EFFECT OF B10 AND B100 PALM OIL BIODIESEL ON PERFORMANCE AND EXHAUST EMISSIONS OF A DIESEL ENGINE

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCES TECHNOLOGY) WITH HONOURS

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Faculty of Mechanical and Manufacturing Engineering Technology

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DECLARATION

I declare that this thesis entitled "Effect of B10 and B100 Palm Oil Biodiesel on Performance and Exhaust Emissions of a Diesel Engine" 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 : Mohamad Afiq Bin Azman

Date : 11 January 2023

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

Signature	:	Taufik
Supervisor Name	:	Dr. Mohd Taufik Bin Taib
Date	:	

DEDICATION

This report was dedicated to my beloved family for their endless love, support and encouragement. This report also dedicated to my supervisor Dr. Mohd Taufik bin Taib who has guided me along the way to finish this project. Thank you for all your support and guidance until this thesis complete.

ABSTRACT

A high concentration of palm oil biodiesel-diesel blend fuel is an upstanding initiative to substitute conventional diesel fuel due to its availability in Malaysia as one of the palm oil primary suppliers in the world and its ability to release fewer gas emissions than conventional diesel. The palm oil biodiesel-diesel blend fuel can be produced to different compositions and gives different engine performance and exhaust emissions. The purpose of this study is to clarify the exhaust gas emissions and engine performance produced from B10 and B100 palm oil biodiesel-diesel blends fuel in a fuel injection single-cylinder diesel engine by 3 different loads. Transesterification process has been used to produce palm oil biodiesel-diesel blend fuel. The engine being coupled to an engine dynamometer to measure the engine performance parameters and a gas analyzer to measure the exhaust emissions from the engine. An engine run has been done by using D100, B10 and B100 to inspect the condition of the engine and to evaluate the data of engine performances and exhaust emissions. The result indicates that B10 biodiesel fuel was the optimum blend that had improved the engine performances without making any modifications to the direct-injection diesel engine and B100 was the optimum blend that produced the best exhaust emission. B100 biodiesel produced the highest horsepower and lowest torque even it consumed highest volume of fuel to travel compared to B10 biodiesel that produced slightly higher horsepower and slightly lower torque produced from D100. Other than that, B100 biodiesel emitted the lowest exhaust emissions except for Nitrogen Oxide and Carbon Dioxide. Biodiesel fuel can be clarified as an effective solution to reduce greenhouse effect that produced from burning of fossil fuel.

ABSTRAK

Kepekatan bahan api campuran diesel-biodiesel minyak sawit yang tinggi merupakan inisiatif yang baik untuk menggantikan bahan api diesel konvensional kerana keberadaannya di Malaysia sebagai salah satu pembekal utama minyak sawit di dunia dan keupayaannya untuk melepaskan penghasilan gas yang lebih sedikit daripada diesel konvensional. Campuran bahan api diesel-biodiesel minyak sawit boleh dihasilkan kepada komposisi yang berbeza dan memberikan prestasi enjin dan pelepasan ekzos yang berbeza. Tujuan kajian ini adalah untuk menjelaskan pelepasan gas ekzos dan prestasi enjin yang dihasilkan daripada campuran bahan api diesel-biodiesel minyak sawit B10 dan B100 untuk memeriksa keadaan enjin dan dalam enjin diesel satu silinder suntikan bahan api dengan 3 beban berbeza. Proses transesterifikasi telah digunakan untuk menghasilkan campuran bahan api diesel-biodiesel minyak sawit. Enjin digandingkan dengan dinamometer enjin untuk mengukur parameter prestasi enjin dan penganalisis gas untuk mengukur pelepasan ekzos daripada enjin. Pengoperasian enjin telah dilakukan dengan menggunakan D100, B10 dan B100 untuk memeriksa dan menilai data prestasi enjin dan pelepasan gas ekzos. Hasil kajian menunjukkan bahawa biodiesel B10 merupakan campuran optimum dalam meningkatkan prestasi enjin tanpa sebarang modifikasi dilakukan terhadap enjin diesel suntikan terus dan B100 adalah adunan optimum yang menghasilkan pelepasan ekzos terbaik. Biodiesel B100 menghasilkan kuasa kuda tertinggi dan tork terendah walaupun ia menggunakan isipadu bahan api tertinggi untuk bergerak berbanding biodiesel B10 yang menghasilkan kuasa kuda lebih tinggi sedikit dan tork lebih rendah sedikit daripada apa yang dihasilkan daripada D100. Selain daripada itu, biodiesel B100 menghasilkan pelepasan gas ekzos terendah kecuali Nitrogen Oksida dan Karbon Dioksida. Bahan api biodiesel boleh dijelaskan sebagai penyelesaian yang efektif untuk mengurangkan kesan rumah hijau yang terhasil daripada pembakaran bahan api fosil.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
NO_x	-	Nitrogen Oxide
HC	-	Hydrocarbon
BSFC	-	Brake Specific Fuel Consumption
BTE	-	Brake Thermal Efficiency
%	-	Percentage
B10	-	Biodiesel 10%
B20	-	Biodiesel 20%
B30	-	Biodiesel 30%
B100	-	Biodiesel 100%

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Diesel was used widely in every country globally that has been used in many types of applications. Diesel is one of the primary sources of air pollution in the world because it was used by diesel vehicles and diesel machinery that release a large number of air pollutants such as nitrogen oxides (NO_x) and carbon monoxide (CO), which affects the surrounding nature and human health. The most recent environmental data in Beijing found that motor vehicles, non-road mobile machinery, and other mobile sources contributed 45% of emissions, with diesel combustion accounting for 25% of emissions, including diesel-powered vehicles and non-road machinery (Faizal & Ateeb, 2018). As widely known, the crude oil source initially collected from nature decreased year by year. Due to this constrain, it will cause higher fuel prices and affect many nations' economic situation.

Diesel was gained from crude oil that can be transformed into various petroleum-based products through distillation. Diesel was used to operate the diesel engine by applying high pressure due to compression in the chamber. At a certain pressure, the fuel will burn and supply torque to the system. The outcome of the combustion process was released through the exhaust system. The combustion that happened in the chamber was not wholly burned because of the inadequate amount of oxygen in the combustion chamber, and it released an amount of carbon monoxide (CO) of approximately around 1.24% but only produced roughly about 5.1% carbon dioxide (CO_2) from total combustion process (Bari & Hossain, 2019)

A solution that has been studied widely to overcome this problem is using a biodiesel-diesel blend that can be produced from palm oil that widely planted in Malaysia. 5.74 million hectares of land in Malaysia had been planted with oil palms and 47% of the area was in Peninsular Malaysia, Sabah and Sarawak had nearly the same land share for oil palms with 27% and 26% respectively in 2016. Johor has the greatest area of oil palm plantations in Peninsular Malaysia with 745,630 hectares, followed by Pahang with 730,052 hectares. Private plantations possessed 61,2% of the total oil palm-planted land, while the remainder was divided between federal and state government agencies and independent smallholders and the numbers keep growing until 2021 by government initiative with FELDA to keep the palm oil sources sustain for the next 30 years (Tang & al Qahtani, 2020).

The various composition of biodiesel blended with diesel fuel will produce different outcomes from the engine. Biodiesel-diesel blends commonly used for testing are B5, B10, B20, B30, B50, and B100; for example, B10 means 10% biodiesel was blended with 90 % of diesel fuel through blending process. Production of biodiesel named as transesterification reaction involving Triglycerides and alcohol produces biodiesel or mono-alkyl esters of long-chain fatty acids, such as Fatty Acid Methyl Esters (FAME). The alkoxy group of an ester can catalyze alcohols like methanol and ethanol (acyl acceptor) to convert Triglycerides to FAME and glycerol in this process. Then, in the presence of alkaline, acidic, or enzymatic catalysts, a lipid interacts with a mono-alcohol to create FAME and glycerol (Rezania et al., 2019).

This present study will investigate the exhaust gas emissions which are Carbon Monoxide (CO) emission, Carbon Dioxide (CO_2) emission, Nitrogen Oxide (NO_x) emission, Hydrocarbon (HC) emission, exhaust gas temperature and smoke opacity between B10 and B100 palm oil biodiesel-diesel blends fuel in a single-cylinder fuel injection diesel engine. This study also will investigate the engine performance consists of torque, brake power, Brake Thermal Efficiency (BTE) and Brake Specific Fuel Consumption (BSFC) produced from the combustion process in a single-cylinder fuel injection diesel engine using B10 and B100 palm oil biodiesel-diesel blends fuel.

1.2 Problem Statement of Study

Before the combustion process happens, the piston will suck in the fresh air entering the chamber, and the injector will inject the diesel. The biodiesel-diesel blends will ignite at a certain pressure point, and the combustion process will happen in the chamber. Torque was produced from the combustion process, and it was supplied to the engine. From this combustion process, the smoke is released through the exhaust system, and it will remove the burned and unburned particles from the chamber. The problems that occur from the combustion process are:

i. Different feedstocks used to produce biodiesel contains different numbers on its physicochemical properties.
ii. Different compositions of biodiesel will produce different numbers of gas emissions.
iii. Different compositions of biodiesel will generate different engine performances from the diesel engine.

Therefore, the aim of this study is to clarify the exhaust gas emissions and engine performance produced from B10 and B100 palm oil biodiesel-diesel blends fuel.

1.3 Objective of Study

The main objective of this project is related to the aspects below:

i. Produce biodiesel using transesterification process
ii. Analyze the diesel engine performance of B10 and B100 biodiesel
iii. Investigate the exhaust emissions of B10 and B100 biodiesel

1.4 Scope of Study

i. Biodiesel production using palm oil as feedstock

ii. Engine performances test, torque and brake power by using engine dynamometer.

iii. Exhaust gas emissions, exhaust gas temperature, Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Oxide (NO_x), Hydrocarbon (HC) and smoke opacity by using gas analyzer.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Biodiesel is one of the alternatives to restore nature and preserves our nature for future generations. Due to the non-renewable nature of petroleum, its stocks will be depleted shortly. Due to the disparity between supply and demand, the cost of petroleum-based fuels rises substantially. Increased environmental concerns also encourage the search for innovative alternative energy sources. To build fuels that could replace petroleum derivatives, scientists have focused on discovering alternative fundamental energy sources. In this search, biodiesel ranks first due to its renewable energy origin, widespread availability, and biodegradability (Singh et al., 2021). Biodiesel can be utilized in existing diesel engines without modification because it is renewable, biodegradable, and non-toxic. Biodiesel emits much less pollution than regular diesel oil and has superior features such as sulphur content, biodegradability, flash point, and aromatic content. Edible oils have a viscosity that is 10 to 17 % higher than ordinary diesel fuel. This increased viscosity may result in large carbon deposits in the engine fuel injector, combustion chamber, and valve seats, producing serious engine fouling problems despite routine maintenance (Raghuvaran et al., 2020). So, the biodiesel needs to be produced until it achieves a given standard from an authorized body to make sure that it will produce power similar or better than the conventional diesel.

2.2 Biodiesel

Biodiesel can be categorized into 4 generations consists of first-generation biodiesel, second-generation biodiesel, third-generation biodiesel and fourth-generation biodiesel. It has been grouped based on their development in past until recent studies. Sugar, starch, and edible oil are used to make the first generation of biodiesel. Biodiesel like ethanol, propanol, and butanol are made when sugars, starches, or cellulose are fermented by the action of microorganisms and enzymes. First-generation biofuel processes are helpful, but there is a limit to how much biodiesel they can make without putting food supplies and biodiversity at risk. Biodiesel of the second generation are generated from lignocellulosic crops. This generation of technology permits the separation of a plant's lignin and cellulose, allowing cellulose to be fermented into alcohol. These biofuels can be derived from several types of biomasses, as the term refers to any source of organic carbon. This is rapidly renewable as part of the carbon cycle. It can provide a greater proportion of biodiesel in a sustainable, cost-effective, and environmentally beneficial manner. Algae was used to create third-generation biofuels. Algae have made a compelling case because they can radically transform the energy sector. In order to thrive, algae require simply carbon dioxide, nutrients, water, and sunlight. Some algae cultures have also been demonstrated to grow in wastewater, which eliminates the need for a freshwater media and further cuts costs. In addition, it has been demonstrated that renewable biodiesel offers a very favorable energy yield when compared to conventional diesel, meaning that the energy gained compared to the energy required is much higher while keeping a far less carbon footprint (Dahman et al., 2019). The fourth generation of biodiesel may include photobiological solar fuels and electrofuels. Solar biodiesels are created by converting solar energy into biodiesel utilising raw materials because they are abundant, inexhaustible, and cheap (Singh et al., 2020). Table 2.1 shows differences of advantages for these 2 types of fuels (Singh et al., 2019).

Table 2.1 Differences of physicochemical between biodiesel and conventional diesel (Singh et al., 2019)

Point	**Explanation**	**Biodiesel**	**Conventional Diesel**
Acid Number	High acid number creates the issue of corrosion in fuel delivery channel of the engine, and this high acid value is due to high free fatty acid content	High	None
Calorific Value	Calorific value of fuel indicates the quantity of energy which liberates when the unit amount of fuel burns. For an internal combustion engine, fuel with a higher CV is advantageous.	Low	High
Cetane Number	The issue of corrosion in the fuel delivery channel of the engine is caused by a high acid number, which is caused by a high free fatty acid concentration.	High	Low, unstable
Flash Point	The lowest temperature at which vapors of fuel catches fire when it encounters some fire source. Higher flash point fuel has superior safety features in transit and storage.	High	Low
Kinematic Viscosity	Injection of fuel in the engine cylinder also affected by the viscosity of fuel because elevated viscosity creates inferior atomization. To obtain higher penetration of fuel in the cylinder, higher viscosity fuel is used. It causes bigger droplet sizes, narrower injection spray angle and inferior vaporization.	High	Low

Sulfur Content	The amount of sulfur oxide produce in the cylinder during combustion is depends on the amount of sulfur present in the fuel. Sulfur oxide is the main cause of acid rain.	Low	High
Cloud Point	When the oil is cooled, the temperature at which a cloud of wax crystals first appears	High	Low
Pour Point	Temperature where the fuel is totally liquefied	High	Low

2.2.1 Compositions of biodiesel

Biodiesel can be produced to various compositions and with various of feedstocks such as edible oil, non-edible oil, waste oil and solar oil. Different compositions produce different output number of performance and emission but it still need to be research further for the most compatible composition that will produce the best performance and emissions that affect nature surrounding. As a result of adding 20% biodiesel by volume, there was a 4% increase in specific fuel consumption and a 2.8% drop in thermal efficiency when compared to conventional diesel usage (Abed et al., 2018). Table 2.2 shows the various compositions that commonly made by researchers to study its physiochemical properties and its emission on diesel engine.

Table 2.2 Compositions of biodiesel

Name	Compositions
B10	90% pure diesel + 10% biodiesel blends
B20	80% pure diesel + 20% biodiesel blends
B30	70% pure diesel + 30% biodiesel blends
B100	100% biodiesel blends

2.2.2 Feedstocks of biodiesel

Biodiesel can be produced from various types of feedstocks according to its availability and sustainability of the sources on every country. The purity and content of biodiesel derived from distinct feedstocks varies. In Canada, canola oil is utilized as feedstock, but in Brazil and the United States, soybean oil is used as feedstock. Indonesia and Malaysia employ coconut and palm oils as biodiesel feedstock, while Italy, Germany, Finland, and the United Kingdom use rapeseed oils as biodiesel feedstock. In India, Karanja and Jatropha are being explored as prospective biodiesel feedstocks (Singh et al., 2020). Among them, sunflower oil, rapeseed oil, soybean oil and mustard oil have been utilized as biodiesel feedstock in the past; however, adverse effects on food crops have hindered their use as biodiesel feedstock. Table 2.3 shows lists of feedstocks that available for each biodiesel generations.

Table 2.3 Feedstocks used for different generation of biodiesel production (Singh et al., 2020)

1st Generation	2nd Generation	3rd Generation	4th Generation
Corn	Calophyllum inophyllum	Biomass pyrolysis	Photobiological solar biodiesel
Palm	Jatropha curcus	Chicken fat	Electrobiofuels
Soybean	Karanja	Waste cooking oil	Synthetic cell

Many researchers from 5 years earlier had made various studies about biodiesel blends productions, engine performances and exhaust gas emissions using many types of feedstocks to clarify their effectiveness against conventional diesel that have been used globally. Table 2.4 shows the differences between feedstocks used by researchers in their study.

Table 2.4 Differences between feedstocks used by researchers in their study

Author	Titles	Feedstocks	Composition	Findings
(Singh et al., 2019)	Chemical compositions, properties, and standards for different generation biodiesels: A review	1^{st} Generation Biodiesel to 3^{rd} Generation Biodiesel	-	Difference of chemical compositions, properties and standards for every Biodiesel Generations
(Ağbulut et al., 2020)	Impact of various metal-oxide based nanoparticles and biodiesel blends on the combustion, performance, emission, vibration and noise characteristics of a CI engine	Waste cooking oil methyl ester and various metal-oxide based nanoparticles (Aluminum Oxide, Titanium Oxide and Silicon Oxide)	B10	The addition of nanoparticles to diesel-biodiesel blends significantly altered their chemical and physical properties. Aluminum Oxide exhibited the lowest Carbon Monoxide emission. Conventional diesel has the

				greatest Nitrogen Oxide emissions. Biodiesel and nanoparticles resulted in a significant reduction of hydrocarbon emissions.
(Gad et al., 2021)	Assessment of diesel engine performance, emissions and combustion characteristics burning biodiesel blends from Jatropha seeds	Egyptian Jatropha seeds	-B20 -B40 -B60 -B80 -B100	Due to its enhanced physical and chemical qualities, oil extracted using a screw press was selected as a biodiesel feedstock. Due to the lower calorific values of biodiesel blends in comparison to diesel oil, an increase in the biodiesel volume fraction reduced the brake output power and mean effective pressure.
(Kim et al., 2018)	Trend of Biodiesel Feedstock and its	-Palm Oil -Sesame Oil		Palm Oil biodiesel

	Impact on Biodiesel Emission Characteristics	-Soybean Oil -Animal Fats -Waste Cooking Oil	B100	produced the lowest Carbon Monoxide and Nitrogen Oxide emissions. Sesame Oil and Animal Fats biodiesel produced the lowest Particulate Matter.
(Elkelawy et al., 2021)	Study of performance, combustion, and emissions parameters of DI-diesel engine fueled with algae biodiesel/diesel/n-pentane blends	Algae Biodiesel with different extents of n-pentane additive	-B50 -B50 with 5, 10 and 15ml n-pentane per liter	Through performance studies, it was determined that 15 ml of n-pentane per liter was the optimal amount, since it increased the brake thermal efficiency and decreased the brake specific fuel consumption compared to the B50.
(Allami & Nayebzadeh, 2021)	The assessment of the engine performance and emissions of a diesel engine fueled by biodiesel produced	Waste cooking oil Biodiesel using catalyst homogeneous	-B10 -B25 -B40	The results indicated that the catalyst type had a negligible effect on the physical properties of the

	using different types of catalyst	and heterogeneous		biodiesel generated and compositions of FAME altered marginally. The total time for biodiesel produced with a heterogeneous catalyst was shorter despite the higher energy use.

2.2.2.1 Palm Oil

Palm oil can be used not only as a food, but also as a fuel called biodiesel. A study showed that now, oil palm plantations cover 14% of all the land in Malaysia (Faizal & Ateeb, 2018). If Malaysia wants to become the world leader in renewable energy, it needs to know more about one of its main biodiesels and how its use could affect the energy sector, the economy and the environment. In terms of market price and oil content, palm oil is the best option since it contains high oil content and being sell with minimum price (Dey et al., 2021) as shown in figure 2.1. The palm tree is the source of crude palm oil. The oil is taken from the fruit's inner shell, and the extracted oil is refined in refineries. The transesterification reaction is applied to refined palm oil to make palm biodiesel.

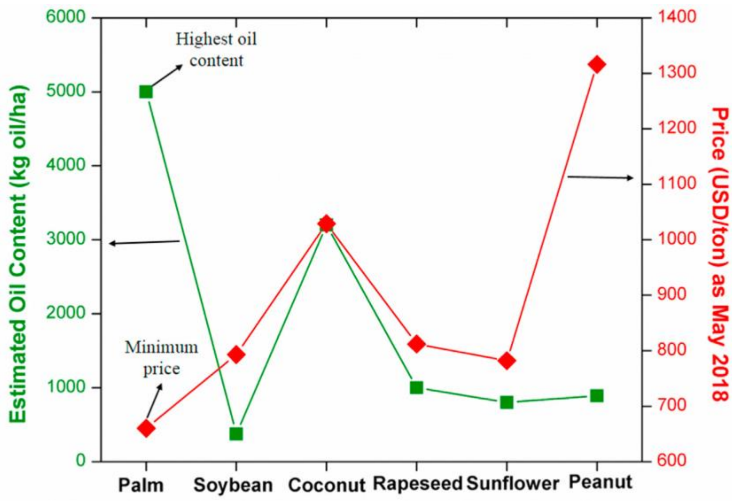

Figure 2.1 Palm oil price and oil content compared to other feedstocks (Dey et al., 2021)

Some advantages of using palm oil for biodiesel productions are low sulphur concentration makes it appropriate for biodiesel manufacturing, high cetane number reduces the knocking tendency, has higher oil yield than other edible oil sources and higher growth rate of palm trees (Singh et al., 2021). Despite advantages that benefit community, there are still drawbacks when using palm oil as feedstock for biodiesel. Table 2.5 shows the advantages and disadvantages of using palm oil as feedstock for biodiesel production (Dey et al., 2021).

Table 2.5 Advantages and disadvantages of using palm oil as feedstock for biodiesel production (Dey et al., 2021)

Advantages	**Disadvantages**
Minimal market price and increased production yield with high oil content	Palm biodiesel's higher density and viscosity cause lower fuel atomization and longer ignition delays
Palm biodiesel is environmentally friendly, sustainable, biodegradable, non-toxic and may be used in any diesel engine without requiring any engine modification	NOx emissions from palm biodiesel are increased by its high oxygen concentration

Palm biodiesel's high cetane number reduces knocking	Due to a lack of flow characteristics at lower temperatures, cold weather performance becomes impaired
Improved safety due to high flash point	Higher fuel usage due to lower energy content than conventional diesel
Low concentration of sulphur	High pour point and cloud point

Palm oil has different physical properties than conventional diesel on some important points such as cetane number, flash point, kinematic viscosity and Sulphur content. Table 2.6 shows full difference of physical properties between palm oil biodiesel and conventional biodiesel (Singh et al., 2021).

Table 2.6 Difference of physical properties between palm oil biodiesel and conventional biodiesel (Singh et al., 2021)

Properties	**Palm Oil Biodiesel**	**Conventional Diesel**
Density at 15 ºC (kg/m^3)	880	833-881
Kinematic viscosity at 40 ºC (g/cm) / cSt	4.50 cSt	10-13 g/cm
Flash point (ºC)	175	70
Highest Calorific Value (mJ/kg)	41.30	44.8
Pour point (ºC)	14	6
Cetane number	52	40-55
Iodine value (g/100 g)	55	-
Acid number (mg KOH/g)	0.33	-
Sulfur % (w/w)	0.04	0.25
Water amount (mg/kg)	306	0.02

2.2.2.2 Waste Cooking Oil

Waste cooking oil is vegetable oil that has been used in the preparation of food but is no longer appropriate for use and is being collected from the food processing sector and restaurants (Kanwar Gaur & Goyal, 2022). An estimated 540 000 metric tonnes of used cooking oil are abandoned each year in Malaysia without being treated as wastes and the majority of this used oil is dumped into drainage and soil (Tang & al Qahtani, 2020). Table 2.7 shows the amount comparison of waste cooking oil generated in Malaysia compared to other Asia countries (Suzihaque et al., 2022). Malaysia is among country that produced high amount of waste ccoking oil compared to other Asia countries.

Table 2.7 Amount of waste cooking oil generated by several Asia countries (Suzihaque et al., 2022)

Country	**Quantity (million tonnes/ year)**
China	5
Malaysia	0.54
Taiwan	0.05-0.03
Indonesia	0.9

Additionally, if waste cooking oil output increases, this might be used as a feedstock for biodiesel manufacturing. The oil is heated to high degrees in the presence of air and moisture during the frying process. The hydrolysis of triglycerides is accelerated in the presence of heat and water, increasing the oil's free fatty acid content (Rekhate & Prajapati, 2019). The cold flow characteristics of biodiesel made from waste cooking oil decreased as the water content, cooking time and temperature increased. Increased viscosity, increased specific heat and changes to surface tension are among the most typical physical changes that can be detected in oil after it has been heated to a high temperature during frying. In terms of density, kinematic viscosity, acid value and iodine value, waste cooking oil has the same attributes as waste to create biodiesel and meet the quality criteria. The concentration of free fatty acids in waste cooking oil is higher than in vegetable oil, making it an important consideration for selecting a catalyst for use in the manufacturing process (Suzihaque et al., 2022). Other than that, high concentration of free fatty acids will cause corrosion to engine parts and shorten the engine lifespan (Rekhate & Prajapati, 2019). Table 2.8 shows the difference of properties between waste cooking oil and conventional diesel (Ulusoy et al., 2018).

Table 2.8 Difference of properties between waste cooking oil and conventional diesel (Ulusoy et al., 2018)

Properties	**Waste Cooking Oil Biodiesel**	**Conventional Diesel**
Density at 15 ºC (kg/m^3)	884.8	815
Kinematic viscosity at 40 ºC (mm^2/s)	5.605	2-4.5
Flash point (ºC)	160.5	58
Higher Calorific Value (mJ/kg)	39.35	44.73
Pour point (ºC)	-4	-33
Cetane number	45-48	55
Iodine value (g/100 g)	54	-
Acid number (mg KOH/g)	1.86	-
Water amount (mg/kg)	285	0.01

2.2.2.3 Non-Edible Oils

Non-edible oils are widely used on countries that have limited source of edible oil and needs to focusing on solving the food issue that happen on the countries. It will be a major concern if they need to mix a food crisis with future potential energy research (Dyundi et al., 2019). Most of non-edible oils that have been researched for the past few years are Jathropa and Karanja (Patel et al., 2019).

Jatropha thrives in dry environments and can be grown in waste soil. 37 % of the oil found in the seeds of this plant is flammable. As a fuel for a basic diesel engine, it burned cleanly and produced no smoke. Depleted soils with a lot of air circulation and minimal supplement content are ideal environments for it to thrive (Dyundi et al., 2019) There is a higher oil content in jatropha seeds than palm oil or soybean. Free fatty acid contributes to soap development and lower biodiesel yields. The increased iodine level of the oil is responsible for the high fatty acid concentration as oleic acid. 34.3 to 45.8 % of Jatropha oil is composed of Oleic acid, followed by 29.0 to 44.2 % of Linoleic acid, 14.1 to 15.3 % of Palmitic acid, 3.7 to 9.8 % of Stearic acid and 0 to 1.3 % of Palmitolic acid (Singh et al., 2021a). Table 2.9 shows the difference of properties between Jatopha oil and conventional diesel (Singh et al., 2021a).

Table 2.9 Difference of properties between Jatopha oil and conventional diesel (Singh et al., 2021a)

Properties	Jatropha Biodiesel	Conventional Diesel
Density at 15 ºC (kg/m^3)	879	833-881
Kinematic viscosity at 40 ºC (g/cm) / cSt	4.84 cSt	3-10 g/cm
Flash point (ºC)	191	70
Higher Calorific Value (mJ/kg)	38.5	44.8
Pour point (ºC)	3	6
Cetane number	51-52	40-55
Iodine value (g/100 g)	86.5	-
Acid number (mg KOH/g)	0.24	-
Water amount (mg/kg)	0.16	0.02
Sulphur % (w/w)	< 0.001	0.25

Due to India's moist and subtropical climate, Karanja can be found on the entire country's land, with yearly precipitation ranging from 500 to 2500 mm. Around 200 million tonnes of oil are produced from the seeds each year (Dyundi et al., 2019). The composition of acids in Karanja oil was declared as 17.17 % of Palmitic acid, 4.96 % of Stearic acid, 44.51 % of Oleic acid, 21.25 % of Linoleic acid (Patel et al., 2019). It is slightly different compared to Jatropha oil because Jatropha has a short reproductive cycle, large oil yields, and low watering and fertiliser requirements but still acceptable as potential feedstocks on nations that need to put a priority on the production of foods. Table 2.10 shows the difference of properties between Karanja oil and conventional diesel (Patel et al., 2019).

Table 2.10 Difference of properties between Karanja oil and conventional diesel (Patel et al., 2019)

Properties	**Karanja Biodiesel**	**Conventional Diesel**
Density at 15 ºC (kg/m^3)	889	833-881
Kinematic viscosity at 40 ºC (g/cm) / cSt	4.79 cSt	3-10 g/cm
Flash point (ºC)	157.4	70
Higher Calorific Value (mJ/kg)	37	44.8
Pour point (ºC)	6.4	6
Cetane number	56.55	40-55
Iodine value (g/100 g)	89	-
Acid number (mg KOH/g)	-	-
Water amount (mg/kg)	0.2	0.02
Sulphur % (w/w)	0.003	0.25

2.3 Transesterification process

There are various biodiesel production technologies that have been applied worldwide and among them is the transesterification process. Each technology has its own advantages and disadvantages in producing high quality biodiesel. Table 2.11 shows the advantages and disadvantages of every biodiesel production technology that had been practiced worldwide (Singh et al., 2020).

Table 2.11 Advantages and disadvantages of every biodiesel production technology (Singh et al., 2020)

Production technology	Advantages	Disadvantages
Catalytic distillation	Division of products are simple	Recovering the catalyst affects the amount of solvent used and the rate of conversion after treatment
Dilution	Simple process	Inefficient combustion and deposit of carbon in the engine cylinders
Micro-emulsion	Simple process	Less volatile and higher viscosity
Microwave technology	Fast response time and heat loss reduced	Catalyst has a huge impact on a chemical reaction's outcome after they are removed from the process
Pyrolysis	Simple process with minimum emissions	Expensive installation costs and high carbon residue that reduces purity

Reactive distillation	Products with low methanol requirements and high concentrations of free fatty acids can be processed since the procedure is simple	The process of conversion is impacted by the need for high energy and catalyst efficiency
Super fluid method	Rapid reaction, high conversion efficiency and no need for a catalyst	High energy consumption and expensive installation cost
Transesterification	Possible to produce biodiesel with similar qualities as conventional diesel	Reduced conversion efficiency and recyclability of the catalyst

The biodiesel production technique of transesterification involves the addition of methanol or ethanol to triglycerides and the formation of esters. When triglyceride interacts with alcohol, glycerol and esters were produced (Singh et al., 2020). Preparation of the feedstock, rate of reaction, separation of phase, dehydration, recovery of alcohol and purification of the ester and glycerin are required for biodiesel transesterification procedures (Singh et al., 2021b). The purpose of the preparation procedure is to reduce acidity and moisture content. After a neutralization operation, drying and dehumidifying activities are performed (Benitha et al., 2021). Figure 2.2 shows the chemical reaction of triglyceride with alcohol to form esters and glycerol (Singh et al., 2020).

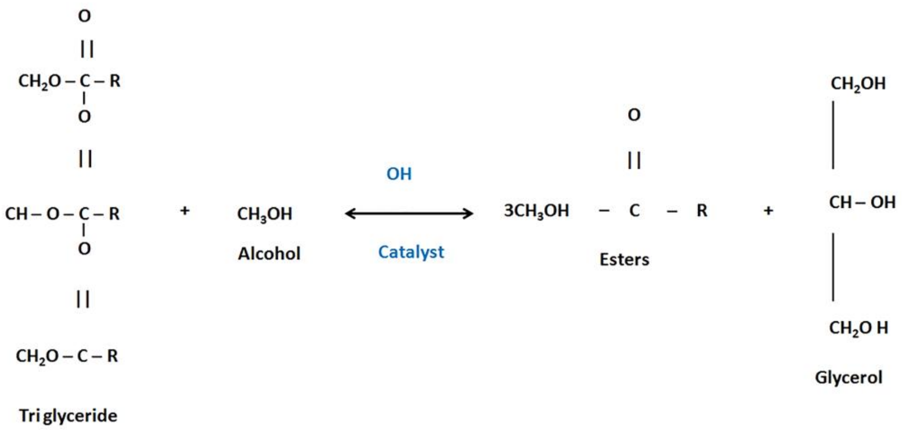

Figure 2.2 Chemical reaction of triglyceride with alcohol (Singh et al., 2020)

The transesterification process requires a catalyst, which can be acidic, basic, or enzymatic, to speed up the reaction. The most used base catalysts are sodium hydroxide (NaOH) and potassium hydroxide (KOH). In general, alkaline catalysis is preferred since the reaction occurs at a moderate temperature range and occurs more rapidly. When oils include high levels of free fatty acid and water, it is advisable to utilize an acid catalyst. Acid catalysts typically corrode machinery and increase the generation of soap, which causes a rise in viscosity, lowers the efficiency of the catalyst, and makes glycerol separation difficult (Singh et al., 2021b).

In the transesterification reaction, the yield of biodiesel produced is influenced by a variety of crucial parameters. Each parameter's optimal value results in a high yield of the final product such as catalyst type, amount of water and free fatty acid in oil, temperature of reaction, catalyst amount, alcohol type, alcohol to oil molar ratio, time of reaction, co-solvent used and mixing speed (Singh et al., 2020).

2.4 Engine Performance Characteristics

Engine performance is the most important criteria that will be evaluated after every biodiesel testing. Engine performance consists of torque and horsepower produced, brake power, brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC). Every composition of biodiesel will produce different outcomes from the engine.

2.4.1 Torque

Torque is a twisting force that corresponds to the rotational force of the engine and quantifies the amount of available twisting force when an engine exerts itself. The pistons in an engine generate this torque as they reciprocate up and down on the crankshaft, causing it to rotate continually. Conventional diesel produces higher torque than palm oil biodiesel and the torque produced becomes lower when the composition of biodiesel increase (Vohra et al., 2020).

2.4.2 Brake Power

The power of an engine's brakes is directly proportional to the torque of the brakes. On average, the brake power of palm oil biodiesel was found to be 5.3% less than that of conventional diesel (Bari & Hossain, 2019). This is because biodiesel made from palm oil has a lower heating value than conventional diesel. In addition to having a lower heating value, the higher density and viscosity of palm oil biodiesel made it harder for air and fuel particles to mix in the combustion chamber because palm oil biodiesel moved more slowly and was less volatile. Figure 2.3 shows the increased brake torque due to the increasing brake power of conventional diesel and palm oil biodiesel (Bari & Hossain, 2019).

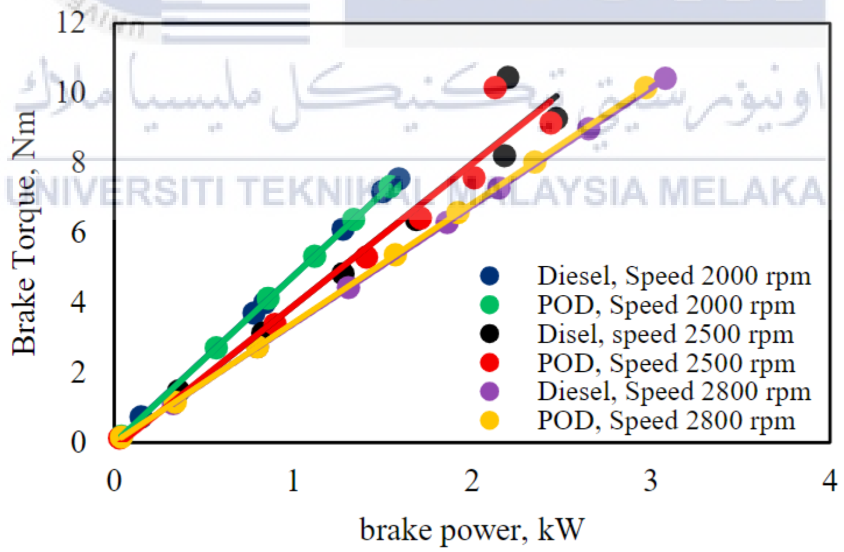

Figure 2.3 Brake torque increase due to brake power increase of conventional diesel and palm oil biodiesel (Bari & Hossain, 2019)

2.4.3 Brake Thermal Efficiency (BTE)

The Brake Thermal Efficiency represents the capacity of the engine to transform the chemical energy of fuel into mechanical energy at the output shaft. More oxygen allowed air and fuel to mix correctly, resulting in complete combustion. Due to biodiesel that has decreased calorific value and increased viscosity compared to conventional diesel, the thermal efficiency was less than conventional diesel. Figure 2.4 shows the comparison of the brake thermal efficiency between conventional diesel and palm oil biodiesel (How et al., 2019).

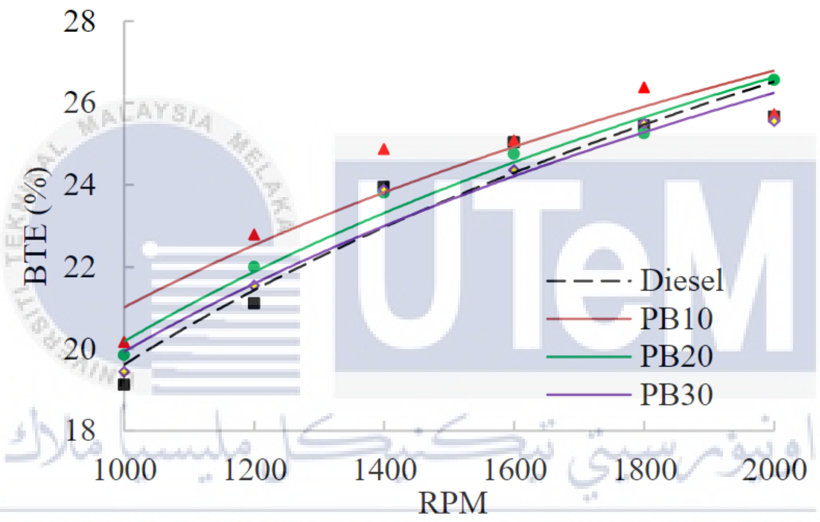

Figure 2.4 Brake Thermal Efficiency comparison of conventional diesel and palm oil biodiesel (How et al., 2019).

In comparison to the oxygen content of biodiesel, the thickness of oil and the amount of energy produced by biodiesel dominated as the biodiesel percentage increased (Kumar et al., 2019). Higher composition of biodiesel will produce lower thermal efficiency and will produce higher Nitrogen Oxide emission.

2.4.4 Brake Specific Fuel Consumption (BSFC)

During the analysis of engine performance, the key metric is the brake specific fuel consumption. The lower this parameter's value, the more effective the energy conversion.

The fuel consumption for braking reduced as engine load increased. During full load, brake-specific fuel consumption at standard injection time was less than that of the other palm oil blends (How et al., 2019). Figure 2.5 shows the difference of brake specific fuel consumption between conventional diesel and palm oil biodiesel (How et al., 2019).

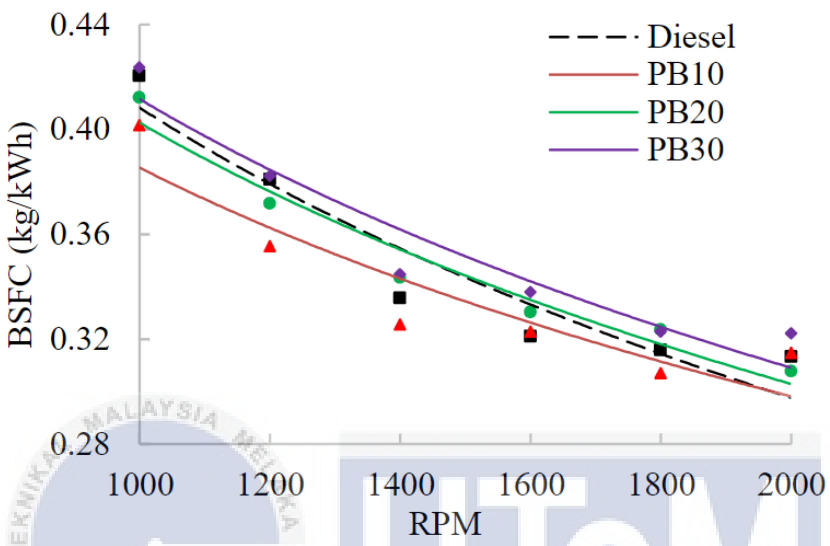

Figure 2.5 Difference of brake specific fuel consumption between conventional diesel and palm oil biodiesel (How et al., 2019)

Higher palm oil biodiesel blends require more fuel to provide the same amount of braking power, resulting in a greater brake specific fuel consumption. This was related to the dominance of fuels with a lower calorific value compared to oxygen content, requiring more fuel to create the same amount of power as conventional diesel fuel (Kumar et al., 2019).

2.5 Exhaust Emissions

Various feedstocks and compositions of biodiesel produces difference numbers of exhaust emissions. This parameter will decide whether the biodiesel blends are suitable to be developed for future purpose or need to be improvised. Exhaust emissions consists of

Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Oxide (NO_x), Hydrocarbon (HC) emissions, exhaust gas temperature and smoke opacity.

2.5.1 Carbon Monoxide

Poor atomization, insufficient oxygen supply, and low cylinder temperatures result in incomplete combustion of fuel, which produces Carbon Monoxide emissions. As biodiesels are known as oxygenated fuels due to their high oxygen content, which aids in the generation of peroxides and hydro-peroxides during burning, they produce less Carbon Monoxide than conventional diesel fuel (Kolakoti, 2021). Figure 2.6 shows graph of Carbon Monoxide emission that being generated by conventional diesel, biodiesel and palm oil blends on different engine loads (Gad et al., 2018).

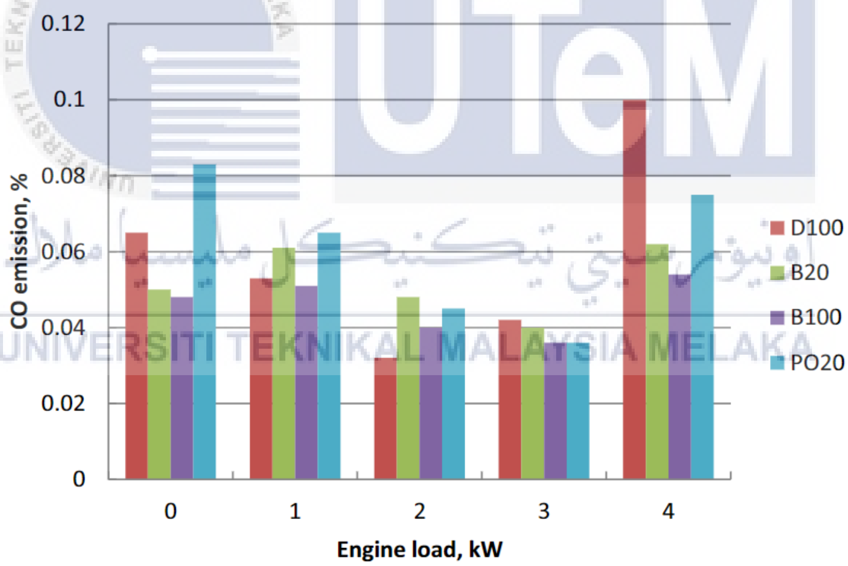

Figure 2.6 CO emission of conventional diesel, palm oil blend and palm oil biodiesel blends on different engine loads (Gad et al., 2018)

B20, B100, and PO20 resulted in decreased Carbon Monoxide emissions compared with conventional diesel because of the considerable reduction in Carbon Monoxide emissions when using palm oil biodiesel as opposed to conventional diesel fuel can be attributed to the fact that palm oil biodiesel contained less carbon than conventional diesel fuel (Gad et al., 2018). Higher biodiesel blends composition emits lower Carbon Monoxide because of higher oxygen content contained on the biodiesel blends and increase the exhaust temperature (Bari & Hossain, 2019). Figure 2.7 shows that increased compositions of palm oil biodiesel emits lower Carbon Monoxide emission (Rusli et al., 2021).

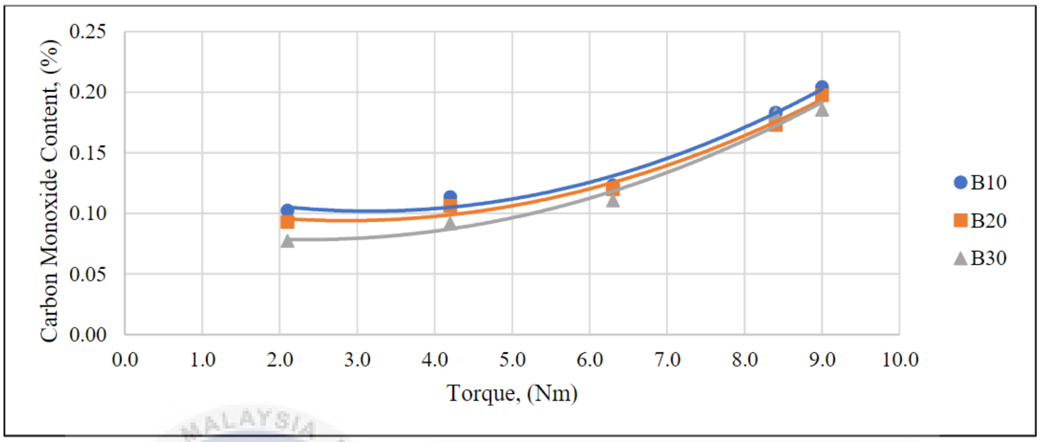

Figure 2.7 CO emissions for different palm oil biodiesel compositions (Rusli et al., 2021)

2.5.2 Carbon Dioxide

Carbon Dioxide succeeded from complete combustion process that happens in the combustion chamber when Carbon Monoxide combines with high content of oxygen contained in the biodiesel. Carbon dioxide emissions from biodiesel fuel can be lower than conventional diesel because biodiesel contains more oxygen atoms and has a lower carbon to hydrogen ratio (How et al., 2019). Carbon Dioxide emissions increased as engine load increased due to the higher fuel consumption associated with increased engine load (Abed et al., 2019). Higher Carbon Dioxide emission produced relatives to increasing compositions of biodiesel blends because of higher number of oxygen content contained in the biodiesel blends (Bari & Hossain, 2019). Figure 2.8 shows the difference of Carbon Dioxide emits from conventional diesel and different composition of palm oil biodiesel (How et al., 2019).

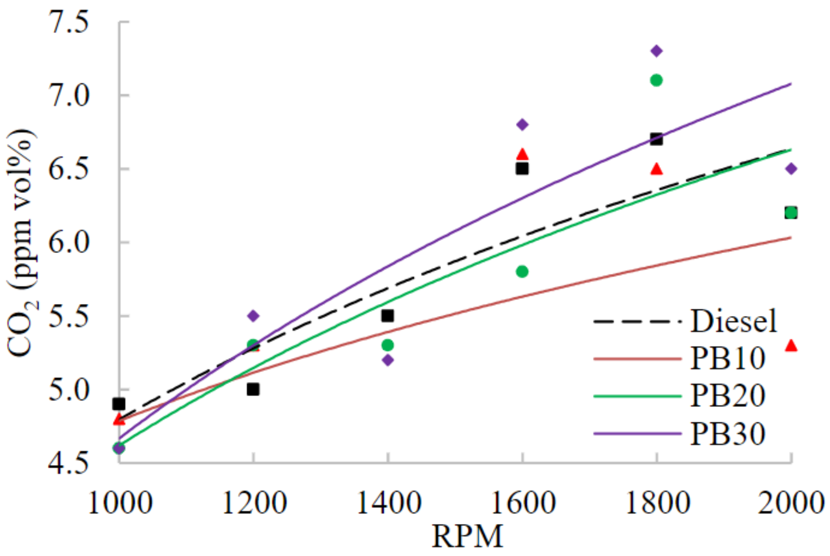

Figure 2.8 CO_2 emission of conventional diesel and different compositions of palm oil biodiesel (How et al., 2019)

2.5.3 Nitrogen Oxide

Nitrogen oxide emissions are mostly determined by the combustion temperatures within the cylinder. For fuels with abundant oxygen content and high cetane numbers are the primary source of NO_x emissions. NO_x emissions are produced when nitrogen combines with oxygen during combustion at high temperatures. Even though diesel and biodiesel do not include nitrogen, ambient air entering the combustion chamber during the suction/intake stroke will react with available oxygen (Kolakoti, 2021). NO_x emissions increased as engine load increased for all loads due to an increase in the amount of gasoline used and the cylinder temperature, both of which are responsible for the thermal creation of NO_x (Gad et al., 2018). Figure 2.9 shows graph of NO_x emission that being generated by conventional diesel, biodiesel and palm oil blends on different engine loads (Gad et al., 2018).

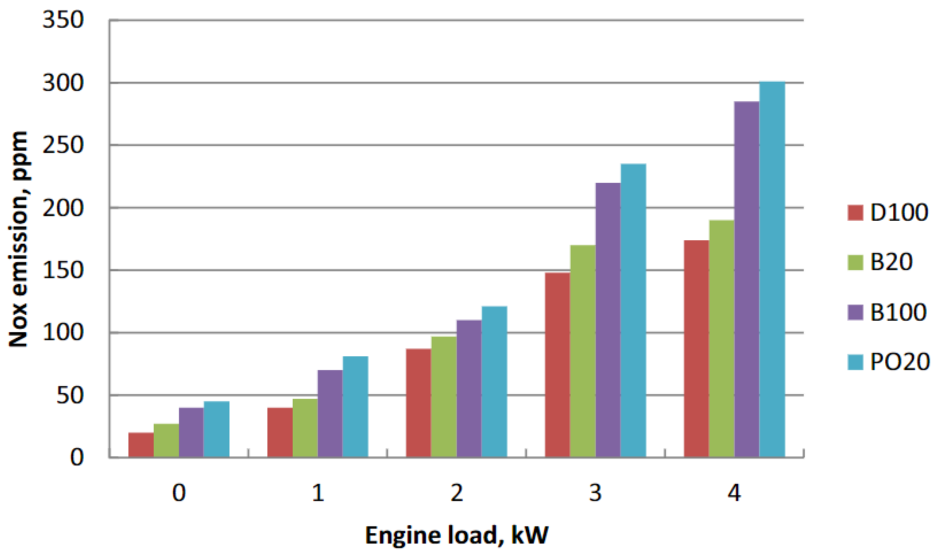

Figure 2.9 NO_x emission of conventional diesel, palm oil blend and palm oil biodiesel blends on different engine loads (Gad et al., 2018)

All test fuels had seen a rise in NO_x emissions with an increase in engine load due to an increase in the amount of fuel consumed and the cylinder temperature, which is responsible for the creation of thermal NO_x. With increasing biodiesel percentage, nitrogen oxide emissions increase (Gad et al., 2018). The adiabatic flame temperature for biodiesel is slightly higher due to its increased oxygen content and NOx emissions.

2.5.4 Hydrocarbon

Unburned Hydrocarbon emissions come from incomplete combustion during the combustion process. This incomplete combustion is also known as a lack of suitable temperature, oxygen, and air-fuel mixture due to the creation of unburned hydrocarbon emissions(Bari & Hossain, 2019). Figure 2.10 shows graph of Hydrocarbon emission that being generated by conventional diesel, biodiesel and palm oil blends on different engine loads (Gad et al., 2018).

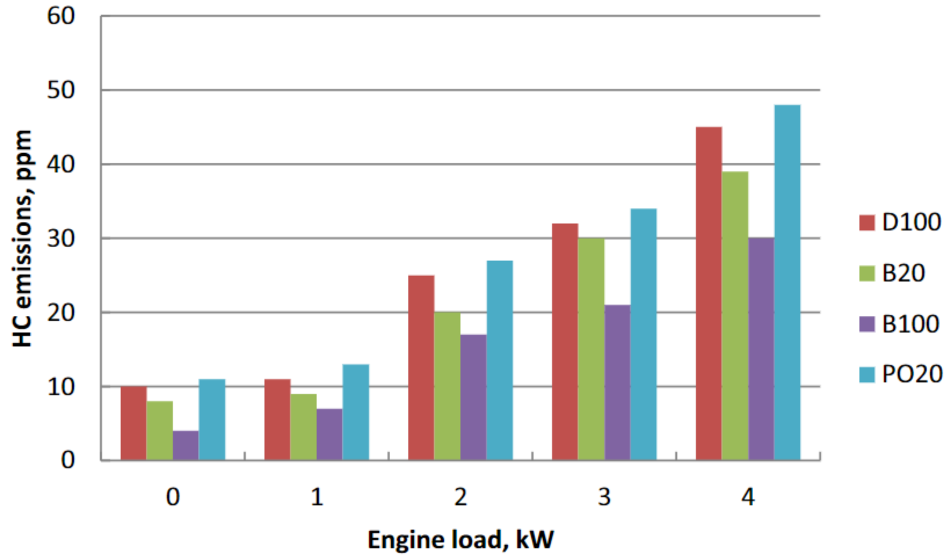

Figure 2.10 HC emission of conventional diesel, palm oil blends and palm oil biodiesel blends on different engine loads (Gad et al., 2018)

Hydrocarbon emissions are lower at low engine loads and increase as loads increase. This is due to the shortage of oxygen produced by the engine's operation, which results in a fuel-rich mixture. A high oxygen content reduces Hydrocarbon emissions at greater engine loads. Due to palm oil's higher viscosity, Hydrocarbon emissions increased for palm oil biodiesel at all engine loads compared to conventional diesel fuel. Due to the higher cetane number, the increase of proportion of biodiesel in biodiesel blends reduces Hydrocarbon emissions. Adding biodiesel to diesel fuel improves combustion by increasing the oxygen content, resulting in decreased Hydrocarbon emissions (Gad et al., 2018).

2.5.5 Exhaust Gas Temperature

Exhaust gas temperature related with speeds and loads. Higher speeds and higher loads will produce higher exhaust gas temperature (Suresh et al., 2018). Palm oil biodiesel produces higher exhaust gas temperature compared to conventional diesel because of amount of oxygen that combined with Carbon Monoxide to form Carbon Dioxide and complete the combustion process. Higher exhaust gas temperature results in higher fuel consumption and the trend will increase with the increase of biodiesel-diesel blends composition (Abed et al., 2018). Figure 2.11 shows graph of exhaust gas temperature that being generated by conventional diesel, biodiesel and palm oil blends on different engine loads (Gad et al., 2018).

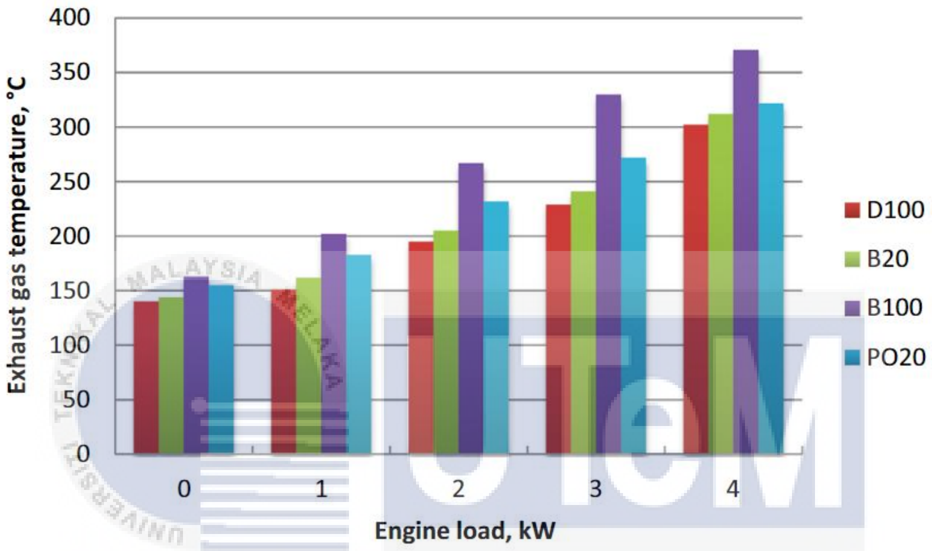

Figure 2.11 Exhaust gas temperature of conventional diesel, palm oil blends and palm oil biodiesel blends on different engine loads (Gad et al., 2018).

2.5.6 Smoke Opacity

The smoke emissions are viewed as unburned carbon particles that were not actively involved in the combustion process and were left over. This is because carbon and hydrogen molecules included in fuel droplets attempt to react with oxygen during the combustion process. During this process, hydrogen predominates carbon by interacting with oxygen, leaving carbon unburned and resulting in the creation of smoke. As biodiesel is an oxygenated fuel and contains surplus oxygen, the carbon will be able to utilize the oxygen, resulting in less smoke emissions (Kolakoti, 2021). Figure 2.12 shows the difference of smoke opacity between conventional diesel and 10% and 20% composition of biodiesel blends that generated from Jatropha oil (JB10), algae oil (AB10), palm oil (PB10) and waste cooking oil (WCOB10) (Abed et al., 2019).

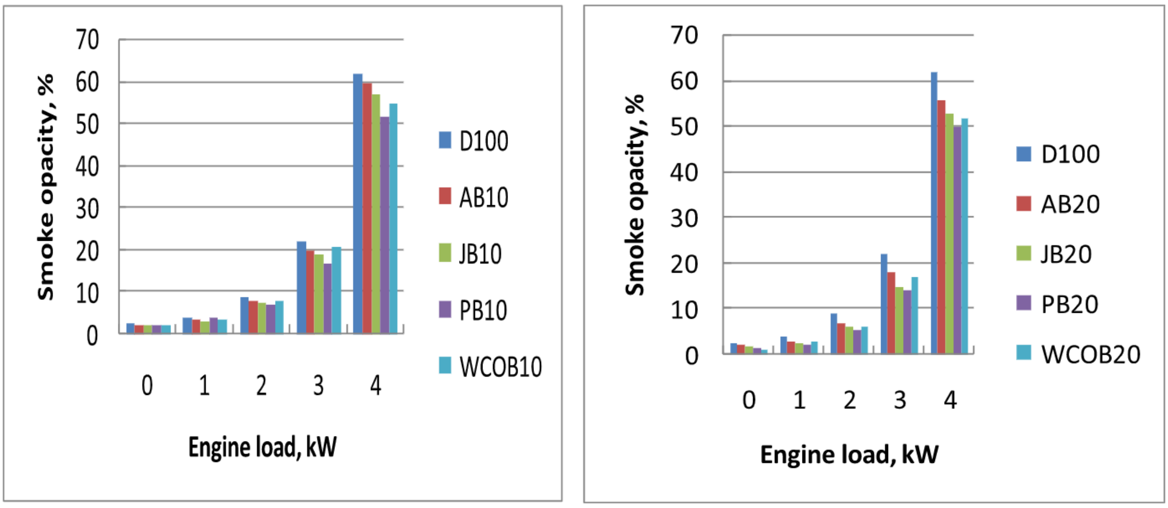

Figure 2.12 Various smoke emission with engine load for biodiesel blends compared to conventional diesel (Abed et al., 2019)

As engine load grew, smoke emissions increased because more fuel was consumed to provide greater power. It was observed that smoke emissions from biodiesel blends were lower than conventional diesel because of oxygen content contains on each biodiesel blends that complete the combustion process by combining with Carbon Monoxide to form Carbon Dioxide.

CHAPTER 3

METHODOLOGY

3.1 Introduction

For this research, a few methods have been used to evaluate the output that need to be recorded and then will be discussed on next chapter. Methods used during this research including blending process of palm oil biodiesel with pure diesel to produce palm oil biodiesel-diesel blend, testing process of palm oil biodiesel-diesel blends in a single-cylinder fuel injection engine and recording process of engine performances using dynamometer machine and exhaust emissions using gas analyzer.

3.2 Planning process

The planning process is the most crucial part before any experiment or testing is done. It needs to be very precise and understandable to make sure that the experiment or testing can be done smoothly. The possibility of delay can be reduced and the experiment or testing can be done at the proposed time. Most of the planning process uses workflow chart to visualize and evaluate every step that wants to be done and next steps of what has been done. This is very important to make sure that the experiment or testing process are not messed up so time and resources will not be wasted.

A workflow chart has been constructed for the whole thesis to evaluate and visualize the flow of work from the beginning of the thesis until the end of the thesis consists of literature phase until submission phase. It has been planned precisely to make sure that there will be no delay for each step that has been chosen for this thesis. The following figure 3.1 shows the overall flow chart for this project research.

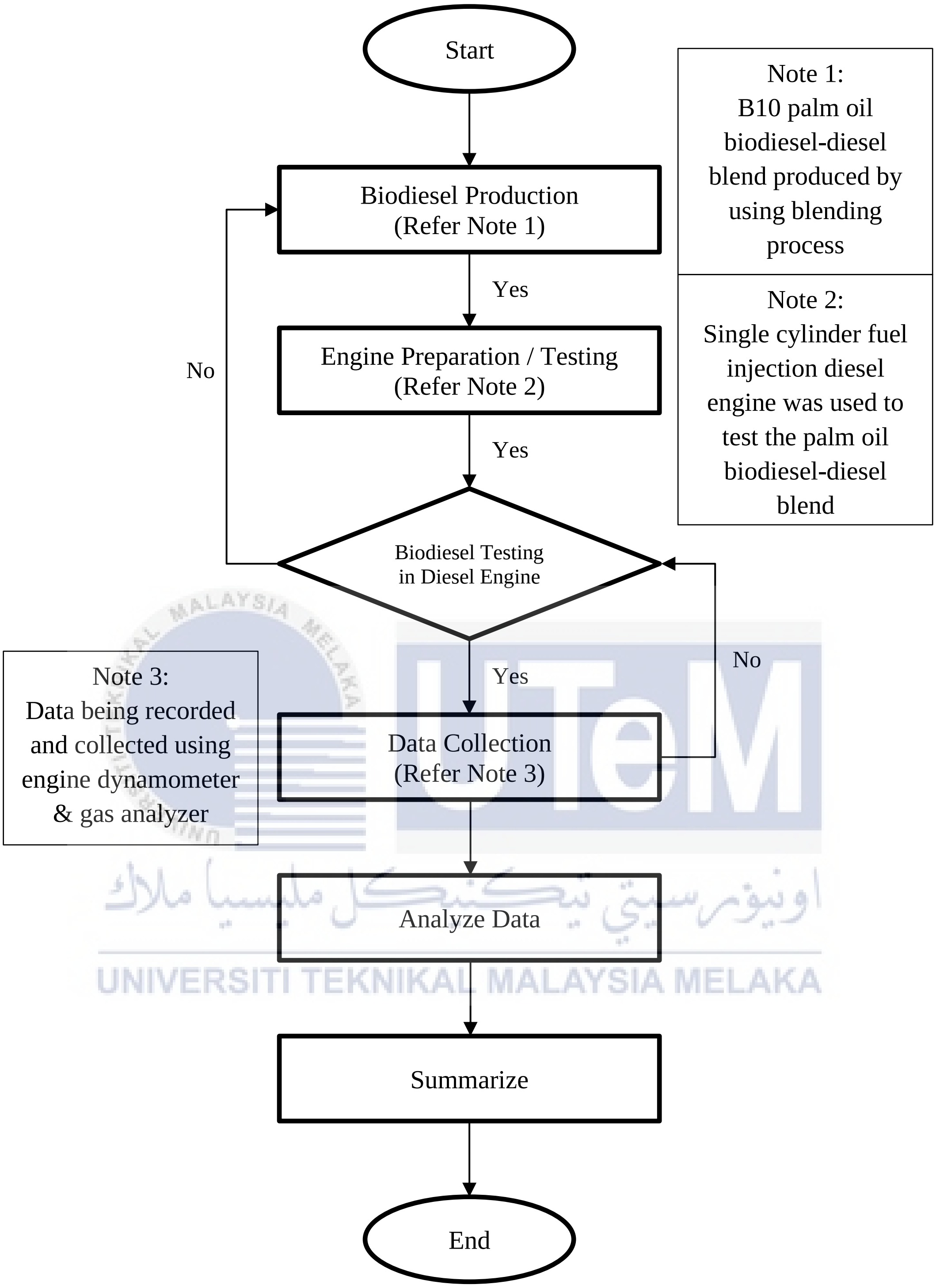

Figure 3.1 Research Workflow Chart

3.3 Selection of biodiesel feedstock and engine performane test machine

Palm oil feedstock used for this research is choose by its availability and capability since Malaysia is one of the biggest suppliers of palm oil to the worldwide market. A single cylinder fuel injection system engine has been used to test the biodiesel-diesel blends for its engine performances and gas emissions emitted from it.

3.3.1 Type of feedstock

Palm oil has been chosen as a feedstock for the biodiesel-diesel blends to study the effects of the blends towards engine performances and gas emissions. There are numerous explanations why palm oil is utilised in biodiesel production such as low Sulphur concentration which makes it excellent for biodiesel production, high cetane number that lowers knocking tendency, a shorter ignition delay resulting in less idling noise and easier cold-starting and there is a considerable supply of vegetable palm oil in specific places around the country (Singh et al., 2021b).

3.3.1.1 Parameters

Table 3.1 shows the difference between physicochemical properties of palm oil biodiesel and diesel fuel (Singh et al., 2021b).

Table 3.1 Parameters of Palm Oil Biodiesel Properties

Properties	Palm Oil Biodiesel	Diesel Fuel
Density at 15 ºC (kg/m^3)	880	833-881
Kinematic viscosity at 40 ºC (g/cm·s)/(cSt)	4.50 cSt	10-13 g/cm·s
Flash point (ºC)	175	70
Higher Calorific Value (mJ/kg)	41.30	44.80

Pour point (ºC)	14	6
Cetane number	52	40-55
Iodine value (g/100 g)	55	-
Acid number (mg KOH/g)	0.33	-
Sulfur % (w/w)	0.04	0.25
Water amount (mg/kg)	306	0.02

3.3.2 Type of engine performance test machine

For this research, a machine that used to evaluate the output of engine is a 125 HP Blower-Cooled AC Engine Dynamometer placed in one of the Faculty of Mechanical Engineering laboratory at Universiti Teknikal Malaysia Melaka. Engine output brake power was evaluated using an AC generator that could produce up to 10.5 kW of power, as well as an overload controller and other devices that were directly attached to the test engine for the purpose of testing. The intake airflow was monitored using a sharp-edged aperture fixed in the side of an air box, which was coupled to the engine inlet to moderate the pulsing airflow. A U-tube manometer was used to gauge the pressure decrease across the aperture. Calibrated thermocouple probes of type (K) were used to detect temperatures in various parts of the experimental setup, including the intake air manifold and the exhaust gas stream. The crankshaft's rotational speed was measured with the aid of a speed tachometer. Burette with stopcock and two-way valves was installed to the front side of the panel to assess fuel flow and switch between diesel fuel and biodiesel fuel. Figure 3.2 shows the dynamometer used for this research.

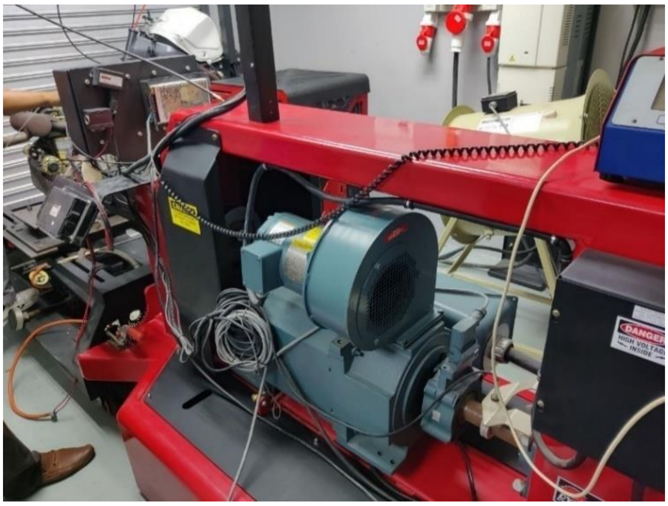

Figure 3.2 125 HP Blower-Cooled AC Engine

All datas including torque, brake power, Brake Thermal Efficiency and Brake Specific Fuel Consumption are recorded by using DYNOmite Dynamometer software and visualize on a screen. Figure 3.3 shows the simple setup during recording process in progress.

Figure 3.3 Desktop that connected to Dynamometer and Gas Analyzer

MRU DELTA 1600-V Gas Analyzer has been used to collect datas related to gas emissions that emits from the engine exhaust. Its sensor was connected to engine exhaust directly and the datas are recorded by using the same dynamometer software and visualize on a screen. Figure below shows an equipment to collect datas of exhaust emission.

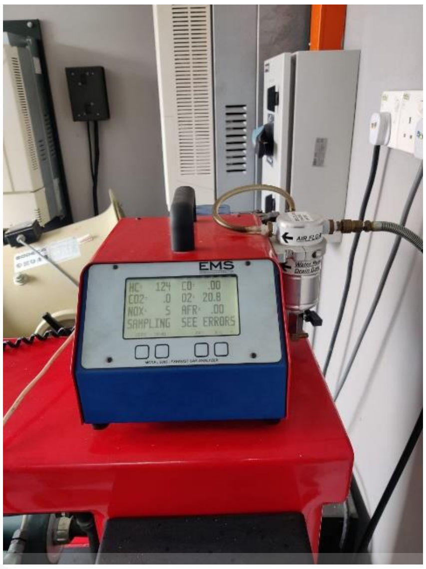

Figure 3.4 MRU DELTA 1600-V Gas Analyzer

3.3.2.1 Parameters

Table 3.2 shows the 125 HP Blower-Cooled AC Engine Dynamometer specifications used to record the engine performances of the diesel engine.

Table 3.2 Specifications of Dynamometer

Dynamometer Parameters	Specifications
Capacity	125 HP at 5000 RPM
Quadrant	4 (loads/ motors in both directions)
Drive ratio	0.8/ 1.250 : 1
Power input	460 VAC, 145 A, Three phase

3.4 Biodiesel Production

3.4.1 Blending Process

Blending process is a process that mix pure biodiesel with pure diesel using stiring method on a laboratory hot plate. The biodiesel-diesel blend has a higher viscosity than ordinary diesel fuel. Engines that run with high viscosity fuel have several operational concerns. Due to its high viscosity, pure biodiesel was mixed with ordinary diesel fuel. The use of highly viscous pure biodiesel directly in diesel engines promotes gum formation, clogging of the injector nozzle, and excessive carbon deposition on the piston heads (Singh et al., 2021b). For this research, 100% Palm Oil Biodiesel was pre-heated and from the Biodiesel, 10% of Palm Oil Biodiesel was blended with 90% of pure diesel to form Biodiesel-diesel blends. Figure below shows pure diesel and Palm Oil Biodiesel that being blend using Electromagnetic Stirrrer.

Pure Diesel	Palm Oil Biodiesel
	

Figure 3.5 Pure diesel and palm oil biodiesel that being blend using Electromagnetic Stirrer

3.5 Engine Preparation

The maintenance work of a diesel engine has been done to check the reliability of every engine components to avoid power lost during running engine process. The air flow was checked to make sure there is no unnecessary things in the intake low and fuel injector also being checked to make sure that it was not clogged from any diesel residue from previous testing. Other than that, all seals and gaskets being checked to make sure that no leaking happen during running engine process. The head and piston also being checked to make sure there was no cracked occured to avoid stucked components during combustion proces due to high compression happened in the chamber.

3.5.1 Parameters

Table 3.3 shows the specifications of fuel injection single cylinder diesel engine used to run the D100 fuel, B10 and B100 biodiesel-diesel fuels.

Table 3.3 Specifications of Engine

Engine Parameters	Specifications
Engine model	170FA
Number of cylinder	1
Bore	70 mm
Stroke	55 mm
Displacement	211 CC
Max output	3.8 PS at 3600 rpm
Starting system	Recoil/ Electric
Fuel tank capacity	2.5 L
Lube tank capacity	0.75 L
Type of injection	Fuel injection
Type of cooling	Air-cooled

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discuss the results that have been obtained from the test that had been performed to determine the engine performance and exhaust emission data. The data was collected from the testing that have been set up properly to determine the best data to be discussed further in this chapter. Conventional diesel and different compositions of biodiesel fuel have been applied on a diesel engine at different engine loads from zero to full load. Results obtained from the testing was analysed based on the result that have been plotted in a graph.

4.2 Engine Performance Analysis

A diesel engine was connected to a dynamometer was run on different loads starting from zero load, half load and full load by a conventional diesel and different compositions of biodiesel fuels which are B10 and B100. The dynamometer had captured several data such as horsepower and torque that produced from the engine. Result collected was plotted in a graph to ease the comparison between D100, B10 and B100. Engine performance is one of the important aspect because it shows the power loss of an engine during operation and will effect the lifespan of an engine.

4.2.1 Horsepower

Figure 4.1 shows that engine load is directly proportional to horsepower produced by the diesel engine. The graph stated that there are big difference between D100 and B10 on zero load but the gap keep getting smaller during half load and D100 produced slightly higher horsepower compared to B10 during full load. It is completely different with B100 that produced approximately 32% lower horsepower compared to D100 on zero load but produced 29 % higher horsepower compared to D100 on half load and the amount slowly to constant when approaching full load. For comparison of B10 and B100, there are also big difference during zero load that giving the advantage to the B10 that have lower composition of biodiesel mixture compared to full composition of biodiesel for B100 that suffered power loss at the starting of the result but the power loss was reduce during half load and producing higher horsepower during full load compared to B10 that produced 14% lower horsepower during full load of the diesel engine.

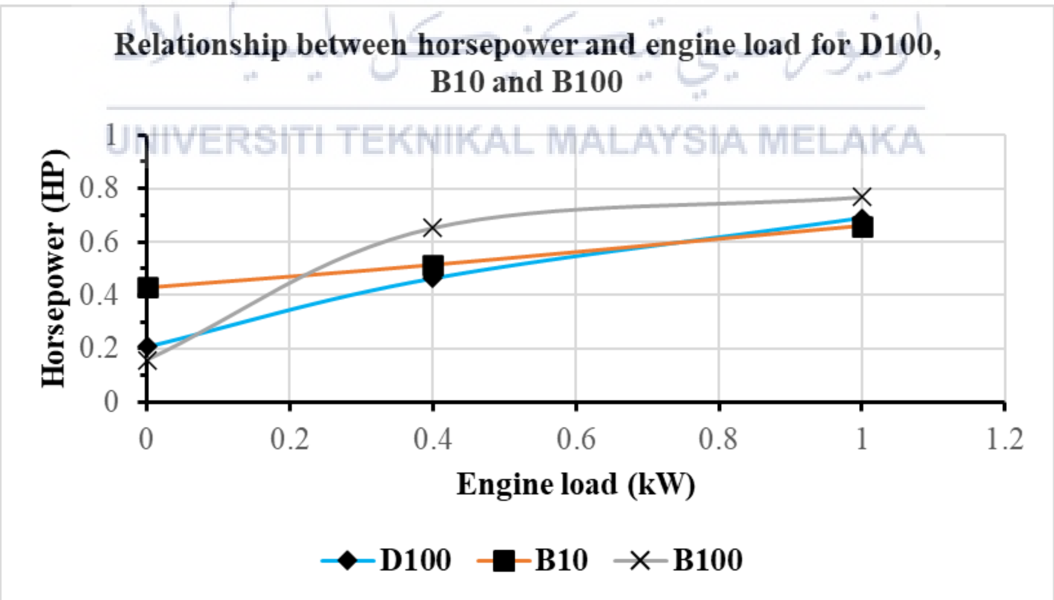

Figure 4.1 Relationship between horsepower and engine load for D100, B10 and B100

4.2.2 Torque

Torque was closely related to engine load as torque keeps increasing when engine load rising from time to time. It was shown on figure 4.2 that higher torque was produced starting from zero load to half load and starting to reach its limit when approaching full load. This trend happened because of the engine load applied was increasing from zero to full load and higher torque is needed to run higher load but will stop escalating when it reaches the limit of torque that can be produced by the engine (Rusli et al., 2021). It shows that D100 produced the best trend for the torque produced from the engine because of its characteristics that empowered the biodiesel fuel compared to biodisel fuels that struggling to produce torque during zero load to half load and taking longer time to reach its maximum output when approaching full load. B100 produced the lowest torque compared to other fuels and it used higher volume of fuels in tank compared to other because of the oxygen content contained in the biodiesel fuel (Kumar et al., 2019).

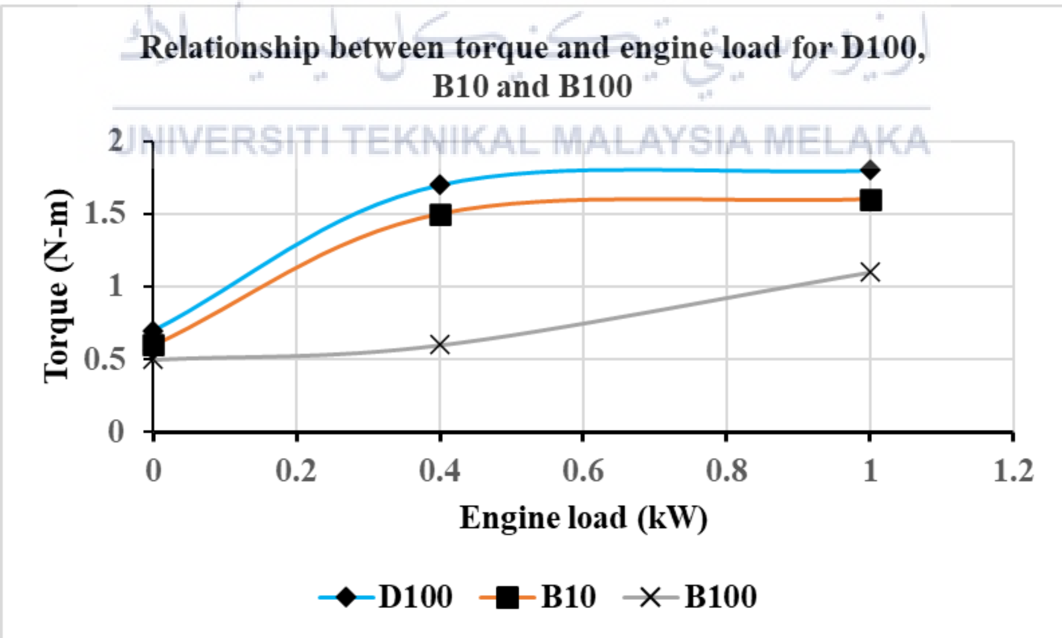

Figure 4.2 Relationship between torque and engine load for D100, B10 and B100

4.2.3 Brake Specific Fuel Consumption

Figure 4.3 shows that BSFC was inversely proportional towards engine loads as the load increases, the brake specific fuel consumption decreases. It demonstrates that as the biodiesel concentration in the blend increases, so does the brake specific fuel consumption. The major difference can be seen during the half load of diesel engine that shows D100 produced 0.5 kg/kW.hr which is the least amount compared to B10 and B100 that produced 0.65 kg/kW.hr and 1.14 kg/kW.hr respectively. Biodiesel fuel blends with a higher concentration have a lower caloric value, resulting in an increase in BSFC (Rusli et al., 2021). As a result, engines using these fuel blends would consume more fuel to maintain the load. In general, engines fueled with B10 will travel further than engines fueled with B100 for a fixed volume of biodiesel fuel blends. In other words, BSFC was inversely proportional towards fuel consumption rate. Higher fuel consumption was applied to produce 1 kW of eletric compared to conventional diesel that used lower fuel to produce the same amount of electricity.

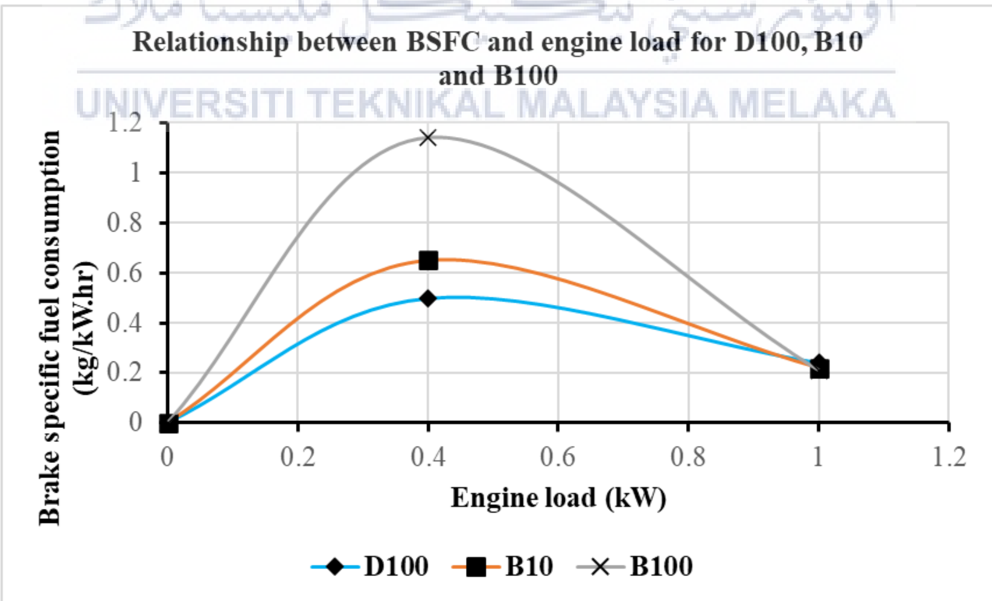

Figure 4.3 Relationship between BSFC and engine load for D100, B10 and B100

4.2.4 Summary of Engine Performance Analysis

B100 produced the best horsepower but the lowest torque value even it consumes higher volume of fuel compared to D100 and B10. It also produced the highest brake specific fuel consumption because of its lowest calorific value contained in the fuel so more fuel needed to produce higher engine braking capability (Kumar et al., 2019). Higher horsepower results in the vehicle faster acceleration and higher torque produced results in shortest possible delay during engine responding phase (Kumar et al., 2019).

4.3 Exhaust Emission Analysis

The exhaust emission data was collected by attaching a sensor to the diesel engine exhaust that capture every data of gases produced from the smoke of burning diesel. The sensor detected several gases produced from the smoke such as Carbon Monoxide (CO), Carbon Dioxide (CO_2), Hydrocarbon (HC) and Nitrogen Oxide (NO_x) emission. Exhaust emission is another important aspect that benefits nature by reducing air pollution in effective way if biodiesel fuels were readily being used on the international market.

4.3.1 Carbon Monoxide (CO) Emission

Figure 4.4 shows that D100 produced the highest amount of CO emission from the diesel engine among the others. All fuels showed clear difference in carbon monoxide produced from the diesel engine and there was only slightly difference between zero load to half load for D100, B10 and B100 biodiesel fuels. The major difference can be seen when all fuel approaching full load as it trend became increasing because of the increase in fuel consumption that lead to rich air-fuel mixture so more fuel were consumed and a greater number of fuel-rich zones with low oxygen levels are produced (Bari & Hossain, 2019).

There are major difference of CO emission between B10 and B100 that had 52% difference in outcome of the engine that were caused by the presence of oxygen in the molecular structure of biodiesel blend fuels, which aids in better combustion and thus reduces CO emissions (Abed et al., 2019). In other words, higher concentration of biodiesel fuel produced lower CO emission because it supports the complete combustion that changed the CO molecule to CO_2 molecule.

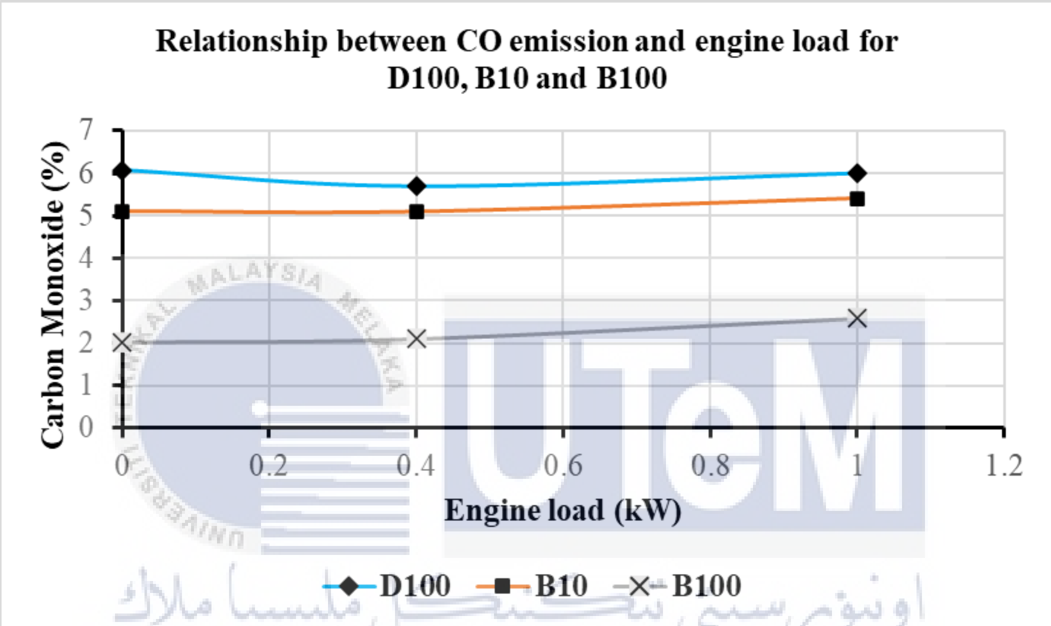

Figure 4.4 Relationship between CO emission and engine load for D100, B10 and B100

4.3.2 Carbon Dioxide (CO_2) emission

Figure 4.5 was the best way to support the previous data because it was the consequences of the action from the incomplete combustion that produced CO emission. CO_2 emission was produced from the complete combustion of rich oxygen content contained in the biodiesel fuel (Gad et al., 2018). Higher composition of biodiesel fuel contained higher oxygen molecule so the result was always better compared to conventional diesel so B100 produced the highest CO_2 emission because of oxygen advantage contained in the mixture. CO_2 emission of B10 was slightly different with D100 because it had lower oxygen content compared to B100 so the emission also had slightly difference which was 39% higher than D100 on full load.

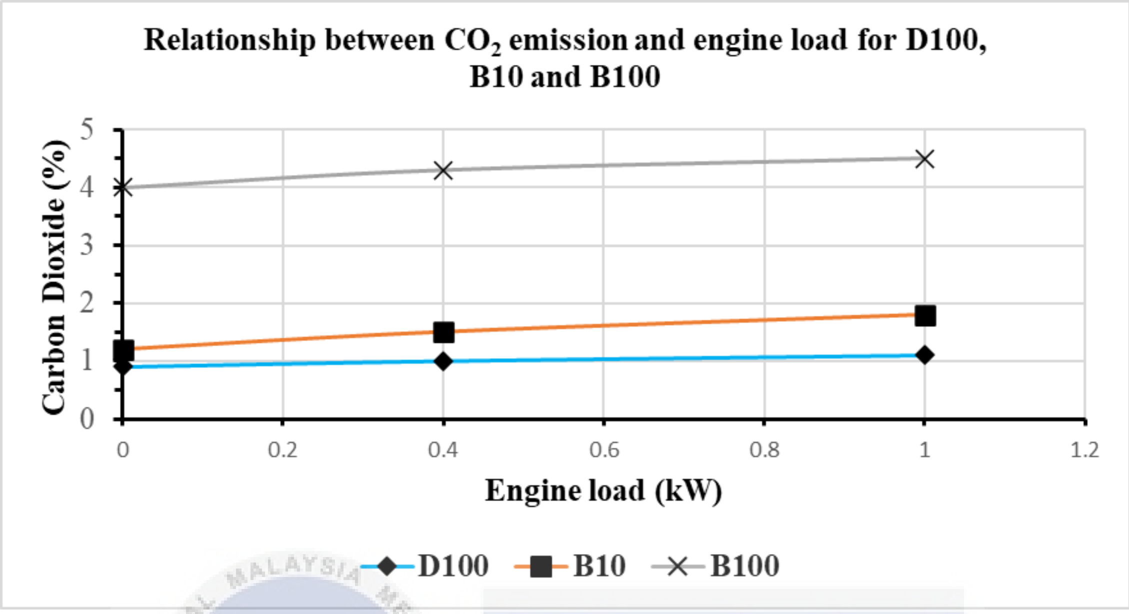

Figure 4.5 Relationship between CO_2 emission and engine load for D100, B10 and B100

4.3.3 Hydrocarbon (HC) Emission

HC emissions are lower at low engine loads and increase as engine loads increase. This is due to the presence of a fuel-rich mixture as a result of the lack of oxygen caused by engine operation (Gad et al., 2018). Figure 4.6 shows that B100 produced the lowest HC emission because at higher engine loads, a high percentage of oxygen results in lower HC emissions. B10 biodiesel fuel had slightly lower HC emissions than diesel fuel at all engine loads because of lower oxygen content. Increasing the percentage of biodiesel in biodiesel blends reduces HC emissions area attributed to the higher cetane (Singh et al., 2020). The addition of biodiesel to diesel fuel increases the oxygen content, resulting in better combustion and lower HC emissions. The difference of HC emission between B10 and B100 was 79% because of oxygen advantage that contained in the B100 biodiesel mixture.

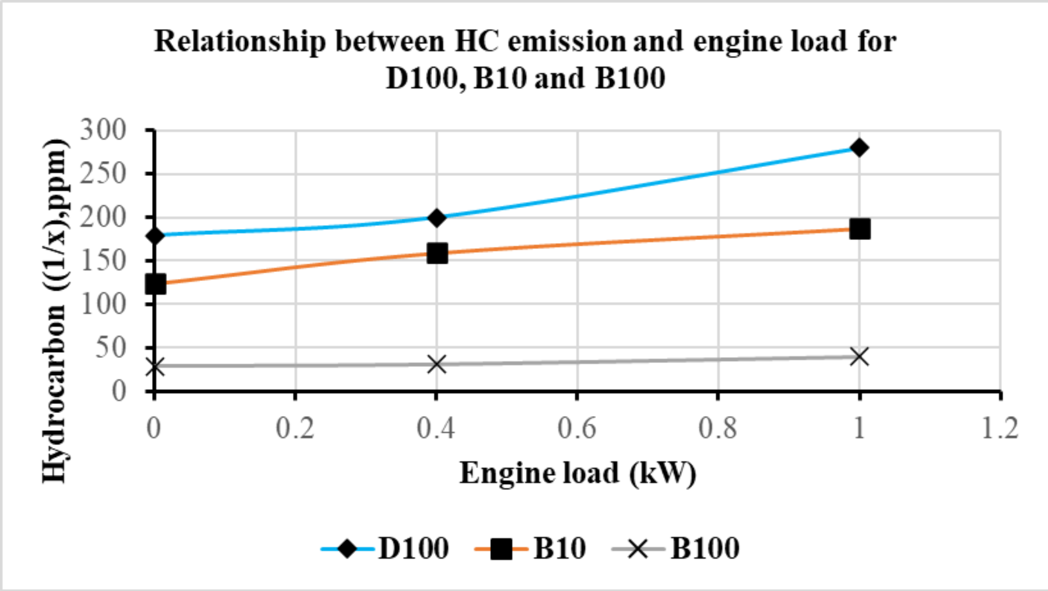

Figure 4.6 Relationship between HC emission and engine load for D100, B10 and B100

4.3.4 Nitrogen Oxide (NO_x) Emission

Figure 4.7 shows that the emission released increases with the increased engine load but decreases with the increasing concentration of biodiesel. NOx emissions increased with the increase in engine load for all the test fuels due to increase in the amount of fuel burned and the cylinder temperature which is responsible for thermal NOx formation (Gad et al., 2018). The adiabatic flame temperature is slightly higher for biodiesel because of its oxygen content and higher NOx emissions. Formation rate of NOx emissions in diesel engines depends on flame temperature, which is closely related to the peak cylinder pressure (Kumar et al., 2019). The increase in NOx emission for B10 and B100 was due to increase in oxygen content compared to D100. Nitrogen oxides emissions increase with increase in percentage of biodiesel and oil in biodiesel. Figure shows that B100 produced highest NOx emission because of the oxygen content contained in the mixture. B10 with lower oxygen content stood near by D100 with 29% difference but there was a gap produced between B10 and B100 biodiesel fuels with 48% difference between them.

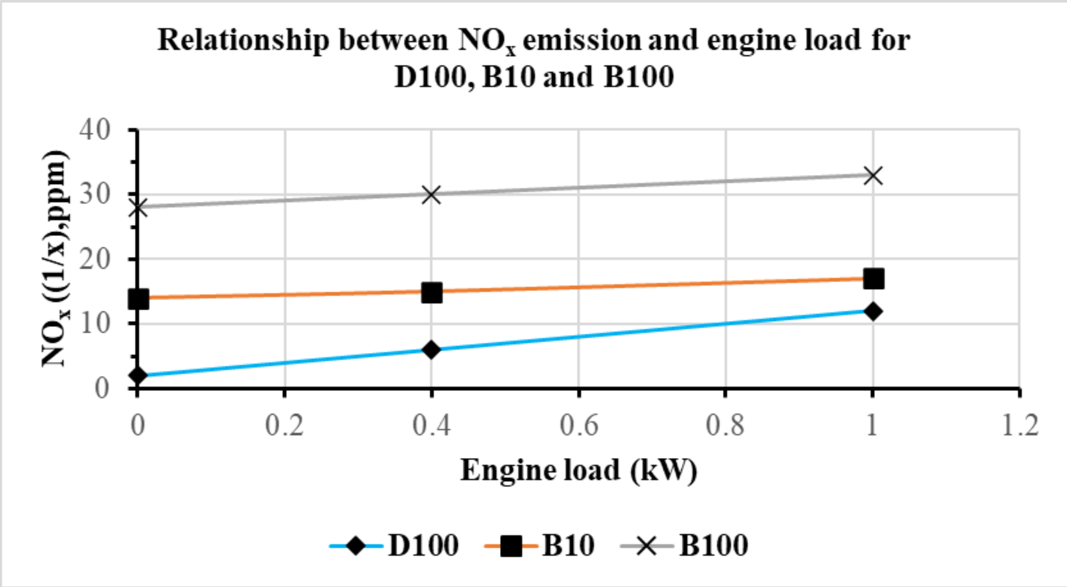

Figure 4.7 Relationship between NO_x emission and engine load for D100, B10 and B100

4.3.5 Summary of Exhaust Emission Analysis

B100 produced the lowest CO emission because of the higher rate of complete combustion that combined the CO particles with higher oxygen content contained in the biodiesel fuel that results higher CO_2 emission (Kolakoti, 2021). B100 also produced the lowest HC emission due to higher cetane contained in the biodiesel fuel that also support higher rate of complete combustion by the biodiesel fuel but B100 produced the highest NO_x emission that contribute to the human body system failure because of higher oxygen content contained in the biodiesel fuel (Faizal & Ateeb, 2018).

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

1. By using transesterification process, pure palm oil biodiesel was produced and being blended with pure diesel by using electromagnetic stirrer to form B10 and B100 biodiesel-diesel fuels. It is to make sure that the two types of oils were well blended and completely mixed for collecting most accurate data.

2. Engine performance of B10 and B100 biodiesel fuels were analyzed by collected data from the engine dynamometer that connected to the fuel injection single cylinder diesel engine and the results showed that B100 produced the highest horsepower but the lowest torque even it consumed higher volume of fuel compared to D100 and B10 fuels. B10 produced slightly higher horsepower and torque compared to D100 so the outcomes were better compared to D100. Higher horsepower results in the vehicle faster acceleration and higher torque produced results in shortest possible delay during engine responding phase. B100 biodiesel fuel also produced the highest brake specific fuel consumption because of its lowest calorific value so higher volume of fuel was needed to produce high engine braking capability. Calorific value of B10 is lower compared to B100 so its brake specific fuel consumption is slightly higher compared to D100 and its can be said that the torque produced was better compared to D100. It can be declared that B10 biodiesel fuel was the best fuel to be used in term of engine

performance due to higher horsepower produced and little margin of horsepower produced compared to D100.

3. Exhaust emission of B10 and B100 biodiesel fuels were analyzed by collected data from the gas analyzer that connected to the fuel injection single cylinder diesel engine exhaust and the result showed that B100 produced the lowest CO emission because of the higher rate of complete combustion that combined the CO particles with higher oxygen content contained in the biodiesel fuel that results higher CO_2 emission. B100 also produced the lowest HC emission due to higher cetane contained in the biodiesel fuel that also support higher rate of complete combustion by the biodiesel fuel but B100 produced the highest NO_x emission that contribute to the human body system failure because of higher oxygen content contained in the biodiesel fuel. It can be declared that B100 was the best fuel that can be used in term of exhaust emission due to its lower CO emission that results in higher CO_2 emission and lower HC emission.

5.2 Recommendations

1. Testing biodiesel fuels with higher engine capacities such as higher number of pistons on direct-injection diesel engine that can be analyzed with dynamometer and gas analyzer.

2. Testing smaller concentration margin of biodiesel fuels such as B10 then followed by B15, B20, B25 and so on to find the most precise mixture that can provide the best data for engine performance and exhaust emission analysis.

3. Adjusting the air-fuel ratio of the engine to make sure that the engine burns the mixture completely during combustion process so the performance of the engine can be improvised.

4. Adding certain nanoparticles such as Cerium Oxide Nanoparticles to support the reduction of NO_x emission in higher concentration of biodesel fuels so that the uses of pure diesel can be reduce to the lowest rate and produce pure biodiesel fuel from feedstocks.

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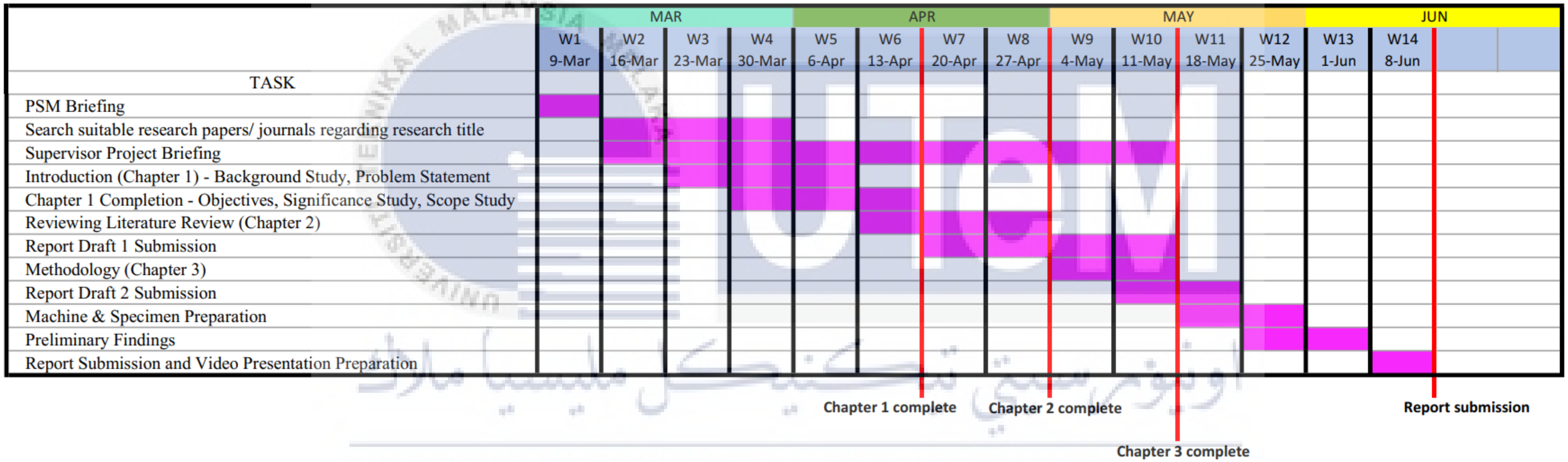
APPENDICES

APPENDIX A Gantt Chart PSM 1



APPENDIX B Gantt Chart PSM 2