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JUDUL : **PRODUCTION OF BIODIESEL FROM WASTE COOKING OIL AND RBD PALM OIL USING BATCH TRANSESTERIFICATION PROCESS**

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PRODUCTION OF BIODIESEL FROM WASTE COOKING OIL AND RBD PALM OIL USING BATCH TRANSESTERIFICATION PROCESS

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PRODUCTION OF BIODIESEL FROM WASTE COOKING OIL AND RBD PALM OIL USING BATCH TRANSESTERIFICATION PROCESS

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**A thesis submitted in fulfillment
of the requirements for the award of the degree of
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I declare that this thesis entitled "Production of Biodiesel from Waste Cooking Oil and RBD Palm Oil Using Batch Transesterification Process" is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

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Dedicated especially to Father, Mother, Brothers and Sisters who give me inspiration and support that made this work possible.

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ABSTRACT

Waste Cooking Oil (WCO) has significant potential as the raw material or starting substance for biodiesel production. The objective of this research is to examine the performance of yield and purity of biodiesel from WCO as the starting material with different catalyst ($NaOCH_3$) concentration and reaction time via single step batch transesterification process. It is also to investigate the extent to which the sodium methoxide ($NaOCH_3$) as the catalyst and the effect of batch transesterification process on various parameters in production of biodiesel. The purity of methyl ester content in biodiesel is measured by Gas Chromatography. The exhaust emissions of biodiesel produced were evaluated by combustion test using Gas Combustion Unit. Results indicate that the higher conversion was obtained when RBD palm oil which is 98.2% yield and 97.5% purity instead of 96.8% yield and 94.7% purity in WCO used as the raw material. Biodiesel produced from WCO gives less exhaust emission of CO and CO_2 compared to commercial diesel thus contributed to the reduction of greenhouse gas that effect the global warming.

ABSTRAK

Minyak masak terpakai mempunyai potensi sebagai bahan mentah dalam penghasilan biodiesel. Objektif kajian adalah untuk memeriksa kadar hasil dan ketulenan biodiesel yang dihasilkan daripada minyak masak terpakai, dengan kepekatan mangkin sodium metoksida dan masa tindakbalas yang berbeza dalam satu langkah proses trasesterifikasi berkelompok. Kajian ini juga adalah untuk menyiasat takat kepekatan mangkin sodium metoksida dan kesan proses trasesterifikasi berkelompok ke atas pelbagai parameter dalam penghasilan biodiesel. Ketulenan metil ester di dalam biodiesel diukur dengan Gas Kromatografi. Pancaran buangan daripada biodiesel yang dihasilkan dinilai dengan ujian pembakaran menggunakan Unit Pembakaran Gas. Keputusan menunjukkan penukaran tertinggi diperolehi apabila minyak sawit digunakan sebagai bahan mentah yang mana memberi 98.2% kadar hasil dan 97.5% ketulenan, sebaliknya 96.8% kadar hasil dan 94.7% ketulenan diperolehi jika minyak masak terpakai diguanakan sebagai bahan mentah. Biodiesel yang dihasilkan daripada minyak masak terpakai memberi pancaran buangan karbon monoksida dan karbon dioksida yang kurang berbanding diesel komersial, seterusnya menyumbang kepada pengurangan kesan gas rumah hijau yang memberi kesan kepada pemanasan global.

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CHAPTER 1

INTRODUCTION

1.1 Overview of Research

With the exception of the hydroelectricity and nuclear energy, the majority of the world energy needs are supplied through petrochemical sources, coal and natural gas. All of these sources are finite and at current usage rates will be consumed in the future (Meher ***et al***, 2006). The depletion of world petroleum reserves and increased environmental concerns has stimulated recent interest in alternative sources for petroleum based fuels (Fukuda ***et al***, 2001).

Biodiesel, derived from vegetable oil or animal fats by transesterification with alcohol like methanol and ethanol, is recommended for use as a substitute for petroleum based diesel mainly because biodiesel is an oxygenated, renewable, biodegradable and environmentally friendly biofuel with similar flow and combustion properties and also low emission profile (Altin and Selim, 2001). It helps to reduces global warming gas emissions such as carbon dioxide. Biodiesel has no aromatics, almost no sulfur and contains 11% oxygen by weight. This characteristics of biodiesel reduce the emissions of carbon monoxide, hydrocarbon and particulate matter in the exhaust gas compared to petroleum based diesel fuels (Peterson and Hustrulid, 1998).

Currently, compared to petroleum based diesel, the high cost of biodiesel is a major barrier to its commercialization. It is reported that approximately 70%-85% of the total biodiesel production cost arises from the cost of the raw material (Fukuda ***et al***, 2001). Use of low cost feedstocks such as waste cooking oil (WCO) should help make biodiesel competitive in price with petroleum diesel. Everywhere in the world, there is an enormous amount of waste lipids generated from restaurants, food processing industries and fast food shops everyday (Mittlebach and Gangl, 2001).

Because of the good properties and the environment improvement, many countries pay much attention to research and development (R&D) of biodiesel industry and constitute favorable legislation for it. More than 2.7 million tons biodiesel in 2003 was made in Europe, and 8-10 million tons is expected in 2010 (Altin and Selim, 2001).

Unfortunately, many of these feedstocks contain large amounts of free fatty acids (FFAs). These FFAs react with alkali catalysts to produce soaps that inhibit the fatty acid methyl esters (FAMEs) formation (Gerpen ***et al***, 2004). In the case of the vegetable oils that contain up to 5% FFAs, the transesterification reaction can still be catalyzed with an alkali catalyst. However, additional catalyst must be added to compensate for the catalyst lost to soap. This soap can exhibit the separation of the methyl ester and glycerol and also contribute to emulsion formation during the washing step (Gerpen, 2005).

1.2 Problem Statement

The problem was to determine the extent to which the sodium methoxide ($NaOCH_3$) as the catalyst and the effect of batch transesterification process on various parameters where WCO and RBD palm oil are used as a raw material in production of biodiesel.

1.3 Objective of Study

The objective of this research is to examine the performance of yield and purity of biodiesel from WCO as the starting material with different catalyst ($NaOCH_3$) concentration and reaction time via single step batch transesterification process.

1.4 Scope of Study

The scopes of this research are:

1. To study the effect of catalyst concentration on yield and purity of biodiesel using batch transesterification process.
2. To study the combustion characteristic of biodiesel from both RBD palm oil and WCO using batch transesterification process and analyze the product using Gas Chromatography.

In the research that we conduct, we used the catalyst concentration of 0.25 to 1.5wt%. While the temperature range used is fixed at 40°C and the time that be conducted is between 20 to 50 minutes.

1.5 Rationale and Significances

The rationale of this research is to identify the important variables and to propose a suitable approach in scaling up the production of biodiesel from RBD palm oil and WCO using batch transesterification process. With the important variables such as catalyst concentration, reaction time, reaction temperature and ratio of methanol to oil used, we can produce high quality of biodiesel which have a high yield and high purity of methyl ester content.

The high energy demand in the industrialized world as well as in the domestic sector, had caused pollution problems due to the widespread use of fossil fuels make it increasingly necessary to develop the renewable energy sources of smaller environmental impact than the fossil fuels such diesel fuels. The alternative fuel must be technically feasible, economically competitive, environmentally acceptable and readily available that is familiar to biodiesel properties. Biodiesel also biodegradable, non-toxic and has low emission profiles as compare to diesel fuel.

CHAPTER 2

LITERATURE REVIEW

2.1 Historical Background on Biodiesel Production

The first record of the use of vegetable oils as liquid fuels in internal combustion engines is from 1900 when Rudolf Diesel used peanut oil (Shay, 1993). However because of its low cost and easy availability, petroleum became the dominant energy source and petroleum diesel was then developed as the primary fuel for diesel engines. Nonetheless, petroleum and its derivatives fuels have periodically been through short supply and consequently, the search for alternative energy sources has emerged (Zanin ***et al***, 2000). At that time the pyrolysis of different triglycerides was also used for liquid fuel supply in different countries. For example, hydrocarbons were produced in Chinaby a tung oil pyrolysis batch system used as liquid fuels (Chang and Wan, 1947). Another approach proposed at this time was the use of fatty acids ethyl or methyl esters, obtained by transesterification or alcoholysis of vegetable oils or esterification of fatty acids combined with transesterification of triglycerides (Keim, 1945).

Biodiesel production is a very modern and technological area for researchers due to the relevance that it is winning everyday because of the increase in the petroleum price and the environmental advantages (Marchetti ***et al***, 2005). It is an alternatives fuel for diesel engines that is produced by chemical reaction of a vegetable oils or animal fats with an alcohol such as methanol. The product is called as methyl ester or biodiesel, which is receiving high attention as an alternative, nontoxic, biodegradable and renewable diesel fuels (Ma and Hanna, 1999). When biodiesel displaces petroleum diesel, it reduces global warming gas emission such as carbon dioxide. Biodiesel has no aromatics, almost no sulfur and contains 11% oxygen by weight. These characteristics of biodiesel reduces the emissions of carbon monoxide, hydrocarbon and particulate matter in the exhaust gas compare petroleum-based diesel fuels (Peterson and Hustrulid, 1998).

Non-food product production from agricultural raw materials is more important than feed protein production in relation to the market economy of Malaysia, which are the biggest palm oil producer and exporter in the world. In 2000, export earnings from palm oil exceeded that from oil products (Malaysia exports some petroleum products after refining) and gas. That has made palm oil the biggest single export revenue earner for the country. Unlike oil and gas, which have a heavy foreign content, palm oil production is virtually 100% local. In 2000, the palm oil industry earned nearly US$ 6.50 billion in exports and US$ 7.5 billion in 2001. The Palm Oil Research Institute of Malaysia (PORIM) has taken an initiative since 1988 to look at the possibilities of converting oil palm products into fuels. One of the first products was the use of methyl ester of palm oil as diesel substitute. The use of methyl esters as fuel proved technically to be a very suitable substitute obtained by PORIM, Malaysia. The methyl ester of palm oil is known as palm oil diesel (POD) (Kalam ***et. al***., 2002).

Vegetable oils are widely available from various sources, and the glycerides present in the oils can be considered as a viable alternative for diesel fuel. Biodiesel, which is synthesized from bio-oil, is a realistic alternative of diesel fuel because it provides a fuel from renewable resources and has lower emissions than petroleum diesel. It is biodegradable and contributes a minimal amount of net greenhouse gases or sulfur to the atmosphere. More specifically, biodiesel cuts down on the amount of carbon dioxide, hydrocarbons, and particulate matter released into the environment (Dalai ***et. al.,*** 2003).

Biodiesel is defined as the monoalkyl esters of long chain fatty acids derived from renewable feed stocks like vegetable oils or animal fats. While most of the properties of biodiesel are comparable to petroleum based diesel fuel, improvement of its low temperature flow characteristic still remains one of the major challenges while using biodiesel as an alternative fuel for diesel engines. The biodiesel fuels derived from fats or oils with significant amounts of saturated fatty compounds will display higher cloud points and pour points (Bhale ***et al***., 2008).

2.2 Raw Material

There are several sources that can be use as raw material for biodiesel production, such as non-edible oil, animal fats and vegetable oil. However, the vegetable oils extracted from plant that are composed of triglycerides was used because it contains similar fuel properties to diesel fuel except the higher viscosity and low oxidative stability that must be encountered before being converted into biodiesel. So, the vegetable oils that mostly used in transesterification reaction include pure plant oils (PPOs) or straight vegetable oils (SVOs) and waste vegetable oils (WVOs) (Knothe ***et al***., 2001).

2.2.1 Straight Vegetable Oils (SVO)

Pure plant oils (PPO) or commonly known as straight vegetable oils is not a by-product of other industries either coming from domestic usage. Actually, the straight vegetable oils is a highly grade of oil extracted primarily from plant, usually, seeds of oilseed plants. In addition, these oils is the best starting material compare to waste cooking oils because of the conversion of triglyceride to fatty acid methyl ester is high and the reaction time is relatively short (Encinar ***et al***., 2006).

2.2.2 Waste Cooking Oils (WCO)

The feedstock coming from waste vegetable oils or commonly known as waste cooking oils is one of the alternative sources among other higher grade or refine oils. Waste cooking oil is easy to collect from other industries such as domestic usage and restaurant and also cheaper than other oils (refine oils). Hence, by using these oils as the raw material, we can reduce the cost in biodiesel production (Canakci and Van Gerpen, 2001). The advantages of using waste cooking oils to produce biodiesel are the low cost and prevention of environment pollution. These oils, need to be treat before dispose to the environment to prevent pollution. Due to the high cost of disposal, many individuals dispose waste cooking oils directly to the environment especially in rural area. Encinar (2006) conclude that use of waste cooking oils is an effective way to reduce the cost of biodiesel production

2.3 Solvent

Sprules and Price (1950), stated that alcohol is primary and secondary monohydric aliphatic alcohols having one (1) to eight (8) carbon atoms. In transesterification process, the main solvent use is alcohol. The examples of alcohol that can be used in the transesterification of triglycerides are methanol, ethanol, propanol, butanol and amyl alcohol. Methanol is the most widely use because of its low price and its physical and chemical advantages (polar and shortest chain alcohol). It can quickly react with triglycerides and sodium hydroxide and easily dissolved in it (Marchetti ***et*** al., 2005).

2.4 Catalyst

A catalyst is a substance that accelerates the rate of reaction by lowering its activation energy. A catalyst recovered unchanged and it does not appear in the product. Catalyst used in the transesterification of triglycerides can be classified as homogeneous, heterogeneous and enzyme catalyst. Fangrui Ma and Milford A. Hanna (1999), stated that excess amount of catalyst would lead to the higher amount of production cost and reduce product yield.

2.4.1 Homogeneous Catalyst

Homogeneous catalyst involves processes in which catalyst is in solution with at least one of the reactant. Basically, in this transesterification process, there are two types of homogeneous catalyst which is acid catalyst (H_2SO_4 or HCl) and alkali catalyst (KOH or NaOH). Homogeneous basic catalyst provides much faster reaction rates than heterogeneous catalyst, but it is difficult to separate homogeneous catalyst from the reaction mixture (Du ***et al***., 2004).

2.4.2 Heterogeneous Catalyst

A heterogeneous catalytic process involves more than one phase, usually the catalyst is a solid and the reactant and product are in liquid or gaseous form. There are many advantages of using heterogeneous catalyst such as non-corrosive, environmental friendly present fewer disposal problems, easier in separation from liquid product and they can be design to give higher activity, selectivity and longer catalyst lifetime (Gryglewicz, 1999). There are many types of heterogeneous catalyst such as alkaline earth metal oxides, anion exchange resins, various alkali metal compounds supported on alumina and various type of zeolite that can be use in various type of chemical reaction including transesterification process. However, most anion exchange resins and supported alkali metal catalyst are easily corroded by methanol and they exhibit short catalyst lifetime in catalyst transesterification. The alkaline earth metal oxides compound is very favorable used in transesterification process because it is slightly soluble in organic solvents (Supes ***et al***., 2004).

2.4.3 Enzyme Catalyst

There also have a different way of synthesizing biodiesel by using bio-catalyst such as lipase enzyme instead of chemically catalyst. Bio-catalyst such as enzyme is a high molecular weight protein or protein-like substance that acts on substrate (reactant molecule) to transform it chemically at a greatly accelerate rate than the uncatalyzed rate (Shuler nad Kargi, 2002).

2.5 Process of Synthesizing Biodiesel

There are different processes which can be applied to synthesize biodiesel such as direct use and blending, micro emulsion process, thermal cracking process and the most conventional way is transesterification process. However, there are a lot of methods can be done through transesterification process such as based-catalyzed transesterification, acid-catalyzed esterification, intergrated acid-catalyzed pre-esterification of FFAs and based-catalyzed transesterification, enzyme-catalyzed transesterification, hydrolysis and supercritical alcohol transesterification (Saka ***et al***., 2001).

2.5.1 Direct Use and Blending

The direct use of vegetable oils in diesel engine is not favorable and problematic because it has many inherent failings. Eventhough the vegetable oils have familiar properties as biodiesel fuel, it required some chemical modification before can be used into the engine. It has only been researched extensively for the past couple of decades, but has been experimented with for almost hundred years. Although some diesel engine can run pure vegetable oils, turbocharged direct injection engine such as trucks are prone to many problems. Energy consumption with the use of pure vegetable oils was found to be similar to that of diesel fuel. For short term use, ratio of 1:10 to 2:10 oil to diesel has been found to be successful (Ma and Hanna< 1999).

2.5.2 Micro-emulsion Process

Schwab ***et al***., (1987) defined micro-emulsion as colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the 1 ± 150 nm range formed spontaneously from two normally immiscible liquids and one or more ionic or non-ionic amphiphiles. Micro-emulsion with solvents such as methanol, ethanol and 1-butanol has been studied to solve the problem of the high viscosity of vegetable oils. They can improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles.

2.5.3 Thermal Cracking (Pyrolysis)

Sonntag, (1979) defined pyrolysis as the conversion of one substance into another by means of heat or heating with the aid of a catalyst. Pyrolysis involves heating in the absence of air or oxygen and cleavage of chemical bonds to yield small molecules (Weist et al., 1979(. Pyrolytic chemistry is difficult to characterize because of the variety of reaction path and the variety of reaction products that may be obtained from the reaction occur. The pyrolyzed material can be vegetable oils, animal fats, natural fatty acids and methyl esters of fatty acids. The first pyrolysis of vegetable oil was conducted in an attempt to synthesize petroleum from vegetable oil (Ma and Hanna, 1999).

2.5.4 Transesterification Process

Transesterification or alcoholysis is the displacement of alcohol from an ester by another in a process similar to hydrolysis, except than alcohol is used instead of water (Srivatava and Prasad, 2000). This process has been widely used to reduce the high viscosity of triglycerides. The transesterification reaction is represented by the general equation as in the following equation. Transesterification is one of the reversible reactions and proceeds essentially by mixing the reactants. However, the presence of a catalyst (a strong acid or base) will accelerate the conversion.

$$\text{Triglycerides} + \text{Methanol} \xrightleftharpoons{\text{Catalyst}} \text{Glycerol} + \text{Methyl Ester} \qquad \textbf{(2.1)}$$

.

Transesterification of triglycerides with methanol and aid of catalyst produce methyl ester and glycerol. The glycerol layer settles down at the bottom of the reaction vessel. The step wise reactions are reversible and a little excess of alcohol is used to shift the equilibrium towards the formation of esters. In presence of excess alcohol, the forward reaction is first order reaction and the reverse reaction is found to be second order reaction. It was observed that transesterification is faster when catalyzed by alkali (Freedman ***et al,*** 1986).

CHAPTER 3

METHODOLOGY

3.1. Introduction

There are several methods in synthesizing of biodiesel. The most and preferred method is transesterification process with the aid of catalyst. In this experiment, single step transesterification were conducted with Sodium Methoxide as the catalyst. Figure 3.1 shows the diagram of experimental methodology. This experimental methodology consists of five basic steps which are:

1. Raw material
2. Equipment selection
3. Design of experiment
4. Experimental procedure
    a. Pre-treatment
    b. Transesterification process
    c. Settling
    d. Washing and methanol recovery
5. Sample analysis

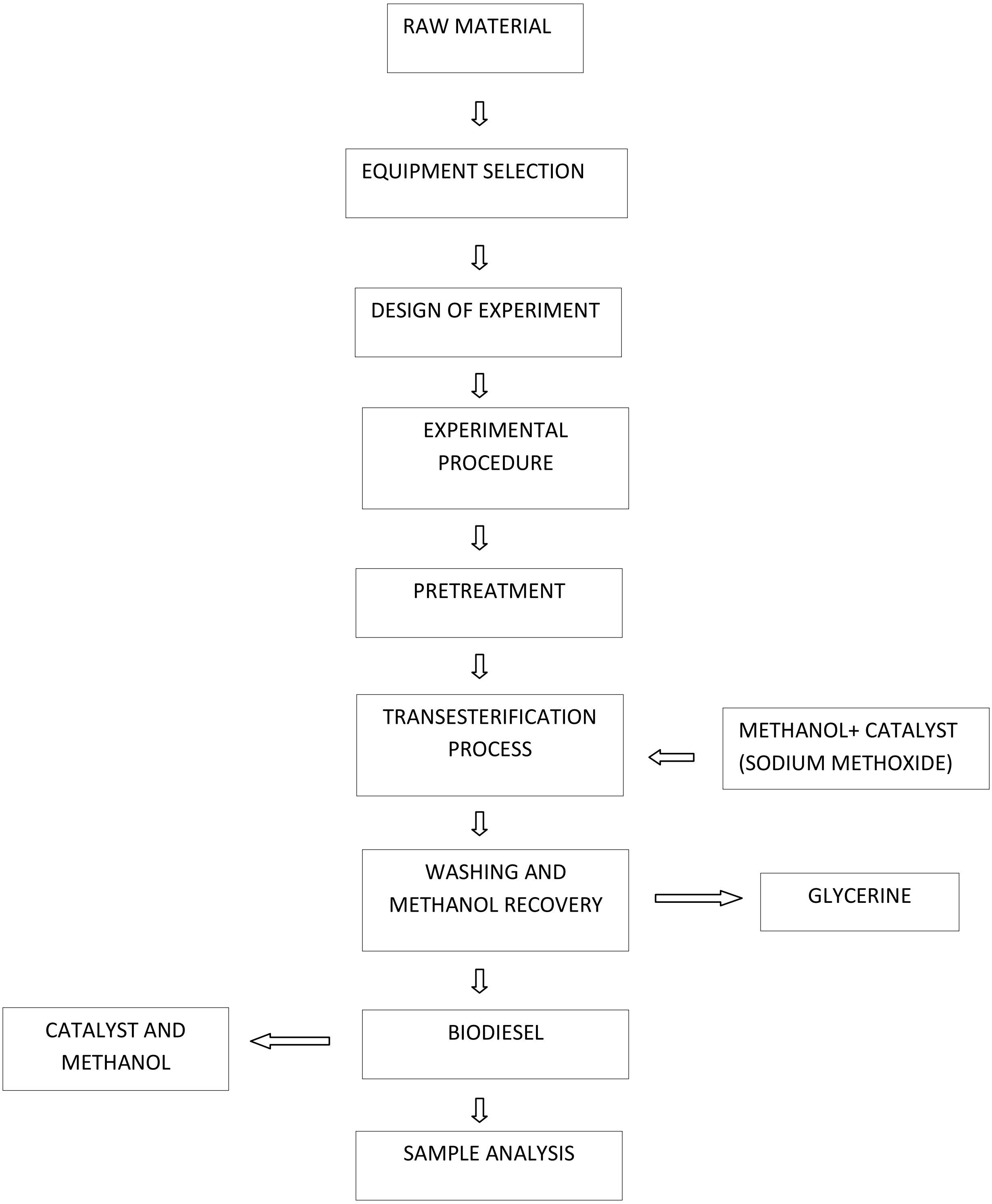

Figure 3.1 Experimental Methodology

3.2 Raw Material

In this experiment, the raw material that used were WCO and RBD palm oil. WCO was collected from nearly restaurants, hostels and canteen while RBD cooking oil was supplied from Minyak Seri Murni. The chemical reaction specialist suggests that refined vegetable oil is the best start material in producing biodiesel. However, WCO is still valuable source because the price is much cheaper.

3.3 Equipment Selection

There are several type of equipment that are used in this experiment. Figure 3.2 to 3.6 shows the picture of some of the equipment. The examples of the equipment are such as:

a. Filter press: to filter solid compound in waste cooking oil.
b. Hot palate: to remove water by pre-heating the waste cooking oil.
c. Shaking water bath with stirrer: use during transesterification process.
d. Rotary evaporator: to recover methanol after transesterification process.

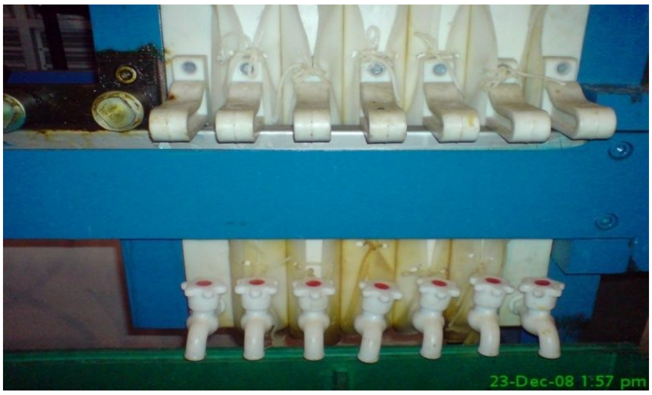

Figure 3.2 Filter Press

Figure 3.3 Shaking Water Bath

Figure 3.4 Hot Plate

Figure 3.5 Rotary Evaporator

Figure 3.6 Mechanical Stirrer

3.4 Design of Experiment

Design of experiment is a technique to make product, process or investigation more robust. It consists of a set of experiment to run. In this design of experiment, three stages method was used to evaluate and study the effects of variables on biodiesel production which are:

a. Catalyst concentration (0.25 - 1.5 wt%)
b. Reaction time (20 – 50 minutes)

The three stages method has generated a model of experiment with different condition of variable. The model of experiment consists of 22 trials and the samples of every trial were used to determine its biodiesel yield and methyl ester purity. The first stages is used to determine optimum value of catalyst concentration at fixed temperature 40˚C and fixed reaction time which is at 40 minutes. The second stages are used to determine optimum value of time. Lastly, the third stages is used to examine the exhaust emission of biodiesel from the optimum value of temperature and time that results from first and second stages of the experiment and compare with conventional diesel.

3.5 Experimental Procedure

In this experiment procedure, it shows the step by step procedure to be followed during the experiment. It consists of five basic steps which are pre-treatment, catalyst preparation, transesterification process, settling process and washing process.

3.5.1 Pre-treatment

Filter press was used in this pre-treatment process to removed solid compound in the WCO. Then, filtrated WCO was heated around 80˚C to 90˚C to removed water. The oil was left to cool before it can be proceeds to the next steps.

3.5.2 Catalyst Preparation

Sodium methoxide catalyst was weighted accordingly to its concentration due to the data provided by the three stages of experiment and fed into a 1liter conical flask. Put the conical flask into the batch reactor (water bath). 0.209 liter of methanol was added into the flask. The solution mixed within few minutes using mechanical stirrer.

3.5.3 Transesterification Process

1 liter WCO was added into the conical flask with molar ratio of methanol to WCO fixed at 6:1. In the meantime, the temperature and reaction time also fixed at 40°C and 40 minutes respectively. Make sure the conical flask mouth covered by aluminum foil to prevented methanol from vaporized as its boiling point was at 65°C. After the

reaction completed, the sample settled out over one night in order to get two layers which make it easier to separate.

3.5.4 Settling Process

After one night it settled down, glycerine and catalyst residue were settled at the bottom while biodiesel and residue of methanol at the top layer. At the top layer, separator funnel was used to separated biodiesel from glycerine by gravitational forces.

3.5.5 Methanol Recovery

Rotary evaporator was used to remove methanol from both crude biodiesel and glycerine. The temperature set was around 60°C to 70°C. At this temperature methanol vaporized while biodiesel and glycerine remains in liquid form. The methanol was collected and stored properly.

3.5.6 Purification Process

For the purification process, water was boiled at 80°C. It was used to washed out the sample for about half to one hour. This process was repeated twice in order to get the better result. After that, the sample was heated-up from 100°C to 110°C using stirring hot plate to removed any residual of moisture content. Continued from the heating process, sample was stored tightly in the sample bottle in order to prevent any residue or particulate moisture from surrounding.

3.6 Analysis

In this experiment, there are three parameters that need to be analyzed which are biodiesel yield, methyl ester content and the emission profile from the biodiesel produced. Every sample from each experiment produced from different condition will be analyzed to find the optimum condition of the experiment.

3.6.1 Biodiesel Yield

Product yield is defined as the weight percentage of the final product (purified biodiesel) relative to the weight of oil at the beginning process. The biodiesel yield (% wt) calculated by the following equation:

$$Product\ yield = \frac{\text{Weight of product}}{\text{Weight of raw material}} \text{x } 100\% \tag{3.1}$$

3.6.2 Methyl Ester Purity

A Gas Chromatography (GC) method for determination of the purity of methyl ester in the biodiesel has been developed. Samples have been prepared by mixing 100 mg biodiesel from each experiment with 5000 µl methyl ester standard solution. Finally, 1 ml samples will be added into a 1 ml vial and the mixture was shaken vigorously and 2 µl aliquots were injected in the GC after at least 10 minutes. The following equation used to calculate the methyl ester purity in biodiesel.

$$Product\ purity = \frac{[\Sigma \mathrm{A}] - \mathrm{A\ EI}}{\mathrm{A\ ei}} \text{x } \frac{\mathrm{C\ ei\ x\ V\ ei}}{\mathrm{m}} \text{x } 100\% \tag{3.2}$$

Where, $[\Sigma A]$ = Total peak area for methyl ester

A_{ei} = Corresponding area for methyl ester

C_{ei} = Concentration of methyl ester standard solution, mg/ml

V_{ei} = Volume of methyl ester standard solution, ml

m = Mass of samples, mg

3.6.3 Exhaust Emission of Biodiesel

Gas combustion unit is an instrumental method for emission test. Exhaust gas emission of CO_2 and CO were measured by an exhaust gas analyzer. The experimental value for each gas was taken from the average value of three measurements.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Homogeneous catalytic reaction is one of the conventional ways to produce biodiesel. In this study, the raw materials used for production of biodiesel are RBD palm oil and WCO with aid of sodium methoxide ($NaOCH_3$) as the catalyst and .methanol as the solvent. In order to optimize and compare the performance WCO towards optimum condition of biodiesel production with RBD palm oil, two parameters were studied which is catalyst concentration and reaction time. As mention previously, the volume of raw material is fixed to 1liter, the catalyst concentration used is in the range 0.25 to 1.5 wt% and the reaction time is varied from 20 to 50 minute. In this batch transesterification process, the molar ratio of methanol to raw material is fixed at 6:1 while the temperature also fixed at 40°C. When the optimum value of catalyst concentration and reaction time was showed, which consumed highest yield and highest purity of methyl ester content for both source of raw material, the next step of experiment was conducted, which is combustion test. The combustion test performed to compare the emission of biodiesel and commercial diesel fuel. After all reaction was completed, results were obtained from analysis data which is the effect of catalyst concentration and reaction time towards biodiesel yield and purity of methyl ester content were studied.

4.2 Effect of Catalyst Concentration

The first parameter studied in this batch transesterification process is catalyst concentration. The concentration of sodium methoxide ($NaOCH_3$) used in the first stage of experiment was varied from 0.25 to 1.5 wt% while the reaction temperature and reaction time were fixed at 40°C and 40 minute respectively. The volume of raw material of both RBD palm oil and WCO also fixed at 1 liter. Table 4.1 and Table 4.2 shows result for the first stage of experiment for both type of raw material used.

Table 4.1: Effect of $NaOCH_3$) concentration for RBD palm oil

Sample (wt %)	Mass of Sample (g)	Mass of Biodiesel (g)	Biodiesel Yield (%)	Purity (%)
0.25	860	761.62	88.56	86.84
0.5	860	776.06	90.24	96.82
0.75	860	745.96	86.74	83.10
1.0	860	686.80	79.86	80.82
1.5	860	668.05	77.68	78.33

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Table 4.2: Effect of $NaOCH_3$) concentration for WCO

Sample (wt %)	Mass of Sample (g)	Mass of Biodiesel (g)	Biodiesel Yield (%)	Purity (%)
0.5	920	644.37	70.04	76.84
0.75	920	693.96	75.43	80.04
1.0	920	780.16	84.80	94.56
1.5	920	739.68	80.40	93.42

The amount of catalyst is one of the most important variables that effects conversion efficiency as well as production cost of biodiesel and the results is given in Figure 4.1 and Figure 4.2.

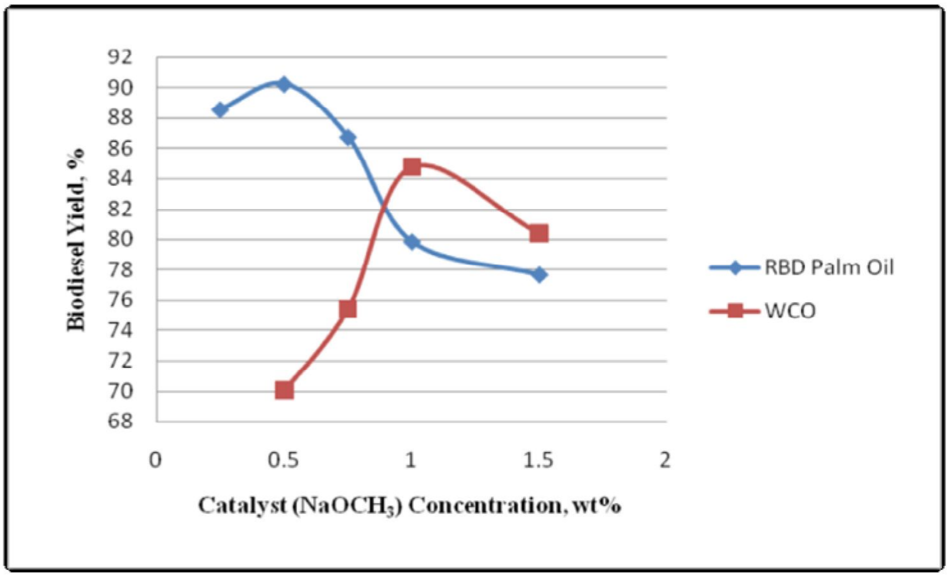

Figure 4.1: Effect of NaOCH$_3$ concentrations on biodiesel yield

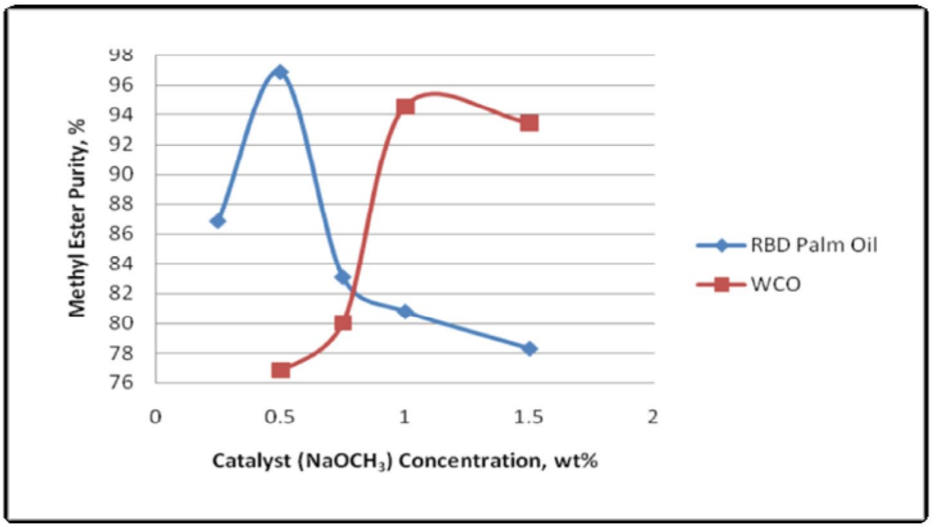

Figure 4.2: Effect of NaOCH$_3$ concentrations on methyl ester purity

It is not only to determine the reaction rates, but the catalyst also causes the hydrolysis and saponification. Both reactions interfere with the separation of the glycerol rich phase and the methyl ester purification (Felizardo ***et al***, 2006). In Figure 4.1, for RBD palm oil shows that, when the $NaOCH_3$ concentration increased from 0.25 wt% to 0.5 wt%, the yield of biodiesel produced will be increased slightly from about 88.56% to almost 90.24% and tend to decreased to 77.68% when $NaOCH_3$ concentration increased further to 1.5 wt%. Meanwhile, for WCO, when catalyst concentration increased from 0.5 wt% to 1.0 wt%, the product yield of biodiesel will increased slowly from 70.04% up to 84.80%, but it start to decreased slightly to 80.40% when the $NaOCH_3$ concentration increased to 1.5 wt%. The 3% value of free fatty acids (FFAs) required completing a base catalyzed transesterification process. The higher the acidity of the oil used, the smaller the conversion efficiency. Excess of both FFAs and moisture content in the oil within insufficient amount of catalyst, may cause soap formation (Meher ***et al***, 2006). RBD palm oil content less than 3% FFAs thus yield 90.24% of biodiesel compare to WCO that contains quite large amount of water and FFAs contents which resulted just 84.80% biodiesel yield.

In Figure 4.2, for RBD palm oil, it is shows that, the increasing in $NaOCH_3$ concentration will decrease the methyl ester purity contents as well as decreased in biodiesel yield. It also can be seen that, the optimum value of methyl ester purity content occurred at 0.5 wt% of $NaOCH_3$ concentration and decreased if an excess catalyst was added. Meanwhile, for WCO, when we increased the $NaOCH_3$ concentration, the methyl ester purity content also will increased as well as biodiesel yield and start to decreased when it's reached its optimum $NaOCH_3$ concentration. The starting materials or raw materials used for the base catalyzed transesterification process should meet certain specification. The triglycerides or vegetable oils should have lower acid value and all material should substantially anhydrous. The addition of more catalyst compensates for higher acidity, but the resulting soap formation causes an increase in viscosity or formation of gels that interferes in the reaction as well as with separation of glycerol (Meher ***et al***, 2006). When we used RBD palm oil, the biodiesel yields are significantly reduced. This happened maybe because of the prolonged contact with air that will diminish the effectiveness of this catalyst through interaction with moisture and carbon dioxide. However, when WCO was used as starting material, pretreatment was performed such as filtration and water removal. Within these pretreatment processes, the biodiesel yields increased slightly with increasing of catalyst concentration.

From this optimum catalyst concentration results for both type of starting material used, the experiment was proceed to the next stage which to determine the effect of reaction time. The optimum value of $NaOCH_3$ concentration for RBD palm oil is 0.5 wt% while for the WCO is 1.0 wt%.

4.3 Effect of Reaction Time

Effect of reaction time was studied in the second stage of experiment. Reaction time will be conducted within range from 20 to 50 minutes while the other parameter setting such as catalyst concentration will be taken from the optimum value from the previous experiment which is 0.5 wt% for RBD palm oil and 1.0 wt% for WCO, reaction temperature fixed at 40°C, volume of both raw material also fixed at 1 liter and so for methanol to oil ratio which is 6:1. Table 4.3 and Table 4.4, shows result for the second stage of experiment for both type of raw material used.

Table 4.3: Effect of reaction time for RBD palm oil

Sample (min)	Mass of Sample (g)	Mass of Biodiesel (g)	Biodiesel Yield (%)	Purity (%)
20	860	775.72	90.2	83.4
30	860	800.66	93.1	94.7
40	860	844.52	98.2	97.5
50	860	807.54	93.9	93.2

Table 4.4: Effect of reaction time for WCO

Sample (min)	Mass of Sample (g)	Mass of Biodiesel (g)	Biodiesel Yield (%)	Purity (%)
20	920	699.20	76.0	90.2
30	920	728.64	79.2	93.1
40	920	830.56	96.8	94.7
50	920	798.56	86.8	93.9

Effects of reaction time on biodiesel yield and methyl ester purity are shown in Figure 4.3 and Figure 4.4.

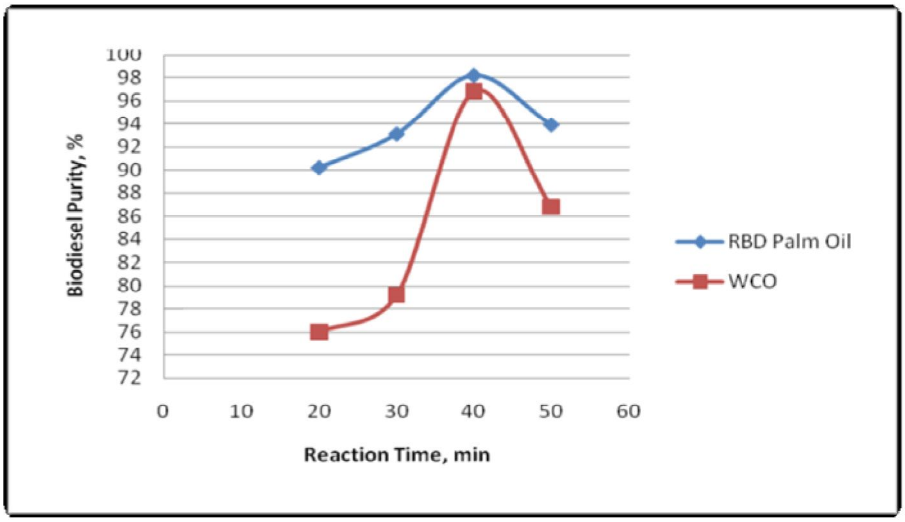

Figure 4.3: Effect of reaction time on biodiesel yield

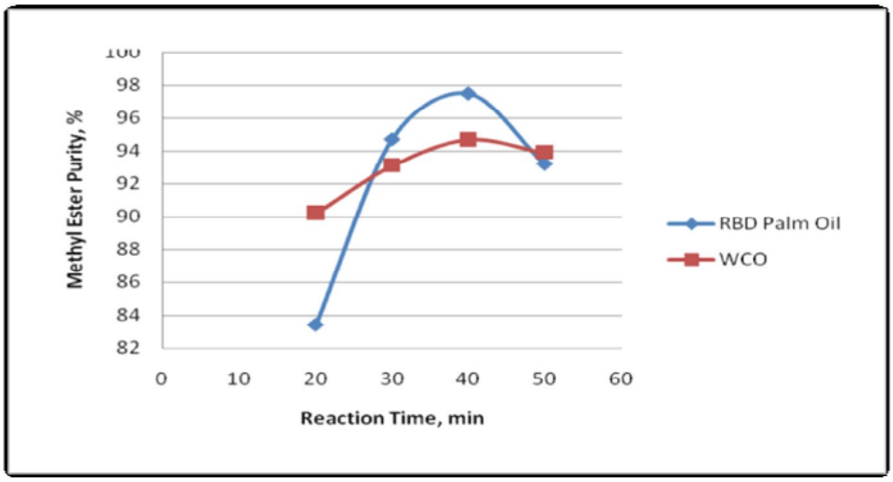

Figure 4.4: Effect of reaction time on methyl ester purity

To achieve perfect contact between the reagents and the oil during reaction, they must be stirred well at constant rate and well mixed together (Xiangmei ***et a***l, 2008). In Figure 4.3 and Figure 4.4, for RBD palm oil, it can be observed that increasing in reaction time from 20 to 40 minutes, will also increased the reaction rate as well as product yield (biodiesel yield), but it start to decreased slightly when the reaction time further increase up to 50 minutes. The product yield reached an optimum value about 98.2% within reaction time of 40 minutes. However, slightly reduction in biodiesel yield occurred after 40 minute is due to longer reaction time thus enhanced the hydrolysis of ester which is reverse reaction of transesterification that could result in loss production. Meanwhile, for WCO, it is shown that the optimum value of reaction time also reached at 40 minutes but consumed low biodiesel yield and methyl ester purity compared with the batch transesterification process of RBD palm oil which is 96.8% and 94.7% respectively. It is indicated that, an extension of reaction time had no significant effect on conversion of triglycerides (waste cooking oil) to methyl ester (biodiesel), but slightly decreased after 40 minutes reaction time due to soap formation resulted from high amount of FFAs contained in WCO. The optimum value of reaction time for both type of raw material used is 40 minutes.

4.4 Combustion Test

Since biodiesel is produced within two different types of oil which is RBD palm oil and WCO, it was necessary to identified and studied the qualified standardization of fuel quality to guarantee engine performance without any difficulties either to consumers and environment. Within fixed reaction temperature at 40°C, raw material volume at 1 liter and also methanol to oil ratio at 6:1, the batch alkali catalyzed transesterification process were performed together with the optimum value of catalyst concentration ($NaOCH_3$) and reaction time that obtained from the first and second stage of experiment respectively, resulted highest biodiesel yield and methyl ester purity for basically two different types of raw material used. From this result, we proceed to the last stage of the experiment which is to identify combustion characteristic of exhaust emissions of biodiesel produced from RBD palm oil and WCO and compared with the commercial diesel fuel. Table 4.5 shows the comparison characteristic of RBD palm oil, WCO and commercial diesel fuel.

Table 4.5: The exhaust emissions of biodiesel samples of RBD palm oil and WCO compared to conventional diesel fuel

Emission	RBD Palm Oil	WCO	Commercial Diesel Fuel
O_2 (%)	10.1	9.8	9.3
CO (ppm)	65	44	376
CO_2 (%)	8.1	8.21	8.7
NO (ppm)	0	0	0.021
NO_X (ppm)	0	0	0.07
H_2S (ppm)	0	0	0.03

Biodiesel is biodegradable, non-toxic and has low emission profile compare to petroleum diesel. The use of biodiesel in a conventional diesel engine results in substantial reduction of unburned hydrocarbons, carbon monoxide and particulate matter compare to emission from diesel fuel (Meher ***et al***, 2006). From Table 4.5, it can be seen that, the content of carbon monoxide (CO) in biodiesel is typically less than those for diesel fuel which is 65 ppm for biodiesel from RBD palm oil and 44 ppm for biodiesel that made from WCO compare to 376 ppm for conventional diesel fuel. This result is due to higher combustion efficiency of biodiesel than conventional diesel fuel. Because carbon monoxide is the product of incomplete combustion, the lower the concentration of carbon monoxide results in higher tendency to form ignitable mixture.

In this test, the production of CO_2 of biodiesel is lower than those in diesel fuel, and this has a neutral effect on the greenhouse effect, because the gas released in the combustion is the same absorbed and fixed by the plant for its growth. Besides that, biodiesel produced had almost no nitrogen oxides (NO) rather than diesel fuels that released for about 0.021 ppm nitrogen oxides when burned. Nitrogen oxide effects on human health, plants and also materials such as respiratory illness, injury to vegetation and greenhouse effects. Then, in commercial diesel, it contains high content of sulfur than in biodiesel that will produce SO_2, SO_3 and SO_4^{2-} in the combustion, source of acids rains, corrosive and irritation. H_2S is released and converted to SO_2. Essentially, sulfur emissions are completely eliminated compare to diesel fuel. So, if the resulted majority of the emission from biodiesel is less than those in diesel fuel, means it is better to used biodiesel rather than diesel to reduced respiratory diseases and control pollution that damage our natural environment

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Scale up production of biodiesel was conducted before commercialization of the product could be realized in order to fulfill the market demand of the products. The production of 1L of raw material which is RBD palm oil and WCO respectively was successfully carried out at constant temperature of 40°C and methanol to oil ratio at 6:1. In the experiment, for RBD palm oil, it gives the optimum value of catalyst concentration at 0.5 wt% and 40 minutes reaction time while 1.0 wt% catalyst concentration within 40 minutes reaction time for WCO as the raw material to produce biodiesel. It also shows that the higher conversion was obtained when RBD palm oil used as raw material which is 98.2% biodiesel yield and 97.5% methyl ester purity instead of 96.8% biodiesel yield and 94.7% methyl ester purity in WCO. Table 5.1 showed the optimum condition from first and second stage of experiment for both types of raw material to produced biodiesel.

Table 5.1: The optimum condition of highest yield and purity of biodiesel production

Sample	Catalyst Concentration (%)	Reaction Time (min(	Biodiesel Yield (%)	Methyl Ester Purity (%)
RBD Palm oil	0.5	40	98.2	97.5
WCO	1.0	40	96.8	94.7

Biodiesel produced both from RBD palm oil and WCO contained less CO, CO_2 and contain no NO, NO_X and H_2S respectively, compared to commercial diesel thus contributed to the reduction of greenhouse gas that effect the global warming.

5.2 Recommendation

In order to get higher conversion and purity of biodiesel, it is recommended to use two step heterogeneous catalyzed reactions instead of single step homogeneous alkali catalyzed. An alkali catalyzed process can achieve high purity and yield of biodiesel product in a short time. However it is very sensitive to the purity of the reactants. Only well refined vegetable oil with less than 0.5 wt% FFAs can be used as the reactant in this process (Yong Wang ***et al,*** 2007). The high cost of raw material is the major obstacle to its commercialization. High amount of FFAs contained in WCO is the major problem towards of transesterification reaction because it was favored to soap formation rather than selectivity of triglycerides on methyl ester conversion. Hence, a process with acid catalyzed pretreatment was developed to synthesized biodiesel from WCO that can reduced the FFAs content thus increased the purity of methyl ester.

The homogeneous alkali catalyst will be replaced by the heterogeneous alkali catalyst which contribute to the easier separation form product as well as increase the production yield. Heterogeneous alkali catalyst also showed good result and favorable because this type of catalyst presence fewer disposal problems and also easier to separate from liquid product. The byproduct of glycerol and soap stock in this process can be easily handled. The catalyst used will give the higher activity and selectivity, more economical and ecological thus contributed to the environmental friendly and also give longer catalyst lifetime which can be regenerated or recover after reaction process.

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APPENDIX A

CALCULATION OF METHANOL NEEDS

A.1 Calculation for Volume of Methanol

Density of RBD palm oil, $\rho = 860\ kg/m^3$
$= (860\ kg/\ m^3) \times (1000g/\ 1\ kg) \times (1m^3/\ 1 \times 10^6\ cm^3)$
$= 0.86g/\ cm^3$

Density of WCO, $\rho = 920\ kg/m^3$
$= (920\ kg/\ m^3) \times (1000g/\ 1\ kg) \times (1m^3/\ 1 \times 10^6\ cm^3)$
$= 0.92g/\ cm^3$

Density of methanol, $\rho = 791\ kg/m^3$
$= (791\ kg/\ m^3) \times (1000g/\ 1\ kg) \times (1m^3/\ 1 \times 10^6\ cm^3)$
$= 0.791g/\ cm^3$

In this experiment, the molar ratio methanol to oil is 6:1 and the required volume of methanol needs was summarized in Table A.1 and Table A.2.

Table A.1: Required volume of methanol in RBD palm oil

Properties	Methanol	RBD Palm Oil
Molar Ratio	6	1
Density, ρ	0.791g/ cm^3	0.86g/ cm^3
Molecular Weight, M_A	39.049 g/mol	1000 g/mol
Mass Ratio	6 mol x 39.049 g/mol = 192.24 g	1 mol x 1000 g/mol = 1000 g
Volume Ratio	$\frac{192.24\ g}{0.791g/\ cm^3}$ = 243.034 cm^3	$\frac{1000\ g}{0.86\ g/\ cm^3}$ = 1162.791 cm^3
Required Volume, V	209.009 cm^3	1000 cm^3

Table A.2: Required volume of methanol in WCO

Properties	Methanol	WCO
Molar Ratio	6	1
Density, ρ	0.791g/ cm^3	0.92g/ cm^3
Molecular Weight, M_A	39.049 g/mol	1000 g/mol
Mass Ratio	6 mol x 39.049 g/mol = 192.24 g	1 mol x 1000 g/mol = 1000 g
Volume Ratio	$\frac{192.24\ g}{0.791g/\ cm^3}$ = 243.034 cm^3	$\frac{1000\ g}{0.92\ g/\ cm^3}$ = 1086.96 cm^3
Required Volume, V	223.59 cm^3	1000 cm^3

APPENDIX B

EFFECT OF CATALYST CONCENTRATION AND REACTION TIME

B.1 Calculation for biodiesel yield (%)

The values of biodiesel yield for each sample from stage 1 through stage 3 were calculated using equation 3.1.

a) For RBD palm oil as raw material,

Sample of 0.5 wt% catalyst ($NaOCH_3$) concentration.

Mass of sample = 776.06 g

Mass of RBD palm oil = 860 g

$$Product\ yield = \frac{\text{Weight of product}}{\text{Weight of raw material}} \text{x } 100\%$$

$$= \frac{776.06\text{ g}}{860\text{ g}} \text{x } 100\%$$

$$= 90.24\ \%$$

b) For WCO as raw material,

Sample of 1.0 wt% catalyst ($NaOCH_3$) concentration.

Mass of sample = 780.16 g

Mass of RBD palm oil = 920 g

$$Product\ yield = \frac{\text{Weight of product}}{\text{Weight of raw material}} \text{x } 100\%$$

$$= \frac{780.16\text{ g}}{920\text{ g}} \text{x } 100\%$$

$$= 75.43\ \%$$

B.2 Calculation for biodiesel purity, (%)

The values of methyl ester purity for each sample from stage 1 through stage 3 were calculated using equation 3.2.

a) For RBD palm oil as raw material,

Sample of 0.5 wt% catalyst ($NaOCH_3$) concentration

$$Product\ purity = \frac{[\Sigma A] - A_{EI}}{A_{ei}} \text{ x } \frac{C_{ei} \text{ x } V_{ei}}{m} \text{ x } 100\%$$

$$= \frac{[1.49574E6] - [2.04761E4 + 1.4351E6]}{2.04761E4} \text{ x } \frac{10 \text{ x } 5}{101.3} \text{ x } 100$$

$$= 96.82\ \%$$

b) For WCO as raw material,

Sample of 1.0 wt% catalyst ($NaOCH_3$) concentration.

$$Product\ purity = \frac{[\Sigma A] - A_{EI}}{A_{ei}} \text{ x } \frac{C_{ei} \text{ x } V_{ei}}{m} \text{ x } 100\%$$

$$= \frac{[6.24972E6] - [2.30804E4 + 1.71327E6]}{2.30804E4} \text{ x } \frac{10 \text{ x } 5}{103.4} \text{ x } 100$$

$$= 94.56\ \%$$

The calculation of biodiesel yield and methyl ester purity for all sample in the experiment are same as in examples and the results were summarized in Table B.1, Table B.2, Table B.3 and Table B.4.

Table B.1: Effect of $NaOCH_3$ concentration for RBD palm oil

Sample (wt %)	Mass of Sample (g)	Mass of Biodiesel (g)	Biodiesel Yield (%)	Purity (%)
0.25	860	761.62	88.56	86.84
0.5	860	776.06	90.24	96.82
0.75	860	745.96	86.74	83.10
1.0	860	686.80	79.86	80.82
1.5	860	668.05	77.68	78.33

Table B.2: Effect of $NaOCH_3$ concentration for WCO

Sample (wt %)	Mass of Sample (g)	Mass of Biodiesel (g)	Biodiesel Yield (%)	Purity (%)
0.5	920	644.37	70.04	76.84
0.75	920	693.96	75.43	80.04
1.0	920	780.16	84.80	94.56
1.5	920	739.68	80.40	93.42

Table B.3: Effect of reaction time for RBD palm oil

Sample (min)	Mass of Sample (g)	Mass of Biodiesel (g)	Biodiesel Yield (%)	Purity (%)
20	860	775.72	90.2	83.4
30	860	800.66	93.1	94.7
40	860	844.52	98.2	97.5
50	860	807.54	93.9	93.2

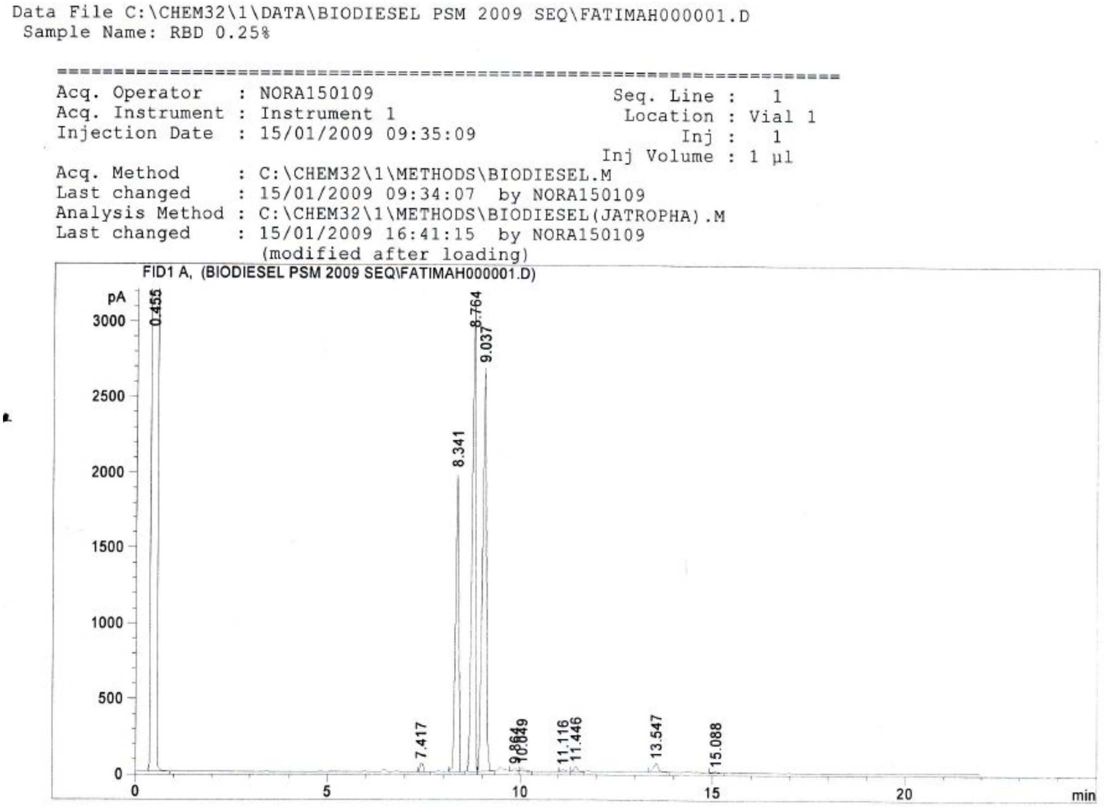
Table B.4: Effect of reaction time for WCO

Sample (min)	Mass of Sample (g)	Mass of Biodiesel (g)	Biodiesel Yield (%)	Purity (%)
20	920	699.20	76.0	90.2
30	920	728.64	79.2	93.1
40	920	830.56	96.8	94.7
50	920	798.56	86.8	93.9

APPENDIX C

RESULT OF ANALYSIS FROM GAS CHROMATOGRAPHY

C.1 Effect of Catalyst Concentration



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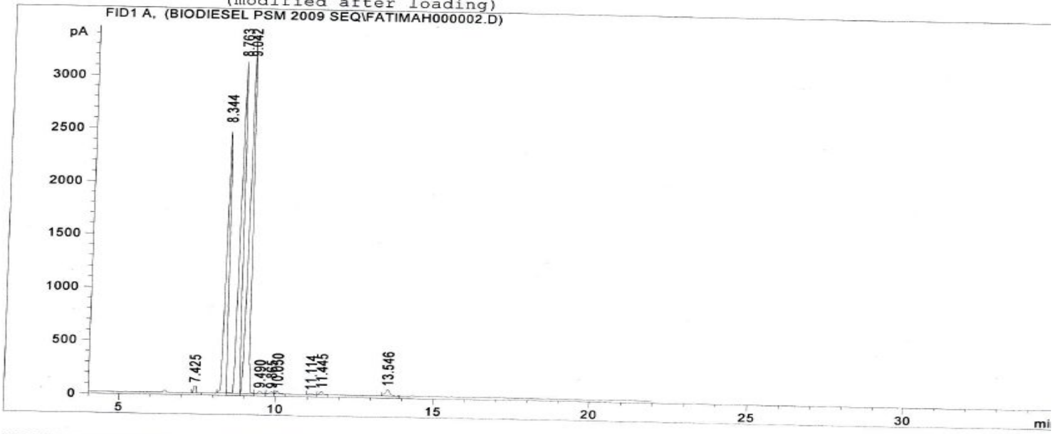
Data File C:\CHEM32\1\DATA\BIODIESEL PSM 2009 SEQ\FATIMAH000001.D
 Sample Name: RBD 0.25%

    =====================================================================
    Acq. Operator   : NORA150109                         Seq. Line :    1
    Acq. Instrument : Instrument 1                        Location : Vial 1
    Injection Date  : 15/01/2009 09:35:09                      Inj :    1
                                                        Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 15/01/2009 09:34:07  by NORA150109
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL(JATROPHA).M
    Last changed    : 15/01/2009 16:41:15  by NORA150109
                      (modified after loading)
```

```
Data File C:\CHEM32\1\DATA\BIODIESEL PSM 2009 SEQ\FATIMAH000002.D
Sample Name: RBD 0.5%

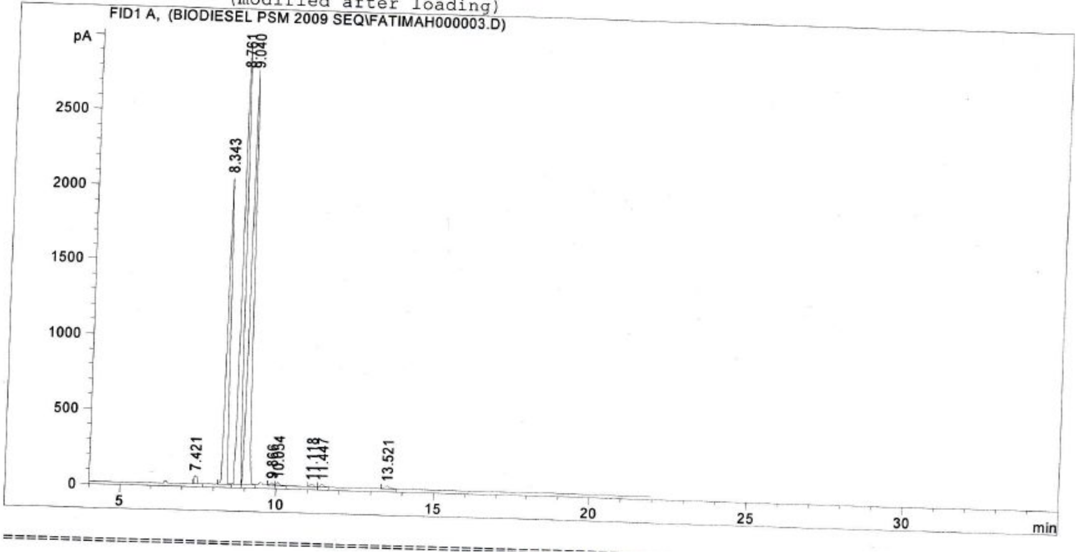
=====================================================================
Acq. Operator   : NORA150109                      Seq. Line :   2
Acq. Instrument : Instrument 1                     Location : Vial 2
Injection Date  : 15/01/2009 10:04:27                   Inj :   1
                                                 Inj Volume : 1 µl
Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
Last changed    : 15/01/2009 09:34:07  by NORA150109
Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL(JATROPHA).M
Last changed    : 16/01/2009 15:00:14  by NORA150109
                  (modified after loading)
```



```
=========================================================
```

```
Data File C:\CHEM32\1\DATA\BIODIESEL PSM 2009 SEQ\FATIMAH000003.D
Sample Name: RBD 0.75%

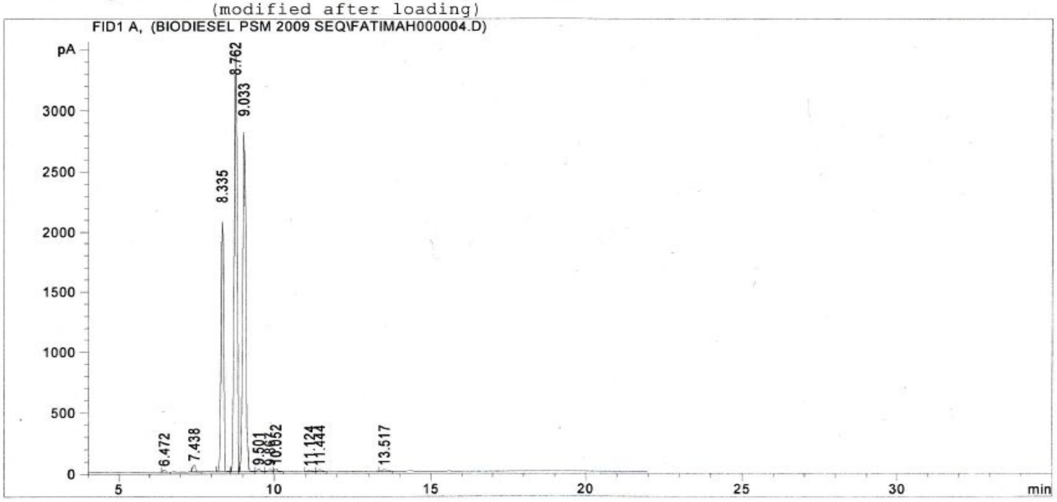
=====================================================================
Acq. Operator   : NORA150109                      Seq. Line :   3
Acq. Instrument : Instrument 1                     Location : Vial 3
Injection Date  : 15/01/2009 11:21:14                   Inj :   1
                                                 Inj Volume : 1 µl
Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
Last changed    : 15/01/2009 09:34:07  by NORA150109
Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL(JATROPHA).M
Last changed    : 16/01/2009 15:00:14  by NORA150109
                  (modified after loading)
```



```
=========================================================
```

```
Data File C:\CHEM32\1\DATA\BIODIESEL PSM 2009 SEQ\FATIMAH000004.D
 Sample Name: RBD 1.0%

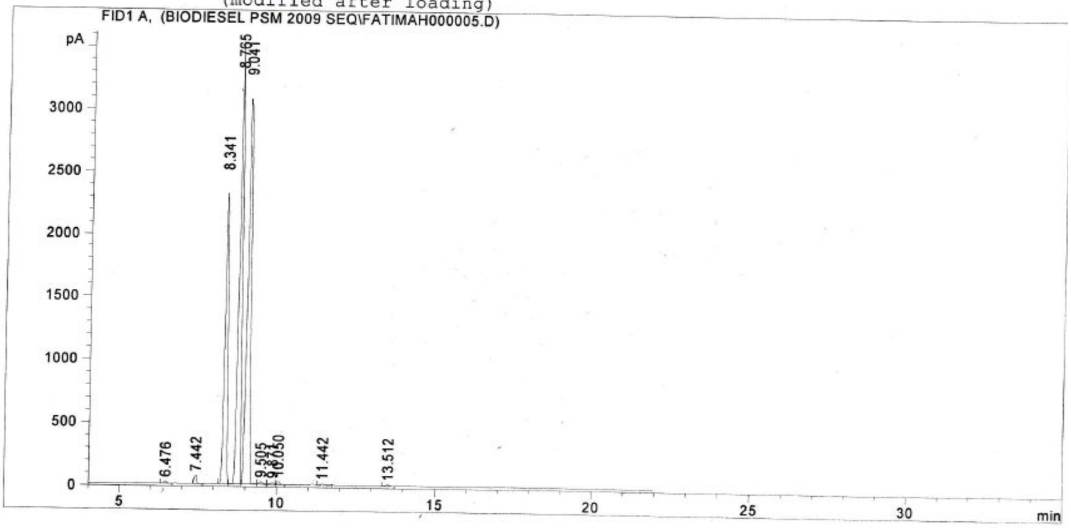
    =====================================================================
    Acq. Operator   : NORA150109                     Seq. Line :    4
    Acq. Instrument : Instrument 1                    Location : Vial 4
    Injection Date  : 15/01/2009 11:50:30                  Inj :    1
                                                   Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 15/01/2009 09:34:07  by NORA150109
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL(JATROPHA).M
    Last changed    : 16/01/2009 15:00:14  by NORA150109
                      (modified after loading)
```



FID1 A, (BIODIESEL PSM 2009 SEQ\FATIMAH000004.D)

```
Data File C:\CHEM32\1\DATA\BIODIESEL PSM 2009 SEQ\FATIMAH000005.D
 Sample Name: RBD 1.5%

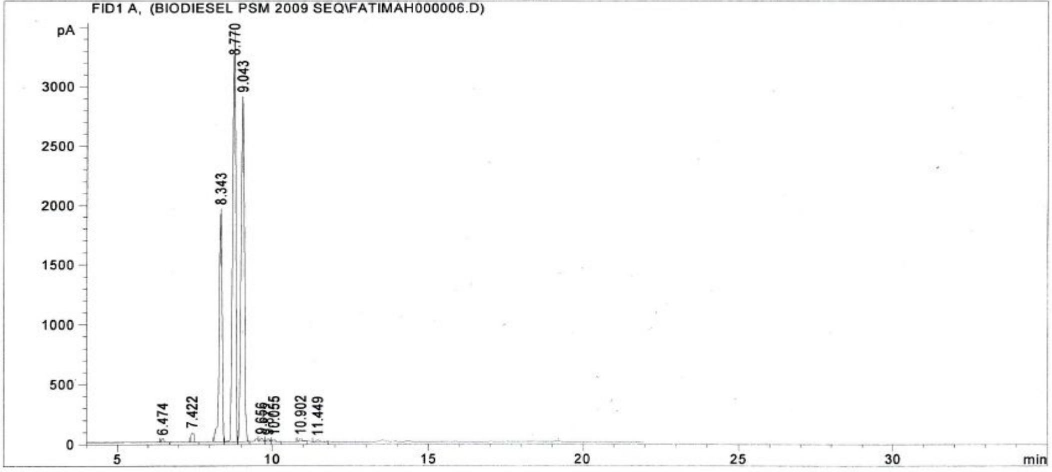
    =====================================================================
    Acq. Operator   : NORA150109                     Seq. Line :    5
    Acq. Instrument : Instrument 1                    Location : Vial 5
    Injection Date  : 15/01/2009 12:19:48                  Inj :    1
                                                   Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 15/01/2009 09:34:07  by NORA150109
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL(JATROPHA).M
    Last changed    : 16/01/2009 15:00:14  by NORA150109
                      (modified after loading)
```



FID1 A, (BIODIESEL PSM 2009 SEQ\FATIMAH000005.D)

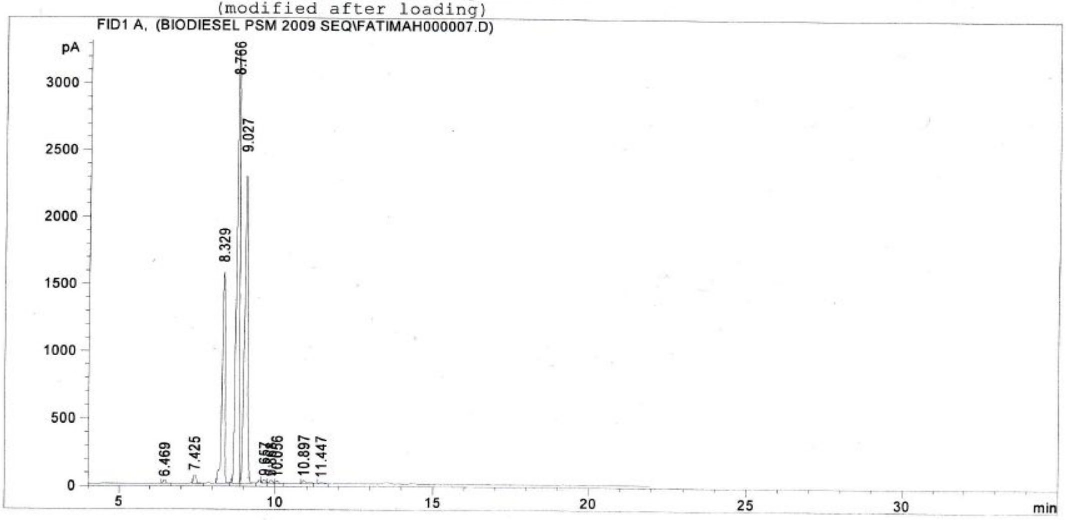
```
Data File C:\CHEM32\1\DATA\BIODIESEL PSM 2009 SEQ\FATIMAH000006.D
 Sample Name: WCO 0.50%

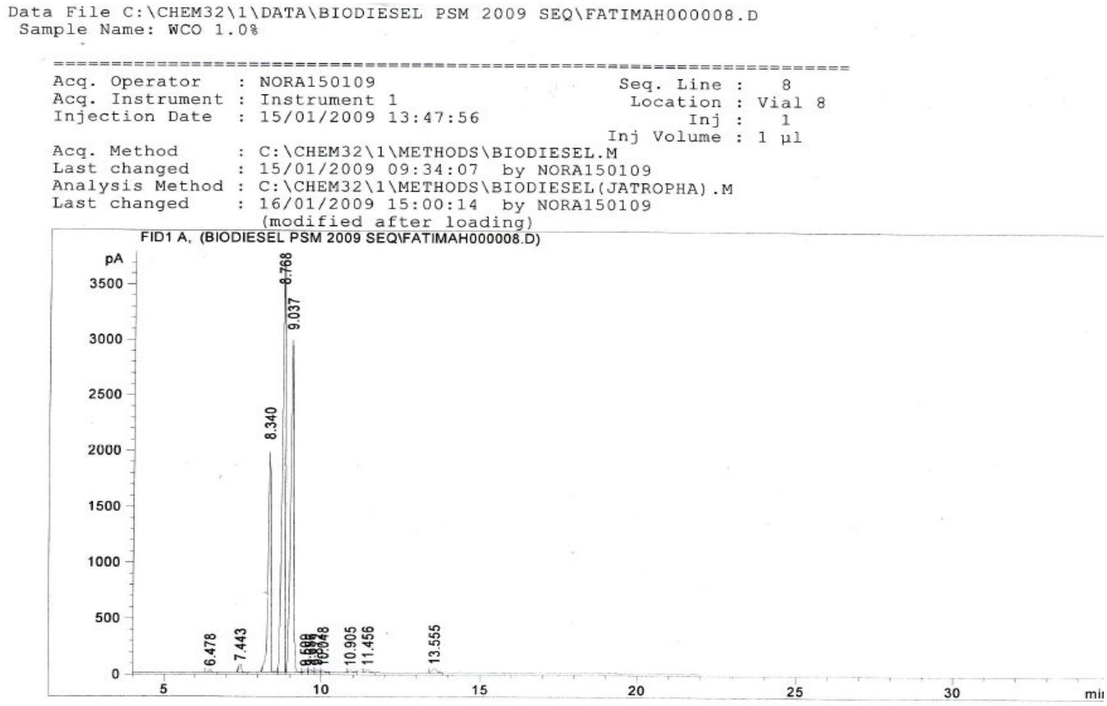
    =====================================================================
    Acq. Operator   : NORA150109                          Seq. Line :   6
    Acq. Instrument : Instrument 1                         Location : Vial 6
    Injection Date  : 15/01/2009 12:49:06                       Inj :   1
                                                        Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 15/01/2009 09:34:07  by NORA150109
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL(JATROPHA).M
    Last changed    : 16/01/2009 15:00:14  by NORA150109
                      (modified after loading)
```



```
Data File C:\CHEM32\1\DATA\BIODIESEL PSM 2009 SEQ\FATIMAH000007.D
 Sample Name: WCO 0.75%

    =====================================================================
    Acq. Operator   : NORA150109                          Seq. Line :   7
    Acq. Instrument : Instrument 1                         Location : Vial 7
    Injection Date  : 15/01/2009 13:18:28                       Inj :   1
                                                        Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 15/01/2009 09:34:07  by NORA150109
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL(JATROPHA).M
    Last changed    : 16/01/2009 15:00:14  by NORA150109
                      (modified after loading)
```

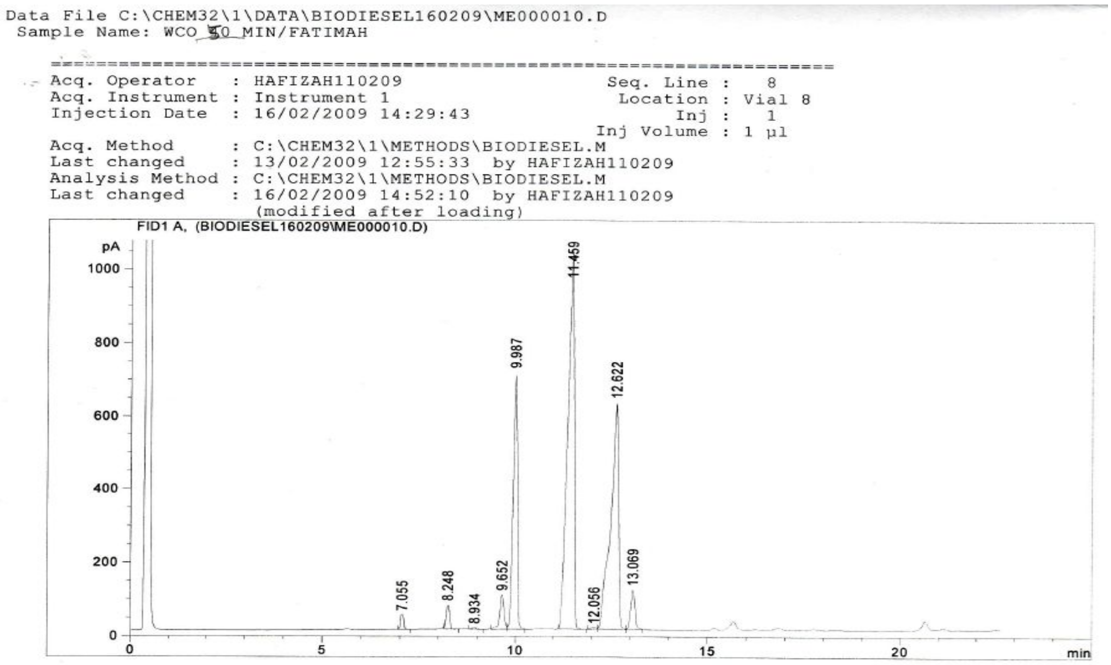




```
Data File C:\CHEM32\1\DATA\BIODIESEL PSM 2009 SEQ\FATIMAH000008.D
 Sample Name: WCO 1.0%

    =================================================================
    Acq. Operator   : NORA150109                    Seq. Line :    8
    Acq. Instrument : Instrument 1                   Location : Vial 8
    Injection Date  : 15/01/2009 13:47:56                 Inj :    1
                                                   Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 15/01/2009 09:34:07  by NORA150109
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL(JATROPHA).M
    Last changed    : 16/01/2009 15:00:14  by NORA150109
                      (modified after loading)
```

C.2 Effect of Reaction Time

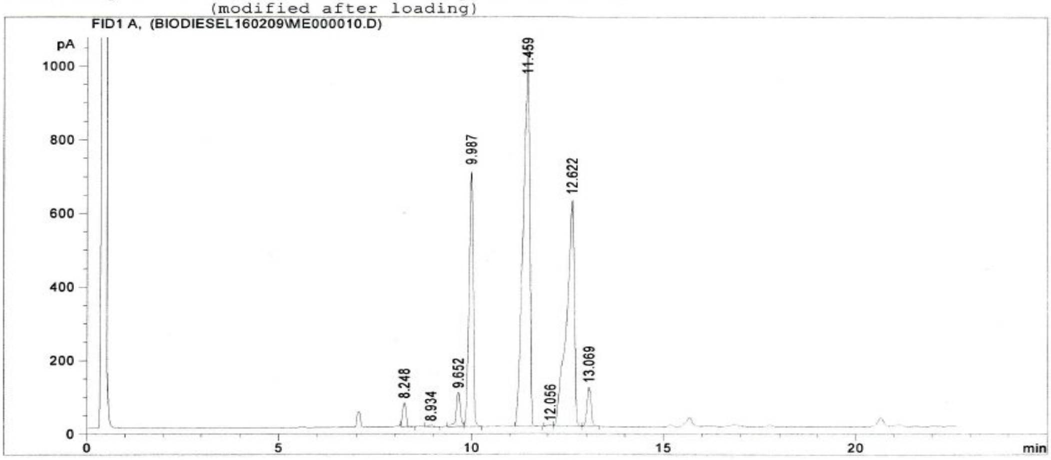


```
Data File C:\CHEM32\1\DATA\BIODIESEL160209\ME000010.D
 Sample Name: WCO 50 MIN/FATIMAH

    =================================================================
    Acq. Operator   : HAFIZAH110209                 Seq. Line :    8
    Acq. Instrument : Instrument 1                   Location : Vial 8
    Injection Date  : 16/02/2009 14:29:43                 Inj :    1
                                                   Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 13/02/2009 12:55:33  by HAFIZAH110209
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 16/02/2009 14:52:10  by HAFIZAH110209
                      (modified after loading)
```

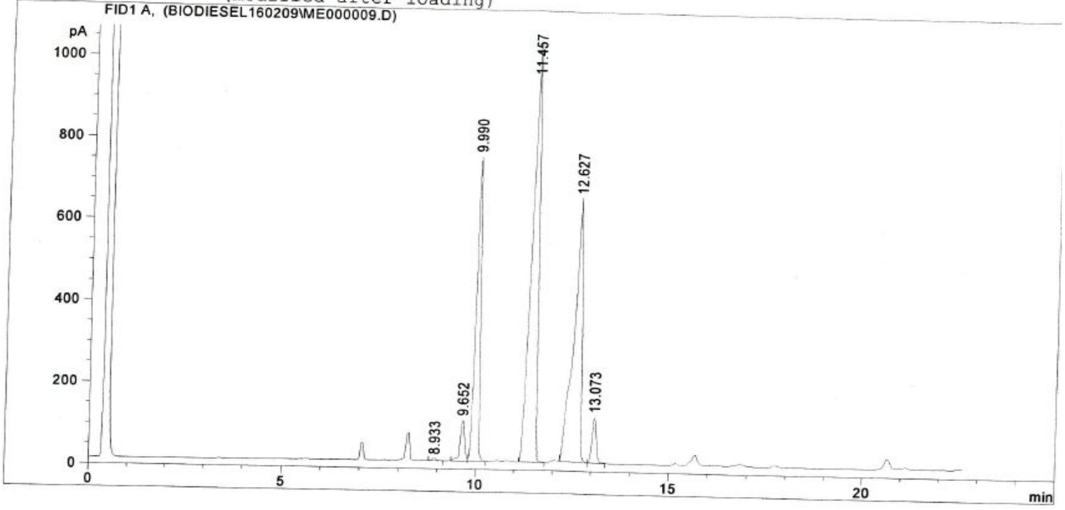
```
Data File C:\CHEM32\1\DATA\BIODIESEL160209\ME000010.D
 Sample Name: WCO 40 MIN/FATIMAH

    =====================================================================
    Acq. Operator   : HAFIZAH110209                   Seq. Line :    8
    Acq. Instrument : Instrument 1                     Location : Vial 8
    Injection Date  : 16/02/2009 14:29:43                   Inj :    1
                                                     Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 13/02/2009 12:55:33  by HAFIZAH110209
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 16/02/2009 14:52:10  by HAFIZAH110209
                      (modified after loading)
```



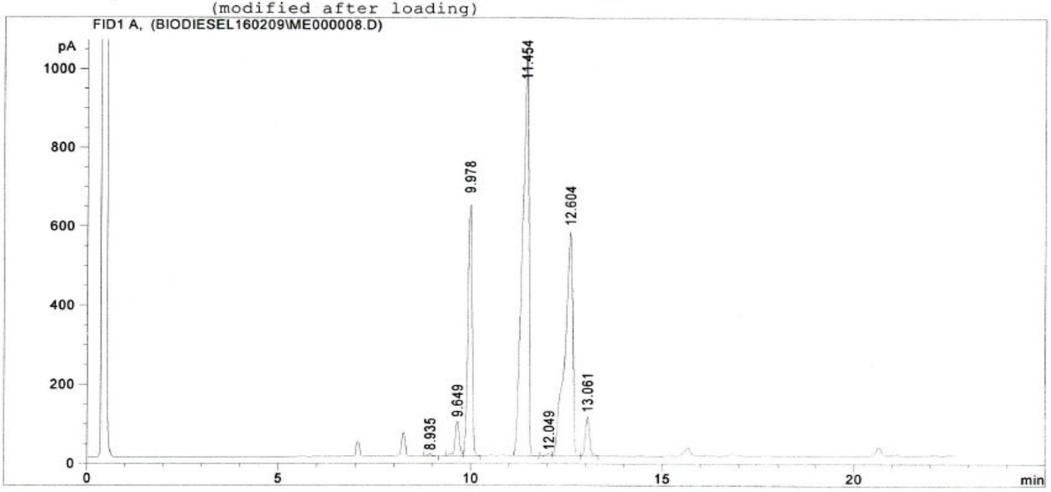
```
Data File C:\CHEM32\1\DATA\BIODIESEL160209\ME000009.D
 Sample Name: WCO 30 MIN/FATIMAH

    =====================================================================
    Acq. Operator   : HAFIZAH110209
    Acq. Instrument : Instrument 1                    Seq. Line :    7
    Injection Date  : 16/02/2009 13:59:55              Location : Vial 7
                                                            Inj :    1
                                                     Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 13/02/2009 12:55:33  by HAFIZAH110209
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 16/02/2009 14:52:10  by HAFIZAH110209
                      (modified after loading)
```



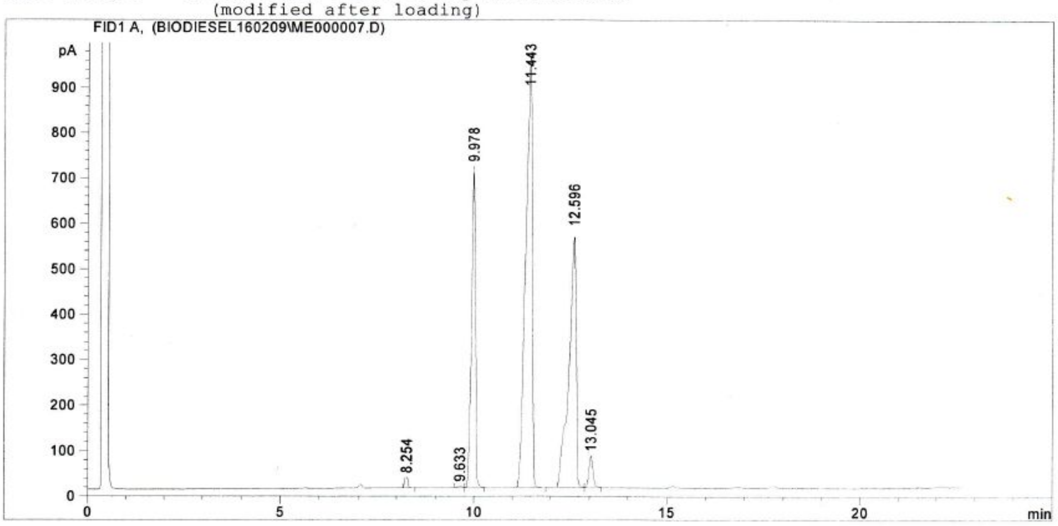
```
Data File C:\CHEM32\1\DATA\BIODIESEL160209\ME000008.D
 Sample Name: WCO 20 MIN/FATIMAH

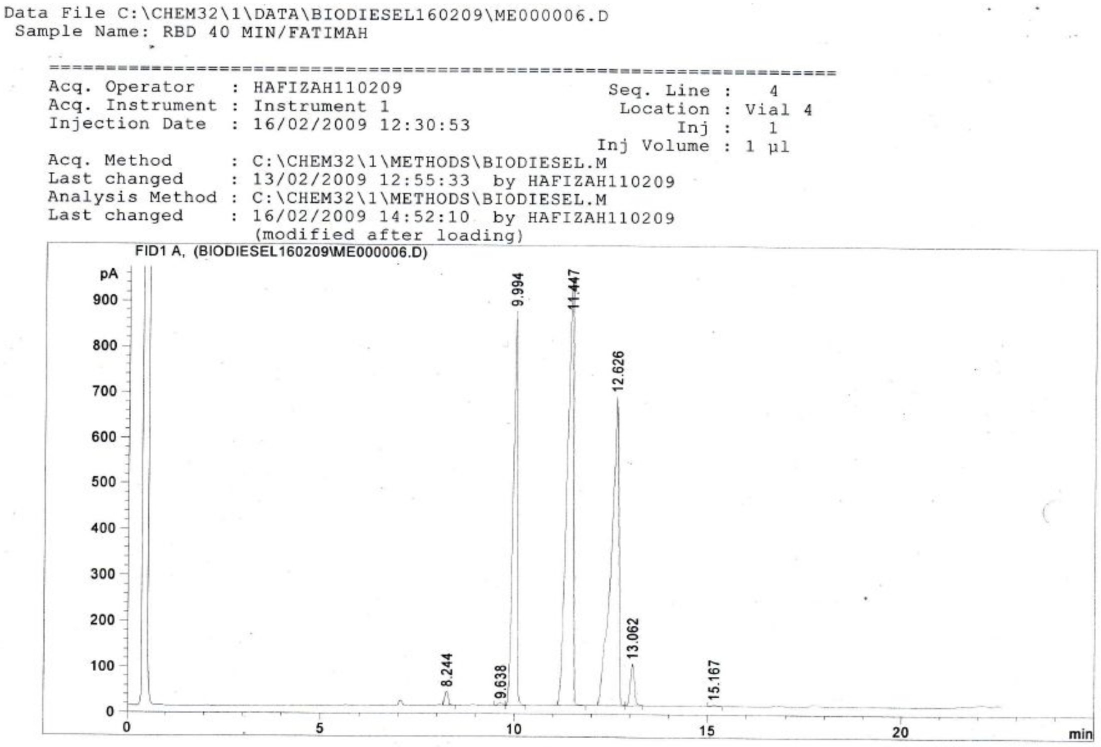
    =====================================================================
    Acq. Operator    : HAFIZAH110209                    Seq. Line :   6
    Acq. Instrument  : Instrument 1                      Location : Vial 6
    Injection Date   : 16/02/2009 13:30:15                    Inj :   1
                                                       Inj Volume : 1 µl
    Acq. Method      : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed     : 13/02/2009 12:55:33  by HAFIZAH110209
    Analysis Method  : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed     : 16/02/2009 14:52:10  by HAFIZAH110209
                       (modified after loading)
```



```
Data File C:\CHEM32\1\DATA\BIODIESEL160209\ME000007.D
 Sample Name: RBD 50 MIN/FATIMAH

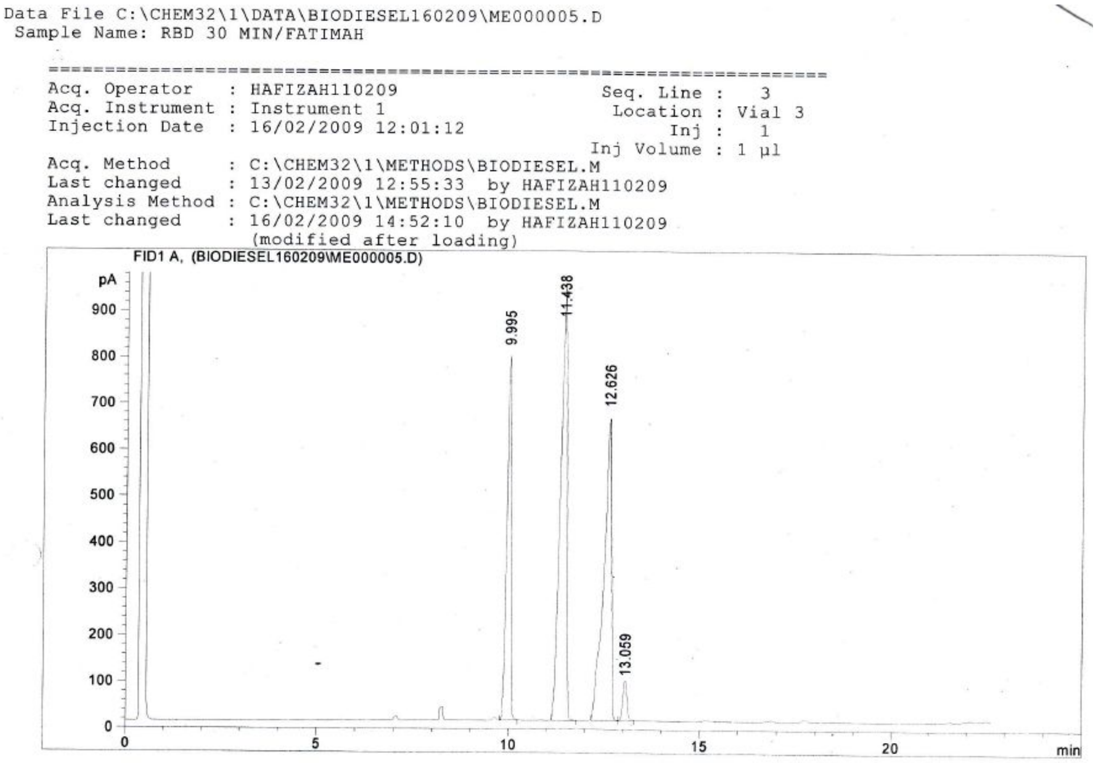
    =====================================================================
    Acq. Operator    : HAFIZAH110209                    Seq. Line :   5
    Acq. Instrument  : Instrument 1                      Location : Vial 5
    Injection Date   : 16/02/2009 13:00:33                    Inj :   1
                                                       Inj Volume : 1 µl
    Acq. Method      : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed     : 13/02/2009 12:55:33  by HAFIZAH110209
    Analysis Method  : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed     : 16/02/2009 14:52:10  by HAFIZAH110209
                       (modified after loading)
```





```
Data File C:\CHEM32\1\DATA\BIODIESEL160209\ME000006.D
 Sample Name: RBD 40 MIN/FATIMAH

    =================================================================
    Acq. Operator   : HAFIZAH110209                       Seq. Line :   4
    Acq. Instrument : Instrument 1                         Location : Vial 4
    Injection Date  : 16/02/2009 12:30:53                       Inj :   1
                                                        Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 13/02/2009 12:55:33  by HAFIZAH110209
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 16/02/2009 14:52:10  by HAFIZAH110209
                      (modified after loading)
```

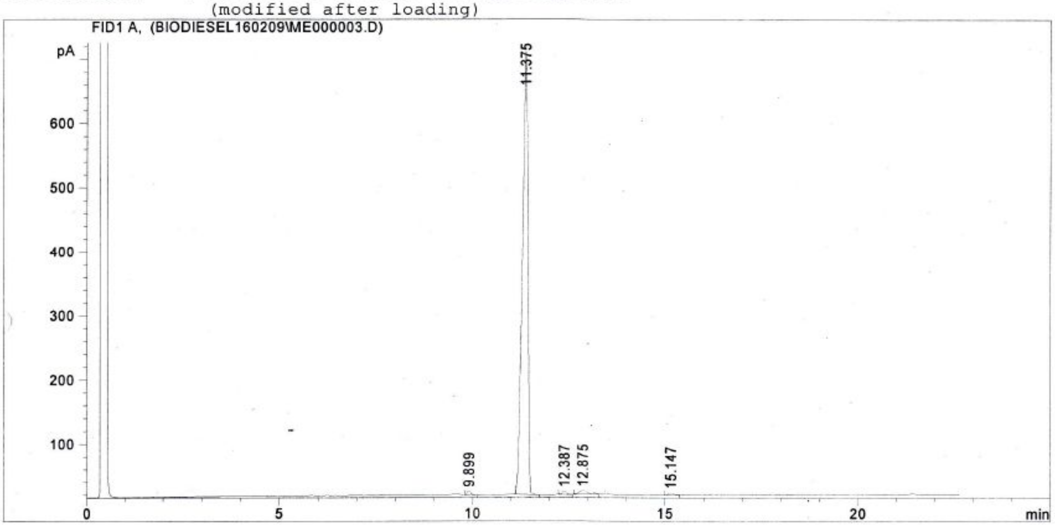


```
Data File C:\CHEM32\1\DATA\BIODIESEL160209\ME000005.D
 Sample Name: RBD 30 MIN/FATIMAH

    =================================================================
    Acq. Operator   : HAFIZAH110209                       Seq. Line :   3
    Acq. Instrument : Instrument 1                         Location : Vial 3
    Injection Date  : 16/02/2009 12:01:12                       Inj :   1
                                                        Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 13/02/2009 12:55:33  by HAFIZAH110209
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 16/02/2009 14:52:10  by HAFIZAH110209
                      (modified after loading)
```

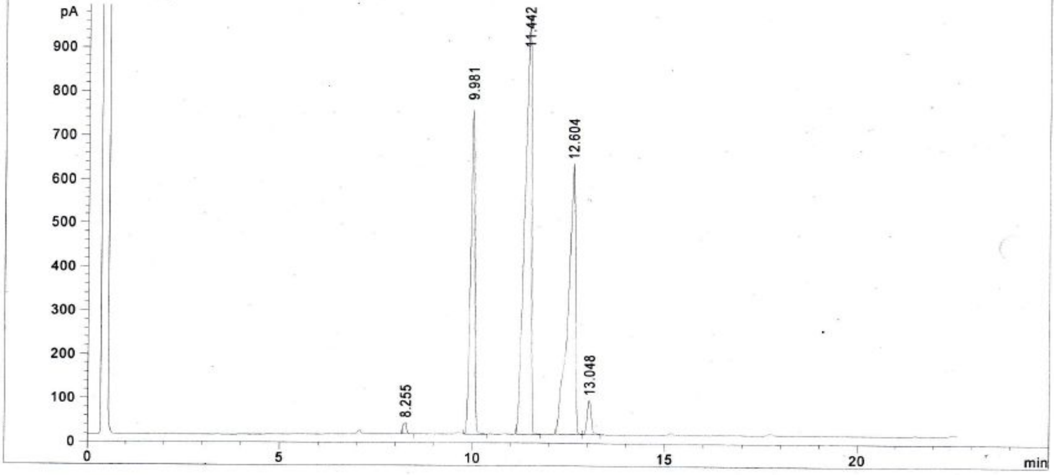
```
Data File C:\CHEM32\1\DATA\BIODIESEL160209\ME000003.D
 Sample Name: STANDARD ME

    ===================================================================
    Acq. Operator   : HAFIZAH110209                   Seq. Line :   1
    Acq. Instrument : Instrument 1                     Location : Vial 1
    Injection Date  : 16/02/2009 11:01:58                   Inj :   1
                                                   Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 13/02/2009 12:55:33  by HAFIZAH110209
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 16/02/2009 14:52:10  by HAFIZAH110209
                      (modified after loading)
```



```
Data File C:\CHEM32\1\DATA\BIODIESEL160209\ME000004.D
 Sample Name: RBD 20 MIN/FATIMAH

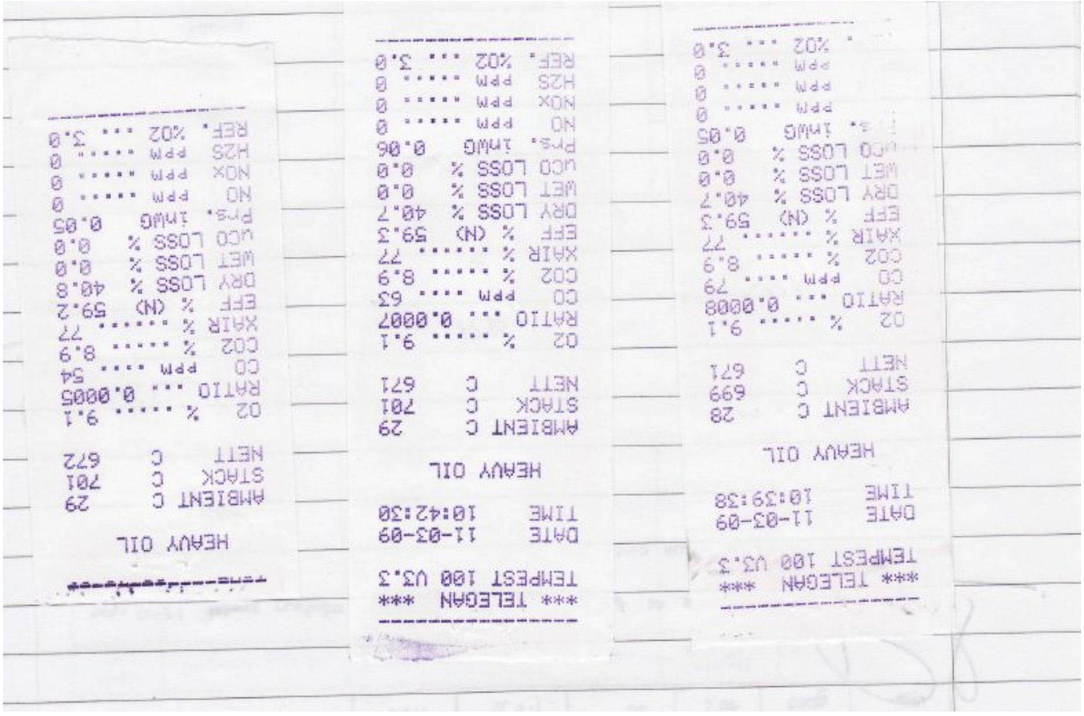
    ===================================================================
    Acq. Operator   : HAFIZAH110209                   Seq. Line :   2
    Acq. Instrument : Instrument 1                     Location : Vial 2
    Injection Date  : 16/02/2009 11:31:30                   Inj :   1
                                                   Inj Volume : 1 µl
    Acq. Method     : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 13/02/2009 12:55:33  by HAFIZAH110209
    Analysis Method : C:\CHEM32\1\METHODS\BIODIESEL.M
    Last changed    : 16/02/2009 14:52:10  by HAFIZAH110209
                      (modified after loading)
```



APPENDIX D

RESULT FROM COMBUSTION TEST

D.1 RBD Palm Oil



```
*** TELEGAN  ***
TEMPEST 100 V3.3

DATE     11-03-09
TIME     10:39:38

   HEAVY OIL

AMBIENT C      28
STACK   C     699
NETT    C     671

O2   % ..... 9.1
RATIO ... 0.0008
CO    PPM .... 79
CO2  % ..... 8.9
XAIR % ...... 77
EFF  % (N)  59.3
DRY LOSS %  40.7
WET LOSS %   0.0
uCO LOSS %   0.0
  s. inWG   0.05
      PPM ..... 0
      PPM ..... 0
      PPM ..... 0
    . %O2 ... 3.0
```

```
*** TELEGAN  ***
TEMPEST 100 V3.3

DATE     11-03-09
TIME     10:42:30

   HEAVY OIL

AMBIENT C      29
STACK   C     701
NETT    C     671

O2   % ..... 9.1
RATIO ... 0.0007
CO    PPM .... 63
CO2  % ..... 8.9
XAIR % ...... 77
EFF  % (N)  59.3
DRY LOSS %  40.7
WET LOSS %   0.0
uCO LOSS %   0.0
Prs. inWG   0.06
NO   PPM ..... 0
NOx  PPM ..... 0
H2S  PPM ..... 0
REF. %O2 ... 3.0
```

```
   HEAVY OIL

AMBIENT C      29
STACK   C     701
NETT    C     672

O2   % ..... 9.1
RATIO ... 0.0005
CO    PPM .... 54
CO2  % ..... 8.9
XAIR % ...... 77
EFF  % (N)  59.2
DRY LOSS %  40.8
WET LOSS %   0.0
uCO LOSS %   0.0
Prs. inWG   0.05
NO   PPM ..... 0
NOx  PPM ..... 0
H2S  PPM ..... 0
REF. %O2 ... 3.0
```

D.2 Waste Cooking Oil

```
*** TELEGAN  ***
TEMPEST 100 V3.3

DATE      11-03-09
TIME      10:48:18

    HEAVY OIL

AMBIENT C      29
STACK   C     697
NETT    C     667

O2   % ..... 9.1
RATIO ... 0.0007
CO   ppm .... 65
CO2  % ..... 8.9
XAIR % ...... 77
EFF  % (N)  59.5
DRY LOSS %  40.5
WET LOSS %   0.0
uCO LOSS %   0.0
Prs. inWG   0.05
NO   ppm ..... 0
NOx  ppm ..... 0
H2S  ppm ..... 0
REF. %O2 ... 3.0
```

```
*** TELEGAN  ***
TEMPEST 100 V3.3

DATE      11-03-09
TIME      10:50:04

    HEAVY OIL

AMBIENT C      29
STACK   C     702
NETT    C     672

O2   % ..... 9.0
RATIO ... 0.0004
CO   ppm .... 36
CO2  % ..... 9.0
XAIR % ...... 75
EFF  % (N)  59.6
DRY LOSS %  40.4
WET LOSS %   0.0
uCO LOSS %   0.0
Prs. inWG   0.04
NO   ppm ..... 0
NOx  ppm ..... 0
H2S  ppm ..... 0
REF. %O2 ... 3.0
```

```
*** TELEGAN  ***
TEMPEST 100 V3.3

DATE      11-03-09
TIME      10:52:31

    HEAVY OIL

AMBIENT C      30
STACK   C     702
NETT    C     672

O2   % ..... 8.9
RATIO ... 0.0003
CO   ppm .... 32
CO2  % ..... 9.0
XAIR % ...... 75
EFF  % (N)  59.7
DRY LOSS %  40.3
WET LOSS %   0.0
uCO LOSS %   0.0
Prs. inWG   0.03
NO   ppm ..... 0
NOx  ppm ..... 0
H2S  ppm ..... 0
REF. %O2 ... 3.0
```