EVALUATION OF FUEL PROPERTIES BEHAVIOUR OF BIODIESEL FROM DIFFERENT OIL STOCK

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A report submitted
in fulfilment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled "Evaluation of fuel properties behaviour of biodiesel from different oil stock" is the result of my own work excepts as cited in the references.

Signature :…………………………………….

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APPROVAL

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-Fluid).

Signature :.......................................

Name : DR. MD ISA BIN ALI

Date :.......................................

DEDICATION

To my beloved father and mother.

ABSTRACT

Biodiesel is an alternative to the petroleum diesel that is getting much attention from the consumers currently. There is a variety of sources in forms of vegetable oil and animal fats that can be used to produce biodiesel. Many types of vegetable oil and animal fats that have been used to produced biodiesel from previous studies. The sources of biodiesel produced from previous studies are based on the availability of the sources locally and researches on the particular sources. Since there are many sources can be used to produce biodiesel, the properties of the biodiesel produced can be different. Many studies and tests have been conducted in order to determine the properties of biodiesel from different sources and to know whether the biodiesel is suitable to be used by the consumers and commercialization purpose. In this project, the biodiesel is produced from three types of vegetable oil that is coconut oil, corn oil, and olive oil that are available locally. Several tests are then conducted to determine the properties of the biodiesel produced such as density, flash point, and viscosity. The results from tests and experiments conducted show that the density of coconut oil and corn oil biodiesel have the same value while density of olive oil biodiesel is slightly lower. Flash point of coconut oil biodiesel is the highest among the three biodiesels while corn oil and olive oil biodiesel show only a slight difference between them with corn oil biodiesel has the higher value of flash point. The viscosity of coconut oil biodiesel is slightly higher than corn oil biodiesel, while olive oil biodiesel has the lowest viscosity.

ABSTRAK

Biodiesel merupakan alternatif kepada penggunaan diesel petroleum. Penggunaan biodiesel semakin mendapat tempat dalam kalangan pengguna pada masa kini. Terdapat pelbagai sumber yang terdiri daripada minyak sayuran dan lemak haiwan yang boleh digunakan untuk menghasilkan biodiesel. Banyak minyak sayuran dan lemak haiwan yang telah digunakan untuk menghasilkan biodiesel dalam kajian yang telah dijalankan sebelum ini. Pemilihan sumber untuk menghasilkan biodiesel dalam kajian-kajian sebelum ini adalah berdasarkan keberadaan sesuatu sumber tersebut di sesuatu tempat itu sendiri. Disebabkan terdapat banyaknya sumber yang boleh digunakan untuk menghasilkan biodiesel, maka sifat-sifat biodiesel yang dihasilkan juga berbeza. Banyak kajian dan ujikaji yang telah dijalankan untuk menentukan sifat-sifat biodiesel dan juga untuk mengetahui sama ada biodiesel ini sesuai untuk digunakan oleh pengguna dan tujuan pengkomersilan. Dalam projek ini, biodiesel dihasilkan menggunakan tiga minyak sayuran yang berbeza iaitu minyak kelapa, minyak jagung, dan minyak zaitun yang boleh didapati di pasaran tempatan. Beberapa ujian kemudiannya dijalankan untuk menentukan sifat-sifat biodiesel yang dihasilkan seperti ketumpatan, takat kilat, dan kelikatan. Keputusan dari beberapa ujian dan eksperimen yang dijalankankan menunjukkan bahawa ketumpatan biodiesel minyak kelapa dan minyak jagung mempunyai nilai yang sama manakala ketumpatan biodiesel minyak zaitun adalah sedikit lebih rendah. Takat kilat biodiesel minyak kelapa adalah yang tertinggi antara tiga minyak tersebut, manakala minyak jagung dan biodiesel minyak zaitun menunjukkan hanya sedikit perbezaan antara mereka dengan biodiesel minyak jagung mempunyai nilai takat kilat yang lebih tinggi. Kelikatan biodiesel minyak kelapa adalah lebih tinggi sedikit daripada biodiesel minyak jagung, sementara biodiesel minyak zaitun mempunyai kelikatan terendah.

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LIST OF ABBEREVATIONS

ASTM	American Society for Testing and Materials Standard
EN	European Standard
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
CP	Cloud Point
PP	Pour Point

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Biodiesel is mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. Biodiesel can be produced through a chemically reversible reaction called transesterification which has been widely used. In this reaction, vegetable oil or animal fat reacts with alcohol such as methanol in the presence of catalyst. The product of the reaction is a mixture of methyl esters and its by-product which is glycerol or glycerin. The properties of resulting biodiesel are quite similar to the petroleum diesel fuel.

There are varieties of oils that are edible and non-edible which can be used to produce biodiesel. However, most of the biodiesel that have been produced originated from edible oils such as palm oil, soybean oil, corn oil, and many more. However, since the price of edible vegetable oils are quite expensive, the less raw materials containing free fatty acids such as waste cooking oil and animal fats are preferred (Nakpong et al, 2009).

Since biodiesel can be produced from a variety of sources, the biodiesel produced also can have a wide range of fuel properties value and behaviour. Properties of biodiesel depends on the concentration of fatty acids and other chemical composition of its source. Therefore, the properties of biodiesel produced from different sources must be evaluated in order to commercialize it and convince the consumers that biodiesel is an alternative way to petroleum diesel.

1.2 PROBLEM STATEMENT

In a world of increasingly advanced and high-tech, energy generation and consumption are also in high demand. Ever since the days of the Industrial Revolution, fossil fuels such as natural gas and petroleum is used to generate energy. As this source is a non-renewable energy, the world is now experiencing problems as the fossil fuel reserves are diminishing and thus causing fossil fuel prices higher. According to statistics, the world's fossil fuel reserves are expected to be exhausted by 2112 (Singh et al.,2012).

Burning of fossil fuel also causes a negative effect to the environment which is global warming. Burning of fossil fuel contributes to the emission of greenhouse gases that causes the Earth climate to increase. The most gases emission comes from transportation where fossil fuel is the source of energy. As a result of these problems, various alternatives are being explored to reduce the dependency on the use of fossil fuel and increase the dependency on green energy resources. One of the alternatives is to use biodiesel fuel. Biodiesel is a fuel that can be derived from natural oils such as vegetable oils and animal fats.

However, to produce biodiesel fuel, the sources should be identified based on the environmental conditions and the availability of the oil stocks. Since there are many sources can be used for biodiesel production, the properties of the biodiesel produced can also be different. The properties of the biodiesel produced must be determined and evaluated in order to identify whether it is suitable to be used in engine or for commercialization purpose.

1.3 OBJECTIVES

Below are the main objectives which would be:

1. To produce biodiesel oil from different oil stocks.

2. To study and evaluate the fuel properties behaviour of biodiesel oil.

1.4 SCOPE OF PROJECT

Throughout this project, first of all, the suitable oil stocks to be used for biodiesel production must be identified. Since there are varieties of fuel properties for biodiesel, a few suitable parameters of the properties need to be identified for evaluation. After the identification of fuel properties of biodiesel, appropriate experiments and test methods for the evaluation of the properties must be determined. Next step is to conduct the experiment of biodiesel production process and fuel properties testing. Final step in this project is to compare and evaluate the properties of biodiesel from the chosen oil stock and write a final report.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

The second chapter is referencing what could be used by the readers to understand the theory and detail about the scope of this project. This literature review will be focusing on the type of oil stocks, fuel properties, fuel sampling process, and analysis.

2.2 TYPE OF OIL STOCKS

Biodiesel can be produced by using vegetable oil or animal fats but commonly used for biodiesel production is vegetable oil. Vegetable oil is comprised of the five most common fatty acids which are palmitic, stearic, oleic, linoleic, and linolenic. The amount of these acids varies among the oil stocks and because their methyl esters have different properties, the biodiesel derived from these oils also show varying properties. Table 2.1 shows the properties of chosen vegetable oil which is coconut oil, olive oil, and corn oil.

Table 2.1: Several properties of chosen vegetable oils.

PROPERTIES	Coconut Oil	Olive Oil	Corn Oil
Density (kg/m3)	800	881.5	886
Flash Point (^oC)	100	182	108
Cloud Point (^oC)	0	7	N/A

(Source: Kostik et al, 2012)

The cost of biodiesel production is largely determined by the cost of the oil stocks; therefore, less expensive oil stocks have been of interest for a considerable length of time (Knothe, 2013). In order to promote the use of biodiesel, various low priced vegetable oil must be explored and commercialized into biodiesel. In this project, there are three different oil stocks have been chosen. They are coconut oil, corn oil, and olive oil. The reason for the selection of the three oil stocks will be explained in the next section.

2.2.1 Coconut Oil

For decades, coconut has been preferred as the raw material for the production of soap and cosmetics. In term of edibility, coconut oil provides many health benefits as being anti-viral, anti-bacterial, anti-fungal, and many more (Bello et al, 2015). Coconut oil is created through a process similar to that used to create olive oil. The main difference is that coconut oil is derived from the meat of the coconut rather than the olive. Coconut oil can be produced through a variety of different processes where there is some that relying on pre-dried coconut and some other use raw coconut. Coconut oil will take the form of solid below 24°C and takes on a creamy white appearance but will easily melt into a liquid form at higher temperatures.

Coconut oil is used in this project because it is one of the main crops and easily available in Malaysia. Coconut oil is also chosen as its price in the local market is cheaper as coconut tree is widely planted in the country. As for the people in the rural area, they also have easier access to coconut oil to produce biodiesel. According to the statistics in IndexMundi (2016), Malaysia is placed in 9^{th} position of the largest production of coconut oil by country.

Coconut oil contains high concentration of saturated fatty acids such as lauric, myristic, palmitic, caproic, caprylic, capric, arachidic, and stearic acid. The concentration of saturated fatty acid in coconut oil can be as high as 90%. Table 2.2 shows the concentration of saturated and unsaturated fatty acid in coconut oil.

Table 2.2: Concentration of fatty acids in coconut oil.

ACID	CARBON	Concentration (%)	Molar mass (g/mol)
Caproic	C6:0	0.04	116
Palmitic	C16:0	9.2	256
Caprylic	C8:0	7.0	144
Capric	C10:0	8.0	172
Lauric	C12:0	48.0	200
Myristic	C14:0	16.0	228
Arachidic	C20:0	0.25	312
Stearic	C18:0	2.0	284
Oleic	C18:1	8.8	282
Linoleic	C18:2	0.5	280

(Source: Kostik et al, 2012)

2.2.2 Corn Oil

Corn oil is one of the product of corn. Corn oil was first extracted in 1898 and initially meant for cooking purposes. It was first extracted by Benjamin and Theodore Hudnut by using machinery that they created themselves. It is initially called as mazoil. Corn oil contains triglyceride that can be broken down further into monounsaturated fatty acid, polyunsaturated fatty acid, and saturated fatty acid (Davis, 2016). Table 2.3 shows the concentration of fatty acid in corn oil.

Table 2.3: Concentration of fatty acids in corn oil.

ACID	CARBON	%	g/mol
Caprylic	C8:0	4.0	144
Capric	C10:0	7.0	172
Myristic	C14:0	0.6	228
Palmitic	C16:0	10.0	256
Stearic	C18:0	3.5	284
Oleic	C18:1	26.8	282
Linoleic	C18:2	48.0	280

(Kostik et al, 2012)

Corn oil is very popular as cooking oil as it has a very high smoke temperature. High smoke temperature means that it will not smoke easily, allowing it to heated at higher temperature compared to other vegetable oils. Other than for cooking purposes, corn oil is also can be used in soaps and textiles manufacturing. Besides that, it also can be used in nitro-glycerine, paints, and insecticides. Recently, corn oil is also one of the preferable oil stock for the production of biodiesel.

Corn oil can be extracted from the germ of corn, which is the small germinating part that will grow into new maize plant. These germs are rich in nutrients and oils. There are various method to extract oil from the seed germs. However, the best oil in terms of health benefits is the cold pressed oil. Although crude corn oil contains almost 99% of triglycerides, it also contains other minor compounds such as free fatty acids, waxes, phospholipids, pigments, and odorous compounds. Therefore, these compounds should be removed from the crude oil through a refining process for it to be accepted (Davis, 2016).

2.2.3 Olive Oil

Olive oil is the product of olive tree (*Olea europaea*). Olive tree has been cultivated for thousands of years. They are highly appreciated and commonly known for their taste and aroma. They also known for their healthy and nutritional properties (López-Cortés et al, 2013). Originally, scientists thought the primary benefit of olive oil was its monounsaturated fat. This is because, almost 75 percent of the fatty acids concentration in olive oil come from monounsaturated fat and only 15 percent of them is saturated fat. That is why blood cholesterol goes down when butter and high-fat meat are replaced with olive oil as the source of fat (Rubio, 2008). Table 2.4 shows fatty acid concentration of olive oil.

Table 2.4: Concentration of fatty acids in olive oil.

ACID	CARBON	%	g/mol
Palmitic	C16:0	11.6	256
Palmitoleic	C16:1	1.0	254
Stearic	C18:0	3.1	284
Oleic	C18:1	75.0	282
Linoleic	C18:2	7.8	280
Linolenic	C18:3	0.6	278
Arachidic	C20:0	0.3	312
Behenic	C22:0	0.1	340
Lignoceric	C24:0	0.5	368

(Kostik et al, 2012)

However, olive oil has become one of the vegetable oil that can be used to produced biodiesel other than its benefits as health and nutrition product. Many studies have been conducted to produce biodiesel from olive oil.

2.3 BIODIESEL PRODUCTION

In order to produce biodiesel, those three oil stocks will undergo transesterification process. Transesterification process is the most common process used to convert triglycerides from vegetable oils to ester or biodiesel. Vegetables oil is made up of triglycerides that contains glycerine. The process of transesterification will convert the oil into esters, and thus separating out the glycerine and biodiesel as shown in Figure 2.1. When separated, the glycerine will sink to the bottom leaving the biodiesel on top.

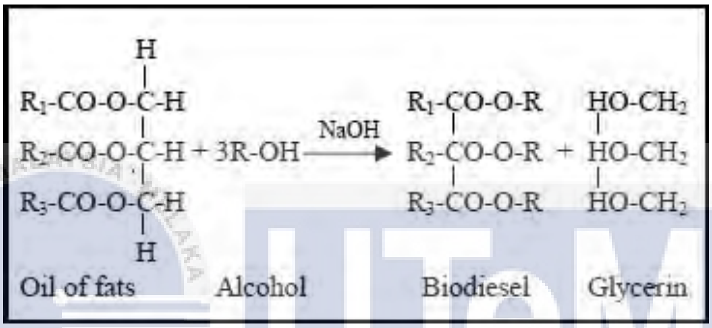

Figure 2.1: Reaction of transesterification.
(Source: Hossain et al, 2012)

The methodology or procedures for the transesterification process will be explained in other section. There are a few parameters need to be considered in transesterification process. They are molar ratio of alcohol to oil, type of alcohol used, type and amount of catalyst, reaction temperature, pressure and time.

2.3.1 Molar Ratio

Molar ratio of alcohol to oil is one of the main factor of biodiesel production. It can affect the conversion efficiency, yield of biodiesel and also the biodiesel production cost. The stoichiometric molar ratio of alcohol to oil for transesterification process is 3:1. Therefore, in order to increase the miscibility and to enhance the contact between alcohol molecule and triglyceride, higher molar ratio is required. Higher alcohol to oil molar ratio also give rise to greater alkyl ester conversion in shorter time.

Previous study by Balat et al (2008) shows that alcohol to oil molar ratio of 6:1 gives better yields of biodiesel compared to 4:1 and 5:1 as shown in Table 2.5. Musa (2016) noted that generally accepted molar ratio of alcohol to oil is 6:1 - 30:1. Therefore, in this project, molar ratio of alcohol to oil is to be 6:1 as it is the mostly applied molar ratio in the biodiesel production from vegetable oil.

Table 2.5: Effect of reaction time and methanol-to-oil molar ratio.

No.	**Reaction Time (min)**	**Percent Conversion at Molar Ratio**			**Percent Yield at Molar Ratio**		
		4:1	**5:1**	**6:1**	**4:1**	**5:1**	**6:1**
1	15	85	89	93	45	46	62
2	30	86	89	94	53	54	66
3	45	88	91	94	57	59	72
4	60	90	92	94	61	67	77
5	120	91	93	94	66	67	72
6	240	92	94	95	66	67	82
7	360	92	95	97	83	82	83

(Source: Balat et al, 2008)

Vegetable oils contain triglycerides that is a combination of glycerol and fatty acids. If 6:1 molar ratio of alcohol to oil is going to be used, 2 mol of alcohol must be allowed to react with each chain of triglycerides since there are three chains of glycerides. Each vegetable oil used in this project such as coconut oil, corn oil, and olive oil have different type of fatty acids. Molar mass of each fatty acid must be determined. Then, the concentration of each fatty acid must be divided with the molar mass of fatty acid. Result of the division must be multiplied with two since two mol of alcohol is needed for each chain of glyceride. The total of the multiplication shows the number of mol for alcohol needed.

2.3.2 Type of Alcohol

Alcohol is one of the most important raw materials for the production of biodiesel. Numbers of alcohol have been explored for biodiesel production and the most widely used are methanol and some of previous studies also used ethanol. There are a few other short-chain alcohols that can be used such as propanol, butanol, isopropanol, tert-butanol, branched alcohols and octanol. However, these alcohols are costly compared to methanol and ethanol.

Methanol and ethanol are the most often used alcohols in the production of biodiesel. Compared to ethanol, methanol is particularly preferred because of its physical and chemical advantages. Methanol has a quick reaction with triglycerides and can be easily dissolved in NaOH. It is also easier to obtain compared to the other alcohols (Musa, 2016).

Musa (2016) also stated that methanol is chosen over ethanol because of two major factors. First, methanol does not form azeotrope, thus making it easier to recycle. Ethanol is said to be easily forming azeotrope with water. Azeotrope forms when a mixture of two or more liquids have constant boiling point where the proportions cannot be altered by simple distillation. Comparison in terms of characteristics as fuels, biodiesel from methanol and ethanol show slight variations. Biodiesel produced from methanol has higher pour and cloud points and lower viscosities compared to biodiesel produced from ethanol. Therefore, in this project, the chosen alcohol for biodiesel production is methanol.

2.3.3 Reaction Temperature

Reaction temperature is one of the parameter that must be determined in transesterification process. It is found that higher reaction temperature increases the reaction rate and shortening reaction time due to the reduction in viscosity of oil. However, increase in reaction temperature beyond the optimal level will lead to the decreasing of biodiesel yield because higher reaction temperature accelerates the saponification of triglycerides (Abbah et al, 2016). The optimum reaction temperature must not exceed the boiling point of alcohol used. If methanol is used, the optimum temperature is 64^{o}C (which is near the boiling point of methanol of 64.7^{o}C) because increase in temperature beyond this point decreases the yield due to the evaporation of methanol. Other than that, increase in temperature also must not exceed the boiling point of alcohol to prevent the volatilization of the alcohol during transesterification.

2.3.4 Catalyst

Yield of biodiesel can be influenced by types of catalyst used in the reaction of transesterification process. The catalyst for transesterification process can either be acidic or basic catalyst. Acidic catalysts are effective but require an extremely long time interval and temperatures which can exceed 100^{o}C for its reaction. Conversions of 99% with a concentration of 1% sulfuric acid in relation to the amount of oil, it takes about 50 hours (EREN., 2003 cited in Guerrero et al, 2010). Examples of acidic catalysts are sulfuric acid (H_2SO_4) and phosphoric acid (H_3PO_4). The recovery of glycerine is more difficult when acid catalyst with alcohol excess is used as the quantities of alcohol are quite large compared to the other type of catalyst (Arbelaez et al, 2007 cited in Guerrero et al, 2010).

Compared to acidic catalysts, basic catalysts accelerate the reaction rate. Despite of that characteristic, the disadvantage of basic catalyst is that it produces soaps due to the high amounts of free fatty acids and water by which we must add the appropriate amount of pure base to neutralize the free fatty acids. The most commonly used basic catalysts are sodium hydroxide (NaOH) and potassium hydroxide (KOH) (EREN., 2003 cited in Guerrero et al, 2010). Although basic catalyst produces soaps as the final product, it is still preferable than acidic catalyst as it consume a very long time interval.

Since the reaction temperature of transesterification process must not exceed the boiling point of alcohol, the two basics catalyst mentioned above have been tested with methanol at 60°C. It has been found that the NaOH catalyst achieve higher yields at 60°C compared to KOH at the same temperature and higher catalyst concentration should be applied to use NaOH (Liu et al, 2006 cited in Guerrero et al, 2011).

2.4 FUEL PROPERTIES OF BIODIESEL

Fuel properties of biodiesel depends on the type of vegetable oil used. Vegetable oil consists of triglycerides that are molecules of glycerol bounded to three fatty acid molecules. Different plant oils have different compositions and this explains why different triglycerides have different physico-chemical properties and they coagulate at different temperatures. Fuel properties stated below are consistent with the standard listed by American Society for Testing and Materials Standard (ASTM) and European Standard (EN). Table 2.6 shows some properties listed by ASTM with their standard test methods and, limitations and specified units.

Table 2.6: Biodiesel properties standard by ASTM D6751.

Property	**Test Method**	**Limit**		**Units**
		min	**max**	
Calcium & Magnesium, combined	EN 14538	-	5	Ppm (µg/g)
Flash Point (closed cup)	D 93	93	-	°C

Property	Test Method	Limit		Units
		min	max	
Alcohol Control (one to be met): 1. Methanol Content	EN 14110	-	0.2	%(m/m)
Water & Sediment	D 2709	-	0.05	%(v/v)
Kinematic Viscosity, at 40 ºC	D 445	1.9	6.0	mm^2/s
Sulfated Ash	D 874	-	0.02	% (m/m)
Sulfur: S 15 Grade S 500 Grade	D 5453 D 5453	- -	0.0015 0.05	% (m/m) % (m/m)
Cetane	D 613	47	-	-
Cloud Point	D 2500	report		ºC
Carbon Residue, 100% sample	D 4530	-	0.05	% (m/m)
Acid Number	D 664	-	0.05	mgKOH/g
Free Glycerin	D 6584	-	0.020	% (m/m)
Total Glycerin	D 6584	-	0.0240	% (m/m)
Phosphorus Content	D 4951	-	0.001	% (m/m)
Distillation-Atmospheric equivalent temperature 90% recovery	D 1160	-	360	ºC
Sodium/Potassium, combined	EN 14538	-	5	Ppm (µg/g)

(Source: Barabas et al, 2011)

2.4.1 Cold Flow Properties

Cold flow properties of biodiesel are cloud point (CP) and pour point (PP). The cloud point is the temperature at which crystals first start to form in the fuel. The cloud point is reached when the temperature of the biodiesel is low enough to cause wax crystals to precipitate. When the temperatures reach below the cloud point, crystal grows larger and agglomerate together to the point that they prevent the fluid to flow.

Cloud point depends on the nature and amount of the saturated fatty compound. Biodiesel that is derived from fats or oils with significant amount of saturated fatty compounds will display higher cloud point. In order to improve the cloud point, biodiesel produced from vegetable oils are usually blended with diesel in a certain percentage. The cloud point of biodiesel can be tested using ASTM D 2500 method.

Pour point is the temperature at which the fuel contains so many agglomerated crystals that it is essentially a gel and will no longer flow. This occurs if the temperature of the biodiesel drops below cloud point, when the microcrystals merge and form large clusters, which may disrupt the flow of the flow of biodiesel through the pipes of the engine fuel system (Barabas et al, 2011). Pour point of biodiesel can be tested by using ASTM D97 method.

2.4.2 Density

Biodiesel density is the mass of unit volume that is measured in a vacuum. Biodiesel performance is strongly affected by the density as some of the fuel properties such as cetane number, heating value and viscosity is connected to density. Besides that, density of biodiesel also affects the quality of atomization and combustion.

The density of biodiesel is usually higher compared to the ordinary diesel. It depends on the fatty acid composition and purity. In many studies, it has been observed that density of biodiesel has not change a lot and does not show many different in terms of value. This is because, the densities of methanol and oil are close to the density of the produced biodiesel

(Alptekin et al, 2008). Biodiesel density varies between tight limits as it is made up of a small number of methyl or ethyl esters that have very smaller densities. Biodiesel density is also indication of contamination as biodiesel contamination slightly affects the density. The density can be measured by using ASTM D1298 method and EN ISO 3675 test method. According to these standard, density should be tested at 15 ºC as density can be affected by temperature. Biodiesel usually has higher density than ordinary diesel density (Barabás et al, 2011).

2.4.3 Viscosity

Viscosity of fuel is their property to resist the relative movement tendency of their composing layers due to intermolecular attraction forces. Allowable kinematic viscosity for biodiesel according to ASTM D6751 is between 1.9 to 6.0 mm^2/s (Barabas et al, 2011). Viscosity is one of the most important properties of fuel. Viscosity can affect the flow of a fuel at all temperature that the fuel is exposed to. Viscosity can also influence the atomization of a fuel upon injection into the combustion chamber and ultimately the possible formation.

One of the reasons that biodiesel usage in diesel engine is limited is because of viscosity. Compared to diesel fuel, biodiesel has higher viscosity due to the presence of the electronegative oxygen. Among biodiesel itself, the viscosity of pure ethyl ester is higher than methyl ester (Barabas et al, 2011). Viscosity also increases as the concentration of saturated fatty acid increase (Yasar et al, 2011). As shown in Figure 2.2, the viscosity of coconut oil biodiesel increased as the percentage of diesel in biodiesel-diesel blends decrease (Hossain et al, 2012). Viscosity of pure biodiesel recorded highest viscosity, while pure diesel has lowest viscosity.

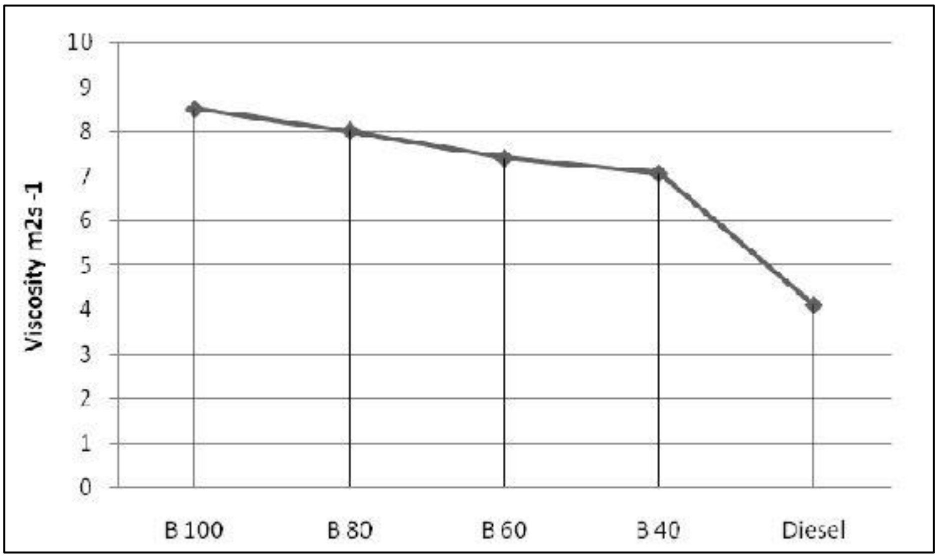

Figure 2.2: Coconut biodiesel-diesel blends vs viscosity.
(Source: Hossain et al, 2012)

Fuel viscosity has both an upper and lower limit. Low viscosity can cause leakage in the fuel system, while high viscosity causes poor fuel atomization and incomplete combustion. High viscosity also increases engine deposits, needs more energy to pump the fuel and wears fuel pump elements and injectors. In cold weather, high viscosity also causes more problems as viscosity increases when the temperature decreases (Alptekin et al, 2008).

2.4.4 Flash point

Flash point is the lowest temperature at which it can form a combustible mixture with air and the fuel starts to ignite. When there are increases in temperature, the vapour pressure also increases and the amount of evaporated flammable liquid in equilibrium with the air also increases (Carareto et al, 2012). The minimum temperature of flash point based on ASTM D93 is 93 ^{o}C. Flash point of biodiesel will vary depending on the oil stocks it is made of. Higher value of flash point makes the fuel safer (Barabas et al, 2011). Table 2.7 shows flash point results of coconut, corn, and olive oil biodiesel that has been recorded from previous study.

Table 2.7: Flash points of biodiesel samples.

Type of Biodiesel	Flash Point (°C)
Coconut Oil	115
Corn Oil	111 – 170
Olive Oil	178

(Source: Barabas et al, 2011)

There are many factors that can affect the change of flash point of biodiesel where the residue or presence of alcohol is one of them. Flash point is also influenced by the chemical compositions of the biodiesel, including the number of double bonds, number of carbon atoms, and many more (Ashraful et al., 2014). Biodiesel flash point can decrease rapidly as the methanol amount increases as methanol flash point is 11 °C-12 °C. Even if there is a presence of 0.5% of methanol in the biodiesel, the flash point can drop rapidly from 170 °C to 50 °C. Therefore, by measuring the flash point the presence of methanol can be indicated (Barabas et al, 2011).

2.4.5 Acid Number

Acid number or acid value is the indicator of the amount or volume of acidic substance that is present in biodiesel. It can be defined as the amount of base which expressed in milligrams of potassium hydroxide (KOH) per gram of sample. Acid number of biodiesel can be determined by using ASTM D664 method. It is required to titrate a sample in the solvent from its initial meter reading to a meter reading that is correspond to a freshly prepared non-aqueous basic buffer solution. Generally, the acid number of biodiesel increases sharply upon oxidation. The increase in acid number is a function of storage time and storage temperature (Kumar, 2016).

The acidic compounds that commonly or could possibly be found in biodiesel are residual mineral acids from the production process, residual free fatty acid from the hydrolysis process or the post-hydrolysis process of esters, and oxidation by-products in the form of other organic acids (Barabas et al, 2011).

2.4.6 Total and free glycerine

After the biodiesel is produced through the transesterification process, the resulting product can contain not only the desired alkyl ester product but also residuals. Other by-products that is produced and occur in the final product with biodiesel are glycerol, residual of alcohol, and residual of catalyst used. The residual of alcohol and catalyst can be recycled for another transesterification process but glycerol is undesirable. Glycerol occur in the final product as the effect of unconverted triglycerides that undergo the transesterification process as shown in Figure 2.3.

Triglycerides	+	3 Methanol	+	Catalyst	<--->	3 Methyl Ester	+	Glycerol
1000 kg		107.5 kg				1004.5 kg		103 kg

Figure 2.3: Example of transesterification reaction.

(Source: Munari et al, 2009)

Total and free glycerine of biodiesel is the indicator of the biodiesel quality. High level of residue of glycerine in biodiesel can cause injector deposits, clogged fuelling systems, and poor cold weather operation. High level of free and total glycerine are caused by the improper or low conversion of oil or fat into the desired mono-alkyl esters. Total and free glycerine of biodiesel can be determined by using ASTM D6584 method (Munari et al, 2009).

Table 2.8 shows the specifications according to EN 14214 of total and free glycerine. Meanwhile, according to ASTM D6751 standard, the content of free glycerol should not exceed 0.02% and 0.24% total glycerol by weight.

Table 2.8: Total glycerine specifications according to EN 14214:2003.

Compound	**Max % (m/m) (EN 14214)**
Free Glycerin	0.02
Mono-glycerides	0.8
Di-glycerides	0.2
Tri-glycerides	0.2
Total glycerin	0.25
**Total Glycerin is calculated as follows: $TG = G + 0.255M + 0.146D + 0.10.3T$, where TG = Total Glycerin, G = Free Glycerin, M = Mono-glycerides, D = Di-glycerides, T = Tri-glycerides.*	

(Source: Munari et al, 2009)

2.4.7 Oxidative Stability

Stability is one of the important criteria regarding fuel properties. The stability of biodiesel is lower than common diesel fuel. Biodiesel quality can be affected by oxidation during storage which is in contact with air or hydrolytic degradation which is in contact with water. Biodiesel oxidation can occur during storage while waiting distribution or within the vehicle fuel system itself. Storage or oxidation stability is very important for biodiesel. Storage stability refers to the ability of the fuel to resist chemical changes during long term storage. These changes usually consist of oxidation due to contact with oxygen from the air (Barabas et al, 2011). The oxidation stability can be tested by using ASTM D7462 method which is included in ASTM D6751.

Generally, biodiesel degraded because of one or combination of the oxidation in the presence of oxygen, thermal oxidation at elevated temperature, hydrolysis in presence of moisture, and microbial degradation due to the presence of bacteria or fungi. Various factors which influence the oxidation process of biodiesel are fatty acid structure, presence of certain metals, elevated temperature, extraneous materials, peroxides, light or pressure and antioxidants, as well as the exposed surface area between biodiesel and air (Kumar, 2016).

2.4.8 Water and Sediment

Biodiesel should be dried after it is washed with water so that the specification of water is below 500 ppm (0.050%). Water in biodiesel could make the fuel go rancid and change the chemical structure of biodiesel. If any moisture is allowed to accumulate for a long time, it will increase the free fatty acid level of biodiesel. Free fatty acids may cause corrosion to the metal part in fuel lines. They can also react to make monoglycerides.

Even when biodiesel is adequately dried, water can still accumulate during transportation and storage. In comparison with regular diesel, biodiesel is more hygroscopic which means it can attract water due to its polar molecule structure at one end. Biodiesel that is stored at high temperatures will absorb water which then precipitates out when the temperature drops. The best way to deal with water in biodiesel is to dry the fuel adequately and use it quickly within a few months to prevent water from accumulating.

The water and sediment specification as also concerned with any substance that is higher in density than biodiesel such as monoglycerides and unreacted oil. Like water, these heavier substances can settle in the tank. Water in biodiesel storage tanks can promote algae growth that can clog fuel filters when transferred to vehicle and equipment tanks (Shrestha, 2012).

CHAPTER 3

METHODOLOGY

3.1 OVERVIEW

This chapter explains in detail about the methodology or experiment that has to be done in order to test the fuel properties behavior of biodiesel produced. It also describes about which oil stock has better performance compared to the rest.

3.2 GENERAL METHODOLOGY

The chosen oil stocks for this project are coconut oil, corn oil, and olive oil. These oil stocks are chosen because of their availability in the local market. Other than that, these three oils are used for different purposes although all of them are edible in which coconut oil is mostly for external body use and corn oil is mostly used for cooking purposes. Meanwhile, olive oil is widely used for health and beauty purposes. After determining oil stocks to be used for biodiesel, fuel properties of biodiesel are identified. There are many fuel properties of biodiesel that is listed by American Society for Testing and Materials Standard (ASTM). However, for this project there are only a few properties that can be tested since the accessibility of the apparatus for the test is limited. Next step is the production of biodiesel by using the chosen oil stocks through transesterification process. After biodiesel is produced, suitable test method must be conducted to determine the properties behavior of biodiesel from chosen oil stocks.

Overall general methodology of this project can be expressed in a flowchart as below.

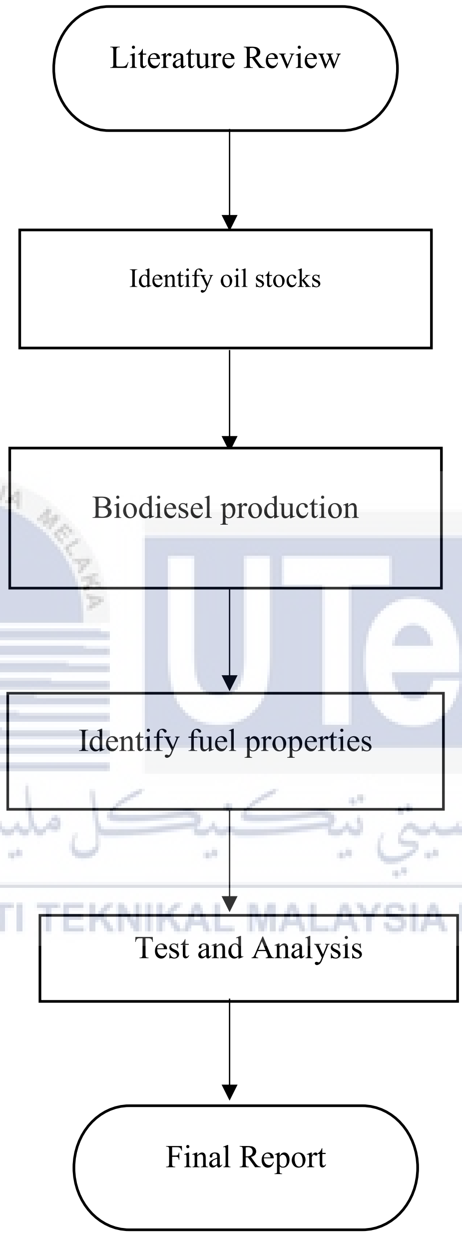

Figure 3.1: Overall general methodology of the project.

3.3 BIODIESEL PRODUCTION

In order to produce biodiesel, the chosen oil stocks which are coconut oil, corn oil, and olive oil must undergo the process of transesterification. The materials needed for the transesterification process are three vegetable oil stocks which are coconut oil, olive oil, and corn oil. Corn oil and olive oil are purchased from the grocery store or local market while coconut oil is homemade or self-extracted. The alcohol used for this process is methanol that is obtained from local chemical store. The molar ratio of alcohol to oil for this experiment is 6:1 as it results in higher percentage of conversion and conversion compared to 4:1 and 5:1 as stated in Chapter 2. The catalyst is potassium hydroxide (KOH) with concentration of 0.75% as concentration of 0.75% is widely used in previous studies and to prevent more soap formation. Optimum temperature for this reaction is 60 ºC which is below the boiling point of methanol of 64.7 ºC. The required experimental equipment for the transesterification process are spherical glass reactor, thermostat, hot stirrer plate, and separating funnel. All equipment needed for this process is already available in the university laboratory.

3.3.1 Experimental Procedure

Firstly, the spherical glass reactor must be preheated to the temperature of 75 ºC moisture elimination. Then, vegetable oil shall be added into the reactor before heating it up in the reactor. The oil must be heated until the reaction temperature of 60 ºC is reached before adding methanol and KOH. The amount of methanol added must be calculated according to the molar ratio. In order to determine the amount of methanol needed, the molar mass of methanol must be multiplied with the number of mol that is obtained based on the fatty acid concentration of chosen oil stock and calculated using Equation 3.1. Fatty acid concentration of each oil is based on previous studies. Table 3.1, 3.2, and 3.3 shows the numbers of mol for each oil based on their fatty acid concentration.

$$no.of\ mol = \frac{\%\ fatty\ acid\ concentration}{molar\ mass\ of\ fatty\ acid} \times 2 \qquad (3.1)$$

The number of mol of each fatty acid is then totaled up to obtain the number of mol needed for methanol.

Table 3.1: Concentration of fatty acids in coconut oil.

ACID	CARBON	Concentration (%)	Molar mass (g/mol)	Concentration /molar mass	[Concentration /molar mass]x2
Caproic	C6:0	0.04	116	0.0003	0.0006
Palmitic	C16:0	9.2	256	0.0359	0.0718
Caprylic	C8:0	7.0	144	0.0486	0.0972
Capric	C10:0	8.0	172	0.0465	0.0930
Lauric	C12:0	48.0	200	0.2400	0.4800
Myristic	C14:0	16.0	228	0.0702	0.1404
Arachidic	C20:0	0.25	312	0.0008	0.0016
Stearic	C18:0	2.0	284	0.0070	0.0140
Oleic	C18:1	8.8	282	0.0312	0.0624
Linoleic	C18:2	0.5	280	0.0018	0.0036
				TOTAL	**0.9646**

(Source: Kostik et al, 2012)

Table 3.2: Concentration of fatty acids in corn oil.

ACID	CARBON	Concentration (%)	Molar mass (g/mol)	Concentration /molar mass	[Concentration /molar mass]x2
Caprylic	C8:0	4.0	144	0.0278	0.0556
Capric	C10:0	7.0	172	0.0407	0.0814
Myristic	C14:0	0.6	228	0.0026	0.0052
Palmitic	C16:0	10.0	256	0.0391	0.0782

Stearic	C18:0	3.5	284	0.0123	0.0246
Oleic	C18:1	26.8	282	0.0950	0.1900
Linoleic	C18:2	48.0	280	0.1714	0.3428
				TOTAL	**0.7778**

(Source: Kostik et al, 2012).

Table 3.3: Concentration of fatty acids in olive oil.

ACID	CARBON	Concentration (%)	Molar mass (g/mol)	Concentration /molar mass	[Concentration /molar mass]x2
Palmitic	C16:0	11.6	256	0.0453	0.0906
Palmitoleic	C16:1	1.0	254	0.0039	0.0078
Stearic	C18:0	3.1	284	0.0109	0.0218
Oleic	C18:1	75.0	282	0.266	0.5320
Linoleic	C18:2	7.8	280	0.0279	0.0558
Linolenic	C18:3	0.6	278	0.0022	0.0044
Arachidic	C20:0	0.3	312	0.00096	0.00192
Behenic	C22:0	0.1	340	0.00029	0.00058
Lignoceric	C24:0	0.5	368	0.0014	0.0028
				TOTAL	**0.7177**

(Source: Kostik et al, 2012)

Number of mol of alcohol is then multiplied with molar mass of methanol to obtain the percentage mass of alcohol for each mass of vegetable oil used as shown in Equation 3.2. Amount of methanol is then can be obtained by using Equation 3.3.

$$\%\, mass\ of\ alcohol\ needed = molar\ mass \times no.\, of\ mol \tag{3.2}$$

$$amount\ of\ methanol = mass\ of\ vegetable\ oil \times (\%\, mass\ of\ alcohol) \tag{3.3}$$

After the addition of methanol and KOH, the mixture must be stirred on the hot stirrer plate as the reaction time starts. The mixture must be vigorously stirred and refluxed for the required reaction time.

After completing the stirring of the mixture, the excess methanol shall be distilled off under vacuum pressure. Then, the transesterification product must be left in a separating funnel in order to let the glycerol separated only by gravity. If the glycerol is not separated by the gravity, approximately 10 g of pure glycerol must be added to the product of transesterification. Then, the separating funnel must be shaken vigorously and the product shall be allowed to stand. Approximately, within an hour the glycerol layer will then separate from the ester layer. After the separation from the glycerol, crude methyl ester must be washed repeatedly by using hot distilled water (50 ºC) in a separating funnel until neutral pH is obtained. In order to eliminate any water presence, the product shall be heated up to 110 ºC.

Pure glycerol shall be added to the mixture to remove the residual catalyst and soaps that might have been formed throughout the transesterification reaction. The addition of pure glycerol also creates a difference in the density between the two phases (methyl ester and glycerol). Density difference will help the separation process glycerol by gravity (Anastopoulos et al, 2009).

3.4 FUEL PROPERTIES TEST METHOD

In order to test the fuel properties, biodiesel produced from transesterification process shall going through a few test methods according to ASTM D6751. Fuel properties that can be tested are density, flash point, viscosity. The tests for determining the fuel properties of biodiesel are conducted based on the availability of the equipment and materials in the laboratory.

3.4.1 DENSITY

Density of biodiesel produced can be vary as they are produced from a variety of sources. In this project, density of the biodiesel samples is tested at the temperature of 15 ^{o}C. In order to determine the density of biodiesel, the important apparatus is hydrometer that is graduated in the unit of density. Other things needed are 100 ml measuring cylinder, thermometer and constant temperature water bath.

3.4.1.1 Procedure

First of all, the temperature of water bath must be set to 15 ^{o}C and wait for a few minutes until the temperature is constant. While waiting for the temperature to become constant, the sample of biodiesel must be poured into the 100 ml measuring cylinder. Then, place the sample in the measuring cylinder into the water bath and wait for a few minutes for the sample in the measuring cylinder to reach 15 ^{o}C.

When the temperature of the sample has almost reach 15 ^{o}C, place the hydrometer into the sample. The hydrometer must be inserted into the sample vertically and make sure there is no air flow or bubble that can disturb the reading or the temperature. Allow a sufficient time for the hydrometer to be at rest and for air bubbles to come to the surface. The hydrometer must be placed vertically in the sample as shown in Figure 3.1.

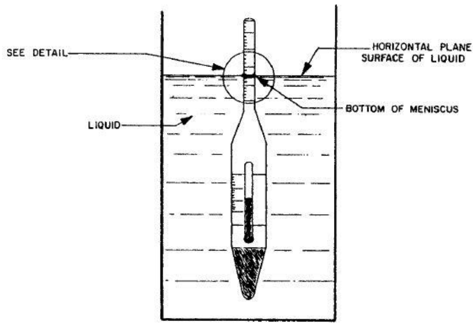

Figure 3.2: Position of hydrometer in the sample (ASTM, 2012).

When the hydrometer is at rest and floating freely away from the wall, record the reading to the nearest one-fifth of a full-scale division. For transparent liquids, the reading must be recorded as the point on the hydrometer at which the surface of the liquid cuts the scale by placing the eye slightly below the level of the liquid and slowly raise it until the surface appear to be a straight line cutting the hydrometer scale (ASTM D 1298, 2003).

3.4.2 FLASH POINT

In order to determine the flash point of biodiesel, the biodiesel shall be tested according to standard by ASTM D 3828. The apparatus used to determine flash point is Setaflash Series 3 Tester 33000-0 as shown in Figure 3.2. This flash tester can test flash point up to 300ºC. Other apparatus needed is a lighter to ignite a spark and tissue to clean the sample from the flash tester.

Figure 3.3: Setaflash Series 3 Tester 33000-0
(SETA, 2007)

3.4.2.1 Procedure

Before the test of flash point is conducted, the instrument must be prepared by checking that the correct "O" Ring Seal is fitted to the sample cup. Then, the sample cup must be wiped to ensure there is no residue left from the previous test. Next, switch on the tester and set the timer. In order to set the timer, the Set Timer Button must be pressed and hold down. The display will start to count down for a few seconds and then a warning beep will sound and the display will change to show “Set Test Time”. Then, release the Set Timer button and rotate the control knob to set the time interval in minutes. The Figure 3.3 below shows the position of buttons, display and parts of the flash tester.

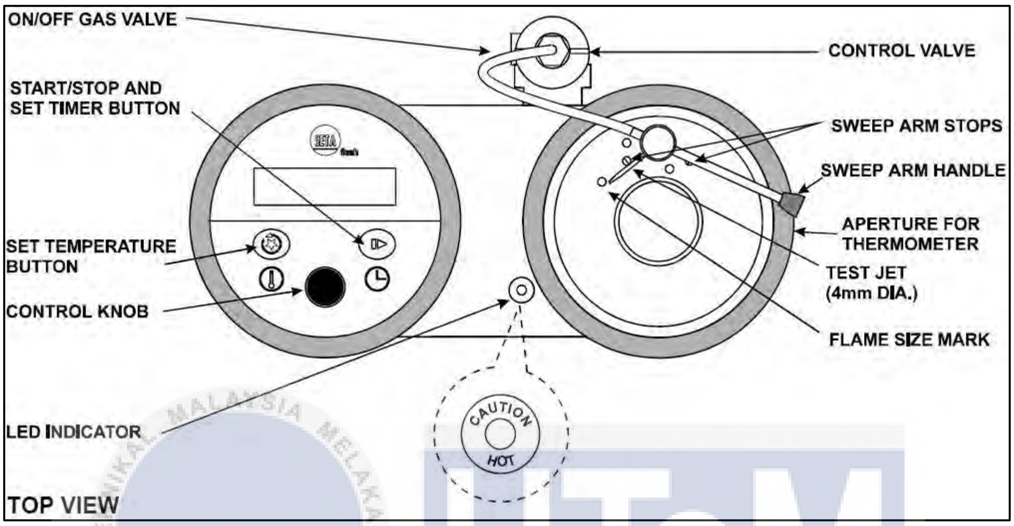

Figure 3.4: Top view and parts of flash tester.
(SETA, 2007)

Next step is to set the temperature for the test. Firstly, the Set Temperature button must be pressed and hold down until a warning beep is heard and display changes to show “Set Temperature”. Then, the Set Temperature button must be released. Next, rotate the control knob until the expected flash point temperature is displayed. When the Sample Cup has stabilized at the set temperature, a warning beep sound will be heard and the display will show “Ready”. When “Ready” is displayed, it means that the test can be started. Then, put the sample to teat in the syringe and inject it into the Sample Cup the Filler Orifice. After syringe removal, press and release Set Timer button to start the timer countdown. The display will show a countdown. Next, switch on the gas supply and light the Pilot and Test Jets. When the countdown reaches 0 seconds, a warning beep will sound. Then, open and close the Shutter for approximately 2.5 seconds.

If a flash is detected, the second line of the display will show "FLASH". Record down the temperature of the flash. If no flash is detected, increase the temperature by setting it to a higher temperature with an increment of 5 °C until flash is detected. When flash is detected during the temperature increment of 5 °C, reduce the temperature to the previous temperature and start again with increment of 0.5 °C to obtain the exact temperature of flash point.

After exact temperature of flash is obtained and the result is recorded, switch off the gas supply and wait until test and pilot flames are extinguished. Then press and release the Set Temperature button to reset the Flash Detector and temperature display. Then, unlock and open the lid, remove the tested sample, and clean the Sample Cup. Next, switch off the instrument at the ON/OFF Power Switch on the rear of the instrument.

3.4.3 VISCOSITY

Viscosity of biodiesel samples produced are tested by using viscometer and water bath as shown in Figure 3.4 and 3.5. As the viscometer in the laboratory can only measure dynamic viscosity, the density must also be measured in order to obtain the kinematic viscosity. Both dynamic viscosity and density are measured at 40 °C. Dynamic viscosity obtained from the viscometer is then divided with the density obtained from the water bath. The calculation to obtain the kinematic viscosity is shown in the equation below.

$$v = \frac{\mu}{\rho} \tag{3.4}$$

Where;

$$1\ cst = 1\ mm^2/s$$

$$v = kinematic\ viscosity, cst$$

$$\mu = dynamic\ viscosity, cp$$

$$\rho = density, g/cm^3$$

Figure 3.5: Water bath
(PROTECH, 2008).

Figure 3.6: Viscometer
(Brookfield, 2015).

CHAPTER 4

RESULTS & DISCUSSION

4.1 OVERVIEW

This chapter involves several experiments and tests to produce biodiesel and determination of biodiesel properties. There are a few properties tested for the produced biodiesel. The properties are density, flash point, and viscosity. The calculations to obtain the results are shown in Appendix A. The results of each test and experiment are displayed in tables and graphs.

4.2 BIODIESEL PRODUCTION

Biodiesel is produced through a process called transesterification. The procedures for the process are already explained in Chapter 3. In transesterification, vegetable oil is firstly heated to 60 ^{o}C. Figure 4.1 and 4.2 shows two samples of vegetable oil, which is coconut oil and corn oil being heated to 60 ^{o}C on the hot stirrer plate. When the temperature of vegetable oil reached 60 ^{o}C, the methanol and potassium hydroxide (KOH) is added into the heated vegetable oil. Figure 4.3 below shows heating of olive oil and Figure 4.4 shows the change in olive oil when methanol and potassium hydroxide is added into it. The mixture of vegetable oil, methanol, and potassium hydroxide is then allowed to reach the reaction temperature of 60 ^{o}C. When reaction temperature of 60 ^{o}C is reached, the reaction time of 1 hour is started and the mixture is left to stir.

Figure 4.1: Heating of coconut oil.

Figure 4.2: Heating of corn oil.

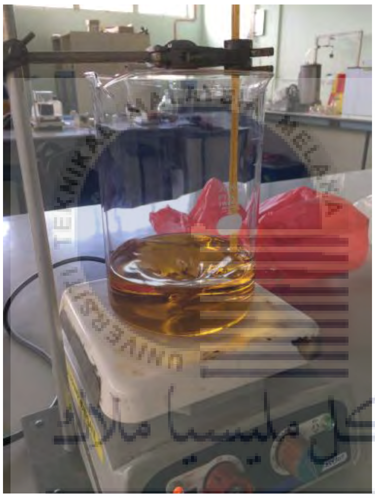

Figure 4.3: Heating of olive oil.

Figure 4.4: Heating of olive oil with methanol and KOH.

After 1 hour, the sample is left in the separating funnel for a few hours for the separation of biodiesel and glycerin. Then, biodiesel is glycerin is extracted out and biodiesel is obtained. Figure 4.5 shows separation of biodiesel and glycerin. Obtained biodiesel is cloudy as there is some residue of glycerin, methanol and potassium hydroxide left. In order to eliminate the residue, the biodiesel must be washed with hot water for several times until it becomes almost clear. Figure 4.6 shows corn oil biodiesel that has been washed for the first time.

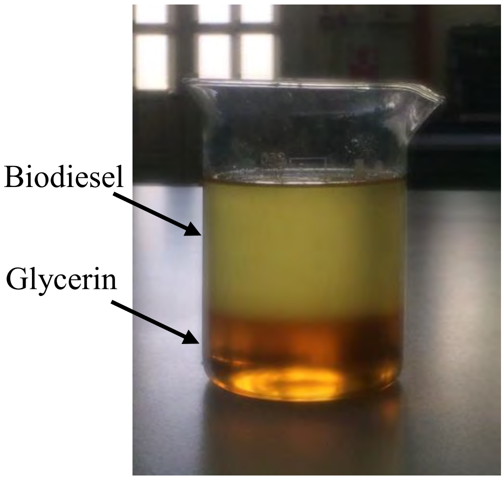

Figure 4.5: Separation of corn oil biodiesel and glycerin.

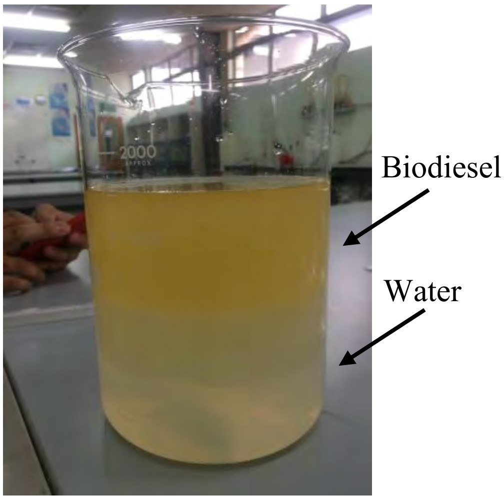

Figure 4.6: Unwashed corn oil biodiesel.

Although biodiesel produced has already been washed for a few times, in this project for two times, there is still some water left in the biodiesel that is the result of washing. Therefore, in order to remove the water, the biodiesel must be heated to 100 ^{o}C, which is the boiling point of water. Figure 4.7 below shows the result of biodiesel after the removal of water residue.

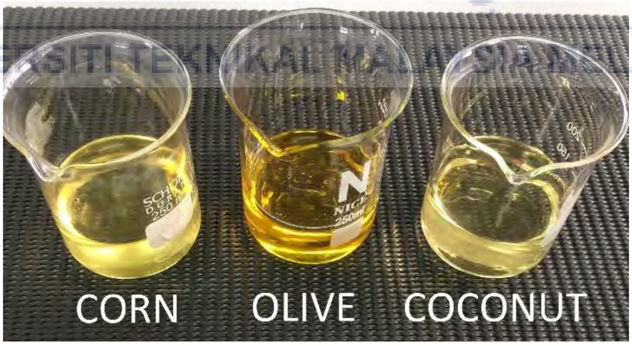

Figure 4.7: Final product of corn oil, coconut oil, and olive oil biodiesel.

During the production of biodiesel, the molar ratio of alcohol to oil used is 6:1. Therefore, for each mass of vegetable oil used, the mass of alcohol is different based on the fatty acid concentration in each oil. Fatty acid concentration is stated in Chapter 2. The mass of coconut oil, corn oil, and olive oil is 986 g, 899.3 g, and 449.9 g respectively.

Number of mol for each fatty acid concentration also must be determined based on the previous studies and the equation to obtain the number of mol is shown in Equation 4.1. Then, the number of mol of each fatty acid is totaled up and the values are 0.9646, 0.7778, and 0.7177 for coconut oil, corn oil, and olive oil biodiesel respectively.

$$no. of\ mol = \frac{\%\ fatty\ acid\ concentration}{molar\ mass\ of\ fatty\ acid} \times 2 \tag{4.1}$$

As mentioned in Chapter 3, the concentration of KOH is fixed to 0.75% for each vegetable oil. Therefore, in order to obtain the amount of KOH, Equation 4.2 is applied.

$$amount\ of\ KOH = 0.0075 \times mass\ of\ vegetable\ oil \tag{4.2}$$

Then, the amount of methanol for each vegetable oil is calculated as shown in Appendix A based on equation 3.2 and 3.3 in Chapter 3. The amount of methanol and KOH needed for each type of vegetable oil is presented in Table 4.1.

Table 4.1: The amount of methanol and KOH needed for each oil.

Type of Oil	**No. of Mol of Alcohol (mol)**	**Percentage mass of methanol (%)**	**Amount of methanol (g)**	**Amount of KOH (g)**
Coconut Oil	0.9646	31	305.66	7.395
Corn Oil	0.7778	25	225.00	6.750
Olive Oil	0.7177	23	103.50	3.375

4.3 BIODIESEL PROPERTIES

Biodiesel samples obtained are produced from three different vegetable oil that is coconut oil, corn oil, and olive oil. Therefore, the biodiesel properties from the three samples can be different. The properties tested for the biodiesel samples are density, viscosity, and flash point.

4.3.1 DENSITY

Results of density tested for each biodiesel is presented in Figure 4.8. Based on the experiment, the density value of biodiesel from corn oil and coconut oil is the same which is 875.0 kg/m^3, while the density of biodiesel from olive oil is slightly lower which is 870.0 kg/m^3.

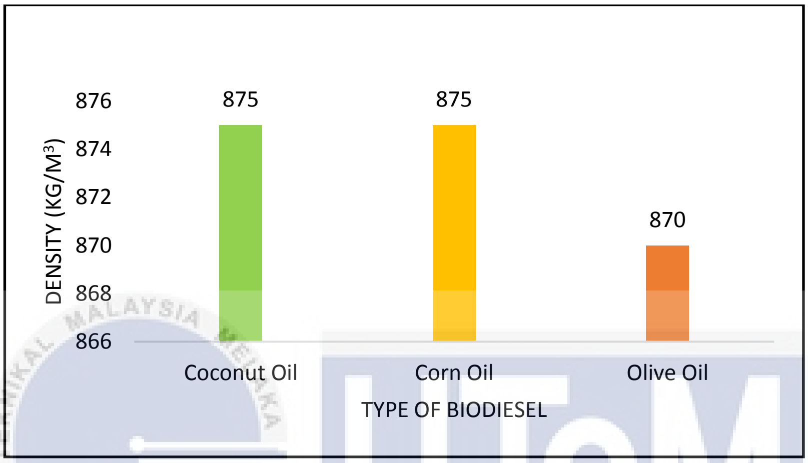

Figure 4.8: Biodiesel density of each sample.

4.3.2 FLASH POINT

Flash point of biodiesel is the lowest temperature at which the biodiesel will ignite. Initially, biodiesel from the three samples were tested at 160 ^{o}C and fire source was ignited towards the sample. Then, the temperature was increased 5 ^{o}C until the sample started to flash. The second test is being held to record the exact temperature of the flash point of the samples. The first test of coconut oil biodiesel, corn oil, and olive oil biodiesel recorded the temperature of 240 ^{o}C, 180 ^{o}C, and 175 ^{o}C respectively. The second test of each sample was conducted to obtain the accurate readings and the results are shown in Figure 4.9.

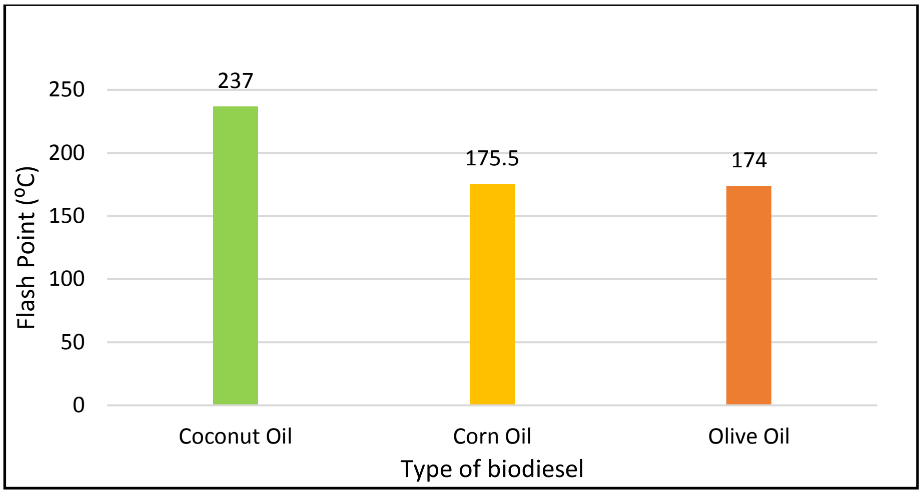

Figure 4.9: Flash point of biodiesel.

4.3.3 VISCOSITY

Kinematic viscosity of biodiesel from a variety of sources commonly range from 1.9 – 6.0 mm^2/s based on ASTM D6751 (Knothe et al, 2016). Based on the tested that is conducted using viscometer, the readings of viscosity of coconut oil, corn oil and olive oil biodiesel is 5.55, 5.13, and 3.35 mm^2/s respectively as shown in Figure 4.10.

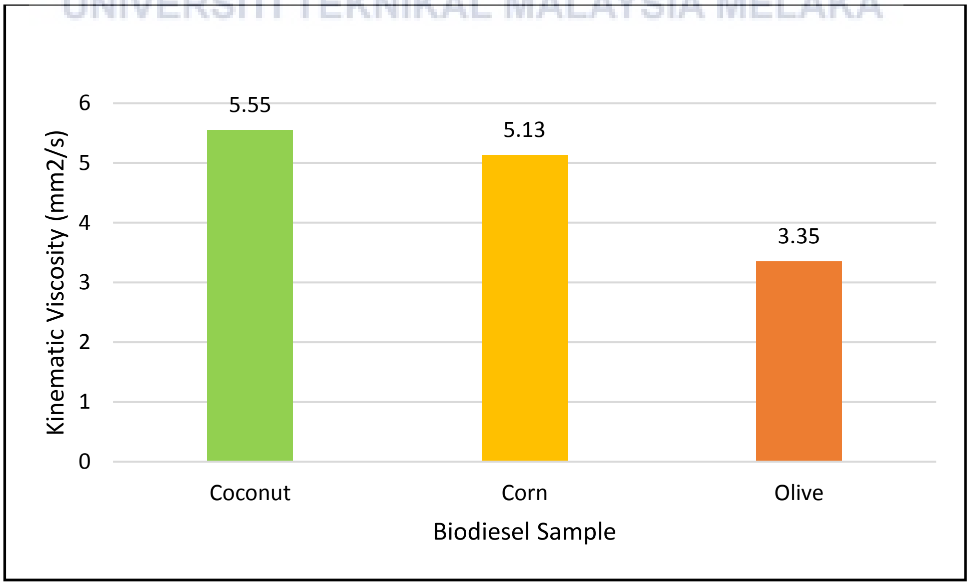

Figure 4.10: Kinematic viscosity of biodiesel.

4.4 DISCUSSION

Biodiesel produced from three vegetable oils that are coconut oil, corn oil, and olive oil shows different colour. As shown above, three of them are transparent and no forms of solid or gel occur that will cause the biodiesel to become opaque. Transparency of each biodiesel sample happens maybe because there is no presence of water residual after the washing process.

Density is defined as mass per unit of volume of a substance. Density of biodiesel varies between 860 and 890 kg/m^3. In this project, density of biodiesel is tested at 15 ^oC by using hydrometer and constant temperature water bath. Results of density of coconut oil, corn oil, and olive oil biodiesel is 875, 875, and 870 kg/m^3 respectively which means the results is still in the range of 860 and 890 kg/m^3. Density of biodiesel samples in this project do not show a lot of different because density of methanol and oil are close to density of the biodiesel produced. On the other hand, the variation of densities for each sample occur because of the variation of the fatty acid composition and their purity where the higher saturated fatty acid concentration in the oil, the density of the biodiesel also will be higher. Therefore, the difference of the densities of coconut oil, corn oil, and olive oil biodiesel goes well with the statement above as coconut and corn oil have higher saturated fatty acid concentration compared to olive oil as stated in Chapter 2.

Flash point of biodiesel decreases as the amount of alcohol residual increases. However, in this project coconut oil biodiesel has higher flash point although the percentage of methanol used is higher in coconut oil. Flash point of coconut oil biodiesel is 237.0 ^oC compared to corn oil and olive oil biodiesel that have flash points of 175.5 ^oC and 174.0 ^oC respectively. This condition occurs maybe because coconut oil used in the production of biodiesel is homemade compared to corn and olive oil that are commercially refined oil.

During the process of preparing the coconut oil, it may have been overcooked causing the disturbance and broken of fatty acid and glyceride chains. Flash point of coconut oil biodiesel is also the highest maybe because there is no presence of methanol residual in the biodiesel produced. Even if there is a presence of 0.5% of methanol in the biodiesel, the flash point can drop rapidly from 170 ºC to 50 ºC. Therefore, in this project, biodiesel produced has no presence of methanol residual as the flash point of each biodiesel samples is consistent.

Biodiesel generally has a higher kinematic viscosity compared to petroleum diesel as it is produced from a variety of sources. According to ASTM D6751, standard biodiesel viscosity is 1.9 – 6.0 mm^2/s. Therefore, viscosities for each biodiesel sample in this project can be accepted as it is still in the range as stated by ASTM D6751. As can be seen in the results above, coconut oil biodiesel has the highest viscosity of 5.55 mm^2/s compared to corn oil and olive oil biodiesel that recorded viscosities of 5.13 and 3.35 mm^2/s respectively. Larger proportions of saturated fatty acids will cause the viscosity to increase. In this case, the result of viscosity for coconut oil biodiesel agrees with the statement above. Coconut oil has the highest concentration of saturated fatty acid than corn oil and olive oil. On the other hand, olive oil biodiesel recorded the lowest reading of viscosity as its concentration of saturated fatty acid is the lowest among the three vegetable oils.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

Through literature study, it is found that there are many sources that can be used to produce biodiesel. Among those many sources, three sources are chosen to produce biodiesel in this project which are coconut oil, corn oil, and olive oil. These three vegetable oils are chosen because of their availability locally.

Biodiesel is successfully produced in this project by using the three vegetable oil stocks. Biodiesel from coconut oil shows the best physical appearance in terms of clarity and transparency. Meanwhile, biodiesel from olive and corn oil are slightly less clear and transparent then biodiesel from coconut oil.

As shown in the results from previous chapter, the density of biodiesel from coconut oil, corn oil, and olive oil shows not much of difference with coconut and corn oil biodiesel show the same value of density while olive oil biodiesel shows a slightly lower value of density. Flash point of coconut oil biodiesel is the highest among the three biodiesels with a lot of difference shown compared to biodiesel from corn oil and olive oil. Flash point of corn oil biodiesel is slightly higher than olive oil biodiesel. Meanwhile, the viscosity of coconut oil and corn oil biodiesel shows a slight difference between them with coconut oil biodiesel shows a higher viscosity while viscosity of biodiesel from olive oil is the lowest among the three.

5.2 Recommendation

Biodiesel can be produced from a variety of sources such as vegetable oils or animal fats. Therefore, in the future work, maybe a different vegetable oil or even animal fat can be used to produce biodiesel. The biodiesel produced also maybe can be tested on an engine.

In terms of the properties of biodiesel, many more properties can be tested such as energy content, acid number, total and free glycerin, water content, and cold flow properties. These properties must be tested and evaluated whether there are suitable to be used in the engine or not. The equipment in the laboratory must also be improved in order to allow the tests to be conducted.

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APPENDIX A

Table 1: Mass measured for each vegetable oil used.

Type of Oil	Mass (g)
Coconut	986.1
Corn	899.3
Olive	449.9

Table 2: Number of mol for each vegetable oil.

Type of Oil	No. of mol (mol)
Coconut	0.9646
Corn	0.7778
Olive	0.7177

Coconut Oil

- 0.9646 mol of alcohol
- 32 g/mol of methanol

Based on Equation 3.2, percentage mass of methanol for coconut oil should be;

$$32\frac{g}{mol}\times 0.9646 = 30.8672 \approx 31\%$$

Therefore, according to Equation 3.3, for alcohol to oil ratio of 6:1, the amount of methanol should be;

$$amount\ of\ methanol = mass\ of\ coconut\ oil \times 0.31$$

In this project, the mass of coconut oil is 986 g. Therefore,

$$amount\ of\ methanol = 986\ g \times 0.31 = \mathbf{305.66\ g}$$

Amount of Potassium Hydroxide is fixed to 0.75% for each oil. Therefore, according to Equation 4.2, the amount of KOH is;

$$amount\ of\ KOH = 986\ g \times 0.0075 = \mathbf{7.395\ g}$$

Corn Oil

- 0.7778 mol of alcohol
- 32 g/mol of methanol

Based on Equation 3.2, percentage mass of methanol for corn oil should be;

$$32\frac{g}{mol} \times 0.7778 = 24.8896 \approx 25\%$$

Therefore, according to Equation 3.3, for alcohol to oil ratio of 6:1, the amount of methanol should be;

$$amount\ of\ methanol = mass\ of\ corn\ oil \times 0.25$$

In this project, the mass of corn oil is 899.3 g which assumed to be 450 g. Therefore,

$$amount\ of\ methanol = 900\ g \times 0.25 = \mathbf{225\ g}$$

Amount of Potassium Hydroxide is fixed to 0.75% for each oil. Therefore, according to Equation 4.2, the amount of KOH is;

$$amount\ of\ KOH = 900\ g \times 0.0075 = \mathbf{6.75\ g}$$

Olive Oil

- 0.7177 mol for alcohol
- 32 g/mol of methanol

Based on Equation 3.2, percentage mass of methanol for olive oil should be;

$$32\frac{g}{mol} \times 0.7177\ mol = 22.9664 \approx 23\%$$

Therefore, according to Equation 3.3, for alcohol to oil ratio of 6:1, the amount of methanol should be;

$$amount\ of\ methanol = mass\ of\ olive\ oil \times 0.23$$

In this project, the mass of olive oil is 449.99 g which assumed to be 450 g. Therefore,

$$amount\ of\ methanol = 450\ g \times 0.23 = \mathbf{103.5\ g}$$

Amount of Potassium Hydroxide is fixed to 0.75% for each oil. Therefore, according to Equation 4.2, the amount of KOH is;

$$amount\ of\ KOH = 450\ g \times 0.0075 = \mathbf{3.375\ g}$$

Table 3: Density of biodiesel.

TYPE OF BIODIESEL	DENSITY (kg/m^3)
Coconut Oil	875
Corn Oil	875
Olive Oil	870

Table 4: Flash points of biodiesel.

TYPE OF BIODIESEL	FLASH POINT (ºC)
Coconut Oil	237.0
Corn Oil	175.5
Olive Oil	174.0

Table 5: Value of dynamic viscosity and density at 40 ºC of each biodiesel.

TYPE OF BIODIESEL	DYNAMIC VISCOSITY (cp)	DENSITY@40ºC (g/cm^3)
Coconut Oil	4.83	0.870
Corn Oil	4.41	0.860
Olive Oil	2.88	0.860

The kinematic viscosity for coconut oil calculated by using Equation 3.4;

$$kinematic\ viscosity, v = \frac{4.83}{0.870} = \mathbf{5.55}\ mm^2/s$$

The kinematic viscosity for corn oil calculated by using Equation 3.4;

$$kinematic\ viscosity, v = \frac{4.41}{0.860} = \mathbf{5.13}\ mm^2/s$$

The kinematic viscosity for olive oil calculated by using Equation 3.4;

$$kinematic\ viscosity, v = \frac{2.88}{0.860} = \mathbf{3.35}\ mm^2/s$$

Table 6: Kinematic viscosities of each biodiesel sample.

TYPE OF BIODIESEL	KINEMATIC VISCOSITY (mm^2/s)
Coconut Oil	5.55
Corn Oil	5.13
Olive Oil	3.35

APPENDIX B

Gantt Chart for PSM 1

ACTIVITY/MONTH /WEEK(W)	SEPTEMBER				OCTOBER				NOVEMBER				DECEMBER		
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
GET PSM TITLE															
LITERATURE REVIEW															
METHODOLOGY															
PROGRESS REPORT 1 SUBMISSION															
REPORT PREPARATION															
SUBMISSION DRAFT FINAL REPORT															
SEMINAR AND PRESENTATION															

= EXPECTED FINISHED TIME

Gantt Chart for PSM 2

ACTIVITY/MONTH /WEEK(W)	FEBRUARY				MARCH				APRIL				MAY		
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
PROJECT PROGRESS AND TESTING															
DATA ANALYSIS															
PROGRESS REPORT SUBMISSION															
DISCUSSION															
CONCLUSION AND RECOMMENDATION															
REPORT SUBMISSION															
SEMINAR AND PRESENTATION															