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**Project Title: Optimization of Ignition Timing in Spark Ignition Engine**

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## **Abstract**

Ignition timing is considered one of the most important functions for achieving the highest efficiency. However, that ignition sometimes happens in time that is different than the one we seek for, in many cases and with different types of engines that use different types of fuel. Sometimes, there some factors related to spark engines while in other times there are reasons for the early ignition that are directly related to types of fuels used for the engine. For example, ignition time varies according to type of petrol, diesel and biofuels as well. In the following project, there is a complete study on the effect of bio/gasoline fuel on ignition time. It finds improvements that optimize ignition timing in Spark Ignition engine. The team of the project used the workshops in PMU to reach optimization results of ignition with bio/gasoline fueled engines. The following projects details all effects of optimization on important factors.

## **Acknowledgment**

Scientific Projects are always important situations where there are always several sources of sincere help that provides guidance, consultation and redirecting efforts to the right place. We greatly acknowledge the Department of Mechanical Engineering, Prince Mohammad Bin Fahd University for allowing us to use their equipment which helped us completing the project. The project members honorably express their ultimate gratitude to Dr. Esam Jassim, the advisor of the project for his continual orientations across the whole project. Furthermore, a special and deep thank you is to be addressed to Dr.Nader Sawalhi, the main source of technical guidance across the project. We feel deep gratitude for his everlasting encouragement.

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# **Chapter 1: Introduction**

## **1.1 Project Definition:**

This Project is intended to optimize ignition timing in spark ignition engines and study how it affects the performance characteristics factors such as efficiency, power, and emissions. The term Spark-ignition engines is usually refers to gasoline engines, or petrol engines. The engine performance is very dependence on setting the correct ignition timing, where if it was soon or late it could even result of damage to the engine. The ignition timing affects multiple factors such as fuel economy and engine performance (power efficiency).

Four Cylinders Mitsubishi Lancer Engine has been settled to be our experimental engine. This Engine has a Maximum Power Output equal 80 kW at 6000 rpm and Maximum Torque Output equal 143 Nm at 4000 rpm at Standard Gasoline Conditions see Table 1.1. However, biofuel will be experimented and Studied on this particular engine. Furthermore, ignition timing plays an essential role corresponding with the bio/gasoline fuel type.

## **1.2 Project Objectives:**

- ❖ Optimizing ignition timing in spark ignition engine
- ❖ Study the effectiveness of the radiator
- ❖ Quantify the impact of changing ignition timing on the exhaust gas emission

### 1.3 Project Specifications:

This Project consists of four parts. Stand, Engine, Radiator, and Gasoline Tank:

- Steel Stand Contains:
  - 1 Square Base (**100cmx60cm**)
  - 4 Standing Beams (**80cmx5cm**)
  - 4 Connecting Horizontal Beams (**82.55cmx5cm**)
  - 1 Mid Beam (**82.55cmx4cm**) (for holding the engine)
  - 4 C Beams (**16cmx8cm**) (for holding the gasoline tank)
  - 1 Side C Beam (**36cmx6cm**) (for Vibration engine holder)
  - 1 Long C Beam (**70cmx4cm**) (for Radiator)
  - 1 Side Square Holder (**22cmx12cm**) (for battery)
  - 1 Side Square Holder (**57cmx26cm**) (for electric wires)
  - 4 Wheels (**d=6cm**) (for moving the stand)
    - Overall Stand:
      - Weight (**34Kg**)
      - Height (**90cm**)
      - Width (**60cm**)
      - Length (**100cm**)
  
- Mitsubishi Engine Lancer GL.X 1.5L (2006)

The tables below (1.1,1.2, and 1.3), shows the specifications and dimensions for our test engine.

*Table 1.1: Mitsubishi Engine Specifications*

Category	Description
Weight	62 Kg
Engine Type	Naturally Aspired Petrol
Engine Code	4A91
Cylinders	4
Capacity	1.5 liter / 1499 cc
Bore x Stroke	75 mm x 84.8 mm
Bore/Stroke Ratio	0.88
Maximum Power Output	80 kW at 6000 rpm
Maximum Torque Output	143 Nm at 4000 rpm
Compression Ratio	10:1
Maximum RPM	7000 rpm

<b>Engine Coolant</b>	Water
<b>Carbon Dioxide Emission</b>	163.0 CO <sub>2</sub> g/km

- Mitsubishi Radiator (2006)

*Table 1. 2: Mitsubishi Radiator Dimensions*

<b>Category</b>	<b>Description</b>
<b>Weight</b>	4.830 Kg
<b>Depth</b>	1.6 cm
<b>Width</b>	68.5 cm
<b>Height</b>	37.5 cm

- Mitsubishi Gasoline Tank (2006)

*Table 1. 3: Mitsubishi Gasoline Tank Specification*

<b>Category</b>	<b>Description</b>
<b>Weight</b>	14 Kg
<b>Length</b>	71.2 cm
<b>Width</b>	40.5 cm
<b>Height</b>	3.1 cm
<b>Capacity</b>	50 liter

## 1.4 Applications:

Gasoline/Biofuel Engines are very Applicable in our daily routine life. However, it has a direct impact regarding obtaining our needs. Such as:

- Cars Engines
- Planes Engine
- Trains Engines

## Chapter 2: Literature Review

### 2.1 Project Background:

On the power stroke, the spark plug fires and starts an explosion that crams the piston down the cylinder, hence produce power. The spark happen a few degrees before the power stroke at the end of the compression stroke. In other word, right as the piston is coming up for compression, just before it reaches top dead center, or TDC, the spark plug fires. That distance before top dead center is what known as ignition timing. Ignition timing is typically read from a market that's on the harmonic balancer on the front of the engine, and the zero point represents top dead center from the number one cylinder in between the compression and power stroke. This zero mark will have been set by the factory on the engine.

Functionally, ignition is the first and most important stage of the process of generating rotation of gears and shafts. In fact, ignition is the internal combustion that uses the fuel of the engine to start igniting in the combustion chamber of the engine. The high temperature generated through the ignition process is basically used to generate high pressure that force pistons attached to the engine to move and generate a high motion energy that affect other parts of the engine like crankshafts leading finally to produce the required mechanical energy [2].

In fact, the whole process takes place in the 2 stroke and 4 strokes engine cylinders that systematically deal with powers and discharge exhausts resulting from combustion process. However, ignition in the engine depends on the type of fuels used for combustion and the spark that starts combustion. A spark plug is powered by electricity and it also varies according to fuel into spark ignition for petrol and gasoline engines and compression ignition for diesel engines.

Ignition timing is an important point to consider when examining spark ignition of petrol and gasoline engines. It is important process that brings spark to the dead point in the combustion chamber near the compression stroke before the pistons. When the ignition timing is incorrect, it results in more consumption of fuel with a very poor engine start and less ability in acceleration. Spark of ignition is described as a spark knock. A non-optimized ignition timing in spark ignition engines leads also to problems of backfiring and general low performance of the engine [4].

In case of petrol engine, ignition is accurately timed because of the volatile nature of petrol. However, ignition timing is far different with gasoline and biofuel engines. In a petrol engine, a spark plug is connected to the engine's cylinder and it is operated through the battery. Matters are quite different with diesel engines that have longer ignition timing with low temperature. Hence, to optimize diesel engines, it requires a higher compression of fuel used to generate higher temperature.

However, the problem may be with gasoline and bio-fuel engines which have a lower temperature and higher ignition timing. That's why gasoline engines are the least used among all types. Indeed, there was a strong need to optimize ignition timing of gasoline engines to achieve a higher performance of those engines.

## **2.2 Previous Work:**

In previous reports/researches on the use and applications of internal combustion engines, the report detailed the functions of the internal combustion engines and the differences it has which distinguishes it from other engines, how optimizing the ignition timing could affect the performance of the engine, and difference analysis on the fuel types. Furthermore, optimization of SI engines is environmentally important for the depletion of petrol and higher controlling of pollutants. In addition, it achieves important socioeconomic aspects.

Ignition timing is an important process that determines ignition at the combustion chamber. Ignition timing has to go in accordance with velocity of piston position and crankshaft that finally give the engine the property and ability of movement. It is important for an engine to set accurate ignition timing in the combustion chamber. That in fact achieves many objectives: it enhances the performance of the engine, and it avoids problems of exhaustion emissions [1].

The performance of spark ignition engines is a function of many factors. One of the most important ones is ignition timing. Also it is one of the most important parameters for optimizing efficiency and emissions, permitting combustion engines to conform to future emission targets and standards [8].

### *2.2.1 Study Effects of Ignition Timing on Gasoline Engines Performance*

- **Project #1**

An experiment was conducted in 2010 at Iran University of science and technology, to examine the effect of ignition timing on performance of SI engines. For achieving this goal, at speed of 3400 RPM, the ignition timing changed in range of 5 degree CA ATDC to 40 degree CA BTDC, the performance characteristics for example power, torque, thermal efficiency are obtained and discussed. Moreover, the tested engine specification as shown in table 2.1 [2].

Table 2.1: Engine specifications [2]

Engine type	TU3A
Number of strokes	4
Number of cylinders	4
Cylinder diameter (mm)	75
Stroke (mm)	77
Compression ratio	10.5 : 1
Maximum power (kW)	50
Maximum torque (NM)	160
Maximum speed (rpm)	6500
Displacement (cc)	1360
Fuel	97-octane

In this experiment they were aiming to have two approach of finding results. First is experimentally and by modeling. They designed a zero-dimensional thermodynamic cycle model with two zone burnt/unburned combustion model. Furthermore, the following Figure 2.1 and figure 2.2 describe the results on both experimentally and by Modeling.

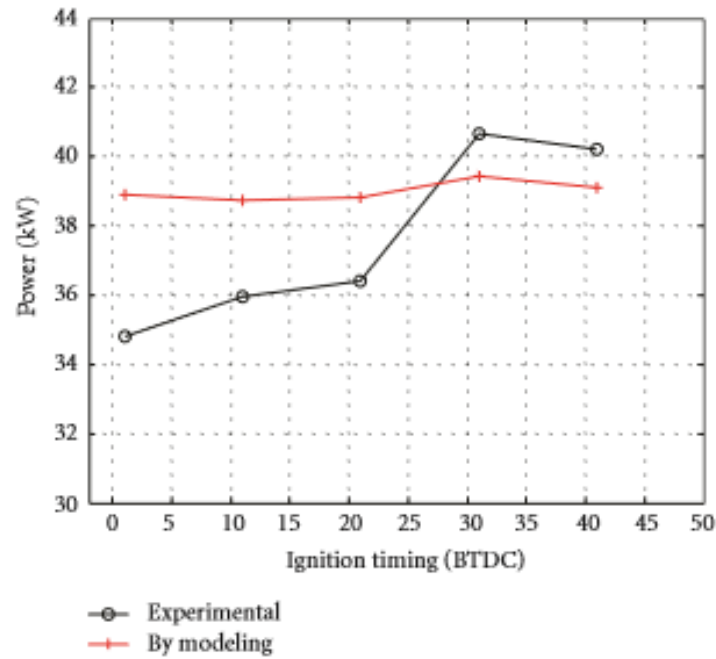


Figure 2.1: Comparison of engine power with ignition timing at 3400rpm [2]

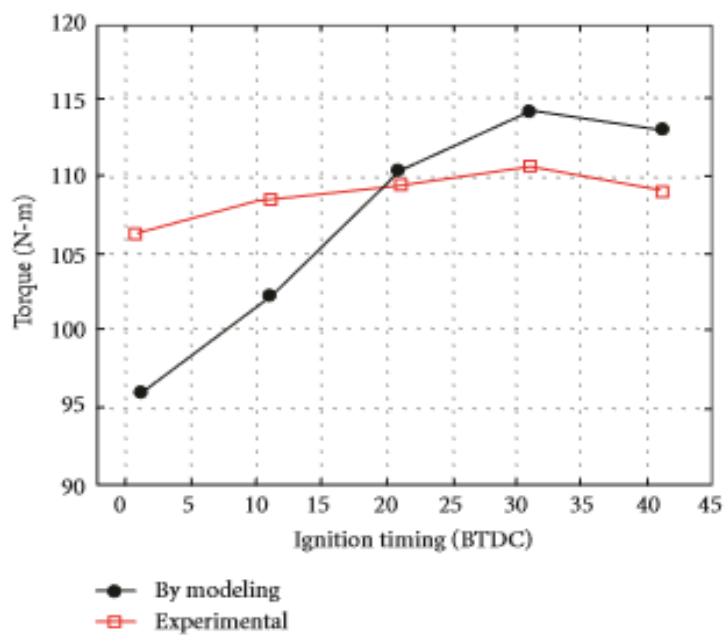


Figure 2.2: Comparison of engine torque with ignition timing at 3400rpm [2]

- **Results**

The result shows that power tend to increase within advancing spark ignition between 17 degree and 35 degree CA BTDC. It is very expected that power would increase within advancing spark ignition to a certain point then starts to drop off. Best performance will be achieved when the highest portion of the combustion takes place near TDC. If the spark is not advanced enough, the piston will already be moving down when much of the combustion takes place. In this case, we lose the ability to expand this portion of the gas through the full range, decreasing performance. If ignition is too advanced, too much of the gas will burn while the piston is still rising. These effects cause a maximum in the power as a function of spark advancing ignition [2].

- **Project #2**

After two years of experimenting from project number one above, another experiment was conducted in Iran University of science and technology. However, this experiment expanded in range of ignition timing, for achieving this goal at 3400 RPM, ignition timing has been in range of 10 degree ATDC to 45 degree BTDC for optimizing operations. The engine was fully mounted on automated test bed and coupled to a Schenck W130 eddy current dynamometer. This experiment was mainly studying the performance of ignition timing without modeling a fuel combustion design. Moreover, same engine was tested from project one above at department of automotive engineering as seen in table 2.2 below.

Table 2.2: Engine specifications [2]

Engine type	TU3A
Number of strokes	4
Number of cylinders	4
Cylinder diameter (mm)	75
Stroke (mm)	77
Compression ratio	10.5 : 1
Maximum power (kW)	50
Maximum torque (NM)	160
Maximum speed (rpm)	6500
Displacement (cc)	1360
Fuel	97-octane

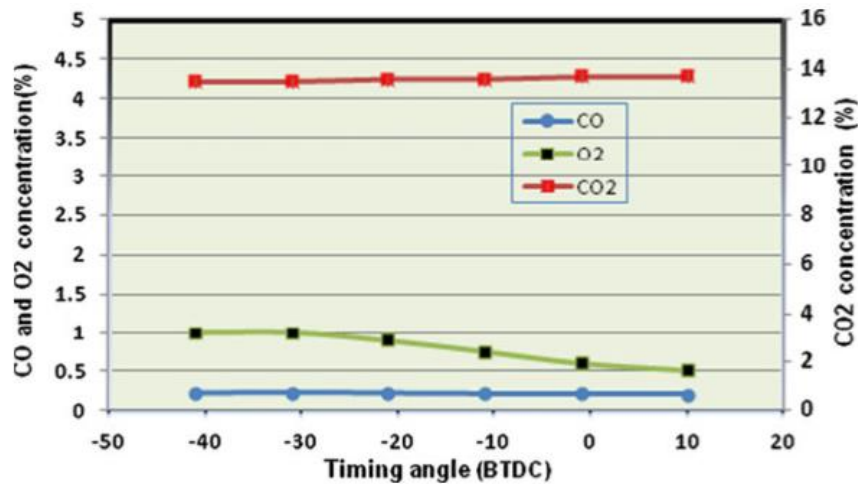


Figure 2.3: The relationship between O<sub>2</sub>, CO and CO<sub>2</sub> concentration versus ignition timing [2]

In figure 2.3 above CO, O<sub>2</sub> and CO<sub>2</sub> concentration change very little with ignition timing in the range studied. However, there was enough O<sub>2</sub> to react most of carbon to carbon dioxide. Carbon monoxide concentration increased and carbon dioxide concentration decreased when there isn't enough oxygen. Some carbon monoxide does appear in the exhaust due to frozen equilibrium concentration of CO, O<sub>2</sub> and CO<sub>2</sub> [1].

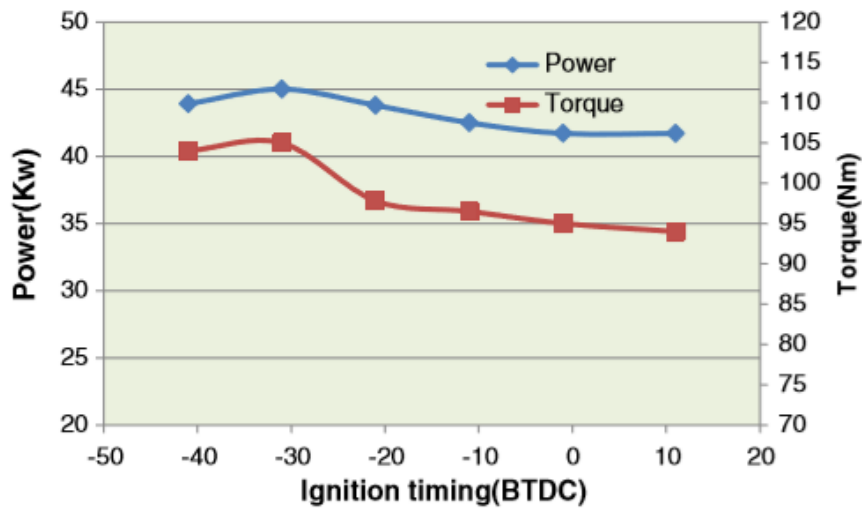


Figure 2.4: The relationship between power and torque versus ignition timing [2]

It can be seen that power and torque increases with advancing ignition timing to a particular point, after that it reduces slightly. This is due to increasing friction at high values of advancing ignition timing and therefore reducing power and torque. According to Figure 2.4 above, the highest amount of the both power and torque occurs at 31°CA BTDC [2].

- **Results**

The aim of this project was to study the effects of ignition timing of a spark ignition engine using different timing angles and engine speed on engine performance by experimental. The result shows that ignition timing can be used as an alternative way for enhance the performance of IC engines. In this project, the highest result was obtained at 31°BTDC for 3400 RPM. Moreover, engine speed and throttle position is significant for influencing the performance in this engine. During rising ignition timing O<sub>2</sub>, CO<sub>2</sub>, and CO has been almost constant and the lowest amount NO<sub>x</sub> is obtained at 10°BTDC.

## 2.2.2 LPG Consumptions and Emissions

- **Project #1**

For LPG (liquefied petroleum gas) vehicles, it was noticed that the nature of the fuel-air mixture in combustion chamber had a positive effect on the avoidance of start problems that distinguishes engines with liquid fuels. As we can see below in Table 2.3 the fuel air mixture is defused through inlets of the LPG engine in low temperature conditions; in addition to that, LPG fuel has less emission than natural gas [6].

*Table 2.3: LPG Emission as Compared to Petrol and Diesel [6]*

<b>Compared to Petrol</b>	<b>Compared to Diesel</b>
Up to 15% less CO <sub>2</sub>	10% less CO <sub>2</sub> emissions of hydrocarbon
Up to 50% less particulates	90% less particulates
Up to 60% less CO	75% less carbon monoxide,
Up to 33% less NO	90% less oxides of Nitrogen
Virtually zero evaporative	85% less Hydrocarbons
Up to 80% less air toxic	87% less ozone forming potential

Previous experiment was done to compare gasoline engines to LPG engines in terms of brake thermal efficiency [3]. The experiment below Figure 2.5 was done on one-cylinder, four-stroke, and @ 1500 rpm.

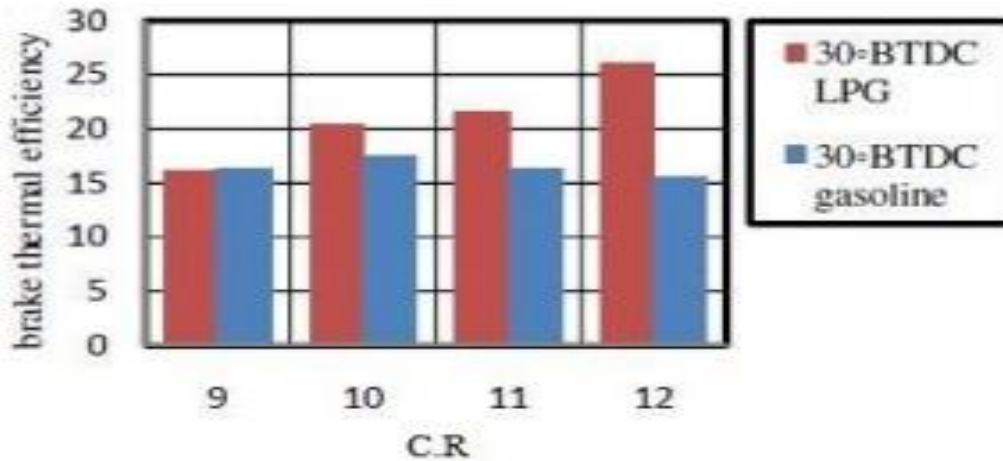


Figure 2.5: Comparison of Maximum Brake Thermal efficiency for both LPG vs. Gasoline [6]

Ignition timing has also a huge impact on fuel consumption and emissions. A previous study was conducted to find the effects of ignition timing on fuel consumption. Based on the data obtained, this experiment describes that the more advance in timing BTDC is resulting higher consumption and power. However, gradually increasing the number or making more degree before top dead center, as we can see in figure 2.6 below [6].

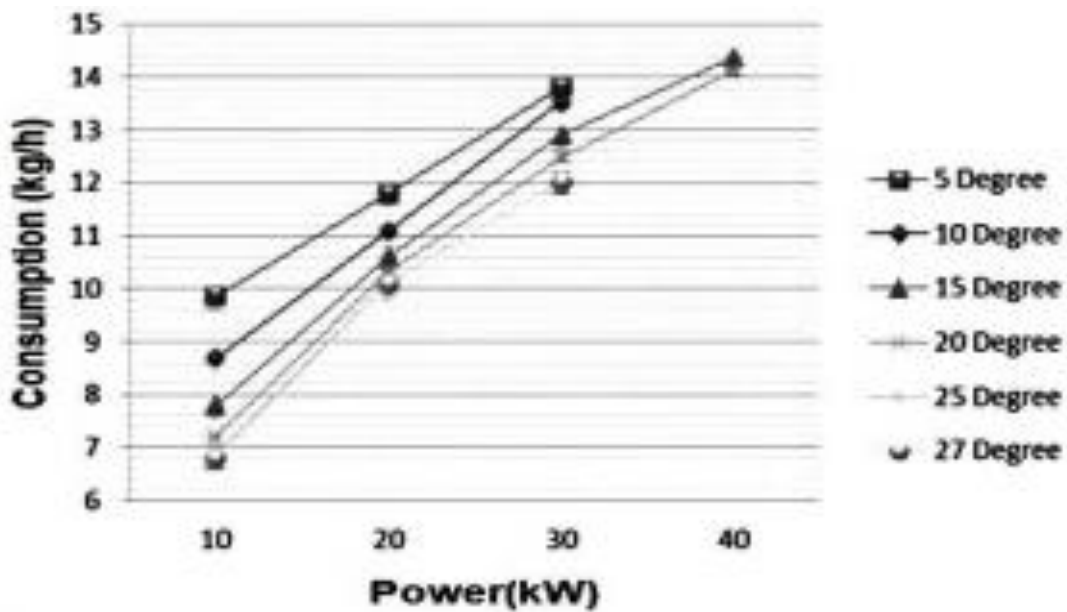


Figure 2.6: Effect of Spark Advance in Fuel Consumption [6]

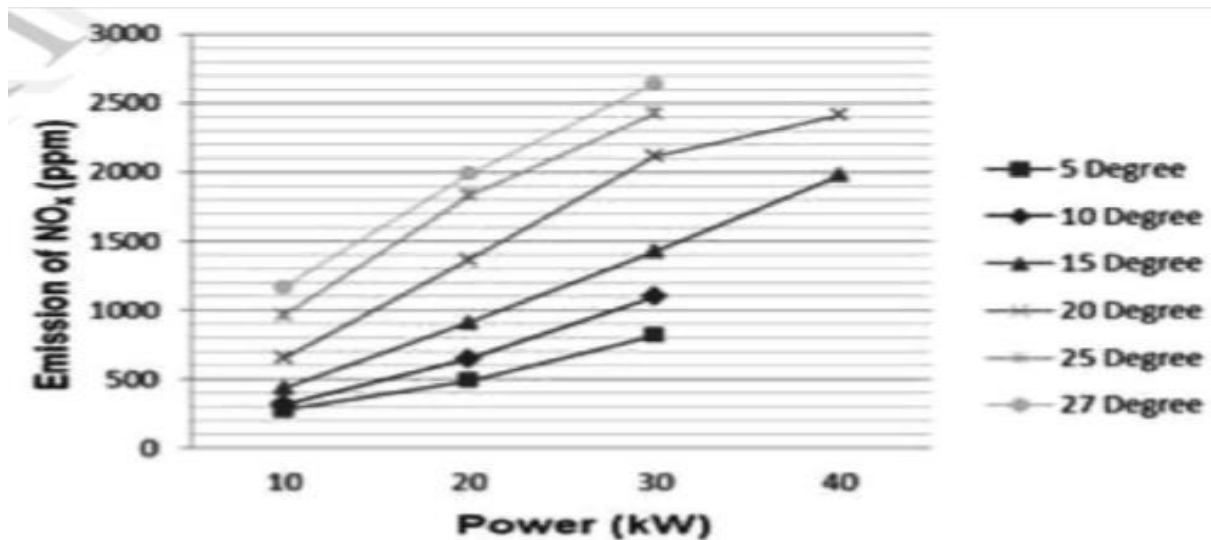


Figure 2.8: Effect of Spark Advance in NOx Emission [6]

- **Results**

There is a connection between the spark Advance angle of ignition timing and fuel consumption, the larger the angle the smaller the consumption. The more spark Advance contributes the more enlarging NOx Production. Furthermore, minimizing the fuel consumption occurs when spark advance angle adjusted.

- **Project #2**

At 2011 an Experiment was conducted in Iran University of Science and Technology Said, bio-ethanol was generated from agricultural products like maize, millet, sweet potatoes, and sugar cane. The fuel obtained was purified at a rate of 99.43%. The fuel obtained was added to another gasoline mixture that was brought from a nearby gas station. Bio-ethanol was added to gasoline in different values of 5%, 10%, 15% and 20% of bio-ethanol. It was able to form a gasoline mixture as E05, E10, E15 and E20 respectively [3].

The experiment started to test a gasoline engine at a speed of 750 RPM. That speed was chosen as a standard speed for all fuels used in the experiment. Furthermore, it was a proper speed to warm up the engine. The first checks of the experiment referred to the engine were able to work smoothly without any hitch with 1 liter of neat petrol. The experiment has given some rates related to speed, and rotation of RPM of 750. In addition, it was set at a consumption of petrol of engine was throttled to the 150 cm<sup>3</sup>. In addition, the experiment also measured brake speed and balancing load that was gradually increased at the dynamometer until the spring balance read zero. Later, the experiment was repeated at different speeds of 1050 RPM, 1350 RPM and 1700 RPM when using the different bio-ethanol with gasoline of E05, E10, E15 and E20 blends [3].

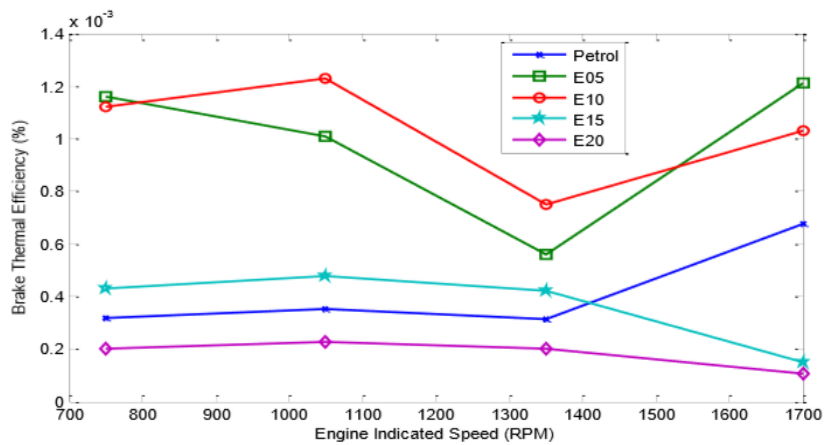


Figure 2.8: Brake Thermal efficiency vs. Engine Speed for petrol and blended bioethanol's [3]

- **Results**

The experiment showed important results of optimization of the engine functions and ignition timing when using the highest blend of E20 at the highest 1700 RPM. These optimizations enhanced a lower Brake thermal efficiency, Fuel Consumption, brake power in addition to the fuel power. The experiment assured the fact those performance characteristics of neat and blended fuels. However, it was important to determine the right ratio of bioethanol blend that is to be added to gasoline fuel to reach the highest performance characteristics, and reduce the exhaust emissions [3].

## 2.3 Comparative Study:

Comparison between our work and results to the two previous works.

- **Project #1:** Study and the Effects of Ignition Timing on Gasoline Engine Performance and Emissions [2].

Although the objectives of our project and the previous one almost the same, the differences are within the type of testing mechanism machines. Where the previous work project is modeled and simulated to a computer programming through a monitor screen where result can be smoothly approached and founded.

- **Project #2:** Effect of Compression Ratio and Spark Timing on Performance and Emission of Dedicated 4-Stroke S.I Engine Fuelled With LPG [8].

The main objectives of this project are mostly the same as ours; in term of type of fuels obtained added to the engine to study the effects of performance using LPG to increase power and torque and overall efficiency. However, some main differences as well between the project and ours by using deferent LPG composition of propane and bioethanol fuel.

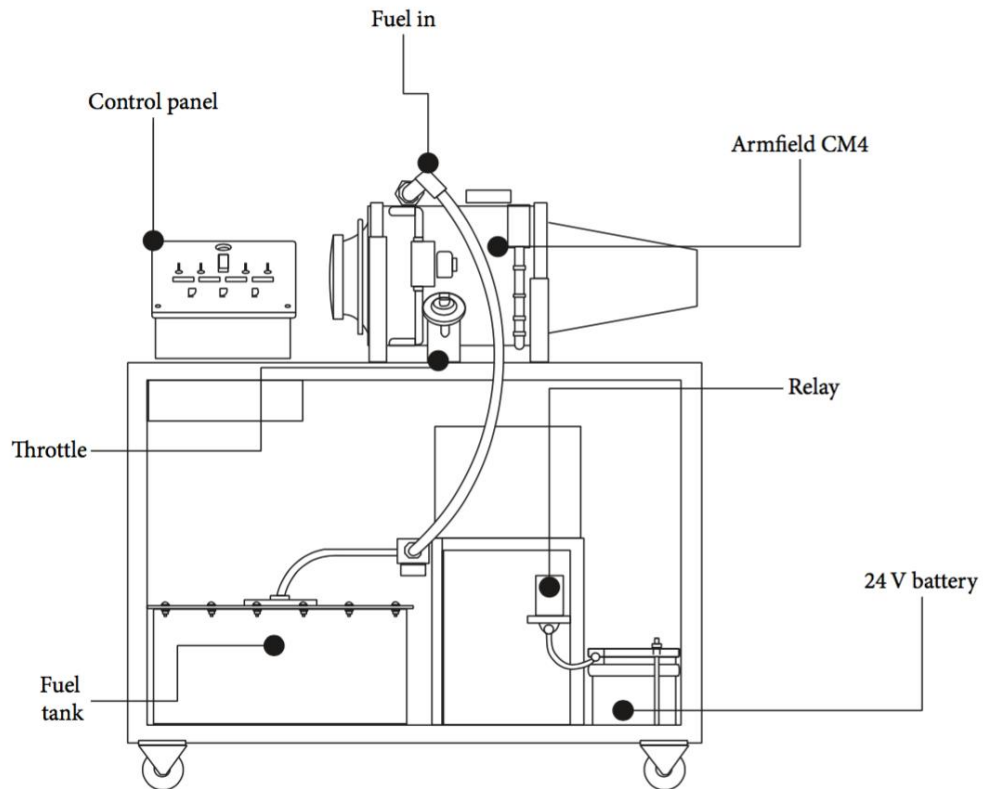
## Chapter 3: System Design

### 3.1 Design Constraints:

The entire idea of the project is about comparing and calculating an engine's performance when on standard fuel, and its performance when using biofuel, from torque of the engine, to the rpm, and the performance, and its efficiency as a whole, as well as the gas emissions of the engine.

Taking into consideration the capital, and resource limitation for this project some compromises had to be done, for the engine that was chosen had to be of a used car, which in return will decrease its efficiency, and in the case of sensors the torque sensor was unfeasible, and difficult to get from the sheer size, and cost the sensor, more over the limited knowledge in the combustion timing which is an intricate process, and is very critical, wrong adjustment can cause irreversible damage to the engine.

The engine chosen was a 2006 Mitsubishi Lancer, which is 2.0-liter 4-stroke engine, with an estimated 120 horsepower at 5500 rpm, and maximum torque of 176.28 Nm, the dimensions of the engine is 121, 37 cubic meters, and runs on gasoline. The parts of the engine that will be adjusted include the camshaft and the overall layout of the wiring and gas tank position. The premise of the idea is similar to that of another research as show in figure 3.1 this figure explains an approach to construct a similar stand for the engine and all its components from the wiring, batteries, and gasoline tank.



*Figure 3.1: Armfield CM4 turbojet engine (similar design approach)*

In the case of the stand a customized with the main idea was to mount the engine on top of the metal stand with specified areas for both the battery, and the fuel 42.0 liter tank.

The stand design is steel stand with 0.81x0.33 m base with a height of 0.84 m with an extra compartment for the battery, and the wiring and the engine computer, the stand was then finish off with yellow paint for esthetic purposes.

## 3.2 Methodology:

First a basic understanding of how an four stroke engine works, the engine block contains four cylinders in which the combustion takes place the combustion forms an up and down motion witch is the translated to rotational motion via the crank shaft, this applies to all types of car engines when it comes to four stroke engines there are four main phases for the cylinder cycle:

- **Intake stroke**

The piston moves from TDC to BDC (down), then the intake valve is open, the exhaust valve is then closed, after that the piston creates suction (vacuum) and air and fuel are sucked into the cylinder.

- **Compression stroke**

The piston moves from BDC to TDC (up), then both valves are closed; then the piston compresses the air and fuel mixture.

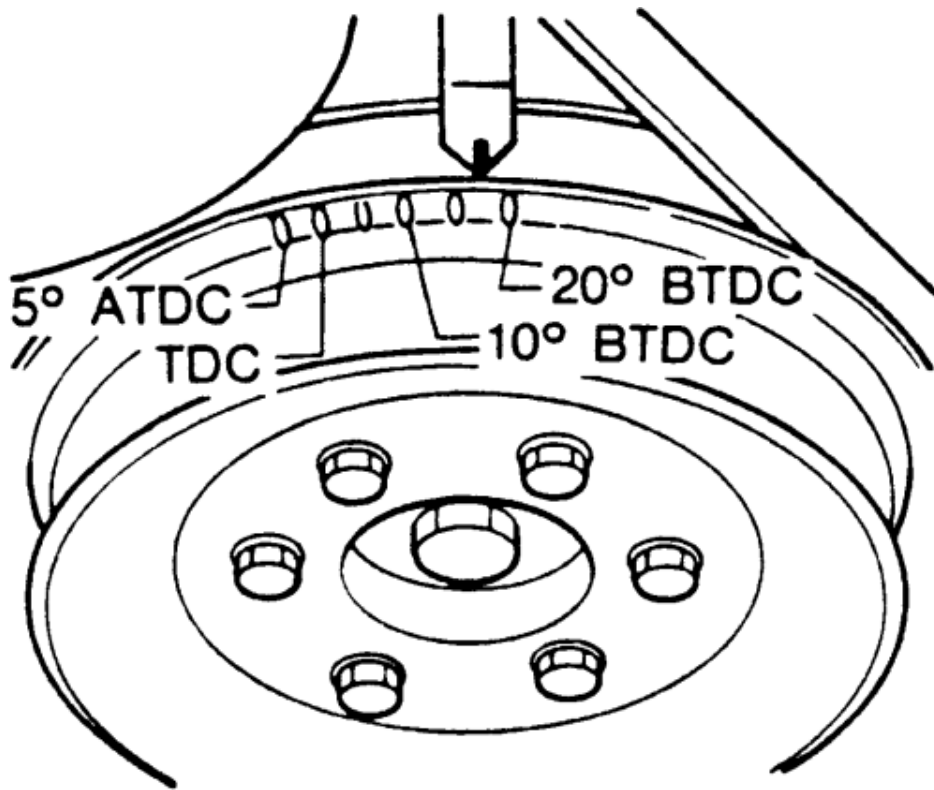
- **Power Stroke**

The piston moves from TDC to BDC (down). Both valves are closed. The spark plug fires, after that the fuel mixture burns rapidly, this expanding heated mixture forces the piston down.

- **Exhaust stroke**

Piston moves from BDC to TDC (up), while the intake valve is closed, then he exhaust valve is open, and after that the piston pushes the exhaust out.

Given how the four-stroke engine works applying the changing to the cam shaft timing in order in order to attempt to increasing the engines efficiency while running on the biofuel, the timing of the closing and opining of the valves are controlled by changing the angle of the cam-shaft as shown in figure 3.2.



*Figure 3.2-camshaft angle adjustment method*

By changing the camshaft angle the intake of fuel and air into a piston changes thus changing the ignition time with respect to piston position, and there for changing the performance as a hole.

The biofuel usage in other research articles shows comparable performance to that of a of the shelf standard gasoline performance, in a study on Performance Evaluation of a Small-Scale Turbojet Engine Running on Palm Oil Biodiesel Blends significant data was acquired that show Comparable results between a blend of B20 that is of 20% biodiesel, and 80% petroleum diesel, and the Jet A fuel. Figure 3.3 explains this comparison

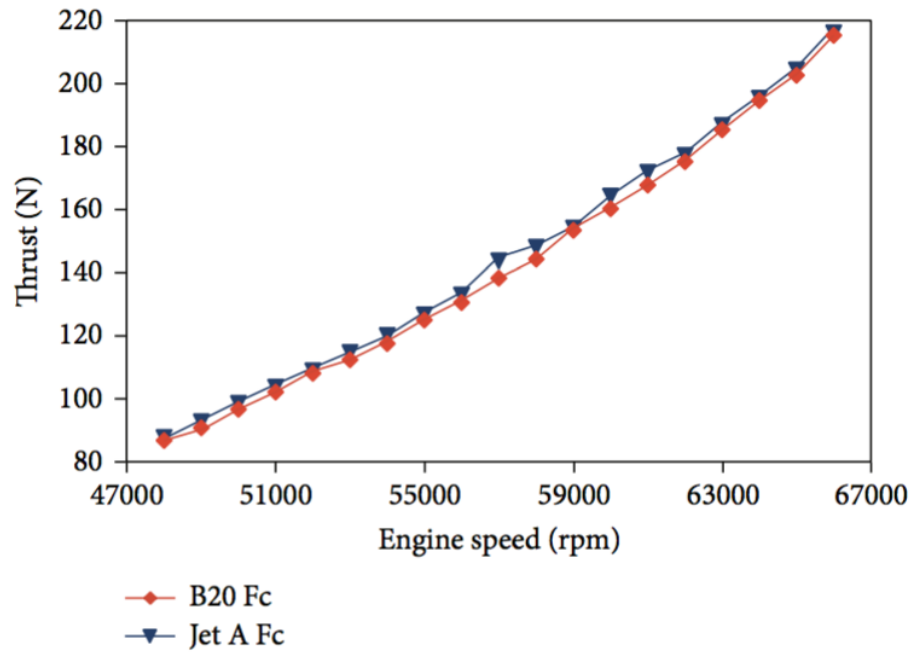


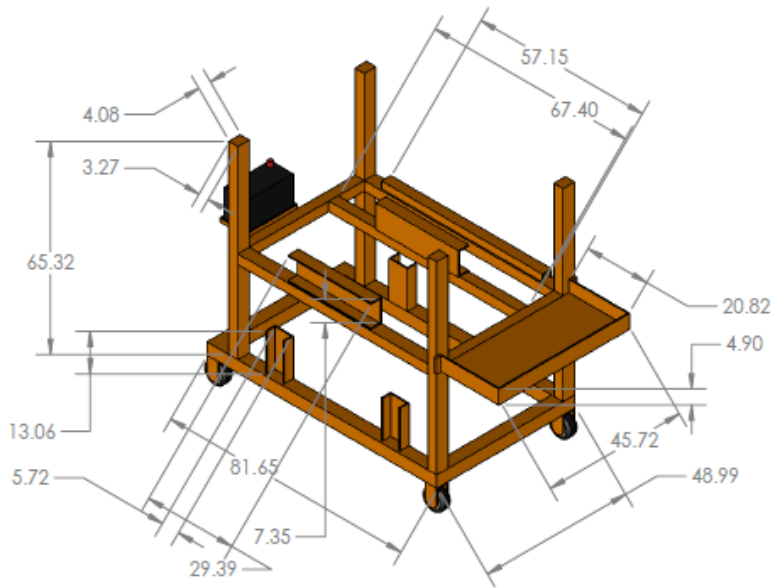
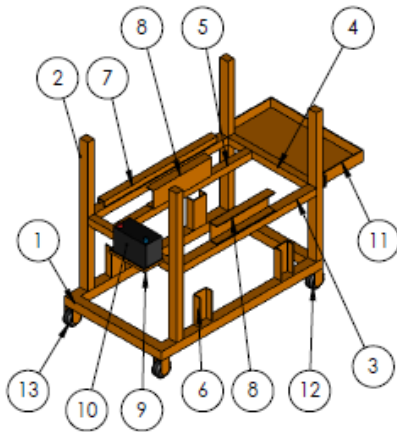
Figure 3.3: Corrected fuel flow rate for B20 and Jet A-1

A similar approach will be taken in this research paper by comparing the engines performance on biofuel, and when on standard fuel.

### 3.3 Product Subsystems and Components:

The subsystem was way to hold all the parts together from the engine, and all the wiring, and the engine computer, the battery, and the fuel tank the stand design will be explained from the following figure 3.4, and table 3.1.

ITEM NO.	PART NUMBER	QTY.
1	Base	1
2	Standing Beam - 1	4
3	Long Beam - 1	2
4	Short Beam - 1	2
5	Mid Beam	1
6	C Beam - 1	4
7	Side C Beam	1
8	Main C Beam	2
9	Battery Holder	1
10	Battery	1
11	Holder	1
12	wheel Holder	4
13	Wheel	4



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS				FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
SURFACE FINISH:							
TOLERANCES:							
LINEAR:							
ANGULAR:							
	NAME	ID	DATE			TITLE:	
Student 1	Muhaf	201100959				Stand Assembly	
Student 2	Ibrahim	201101256					
Student 3	All	201101315					
Student 4	Majid	201100716					
Student 5	Abdulrah	201100049					
				MATERIAL:	Steel	DWN	PMU
							A4

Figure 3.4: Stand design with Bill of Material

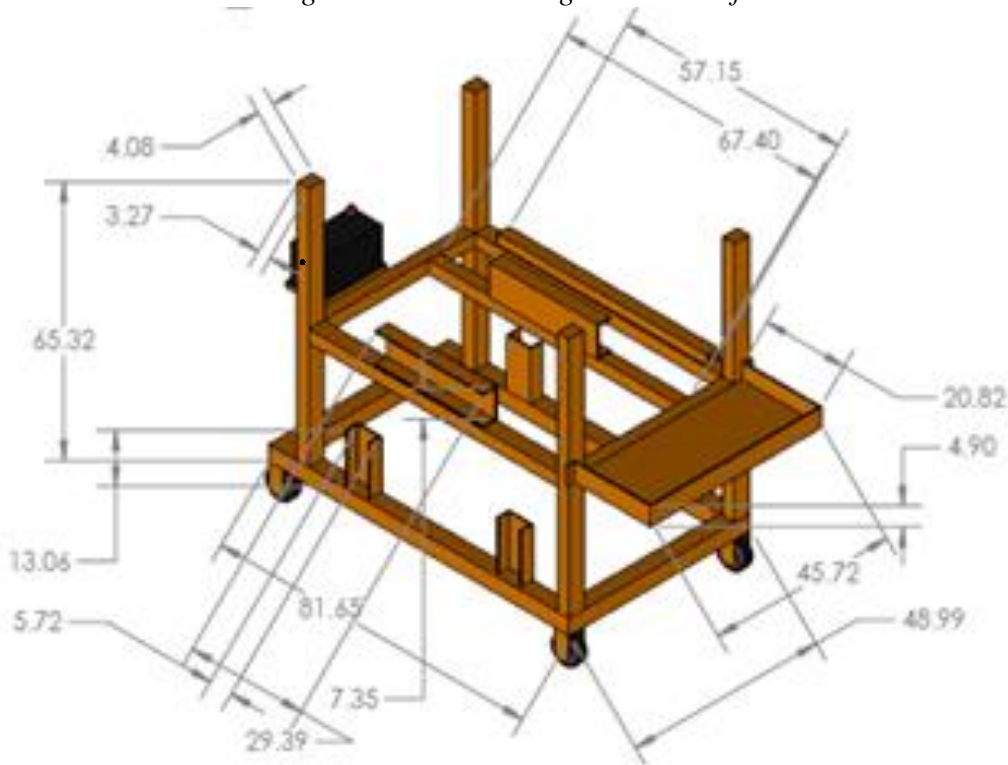


Figure 3.5: Engine Stand Dimensions and Specification



Figure 3.6: The test engine

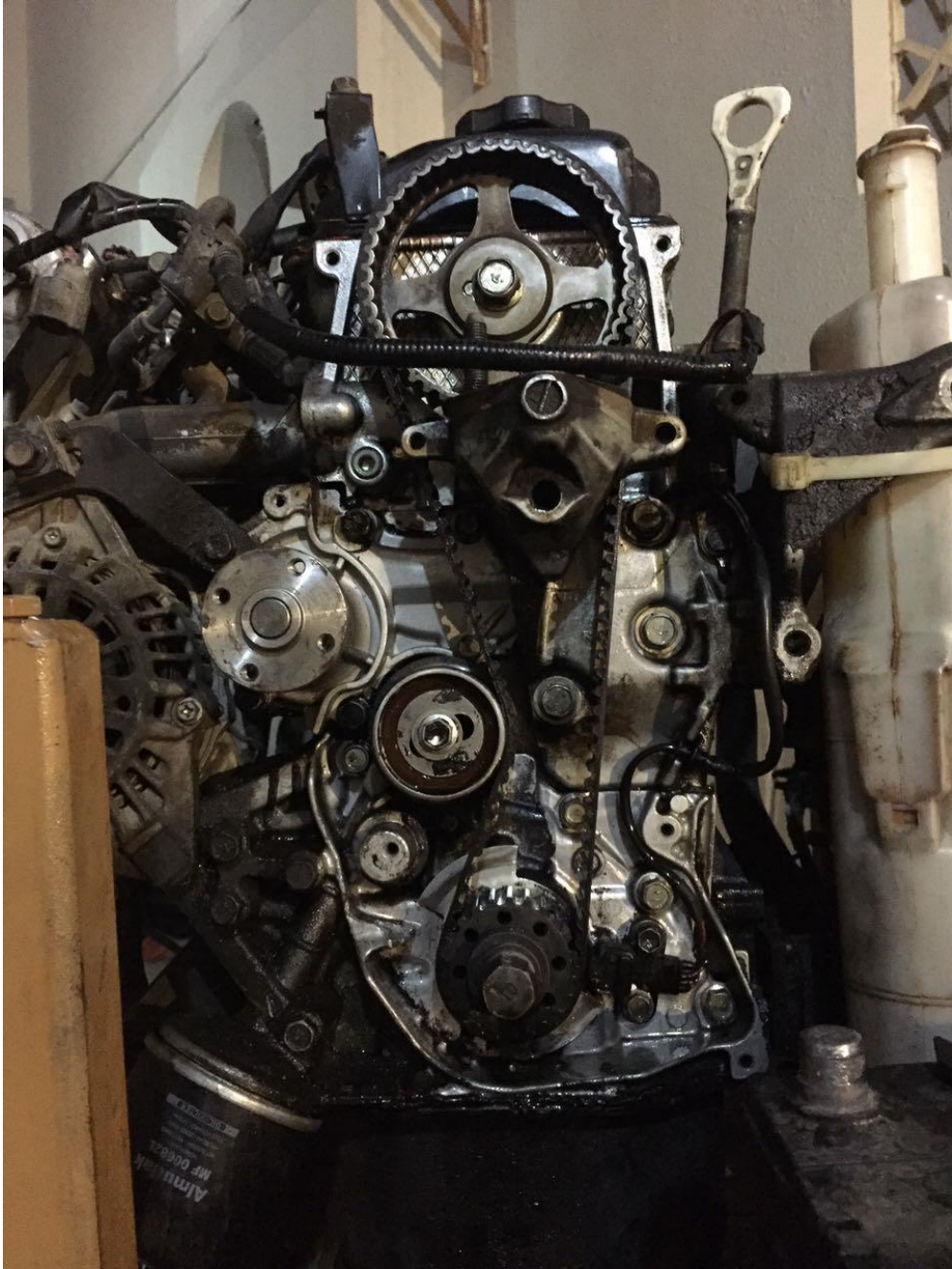


Figure 3.7: A closer look at the test engine

### 3.4 Implementation:

The first step was to buy all needed parts, and sensors needed to create the prototype, which includes a 2006 Mitsubishi lancer engine with a 120 hp 2.0-liter four-cylinder engine with all electronic boards, and wiring, and a custom designed metal stand in order to place the engine. Furthermore for the sensors the university has the tachometer to calculate the RPM; we needed to buy both the inbuilt to calculate the temperature, and the Ventis MX4 to calculate the emitted gasses from the engine.

For the project we also needed to calculate the torque of the engine, which is an expensive sensor so we choose to go with an alternative solution, which is getting a motor to calculate the actual horsepower and then using a formula to find the torque of the engine.

The next part was the assembly of the engine, by mounting the engine on the metal stand, and then connecting the wires, and boards to the engine. In the case of the sensor we are still undergoing the process of connecting the inbuilt to the radiator in order to calculate the heat exchange between the engine, and the coolant. We then need to buy the biofuel so that we can then use the MX4 gas sensor. The same applies to the tachometer for calculating, and the motor to calculate the horsepower.

After all parts and sensors are assembled we are then going to need a car mechanic to help us change the camshaft timing (combustion timing), in order to see if there is an effect on the efficiency by comparing the engine with normal fuel, and the efficiency when infused with the biofuel, we also plan on comparing the environmental aspect of the engines gas emissions on the regular fuel, and when on the biofuel.

Some calculations must be applied to get the actual torque due to the unavailability of the actual torque sensor. Instead of getting the torque directly an extra motor must be connected to get the horsepower the using this formula  $TORQUE = HP \times 5252 \div RPM$  thus giving the actual torque of the engine, the relation between horsepower, RPM, and torque.

# Chapter 4: System Testing and Analysis

## 4.1 Radiator Temperature Calculations

After setting up the engine, we had the remaining data we need to measure the radiator's water out ( $T_{\text{water out}}$ ). We will be conducting to sets of measurements, theoretical and experimental.

**Objective:** To measure the temperature of radiator's water out ( $T_{\text{water out}}$ )

### Given Data:

- Length of radiator tube ( $L_r$ ): 20 cm x 68 cm = 1360 cm = 13.6 m
- Diameter of radiator ( $D_r$ ) = 1.5 cm = 0.015 m
- Mass flow rate of air ( $\dot{m}_{\text{air}}$ ) = 2.39235 kg /s
- Mass flow rate of water ( $\dot{m}_{\text{water}}$ ) = 0.7333 kg /s
- Temperature of air ( $T_{\text{air}}$ ) = 35.00 °C
- Heat capacity of water ( $C_{\text{water}}$ ) = 3072.527 w/k →  $C_{\text{max}}$
- Specific heat capacity of air ( $C_{\text{air}}$ ) = 2404.312 w/k →  $C_{\text{min}}$
- Thermal transmittance of radiator ( $U$ ) = 500 w/m<sup>2</sup>.C
- Density of air ( $\rho_{\text{air}}$ ) = 1.225 kg/m<sup>3</sup>
- Density of water ( $\rho_{\text{water}}$ ) = 1000 kg/m<sup>3</sup>

### Equations to be used:

- Equation 1: Heat Required  $Q_{\text{max}} = C_{\text{min}} (T_{\text{w. in}} - T_{\text{air. in}})$
- Equation 2: Number of Transfer Units (NTU) =  $\frac{U \times ((\pi D) \times L)}{C_{\text{min}}}$
- Equation 3: The actual heat required =  $Q_{\text{act}} = \epsilon Q_{\text{max}}$
- Equation 4: temperature of the radiator's water =  $T_{\text{w. out}} = T_{\text{w. in}} - \frac{Q_{\text{act}}}{4.19 \text{ m.w}}$

### **4.1.1 for the optimum angle (10° BTDC)**

*From using the following Equations*

- Eq1  $Q_{max} = 28.251 \text{ kw}$
- $C_{min} = 2404.3 \text{ w/k}$  ,  $C_{max} = 3072.527 \text{ w/k}$ ,  $\frac{C_{max}}{C_{min}} = 0.783$
- Eq2  $NTU = 0.13327$  , using NTU method we get the effectiveness ( $\epsilon$ ) = 30% x correction of fins (3) = 90%
- Eq3  $Q_{act} = 25.426 \text{ kw}$
- Eq4  $T_{w. out} = 38.47^\circ\text{C}$

### **4.1.2 For the Advanced angle (12° BTDC)**

*From using the following Equations*

- Eq1  $Q_{max} = 21.639 \text{ kw}$
- $C_{min} = 2404.3 \text{ w/k}$  ,  $C_{max} = 3072.527 \text{ w/k}$ ,  $\frac{C_{max}}{C_{min}} = 0.783$
- Eq2  $NTU = 0.13327$  , using NTU method we get the effectiveness ( $\epsilon$ ) = 30% x correction of fins (3) = 90%
- Eq3  $Q_{act} = 19.475 \text{ kw}$
- Eq4  $T_{w. out} = 37.66^\circ\text{C}$

### **4.1.3 For the Retard angle (7° BTDC)**

*From using the following Equations*

- Eq1  $Q_{max} = 36.762 \text{ kw}$
- $C_{min} = 2404.3 \text{ w/k}$  ,  $C_{max} = 3072.527 \text{ w/k}$ ,  $\frac{C_{max}}{C_{min}} = 0.783$
- Eq2  $NTU = 0.13327$  , using NTU method we get the effectiveness ( $\epsilon$ ) = 30% x correction of fins (3) = 90%
- Eq3  $Q_{act} = 33.0858 \text{ kw}$
- Eq4  $T_{w. out} = 45.6^\circ\text{C}$

## 4.2 Gas Emissions Calculation

The second step for our testing is to analyze the exhaust gas emissions. We used sets of equations to help us find the percentage of each gas coming out of the exhaust. We did the same steps for the three different ignition timing (angle) 7, 10, and 12 BTDC.

### Given Data:

- At 12° BTDC, %CO = 6%
- At 10° BTDC, %CO = 5%
- At 7° BTDC, %CO = 4%

### Equations to be used:

Eq1: Combustion reaction,  $C_8H_{18} + a(O_2+3.76N_2) \rightarrow bCO_2+dCO+eH_2O +fN_2$

From the combustion reaction equation, we obtain the following sets of equations:

- Eq2:  $\%CO = \frac{d}{b+d+e+f}$
- Eq3: C:  $8 = b + d$
- Eq3: H:  $18 = 2e \rightarrow e = 9$
- Eq4: O:  $2a = 2b + d + e$
- Eq5: N:  $f = 3.76 a \rightarrow f = 1.88 (2b + d + 9)$
- Solving for **d** gives us
- Eq6:  $d = \frac{\%CO \cdot 64}{1+(1.88 \%CO)}$
- Eq7: Equivalent Ratio ( $\emptyset$ ) =  $\frac{\left(\frac{A}{F}\right)_{actual}}{\left(\frac{A}{F}\right)_{ideal}}$  (Notice: When  $\emptyset > 1$  its Rich Mixture =

Less Air, When  $\emptyset < 1$  its lean mixture = more air)

### ***4.2.1 For the Advancing angle (12° BTDC)***

**From using the following equations**

- Eq6: **d**=3.4507 mole
- Eq3: **b**=4.549 mole
- Eq5: **f**= 40.512 mole
- Eq5: **a**= 10.7745 mole
- Eq4: **e**= 9 mole
- Eq7:  $\emptyset = 6.2869$

### The percentage of gases

- $\%CO_2 = \frac{b}{b+d+e+f} = 7.91\%$
- $\%CO = 6\%$
- $\%H_2O = \frac{e}{b+d+e+f} = 15.65\%$
- $\%N_2 = \frac{f}{b+d+e+f} = 70.44\%$

### 4.2.2 for the optimum angle (10° BTDC)

#### From using the following equations

- Eq6:  $d=2.8756$  mole
- Eq3:  $b=5.1244$  mole
- Eq5:  $f= 41.5939$  mole
- Eq5:  $a= 11.0622$  mole
- Eq4:  $e= 9$  mole
- Eq7:  $\emptyset = 6.45479$

### The percentage of gases

- $\%CO_2 = \frac{b}{b+d+e+f} = 8.75\%$
- $\%CO = 5\%$
- $\%H_2O = \frac{e}{b+d+e+f} = 15.36\%$
- $\%N_2 = \frac{f}{b+d+e+f} = 70.99\%$

### 4.2.3 For the Retard angle (7° BTDC)

#### From using the following equations

- Eq6:  $d=2.3809$  mole
- Eq3:  $b=5.6191$  mole
- Eq5:  $f= 42.5239$  mole
- Eq5:  $a= 11.3096$  mole
- Eq4:  $e= 9$  mole
- Eq7:  $\emptyset = 6.5992$

### The percentage of gases

- $\%CO_2 = \frac{b}{b+d+e+f} = 9.44\%$
- $\%CO = 4\%$
- $\%H_2O = \frac{e}{b+d+e+f} = 15.12\%$
- $\%N_2 = \frac{f}{b+d+e+f} = 71.44\%$

## 4.3: Overall Results, Analysis and Discussion

Table: 4.1. Data collected from i100, and the theoretical calculation showing ignition angle, and coolant temperature

BTDC	Tw out predicted (C°)	Tw out measured (C°)
7	39.522	45.6
10	38.47	37.2
12	37.66	34.4

The Tw out predicted (C°) was calculated using formulas explained in the previous section of this chapter, where the measured (C°) was calculated using the i100 which is a device that measures the temperature going in to the radiator, as well as the temperature leaving the radiator in various ignition angles giving a clearer comparison between ignition angle, and Tw out. The measured data is given via the built in thermo couples of the engines radiator thus giving an accurate reading.

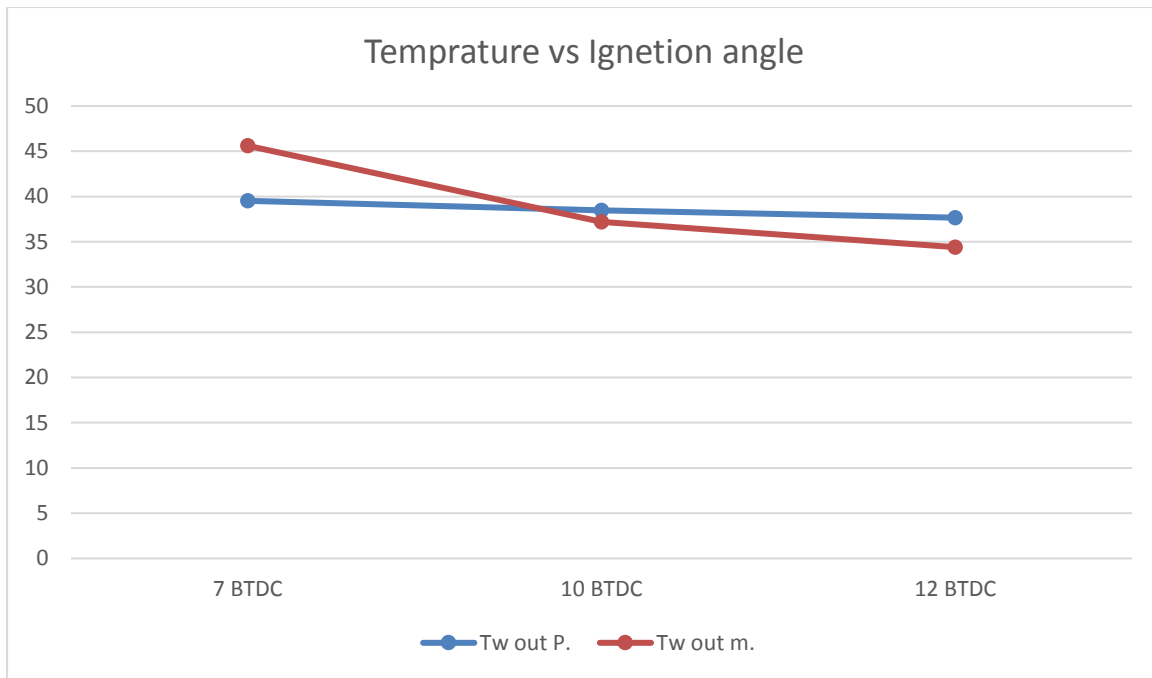


Figure: 4.1. Temperature leaving the radiator for both theoretical and measured in three different angles

As shown in figure 4.1 the most affective angle or (optimum angle) in the case of heat change in the radiator coolant the data shows that the optimum angle would be at 12°, at 12° degrees the temperature of the coolant leaving would be at 34.4 C°.

Table: 4.2. Gas analyses of exhaust emissions using the HG-510 at different angles

BTDC	$\phi$	CO <sub>2</sub> (%)	CO (%)	H <sub>2</sub> O (%)	N <sub>2</sub> (%)
12	6.2869	7.91	6	15.65	70.44
10	6.45479	8.75	5	15.36	70.99
7	6.5992	9.44	4	15.12	71.44

The table 4.2 shows the percentage of each gas emitted from the engines exhaust for the three different angles, that being said the gas the effects the ecosystem with a negative impact is the carbon emissions, it also indicates that lowest amount of carbon released is when the ignition angle is 12° BTDC thus making it the most suitable angle.

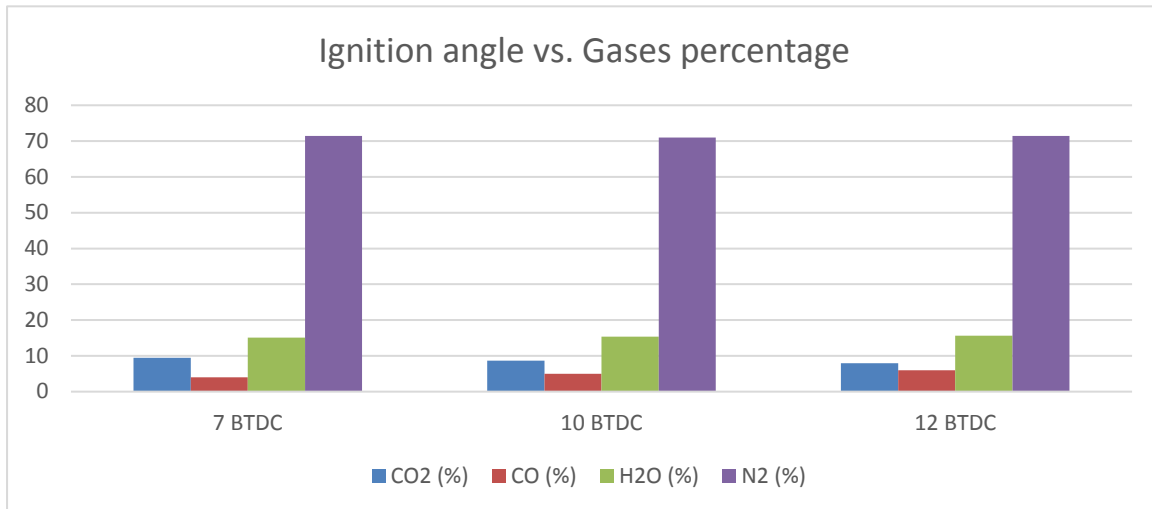


Figure: 4.2. Ignition angle vs. gas emissions percentage

As shown in Figure: 4.2 the variation of gasses within the changing of ignition angle for the engine. However, the more advancing on the ignition angle the more Carbon Oxide increase and Carbon Dioxide decrease and vice versa. On the other hand, Nitrogen and water moisture will remain the same with very small percentage changing.

## Chapter 5: Project Management

### 5.1 Project Plan:

Having a plan for the project is very important steps towards completing the project. In our group we first nominated a team leader, and then we began distributing the project into several tasks. Each task had a deadline to complete, and the team members were very flexible and followed the project timeline. However, three important aspects were taken into consideration in this plan; Project time management, meeting the project design and objectives, over all high efficiency of the project.

*Table 5.1: Shows the implementation plan regarding time, task, and description.*

Week	Main Task	Description
1-2	Project design stage #1	First design draft. Starting the first bill of material specification of the parts
2	Market Survey	Market survey for different specification following the bill of material. Also looking of in consideration availability, price, and quality
3	Project design stage #2	Second design draft using the result of survey. Come up with some alternatives.
3	Virtual design	Designing the solid work.
3	Final design stage	Writing the final bill of material with the needed specification.
4-5	Purchasing parts	Collecting the budget and Purchasing all the required parts.
6	Manufacturing the Holder	The holder was the main body that where all the parts built on.
7-8	Installing the engine	Installing the engine and all parts and belongings on the body holder using appropriate iron beams.
8	Installing the radiator, Gasoline tank	Full installation of the radiator and gasoline tank on the holder with fabrication on the holder.

8-10	Completing Installation	Completing all installation stage with electric wires, battery, and iPad monitor for result testing.
11	Starting data collection	First full engine test with gathering reference data for our engine system by testing the normal gasoline with same fixed ignition angle.
12	Collecting data stage #1	Collecting data for our tests and analysis discussion.
12	Adjusting the ignition angle	Adjusting ignition angle considering variation in result.
12	Collecting data stage #2	Collecting data after Adjusting ignition angle.
12	Data analysis	Comparing the two stages of the data collections. Study the effect of adjusting the ignition angle in the engine in order of behavior to the overall performance.
12	Finalizing the final report	Finishing the calculation and finalizing the presentation.

## 5.2 Contribution of Team Members:

In Table 5.2 All team members had a positive impact on completing the project. Each member delivered/completed his tasks on time. Below is the table shows all the contribution from members.

Table 5.2: Task

<b>Task</b>	<b>Ibrahim AlAbdullhadi</b>	<b>Mushari Al-Harbi</b>	<b>Ali Al-Rahdi</b>	<b>Abdullah Al-Bassri</b>	<b>Majed Al-Otaibi</b>
<b>Design</b>	100%	70%	60%	60%	60%
<b>Market survey &amp; parts purchasing</b>	100%	80%	60%	60%	60%
<b>Building the system</b>	100%	70%	60%	60%	60%
<b>Oral presentation &amp; complete literature review and first progress report</b>	50%	100%	100%	100%	100%
<b>Testing</b>	100%	100%	100%	100%	100%
<b>Second progress report</b>	100%	100%	100%	100%	100%
<b>Finalize thesis writing, poster, project PowerPoint and summary document for publication.</b>	100%	100%	100%	100%	100%

### 5.3 Project Execution Monitoring:

- **Meetings:**

We met on weekends and we divide the tasks between each other. Our group met with Dr.Esam on weekly basis, to discuss what we have accomplished so far on the project, and if we needed any feedback.

- **Testing:**

The time for testing was very challenging due to early final exams changing period. Also, we had planned to take different readings to make sure the testing accurate as we could.

## **5.4 Challenges and Decision Making:**

- **Engine**

We had to search at the scrapyards in Al-hassa Road around 66 Km far from our homes. However, finding the good working engine regarding our limited budget was very hard and time consuming. Moreover, another consideration was taken into account that purchasing only an engine will have further fabrication and wiring connection process, which indeed more time and money spending beyond our budget limit.

- **Engine Mounts**

Engine mounts are highly important to carry the engine and hold it. However, spare part shops were completely not very cooperative with the student. So, we had to visit 17 spare shops looking for specific mounts that can hold the engine. Finally we used Toyota mounts to hold Mitsubishi engine.

- **Steel Engine Stand**

Three manufacturing areas were visited in Dammam to design an appropriate steel holder for the engine. Most of the shops had no time to do our stand but within two weeks of searching we found one shop to do our stand in 10 days.

- **Engine Belongings Fabrication**

We had to start from the zero to get the engine work perfectly without any errors. However, we had to fabricate the cam shaft to an external beam to make the ignition key stable to start up the engine. And we had to insert a 4 mounts on the stand to stabilize the engine. Also, engine cooling system was taken to consider which include two fans and radiator in front for the water cooling system. We had connected the gasoline tank below the engine with tubes connection to the engine. Furthermore, we filled the tank with 30 Liter gasoline and we checked the oil inside the engine and changed it. We had to buy a new battery for the engine because the actual battery for the car has been broken. We connect all the wires with the car computer dash board and a lot of wires and needed fabrications and checking. Each day we had to go to the scrapyard and repair shops to collect parts and fabricate it to our tested engine to make the testing accurate as we can.

- **Engine Transportation**

Engine was very heavy and we couldn't easily move it to each shop for designing the stand. Furthermore, taking the engine, radiator, gasoline tank, and belongings from scrapyard to Ibrahim house was very risky due to police rules on roads because we connected the car with rear small cart to carry the engine to Ibrahim home, permission has to be taken from police to do similar action.

## 5.5 Project Bill of Materials and Budget

Table 5.3: Bill of Materials and Cost

Part Number	Part Name	Quantity	Cost (SR)
1	Engine	1	3500
2	Engine Stand	1	1650
3	Paints	1	55
4	Engine Mounts	4	120 (30 each)
5	Gas Sensor	1	350
6	Radiator	1	150
7	Radiator's Water	1	20
8	Batteries	1	130
9	Gasoline Tube Welding	1	50
10	Exhaust Tube	1	60
11	Fuse Box	1	450
12	Engine Oil	1	80
13	Labor	1	1550
<b>Total Cost</b>			8165SR

As shown in table 5.2, the overall cost is 8000SR, which was a little bit higher than our expected cost (7500SR). Since we are all full time students we had a limited budget, to satisfy it and not go too much above it, we had to put extra work to search for cheaper engine, equipment, and labor.

## Chapter 6: Project Analysis

### 6.1 Life-long Learnings:

- ❖ Skills: Team management while working on the project, leadership, research and interpretation of data collected, finding alternative solutions, tracking costs and budgets, trial and error process. Using CAD to render the prototype in 3D, and finally time management by help of Gantt-charts.
- ❖ New devices: Taco meter, car engine as well as its computer and wiring, gas emissions reader (VENTIS MX4), and the iPad simulated dashboard program, and the electric motor.
- ❖ Tools & search engines to find information: research articles, and journals (*Performance Evaluation of a Small-Scale Turbojet Engine Running on Palm Oil Biodiesel Blends, and Sensitivity and Effect of Ignition Timing on the Performance of a Spark Ignition Engine: An Experimental and Modeling Study*), as well as some scientific research engines such as (Google scholar).
- ❖ Software used: Solid works, and dashboard simulator, Gantt chart.

### 6.2 Impact of Engineering Solution:

This research has the main idea of using an alternative source of fuel combined with the already used standard fuel, and achieve as less as possible losses from engine performance, and efficiency, that is by increasing the overall efficiency of the engine after it drops due to usage of biofuel by finding the optimum ignition timing for the given particular biofuel, that being said when that is achieved it would be great for the environment as biofuels emits far less greenhouse gases the standard petroleum based fuels, this is indeed needed in time of strong increase in global warming, and air pollution in general.

### **6.3 Contemporary Issues Addressed:**

As the population of the world increases, as well as the demands of living increase in the Kingdom of Saudi Arabia so does the number of cars increase on the day to day basis, this increase will show huge spike in gas emissions, as result this could affect the environment and have its negative impact, the study shows that the use of biofuel could help in decreasing that impact, and there are a lot of other ways to approach this problem this could help aid that goal.

## **Chapter 7: Conclusion and Future Recommendation**

### **7.1 Conclusion:**

Our project is to perform an experiment on a four-cylinder engine by changing the ignition timing to different variables. Our experiment and results showed that a wide range of variables change with the ignition timing, we found that the optimum angle was 12 BTDC, because it had the least radiator temperature and exhaust gas emissions. From the data we obtained, we found that there is a relationship between the ignition timing, the temperature of radiator, and exhaust gas emissions. With the increase of ignition timing, the temperature of radiator and exhaust gas emission decreases.

### **7.2 Future Recommendation:**

Due to the limited time we had in this course, we couldn't perform a full testing in some of the variables that affected from changing ignition timing, such as: power, and efficiency of the engine. If someone is interested in conducting a similar experiment, we recommend putting a high budget and a lot of time. Some of the sensors cost a lot, and we suggest searching for alternatives and setting a good budget. Using a new technology to measure the data such as computer and testing lab, to get a better and more accurate results.

In the previous semester we took a course of mechanical engineering design II, that having a Automatic Control System which all the real life experiments are simulated through LABVIEW program. Moreover, having our Senior Project engine simulated in the program at the LAB will make the testing and feedback much more valuable. A lot of my friends who are studying at deferent universities are all working on their senior projects inside the university. I hope future student of Prince Mohammed Bin Fahd could work on their senior projects inside the University.

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## Appendix A: Progress Reports

### Month 1: February

ID Number	Member Name
201101256	Ibrahim AlAbdulhadi
201100959	Mushari AlHarbi
201100716	Majed AlOtaibi
201101315	Ali AlRadji
201103049	Abdullah Bassri

List the tasks conducted this month (February) and the team members assigned to conduct these tasks

#	Task description	Task's Champion	Progress 0%-100%	Delivery proof
1	Search for engine	Ibrahim & Abdullah	100%	Picture of the Engine
2	Acquisition the Engine	Ibrahim & Mushari	100%	Picture of the Engine in our car
3	Design stand for engine by AutoCAD	Mushari	100%	Send it to group members
4	Write the Abstract and Acknowledgment	Majed	100%	Send it to group members

### Month 2: March

ID Number	Member Name
201101256	Ibrahim AlAbdulhadi
201100959	Mushari AlHarbi
201100716	Majed AlOtaibi
201101315	Ali AlRadji
201103049	Abdullah Bassri

List the tasks conducted this month (March) and the team members assigned to conduct these tasks

#	Task description	Task's Champion	Progress 0%-100%	Delivery proof
1	Fabricating a stand for the engine	Ibrahim	100%	Invoice
2	Delivering the engine to the lathe shop	Ibrahim	100%	Video
3	Delivering the radiator to lathe shop	Mushari	100%	Picture
4	Checking for leakage in the radiator and searching for skilled electrician	Ali	50%	Picture
5	Start assembling the engine in the stand	Ibrahim	100%	Picture
6	Looking for new engine mountings	Ibrahim & Mushari	100%	Invoice

**Month 3: April**

ID Number	Member Name
201101256	Ibrahim AlAbdulahadi
201100959	Mushari AlHarbi
201100716	Majed AlOtaibi
201101315	Ali AlRadji
201103049	Abdullah Bassri

List the tasks conducted this month (April) and the team members assigned to conduct these tasks

#	Task description	Task's Champion	Progress 0%-100%	Delivery proof
1	Deliver Engine to Ibrahim's home	Ibrahim & Abdullah	100%	Picture
2	Searching for electrician	Ibrahim	100%	Invoice
3	Searching for temperature sensor	Abdullah	50%	Picture
4	Searching for gas sensors	Ibrahim	100%	Picture
5	Writing chapters 1,2	Mushari & Majod	100%	Email
6	Writing chapter 3	Ali & Abdullah	100%	Email
7	Searching for biofuel	Ali	50%	Picture
8	Preparing for the Mid presentation	All the team	100%	Presentation

**Month 4: May**

ID Number	Member Name
201101256	Ibrahim AlAbdulahadi
201100959	Mushari AlHarbi
201100716	Majed AlOtaibi
201101315	Ali AlRadji
201103049	Abdullah Bassri

List the tasks conducted this month (May) and the team members assigned to conduct these tasks

#	Task description	Task's Champion	Progress 0%-100%	Delivery proof
1	Changing the ignition timing (3 angles)	Ibrahim	100%	Pictures
2	Monitoring the effects of changing the ignition timing (temperature, exhaust emission)	Ibrahim	100%	Picture and report
3	Calculate the effects of changing the ignition timing	Mushari & Ibrahim	100%	Report
4	Writing chapter 4	Abdullah & Majed	100%	Email
5	Writing chapter 5	Majed & Mushari	100%	Email
6	Writing chapter 6	Ali & Abdullah	100%	Email
7	Writing chapter 7	Majed	100%	Email
8	Making a brochure, roll-out Poster	Ali	100%	Print out
9	Printing the report as book form	Ali	100%	Print out
10	Delivering the engine to the University	Ali	100%	Picture
11	Final presentation	All Group	100%	Presented
12	Reviewing the final report	Ibrahim	100%	Email
13	Collecting all papers in portfolios	Mushari	100%	Deliver it

## Appendix B: Bill of Material

Table B.1: Bill of Material for Senior Project

Part Number	Part Name	Quantity	Cost (SR)
1	Engine	1	3500
2	Engine Stand	1	1650
3	Paints	1	55
4	Engine Mounts	4	120 (30 each)
5	Gas Sensor	1	350
6	Radiator	1	150
7	Radiator's Water	1	20
8	Batteries	1	130
9	Gasoline Tube	1	50
	Welding		
10	Exhaust Tube	1	60
11	Fuse Box	1	450
12	Engine Oil	1	80
13	Labor	1	1550
14	Brochure	40	120
15	Roll Up	1	200
16	Leather Report	3	300
<b>Total Cost</b>			<b>8,785.00SR</b>

## Appendix C: Datasheets

Table C.1: Calculations of the radiator water

BTDC	Q max (Kw)	Q actual (Kw)	Tw out predicted (C°)	Tw out measured (C°)
<b>7</b>	36.762	33.0858	39.522	45.6
<b>10</b>	28.251	25.426	38.47	37.2
<b>12</b>	21.639	19.475	37.66	34.4

Table C.2: Calculation of the radiator water out compared with the measured values

	Tw out predicted (C°)	Tw out measured (C°)
<b>7</b>	39.522	45.6
<b>10</b>	38.47	37.2
<b>12</b>	37.66	34.4

Table C.3: Calculations of coefficient of the different gasses

BTDC	Co (%)	a	b	d	e	f
<b>12</b>	0.06	10.7745	4.549	3.4507	9	40.512
<b>10</b>	0.05	11.0622	5.1244	2.8756	9	41.5939
<b>7</b>	0.04	2.3809	5.6191	2.3809	9	42.5239

Table C.4: Percentages of gasses from the exhaust

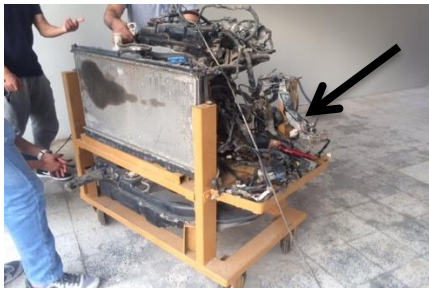
BTDC	Ø	CO2 (%)	CO (%)	H2O (%)	N2 (%)
<b>12</b>	6.2869	7.91	6	15.65	70.44
<b>10</b>	6.45479	8.75	5	15.36	70.99
<b>7</b>	6.5992	9.44	4	15.12	71.44

# Appendix D: Operation Manual

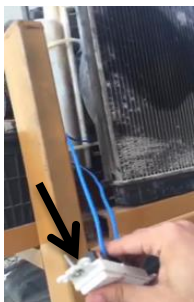
1- Check Oil Level and Radiator Water



2- Wire Connections to Battery, and Radiator Fans



3- Start up Radiator Fans



4- Engine Start up

