Faculty of Mechanical Engineering

AN EXPERIMENTAL INVESTIGATION OF PERFORMANCE AND GASSEOUS EXHAUST EMISSION OF A DIESEL ENGINE USING BLENDS OF A VEGETABLE OIL

Muhammad Syakir Bin Ab Rahim

Bachelor of Mechanical Engineering (Thermal-Fluids) with Honours

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AN EXPERIMENTAL INVESTIGATION OF PERFORMANCE AND GASSEOUS EXHAUST EMISSION OF A DIESEL ENGINE USING BLENDS OF A VEGETABLE OIL

MUHAMMAD SYAKIR BIN AB RAHIM

A report submitted
in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering (Thermal-Fluids) with Honours

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DECLARATION

I declare that this thesis entitled "An Experimental Investigation of the performance and Gaseous Exhaust Emission of A Diesel Engine Using Blends of a Vegetable Oil" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : **MUHAMMAD SYAKIR BIN AB RAHIM**

Date : ....

SUPERVISOR'S DECLARATION

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluids) with Honours.

Signature : ....

Name of Supervisor : **MD ISA BIN ALI**

Date : ....

DEDICATION

To my beloved mother and father.

ABSTRACT

Alternative fuels have received much attention due to the depletion of world petroleum reserves and increased environmental concerns. Vegetable oils can provide cleaner burning and renewable alternatives to diesel fuel. Thus, vegetable oil offers as an attractive alternative fuel to compression ignition engines. However, their inherently high viscosity as compared to petroleum based diesel is undesirable for diesel engines. This research concentrates on the study of the prospect of using vegetable oils as a replacement for diesel fuel by configuring an experiment to test the engine's performance and to determine the level of emission on three fuel blends of coconut oil such as 10%, 20% and 30% of coconut oil – diesel blends. The presented work investigates the engine performance parameters and emissions characteristics for direct injection diesel engine using coconut diesel blends without any engine modifications. Experiment has been conducted at a fixed engine speed of 2500 rpm, and then it was gradually loaded. The experiments were conducted at five loads, namely 0 bar (no load), 10 bar, 20 bar, 30 bar and 40 bar. For each load condition the engine was run for at least 4-5 minutes. Results show that the basic engine performance such as power output and fuel consumption is comparable to diesel. When fueled with diesel blends, reduction of power output and incline fuel consumption was noted and with the increased amount of coconut oil in the blends. In case of engine exhaust gas emissions, lower CO_2 and NOx, while higher CO and HC emissions have been found for blended fuels compared to diesel fuel.

ABSTRAK

Bahan api alternatif telah menerima banyak perhatian kerana pengurangan rizab petroleum dunia dan peningkatan kebimbangan alam sekitar. Minyak sayuran boleh menyediakan pembakaran yang lebih bersih dan alternatif yang boleh diperbaharui untuk bahan api diesel. Oleh itu, minyak sayur-sayuran menawarkan bahan api alternatif yang menarik kepada enjin pencucuhan mampatan. Walau bagaimanapun, minyak sayuran mempunyai kelikatan yang tinggi berbanding diesel konvensional yang tidak diingini. Kajian ini menumpukan kepada kajian prospek menggunakan minyak sayuran sebagai pengganti bahan api diesel dengan mengkonfigurasi eksperimen untuk menguji prestasi enjin dan untuk menentukan tahap pelepasan kepada tiga campuran bahan api minyak kelapa seperti 10%, 20% dan 30% daripada minyak kelapa - campuran diesel. Kajian yang dilakukan mengkaji parameter prestasi enjin dan ciri-ciri pelepasan untuk enjin diesel menggunakan campuran diesel kelapa tanpa sebarang pengubahsuaian enjin. Kajian dijalankan pada kelajuan enjin tetap 2500 rpm, dan kemudian ia secara beransur-ansur dimuatkan. Kajian ini telah dijalankan di lima beban, iaitu 0 bar (tanpa beban), 10 bar, 20 bar, 30 bar dan 40 bar. Bagi setiap keadaan beban enjin telah dijalankan sekurang-kurangnya 4-5 minit. Keputusan menunjukkan bahawa prestasi enjin asas seperti bekalan kuasa dan penggunaan bahan api adalah setanding dengan diesel. Apabila dibandingkan dengan bahan api diesel yang telah dicampurkan, penurunan terhadap penghasilan kuasa enijn telah ditemui dan terdapat peningkatan dan kadar penggunaan minyak bagi setiap minyak dengan peningkatan jumlah campuran minyak kelapa. Dalam kes pelepasan gas ekzos enjin, CO_2 yang lebih rendah dan NOx, manakala pelepasan CO dan HC lebih tinggi telah didapati untuk bahan api blended berbanding bahan api diesel.

ACKNOWLEDGEMENT

Bismillahirrahmanirrahim,

Gratefully to Allah S.W.T for His blessing, I am successful to complete my final year project. First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Dr. Md Isa Bin Ali from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this report.

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LIST OF ABBREVIATIONS

VCO	Vegetable Coconut Oil
WCO	Waste Cooking Oil
NGO	Non-governmental Organization
HC	Hydrocarbon
NOx	Nitrogen Oxides
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
CO_2	Carbon Dioxide
CO	Carbon Monoxide
PM	Particulate Matter

LIST OF APPENDICES

LIST OF SYMBOLS

°C	-	Temperature Degree
%	-	Percentage Emission
H_u	-	Calorific Value (kJ/kg)
P	-	Power (kW)
ρ	-	Density (kg/m^3)
p	-	Pressure (Pa)
Q_a	-	Volumetric Flow-rate (m^3/s)
ω	-	Angular Velocity (rad/s)
τ	-	Torque (Nm)
$\dot{m}$	-	Mass Flow-rate (kg/h)

CHAPTER 1

INTRODUCTION

1.1 Background

Petroleum oil the most important and abundantly available energy source, is largely consumed in the world. In a study by Ramadhas (2011) reviewed that on a daily average, over 43 million barrels are consumed by the industrialized country, while at the same time around 22 million barrels are being consumed by a developing country.

Table 1.1: World's Primary Oil Demand (Million Barrels Per Day)

	1980	2000	2006	2010	2015	2030	2006-2030 (%) p.a.
OECD	41.8	46.0	47.3	49.0	50.8	52.8	0.5%
North America	20.9	23.4	24.9	26.2	27.7	30.0	0.8%
Europe	14.7	14.2	14.3	14.5	14.7	14.7	0.1%
Pacific	6.3	8.4	8.1	8.3	8.3	8.1	0.0%
Transition economies	9.4	4.2	4.5	4.7	5.1	5.6	0.9%
Russia	-	2.6	2.6	2.8	3.0	3.3	0.9%
Developing countries	11.3	23.1	28.8	33.7	38.7	53.3	2.6%
China	1.9	4.7	7.1	9.0	11.1	16.50	3.6%
India	0.7	2.3	2.6	3.1	3.7	6.5	3.9%
Other Asia	1.8	4.5	5.5	6.2	6.9	8.9	2.0%
Middle East	2.0	4.6	6.0	7.0	7.9	9.5	1.9%
Africa	1.3	2.3	2.8	3.1	3.4	4.8	2.2%
Latin America	3.5	4.7	4.8	5.2	5.6	7.1	1.6%
Int. marine bunkers and stock changes	2.2	3.6	.1	3.7	3.9	4.5	-
World	64.8	77.0	84.7	91.1	98.5	116.3	1.3%
European Union	-	13.6	13.8	13.8	14.0	13.8	0.0%

(Source: Ramadhas, 2011)

Nowadays, the supply of petroleum has yet to suffice with its high demands due to its declining resources. In referring to the Malaysia's National Depletion Policy (1980) that prioritize to lengthen the nation's life span of oil and gas reserves, many research has been conducted to support the nation's goal.

On top of that, recent studies indicate that burning fossil fuel bring damages and harms to our eco system, thus, has raising many concerns among the public community. For example, it has been known that carbon monoxide emissions have been linked to climate changes. Unfortunately, burning of petroleum is a necessity for us to go about our daily day, even know that the toxic fumes produces by burning these fuels have led to problems such as asthma and other disorders due to exhausts from diesel. From these ever-growing needs of petroleum and its fatal effects to the society, an alternative solution in finding a sustainable energy sources are needed to ensure not only the safety of the people but also to help sustained its economic demands.

Scientist since have been rigorously conducting research on a cleaner, safer and greener option fossil fuel in their way of supplying the nation's demand, while battling the rise of global warming, immense level of pollution and climate change. Therefore, scientist have been looking at the possibility of renewable product's which could replace gasoline, diesel fuel and other pollutants. Recommendations of new and alternative energy resource are available. As a result, biofuel gets into the attention as a potential investment in supplying the world's need for energy without causing serious damages to the environment.

Apart from focusing on finding the most viable alternative fuels, there are other aspects that need to be taken into consideration. Therefore, to establish innovative technologies for highly effective utilization of energy, fundamental research must be conducted in the following areas.

1.2 Problem Statement

Since the early 1900 many scholars have forecasted the fossil fuel source will soon be depleted (Deffeyes, 2005). This problem has been made certain as the needs for non-renewal energy sources is growing rapidly. Due to the condition of today's fuel depletion, there is a huge incapability to keep up with the current necessity. Industries are facing the ever-growing demands for a liable energy source. If this continues to rise in the future, the demand to supply ratio of non-renewable energy sources would be unbalanced which can lead to energy crises. Therefore, the idea of using vegetable oil for substitution and as an alternative fuel is suggested.

Rudolph Diesel have used peanut oil in a compression ignition engine to demonstrate the use of vegetable oil in his engine (Paterson et al.,1990). However, it is found that a through a prolong test of using the vegetable oil in the engine have led to injector coking and the thickening of crankcase which resulted in piston ring sticking. These problems are expected to be the result of the high viscosity and non-volatile properties of the vegetable oil which are determined can led to insufficient fuel atomization and incomplete combustion. Therefore, this have led to a conclusion that the vegetable oils cannot be use directly in direct injection diesel engines.

Moreover, fossil fuel over-consumption has led to serious environmental issues such as global warming and air pollution. There have been many studies conducted which emphasize on the importance of reducing the amount of harmful gasses emission such as nitrogen oxide (NO_x), hydrocarbon (HC), carbon dioxide (CO_2) and carbon monoxide (CO), which are found to be among the leading cause of climate change, global warming and huge increase in the level of pollution. Therefore, by changing from the use of fossil sources to renewable energy sources can greatly reduce the effect global warming and other issues, renewable energy sources have better dispersal than fossil resources and does far less environmental harm and social concerns (Cherubini & Stromman, 2011).

Hence, to overcome this problem and avoid these incidents, the blending of fuel is a solution to decrease the high viscosity of vegetable oil. Therefore, this research will be conducted to test several fuel blends formula of vegetable oil and diesel with 10%, 20% and 30% ratio to reduce the viscosity of the vegetable oil. In every test, fuel consumption during the running condition and exhaust gas emission such as nitrogen oxide (NO_x), hydrocarbon (HC), carbon dioxide (CO_2) and carbon monoxide (CO) are measured. This research will determine which percentage of mixed between diesel and vegetable oil would provide the most fuel efficiency and low emission.

1.3 Objectives

This project aims to achieve several objectives. These objectives are used as a guideline to gain better results in this research. The research objectives of this study are:

i To study the performance and the exhaust emission characteristics of the diesel engine.

ii To investigate the diesel engine fueled with vegetable oil and its blends, and compared to those of ordinary diesel fuel.

iii To investigate the effect of the variation of the diesel blend ratio, towards the engine's performance and exhaust emission.

1.4 Scope of Study

The scope of this project is divided into 3 parts i.e. sampling process, engine test performance and exhaust gas emission. Below are the detail descriptions of the scope of this research:

i. Sampling Process

   There will be several blends of vegetable and diesel oil with the percentage of fuel blends of vegetable oil such as 10%, 20%, and 30%.

ii. Engine Test Performance

   The engine will be put on several testing conditions to know the engine's performance while running on the mixed fuel.

iii. Exhaust Gas Emission

   Exhaust gas from the engine will be analyzed to determine the level of toxicity present in the combustion by-product. This include, nitrogen oxide (NO_x), hydrocarbon (HC), carbon dioxide (CO_2) and carbon monoxide (CO).

The method of the test will be discussed in the project. The chemical reaction of the combustion process is outside the scope of this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Vegetable Oil

When the first energy crisis arose in the 1970's, the research on vegetable oil for fuel purposes had begun once again. Rudolph Diesel has demonstrated that his engine is capable to run using peanut oil in a compression ignition engine to demonstrate the use of vegetable oil in his engine (Ramadhas, 2011).

Due to price of vegetable oil fuel to be more expensive compared to petroleum fuels led to its inability to compete with the current market fuel. However, there are high possibility that vegetable oils and derivatives have the potential to replace a fraction of distillate petroleum and petrochemical petroleum-based. Furthermore, using vegetable oil as a fuel can greatly enhance farm incomes and improve rural economies.

Vegetable oil has a heat content of about 90% of the diesel fuel and the potential of alternative fuels. However, Saravanan et al. (2007) and Schwab et al. (1987) found that a major obstacle that is preventing the use of vegetable oil in the direct-injection diesel engine would be due to its level of viscosity, which are found to be almost 10 times higher as compared to conventional diesel fuel. Due to the facts that raw vegetable oil is not biodiesel, which is the ester of vegetable oil produced through a process called transesterification. This results in poor fuel atomization and improper mixing with air, which in turn results in inefficient combustion. Vegetables oil fueled engine requires frequent maintenance.

This is literature review is about the viability of using vegetable oil as a replacement for diesel fuel. Note that, the term vegetable oil discussed refers to vegetable oil that have not been modified through transesterification or similar processes resulted to a product called biodiesel.

2.1.1 Palm Oil

There are two distinctive types of oil which are produced by the palm fruit, one would be palm oil and the other is palm kernel oil. There are major different between these two types of oil. For example, palm oil is produced through the extraction from the pulp of the fruit, it is edible and are largely used the food industry. Whereas, the palm kernel oil is produced through the extraction process from the seed and are most likely used for the manufacturing cosmetics and soaps, while the by-product of the extraction processes a used for feeding of livestock and biofuel. While on the on the other hand, palm oil is highly productive, able to produce more oil with less lass as compared to any other vegetable, with relatively modest inputs. As a result, palm oil production has become an important source of income and a major part of the economy in the regions where it is grown, providing the locals with sustainable income and boost its economics.

As one of the largest world's producers and exporters of palm oil and products, Malaysia is accountable for 39% of the world's production of palm oil and 44% of the world's export. The Figure 2.1 shows the areas of palm plantation in Malaysia in terms of hectares' square from the year 2010 till 2015. The finding indicates that this plant is largely grown in the peninsular Malaysia as compared to Sabah and Sarawak.

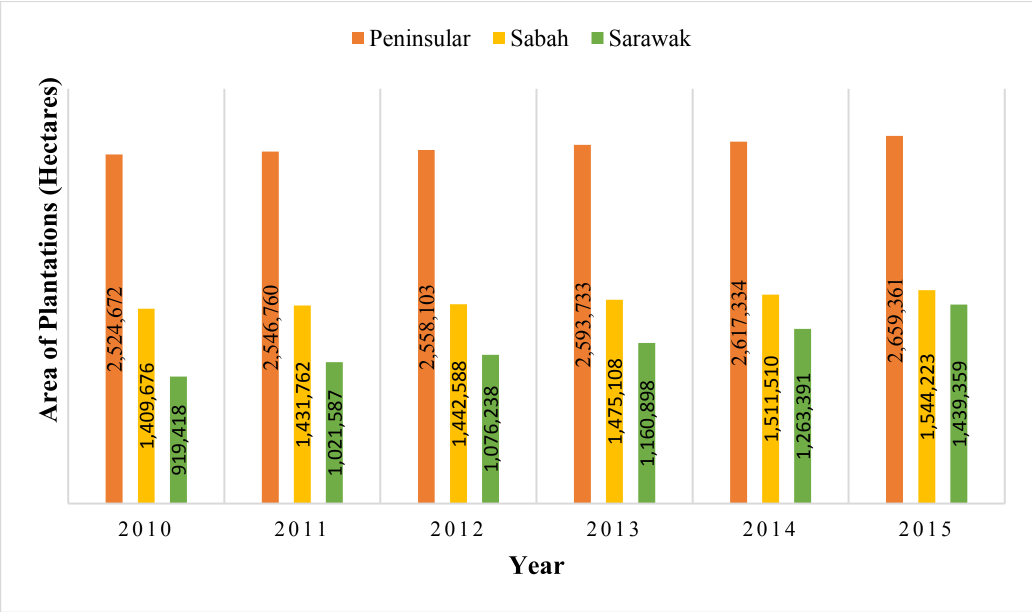

Figure 2.1: Area of palm plantation from 2010 till 2015

(source: http://www.data.gov.my/data/ms_MY/dataset/malaysia-planted-area-under-oil-palm2 [22 July 2016])

Figure 2.2 shows statistic which have been conducted by the Malaysian government, it shows that the palm oil production in Malaysia from the year 2010 until 2015 has increased at a steady rate over the years, with the production amount of 16.9 million tons in 2010 to 19.2 million tons in 2013 and latest update showed that nearly 20 million tons production of crude palm oil in the year 2015. Apart from that, this number have been expected to be kept on the rise as time progresses. Even though, this number is predicted to keep on rising in the near future. The Malaysian palm oil industry are confident that it is capable to coop with the demands and easily meets the demand.

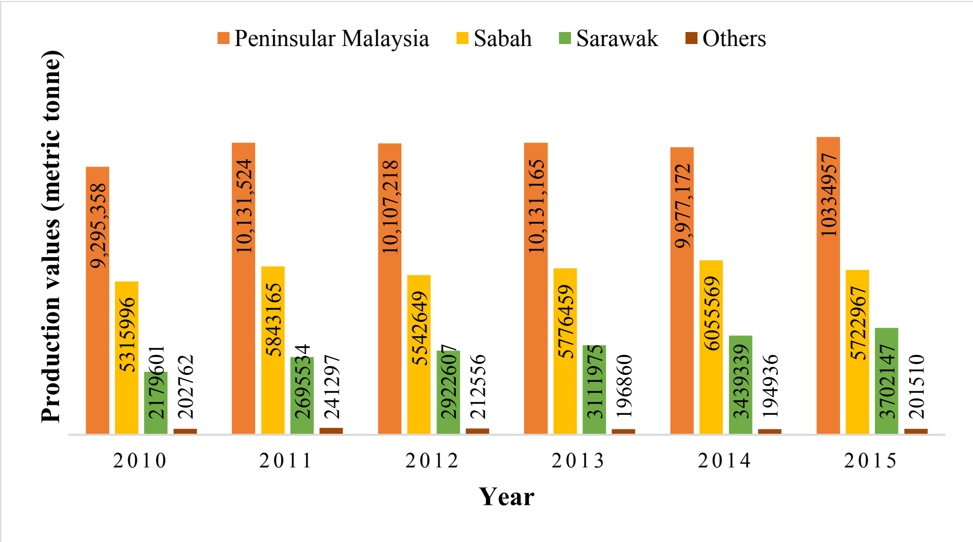

Figure 2.2: Production of crude palm oil from 2010 till 2015
(source: http://www.data.gov.my/data/ms_MY/dataset/malaysia-production-of-crude-palm-oil-by-state-3 [22 July 2016])

Palm oil have also been found to be a suitable alternative for diesel fuel. A study conducted by Sapuan et al. (1996) reported that using palm oil as diesel fuel substitutes had shown an encouraging result. In the studies, it has been determined that the engine's performance tests showed that the power output produced are nearly the same palm oil, blends of palm oil and diesel fuel and 100% diesel fuel. Though, the short-term test using palm oil fuels showed no sign of unwanted combustion chamber wear, increase in carbon deposits, or lubricating oil contamination. However, in the studies were not mentioned about any long-term effects of running the blended fuel in the diesel engine.

2.1.2 Corn Oil

It has been proven that it is plausible to run a diesel engine with only vegetable oil, but full replacement of diesel fuel on biofuel or its produce is unlikely. Although, it is not uncommon to have a mixture between these two sources. Even small additive (5-10%) of biofuel or its products leads to improvements in exhaust toxicity of diesel engine. Corn oil is one of the widest spread vegetable oils. Malaysia is the second largest palm oil producer next to Indonesia, but it produces little corn agricultural product as it widely imported to make up for the demands. Table 2.1 shows the properties of corn oil.

Table 2.1: Physically-chemical Properties of Corn Oil

Physically-chemical properties	Corn Oil
Density (20°C)/kg/m^3	921.2
Kinematic viscosity, mm^2/s with	
20°C	66.6
40°C	31.2
100°C	7.57
Surface tension ratio (20°C), mN/m	33.0
Least combustion heat, kJ/kg	37040
Cetane number	37.6
Self-flammability point, °C	-
Clouding point, °C	-7
Solidification point, °C	-15
Air quantity for combustion for combustion of 1 kg of fuel, kg content, % in mass	12.38
Carbon	77.5
Hydrogen	11.5
Oxygen	11.0
Common sulfur content, % in mass	0.002
Coking behavior of 10 % residuum, % in mass	0.5

(Source: Markov et al., 2016)

Usually corn oil is made of corn fetuses, which are side product of corn grain. Presence of corn fetuses in this product is unlikely, since the oil housed in it, is hydrolyzed and acidified, which causes deterioration of quality. Oil content of corn fetuses is within 32 and 37%. Corn oil is half-dry vegetable oil, it constitutes the liquid of light-yellow with freeze point -10…-20ºC, density 914-926 kg/m^3, dynamic viscosity 63-72 MPa (with 20ºC), iodine number 111-113 (Makarov et al., 2011).

A study by Markov et al. (2016) found that corn oil has less heating value comparing to diesel fuel: least combustion heat of both fuels is H_u = 42500 and 37040 kJ/kg, which is due to the presence of significant quantity of oxygen atoms in fatty acids corn oil molecules (11% in mass). In the research, it has come out with one feasible way to improve the diesel operation indicators, which is by working on the optimization of diesel fuel and corn oil mixtures composition. The results of the conducted research indicate that the experimental work confirmed the efficiency of using corn oil as an ecological additive to diesel fuel. Also, it is found that the amount of toxic emission in exhaust gases have reduced when using diesel fuel and corn oil mixtures.

2.1.3 Coconut Oil

The coconut tree is a plant that only grows in the tropical climate. Apart from there are over 150 different coconut species. This plant can be found in over 70 different countries throughout the world. Malaysia is also listed in that list of countries. In Malaysia, in terms of total plantation area, coconut is the fourth important industrial crop next to palm oil, rubber and paddy. Moreover, coconut is highly popular in Malaysia and are more often consumed. Other than the flesh, coconut water, milk and oil can be used in the preparation of various healthy dishes. However, considered as one of the oldest agro-based industries, it has very minor impact in its contribution the country's overall economies. It is estimated that Malaysia has about 110,000 hectares' coconut plantations around." (Agriculture Department). However, past competition for land between palm plantation and coconut plantation has led to the declination of the total area under coconut plantation due to the more favorable palm plantation. Yet, there are still efforts and pursue in booming the growth of more coconut plantations in Malaysia, specifically Sarawak.

Figure 2.3 shows the areas of coconut plantation in Malaysia according to states in terms of hectares' square. As in the year 2009, Sarawak single handedly has the largest area of coconut plantation with 23, 886 hectares' square. However, Sarawak's area of coconut plantation has been on the falling trend from 2010 till 2011, this significant decreasing trend in the width of plantation area that is also noticeable in other area too. Nowadays, Sarawak once again is e leading state for coconut plantation. Next to that, Sabah with 19,760 hectares square in 2013, another state that should not be taken lightly, as it is among the widest area of coconut plantation among other states.

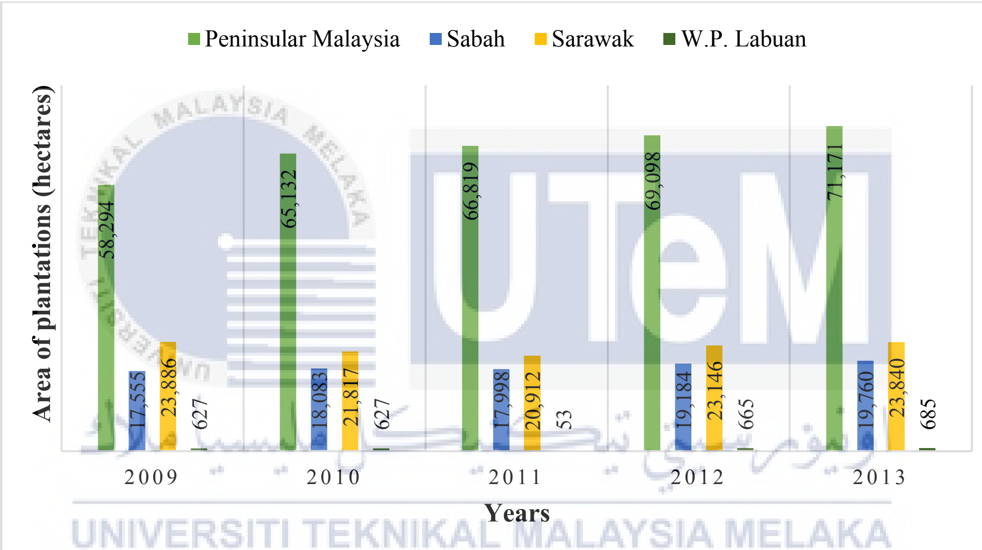

Figure 2.3: Area of coconut plantation from 2009 till 2013.

(source: Booklet Statistik Tanaman (Sub Sektor Makanan), Unit Perangkaan Bahagian Perancangan, Teknologi Maklumat dan Komunikasi, Jabatan Pertanian Semenanjung Malaysia [2013])

Figure 2.4 shows coconut oil production in Malaysia has increased over the years, from estimated 300 thousand tons in 2009 to more than 600 thousand tons in 2013. Now, coconut based products have commercialized by various countries and are widely accepted by the world. If the coconut product were to get more interest from investors and consumers, it is possible that the number of coconut plantation in Malaysia would be increased.

Therefore, NGOs such as Sime Darby and United Plantation also should consider in partaking the role in increasing the land used for coconut plantation in Malaysia. In addition, the NGOs will be able to help in providing more job opportunities and help the locals to have a sustainable income for the future.

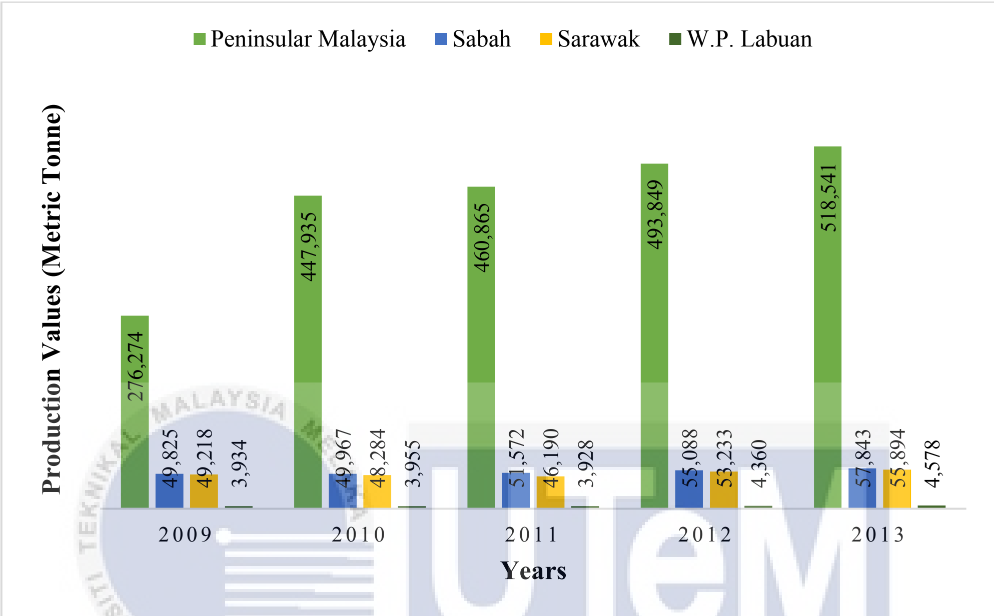

Figure 2.4: Production of coconut from 2009 till 2013.

(source: Booklet Statistik Tanaman (Sub Sektor Makanan), Unit Perangkaan Bahagian Perancangan, Teknologi Maklumat dan Komunikasi, Jabatan Pertanian Semenanjung Malaysia [2013])

A research by Herchel et al. (2001) studies the effect of coconut oil as diesel fuel alternatives or as direct fuel blends by using a single-cylinder, direct-injection diesel engine. In the studies, pure coconut oil and coconut diesel fuel blends have been tested for a wide range of engine operating condition and the results have shown successful operation even without any engine modification. Furthermore, the results of the conducted research also showed that neat coconut oil fuels gave lower smoke and NO_x emission.

2.1.4 Waste Cooking Oil

Malaysia is known for its wide and everyday use of oil in their preparation of food and cuisine. It is very well known that a method such as oil-frying is most commonly cooking style due to its influence on adding more flavor, attractive colour and better presentation of the food. However, since this method is most popularly used, it has led to large amount of waste cooking oil (WCO) resulted from the accumulation cooking oil. It is also found that WCO is widely produced all over the world (Hanisah et al., 2013). This is estimated to keep on rising throughout the coming year. In estimation, there has been over 40,000 tons per year of WCO produced in Asia alone, from countries such as China, Malaysia, Indonesia, Thailand, Hong Kong, India and many more (Razali, 2005).

Lack of waste management of waste cooking oil and uncontrolled disposal of WCO to the environment would led to a major environmental pollution, particularly land and water pollution. In water, the layers of oil on its surface would prevent the dissolution of oxygen, thus could led to the extinction of marines' life. Therefore, the option to dispose of waste cooking oil is difficult because of regulations restricting the disposal of liquid waste in landfills. Due to this regulation, there have been a rising number in unlawful method of disposal which includes open burning that causes black smokes, pouring down to drains that can clogged the sewer system and eventually lead to unsanitary conditions. All this irresponsible action has disturbed the ecological environment, marine life and lead to global warming.

Table 2.2 shows the chemical characterization of the waste cooking oil. Based on the table, about 50% of the oil was infected by acidity while about 25% of moisture content. Since the re-use of domestic oil has a substantial risk to the health of consumers, depending on the type of food subject to fry, it absorbs between 5% and 20% of the used oil that can significantly increase the number of harmful compounds.

However, waste cooking oil is the next sought after as a substitute for diesel fuel. Waste cooking oil can be obtained from many sources such as local fast food restaurants, cafeterias, hotels and other commercial food establishments.

Table 2.2: Chemical Characterization of Waste Cooking Oil.

Features	**Oil collected by food hotel sector**
Acidity (%)	0.56
Moisture	0.25
Viscosity at 37°C	44.78
Iodine Index (O_2 / kg sample)	108.22
Peroxide index (CgI_2/g)	16.61
Unsaponification index (%)	1.70
Saponification index (mg KOH/ g)	195.87
Ash (%)	0.030
Refractive index 25 °C	1.4700
Density at 15°C (g/mL)	0.9216

(Source: Ullah et al. 2014)

2.2 Diesel Blend Technology

From earlier research on various kinds of vegetable oils it was inferred the most vegetable oils could be directly used as a CI engine fuel without any engine modification is the existing engine. Thus, suggesting that vegetable oil-based fuels have immense potential as a fuel substitute. However, through extended operation of using vegetable oils have risen few concerns, such as, the carbonization of critical engine components, this would shorten the engine's life span and led other premature engine failure. The idea of blending diesel with vegetable oil partially reduces the level of viscosity in vegetable oil and was to be a method to reduce choking and extends engine life

Bettis et al. (1982) have conducted an experiment on several vegetable oils and have evaluated rapeseed, safflower and sunflower oil as a possible fuel sources. Since the chosen vegetable oil are found to have 94% to 95% of the energy content as found in a conventional diesel. However, it is also found to be approximately 15 times more viscous as compared to an actual diesel fuel. Also, upon conducting a short-term engine test using raw vegetable oil showed that the power output from these vegetable oils a nearly equal to the one produced by conventional diesel fuels, but through a prolong period of testing indicate several problems due to the carbonization of the combustion chamber.

Another study by Pryde (1982) assessed the successes and setbacks reported for alternative fuel research. This article mentioned while a short-term engine test using vegetable oil as an alternative fuel source had shown a promising result, quite the opposite had happened when it is put under long-term engine test due to the carbon buildup and lubricating oil contamination. Thus, this has led to a conclusion that an additional step must be added such chemically altering the vegetable oils before infusing it with diesel fuel to prevent premature engine failure.

2.3 Contribution of Vegetable Oil in Diesel Engine

Therefore, there is no question that vegetable oil can be used in a diesel engine and it will continue working while still delivering acceptable performance. Several vegetable oils have been evaluated to be a viable potential as substitute for fuel source (Bacon et al., 1981).

A study conducted by Knothe (2008) had found that the use of biodiesel reduces most regulated exhaust emission from a diesel engine. The type of emission reduced include carbon monoxide, hydrocarbon, and particulate matter (PM). However, nitrogen oxide (NO_x) emission are slightly increased.

2.4 Properties of Diesel

2.4.1 Density

Density is actually giving the meaning of characteristic properties of a matter (Allen et al., (2001). The density of a substance is the relationship between the mass on how much volume it takes up in an amount of material. Density of a substance is equal to its mass divided by its volume (Finkel, 1989). The SI unit for density is kg/m^3. Different matter will possess different density properties. The formula of getting density value for an element is as Eq. (2.1);

$$\rho = \frac{m}{v} \tag{2.1}$$

Density is used in many fields of application to assign specific properties of materials or products. Furthermore, knowing the density of a material would provide some information for what could be done or could possibly be change.

Therefore, the connection of density of fuel with this engine performance testing is very huge. The same amount of two different fuels will have different weights because they have different masses. Different amount of density of varying fuel samples gives effect on flame quality during combustion. Based on past research standard, density value of 919 - 937 kg/m^3 in 15 °C for coconut oil, 921 - 947 kg/m^3 in 15°C for palm oil, corn oil with 918.8 kg/m^3 in 20°C, 0.832 kg/m^3 with 15 °C for diesel oil. This data was obtained from Aydin et al., (2015).

2.4.2 Viscosity

The viscosity of the fuel plays a powerful influence on the shape of the fuel spray. For example, if the fuel has high viscosity, it would lead to low atomization which means that it will insert large droplet size into the chamber and causes high penetration of spray jet. Therefore, the reason some cold engine is difficult to start and emits dark smoky gas from its exhaust, due to the high viscous oil in the tank that once discharge into the combustion chamber produces almost a solid like stream of fuel. On the other hand, if the viscosity of the fuel is too low, it would cause the fuel to pass through leakage of the piston and piston wall especially after wear has occurred and it could lead to deficiency of lubrication. Thus, preventing an accurate metering of fuel.

2.5 Engine Performance

In the engine performance section, it will be focused in learning about engine torque, horsepower, and brake fuel efficiency to determine the engine's performance.

2.5.1 Engine Torque

Torque is most needed while moving the vehicle from standing still and / or climbing slopes. The same concept applies to heavier vehicle which requires higher amount of torque to get it moving. In a piston engine, the combustion of gas in the cylinder creates pressure against the piston. The resulted pressure forces the piston to go downwards, pushing the connecting rod that forces the crankshaft to rotate. The expression of this rotational or twisting force around an axis is called torque, which is measured in units of force times distance from the axis of rotation. Normally, the engine's torque controls its acceleration, thus, the rate of acceleration depended on the weight and load in carries. Therefore, the measure unit of torque in SI system is derived as Newton-metre (Nm.

2.5.2 Brake Power

Brake power is the power output the engine's drive shaft without the power loss caused by gears, transmission, friction, etc. The actual horsepower delivered to the driving wheels is less.

2.5.3 Brake Specific Fuel Consumption

Brake specific fuel consumption (BSFC) is the rate of fuel used in an engine during the combustion process. BSFC results are used to compare the fuel consumption with the brake power produced by the engine. It measures the amount of fuel consumption of the consumption in kilogram to produce per kilowatt hour energy. It is also described the fuel consumption per unit time to power, therefore, it indicates the engine performance and fuel efficiency. The lower the BSFC, the higher the brake power and efficiency of the engine. BSFC is strongly linked to the density of the fuel whereby is affects the mass flow rate of the fuel. Brake specific fuel consumption (BSFC) is one of the fundamental parameters which are used for comparing the effects of fuels on the engine performance.

2.5.4 Exhaust Gas Temperature

The main reason of measuring the exhaust temperature is to identify the life time and the efficiency of the engine. Today's energy concept should also include the awareness that heat is a wasteful form of energy, always downhill, hence efficiency is at the most 30-40% and that of an automobile is as low as 15-20% (De, 2008). Usually, when engine operates under a normal condition, its exhaust gas temperature normally maintain within the safe limit. However, there will be situation arise where the temperature of the exhaust gas gets too high, which indicates excessive burnt and could bring about severe damage to the engine. Therefore, the gas temperature is monitored because it is an indication of the temperature of the combustion process in the cylinders, and the amount of "afterburning" that is occurring in the exhaust manifold.

Moreover, the exhaust temperature is directly related to the air-fuel ratio. For example, a higher exhaust gas temperature indicates a richer air-fuel ratio in the diesel compression mixture. Therefore, there are two things which can influence this, one situation is due the rich mixture under heavy loads. While the other, the engine is under full throttle when the mixture either have too much fuel or too little air. Similar case could arise when there is problem in the air intake, such as, restricted intake airflow, or intake air density, which would reduce the amount of air that gets into the cylinder. In view, the amount of oxygen that gets into the cylinder will affect the combustion of the fuel.

2.6 Exhaust Emission

Just as any other internal combustion engines, a diesel engine works through the conversion of chemical energy from the fuel and converting it into mechanical power. Therefore, there are present mixture of hydrocarbons contained in diesel fuel, where upon an ideal combustion process the hydrocarbons would reacts to produce only carbon dioxide (CO_2) and water vapor (H_2O). However, there know to also produced other pollutants due to various non-ideal process that had occurred during combustion. For example, an incomplete combustion of the fuel, due to the improper mixture that occurred under high pressure and temperature. There could be contamination, due the leakage of engine's lubricating oil into the combustion chamber, and oil additives as well as combustion of non-hydrocarbon components of diesel fuel, such as sulfur compounds and fuel additives.

Total concentration of pollutants in diesel exhaust gases typically amounts to one percent as shown this is schematically illustrated in Figure 2.5. This one percent common pollutant includes unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM). Though this may seem relatively low, if multiplied by the number of vehicles and machineries that runs of diesel engine, it will surely have an effect to the environment.

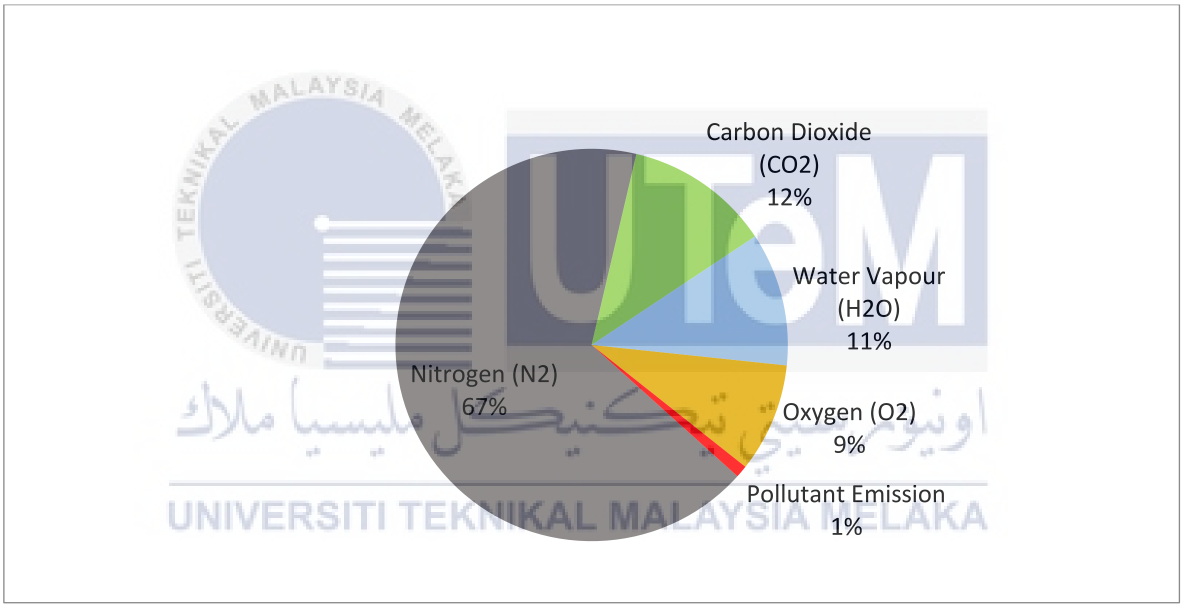

Figure 2.5: Composition of diesel exhaust

2.7 Pollutant

A pollutant is an unwanted material which could have undesirable effects or negatively impacts to the environment. This substance could bring about harm to the growth of plants or animals, or could also affect the humans too. In this study, the type of pollutant that will be tested includes and nitrogen oxide (NO_x), hydrocarbon (HC), carbon dioxide (CO_2) and carbon monoxide (CO).

2.6.1 Nitrogen Oxides (NO_x)

It is widely known that a diesel engine is one type of internal combustion engine. However, in contrast to a gasoline engine which burns or ignites its fuel by using spark, a diesel engine works different with the use of highly compressed hot air to burn or ignites its fuel. Air is known to consist of nitrogen and oxygen. As air is drawn into the combustion chamber of the engine, it is then compressed to a pre-determined pressure, once it has achieved the required pressure the fuel will then be injected with the compressed air at about the top of the compression stroke in the combustion chamber. Hence, fuel is burned and the heat is released. Normally, the nitrogen particle in the air does not react with oxygen in the combustion chamber and will be emitted out of the engine in its original form. However, the case would be totally different once the temperature inside of the combustion chamber had reach above 1600°C in the cylinders, this led to the reaction between nitrogen and oxygen and produce NO_x emissions (Resitoglu et al., 2014). In other words, the formation of NO_x is influenced by the temperature and oxygen concentration in the combustion process.

Lee, et. Al (2013) studies found that the quantity of NOx produced is dependent on the time taken in the cylinder, maximum temperature and the amount of concentration oxygen. Furthermore, all the emitted NO_x is formed during the early stage of the combustion process, when the piston is still near the top of its stroke. During at which the time where the temperature of the burning process is at its peak. Therefore, this meant that the increase in temperature during the process of combustion, would also led to the increased amount of NO_x. It is estimated that the amount of NO_x produced would also increase by as much as threefold for every 100 °C increase.

Nitrogen oxides (NO_x) is a common term used to refer to nitrogen oxide (NO) and nitrogen dioxide (NO_2). Whereas, up to 85-95% of NO_x is made up of NO. Upon emission, NO reacts with the atmospheric air and gradually converted into NO_2. Thus, for ease of reference, NO and NO_2 is compacted together and is discussed as NO_x, Though, there are some distinctive differences between these two pollutants. NO is made up of a colorless and odorless gas, while a pungent odor with a reddish-brown gas is NO_2 (Chong, et al. 2010; Hoekman and Robbins 2012).

Recent studies suggested that road transport are the main contributors of urban NO_x emission worldwide which make up to 40-70% of NO_x. Diesel vehicles are found to be the main contributor NO_x emissions as compared to vehicles that runs on gasoline. This is due to the facts that higher temperature is needed to operate diesel engines because they are compression-ignition engines. The studies also showed that diesel engine is responsible for about 85 % of all the NO_x emissions, most of which are in a form if NO emission (Lee et al. 2013; Wang et al. 2012).

Furthermore, nitrogen oxides (NO_x) is considered one of the most dangerous pollutants found in diesel exhaust. This pollutant emission is responsible to the environmental and health hazard. It also found that NO_x emissions are highly active ozone precursors playing a prominent role in the smog chemistry contribute to nutrient enrichment and acidification, which have become a growing problem in most of the large cities worldwide (Grewe, Dahlmann, Matthes, & Steinbrecht, 2012). It is viewed to be very dangerous, due to the facts that NO_x emissions would chemically reacts to other pollutants in the atmosphere, forming a layer of tropospheric ozone (the primary component of photochemical smog) and other toxic pollutants. It also the source of pollutant haze, which impairs visibility.

According to Hoeft, et al. (2012) and Kagawa (2002), stated that NO and NO_2 are both considered as toxic, however, NO_2 toxic level are five times greater as compared to

NO. NO_2 have been found to accelerate to any human lung infection and diseases it can irritate the lungs and lowers the lung's immunities to fight of any respiratory infection (such as influenza). Furthermore, NO_x emissions are known to be the cause of acid rain, which may cause harm to both terrestrial and aquatic ecosystems.

2.6.2 Hydrocarbons (HC)

There is a mixture of hydrocarbons contained in diesel fuel. Therefore, the hydrocarbon emissions by the diesel engine exhaust is from the unburned fuels inside of the combustion chamber near the cylinder wall due to inadequately required temperature to efficiently burn fuel. Also, it is found the air and fuel mixture temperature is significantly lower than the mixture temperature of that at the center of the cylinder (Correa, et al. 2008; Demers, et al. 1999).

Zheng, et al. (2008) studies has discovered that normally diesel engine would release low levels of hydrocarbons. Diesel hydrocarbon emissions occur principally at light loads. The low-level hydrocarbon emission formed due to the lean air-fuel mixing. In lean mixtures, during the power stroke, the flame's speed might be too slow for a complete combustion or no combustion will occur, and these conditions resulted to high hydrocarbon emissions.

Furthermore, there are several main factors that could affect the content of hydrocarbon, such as, fuel type, engine design and adjustment. If the engine is operated on an irregular working condition, it could also affect HC emissions level in the exhaust gas, such as, excessive nozzle cavity volumes, sudden change in engine speed, untidy injection, and injector needle bounce could lead to the rising quantities of unburned fuel to pass into the exhaust (Payri et al, 2009).

Faiz, et al. (1996) studies mentioned that the hydrocarbon emission does not only originates from the vehicle's exhaust tailpipe, it could also come from the engine's crankcase, the atmospheric venting of vapors during fuel distribution and dispensing and the fuel system. It is also found that the unburned hydrocarbons would reacts in the exhaust with the presence of oxygen and if the temperature would rise above 600 °C. Therefore, the amount of hydrocarbon emission at the tailpipe would be much lower as compared to the amount that is leaving the cylinder.

Furthermore, a study by Dhariwal (1997) indicated that the tailpipe hydrocarbon emissions are about 50-60 %, on the other hand, the total hydrocarbon emission from the crankcase hydrocarbon emissions and evaporative losses of hydrocarbon emissions have, respectively, 20-35 and 15-25 %.

Hydrocarbon are toxic, studies found that it is also related to the cause of lung cancer and respiratory tract irritation. HC emission is dangerous and could have harmful effects on human health and environment, as it too played a prominent part in the formation of ground-level ozone. Furthermore, studies found that vehicles are accountable up to about 50 % of the formation that form ozone (Krzynowski et al., 2005).

2.6.3 Carbon Monoxide (CO)

Carbon monoxide is a colorless, tasteless and odorless gas that is slightly denser than air. Although it has no detectable odor, CO is often mixed with other gases that do have an odor. A person could be exposed to CO without even realizing it, if inhaled by the human the lungs and transmitted into the bloodstream, as it is highly toxic and attaches itself to the hemoglobin cells in the body system. Afterward, it will deprive the hemoglobin of its oxygen transfer capacity, thus, led to the person experiencing suffocation due to the lack of oxygen in the body system. Excessive inhaling of CO could lead to asphyxiation, which could affect the function of different organs, slowing the bodies reflexes, causing confusion and impaired concentration, depending on the level of CO concentration in the air (Resitoglu, et al 2015; Walsh 2011; Kampa and Castanas 2008; Strauss et al. 2004; Raub 1999).

Furthermore, carbon monoxide is a harmful pollutant release by diesel engine, CO is a product imperfect oxidation process which resulted from an incomplete combustion that occurred in the combustion chamber. The amount of CO concentration mainly dependent on air-fuel mixture and it is highest where the excess-air factor (λ) is less than 1.0 that is classified as rich mixture (Wu et al., 2004). The highest amount of CO is mostly found at time where the engine had just started and during sudden acceleration of the engine, the time when the rich mixture is required. In the rich mixture, due to the reactant concentration and air deficiency, all the carbon conversion to CO_2 process has been stalled and lead to the high concentration of CO formation. Although CO production mostly occurred during rich mixture operation, a small portion of CO is also found to be emitted while the engine is operating in lean condition due to the chemical kinetic effects (Faiz et al., 1996).

A diesel engine is characterized in a lean combustion engine which have a consistently high air–fuel ratio. This meant that the formation of CO is minimal in diesel engines. Nonetheless, if the droplets in a diesel engine are too large or if insufficient turbulence or swirl is created in the combustion chamber this will lead to the production of CO (Demers & Walter, 1999).

2.6.4 Carbon Dioxides (CO_2)

Although CO_2 have its important value and benefits, it is still included in the encyclopedic definition of "pollutant", due to the facts that it could still pose a threat to the public's health and welfare. Apart from that, vehicles that operates using diesel engine have higher fuel economic and much lower CO_2 when compared to the one which operates under gasoline engine (Sullivan, et al., 2004).

Even though, it is widely known that the increase amount of CO_2 in the atmosphere originated from excessive burning to support the human activity. This has led to the declining rate of atmospheric oxygen, while at the same time has led to the increasing number of atmospheric CO_2. Which pointed that the cost of change and rapid growth have contribute to the rising of excess carbon release into the atmosphere as compared to the one that occurred naturally. Therefore, it is high time that responsibility must be taken to re-stabilize the amount of CO_2 that have been due human error.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discreetly review the methodology and procedure on how the chosen vegetable oil is blended with diesel in predetermined mixing ratio. The blended fuels are put into test to determine the engine's performance which have been classify into few different parameters i.e. torque, brake power, brake specific fuel consumption, exhaust gas temperature and its gas emissions.

3.2 Fuel Sample Preparation

The vegetable oils chosen were coconut oil. Coconut is chosen due to insufficient studies conducted in its effectiveness. In addition, the usage of palm oil will result to more of its demands. This will lead to wider plantations that can cause further damage in the infrastructure due to over plantation. The oil was obtained from the nearest local market while diesel was bought form the local petrol station. The way the vegetables oils is converted to fuel is through blending process. Several batch are prepared through the mixture of diesel and Vegetable Coconut Oil (VCO) in the following proportion by mass of fuel.

i Diesel – consist of 100% of diesel fuel,

ii S10 - consist of 10% VCO + 90% of diesel fuel,

iii S20 - consist of 20% VCO + 80% of diesel fuel, iv S30 - consist of 30% VCO + 70% of diesel fuel.

As for the example, the sample fuel will be mixed with 10:90 ratio of coconut oil and diesel respectively. To minimize error that could temper with the result of this experiment, precautionary step has been taken to ensure with the used of special device to stir the mixture constantly to get uniformly blended oil. The stirring device used was the ultrasonic homogenizer as shown in Figure 3.1. The specifications of the device are listed on Table 3.1.

Table 3.1: Lab Sonic Homogenizer Specification

Technical Specification	
Dimensions	W x H x D = 135 x 280 x 95 mm
Weight	8.8 kg
Line Voltage	230 V [50 Hz or 115 V] 60 Hz
Output	400 W (300 W in aqueous media)
Output Voltage	20% to 100%, continuous
Duty Cycle	10% to 100%, continuous
Timer	Optional, by external timer
Working Frequency	24 kHz according to US standard
Accuracy	+/- kHz
Maximum energy density	12 to 600 W/cm² depending sonotrode
Maximum amplitude	12 to 260 µm depending on sonotrode
Operational stability	Permanent operation, also in air
Fuses	T2A primary (internal)
Protection class	I, grounded device |IP 40
Interference	According to EN 55011|EN 50082-2
PC-connection	Optional, socket integrated
Ambient temperature	+5 °C to +40 °C
Humidity	Avoid extreme humidity

(Source: http://www.ultrasonichomogenizer.com)

Figure 3.1: Lab Sonic homogenizer device

(Source: UTeM's Turbo Laboratory)

Once the coconut oil and the diesel were poured into a beaker, it is then place into the device, at which the beaker is then placed at its center. The device converted electrical energy to very high-frequency mechanical motion, with a titanium probe or "horn" which rapidly vibrates in a longitudinal direction, transmitting the ultrasonic energy to the sample fuel inside the beaker to ensure that the mixture of two mutually non-soluble liquids the same throughout. The machine was to set to 50 Hz. The sample fuel is left to homogenized for about 15 to 20 minutes to get the uniform blended oils without seeing any separate layer between the mixture. Then same process was repeated for rest of the fuel samples prepared.

3.3 Properties of Diesel and Their Blend Analysis

3.3.1 Density

A hydrometer provided in the laboratory are used to measure the density of the fuel samples. A hydrometer is a basic tool used to measure the ratio of a sample liquid's density to the density of water.

The determination process of the fuel density is started by filling the glass cylinder with fuel samples until the point that when hydrometer is submerged into the cylinder, it can float by itself. Next, put the hydrometer with the bulb end down, with a gentle twist and swirl of the hydrometer to ensure there will be no trapped air pocket at the submerged end of the hydrometer. The hydrometer will float in the fuel sample. The hydrometer is assured to not in contact with the sides of the cylinder because it will give effect on the reading. Finally, the reading is taken and recorded. All fuel samples reading was recorded orderly in a table. The hydrometer used is shown in Figure 3.2.

Figure 3.2: Hydrometer

3.3.2 Viscosity

One of the important parameter that is normally considered would be the fuel's viscosity. Due to the fact, higher pressure is produced, if the fuel is highly viscous. This can cause damage on the fuel pump.

The determination process of the fuel viscosity is conducted by assuring that the fuel tested is to be at 40°C. It is accomplished through tubes that carries water that have been heated to 40°C connected to the viscometer. Next, the spindle of the viscometer was turned on to get gain the fuel’s viscosity. The viscometer was assured to be centered and well balanced because any imbalance could lead to error of the reading due to the friction caused by the spindle having contacts with the cylinder wall which holds the fuel sample. Finally, the reading is taken and recorded. All fuel samples reading was recorded orderly in a table. The viscometer used is shown in Figure 3.3. The viscometer specification is given in Table 3.2.

Figure 3.3: Viscometer apparatus

(Source: UTeM’s Chemistry Laboratory)

Table 3.2: Technical Specification of Viscometer Apparatus

Technical Specification	
Principle of measurement	Rotational viscometer
Rotational Speed rpm	0,3 / 0,5 / 0,6 / 1 / 1,5 / 2 / 2,5 / 3 / 4 / 5 / 6 / 10 12 / 20 / 30 / 40 / 50 / 60 / 100 / 200 / 250 / 300 400 / 500 / 600 / 700 / 800 / 900 / 1000 / 1100 1200 / 1300 / 1400 / 1500
Torque	0,1 ... 30 mNm
Viscosity	20 ... 510 000 000 mPa·s (cP)
Temperature integrated PT 100 sensor	-20 ... +120 °C
Display ads	temperature Revolutions / min. or shear number torque measuring system viscosity time
Energy supply	90 ... 240 V AC 50 / 60 Hz
Dimension probe elevation unit	310 mm x 75 mm Ø 140 x 245 x 62 mm
Weight	2 kg

(Source: http://www.pce-instruments.com)

3.4 Experimental Setup

The test experiment is conducted using a single cylinder, four-stroke, direct injection KIPOR KM 170F diesel engine. The engine was connected to a fluid pump for loading on the crankshaft. The engine was connected to the pump via pulley system. A gleam sticker is then attached to the pulley system, to enable measurement of speed reading using tachometer device. Furthermore, gravity is used to assist the flow of fuel to ensure that it reached the engine fuel pump. The engine's specification is given in Table 3.3.

Table 3.3: Technical Specification of Test Engine

Model	KIPOR KM 170F
Type	Single cylinder, 4-stroke, air cooled, direct injection
Engine Power (kW/r/min)	2.8/600
Piston Displacement (L)	0.211(0.219)
Bore x Stroke (mm)	70x55
Fuel Tank Capacity (L)	2.5
Piston Average Speed/ Rotate Speed (m/s/r/min)	5.5/3000 (5.7/3000) 6.6/3600 (6.84/3600)
Mean Effective Pressure/ Speed (kPa/r/min)	436/3000 (420/3000) 395/3600 (381/3600)
Lube Oil (L)	2.5
Cooling System	Air cooled
Compression Ratio	20
Rotation Direction	Anticlockwise
Fuel Consumption g/(kW.h)	≤4.08
Engine Weight (kg)	27

(Source: KIPOR KM 170F manufacturer)

3.5 Experimental Procedures

This section will explain on the condition preset to conduct the experiment to determine the engine's performance and emission while it run using the blended fuels prepared during the sampling process.

3.5.1 Engine Test

The engine is set to run at constant speed of 2500 rpm under various load form zero bar to 40 bar to carry out the engine performance and emission test. The load was increased by 10 bar for each test until maximum load has reached 40 bar. The engine was then put to run with normal diesel fuel to get the initial data. Once the data is set, the engine will then be put to run with the prepared fuel samples. The diesel engine used is shown in Figure 3.4.

Figure 3.4: Diesel engine used in experiment

The procedure of testing the engine are as follow. Firstly, the fuel tank was filled with the selected to be test, in which case the first chosen fuel was conventional diesel. Afterwards, the engine was started by turning the fuel tap to “on” position. Then, the throttle lever is moved down to start position and knob is tightened. Then, the ignition switch is turned on. Once the engine has started, it was left to warmed up for 10 minutes at no load condition. After 10 minutes, the test was begun with the reference fuel, diesel. The engine’s throttle was either increased or decreased, while a tachometer was used to ensure that the engine was running at the speed of 2500 rpm at zero load. Once the reading on the tachometer have stabilized, the engine was then left to run for about 5 minutes. Furthermore, the reading of the fuel’s consumption was also noted at the beginning and the end of the 5 minutes test run. Afterwards, a 10 bar load was added to engine by increasing the pressure of the pump which was initially connected via a pulley system. Once again, the engine’s throttle was either increased or decreased, while a tachometer was used to ensure that the engine was running at the constant speed of 2500 rpm. Once the engine’s speed is constant, it was left to run for 5 minutes while the amount fuel consumption would also be measured. The procedures are repeated for the load of 20, 30 and 40 bar. Once finished the throttle lever is pulled up to the stop position and knob is tightened. Then, the ignition switch is fully turned off.

After diesel has completely tested and reading has fully recorded, the working fuel was changed to S10. Once the test on S10 is finished, the engine is run with diesel for over 10 minutes to flush out the remaining S10 in the fuel line. The procedure was repeated for S20 and S30.

3.5.2 Emission Test

While the engine was running at constant speed of 3000 rpm under various load starting from zero bar to 40 bar, an emission test is also carried out. A gas analyzer MRU VARIOplus Portable Fuel Gas Monitoring System as shown in Figure 3.5 was used to measure the by-product content from the exhaust gas. The device's specification is included in Table 3.4. The device works by placing the sensor of the device into the exhaust pipe of the engine, at which, the amount nitrogen oxide, hydrocarbon, carbon monoxide, and carbon dioxide are measured and stored. Readings are taken and recorded from the various loads.

Figure 3.5: MRU VARIOplus Portable Fuel Gas Monitoring System
(Source: UTeM's Turbo Laboratory)

Table 3.4: VARIOplus Portable Fuel Gas Monitoring System Specification

	Range	Accuracy	Resolution	Method
Gas flow in duct	1 – 100 m/sec	0.1 m/sec	1 m/sec	Differential pressure
Oxygen O_2	0 – 25%	0.1%	0.01%	Paramagnetic cell
Carbon dioxide CO_2	0 – 10% / 30% / 100%	0.3% or 3% reading	0.01%	NDIR multi-gas bench
Carbon monoxide CO	0 – 10.000 ppm	10 ppm or 5% reading	1 ppm	Electrochemical cell
Nitric monoxide NO	0 – 5.000 ppm	5 ppm or 5% reading	1 ppm	Electrochemical cell
Nitric dioxide NO_2	0 – 1.000 ppm	5 ppm or 5% reading	1 ppm	Electrochemical cell
Sulfur dioxide SO_2	0 – 4.000 ppm	10 ppm or 5% reading	1 ppm	Electrochemical cell
Differential pressure	+/- 100 hPa	0.1 hPa	0.01 hPa	Piezo resistive
Gas temperature T-gas	0 – 1.1000 ºC	1 ºC	1 ºC	Thermocouple K-type
Calculated component	Gas flow velocity [m/sec] Gas flow rate [m/sec], normalized to gas standard condition			
Response time T90	30 s (from analyzers inlet)			
Detection limit	0.05% respective 1 ppm			
Linearity error	1% FS			
Repeatability	1% FS			
Offset drift	Negligible with standard auto-zero			
Span drift	2% FS / month			
HMI human machine interface	Backlit, graphic type display, Tactile keyboard, password protected calibration menu 8x analog output 4-20 mA, floating, max. load 500 R (OPTION) RS 232 digital interface RS 232 to RS 485 (Modbus RTU) converter (OPTION) Integrated, high speed printer			
Sample conditioning	Electric gas cooler (Peltier) and condensate draining pump Teflon particle filter, internal Viton hosing Monitored gas sample flow: 60 - 80 l/h Sample inlet pressure: - 200 hPa to + 100 hPa Sample venting: atmosphere pressure			

(Source: MRU VARIOplus manufacture)

3.6 Engine Performance

In this section, it will describe on the procedures of each of the test that is conducted to gain information regarding the engine's performance.

3.6.1 Engine Torque

The engine torque was measured from the pump speed. The engine speed is then converted to engine torque. At the beginning, gleam stickers were attached to the round trip and must double the size of the lighting source of the image between 6 mm to 25 mm. Next, the on button is pressed and held next in the range of one to two. Infrared light beams are shown in the central part of the band when light is reflected from the target received instructions on light. Then, the results of the reading will be displayed on the device. The measurement obtained will then be used to calculate the output torque of the pump.

$$\mathrm{P_p} = p \times Q_a \tag{3.1}$$

$$\omega_p = \frac{2\pi N_p}{60} \tag{3.2}$$

$$\tau_p = \frac{P_p}{\omega_p} \tag{3.3}$$

$$\tau_e = \frac{\tau_p}{n} \tag{3.4}$$

Where $\mathrm{P_p}$ is the power of the pump (kW), p is the pressure applied on the pump (Pa), Q_a is the volumetric flow rate of the pump (m^3/s), ω_p is the angular velocity of the pump (rad/s), N_p is the pump's speed (rpm) and n is the pulley ratio between the pump and engine.

3.6.2 Brake Power

From the data obtained from the power output of the diesel engine. By simple manipulation of the given equation, this data can also be gained. Thus, the manipulated equation as follow:

$$BP = P_e = \tau_e \times \omega_e \qquad (3.5)$$

Where τ_e is the torque produced by the engine (Nm) and ω_e is the angular velocity of the engine (rad/s), P_e is the power produce by the engine and BP is the brake power.

3.6.3 Brake Specific Fuel Consumption

From the data obtained from the power output of the diesel engine. By simple manipulation of the given equation, this data can also be gained. The BSFC is measured by dividing the mass flow rate of each fuel with the brake power of the engine.

$$BSFC = \frac{\dot{m}}{P_e} \qquad (3.6)$$

Where $\dot{m}$ is the mass flow rate in unit (kg/h) and P_e is the power delivered by the engine.

3.6.4 Exhaust Gas Temperature

The temperature of exhaust gas is measured via MRU Varioplus Portable Gas Monitoring System while the test is conducted. In order to do so, the device is place as close as possible to the rear end of the engine, which the exhaust pipe. All the data gathered will then be used for further analysis.

3.7 Exhaust Emission

The emission of the gases was measured by MRU Varioplus Portable Gas Monitoring System. The device needed to set to zero to get an idling condition for over 30 minutes. As the devise is set to zero, the sensor at the end of the rod was inserted into the exhaust about 10 to 15 minutes for each test. The results of unburnt hydrocarbon, carbon monoxide, carbon dioxide, and nitrogen oxide were obtained.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter is divided into three sections, which consist analyzing of fuel properties, engine performance and gases emission. Firstly, the properties that have been analyzed are the fuel's density and viscosity. The next section deals with the engine's performance test using Diesel, S10, S20 and S30. The tests carried out enable to gain valuable data, such as, brake horse power, brake specific fuel consumption, engine's torque and exhaust gas temperature. Lastly, this section will include the amount of emissions gaseous released from the exhaust pipe after combustion.

4.2 Properties of Diesel and Their Analysis

The bio-fuel produced from a mixture of diesel and coconut oil has comparable fuel properties with the conventional fossil diesel. Therefore, a need of comparative studies is needed between conventional diesel and bio-fuel blends are carried out to find out the suitable blending of the fuel. In the study Diesel, S10, S20 and S30 blend have been prepared to compare the fuel properties of different blends.

4.2.1 Density

Figure 4.1 shows the comparison of density value between conventional diesel and the blended fuel. Based on the data, it shows that the density of diesel is the lowest among the other. Diesel records a reading of 830 kg/m^3 followed by S10, S20 and S30 by 835 kg/m^3, 845 kg/m^3 and 855 kg/m^3 respectively. Therefore, this result indicates that density of the various blended ratio of coconut oil with diesel seemed to be identical. The difference between the lowest and the highest density was about 3% only.

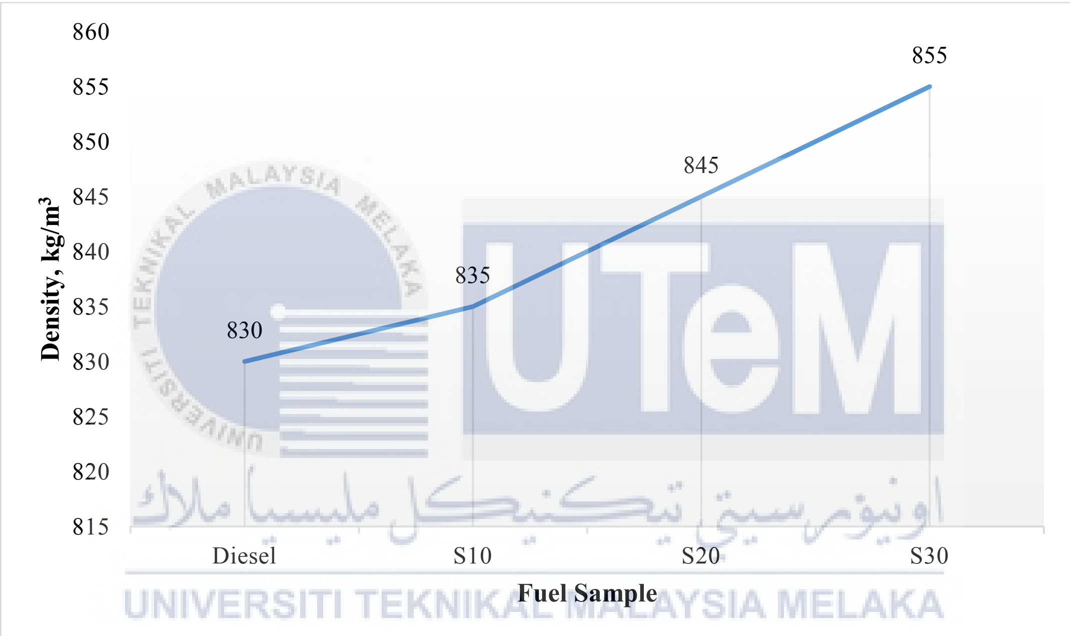

Figure 4.1: Density of the fuel samples 15°C.

Density is all about a molecule that occupies space of a substance. The higher the density, the more compact the molecular structure of the substance. Therefore, fuels that has lower density gives a lot of advantage during combustion such as more flames, easily burnt, and high percentage of complete combustion. These advantages will improve the efficiency of the engine performance. Fuels that has higher value of density are not suitable to be used in a diesel engine because it will lead to elevated level of incombustible materials in the fuels.

4.2.2 Viscosity

For practical purposes, the flow characteristic of a liquid fuel is often described or specified in terms of its kinematic viscosity, defined as the ratio of the dynamic viscosity to density.

Figure 4.2 indicates that, S10, S20 and S30 have almost the same viscosity at 40°C and it is about 15-20% higher than fossil fuel. But a slight preheating would cause to achieve comparable viscosity as that of diesel fuel. So, using S10 and S20 blend would not cause much change on the fuel spray pattern, and thus these fuels can be used in the diesel engine without modification of the fuel supply system.

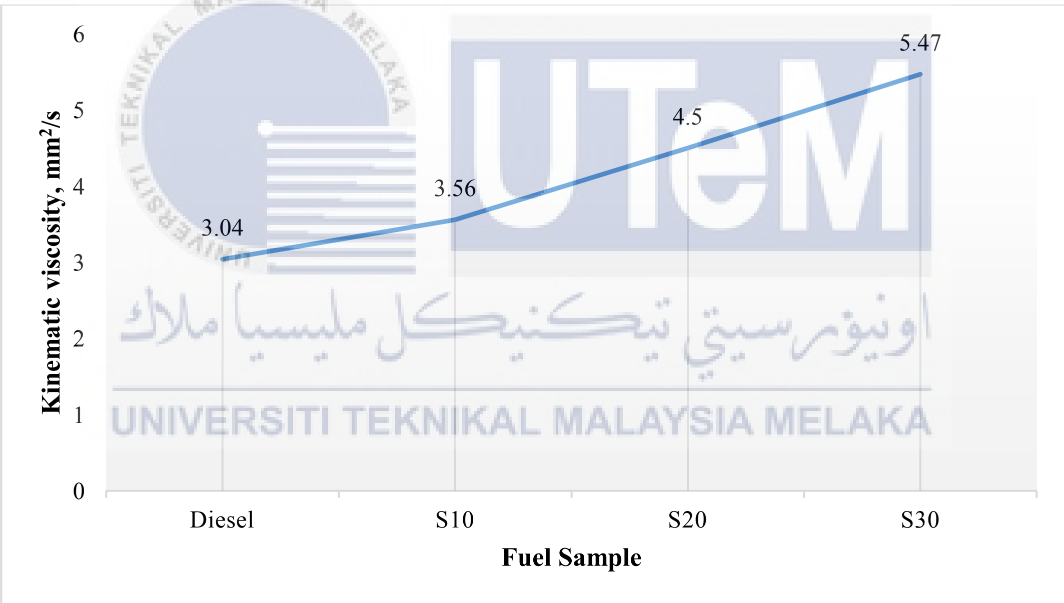

Figure 4.2: Kinematic viscosity of the fuel samples

On the other hand, S30 is a much viscous fuel, and its viscosity is much higher than diesel fuel. The high viscous fuel would exhibit almost a solid stream of spray pattern in the combustion chamber and so cold starting of the engine would be difficult. So, using S30 fuel in the existing diesel engine would require modification of that fuel system so that fuel supply system exerts high sprat pressure to achieve the desired spray pattern inside the engine cylinder.

4.3 Engine Performance

In this section, it will discuss about the data and result gathered from the experiment that have been conducted, more specifically it will discuss about engine torque, horsepower, and brake fuel efficiency to determine the engine's performance.

4.3.1 Engine Torque

Torque refers to the turning force that the engine generates to get the shaft rotate or moving. A higher torque value is desired in heavy transportation because it must be able to work with heavy loads. Which is the reason to why trucks have diesel engines that produce high torque. If the engine can do a lot of work, it can pull a lot of weight around. That's why trucks use diesel engines that produce high torque. Therefore, the experiment has been configured to gain data results which enables comparison of torque produced with each sample fuels. Figure 4.3 illustrated the torque variations with load for Diesel, S10, S20 and S30.

From the graph, it shows that the torque produced by the various fuels are nearly identical with little different between it. Furthermore, as the load increase it seems that the difference of torque produced by the engine are hardly noticeable nor visible as the torque's reading increases constantly.

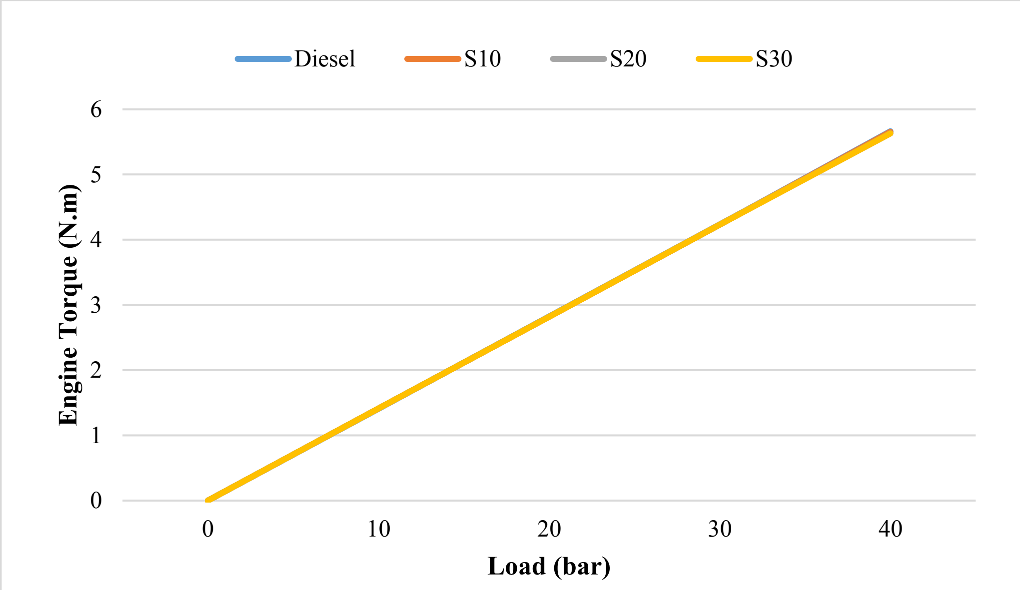

Figure 4.3: Engine's torque versus load.

In the data gained from the conducted experiment, it shows that During peak load the difference between the highest torque value is 0.58%. Though there are only slight difference between the diesel's overall torque produced as compared to S10 fuel sample, this may be related to the low value of density. Therefore, this is highly desirable as the amount of torque shouldn't be any less even if the engine is running on an alternative fuel. In the graph, the data appeared to be coincide, this may due to the scaling of the data. If the data set for the loading were to be increased, it is possible that the difference in line would be more visible. However, the results are favorable since it supports the finding that have been conducted by previous studies. As previous studies dictated that there should at least be a visible difference in comparing to conventional diesel, this is due to the difference in the fuel's density, as it is known that the lower the density of the fuel, the easier the molecule in the fuel to react with oxygen and burnt. This study shows that density of the fuel has affected the engine's performance.

4.3.2 Brake Power

Power is mostly desired in an engine because it is needed to achieve top speed. It this case, power is essential to measure the rate of work of an engine. So, if the engine can do a lot of work quickly, it's termed as very powerful. The Figure 4.4 shows the result and measurement of power produced by the engine. In general, diesel recorded the highest brake power as compared to all vegetable oils and their blends with diesel.

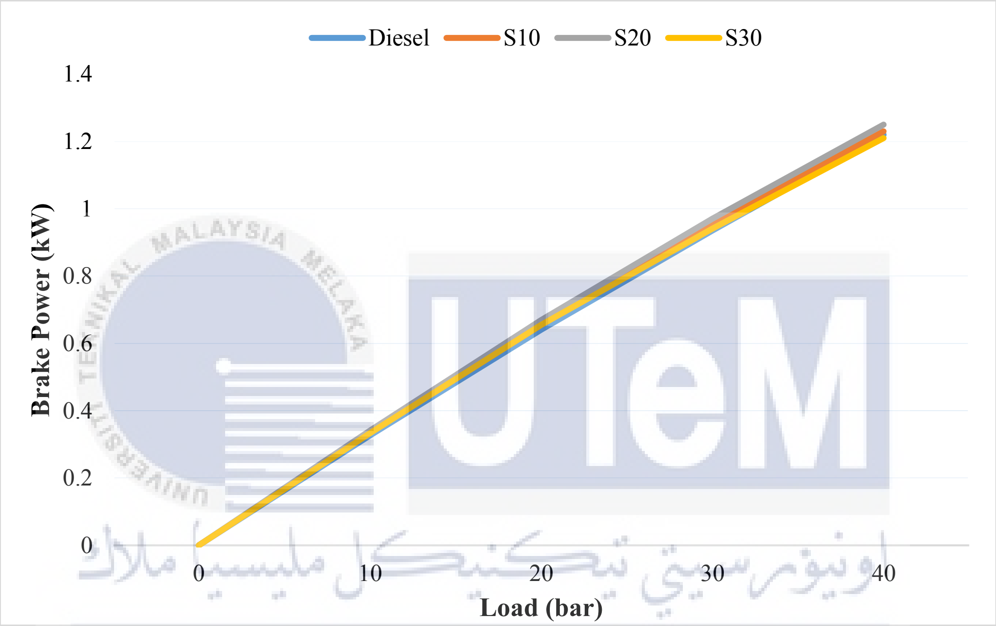

Figure 4.4: Brake horse power versus load

The statistical results of brake power obtained for Diesel, S10, S20 and S30 differ slightly as load increases. As shown in the figure above, the brake power has increases as the load was increases. The highest brake power for overall load would S20 followed by Diesel. Furthermore, S30 generated the lowest brake power in 40 bar load with 1.21 kW followed by Diesel with 1.22 kW. It is suspected that the S30 fuel sample reduction of brake power due to the result of high density and viscosity properties.

4.3.3 Brake Specific Fuel Consumption (BSFC)

BSFC is the amount the energy consumed to produce the one unit of power per unit hour. Therefore, it can be assumed that the lower the BSFC, the higher the brake power and efficiency of the engine.

Figure 4.5 shows the results of BSFC obtained through the data gathered from the conducted experiment. It is observed from this figure that, in most cases, the specific fuel consumption for all fuel blends is a little higher than the corresponding one for the diesel fuel for load of 10 and 20 bar. From the plotted graph, the reference fuel, Diesel appears to be the best consumption of fuel to produce power as it has the overall lowest usage of fuel at any loads compared to the other oils at any loads except 40 bar. From the graph shown, the polar of BSFC for each fuel tested by increasing the load 10 bar starting from zero bar until 40 bar was decreasing, especially, fuel sample S20 and S30. After the load increased by 10 bar, the BSFC reading for Diesel recorded the lowest value for overall load.

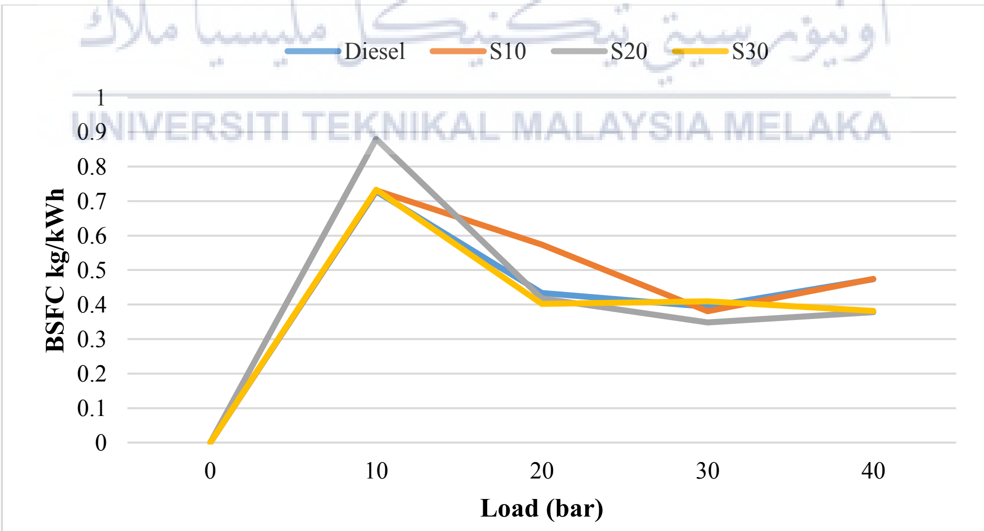

Figure 4.5: BSFC versus load.

This is the more expected behavior due to the viscosity value of the coconut oil mixtures compared to that for the neat diesel fuel. This may be linked to the facts that the blended fuel properties, such as, density and viscosity are higher as compared to conventional Diesel. Furthermore, this should do with the fact that the engine has a mechanical fuel feed. Even though that the amount of fuel injected are the same, however, due to the fuel's high viscosity have reduce the fuel's rate of atomization which led to the fuel burnt decreases. Moreover, the high-density value has the most compact particle inside it. The more compact the particle, the harder for it to move and high energy is needed to be burnt. The induction of the mass flow rate resulted decreasing BSFC for every fuel tested.

4.3.4 Exhaust Gas Temperature

Generally, the increase of load led to increase to exhaust gas temperature also for all fuels. Results of exhaust gas temperature (EGT) of the vegetable oils and their blends with diesel is shown in Figure 4.6. It can be seen at the zero load until the maximum load, the EGT for Diesel were varied between 118 °C until 249 °C, whereas, fuel sample S30 with the highest gas temperature was between 144 °C until 299 °C. The difference of EGT between the two was 20%.

As the load increased to the maximum, EGT for S30 increased abruptly to almost 25% as compared to the Diesel. All the blended fuel has a higher EGT value compared to Diesel. Reason behind this may related that the blended fuel needed a higher activation energy compared to Diesel in the engine's combustion chamber. It could also be the cause from an immature injection into the combustion chamber, since the fuel sample have a higher density value. This reduces the time taken to compress the fuel as it builds up pressure at a much higher rate, which led to too much fuel and the second is not enough air.

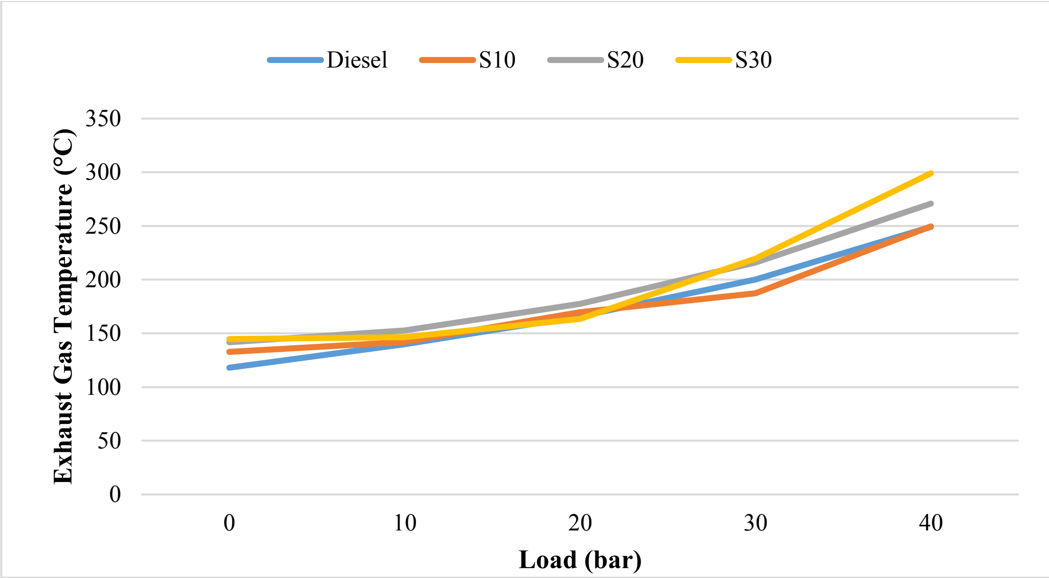

Figure 4.6: Exhaust gas temperature versus load.

4.4 Engine Emission

In this section, it will discuss about the data and result gathered from the experiment that have been conducted, more specifically it will discuss about engine's emission, such as, hydrocarbon (HC), carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen oxide (NO_x).

4.4.1 Nitrogen Oxide

In the Figure 4.9 shows the amount of NO_x emission at various load. In this study, the NO_x emission in Diesel and S20 have much higher NO_x emission as compared to S10 and S30. It is believed that the elevated temperature inside the combustion chamber affecting the formation of NO_x emission. At the load of 0 bar, S30 emitted highest NOx with 81 ppm while Diesel produced the lowest NO_x emission with 66 ppm. The NO_x emissions increased gradually after the load is set to 20 bar, there was slightly induction and it can be explained by the enrichment of oxygen the vegetable oils.

The polar of the NO_x graph showed inconsistent increasing pattern at load 30 bar. The rise of power in the engine could be the cause in the induction of NO_x, due to the amount of fuel supplied into the chamber as the load increases, which resulted in the elevated of temperature inside combustion chamber. Based on the results, it showed that at maximum load the Diesel and S30 emits the highest NO_x reading with 194 ppm and 189 ppm respectively. While compared to S10 with only 132 ppm.

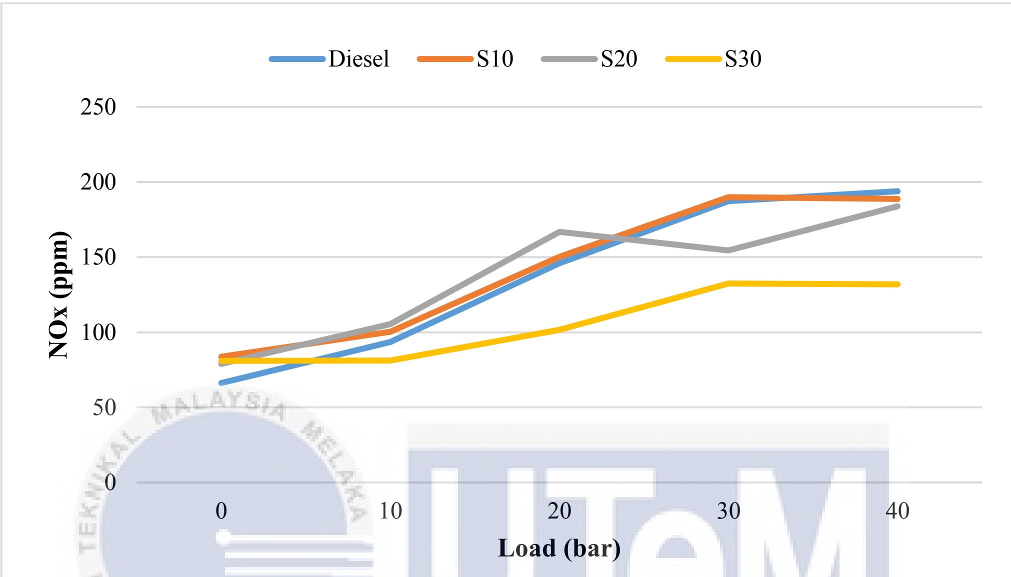

Figure 4.7: Nitrogen oxide versus load

4.4.2 Hydrocarbon

In the Figure 4.8 shows the HC emissions at 2500 rpm speed of various load condition for Diesel, S10, S20 and S30 respectively. From the beginning load until the higher load, the HC reading for each fuel showed no significant changes. The reading was inconsistent whereby for load 0 bar, S20 held the highest reading with 17 ppm compared to the lowest, Diesel with reading of only 7 ppm. The difference between the lowest and the highest at this load was 83 %.

After the load was increased by 20 bar and 30 bar, the reading seemed differ a bit as the S20 held the increment with 15 ppm for the both loads. The HC emissions for Diesel, S10 and S20 were lower than S30 during the maximum load. S30 showed dramatic difference in HC emission at load 40 with a reading of 34 ppm. The rise in HC was mostly due to the incomplete combustion quality that had occurred in the combustion chamber, thus, resulted in large number of unburnt hydrocarbons was present in the engine exhaust gasses.

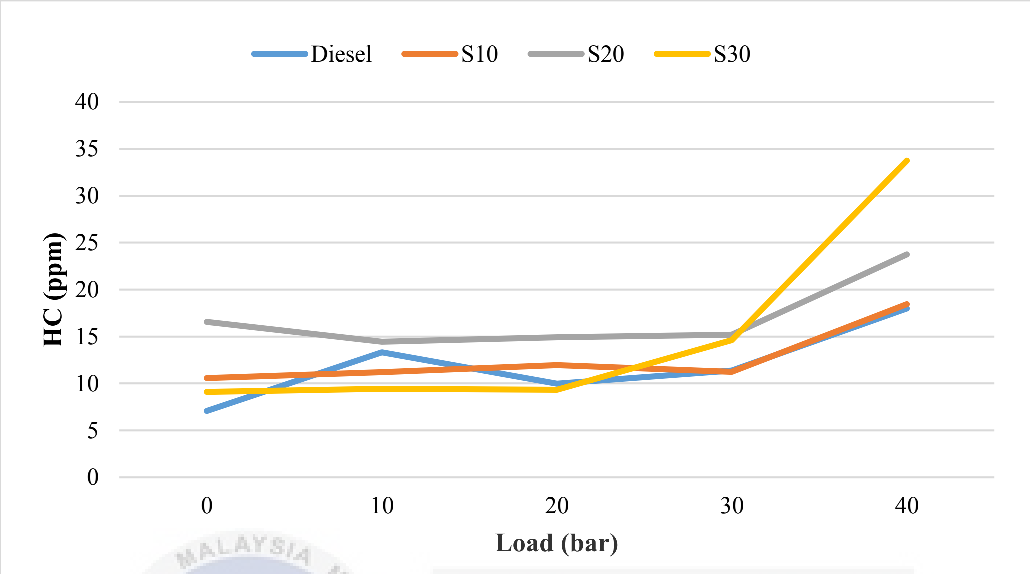

Figure 4.8: Hydrocarbon versus load

Existence of HC is a sign of poor fuel ignition during combustion. Therefore, fuel sample S30 shows that in emits the highest number of HC emission, due to the high molecule content of hydrogen and carbon. In addition, it has the denser density with 855 kg/m³ Hence, lot of unburnt HC left in that combustion chamber and expelled to the surrounding through exhaust.

4.4.3 Carbon Monoxide

The data gathered for CO emission of diesel and blended fuel is shown in Figure 4.9. The polar of the results seemed to be similar in all loads for every working fuels. It can be seen at the load 0 bar, Diesel emitted the lowest CO emission with only 500 ppm while S30 produced the highest CO emission with 647 ppm. The difference between the highest and the lowest was about 25%.

When the load was increased to 10 bar, each working fuel showed the quite comparable results as the 0 bar except S20 now emitted highest reading of CO emission with 579 ppm, in rises to 6% CO emission as compared to the previous load of 545 ppm. Moreover, Diesel showed a decreasing amount of CO emission as the load was increased to 30 bar, but later increase when the load was increased to 40 bar. This could be due to poor quality flames and incomplete combustion that had occurred. As it can be seen in the figure below, the CO emission for most of the load showed a decreasing pattern, but the increased dramatically when it is at maximum load. This was due the oxygen and carbon content as the load increased where the particles getting incomplete burnt combustion. Besides that, the density value of S30 is the most denser compared to others. Hence, it gave result for S30 to emit the highest of CO emission.

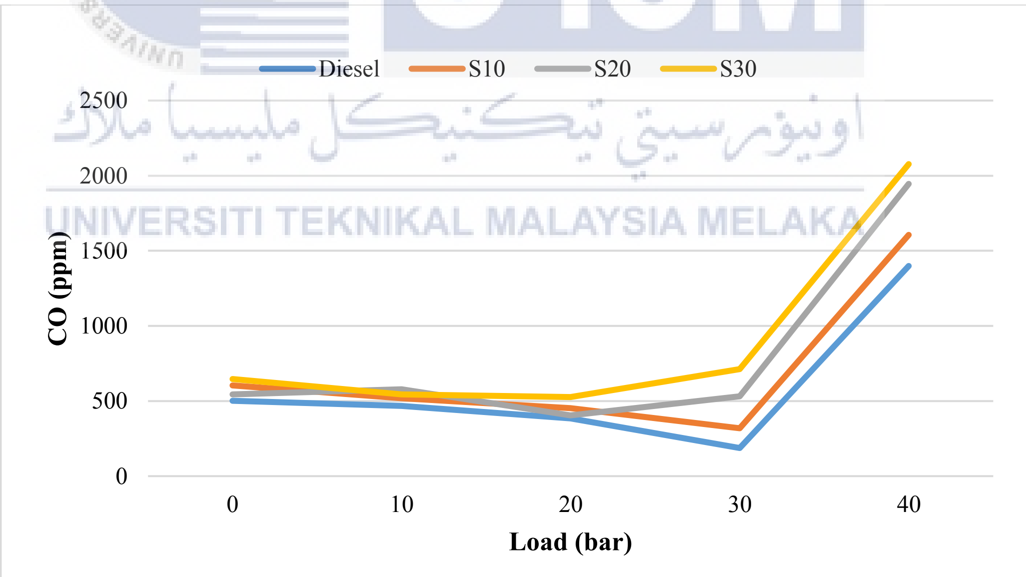

Figure 4.9: Carbon Monoxide versus load

The CO emission usually higher for fuels that has high density and rich mixture because the emission depends upon oxygen content, carbon content and combustion efficiency of the fuel. The carbon content of the fuel will oxidize the oxygen present in air to CO and subsequently to CO_2. If there is availability of oxygen, it will cause incomplete combustion of fuel and hence release the CO compound.

4.4.4 Carbon Dioxide

Carbon dioxide isn't only affecting the atmosphere. It has also made the oceans about 30 percent more acidic, affecting a wide variety of sea organisms. That percentage is also expected to rise in the coming years. However, all this carbon that have been added to the atmosphere will not go away overnight. Its effects will be destructive and long-felt, but by understanding the impact of CO_2. Therefore, action must be taken toward reducing CO_2 emissions and avoid the worse effects of climate change yet to come.

Figure 4.10 depicts the CO_2 emission of Diesel, S10, S20 and S30. The CO_2 emission reaches a maximum value at S30 with 4.22% in the load of 40 bar, while sample fuel S20 have the lowest value of CO_2 with just only 2.73% emitted at that load. The source of CO_2 was emitted is due to the oxygen content from the compression process in the fuel that was injected during the injection-combustion process.

The polar of each fuel tested was same increasingly but significantly changes occurred during various load. However, the overall emission showed that the highest CO_2 emission was from fuel sample S30, as this might indicate ineffective combustion had occurred in the combustion chamber. This could be from the fuel having such a high viscosity value which reduced the fuel capability to atomized. Hence, higher amount of CO_2 emission of S30 in exhaust emission is an indication of the incomplete combustion of fuel.

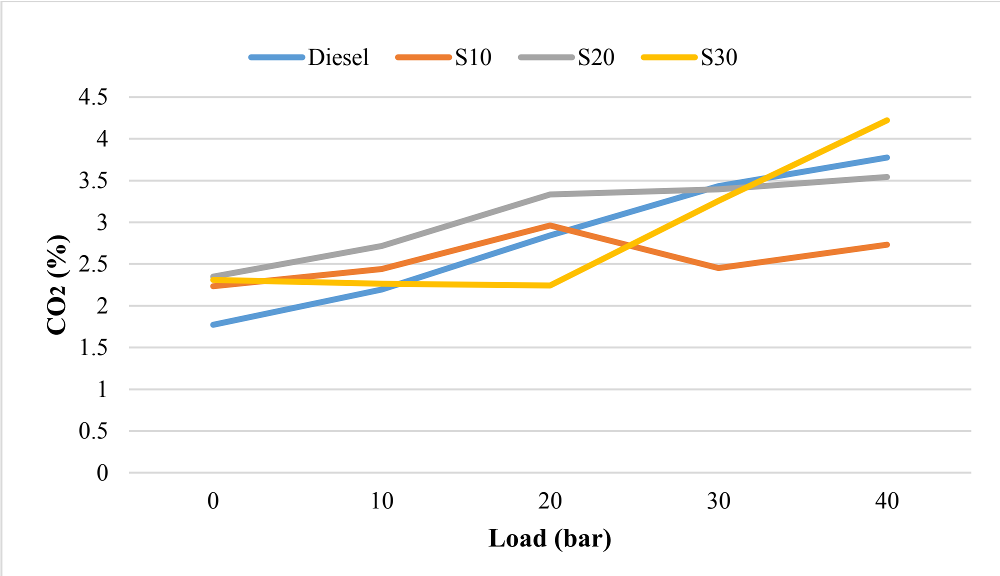

Figure 4.10: Carbon dioxide versus load

CHAPTER 5

CONCLUSION AND RECOMENDATION

Nevertheless, the development of new fuels and fuel additives requires extensive testing. It is difficult to duplicate the thousands of hours of operation and/or millions of miles of on-road operation within the limits of a research laboratory project. In this study, it was shown that coconut oil as alternative diesel engine fuels can be used successfully without modifications to the engine or the injector system. There is no question that vegetable oil can be placed in the tank of a diesel-powered engine will continue to run and deliver acceptable performance.

In this study, it has shown that in terms of engine performance, Diesel fuel have been able to produce the highest amount of torque as compared to the other fuel samples. However, it also indicates that there was no significant difference between the highest torque value and the lowest torque value of respective fuels. In the case of BSFC reading, once again Diesel consumed the overall lowest BSFC as compared to the other sample fuels.

During the emission testing process, on an average, there is a reduction CO_2 and NOx. However, there is an increase in HC as well CO emissions for the fuel samples compared to Diesel. Therefore, it can be concluded that it is feasible S10 and S20 can be used in diesel engines without any engine modifications and have beneficial effects both in terms of emission reductions and alternative petroleum diesel fuel. As it proves to be the best among the rests based on its density value and other performance and emission results shown after the tests. For overall, diesel still the best fuel to be used in diesel.

Most studies show that power and fuel economy, when compared to operation on diesel, are proportional to the reduced heat of combustion of the vegetable oil fuel. Despite the success when diesel engines are operated on vegetable oil for short term performance tests, the real measure of success when using vegetable oil as a diesel fuel extender or replacement depends primarily on the performance of vegetable oils in engines over an extended period. Moreover, a research could be conducted to evaluate long term performance characteristics.

In addition of that matter, it is recommended that for further studies in the future, the coconut oil to be converted into biodiesel, one that involves a chemical process called transesterification. This could help further reduce the coconut oil viscosity and density. Moreover, further could be done to study atomization characteristics of coconut oil, and improving the combustion efficiency. Other properties testing of the fuel could be included, such as, cetane number, calorific value, cooling value, flash point or any other test that could prove to be beneficial.

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APPENDIX A

Sample Calculation

I. Pump power, P

$$P_p = p \times Q_a$$

$$P_p = (10\times10^5)\times(3.3\times10^{-4})$$

$$P_p = 330 \text{ W}$$

II. Pump's torque, τ_p

$$\omega_p = \frac{2\pi N}{60}$$

$$\omega_p = \frac{2\pi(604)}{60}$$

$$\omega_p = 63.27 \text{ rad/s}$$

$$\tau_p = \frac{P_p}{\omega_p}$$

$$\tau_p = \frac{330}{63.27}$$

$$\tau_p = 5.22\ Nm$$

III. Engine's torque, τ_e

$$r_p = 240 \text{ mm}$$

$$r_e = 65 \text{ mm}$$

$$n = \frac{r_p}{r_e}$$

$$n = \frac{240}{65}$$

$$n = 3.7 \text{ mm}$$

$$\tau_e = \frac{\tau_p}{n}$$

$$\tau_e = \frac{5.22}{3.7}$$

$$\tau_e = 1.41\ Nm$$

IV. Brake power, BP

$$P_e = \tau_e \times \omega_e$$

$$P_e = 1.41 \times 258.48$$

$$P_e = \text{BP} = 3.27 \text{ W}$$

V. Brake specific fuel consumption, BSFC

$$\dot{m} = \rho \times q$$

$$\dot{m} = 2.36 \times 10^{-3} \frac{kg}{\text{h}}$$

$$BSFC = \frac{\dot{m}}{P_e}$$

$$BSFC = \frac{2.36 \times 10^{-3}}{3.27 \times 10^{-3}}$$

$$BSFC = 0.723 \frac{kg}{kWh}$$

APPENDIX B

Pump Performance Data

I. Pump's torque, Nm

	Diesel	S10	S20	S30
0	0	0	0	0
10	5.214	5.322	5.217	5.224
20	10.445	10.436	10.444	10.442
30	15.653	15.664	15.668	15.653
40	20.835	20.929	20.838	20.958

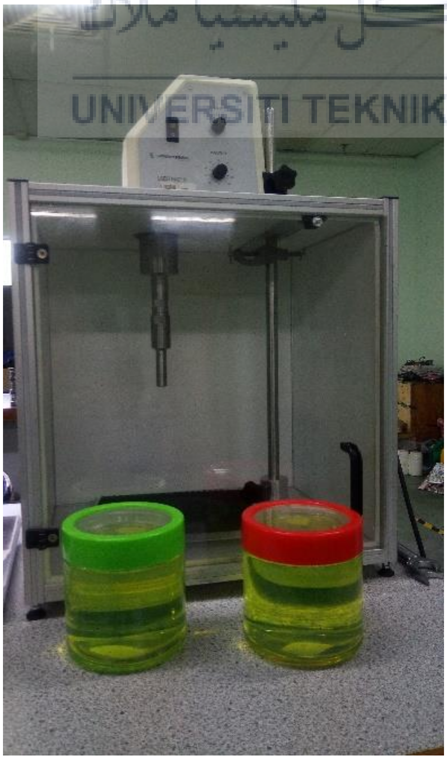
II. Pump's power, W

	Diesel	S10	S20	S30
0	0	0	0	0
10	330	338	344	337
20	649	663	677	663
30	948	970	985	954
40	1240	1250	1270	1240

APPENDIX C

Sample Preparation and Testing Process

I. Fuel sample preparation.



II. Fuel’s properties testing process.

III. Engine performance and emission testing process.