Investigation of Multi-cylinder Diesel Engine Performance and Emission Using Bio-diesel Fuel

by

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Dissertation submitted in partial fulfilment of
the requirement for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Proramme
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Approved by,

(Dr. Chalillullah Rangkuti)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
June 2004

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

MUHAMMAD EFFIRDAUS BIN ABDUL HAKIM

ABSTRACT

This final report is written to compile all the progress and activities conducted since the initial stage of this final year project. The project; Investigation of multi-cylinder diesel engine performance and emission using bio-diesel fuel, had been carried out based on initial plan.

This report would explain the background of the project and understanding to the significant of continuing the project. It would define the problem statement and what to be solved by the end of this project. The identification would be crucial as it would guide where this project is heading to. The main objective of this project would be in studying the effects of using bio-diesel to run the normal diesel engine. The ultimate goal would be decrease the dependency on the hydrocarbon fuels and having other alternatives.

The next part of the report will state the fundamental idea of understanding the project by explaining related information in the theory section. Understanding of how the engine works and the fuel being used is important in assuring the completion of this project. The report also explains how this project would be carried out and what is going to be found as the result. Methodology of how this project will illustrate the basic idea how the project is going to be conducted.

Some findings of done research were discussed in the report. Understanding the results will assist student in completing the project. Most of the findings are related to the understanding of the engine and familiarization to the interested parameters of engine performance and emission. May the report is beneficial as concluding this final year project and all assists and guidance are highly appreciated.

ACKNOWLEDGEMENT

This study would not have been possible without the assistance and guidance of certain individuals and organizations whose contribute in completion of this project.

First of all and most importantly, I would like to record my sincere thanks and appreciation to the project supervisor, Dr. Chalillullah Rangkuti, for his guidance and valuable input throughout the completion of this study.

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Not to be forgotten an appreciation to all Mechanical Department technicians that helped in assisting this project especially to Mr. Fahmi and Mr. Zailan. The time and effort contributed are highly appreciated.

And I would like to give my best wishes of appreciation to my parents and my thanks to all individual who had contributed to this project in one way or another but have been inadvertently not mentioned.

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CHAPTER 1
INTRODUCTION

1.1 Background

Diesel engine was designed by Rudolph Diesel in the 1890s. Diesel engine is operates by using diesel as the fuel. The engine operation is similar like spark-ignition engine that run by using gasoline as the fuel. The different is mainly in the method of initiating combustion. In diesel engine, the air is compressed to a temperature that above the auto-ignition temperature of the fuel. The combustion starts on contact as the fuel is injected into the hot air.

The diesel engine can operate at higher compression ratio and run on less refined fuel. Diesel engine is widely used in industries and automotive as its capability to produce high power and offering higher engine efficiency. This project will focus on using bio-diesel fuel to investigate the multi-cylinder diesel engine emission and performance.

This project would be as a basic ground to study the related factors of operating a diesel engine by an alternative fuel. The significant of this project is to find the required solution of the stated problem and to have a better engine running on a bio-diesel fuel.

This project would require student to be good in internal combustion engine and expose student to a real engineering problem. This project would be a good basis for student to relate the theoretical knowledge of combustion to a real problem.

1.2 Problem Statement

The engine is running on a diesel coming from the distillation of petroleum crude oil. The engine is highly depending on the petroleum resource that is decreasingly available. It is projected that in a few coming decades, world would face a serious petroleum

resources and the increasing price of petroleum based fuels. It is important to get prepared and doing a research to find an alternative fuel or renewable source of fuel.
This project would study how biological source can replace the diesel as fuel, knowing as biodiesel. The project would choose palm oil methyl ester (POME) as the bio-diesel. It is interested to examine what is the best condition of biodiesel to be used. Can a palm oil completely replace the diesel or require a mixture with diesel. So another interesting factor to be determined is what would be the best mixture of these two fuels would give out the best result.

The second constraints of diesel engine is the concerning factor of environment. The emission of today engines should be monitored as the diesel combustion had affected the environment ad highly contributes to air pollution. This project would find method to decrease the hazardous effect by manipulating any important parameters related to internal combustion engines.

The two major parameters of this project would be the engine performance and emission of the combustion.

1.3 Objectives

The objectives of this project are:

1. To investigate the performance and emission of multi-cylinder diesel engine running on palm oil as fuel.

2. To study an alternative fuel to be used by a diesel engine. Ultimate goal of the project is to completely replace the diesel with palm oil fuel (biodiesel fuel).

3. To study the feasibility of the fuel replacement and to find what mixture of diesel fuel and biodiesel to be used for desired performance and engine emission.

4. To investigate any probability of reducing the environmental pollution by using fuel from agriculture resource.

1.4 Scope of Study

The study will be conducted to find the required solution to meet the objectives. The scope of this project:

1.4.1 Understanding the internal combustion engine

Student should know how the engine operates in order to be able in manipulating the knowledge to complete the project. The study would focus on diesel cycle engine and the operation of the engine by using other type of fuel.

There are many factors that influent the way of an engines work. It would depend on the construction and the design of the engine. A diesel engine is highly dependent on the fuel injection methods that affect the way fuel will be burned. Combustion characteristic would then affect the performance and emission of the engine.

1.4.2 Understanding the characteristic of the selected fuel

It is important to have knowledge upon the characteristic of the selected fuel. Each different fuel would demonstrate different result in emission and performance. Diesel and palm oil came from totally different source. Both have different characteristic but are suitable to be used as fuel.

The project would be interested to see how palm oil can replace diesel with no engine modification as the best intention. The project would also study the effect of blending these two fuels as a mixture. At what composition of fuels it would turn out as the best fuel characteristic to be used for the engine.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2. LITERATURE REVIEW AND THEORY

Before the project being continued to experiment phase, there were a lot of information findings conducted. It covers the reading through some other projects regarding bio-diesel as a literature review. Some studies were also conducted regarding the theory of combustion to understand what are performance, emission and the difference between diesel and bio-diesel.

2.1 Literature Review

Bio-diesel had attracted many scientists all over the world as an interesting fuel to be studied. There are many researches conducted to study and investigate the feasibility of replacing diesel with bio-diesel to run the normal diesel engine. In fact, the first diesel engine designed by Rudolf Diesel in 1890s was only running by using peanut oil.

Dr Evita Legowo, Director of Research and Development Center for Energy and Electricity Technology, Indonesia, had conducted a test of using the palm oil as the bio-diesel; to run a normal diesel engine. The result had turned out that palm oil is capable to replace the diesel.

Gumpon Parteepchaikul from Prince of Songkla University, Thailand, had also conducted the similar experiment. But the experiment concerned more on fuel consumption. The experiment concluded that the engine consume more fuel when running on palm oil.

Malaysian Palm Oil Board (MPOB) also had conducted several experiments to prove that palm oil is feasible to replace the normal palm oil. Recently, Dr Choo Yuen May from the board had successfully developed a palm oil mixture that has lower freeze temperature. This is important to ensure the fuel remain as fluid at low temperature especially for those low temperature climate countries. The research would assist in having a better palm oil fuel to be used as diesel engine.

This project would be conducted to investigate the performance and emission of multi-cylinder engine using the palm oil methyl ester as the fuel. The project would determine the required methodology of conducting the experiments. And as stated earlier in the report, this project will study the feasibility of the fuel replacement and to find what mixture of diesel fuel and biodiesel to be used for desired performance and engine emission.

2.2 Theory

2.2.1 Diesel Engine

Diesel engine was designed to have an engine with higher efficiency. It runs on diesel which is different from gasoline. Diesel has higher temperature of self ignition which allow diesel engine to have higher compression ratio. The diagram shows the layout of average diesel engine.

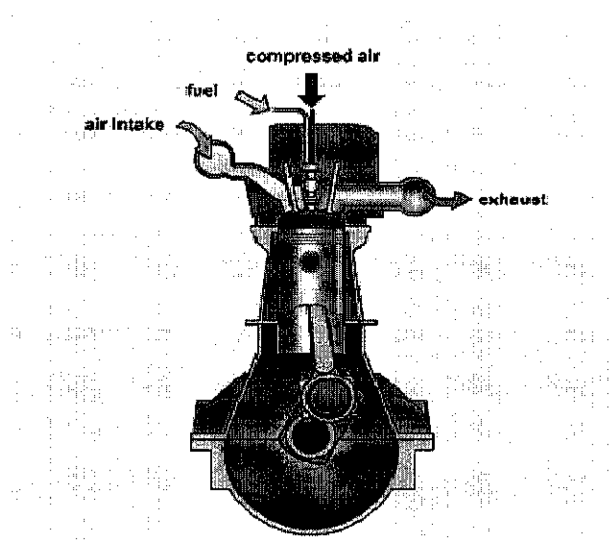

Figure 1: Layout of average diesel engine

Note from the following figure that the diesel engine has no spark plug, that it intakes air and compresses it, and that it then injects the fuel directly into the combustion chamber known as direct injection. It is the heat of the compressed air that lights the fuel in a diesel engine.

Diesel cycle is executed in a piston cylinder device, work as a closed system. The heat transferred to the working fluid at constant pressure and rejected at constant volume. P-v diagram would illustrate the relationship of pressure and specific volume of the cycle. This diagram would be noted with points that could be related to the cycle of diesel engine.

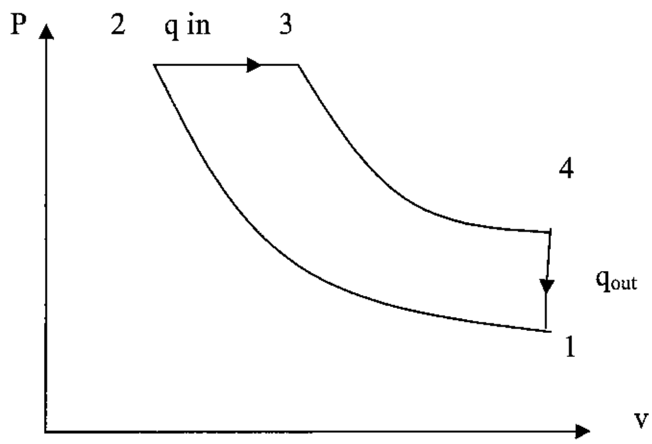

Figure 2: P-v diagram of diesel cycle

Process 1-2: Isentropic compression

Process 2-3: Energy in

Process 3-4: Isentropic expansion

Process 4-1: Energy out

Energy in

$q_{in} - w_{b,out} = u_3 - u_2$

$q_{in} = P_2 (v3 - v2) + (u3 - u2)$

$= h3 - h2 = Cp\ (T3 - T2)$

Energy out

$- q_{out} = u1 - u4$

$q_{out} = u4 - u1 = Cv\ (T4 - T1)$

Cp – specific heat at constant pressure
Cv – specific heat at constant volume

* from *Thermodynamics, An Engineering Approach*

The engine is also influent by the compression ratio. This ratio represents the ratio of maximum volume of combustion space to the minimum volume.

Compression ratio, r = Vmax / Vmin

*from *Internal Combustion Engine Fundamentals,*

Compression ratio could determine the efficiency of the engine. Diesel engine would have higher efficiency compared to Otto cycle (gasoline). Otto cycle is limited to lower compression ratio due to auto-ignition of gasoline fuel.

As the ratio increase, the pressure would increase thus increase the temperature. This high temperature can ignite gasoline resulting premature ignition of the fuel. It is called as auto-ignition, produces an audible sound, which is called engine knock that can reduce performance and cause engine damage.

Compared to Otto cycle, Diesel cycle only compress air, thus eliminating any possibilities of auto-ignition. The engine would go for high compression ratio, normally between 12 and 24. No auto-ignition constraints would allow the engine to use less refined fuel. And this is why biodiesel fuel would be feasible to replace diesel as fuel.

2.2.2 Diesel Fuel

Diesel fuel is heavier and oilier. Diesel fuel evaporates much more slowly than gasoline and its boiling point is actually higher than the boiling point of water. It contains more carbon atoms in longer chains than gasoline does (gasoline is typically C_9H_{20}, while diesel fuel is typically $C_{14}H_{30}$). It takes less refining to create diesel fuel, which is why it is generally cheaper than gasoline.

Diesel fuel has a higher energy density than gasoline. On average, 1 gallon (3.8 L) of diesel fuel contains approximately $155x10^6$ joules (147,000 BTU), while 1 gallon of gasoline contains $132x10^6$ joules (125,000 BTU). This, combined with the improved efficiency of diesel engines, explains why diesel engines get better mileage than equivalent gasoline engines.

2.2.3 Bio-diesel Fuel

This project would study how to run a diesel engine by using alternative fuel such as bio-diesel. Palm oil will be the first choice to be tested as it is already available in the laboratory. Bio-diesel normally comes from agricultural product and had been studied on how this product can be used as fuel for internal combustion engine.

Chemically, it is a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. It is produced by a chemical process (transesterification) which removes glycerol from the oil. Biodiesel is nonflammable and nonexplosive (flash point 150°C for biodiesel and 64°C for petrodiesel) . It is biodegradable and nontoxic

Bio-diesel is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant greases. Bio-diesel is safe, biodegradable, and reduces serious air pollutants such as particulates, carbon monoxide, hydrocarbons, and air toxics. Blends of 20% bio-diesel with 80% petroleum diesel (B20) can be used in unmodified diesel engines, or bio-diesel can be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems.

Theoretically, using bio-diesel in a conventional diesel engine substantially reduces emissions of unburned hydrocarbons, carbon monoxide, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter. These reductions increase as the amount of bio-diesel blended into diesel fuel increases. The best emissions reductions are seen with B100.

2.2.4 Fuel Characteristic

To replace diesel, it is important to find a fuel with close characteristic with diesel fuel. Based on research, biodiesel has physical properties that make it possible to replace conventional diesel.

Table 1: Properties of diesel and palm oil as fuel

Properties of diesel and palm oil as fuel		
Fuel properties	Diesel	Palm oil
Cetane number	49 (min)	50
Specific gravity	0.84	0.92
Carbon residue	<0.001	0.217
High heating value (MJ/kg)	44.3	39.3
Sulphur (wt %)	0.05 (max)	0.0 to 0.0024
Flashpoint	55 (min)	>300

* from http://journeytoforever.org

The quality of engine combustion depends on the cetane number of the fuel. The number indicates how readily the fuel self-ignites. Another important factor would the flashpoint and its heating value.

It is a target to use palm oil on the diesel engine and have a performance that can match diesel. Besides performance, emission would also be a considered factor. Theoretically, using biodiesel in a conventional diesel engine substantially reduces emissions of unburned hydrocarbons, carbon monoxide, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter. A study would be done to understand how the fuel properties would affect the combustion and engine performance.

2.2.5 Effect of Fuel Properties to Performance and Emission

It is important to understand the properties of the fuel. The properties would directly affect the combustion and performance of the engine. Study on fuel properties is important as a way to ensure that biodiesel is competence enough to replace diesel.
Some properties to take into account:

i) Density

Density is a measure of the fuel's mass per unit volume. Variations in fuel density can result in variations in the energy content of the fuel injected into an engine. Consequently, engine power, emissions and fuel consumption may be affected. A narrower density range allows more efficient fuel consumption, better engine performance and reduced emissions.

Current regulation:
Density at 15°C: 810 kg/m^3 minimum; 860 kg/m^3 maximum

ii) Cetane number

Cetane number is a measure of how easily diesel fuel ignites in an engine. The higher the cetane number, the shorter the delay period from the start of fuel injection to the start of combustion. This result is smoother combustion, lower engine noise, and improved starting, particularly in cold conditions. Current regulation of minimum cetane number is set as 45.

iii) Sulphur content

Sulphur occurs naturally in crude oils and must be removed to an acceptable level during the refining process. Sulphur in diesel contributes to the formation of particulate matter, a component of engine exhaust that is linked to health problems.

Sulphur also degrades the performance of vehicle emissions-control equipment. The current European requirement is a limit of 350 parts per million (ppm) of sulphur in diesel.

iv) Viscosity

Viscosity is a measure of the fuel's resistance to flow. High viscosity can reduce fuel flow rates resulting in insufficient fuel flow. Low viscosity will increase leakage from fuel pumps, can increase engine wear and may result in hot starting difficulties.

Therefore, good control of viscosity is critical to the optimum performance of diesel fuel pumps and fuel injection systems.

v) Flash points

Flash point is the lowest temperature at which enough vapor has combined in the air above a liquid that it will ignite when exposed to a flame. Flash point is a measure of both volatility and flammability. It is important primarily from the standpoint of safe handling and storage of fuel.

2.2.6 Performance

There are a few criteria that determine the engine performance. And some of the criteria are listed below.

i. Brake Horse Power and Torque
ii. Brake Mean Effective Pressure (BMEP)
iii. Mechanical Efficiencies
iv. Fuel consumption

Torque could be measures as an engine's ability to do work while *Power* indicates the rate at which work is done. The value of engine power measured would be indicated as brake power. It is a usable power delivered by the engine to the load.

Mean effective pressure is a measure of the work output per unit swept volume. While torque is valuable measure of a particular engine's ability to do work, it depends on engine size.

$$mep = \frac{P n_r}{V_d N}$$

P = power (kW) — V_d = swept volume (m^3)

N = engine speed (rpm) — n_r = no. of crank revolution for each power stroke

The fuel consumption is measured as a flow rate of fuel mass flow per unit time. Specific fuel consumption (sfc) represents the fuel flow rate per unit power output. It measures how efficiently an engine is using the fuel supplied to produce work.

$$sfc\ (mg/J) = m_f / P$$

$$sfc\ (g / kW.h) = \frac{m_f\ (g/h)}{P\ (hp)}$$

2.2.7 Emission

The flash point is used to classify flammable liquids and therefore affects the design of equipment and the control of potential ignition sources.

The understanding of combustion process would increase understanding in emission cause. Combustion is complete if all the carbon in the fuel burns to CO_2, all hydrogen turns to H2O and existing sulphur turns to SO_2. The combustion is considered incomplete if the combustion product contains unburned fuel or components such as C, H_2, CO or OH.

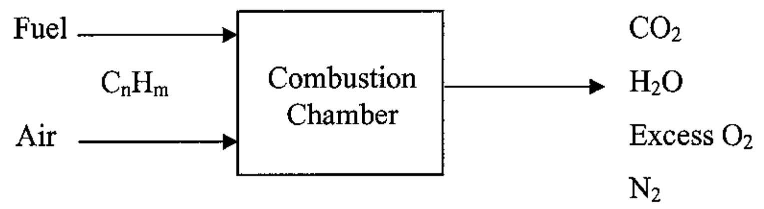

Figure 3: The basic schematic flow of combustion process

The main concern of how these NOx is produced is how the fuel burned in the combustion chamber. The non-uniform fuel distribution during combustion would cause incomplete combustion that would contribute high emission.

Insufficient amount of oxygen would lead to incomplete combustion. Insufficient mixing in the combustion chamber could cause low combustion performance thus preventing complete combustion, even with excess oxygen.

Carbon monoxide (CO) is a colorless, odorless and at high levels, a poisonous gas, formed when carbon in fuel is not burned completely. CO emission also affected by the adjustment of air/fuel ratio. Theoretically, the CO volumetric percentage decrease as air air/fuel ratio increase.

The minimum amount of air needed to combust the fuel would be called as stoichiometric. Normally the engine combustion occurs near to stoichiometric. This requires controlling the amount of air to be drawn in to mix with the fuel before it is injected into the chamber.

Replacing diesel with palm oil would require different air/fuel ratio to have the best performance and to lower the emission. This ratio might be a new parameter to be studied as to have a better result of this project.

Unburned hydrocarbons exist in the combustion product as a result of incomplete combustion of the fuel. Not all fuel did burn in the chamber as the reaction is too fast or the mixing was not well done. The existence of the unburned hydrocarbon would be caused by many conditions and one of them would be the mixing process of fuel and air. Some example causes are stated below:

1) Uneven burn – flame unable to penetrate all the fuel in the chamber.
2) Engine oil – the lubricating oil get burned together with the fuel.
3) Effect of deposit – deposit buildup in the chamber increases the unburned HC emission.

As stated in previous report, air/fuel ratio would affect the combustion emission and even the performance as well. The main interest of the project would be comparing the emission of diesel as fuel and palm oil as fuel. Adjusting the air/fuel ratio would be extra contribution that might give a good result of this project.

The hydrocarbon normally measured by parts per million carbon atoms (ppm). Higher ppm value indicates there are more unburned hydrocarbons compared with the lower ppm value. The combustion aim would be to have this ppm as low as possible. Low ppm value would also indicate higher efficiency of the engine combustion.

Fuel composition would be a significant factor in determining the magnitude of the hydrocarbon emission. An experiment will be conducted to compare the emission of normal diesel fuel and when using palm oil as the fuel.

The result would determine which fuel has more unburned hydrocarbons in its combustion product. Basically diesel fuel has high boiling points and higher molecular weight, giving it more difficult to burn completely compared to gasoline.

Soot existence is closely related to unburned HC in the combustion. Increasing the combustion efficiency would contribute to lower emission. The project would be interested in studying the effect of fuel replacement from ordinary diesel to palm oil.

Particulate matter (PM) is the general term used for a mixture of solid particles and liquid droplets found in the air. Some particles are large or dark enough to be seen as soot or smoke. Others are so small they can be detected only with an electron microscope. These particles come in a wide range of sizes "fine" particles are less than 2.5 micrometers in diameter and coarser-size particles are larger than 2.5 micrometers.

CHAPTER 3

METHODOLOGY

3. METHODOLOGY

The project would be conducted based on the planned schedule There are several compartment of the project to accomplish the objectives of this study. It was important that the project was conducted by following standard procedures to ensure the reliability of the data and results.

3.1 Literature Review and Theory

This is necessary to gather all related information regarding the project. It would be focused on how the engines work and what affect the performance of the engine. Emission characteristic would be as another factor that comes in evaluating using palm oil as fuel to operate the engine. It is important to understand the characteristic of diesel and palm oil as biodiesel. Reading would be done to gather related information.

3.2 Experimental Activities

The project would be continued by doing the further research by using a real engine to test the engine performance by using diesel engine test-bed. The engine is ready to be operated and student would require to understand the operation of this test engine by referring to the operation manual. The experiment result would be highly valuable in order to verify the feasibility of this project.

The experiment would focus on few parameters:

i. Engine torque
ii. Power
iii. Specific fuel consumption
iv. Engine emission – data of combustion product

3.2.1 Tools and equipment required

1. Diesel and palm oil as alternative fuel.
2. Internal combustion engine
3. Cussons Testbed software to gather combustion data
4. Exhaust gas analyzer
5. Particle measurement apparatus for emission monitoring

3.2.2 Methodology of conducting the performance test

1. There are four main things which have to be checked before starting the experiment of the multi-cylinder diesel engine. There are lubricant oil, fuel, coolant and water temperature. It has to be ensured that all are within appropriate level.

2. Cussons Testbed software (which is connected to the engine) is used to test the engine.

3. Cooling water was ensured to flow before the test bed had been started. Failure of cooling water availability could cause engine failure due to overheat.

4. The engine was started and was let to run at idle speed for five minutes for warming up.

5. Then, manual test is selected from the software options list. In this test, the torque value would be set at desired point (50, 60 and 70 Nm) for each different revolution per minute (rpm) setting; which varies from 1000, 1500 to 2000.

6. From the test, the engine performance data which includes specific fuel consumption (sfc), break mean effective pressure (bmep), break horse power (bhp) and torque; are recorded from the software interface.

7. Data obtained from the test are analyzed.

3.2.3 Methodology of conducting emission test using gas analyzer

1. The content supply must be checked in a good condition. The analyzer parts should be assembled properly.
2. Switch on the analyzer.
3. The analyzer will display a 30 seconds stabilizing sequence. Let the sequence completed.
4. The pump should be ensured running.
5. The battery level should be checked. It is advisable to be above 40% or else it should be charged.
6. The probe then must be paced at the end tip of the engine exhaust.
7. Press the data button to capture the emission data. The analyzer would give out the emission concentration level.

3.2.4 Methodology of conducting emission test using particulate measurement

1. The air tube from air compressor was connected to the particulate matter machine and the exhaust gas splitter was connected into the particulate sampler.
2. The air compressor and the particulate machine were switched on.
3. Measurement of the weight of a filter paper was conducted.
4. A filter paper was placed into the filter column. The filter paper will trap the particulate in the emission.
5. The engine was set to run at desired speed and load.
6. The engine was let to run smoothly and stabilized and data collection was done under steady state conditions.

7. Then some of the emission gases were bypassed into the sampler for some period of time.

8. The bypass was stopped and switch off the machine and air compressor.

9. The weight of the filter paper from the column was measured. The weight different is the particulate that trapped on the filter paper.

10. The experiment at different engine speed and load was then continued

3.3 Data Analysis

Data would be collected based on the conducted experiment activities. The data would demonstrate the results achieved and would be an indication of how far the objectives of this project are already achieved.

An experiment would be used to verify all the theories and data gathered to prove that palm oil is capable to be used as fuel. The experiment would demonstrate the different of performance and emission of an engine by using two different type of fuel.

This project would be completed by continuous monitoring by the project supervisor that the student is attached to.

CHAPTER 4

RESULTS AND DISCUSSION

4. PERFORMANCE AND EMISSION

Experiments had been conducted to understand the performance and the emission of the diesel engine. The engine was operated by using diesel as fuel and uses a computerized control to enable data gathering. Then the experiment was repeated with different fuel blends and data were collected.

4.1 Performance

The objectives of this experiment are to investigate the performance of the 2000 cc diesel engine. There are four criteria for the engine performance that need to be examined. The criteria are

i. Brake Horse Power and Torque
ii. Brake Mean Effective Pressure (BMEP)
iii. Mechanical Efficiencies
iv. Fuel consumption

The engine performance parameters stated would be gained by collecting these data:

i. Power as a function of speed (rpm)
ii. Fuel flow as a function of engine speed (rpm)
iii. Fuel flow as a function of torque
iv. Specific Fuel Consumption as a function of speed (rpm)
v. Fuel economy as a function of engine speed (rpm)

The performance test was conducted through two parts, full load performance test and part load performance test.

At full load performance test the throttle was set to maximum level and the engine would run from its low idle speed to the highest it could achieve.

Another performance test is done under part load set up. The engine is set to run at desired speed (RPM) and engine load. Different load at same speed would give out different engine performance.

The following table represents the data of performance parameters with respect to engine speed. The engine was set to run with maximum throttle, allowing the engine to reach its maximum magnitude in performance at respective engine speed.

Table 2: The performance of engine using diesel

Engine Speed rev/min	Air Temp °C	Barometric Pressure kPa	BMEP Bar	Corrected Brake Power kW	Corrected Brake Power BHP hp	Specific Fuel Consumption g/kWhr	Torque Nm
1000	37.7	101.2	5.11	7.71	10.05	299.3	71
1800	38.3	101.2	6.34	17.20	22.39	270.0	89
2600	38.3	101.3	6.91	26.95	35.12	286.6	96
3400	38.7	101.2	6.65	33.00	44.24	279.2	93
4200	39.1	101.2	5.93	37.57	48.79	296.8	83
5000	39.0	101.3	5.19	39.10	50.80	338.5	72

4.1.1 Brake torque and power

The engine torque normally is measured by using a dynamometer. The devices are used to measure torque and power over the engine operating ranges of speed and load.

Torque = measure an engine's ability to do work

Power = the rate at which work is done

The value of engine power measured would be indicated as brake power. It is a usable power delivered by the engine to the load.

From the following graph, it could be seen that from 1000rpm idle speed, maximum torque would increase as the engine speed increase. This increase will reach a point where it reaches its maximum value, where there will be no more torque increase even the speed was increased.

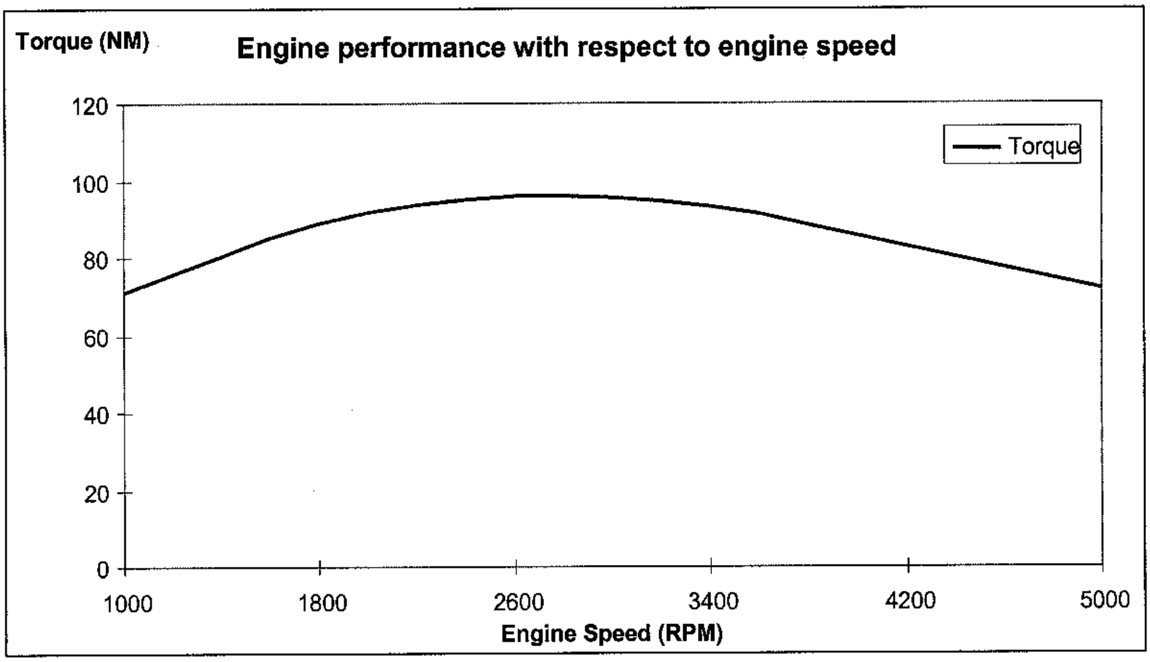

Figure 4: Engine performance with respect to engine speed

After the maximum point, any increase of engine speed will reduce the maximum achievable torque value. This phenomenon occurs due to friction. As speed increase, more energy will be required to overcome the friction generated to the rotation.

Referring to Table 2 above, the highest torque of the engine was 96 NM occurred at 2600 and 2800 RPM. At 3000 RPM, the torque was reduced to 95 NM and further speed increase would reduce the maximum torque value. At 5000 RPM, the torque was reduced to 72 NM.

The experiment then was continued with several mixture percentages of diesel and the palm oil methyl ester (POME - bio-diesel fuel). There are five different fuel mixtures which are 10%, 20%, 30%, 40% and 50%. 10 % of bio-diesel will be indicated as B10 and so on. To avoid data congestion, the result would only be discussed on comparison of three mixtures, B10, B30 and B50.

From the following graph, it could be seen that different mixtures gave different torque output. It can be concluded that by increasing the percentage of POME fuel, the torque at any engine speed would decrease comparatively.

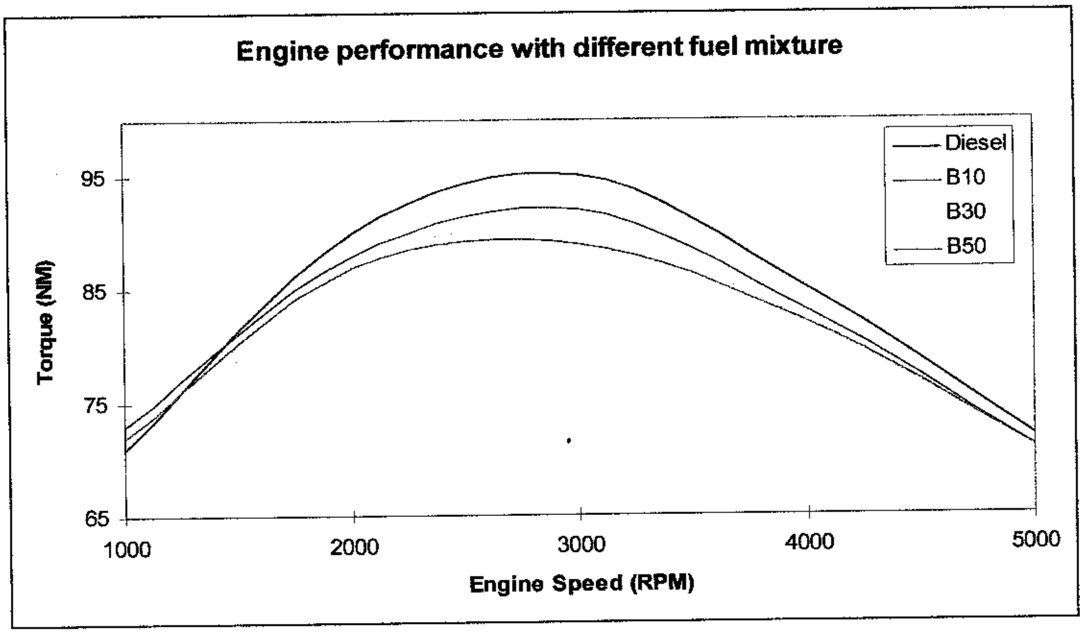

Figure 5: The different engine performance with different fuel mixture

For instance, maximum torque for diesel fuel is 96 Nm, B10 is 92 Nm, B30 is 90 Nm and B50 is 89 Nm. This decreasing performance indicates that bio-diesel is less capable to drive the engine to its maximum torque compared with 100% diesel. A complete data are listed in Appendix 2.1.

The following table would illustrate the percentage of reduction for torque with different percentage mixture of POME into diesel.

Table 3: Percentage of Torque (NM) reduction (%) from pure diesel

RPM	Percentage of Torque reduction (%)				
	B10	**B20**	**B30**	**B40**	**B50**
1000	-2.82	0.00	2.82	2.82	7.04
2000	2.22	3.33	3.33	3.33	3.33
3000	3.16	4.21	5.26	6.32	6.32
4000	2.35	3.53	3.53	3.53	3.53
5000	1.39	1.39	1.39	1.39	2.78
Average (%)	**1.26**	**2.49**	**3.27**	**3.48**	**4.60**

Table 3 shows that B10 had 1.26% and B50 with 4.60% average torque reduction. This proved that increasing in POME percentage in the mixture will gradually decrease the torque of the engine.

4.1.2 Break Mean Effective Pressure (bmep)

Mean effective pressure is a measure of the work output per unit swept volume. The performance comparison of an engine also is determined by this bmep value. Higher value would indicate higher performance of the engine. The brake mean effective pressure (bmep) increases as engine run at higher value of engine speed and torque

The same pattern is applied when studying the effect of break mean effective pressure with the increasing engine speed.

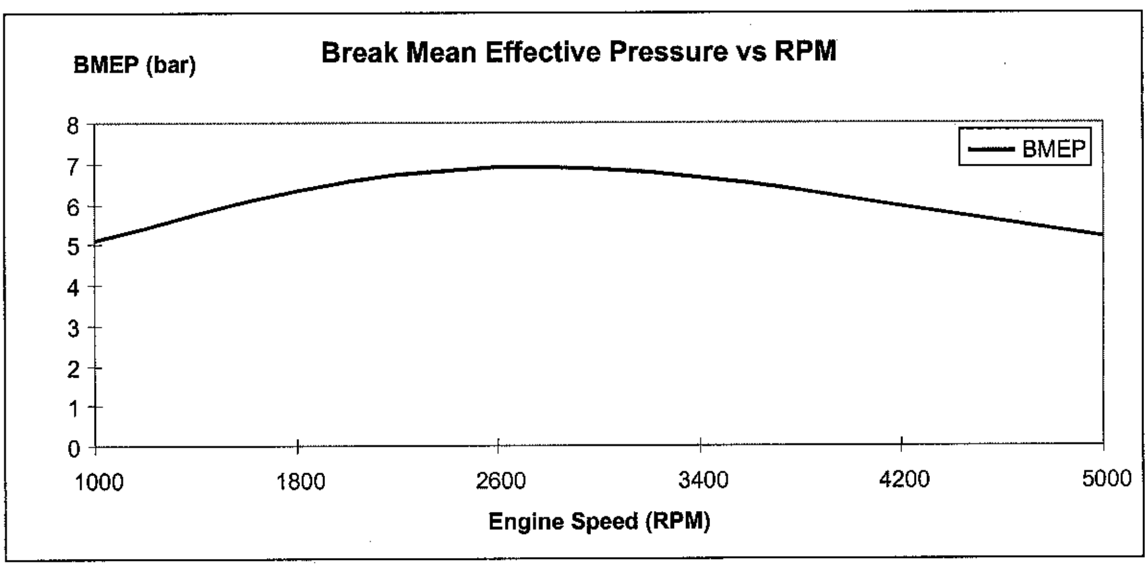

Figure 6: BMEP with respect to engine speed running on diesel

As explained in the maximum torque section, speed increase would cause the bmep increase to a maximum point. Then at certain turning speed, bmep decreases as the speed increase. These maximum points normally occur in a 2500 rpm to 3000 rpm region.

Maximum pressure achieved was 6.91 bar occurred at 2600 RPM.

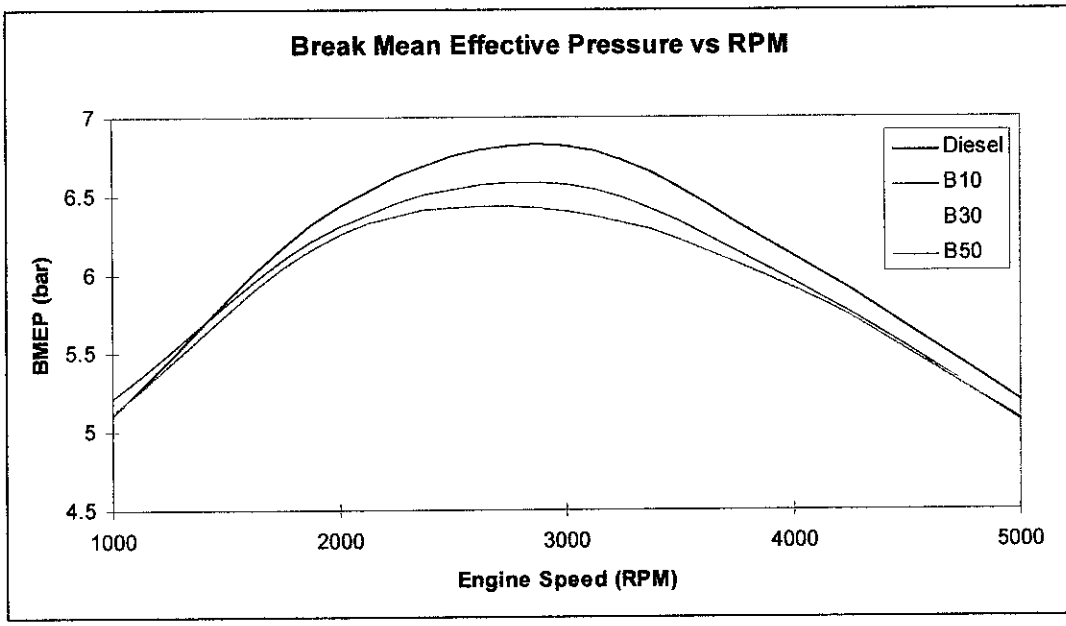

Figure 7: BMEP comparison of different fuel mixture

Based on the result, pure diesel would give highest value of bmep value. The same trend like torque is occurred again as the result is decrease in value when using fuel with more bio-diesel composition.

It can be seen an obvious decrease of maximum pressure just with an addition of 10% bio-diesel into the diesel. Then, the pressure decreases are not so significant with increasing percentage of bio-diesel. At maximum performance speed around 3000RPM, bmep of B10 decrease about 0.25 bar. B10 and B30 differ about 0.12 bar. B30 and B50 then differ only about 0.05bar.

Table 4: Percentage of BMEP (bar) reduction from pure diesel

RPM	Percentage of BMEP reduction (%)				
	B10	**B20**	**B30**	**B40**	**B50**
1000	-2.15	-0.98	2.94	3.13	3.52
2000	1.87	2.18	2.80	2.95	2.80
3000	3.67	4.25	5.43	6.01	6.16
4000	2.62	2.95	3.27	3.27	3.27
5000	2.12	1.93	1.93	2.12	2.31
Average (%)	**1.62**	**2.06**	**3.27**	**3.50**	**3.61**

Maximum reduction occurred at 3000 rpm when using B50 fuel with 6.16% BMEP reduction. This maximum point occurred at engine speed where the engine can reach its maximum BMEP before it reduced again as speed increase. Notice also that for all mixture, maximum reduction occurred at this 3000 speed.

From the table, it shows that B10 had 1.62% average BMEP reduction and B50 with 3.61% average BMEP reduction. This proved that increasing in POME percentage in the mixture will gradually decrease the BMEP of the engine.

The following table is a result of the performance of the engine running at different speed and load. From the data, a graph is established to view the relationship of torque, engine speed and engine power.

Table 5: Performance of the engine running at different speed and load

RPM (rev/min)	Torque (Nm)	Specific Fuel Consumption (g/KWHr)	Break Mean Effective Pressure (BMEP)	Power (BHP)
1000	50	277.9	3.57	6.9
	60	285.4	4.32	8.1
	70	293.0	5.15	10.1
1500	50	273.9	3.60	10.5
	60	254.1	4.33	12.6
	70	248.2	5.12	15.0
2000	50	284.3	3.59	14.2
	60	264.9	4.42	17.1
	70	258.8	5.05	19.7
2500	50	282.1	3.61	17.5
	60	269.8	4.32	20.9
	70	264.2	5.04	24.1
3000	50	290.9	3.60	21.0
	60	281.9	4.29	25.1
	70	271.1	5.02	29.3
3500	50	307.6	3.57	24.2
	60	288.4	4.29	29.3
	70	280.7	5.01	34.2
4000	50	320.7	3.66	28.4
	60	304.5	4.38	34.2
	70	294.4	5.14	39.9
4500	50	337.3	3.68	32.3
	60	318.9	4.36	38.4
	70	309.7	5.13	44.7

In this test, the torque throttle position is set to 50, 60 and 70 Nm for each revolution per minute (rpm) setting. From the graph, taking constant torque, it could be seen that engine gives more power as the engine speed increase. In the other hand, at constant engine speed, the power increase as it use higher torque value.

This data would be used to understand the performance of the diesel engine. The same procedure would be repeated with different fuel, which would be palm oil. Different mixtures would be studied to find at what condition it would turn out as a good result.

4.1.3 Engine Break Horse Power (BHP)

Based on the same experiment conducted for power and torque, a set of tests were run at different engine speeds and loads to measure the break horse power.

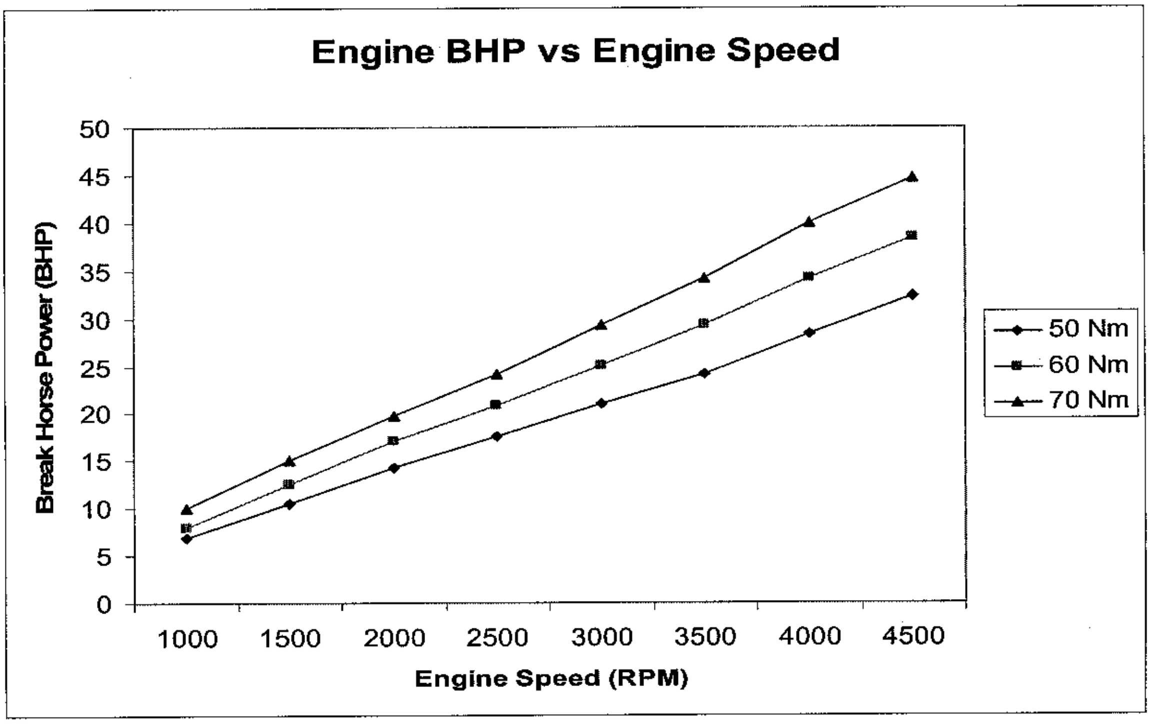

Figure 8: Engine Power BHP vs engine speed (rpm)

It could be seen that the bhp increase with the increase of engine speed. Comparison also could be done between different engine loads. It can be conclude that bhp value increase with the increase torque value.

The bhp analysis was also done by using the full load performance test. Then the experiment was repeated with various fuel mixtures. The next graph would illustrate the difference of horse power with increasing engine speed. The data are listed in Appendix 2.3.

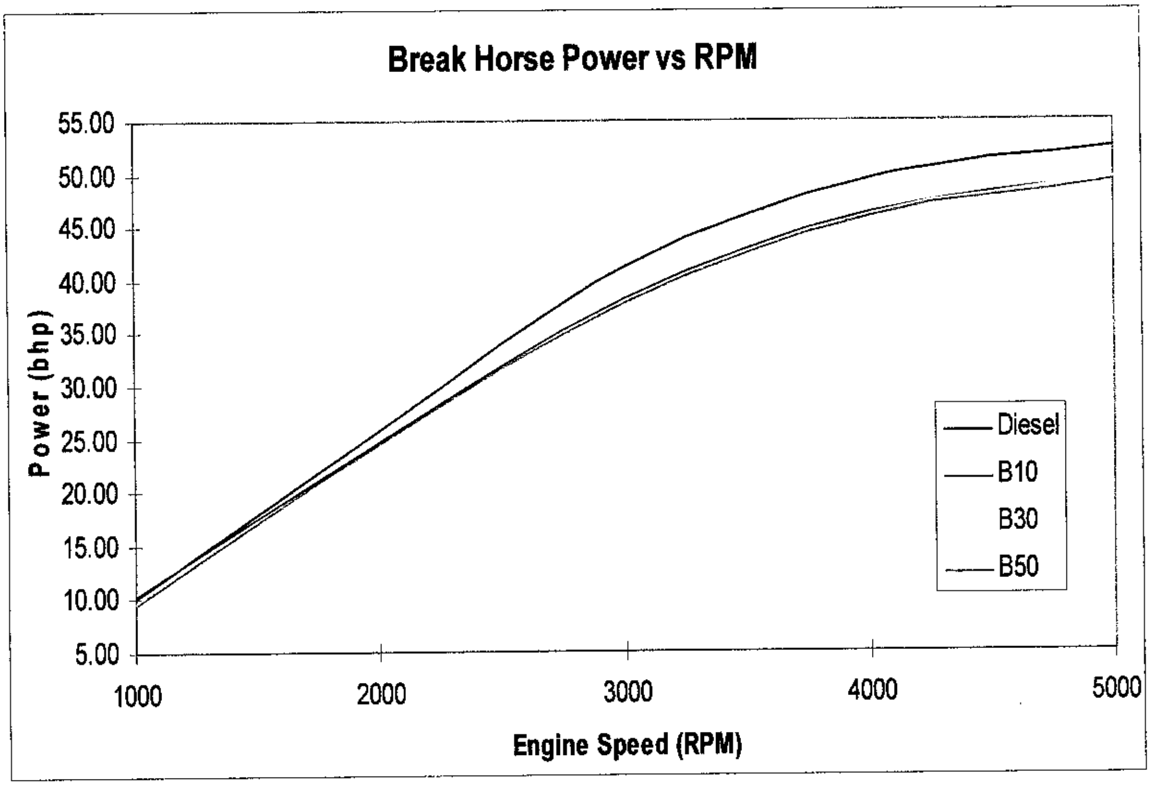

Figure 9: Break Horse Power comparison of different fuel composition

From this result, it shows that adding POME into diesel decrease the engine break power. For instant, at 5000 rpm, adding 10% POME would reduce the power from 52.4 BHP to 49.4 BHP, that is 4.49% in BHP reduction. Maximum reduction occurred when using B30 and running at 3000rpm with 8.32%.

Referring to the graph, there are no significant differences of bhp when using different mixtures of fuel. It is look like that the power values of diesel mixed with POME bio-diesel are overlapping with each other.

But as previous performance parameters, a closer analysis would say out that mixing diesel with more bio-diesel will decrease the performance magnitude. It can be concluded that the horse power value decrease with increasing percentage of bio-diesel.

Table 6: Reduction Percentage of Break Horse Power (bhp) from pure diesel

RPM	Percentage of BHP Reduction (%)				
	B10	**B20**	**B30**	**B40**	**B50**
1000	-1.49	1.49	4.48	4.48	6.47
2000	4.49	5.26	5.65	6.03	5.65
3000	7.35	7.59	8.32	8.32	8.08
4000	6.33	6.53	6.74	7.14	7.34
5000	5.76	5.57	5.57	5.76	5.95
Average (%)	**4.49**	**5.29**	**6.15**	**6.35**	**6.70**

This table is produced from a calculation to determine the magnitude of power reduction with increasing percentage of POME in the diesel. It could be see that the average reduction is 4.49% when using B10 and increase to average reduction of 6.70% when using B50.

4.1.4 Specific Fuel Consumption

Specific fuel consumption (SFC) represents the fuel flow rate per unit power output. It measures how efficiently an engine is using the fuel supplied to produce work. The SFC is represented in g/kWhr unit.

The fuel consumption is measured as a flow rate of fuel mass flow per unit time. SFC indicates the fuel flow rate per unit power output. It measures how efficient an engine use the fuel supplied to produce work.

Low values of SFC are desirable as it use less fuel to produce more work. Based on the gathered data, a graph is produced to visualize the relationship of fuel consumption and engine performance. The following graph would represent the SFC of using pure diesel fuel at different engine torque.

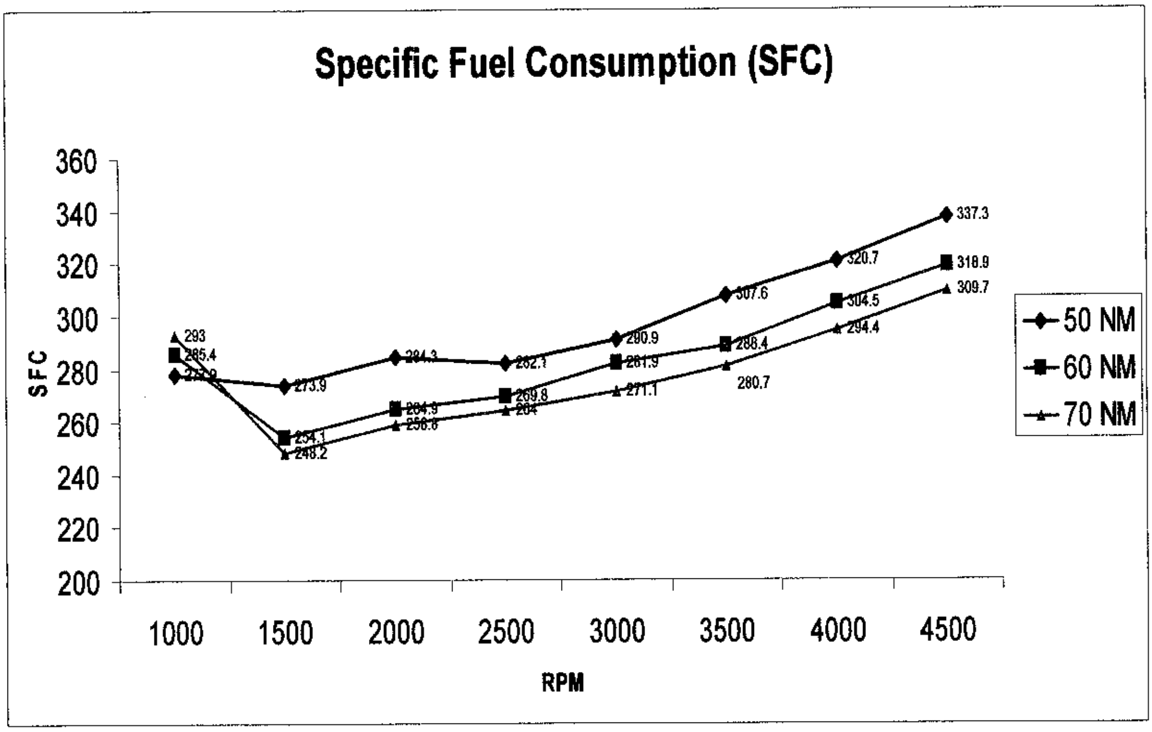

Figure 10: Specific Fuel Consumption vs Engine Speed

From the graph, it could be seen that initially, the SFC decrease with the increasing in speed. But when the engine speed exceeds roughly around 1500rpm, the SFC value increases with the increasing in speed. Another comparison is the sfc value at different engine torque. Higher torque value would produce lower SFC value.

The SFC analysis was also done by using the full load performance test. Then the experiment was repeated with various fuel mixtures. The next graph would illustrate the difference of horse power with increasing engine speed. The full data is attached in Appendix 2.4.

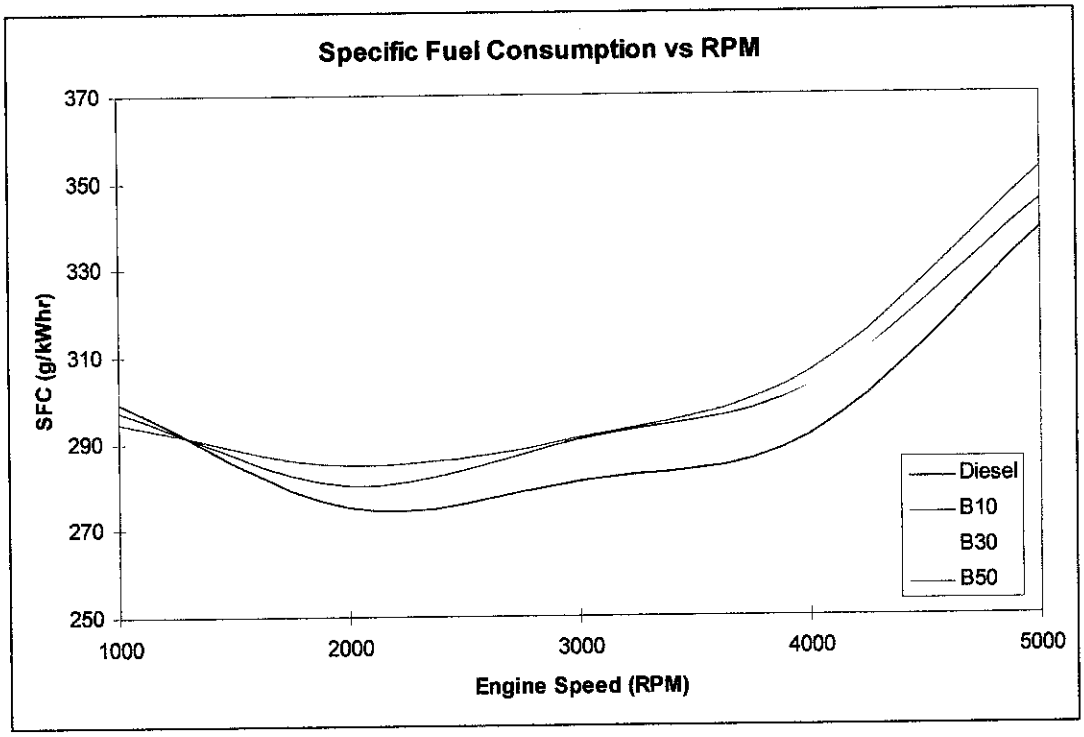

Figure 11: SFC comparison of different fuel composition

From the graph, it showed that SFC value increase with the increasing percentage of bio-diesel in the fuel. This can be explained by understanding previously that bio-diesel is has lesser value of performance magnitude.

The engine requires higher fuel flow rate to give out the same amount of power given out by diesel fuel. Higher SFC value represent that the engine consume more grams of fuel to give unit power output. Higher SFC showed that the fuel is less efficient to be used to produce work.

Table 7: Percentage of SFC (g/kWHr) increase for different fuel mixtures

RPM	Percentage of SFC (g/kWHr) increase (%)				
	B10	B20	B30	B40	B50
1000	-0.74	-0.34	0.89	0.13	-0.34
2000	1.82	2.69	2.93	3.34	3.51
3000	3.30	3.57	4.06	4.03	3.47
4000	3.89	3.89	3.86	4.40	4.86
5000	1.91	2.25	2.45	3.20	3.97
Average %)	**2.04**	**2.41**	**2.84**	**3.02**	**3.10**

Highest increment occurred when using B50 running at 4000 rpm with 4.86% of increment. Comparatively, B50 SFC is higher compared to B30 and B10. This concludes that more fuel is required and consumed when having more bio-diesel in the mixture to achieve same power output. The SFC increase 2.04% when using B10, 2.84% when using B30 and 3.10% when using B50.

From all the performance parameters, it can be concluded that bio-diesel has less output of performance. Compared to pure diesel, it is shown that increasing percentage of bio-diesel into the fuel mixture will decrease the performance magnitude.

4.2 Emission

Besides of many parameters of engine performance, emission of the engine does contribute into consideration of replacing the diesel with palm oil to run the engine. This project does include the research and analysis of the palm oil effects in the term of emission. The study would be beginning with understanding what emission is. Initial study would cover the understanding of diesel engine emission.

The term 'engine emission' refers primarily to pollutants in the engine exhaust. The combustion of the engine would produce exhaust gases containing:

1. Oxides of nitrogen (nitric oxide, and nitrogen dioxide)
2. Carbon monoxide (CO)
3. Hydrocarbons (HC)
4. Soot (particulate)

4.2.1 Nitric Oxide Formation

The mixture of nitric oxide (NO) and Nitrogen dioxide (NO2) is referred to as NO_x. Major part of NO_x would be NO.

Nitric oxide is formed by

$$O + N2 = NO + N$$

$$N + O2 = NO + O$$

$$N + OH = NO + H$$

The producing of NO_x would increase with the increasing flame temperature and lower flame speed. NO are highly produced as temperature and pressure of the combustion increase. This is due to the compressing fuel mixture, contributing to higher NO producing rate.

The following graph would describe the effect of adding bio-diesel to the emission value. The data taken would be analyzed and comparison would be made regarding the NOx emission.

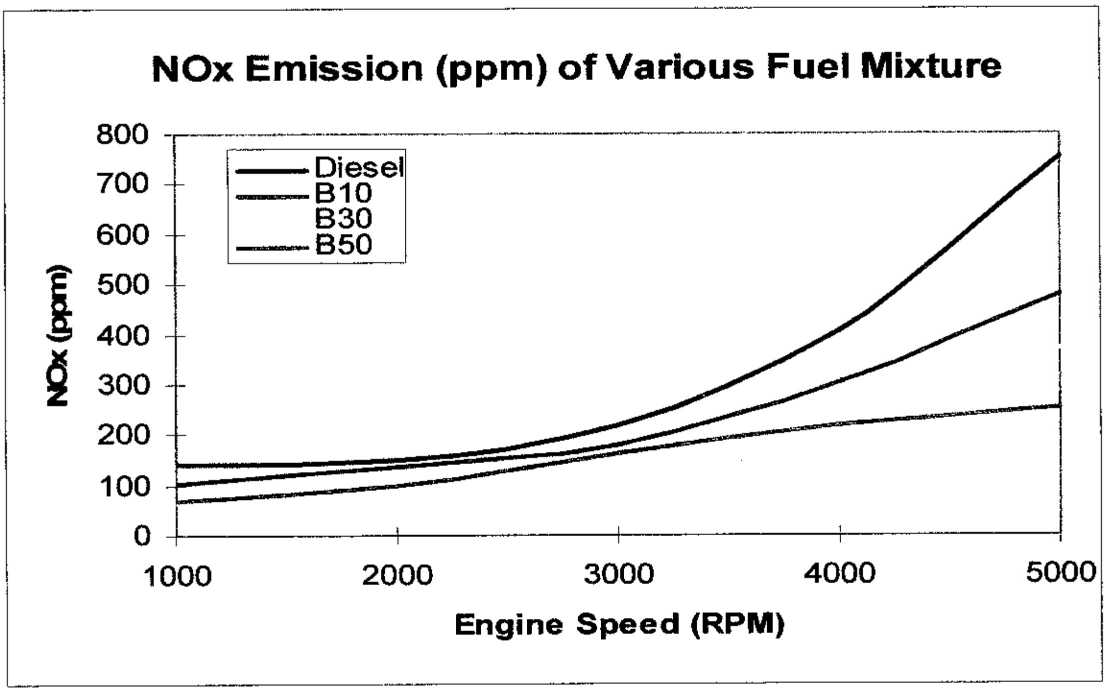

Figure 12: NOx emission of different fuel composition

As the graph represent, the carbon monoxide emission increased with the increase of engine speed. For diesel fuel, there is a very slight increase from 1000 rpm to 2000 rpm. Beyond 2000 rpm, emission starts to increase significantly with the speed increase.

The same trend is also applicable to other fuel mixture. B10 fuel showed that mixing diesel with POME will reduce its NOx emission value. B30 have lower NOx emission and B50 is even lower. This can conclude that NOx emission value would decrease with more bio-diesel composition in the fuel.

Table 8: Percentage of NOx reduction with different POME composition in diesel

RPM	Percentage of NOx reduction (%)				
	B10	**B20**	**B30**	**B40**	**B50**
1000	27.97	38.46	55.24	48.95	51.05
2000	9.33	19.33	28.00	31.33	33.33
3000	17.73	23.64	30.45	26.82	25.45
4000	25.43	34.57	44.44	45.43	45.93
5000	36.12	42.76	50.46	61.75	66.40
Average	**23.32**	**31.75**	**41.72**	**42.86**	**44.43**

Taking averagely, 10% of POME in diesel (B10) gave a 23.32% of NOx reduction. This value is increasing with more POME is added into the mixture. B50 reduction is almost double the B10 reduction with average of 44.43 %.

4.2.2 Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless and at high levels, a poisonous gas, formed when carbon in fuel is not burned completely. It is a desire to have combustion with lesser CO emission.

An experiment was conducted to study the effect of using bio-diesel as fuel to carbon monoxide value. Data on pure diesel would be used as reference base to compare with using bio-diesel as fuel.

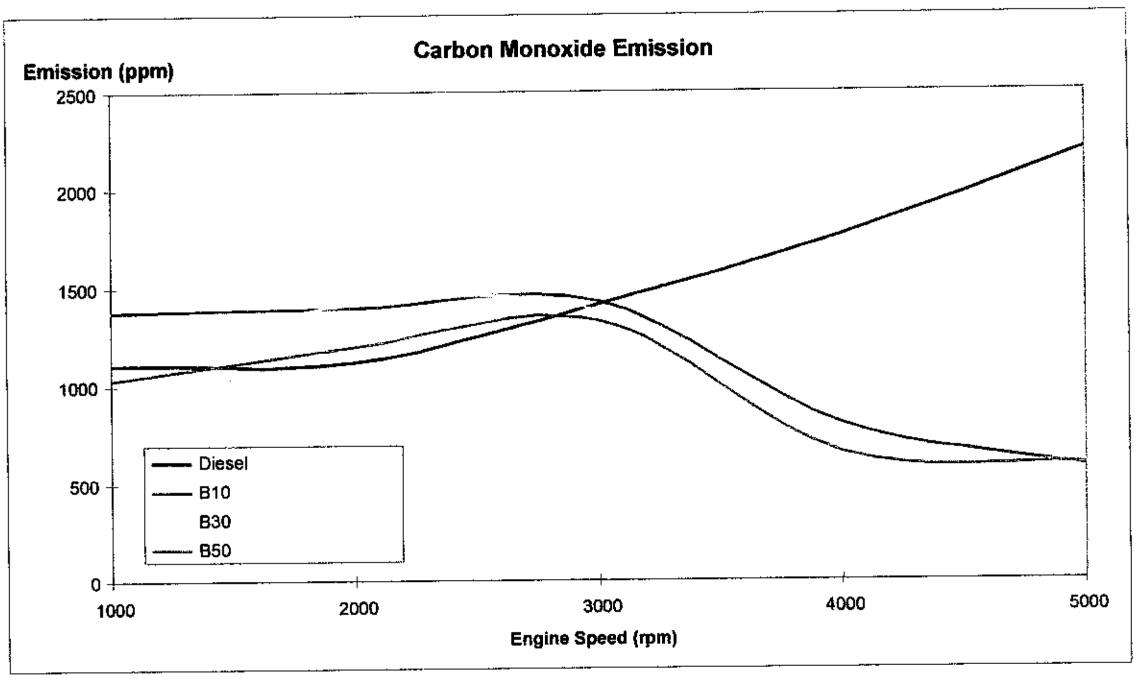

Figure 13: Carbon monoxide emission with different fuel mixtures

As the graph represent, the carbon monoxide emission of pure diesel fuel increased with the increase of engine speed. The emission is represented by the blue line. There is a very slight increase from 1000 rpm to 2000 rpm. Beyond 2000 rpm, emission starts to increase significantly with the speed increase.

But this trend is not applicable when mixed fuel is used. The emission of these mixtures is higher compared to diesel when the engine is running below 3000 RPM. But interestingly, the emission decrease significantly after this 3000 RPM speed. Observe how the bio-diesel emission line crossed with diesel line around 3000 RPM. This showed that bio-diesel burn more completely when the combustion occurred at higher engine speed. Other comparison can be made that higher percentage of bio-diesel has lower value of carbon monoxide emission. The comparisons are presented in the following table.

Table 9: Percentage of CO reduction with different POME composition in diesel

RPM	Percentage of CO reduction (%)				
	B10	**B20**	**B30**	**B40**	**B50**
1000	-24.66	-9.21	-1.26	0.72	6.68
2000	-24.40	-13.98	-26.45	-11.58	-6.86
3000	-1.42	0.99	2.06	4.11	6.03
4000	54.60	58.57	61.98	62.26	63.11
5000	73.67	72.72	72.76	73.17	73.40
Average (%)	**15.56**	**21.82**	**21.82**	**25.74**	**28.47**

4.2.3 Diesel Particulate

Diesel particulate normally referred as soot. As other emission, soot is normally generated through incomplete combustion of the fuel.

The composition of soot depends on:

i. Condition in the engine exhaust
ii. Particulate collection system

Particulate measurement would determine the amount of particulate released to atmosphere during the engine combustion. An experiment would be conducted to study the different of particulate level of two different fuel; diesel and palm oil.

Lower particulate level would be preferred and lowering the value would decrease the emission of the combustion

An experiment was conducted to study the effect of using bio-diesel as fuel to particulate data value. Data on pure diesel would be used as reference base to compare with emission data using POME as fuel.

The experiment was conducted at single speed. It was done at 3000 RPM as that is the average speed when all the fuel blends reaches their peak in performance. The data were taken and analyzed to determine the effect of bio-diesel in emission.

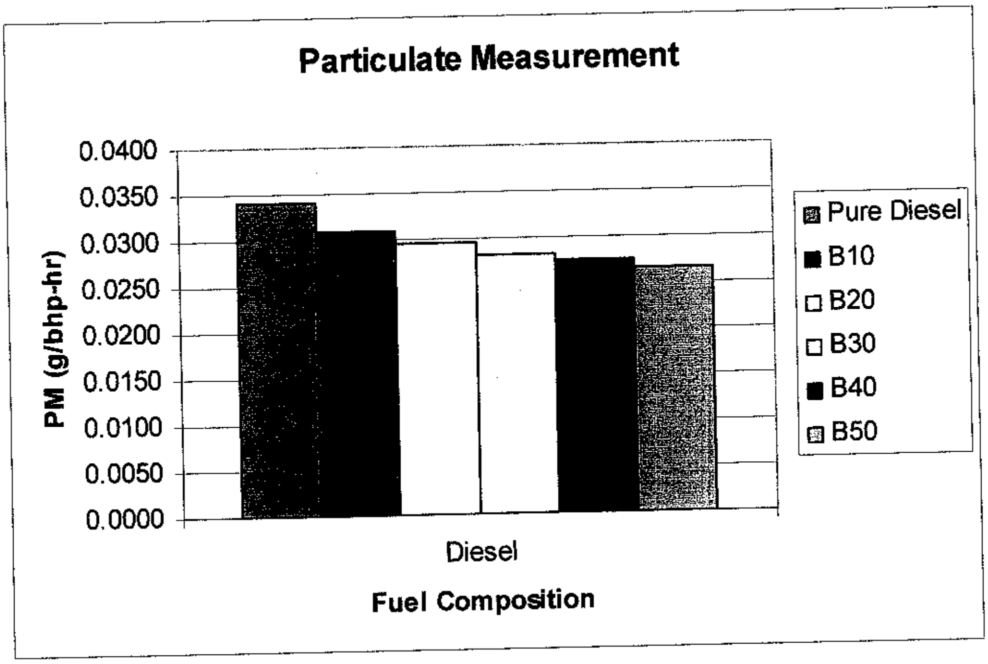

Figure 14: The different particulate level for different fuel composition

The following table would indicate the percentage of particulate matter (PM) reduction of different fuel blends comparing to pure diesel.

Table 10: The particulate matter level for different fuel mixture

Fuel Mixture	PM (g/bhp-hr)	Particulate reduction (%)
Diesel	0.0340	-
B10	0.0310	8.82
B20	0.0295	13.24
B30	0.0281	17.35
B40	0.0274	19.41
B50	0.0267	21.47

From the Figure 14 and Table 10, it could be seen that the PM level decreased with more addition of bio-diesel into the fuel mixture. The PM level decrease gradually from B10 mixture to B50 mixture. B50 fuel can reduce the PM by 21.47%. This could be concluded that using bio-diesel as fuel can reduce the PM emission level.

From the three emission parameters; CO, NOx and particulate measurement, it could be concluded that bio-diesel produce less pollution compared to conventional diesel fuel. This good result indicates that there is alternative fuel available with lesser emission to reduce the dependency on diesel fuel.

Reducing particulate in emission is important because it is hazardous to human health and environment. Toxicity of particles retained in the lungs varies with chemical composition. Some chemicals such as sulfuric acid may react directly with the system, while others may act to retard clearance of other particles from the lungs. Particulates may also act as carriers for gaseous pollutants and can cause synergistic effects, such as when sulfur dioxide and particulate exposures occur simultaneously.

CHAPTER 5

CONCLUSION

This project was conducted to achieve all the objectives as stated in the first chapter of this report. By doing this project, author would be exposed to the diesel engine and alternative fuels. Author basically would be required to master knowledge in internal combustion engine to complete the project.

Information gathered through reading and researches were combined with data gathered through experiment to verify the feasibility of this project. It is important to have a clear understanding upon the characteristics of bio-diesel fuels in order to have the diesel engine run normally.

From all the findings and data discussion, it can be concluded that bio-diesel is feasible to be used as a fuel for diesel engine. From all the performance parameters, it shows that bio-diesel has less output of performance. Compared to pure diesel, it is shown that increasing percentage of bio-diesel into the fuel mixture will decrease the performance magnitude. B10 has the least performance reduction while B50 has the most performance decrease.

But this performance reduction is not severe enough to stop further usage of this bio-diesel fuel. Comparing the four performance parameters; torque, break mean effective pressure, horse power and specific fuel consumption, the performance reduction was not more than 10%, even when the fuel was blended with 50% POME.

For five different blends, ranging from B10 to B50, it shows that all the blends are feasible to be used. Proper mixture will give the required output as most diesel application is not going for maximum performance at all the time. So proper performance requirements of engine is required to determine what mixture is the best to be used as fuel.

Another factor to encourage the usage of bio-diesel is the reduction of emission. From the three emission parameters; carbon monoxide, nitrogen oxides and particulate measurement, it could be concluded that bio-diesel do less pollution compared to conventional diesel fuel. This good result indicates that there is alternative fuel available with lesser emission to reduce the dependency on diesel fuel.

Comparing the emission between pure diesel with mixed fuel shows a reduction in emission. From the results, it shows that with more bio-diesel in the fuel blend, the combustion gave less Nitrogen Oxides (NOx) emission. B10 fuel caused a reduction of 23% and B50 fuel gave out 44% in NOx reduction.

NOx emission does increase with the increasing of engine speed. For diesel, the NOx emission at 5000 rpm (753 ppm) is about 5.3 times greater compared to emission while running at 1000 rpm (143 ppm). When using B10 blends, the comparison value reduced to about 4.7 and B50 shows about 3.6. This shows that the increase of emission is less when diesel is blend with POME. The slope of the increase became less steep when more percentage of POME is blended with diesel.

Carbon Monoxide (CO) emission also reduced with the present of POME in the fuel. From the results, it showed that more POME blended in the fuel would reduce the CO emission of the combustion. B10 fuel had reduced about 15% CO emission and with B50, the emission is reduced to more then 28%.

For CO emission compared to NOx, there is a different of emission with respect to engine speed. At low speed below 3000 rpm, the emission was slightly higher compared to normal diesel fuel. But magnificent emission reduction occurred as engine speed higher then 3000 rpm. This could be explained due to effect of fuel and air mixing process. At low speed, the fuel was not completely mixed with the air before the combustion occurred. Complete mixing would contribute lower emission by having more complete combustion. But at high speed, the rapid compressions force the air to be more turbulent and this would help in having better mixing process.

For particulate matter, it also shows that POME blended into the fuel can reduce the emission level. More percentage of POME in the mixture would give more emission reduction. B10 mixture reduces particulate for almost 9% and B50 can reduce particulate emission for more than 21%. Reducing particulate in emission is important because it is hazardous to human health and can cause lungs infections.

From these findings, it is up to further study to identify what would be the best blends to be used in compromising performance and emission. This is to be determined by the end users, the requirement of the work and the specification of the engine. Correct identification of required performance and emission constraints can give out the best result when using correct type of fuel blends.

The results of this project are based on the one type of engine as specified in the report. It is a suggestion to continue this project with different type of engine manufacturer and engine specification. The same pattern of result while using different engine specifications would strengthen the accuracy of this project.

The project experiments were conducted without any modification to the diesel engine. Some study should be done to identify any modification like air-fuel mixer that may improve the outcome of this study. Good result from zero engine modification indicates that normal diesel engines are capable to use POME - diesel blends as fuel.

It is a hope that by proving that palm oil can replace diesel, palm oil would be further utilized. Malaysia is the biggest crude palm oil exporter in the world and it is a waste if palm oil is unable to be used as power fuel. The palm oil might be as an alternative fuel to common petroleum resources. It could be a primary fuel to be used by agricultural sector. Palm oil also can be used to generate electricity and reduce the dependency on natural gas firing power plant.

The feasibility of palm oil usage as power fuel will boost the agricultural sector and can support the palm oil plantation. Increase in demand would enable more work opportunity especially in agricultural industry.

Reducing dependency on petroleum resources is important as the source is decreasing and has its limitation. Agricultural source fuel is renewable and less pollutants as compared to petroleum. It is more biodegradable compared to petroleum and this would be a great contribution in conserving the environment.

This project had indicated and proves the usability of palm oil as fuel. Further experiments and research shall be conducted by any other parties to determine how far palm oil is good and feasible as a fuel for diesel engine. All contribution and guidance to writer in completion of this project are highly appreciated.

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APPENDIX

Appendix 1 - Gant Chart of Final Year Project

Appendix 2 – Experiment Data on Performance

Appendix 3 – Experiment Data on Emission

Appendix 4 – Engine Specification

APENDIX 1 GANTT CHART FOR MECHANICAL ENGINEERING FINAL YEAR PROJECT

	SEMESTER 1																	
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
	21/07 – 27/07	28/07 – 03/08	04/08 – 10/08	11/08 – 17/08	18/08 – 24/08	25/08 – 31/08	01/09 – 07/09	08/09 – 14/09	15/09 – 21/09	22/09 – 28/09	29/09 – 05/10	06/10 – 12/10	13/10 – 19/10	20/10 – 26/10	27/10 – 02/11	03/11 – 09/11	10/11 – 16/11	17/11 – 23/11
Topic Selection	▒	▒	▒															
Preliminary Research Work			▒	▒														
Preliminary Report				●														
Literature Review				▒	▒	▒	▒	▒	▒									
Project Work							▒	▒	▒	▒	▒	▒	▒	▒	▒			
Progress Report										●								
Interim Report Final Draft														●				
Oral Presentation															●			
Project Dissertation																		●

Week 16 - 18 : Exam Week

Main Activities	SEMESTER 2																	
	01	02	03	04	05	06	07		08	09	10	11	12	13	14	15	16	17
	19/01 – 25/01	26/01 – 01/02	02/02 – 08/02	09/02 – 15/02	16/02 – 22/02	23/02 – 29/02	01/03 – 07/03	08/03 – 14/03	15/03 – 21/03	22/03 – 28/03	29/03 – 04/04	05/04 – 11/04	12/04 – 18/04	19/04 – 25/04	26/04 – 02/05	03/05 – 09/05	10/05 – 16/05	17/05 – 23/05
Emission Methodology																		
Diesel Performance Review																		
Progress Report					●													
Diesel Emission																		
Project Work on Bio-diesel																		
Progress Report 2										●								
Poster Exhibition													●					
Interim Report Final Draft														●				
Oral Presentation															●			
Project Dissertation																		●

10 - 28 May : Final Exam

8 – 14 March : Mid semester Break

Appendix 2 Experiment Data On Performance

2.1 Max Torque (Nm)

RPM	Diesel	B10	B20	B30	B40	B50
1000	71	73	71	69	69	66
2000	90	88	87	87	87	87
3000	95	92	91	90	89	89
4000	85	83	82	82	82	82
5000	72	71	71	71	71	70

2.2 Break Mean Effective Pressure (bar)

RPM	Diesel	B10	B20	B30	B40	B50
1000	5.11	5.22	5.16	4.96	5.09	5.12
2000	6.43	6.31	6.29	6.25	6.24	6.25
3000	6.82	6.57	6.53	6.45	6.41	6.40
4000	6.11	5.95	5.93	5.91	5.91	5.91
5000	5.19	5.08	5.09	5.09	5.08	5.07

2.3 Break Horse Power (bhp)

RPM	Diesel	B10	B20	B30	B40	B50
1000	10.1	10.2	9.9	9.6	9.9	10.0
2000	25.9	24.7	24.5	24.4	24.3	24.4
3000	41.2	38.2	38.1	37.8	37.8	37.9
4000	49.4	46.3	46.2	46.1	45.9	45.8
5000	52.4	49.4	49.5	49.5	49.4	49.3

2.4 Specific Fuel Consumption (g/kWhr)

RPM	Diesel	B10	B20	B30	B40	B50
1000	299.3	297.1	298.3	302.0	299.7	294.6
2000	275.0	280.1	282.6	283.3	284.5	285.0
3000	281.0	290.6	291.4	292.9	292.8	291.1
4000	291.4	303.2	303.2	303.1	304.8	306.3
5000	338.5	345.1	346.3	347.0	349.7	352.5

Appendix 3 Experiment Data on Emission

3.1 Nitrogen Oxides Emission (ppm)

RPM	Diesel	B10	B20	B30	B40	B50
1000	143	103	88	64	73	78
2000	150	136	121	108	103	100
3000	220	181	168	153	159	174
4000	405	302	265	225	221	219
5000	753	481	431	373	288	253

3.2 Carbon Monoxide Emission (ppm)

RPM	**Diesel**	**B10**	**B20**	**B30**	**B40**	**B50**
1000	1107	1380	1209	1121	1099	1033
2000	1123	1397	1280	1420	1253	1200
3000	1410	1430	1396	1381	1352	1325
4000	1762	800	730	670	665	650
5000	2203	580	601	600	591	586

3.3 Particulate Matter (g/bhp-hr)

Data taken at constant speed of 3000 RPM

Type of Fuel	**PM (g/bhp-hr)**
Diesel	0.0340
B10	0.0283
B20	0.0231
B30	0.0187
B40	0.0153
B50	0.0136

Appendix 4 Engine Specification

Manufacturer: FORD

Model: FORD XLD 418

Specification:

Engine type	4 cylinder, in-line, indirect injection
Bore	82.5mm
Stroke	82.0mm
Cubic capacity	1752 cc
Compression ratio	21.5 : 1
Max engine no load speed	5350 rpm
Idle speed	850 rpm