/mole] =170.7459 gr = 0.1707459 kg

$Mass_{H2O}$ = 11.086 × 18 =199.548 gr = 0.199548 kg

Mass for 1 litter of diesel:

M= ρ × 1litter = 0.827 × 1 = 0.827 kg

1 mole diesel $\Longrightarrow$ *0.199548 kg diesel*

x mole diesel $\Longrightarrow$ *0.827 kg diesel*

x = 0.827/0.199548 = 4.144366 moles diesel in 1 liter.

After we calculate the number of moles diesel in 1 liter, we can calculate the number of water moles produced from burning this amount of diesel at stoichiometric condition:

1 mole diesel $\Longrightarrow$ 11.086 moles H_2O

4.144366 mole diesel $\Longrightarrow$? moles H_2O

? = 4.144366 × 11.086 = 45.945 moles H_2O

To get the mass of water use equation (2.8):

Mass = number of moles × molar mass

= 45.945 × 18 = 827 gr

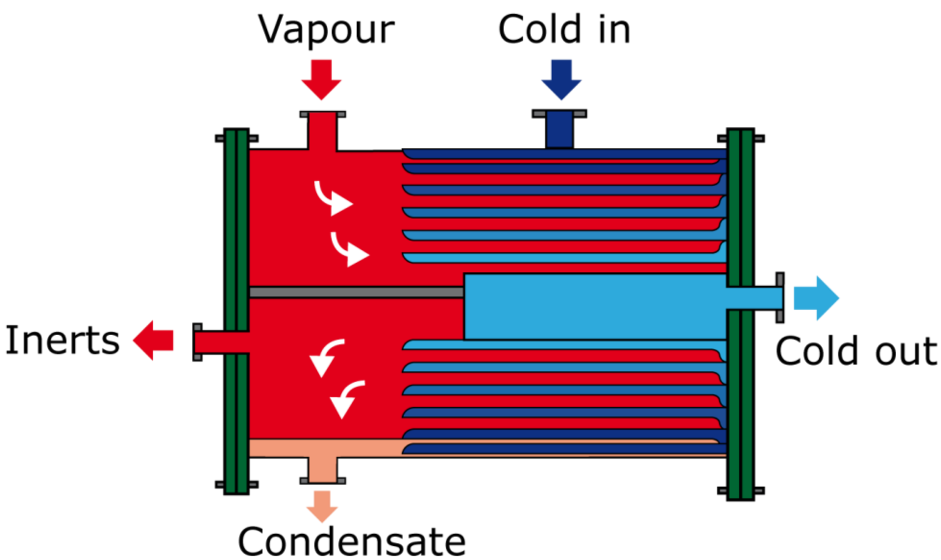
= 0.827 kg

Mass ratio = $\frac{mass\text{H2O}}{mass\ diesel}$= $\frac{827}{827}$ = 1.0

The mass of H_2O (0.827) produced from stoichiometric combustion equation but in actual the combustion will not be at stoichiometry, so this result given us vision about actual value that will be emerged. This result fit with previous result that we read in precedent research, and tell us the amount of water greater than the amount of diesel which burnt. This help us to choose the suitable equipment to collect water in the project.

In this chapter the theoretical mass ratio calculated, and it will be used in the comparison with the actual value of the mass ratio calculated from the real experiments in many vehicles to determine the percentage of error.

3



CHAPTER THREE

Refrigeration Cycle

3.1 Introduction:

In this project we need to design the refrigeration cycle in order to condensate as must as possible water vapor in exhaust gases. So, we need to design appropriate heat exchanger (condenser) to condensate water vapor emerging at high temperature and high flow rate in exhaust gases and determine the power required to run the compressor in the refrigeration cycle.

Figure (3.1) show the states of refrigeration cycle, in an idle vapor-compression refrigeration cycle, the refrigerant enter the compressor at state 1 as saturated vapor and is compressed isentropically to the condenser pressure. The temperature of the refrigerant increases during this isentropic compression process to well above the temperature of the surrounding medium. The refrigerant then enter the condenser as superheated vapor at state 2 and leaves out as saturated liquid at state 3 as a result of heat rejection to the surroundings. The temperature of the refrigerant at this state is still above the temperature of the surroundings.

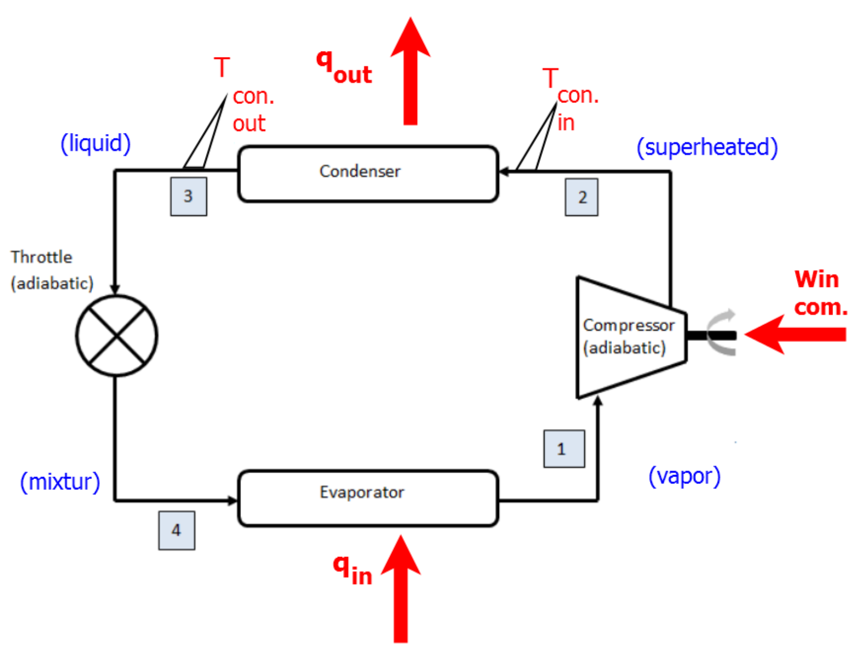


Figure 3.1: Refrigeration cycle state.

The state properties in ideal refrigeration cycle:

- 1-2 Isentropic compression in a compressor (S1=S2).
- 2-3 Constant pressure heat rejection in a condenser (P2=P3).
- 3-4 Throttling in an expansion device (h3=h4).
- 4-1 Constant pressure heat absorption (P4=P1).

Where S: entropy in (J/K)

P: pressure in (bar)

h: specific enthalpy in (kJ/ kg)

3.2 Refrigeration cycle component

There are five basic components of a refrigeration system, these are: Evaporator, Compressor, Condenser, Expansion Valve and Refrigerant gas.

1. **Evaporator**

The purpose of the evaporator is to remove unwanted heat from the product via the liquid refrigerant. The liquid refrigerant contained within the evaporator is boiling at a low-pressure. The level of this pressure is determined by two factors: The rate at which the low-pressure vapor is removed from the evaporator by the compressor To enable the transfer of heat, the temperature of the liquid refrigerant must be lower than the temperature of the product being cooled. Once transferred, the liquid refrigerant is drawn from the evaporator by the compressor via the suction line. When leaving the evaporator coil the liquid refrigerant is in vapor form; so it's necessary to choose gas heat exchanger as an evaporator in which is required in our project to perform a water condensation process.

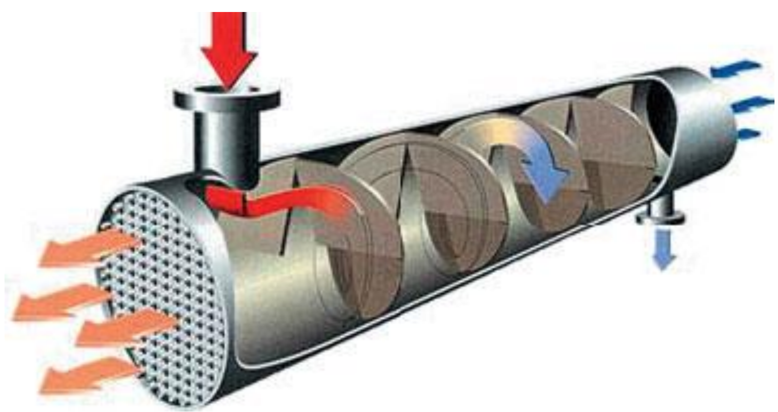


Figure 3.2: Evaporator.

2. Condenser

The purpose of the condenser is to extract heat from the refrigerant to the outside air. The temperature of the high-pressure vapor determines the temperature at which the condensation begins. The high-pressure vapor within the condenser is then cooled to the point where it becomes a liquid refrigerant once more, whilst retaining some heat. The liquid refrigerant then flows from the condenser in to the liquid line.

Figure 3.3: Condenser.

3. Compressor

The purpose of the compressor is to draw the low-temperature, low-pressure vapor from the evaporator via the suction line. Then, the vapor is compressed to increase its temperature. Therefore, the compressor transforms the vapor from a low-temperature vapor to a high-temperature vapor, in turn increasing the pressure. The vapor is then released from the compressor in to the discharge line.

Figure 3.4: Refrigerator compressor.

4. **Expansion valve**

The expansion valve is located at the end of the liquid line, before the evaporator. The high-pressure liquid reaches the expansion valve, having come from the condenser. The valve then reduces the pressure of the refrigerant as it passes through the orifice, which is located inside the valve. On reducing the pressure, the temperature of the refrigerant also decreases to a level below the surrounding air.

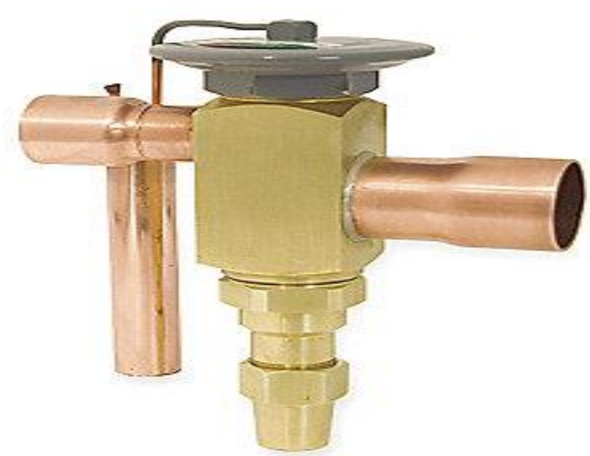


Figure 3.5: Expansion valve.

3.3 Selecting the Refrigerant

We have compared between R22, R134a and R507 in order to choose a suitable refrigerant as a working fluid for our application, and we found that R22 is less stable than R134 and R507 referred to R22 chemical components, also R134a, R507 are more environmentally friendly than R22 refrigerant in additional to that R507 is less toxic, more availability and lower cost compare with R22 and R134a in additional to the height latent heat of vaporization at boiling point which equal to 200.5 kJ/kg which give more performance in heat absorption , also R507 has a theoretical efficiency about 0.94 referring to its temperature and pressure discharging capability, table (3.1) shows comparison between R22,R134a and R507 at 1amto [9].

Table 3.1: Comparison between R22 and R134a at 1 atom.

Refrigerant	Chemical compound	Freezing point (C)	Boiling point (C)	Flammability
R22	chloro-di-flouro methane C_3H_8	-160	-40.7	NO
R507	hydro-fluoro-carbon mixture HFC-125 and HFC-143a	-253	–48.7	NO
R134a	tetra-flouro-ethane, CH_2FCF_3	-96.6	-27	YES

So, we decide that we have to select R507 as a working fluid in this application due to high temperature discharging capacity.

3.4 Calculation the load of compressor:

In order to begin the design process. It is necessary to know the cooling load required for the water separation process. The following table (3.2) shows some experimental measurement taken from different cars with different engine capacities and fuel systems in Hebron city also shows some information needed using Air flow meter and humidity sensor to determine the cooling load required, all data are taken with engine at operation temperature.

Table 3.2: Experimental measurements from different cars.

			Idle speed (750-850)rpm			Part load (2500)rpm		
vehicle	type of fuel	Engine capacity (L)	Exhaust speed (m/s)	Humidity (%)	Exhaust temperature (C)	Exhaust speed (m/s)	Humidity (%)	Temperature (C)
Skoda	Diesel	2.0	2	60	53	9.5	45	58
Isuzu	Diesel	3.0	3.4	63	51	7.3	42	57
Jeep	Diesel	3.0	2.6	72	54	6.7	49	61
Caddy	Diesel	1.9	2.9	60	50	8.5	38	57
Ford Mustang	Gasoline	3.7	2.1	97	42.2	5.0	50	48
Subaru	Gasoline	2.0	4.4	98	32.6	4.0	65	60
VW	Gasoline	1.4	2.3	97	42	4.2	57	48
Audi	Gasoline	2.0	2.6	92	32.6	4.0	65	60
Seat	Gasoline	1.6	2.3	93	42	4.2	57	48

Also we need some physical parameter for exhaust gases in order to calculate cooling load required to cool down these gases to obtain accurate cooling load. Table (3.3) shows physical property exhaust gases various with temperatures [10].

Table 3.3: Exhaust gases probity.

T [C]	***ρ*** [kg/m3]	***c_p*** [kJ/kg.K]	***μ*** ***10⁶** [Pas]	***ν*** ***10⁶** [m²/s]
0	1.295	1.042	15.8	12.2
100	0.95	1.068	20.4	21.54
200	0.748	1.097	24.5	32.8
300	0.617	1.122	28.2	45.81
400	0.525	1.151	31.7	60.38
500	0.457	1.185	34.8	76.3
600	0.405	1.214	37.9	93.61
700	0.363	1.239	40.7	112.1
800	0.33	1.264	43.4	131.8
900	0.301	1.29	45.9	152.5
1000	0.275	1.306	48.4	174.3
1100	0.257	1.323	50.7	197.1
1200	0.24	1.34	53	221

Where:

T – Temperature (C)

ρ – Density (Kg/m^3)

Cp - specific heat (kJ/kg.K)

μ - Dynamic viscosity (Pas)

ν - Kinematic viscosity (m2/s)

The load in compressor (W_{in}) that need to cooling the high exhaust gas temperature possible (60℃) to the low temperature (4℃) possible exhaust gases at high flow rate (12m/s) to condensate of high amount of water as possible, by used figure (3.6) R507 ph diagram to get the enthalpy at each state to determine the amount of heat transfer.

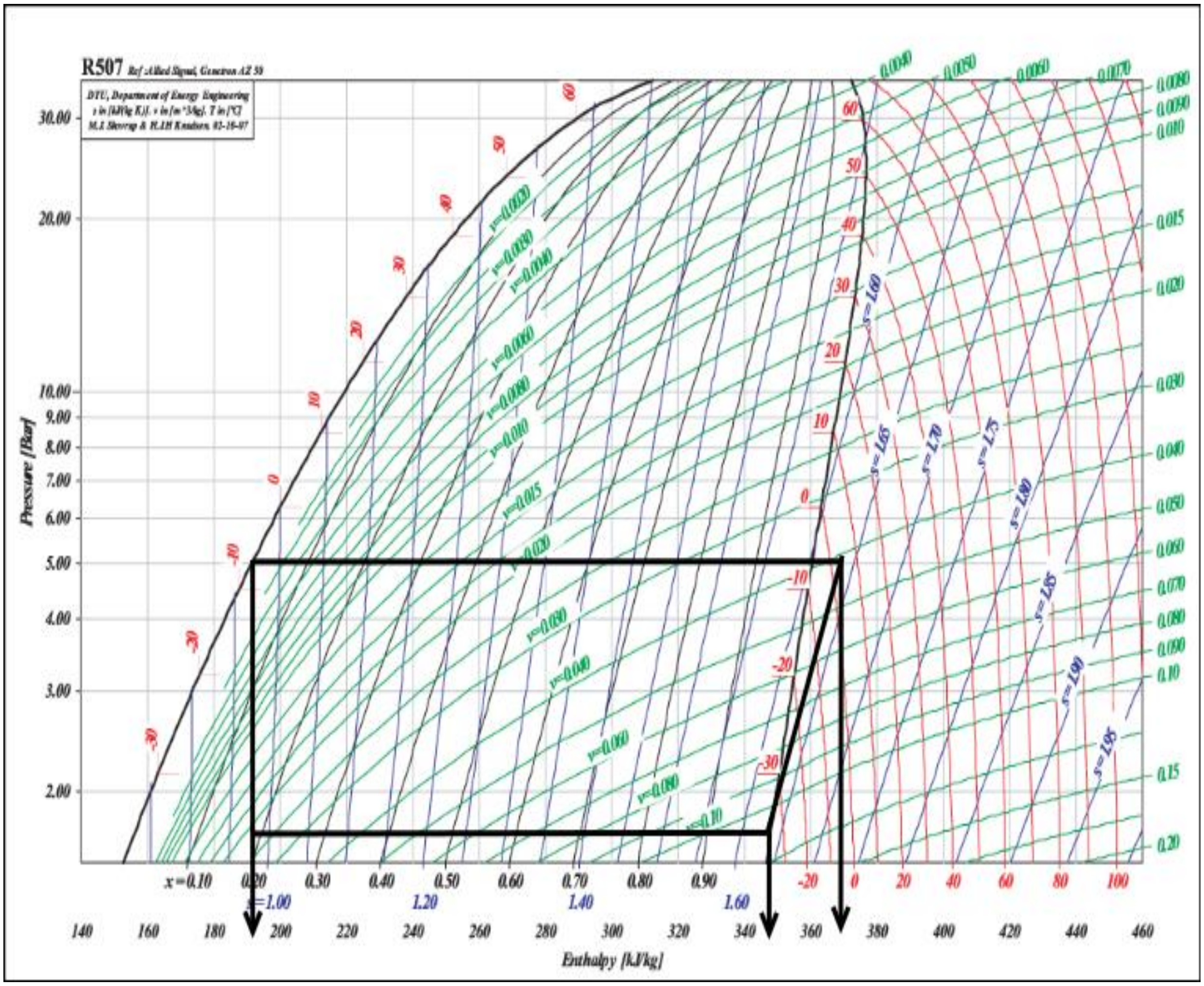


Figure 3.6: The p-h diagram for refrigerant R507a.

In Figure (3.7) we have to simplifying the cycle in order to show the temperatures and enthalpies at each stage.

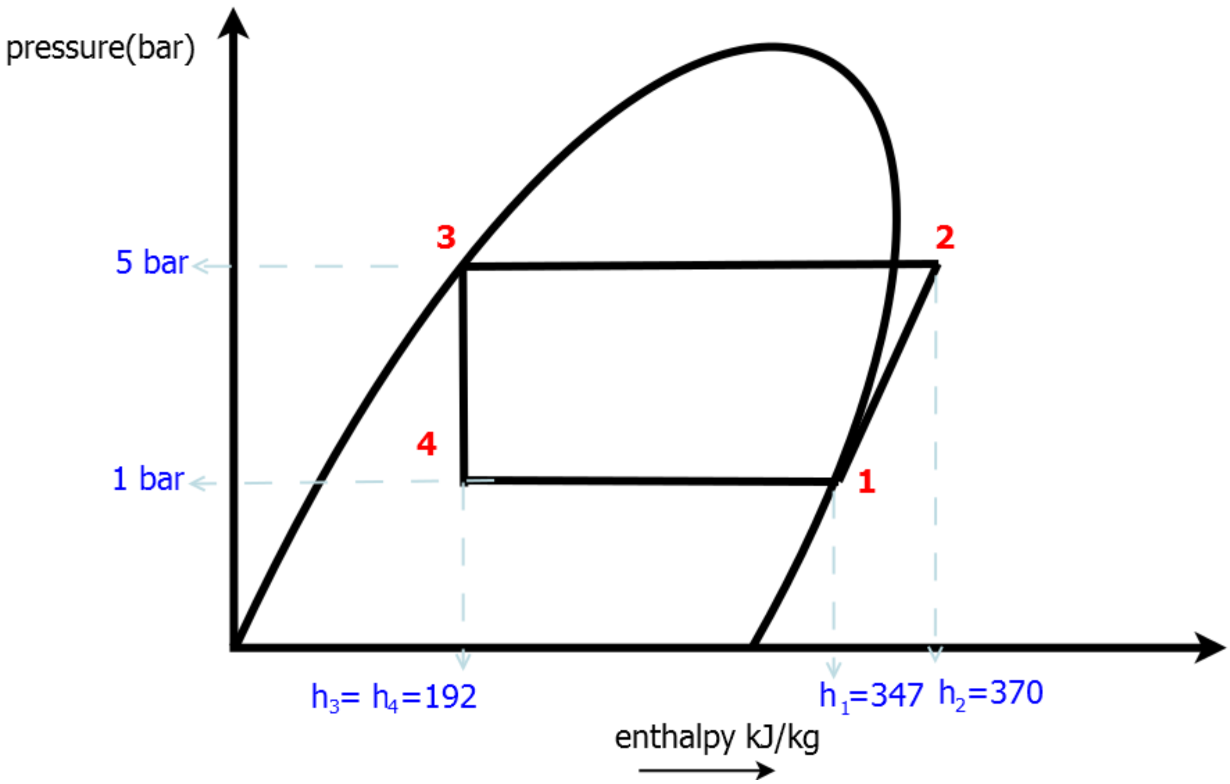


Figure 3.7: Simple p-h diagrahm of refregerant R507.

$q_{evp} = h_1 - h_4$

$= 347 kJ/kg – 192 kJ/kg = 155 kJ/kg$

A = $2.83\times10^{-3} m^2$: area of exhaust tube by assumed exhaust diameter = 6cm.

$\rho = 1.051\ kg/m^{3:}$

v =12 m/s

$\dot{m}_{exh} = \rho\times v\times A$ (3.1)

$=1.05\times2.83\times10^{-3}\times12 = 0.0356\ kg/s$

c_p =1.0083 J/kg℃ from Table 3.3

$(T_{exh1}-T_{exh2})$ = 60℃ - 4℃ = 56℃

$$\mathbf{Q_{evp.} = \dot{m}_{exh.} \times c_p \times (T_{exh1}-T_{exh2})} \tag{3.2}$$

=0.0356 ×56×1.008 = 2.01kw

$$\mathbf{\dot{m}_R = Q_{evq}/q_{evq}} \tag{3.3}$$

=2.01/155= 0.013kg/s

$w_{in} = h_2 - h_1$

=370 – 347 = 23 kJ/kg

$$\mathbf{COP_{cooling} = \frac{q_{in}}{w_{in}}} \tag{3.4}$$

$$= \frac{h_1 - h_4}{h_2 - h_1} = \frac{347-192}{370-347} = 6.74$$

$$\mathbf{COP_{\mathit{heating}} = \frac{\mathit{q_{out}}}{\mathit{w_{in}}}} \tag{3.5}$$

$$= \frac{h_2 - h_3}{h_2 - h_1} = \frac{370-192}{370-347} = 7.74$$

$$\mathbf{W_{in} = w_{in} \times \dot{m}_R} \tag{3.6}$$

=23×0.013=0.3kw

= 0.4hp.

Where:

q_{evp} :heat transfer in evaporator .

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

h1: enthalpy before compressor.

h2: enthalpy before condenser.

h3:enthalpy before throttle.

h4 : Enthalpy Before Evaporator.

$\dot{m}_{Exh}$: mass flow rate of the exhaust gas.

$\dot{m}$ r :mass flow rate of refrigerant R507.

ρ : Density Of Exhaust Gas.

v :Velocity Of Exhaust Gas.

A: area of Exhaust tube by assumed exhaust diameter 6cm.

cp : Specific Heat of Exhaust Gas .

T_{exh1} : Temperature of Exhaust Gas at the inlet of Heat Exchanger.

T_{exh2} : Temperature of Exhaust Gas at the inlet of From Heat Exchanger .

Win : Compressor work.

Win : Compressor Power.

Cop cooling : coefficient of performance for cooling.

Cop heating : coefficient of performance for heating.

So, we need at least **0.5 hp** compressor to cool the exhaust gases from 60℃ to 4℃ at flow rate 9 m/s and exhaust diameter 6 cm, but practically it's better to select a **0.75 hp** compressor in order to avoid extra noises production when heavy duty load take place, also the refrigerant compressor and condenser become one package for the given power; for better condensation performance of the refrigerant during condensation process.

3.5 Design the heat exchanger

We need to choose the appropriate heat exchanger to condensate high amount of water at low space possible to get a device with high accuracy and low size to easy transport.

Depending on equation (3.2) we calculated the heat transfer in heat exchanger:

$Q_{H.E} = Q_{evp}$=2.01kw

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

$$\mathbf{Q_{H.E} = U \times A \times LMTD} \quad (3.7)$$

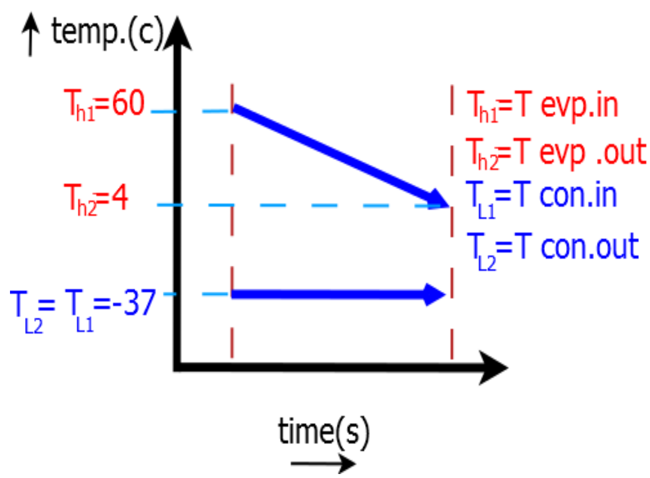


Figure 3.8: Temperature profile for parallel flow heat exchanger.

$$\mathbf{LMTD} = \frac{(Th1-TL1)-(Th2-TL2)}{Ln(\frac{(Th1-TL1)}{(Th2-TL2)})} \quad (3.8)$$

$$= \frac{(60+37)-(4+37)}{Ln(\frac{(60+37)}{(4+37)})} = 2.66°\text{C}$$

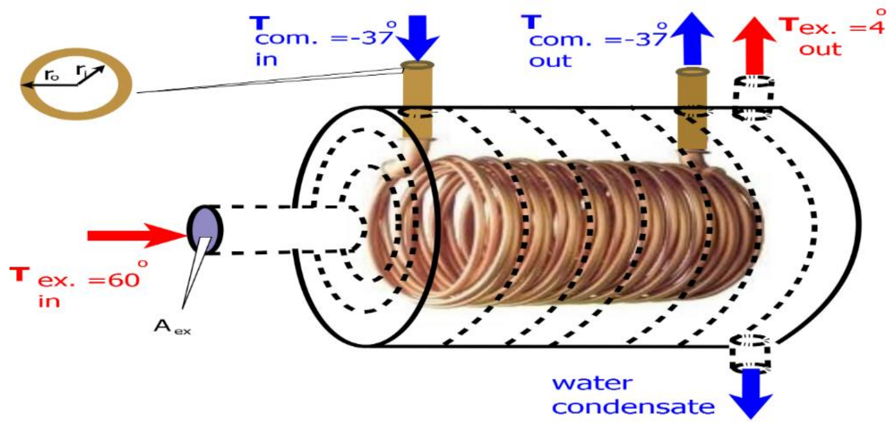


Figure 3.9: Simple form for heat exchanger.

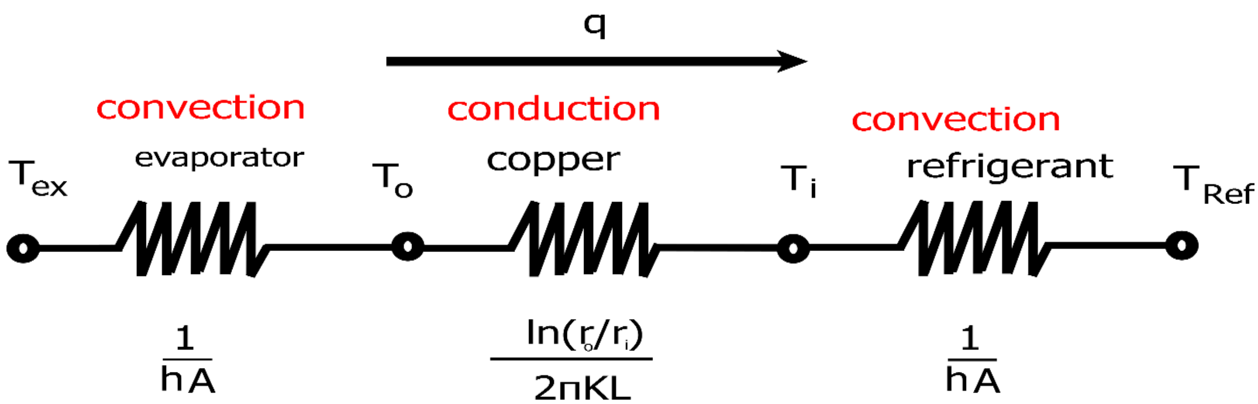


Figure 3.10: Thermal-resistance network for overall heat transfer

r_o =5mm
r_{in}=4.5mm

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

$$\mathbf{U}=\frac{1}{\frac{1}{hA_{evp.}}+\frac{\ln(\frac{ro}{ri})}{2\pi kl\ copp.}+\frac{1}{hA_{ref.}}} \tag{3.9}$$

$$=\frac{1}{\frac{1}{333.564*0.01823}+\frac{\ln(\frac{5}{4.5})}{2*3.14*401*l}+\frac{1}{h*1.43*10^{-4}}}$$

$\mathbf{A}=2\times3.14\times5\times10\text{-}^{3}\times L$
$=0.0314\ L$

From equation (3.7):

$$2.01 = \frac{1}{\frac{1}{333.564*0.01823}+\frac{\ln(\frac{5}{4.5})}{2*3.14*401*l}+\frac{1}{h*1.43*10^{-4}}} \times 0.0314L\times 2.66$$

For $\mathbf{h_{ref}}$ **=2kw/m²**°C . [11]

$$2.01 = \frac{0.0835L}{0.1644+\frac{4.18*10^{-5}}{l}+\frac{6993}{2000}}$$

$0 = -0.0835L^2 +0.7358L+8.4\times10^{-5}$
L= 8.814 m

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.

T_{h1}: Temperature of Exhaust Gas That Inlet Heat Exchanger.

T_{h2}: Temperature of Exhaust Gas That Outlet Heat Exchanger.

T_{l1}: Temperature of Refrigerant Gas That Inlet Heat Exchanger.

T_{l2}: Temperature of Refrigerant Gas That Outlet Heat Exchanger.

h_{evp}: convection heat transfer coefficient of exhaust gas .

A_{evp}: Area of Evaporator.

h_{ref}: Convection Heat Transfer Coefficient.

A_{ref}: Area of Refrigerant Tube.

r_o: outer radius of refrigerant tube

r_i: 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 **8.8m** at **diameter 10 mm** and **thickness 1.0mm.**

3.5.1 Design results

Summary of heat exchanger properties, were the actual values are given from a monistic market as shown in the table (3.4) below.

Table 3.4: Design Result.

#	Name	Value	Unit
1	Refrigerant gas type	R507	-
2	Refrigerant tube diameter	10	mm
3	Refrigerant tube thickness	1	mm
4	Refrigerant tube material type	Copper	-
5	Refrigerant tube length	8.8	m
6	Heat exchanger diameter	6	Inch
7	Compressor Power (theoretical / practical)	0.5 /0.75	hp
8	Heat exchanger material	PVC	-

4

CHAPTER FOUR

Installation of Software and Mechanical Components

4.1 Software Methodology

Our project is based on comparing between the theoretical quantity and the actual quantity of water emerging with exhaust gases. In order to calculate the theoretical amount of water in both gasoline and diesel engines processor unit is required.

4.1.1 General Description

The methodology of software component operation is biased on modeled equation and real time measurement of some engine management sensors such as mass air flow sensor (MAF), RPM sensor and specific fuel consumption (sfc) calculated from engine control module and some external sensor such as a humidity sensor and temperature sensors, the software operation is conducted in the algorithms shown in the Figure (4.1).

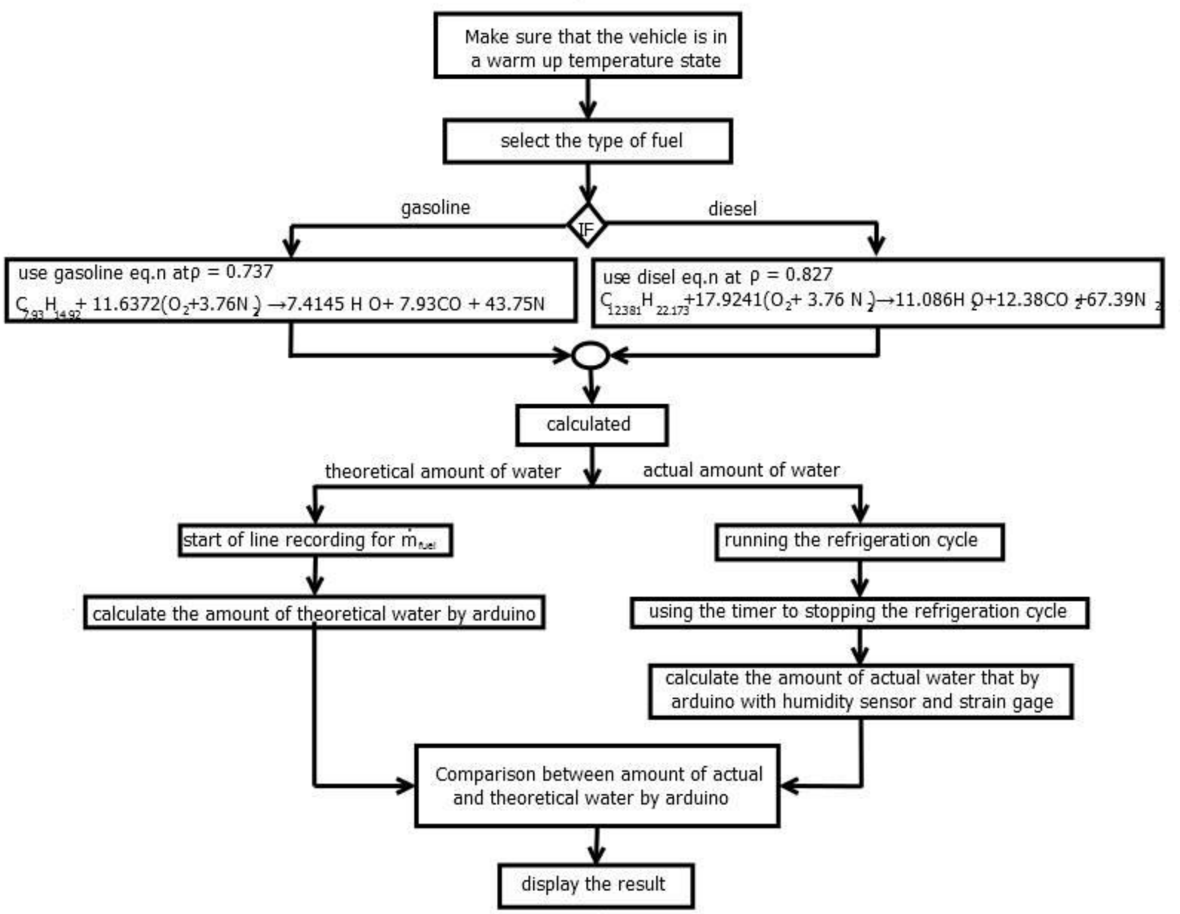


Figure 4.1: Software Algorithms.

4.1.2 Software Equations Model “ Diesel ”

From the stoichiometric diesel combustion equation were λ=1, we want to calculate the mass of water $\dot{m}_w$ as a function of given mass flow rate of the fuel $\dot{m}_f$ with respect to theoretical amount of air for diesel combustion.

$$n\ C_{12.381}H_{22.1739} + 17.924\ (O_2 + 3.76\ N_2) \rightarrow x\ H_2O + yCO_2 + zN_2$$

C balance: 12.381× n = y

H balance: 22.1739 × n = 2 x

O balance: 2×17.924 = x + 2×y

From H balance equation

$$x = 11.086 * n \tag{4.1}$$

Now, number of fuel moles are equal to mass flow rate of the fuel with respect to the time taken during the diagnostic process divided by fuel molar mass for diesel (170.74 gr/mole) where:

$$n = \frac{\dot{m}f}{MM\ f} \tag{4.2}$$

Some engines control module give specific fuel consumption (*sfc*) as a volume flow rate $\dot{V}f$ in (L/h) in this case we have:

$$\dot{m}f = \dot{V}f * \rho f \tag{4.3}$$

Now by unit conservation:

$$\dot{m}f = \frac{\dot{m}f * \rho f}{60000} \tag{4.4}$$

Another type of engine control module gives the calculated specific fuel consumption (*sfc*) in term of (mg/stork), in case of 4 cylinder engine $\dot{m}f$ expressed as a function of RPM, we have:

$$\dot{m}f = \dot{m}f * \frac{mg}{str} * \frac{1g}{1000mg} * \frac{2str}{1revo} * \frac{revo}{min} \tag{4.4a}$$

Now by substitution (4.4) or into (4.2) we get:

$$n = \frac{\dot{V}f * \rho f}{60000} * \frac{1}{MMf} * time \qquad (4.5)$$

Or by substitution (4.4a) in equation (4.2) we get:

$$n = \dot{m}f * \frac{1}{MMf} * time \qquad (4.5a)$$

Now substitution equation (4.1) into equation (4.5) and (4.5a) in order to get the number of mole water emerging with exhaust gases:

$$x = 11.086 * \frac{\dot{V}f * \rho f}{60000} * \frac{1}{MMf} * time \qquad (4.6)$$

Or

$$x = 11.086 * \dot{m}f * \frac{1}{MMf} * time \qquad (4.6a)$$

Now, the mass of water emerging when burning n moles of fuel is:

$$\dot{m}w = xMMw \qquad (4.7)$$

Now, the theoretical mass of water during diagnostic process time is obtained by substitution equation (4.5) into equation (4.6) and (4.6a) respectively where:

$$mw = \left(\left(11.086 * \frac{\dot{V}f * \rho f}{60000} * \frac{1}{MMf} * time\right) * MMw\right) \qquad (4.8)$$

And

$$mw = \left(\left(11.086 * \dot{m}f * \frac{1}{MMf} * time\right) * MMw\right) \qquad (4.8a)$$

Where:

ρf: the density of fuel, 0.872 (gr/ml)for diesel.

$\dot{m}f$: Mass flow rate of fuel (gr/min).

mw : Mass of water (gr).

x : Number of moles of water (mole).

n : Number of moles of fuel (mole).

4.1.3 Software Equations Model " Gasoline "

From the stoichiometric gasoline combustion equation were λ=1, also we want to calculate the mass of water $\dot{m}_w$ as a function of given mass flow rate of the fuel $\dot{m}_f$ with respect to theoretical amount of air for gasoline combustion equation.

$$n\ C_{7.93}H_{14.92} + 11.637\ (O_2 + 3.76\ N_2) \rightarrow x\ H_2O + yCO_2 + zN_2$$

C balance: $7.93\times n = y$

H balance: $14.92 \times n = 2x$

O balance: $2\times 11.637 = x + 2\times y$

From H balance equation

$$x = 7.46 * n \qquad (4.9)$$

Now, number moles of fuel are equal to mass flow rate of the fuel with respect to the time taken during the diagnostic process divided by fuel molar mass for gasoline where:

$$n = \frac{\dot{m}f}{MM\ f} \qquad (4.10)$$

Some engines control module give specific fuel consumption (*sfc*) as a volume flow rate $\dot{V}f$ in (L/h) in this case we have:

$$\dot{m}f = \dot{V}f * \rho f \qquad (4.11)$$

Now by unit conservation:

$$\dot{m}f = \frac{\dot{V}f * \rho f}{60000} \tag{4.12}$$

Another type of engine control module gives the calculated specific fuel consumption (*sfc*) in term of (mg/stork), in case of 4 cylinder engine $\dot{m}f$ expressed as a function of RPM, we have:

$$\dot{m}f = \dot{m}f * \frac{mg}{str} * \frac{1g}{1000mg} * \frac{2str}{1revo} * \frac{revo}{min} \tag{4.12a}$$

Now by substitution (4.10) into (4.12) and (4.12a) respectively we get:

$$n = \frac{\dot{V}f * \rho f}{60000} * \frac{1}{MMf} * time \tag{4.13}$$

Or

$$n = \dot{m}f * \frac{1}{MMf} * time \tag{4.13a}$$

Now substitution equation (4.13) and (4.13a) into equation respectively (4.9) in order to get the number of mole water emerging with exhaust gases:

$$x = 7.46 * \frac{\dot{V}f * \rho f}{60000} * \frac{1}{MMf} * time \tag{4.11}$$

Or

$$x = 7.46 * \dot{m}f * \frac{1}{MMf} * time \tag{4.11a}$$

Now, the mass of water emerging when burning *n* moles of fuel is:

$$\dot{m}w = x * MMw \tag{4.12}$$

Now, the theoretical mass of water during diagnostic process time is obtained by substitution equation (4.11) and (4.11a) respectively into equation (4.12) where:

$$mw = \left(\left(7.46 * \frac{\dot{V}f * \rho f}{60000} * \frac{1}{MMf} * time\right) * MMw\right) \tag{4.13}$$

If $\dot{m}f$ expressed as (mg/str) then:

$$mw = \left(\left(7.46 * \dot{m}f \ * \frac{1}{MMf} * time\right) * MMw\right) \qquad (4.13a)$$

Where:

ρf: the density of gasoline , 0.737 (gr/ml)for gasoline.

$\dot{m}f$: Mass flow rate of fuel (L/h).

mw : Mass of water (gr).

x : Number of moles of water (mole).

n : Number of moles of gasoline (mole).

4.1.4 Humidity Modeling

In this section, we will calculate the amount of water comes from humidity of the ambient air which inter to the combustion chamber via intake manifold.

This amount considered as an external source of water emerging from the engine regarding to the combustion process , this quantity will be add to the theoretical mass of water calculated in the processor unit depending on relative humidity definition.

Relative humidity defined as the ratio of the water vapor pressure to the saturation water vapor pressure at the gas temperature, we used the humidity sensor to measure the relative humidity and use this reading as an input for the following equation [12].

$$P_{ws}= \frac{A10^{(\frac{m*T}{T+T_n})}}{10} \tag{4.14}$$

$$\text{RH} = \frac{Pw}{Pws}\ (\%) \tag{4.15}$$

$$\text{M}w = 0.622\ \frac{Pw}{P-Pw} \tag{4.16}$$

Now by substitution equation (4.15) in (4.14) for Pw we obtain:

$$Pw = \text{RH} * \frac{A10^{\left(\frac{m*T}{T+T_n}\right)}}{10} \tag{4.17}$$

In order to find mass of water Mw we have to substitute equation (4.17) in (4.16) where:

$$\text{M}w = 0.622 * \frac{\text{RH} * \frac{A10^{\left(\frac{m*T}{T+T_n}\right)}}{10}}{P-\left(\text{RH} * \frac{A10^{\left(\frac{m*T}{T+T_n}\right)}}{10}\right)} \tag{4.18}$$

By simplifying equation (4.16) we get:

$$\text{M}w = 0.6221 * \frac{1}{\left[\left(\frac{P}{\text{RH} * \frac{A10^{(\frac{m*T}{T+T_n})}}{10}}\right) -1\right]} \tag{4.18a}$$

Where:

Pws: water vapor saturation pressure in (Kpa).

Pw: Water vapor pressure in (Kpa).

RH: Relative humidity in (%)

M*w:* mass of water in (gr/gr dry air)

T: ambient temperature in (C).

A, m, Tn: are constant parameters of water for water vapor saturation pressure *Pws* equation which are given from the following Table (4.1) [12].

Table 4.1: Constants Parameter.

	A	m	Tn	max error	Temperature range
water	6.116441	7.591386	240.7263	0.083%	-20...+50°C
	6.004918	7.337936	229.3975	0.017%	+50...+100°C
	5.856548	7.27731	225.1033	0.003%	+100...+150°C
	6.002859	7.290361	227.1704	0.007%	+150...+200°C
	9.980622	7.388931	263.1239	0.395%	+200...+350°C
	6.089613	7.33502	230.3921	0.368%	0...+200°C
ice	6.114742	9.778707	273.1466	0.052%	-70...0°C

4.1.5 Final Equation Model.

Then the final equation for the theoretical mass of water emerging is:

Mw, Theo = [*Mass of water due to burn n mole of fuel*] (4.19)

4.2 Mechanical Equipment's

After complete the design of each component the assembly process take place, starting from the stand, expansion valve, compressor and condenser installation, heat exchanger assembly design regarding a water slope till sensor and processor unit installation.

We have designed the stand in rectangular form with the dimensions of 80 x 100 cm, then installation of compressor and condenser with its vane and thermocouple switch and cover them with a metal case to protect them , after that the heat exchanger become installed with water slope bout 15 degree and finally the electrical equipment and sensors.

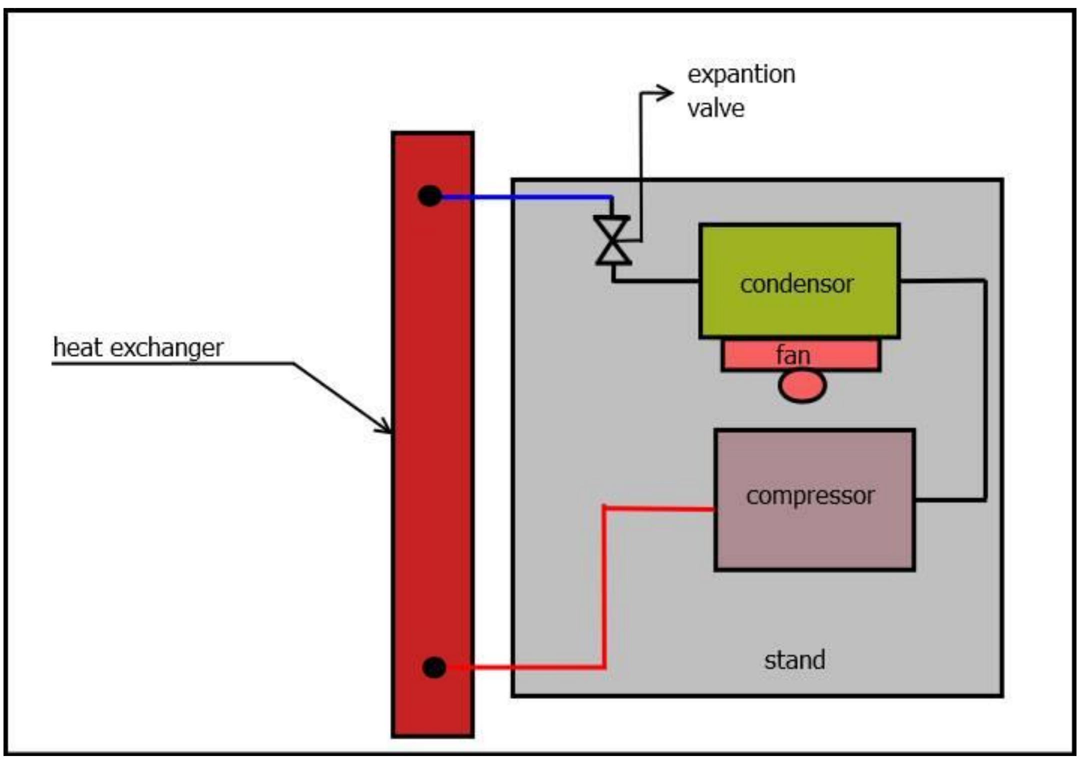


Figure 4.2: Component Installation

In heat exchanger design we puts a set of an aluminum plates acting as an obstacle in order to reduce exhaust gas velocity which resulting in increase heat transfer time, also to make the exhaust gasses whirl around refrigerant coil which increase system performance and heat transfer efficiency, we used three types of obstacles with different holes shape to avoid back pressure on the engine as shown in the figures (4.3), (4.4), (4.5) below.

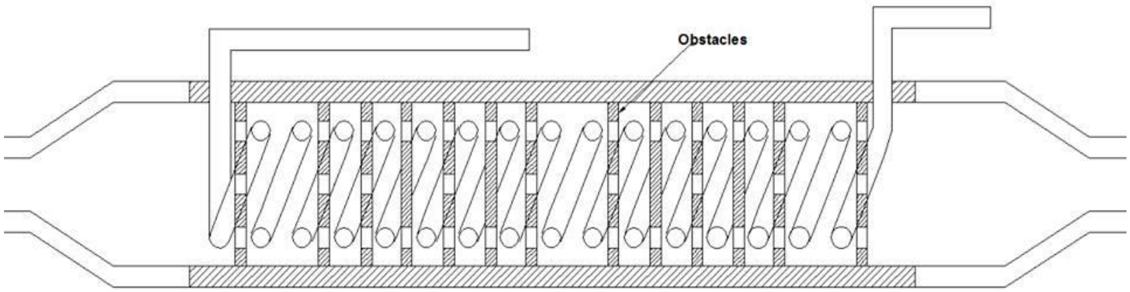
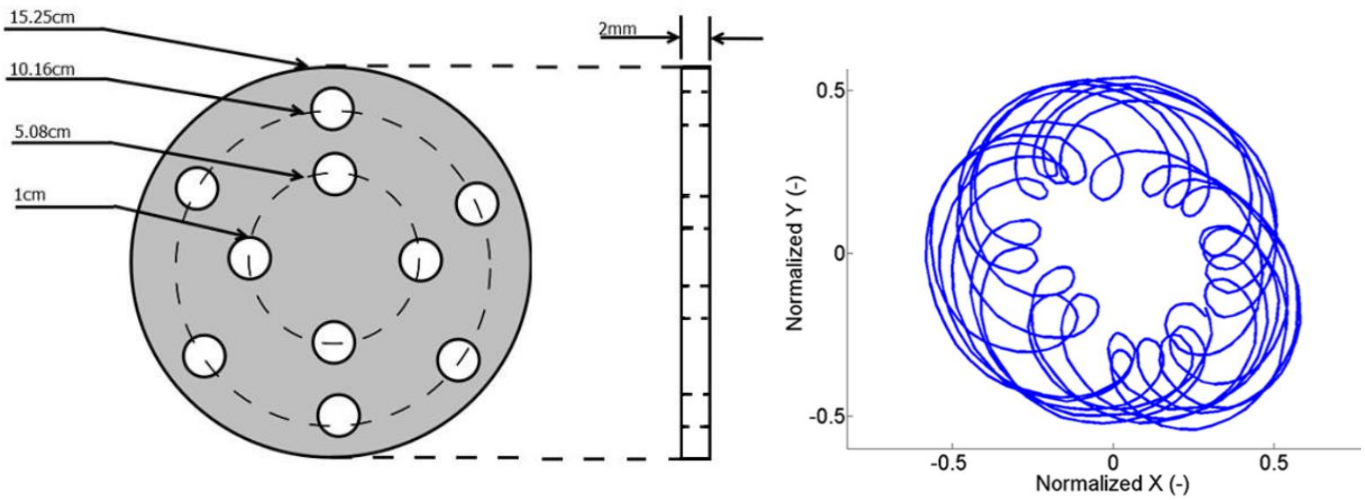


Figure 4.3: Set of Exhaust Gases Obstacle in the Exchanger.



Figures 4.4: Shape Exhaust Gases Whirls via Obstacles.

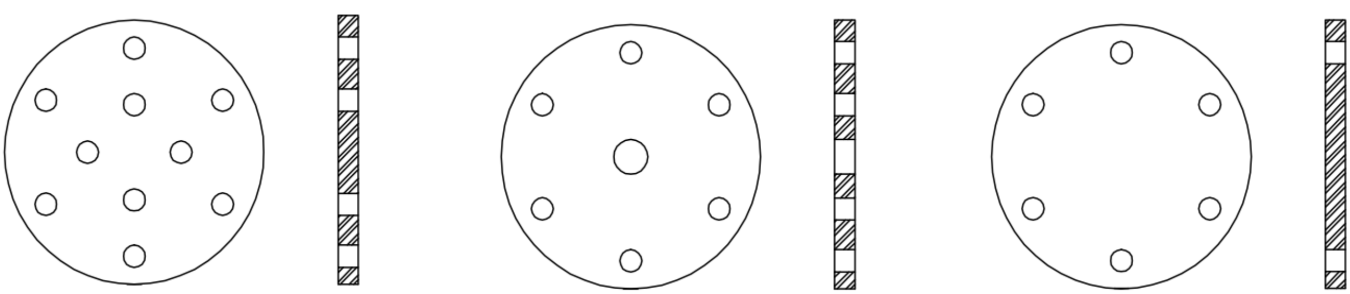


Figure 4.5: Shapes of Obstacles Used.

4.3 Electrical Equipment's

In this section we want to talks about the electrical components used in our project which include sensing elements, feedback sensors, and processor unit also we want to provide a general overview about each component and what is the function of each one, in addition to 220V component connections.

1) Thermocouple: When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is a continuous current which flows in the thermoelectric circuit. If this circuit is broken at the center, the net open circuit voltage (the See beck voltage) is a function of the junction temperature and the composition of the two metals. Which means that when the junction of the two metals is heated, or cooled, a voltage is produced that can be correlated back to the temperature. In this application the thermocouple acts as a feedback sensor in order to shut off the compressor when the temperature of exhaust gas emerging from heat exchanger is around 4℃. Figure (4.6) shows the thermocouple used in our project.

Figure 4.6: Thermocouple.

2) Humidity sensor: "AM2302" capacitive humidity sensing digital temperature and humidity module is one that contains the compound has been calibrated digital signal output of the temperature and humidity sensors. The sensor includes a capacitive sensor wet components and a high precision temperature measurement devices, and connected with a high-performance 8-bit microcontroller. The product has excellent quality, fast response, and strong ant jamming capability. Each sensor is extremely accurate humidity calibration chamber calibration. The form of procedures, the calibration coefficients stored in the microcontroller, the sensor within the processing of the heartbeat to call these calibration coefficients. Standard single-bus interface, system integration quick and easy. Small size,

low power consumption, signal transmission distance up to 20 meters, making it the best choice of all kinds of applications and even the most demanding applications. Here we used tow relative humidity sensors to measure ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at outlet temperature of heat exchanger and the other sensor for ambient relative humidity. Figure (4.7)shows the humidity sensor used in our project

Figure 4.7: Humidity sensor.

3) Processor unit: The Arduino Mega is a microcontroller board based on the ATmega1280 (datasheet). It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila. We use it to calibrate the sensors to use its readings in modeling to calculate the theoretical mass of water and comparison this value with the actual one. Figure (4.8) shows the Arduino microcontroller used in our project.

Figure 4.8: Arduino MEGA.

4) Condenser fan motor: a 10W, 220V high speed condenser fan motor used to handle full rated load at high temperature in the condenser. Figure (4.9) shows a high speed Condenser fan motor.

Figure 4.10: Condenser Fan Motor.

After installed these elements, the project is ready for testing and to take readings. The following figure (4.11) shows the electrical component, sensors and the processing unit connections, which shows the final shape of the project, but we would like to mention that the results will be displayed on the computer screen by connecting the processor unit with the computer.

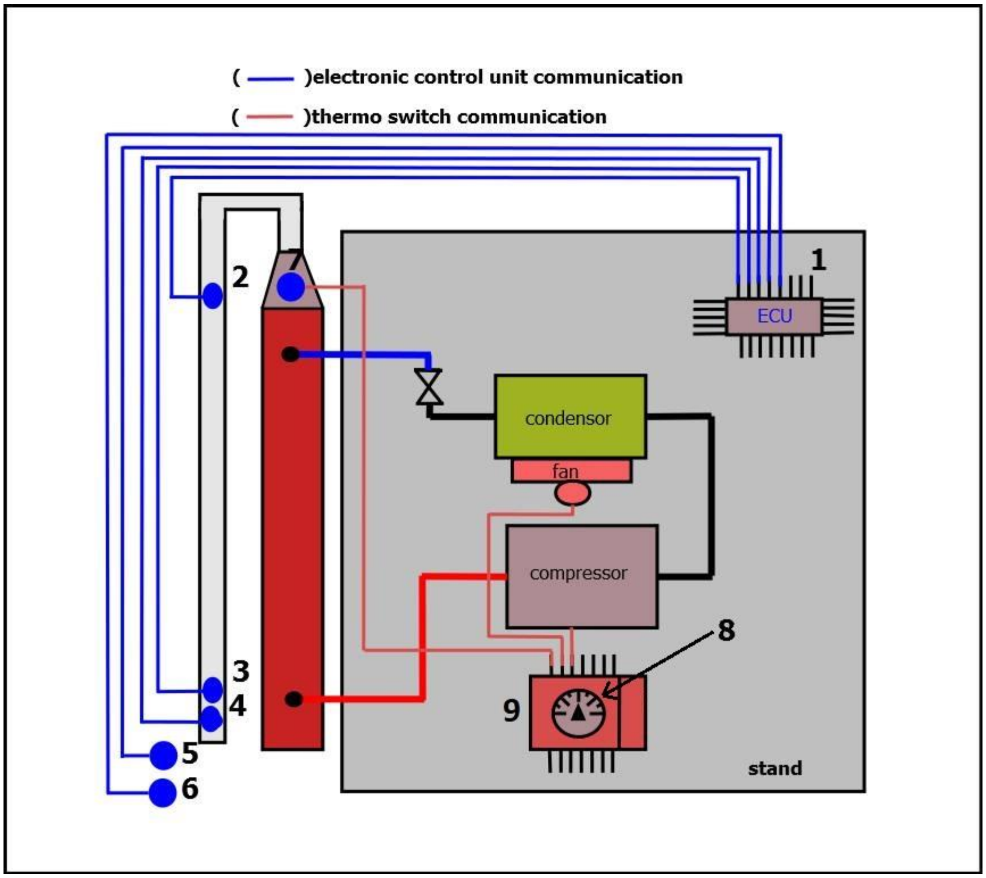


Figure 4.11: Electrical Communications.

Where:

1) Processor unit.
2) Temperature sensor “one”
3) Temperature sensor “two”
4) Exhaust gasses humidity sensor
5) Ambient temperature sensor
6) Ambient humanity sensor
7) Thermocouple
8) Thermo switch
9) Electrical connections assembly box

5

CHAPTER FIVE

Diagnostic Results

5.1 Introduction
5.2 Result Analysis
4.3 Conclusion
5.4 Problems and Recommendation

5.1 Introduction

In this chapter we will present the results of the diagnosis we obtained through the experiment on many different cars. Also we want to show the way to the results achievement, analysis of these results and we want to do a comparison between the theoretical and actual amount of water emerging in order to determine the device efficiency in diagnostic process. Finally we want to present the reading we obtained.

5.2 Result analysis

The diagnostic process can't start until the engine reach the operation temperature " worm up temperature " which is about 90 ℃ for most vehicles. Then connect the exhaust tail pipe with heat exchanger and lunch the refrigeration cycle, in this condition we can't start recording the sensors reading; because we have to wait about two to three minute to allow the refrigerant gas circulate into the heat exchanger to optimize lowest temperature of the refrigerant gas in the exchanger coil.

After that we have to raise the engine RPM to reach a part load situation which is about (1500 - 2000) RPM. Now the processer unit is start a timer, at the same time the diagnostic scanner is connected via a 16 pin OBD II port in order to record engine management sensors reading during the diagnosis time. Now OBD II scanner is start record mass air flow sensor reading, specific fuel consumption, intake air temperature and RPM sensor reading, then the average value of these sensors is computed.

During recording engine management sensors reading the water is start condensate in the heat exchanger, the temperatures and relative humidity sensors reading on the exchanger are also recorded the average values of these sensors are computed.

Using Mat lab software to convert the saved reading from vector configuration to table arrangement. the following engine management sensor reading are taken by using VCDS VAG com diagnostic interface table (5.1), they are the first reading we have to analyze it which is a small section from the overall time reading, they are from (0-10) sec. they are form "VW CADDY 1.9L TDI".

Volkswagen

Table 5.1: Real Time Reading Using VCDS VAG com (VW).

Time division (sec)	Engine Speed (RPM)	Time division (Sec)	Injection Quantity (mg/str)	Time division (Sec)	Mass Air Flow - (actual) (mg/str)
0.26	1512	0.26	6	0.1	270
0.59	1512	0.59	6.3	0.42	265
0.9	1512	0.9	6.3	0.75	270
1.23	1512	1.23	6	1.07	270
1.56	1491	1.56	6.3	1.4	270
1.88	1491	1.88	6.9	1.73	260
2.21	1512	2.21	6.6	2.05	270
2.54	1491	2.55	6.6	2.39	255
2.85	1512	2.85	6.3	2.69	250
3.18	1512	3.18	6.3	3.03	260
3.49	1512	3.49	6.3	3.34	270
3.82	1512	3.82	6.3	3.67	270
4.13	1512	4.13	6.3	3.97	265
4.46	1512	4.46	6.3	4.3	255
4.77	1512	4.77	6.3	4.62	265
5.1	1512	5.1	6	4.95	270
5.41	1512	5.41	6.3	5.26	250
5.74	1512	5.74	6	5.59	265
6.05	1512	6.05	6.3	5.9	270
6.38	1512	6.38	6	6.23	270
6.69	1512	6.69	6.3	6.54	270
7.02	1512	7.02	6	6.87	275
7.33	1491	7.33	6.3	7.18	270
7.66	1512	7.66	6	7.5	260
7.97	1512	7.97	6.3	7.82	250
8.3	1512	8.3	6.3	8.14	270
8.61	1512	8.61	6.3	8.46	275
8.94	1512	8.94	6.3	8.78	285
9.25	1512	9.25	6.3	9.1	265
9.59	1512	9.59	6.3	9.43	260
9.89	1512	9.89	6	9.74	255
10.22	1512	10.22	6.3	10.07	260
Average value for 10 minute	1509.846	---	6.253846	---	265.641

Now the mass air flow in (g/min) is converted as the following:

$$\dot{M}a = 265.65 \left(\frac{mg}{str}\right) * \frac{1g}{1000mg} * \frac{2str}{1revo} * 1509.84 \frac{revo}{min}$$

$\dot{M}a = 796.95$ (Gr air /min)

For 10 minute the mass of air inter to the combustion champers is:

$$Ma = 796.95 \frac{g}{min} * 10\, min$$

$Ma = 7.965$ Kgr of air

Now the mass of diesel in (g/min) is converted as the following:

$$\dot{m}f = 6.25 * \frac{mg}{str} * \frac{1g}{1000mg} * \frac{2str}{1revo} * 1509.84 \frac{revo}{min}$$

$\dot{m}f =$18.86 (Gr diesel /min)

For 10 minute the mass of diesel injected to the combustion champers is:

$$mf = 18.86 \frac{g}{min} * 10\, min$$

$mf =$ 188.6 Gr of diesel

Or expressed as a volume as the following:

$vf =$0.2289 Liter of diesel

The results shown in this table (5.2) for 10 minute test:

Table 5.2: Experimental Results for VW.

Vehicle Manufacturer **VW CADDY 1.9L TDI**	Value	Unit
Test time	10	Minute
Fuel system	Diesel	---
Engine Capacity	1.9	L
Average Engine speed	1523	RPM
(A/F) lambda	≈1.06	---
Ambient temperature	22	C
Ambient humidity	60	%
Emerged gases humidity	23	%
Average Mass air flow	265.64	mg /str
Mass of air consumed	7.965	Kg
Average Specific fuel consumption (sfc)	6.25	mg /str
Mass of fuel burned	188.65	gr
Theoretical mass of water	220.86	gr
mass of water due to the ambient Humidity	61	gr
mass of water due to Humidity of the emerged gases from the exchanger	14	gr
Actual mass of water	183	gr
Net actual mass of water	163	gr

Condensation Efficiency	**62 %**
Water Consumption	**No**

Due to this experiment the actual mass of water emerged is near the theoretical mass but with percentage error about 38% this error related to sensors accuracy, refrigeration cycle performance, reference values we used to design , mean value of vehicle sensors and the DPF regeneration process was occurred. So we have to make another trial in order to get a higher efficiency and correct result.

We have done a second experiment on lower RPM between (1200 -1400) in order to avoid regeneration process in diesel particle filter (DPF) to reduce exhaust gases temperature.

This trial is done on Škoda OCTAVIA 1.9L and for 10 minute, also this reading table (5.3) are a section for the first 10 second from the overall test time by using VCDS VAG com diagnostic interface.

Table 5.3: Real Time Reading Using VCDS VAG com (Skoda)

Time division (sec)	Engine Speed (RPM)	Time division (sec)	Injection Quantity (mg/str)	Time division (sec)	Mass Air Flow (actual) (mg/str)
0.15	1428	0.15	6.3	0.48	290
0.79	1378	0.79	6.6	1.12	285
1.43	1428	1.43	6.6	1.76	290
2.07	1428	2.07	6.6	2.4	270
2.71	1428	2.71	6.3	3.04	285
3.35	1428	3.35	6.3	3.69	285
4.01	1428	4.01	6	4.34	290
4.65	1428	4.65	6.3	4.98	290
5.29	1428	5.29	6.6	5.6	275
5.9	1428	5.9	6.3	6.24	280
6.54	1428	6.54	6.3	6.87	285
7.18	1428	7.18	6.3	7.51	295
7.83	1428	7.83	6.3	8.15	290
8.46	1428	8.46	6.6	8.79	290
9.11	1428	9.11	6.3	9.43	285
9.74	1428	9.74	6.3	10.07	280
10.38	1428	10.38	6	10.71	280
Average value for 10 min	1426	---	6.035	---	287

The results shown in this table (5.4) for 10 minute test:

Table 5.4: Experimental Results for Skoda.

Vehicle Manufacturer **Skoda OCTAVIA 1.9L**	Value	Unit
Test time	10	Minute
Fuel system	Diesel	---
Engine Capacity	1.9	L
(A/F) lambda	≈1.0	---
Average Engine speed	1426	RPM
Ambient temperature	18	C
Ambient humidity	47.7	%
Emerged gases humidity	21	%
Average mass air flow	287	mg / str
Mass of air	8.49	Kg
Average Specific fuel consumption	6.035	mg / str
Mass of fuel burned	172.1	gr
Theoretical mass of water	142.5	gr
mass of water due to the ambient Humidity	46.04	gr
mass of water due to Humidity of the emerged gases from the exchanger	12.6	gr
Actual mass of water emerged	155	gr
Net Actual mass of water	121.56	gr

Condensation Efficiency	**85.3%**
Water Consumption	**No**

$$\frac{mass\ of\ \mathrm{H2O}}{mass\ of\ diesel} = \frac{121.56}{172.1} = \mathbf{0.704\ :\ 1}$$

In this experiment we have the highest condensation efficiency for diesel engine which its reach 85.3%, this improvement refer to avoid the obvious mistakes, so we obtain a good result but the mass ratio we obtained is far from the typical one as a result of injector fault. The fault is founded where the injector is inject both of fresh air bubbles and diesel where the theoretical amount of diesel given from control module is not accurate also we found there are misfire fault code stored in engine control module which affect on the overall mass ratio.

The main result we conclude in this experiment that if there are any fault in engine management system (intake air and fuel injection system) the test will be fail as result of incorrect amount of fuel and air calculated.

The next experiment is on 1.6L gasoline Ford Focus, the data is taken using DELPHI diagnostic interface. Table 5.5 shows the results obtained from the vehicle.

Table 5.5: Ford Focus Diagnosis Result

Vehicle Manufacturer **Ford focus 1.6 L**	Value	Unit
Test time	15	Minute
Fuel system	Gasoline	---
Engine Capacity	1.6	L
(A/F) lambda	≈1.0	---
Average Engine speed	1550	RPM
Ambient temperature	23	C
Ambient humidity	23	%
Emerged gases humidity	47	%
Average mass air flow	3.73	gr/s
Mass of air	3.357	Kg
Average Specific fuel consumption	1.3	L/h
Mass of fuel burned	248.7	gr
Theoretical mass of water	303.5	gr
mass of water due to the ambient Humidity	13.31	gr
mass of water due to Humidity of the emerged gases from the exchanger	5.9	gr

Actual mass of water	282.62	gr
Net actual mass of water	290	gr

Condensation Efficiency	**93.7%**
Water Consumption	**No**

$$\frac{mass\ of\ \mathrm{H2O}}{mass\ of\ gasoline} = \frac{282.62}{248.7} = \mathbf{1.13\ :\ 1}$$

In this experiment we have highest condensation efficiency which its reach 93.7%, so we obtain a very good result and very high accurate mass ratio. In this case (Gasoline Engines) we can judge if the engine consume water or not.

The next experiment is on 2.0L Diesel Hyundai, the data is taken using DELPHI and VCDS diagnostic interface. Table 5.6 shows the results obtained from the vehicle.

Table 5.6: Hyundai Tucson Diagnosis Result for 20 Minute at Idle Speed

Vehicle Manufacturer **Hyundai Tucson 2.0 L**	Value	Unit
Test time	20	Minute
Fuel system	Diesel	---
Engine Capacity	2.0	L
(A/F) lambda	≈1.0	---
Average Engine speed	790	RPM
Ambient temperature	23	C
Ambient humidity	17	%
Emerged gases humidity	28	%
Average mass air flow	10.33	gr/s
Mass of air flow consumed	12.39	Kg

Average Specific fuel consumption	0.6	L/h
Mass of fuel burned	165.4	gr
Theoretical mass of water	168.68	gr
mass of water due to the ambient Humidity	37	gr
mass of water due to Humidity of the emerged gases from the exchanger	12.4	gr
Actual mass of water	160	gr
Net actual mass of water	136	gr

Condensation Efficiency	**80 %**
Water Consumption	**No**

$$\frac{mass\ of\ \mathrm{H2O}}{mass\ of\ diesel} = \frac{160}{165.4} = \mathbf{0.82 : 1}$$

In this experiment, we obtain higher condensation efficiency for diesel engine, which achieve 80% at lower engine speed to reduce exhaust gasses temperature and to avoid regeneration process. In addition, we have a high mass ratio accuracy which is near to the ideal one. Therefore, the engine is in good case and there are no trouble code detected in any engine management system.

This picture is taken for the emerged water from the exchanger figure (5.1), the orange color due to incomplete combustion, so there are a little of unburned diesel condensate as shown below.

Figure 5.1: Water Emerged from the Exchanger.

5.3 Conclusion

From the diagnosis result tables we conclude that:

1) The Device efficiency in gasoline engines diagnosis greater than diesel engines, so the accuracy of the device in gasoline engines reaches 94% whereas in diesel engines reaches the maximum value about 85.3%.
2) When we compare these results, we found that satisfy the mass ratio between the mass of fuel burnt and the mass of water emerged.
3) The difference between the efficiencies of gasoline and diesel tests related to :
    a. The gasoline exhaust gas temperature less than that in diesel.
    b. The amount of mass airflow in gasoline less than in diesel.
    c. The mass airflow sensor inserted to the diesel engines to satisfy environment criteria (smoke limitation), so that the reading of this sensor do not affecting directly in amount of fuel injection as in gasoline engines.
4) From experiment the efficiency of the test increase as the engine speed decrease.

5.4 Problems and Recommendations

In this section, we have to show the problems faced us in executing our project, then we have to show some of recommendations and Tips that help any group in developing the project, this recommendations coms from our experiment.

The recommendations are:

1) The project may need an insulated second stage evaporator, which increase the project performance and give more condensation efficiency.
2) Increase the number of obstacles will improve the heat exchanger efficiency, but the back pressure may take place which may effect on the engine operation.
3) Fins is very useful way to increase heat transfer area that will increase the condensation efficiency.
4) Don't try to lunch the device and start the test in closed area in order to avoid toxic gases which may cause sickness.
5) Take the reading with high accuracy devices.

The problems are:

1) No efficient accuracy from the measurement devices that we used which effect on our result.
2) Obtain data from vehicles control units and the variety of measurements units.
3) The rest of water in heat exchanger channel which result in our reading efficiency.
4) The availability of the suitable electrical component in both design and efficiency.
5) Due to our diagnostic process conditions many diesel vehicle make DPF regeneration, which result in our reading due to increase the exhaust gas temperature.

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