STUDY ON THE FAME OXIDATION AND THERMAL STABILITY OF BIODIESEL

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ABSTRACT

Fatty acids methyl esters (FAME) have a major effect in displacing Diesel fuel of crude oil origin and also to minimize the emission of gases which contribute to the global warming phenomenon. Furthermore, FAME easily biodegrades as compared to the fossil fuel. In order to investigate the oxidation of stability of FAME, there are various methods which can be employed, namely FAME in relation to European standard PN EN 14214. This research project produces a critical result of determination of FAME oxidation stability with different type of biodiesel sample. From this research report, the most suitable biodiesel that can be used for consideration for alternative renewable energy would be jatropha biodiesel. Jatropha biodiesel good in thermal stability, can maintain fuel properties in higher temperature, low acid value, low density, has a higher total base number, low viscosity which indicates that jatropha biodiesel is thermally stable and has a longer period of oxidation rate.This research is very important for further biodiesel development in our country to develop in future pure biodiesel fuel or partially biodiesel fuel mix with crude oil.

ABSTRAK

Penyelidikan ini merangkumi pelbagai aplikasi kejuruteraan bagi menyediakan landasan dari segi aspek minyak biodiesel. Secara tuntasnya, kandungan lemak asid ester di dalam minyak biodiesel dapat mengurangkan kesan rumah hijau, pelepasan gas merbahaya daripada kenderaan, pemanasan global dan lain loain pencemaran alam. Justifikasinya, minyak biodiesel berupaya mengurangkan karbon dioksida, NOx, SOx, dan asap merbahaya. Selain itu minyak biodiesel mudah diuraikan berbanding dengan minyak diesel daripada pelantar minyak. Kajian ini berasaskan bagi menstabilkan proses pengokisadaan dan juga suhu dengan mengunakan pelbagai jenis sampel biodiesel. Melalui kajian ini secara eksperimental, dibuktikan secara analysis graf bahawa minyak Jatropha biodiesel mempunyai suhu yang stabil, boleh mengekalkan cirri-ciri asas pada suhu yang tinggi, nilai asid yang rendah, nilai asas yang rendah, kelikatan rendah, sekaligus membuktikan bahawa stabil dari segi perbezaan suhu dan propses pengokisadaan yang mengambil jangka masa yang panjang. Kajian ini penting bagi mempelbagaikan sumber bahan bakar selaras dengan wawasan 2020.

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ABBREVIATIONS

JCB	-	Jatropha curcas biodiesel
PY	-	Pyrogallol
N	-	viscosity
PV	-	peroxide value
AV	-	acid value
r	-	density
S	-	specific gravity
PG	-	propyl gallate
BHA	-	butylated hydroxyanisole
BHT	-	butylated hydroxytoluene
FFA	-	free fatty acid
UV	-	ultra violet
IP	-	induction period
RME	-	rapeseed oil methyl esters
Fe	-	iron
Ni	-	nickel
Cu	-	copper
OSI	-	oxidation stability index
TAN	-	total acid number

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CHAPTER I

INTRODUCTION

1.1 Background of study

Biodiesel refers to a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl esters. Biodiesel is typically made by chemically reacting lipids.

Biodiesel is meant to be used in standard diesel engines and is thus distinct from the vegetable and waste oils used to fuel converted diesel engines. Biodiesel can be used alone, or blended with diesel. Biodiesel can also be used as a low carbon alternative to heating oil. Biodiesel is the name of a clean burning alternative fuel, produced from domestic, renewable resources. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. It can be used in compression-ignition engines with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics.

The use of biodiesel reduces matter emissions by as much as 40 percent compared to petroleum diesel. According to the California Air Resources Board and American Lung Association, particulate matter from diesel emissions contributes to 2,000 premature deaths in California and as many as 15,000 premature deaths nationwide every year 5 Reducing exposure to diesel emissions through the increased use of biodiesel will have potentially significant implications for the health and welfare of all Americans as well as the economy through reduced health care expenditures and increased productivity. An assessment of public health implications of diesel emissions prepared by the West Coast Collaborative, a public interest group aimed at improving air quality reports that an EPA analysis estimated that a voluntary diesel retrofit program aimed at reducing diesel emissions would create as much as $2 billion in health benefits from reduced health care expenditures associated with premature deaths, hospital visits, and other costs.

Biodiesel is made through a chemical process called transesterification whereby the glycerin is separated from the fat or vegetable oil. The process leaves behind two products - methyl esters and glycerin (Fuel-grade biodiesel must be produced to strict industry specifications (ASTM D6751) in order to insure proper performance. Biodiesel is the only alternative fuel to have fully completed the health effects testing requirements of the 1990 Clean Air Act Amendments. Biodiesel that meets ASTM D6751 and is legally registered with the Environmental Protection Agency is a legal motor fuel for sale and distribution.

Biodiesel is defined as mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats which conform to ASTM D6751 specifications for use in diesel engines. Biodiesel refers to the pure fuel before blending with diesel fuel. Biodiesel blends are denoted as, "BXX" with "XX" representing the percentage of biodiesel contained in the blend B20 is 20% biodiesel, 80% petroleum diesel.

1.2 Background of Study and Problem Statement

People these days have started considering the options of an alternative fuel over petroleum or diesel. Our present fuel resources are not going to be around forever and with the ever increasing consumption their extinction is nearly unavoidable. Also our fuel resources which are mostly made up of fossil fuels are not renewable in nature. According to an estimate the demand for these fuels will suddenly outstrip their availability in a matter of centuries-or less.

No matter how safely the fossil fuels are used, they continue to take a toll on the atmosphere. This is because on combustion these types of fuels release various pollutants. These pollutants include dangerous gases like sulfur dioxide that causes acid rain. Also the combustion of fossil fuels emits carbon dioxide. This harmful gas when released into the atmosphere makes a huge contribution to the greenhouse effect. This effect prompts the atmosphere to capture and reflect back the energy that radiate from the surface of the earth, instead of letting them to escape back into space. This causes global warming that melts the polar ice caps and affects weather all around the world. The rampant warnings of global warming are the biggest reason for the world to look beyond these fossil fuels. The consumption is not the only thing that adds to the pollution. The development in technology has made it possible to extract fossil fuels in a much easier and more cost effective way. This has lead to the corporate race of finding more resources. This involves digging deeper and deeper into the ground. This further causes the scraping off ever more layers of precious topsoil.

Alternative fuels on the other hand are safer. Also unlike the fossil fuels, the resources for the alternative fuels are entirely renewable. This makes it a smart decision to opt for the alternative fuels. Like any other perishable commodities on the Earth, fossil fuels also have a limited life span. You use them without thinking today, but one day all the fossil fuels will be depleted. Experts have already set a date when this planet will have no fuel left to run cars. Without fossil fuels, owning a Lamborghini, Jaguar or a Mercedes will not matter. Considering this it becomes important to iron out all glitches on alternative fuels arrangements that have been invented over the years.

In anticipation of the day when natural fuels will perish, other sources have been found but their full potential is yet to be tapped. These alternative fuels when used can prove to relieve the worries of the entire global community and also be easier on the pocket unlike fossil fuels. There might have to be minor re-arrangements made to our machines but it will prove to be an advantage in the long run.

Because of its chemical structure FAME can be very sensitive to oxidative and thermal degradation. When FAME are exposed to high temperatures and the oxygen in air, they can undergo chemical changes that form deposits and sediments as well as cause an odour and colour changes, and an increase in acid number, peroxide number and viscosity. Furthermore, the need to study in control thermal stability and oxidation rate should be studied. Thus, this research will provide a solution to reduce oxidation effect.

1.3 Importance / Significance of Study

The research can indicate the biodiesel's thermal stability and oxidation effect. The importance and significance of the project are as follow:

a) The study can contribute to a fundamental need in improving thermal stability and lengthen the period of oxidation rate.

b) The study can reduce the emission of exhaust particles such as NOx, SOx, CO and other harmful gaseous.

c) This report can contribute to better understanding on the Fame oxidation and thermal stability of biodiesel for future green aspect fuel development.

d) This research project can be used for the next implementation of biodiesel studies and development, thus providing a more realistic approach in developing a perfect biodiesel oil technology application dedicated to enhance the better fuel and lubricant in future.

1.4 Objective of Study

It is essential for the work of this research to be focused in order to obtain desired results. Objective indicated the result of the project after accomplish it.The main objectives of the project are as follow:

a) To Conduct Experimental Work by using six sample of palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil. The experimental work are based on European Standard PN EN 14214.

b) To obtain crucial data on density, viscosity, total base number and total acid numbers for palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil.

c) To determine the suitable type of oil to be used in application of biodiesel fuel.

1.5 Scope of Study

The research of the project is to analyze the critical parameters based on biodiesel fuels. Hence, the scopes of study are as follows:

a) The oxidation and thermal stability will be measured by using the standard measurement of European standard PN EN 14214 requirements

b) The experiment has been conduct with crude oil (diesel fuel), pure biodiesel fuel and mix of diesel fuel.

c) The experiment will be conducted in closed environment in a Tribology Laboratory.

1.6 Expected Result

It is expected from the research that the suitable biodiesel oil will be determined and will lengthen the oxidation period and increase thermal stability for biodiesel fuel. This research will be used as a supportive to current biodiesel power plant to improve their production.

CHAPTER II

LITERATURE REVIEW

2.0 Facity Acid Methyl Ester (FAME)

FAME are substances obtained from renewable lipid sources which may be sourced from plant sources such as soybean oil, rapeseed oil, palm oil, coconut oil, corn oil, cottonseed oil, mustard oil, used cooking oils, float grease from wastewater treatment plants as well as animal fats such as beef tallow and pork lard. FAME are utilized as the renewable diesel blending fuel known widely as biodiesel. Due to its chemical structure FAME displays high sensitivity towards oxidative and thermal degradation. In the case whereby FAME are exposed to high temperatures and the oxygen in air, they potentially undergo chemical changes that form deposits and sediments and at the same time causing odour and colour changes, and an increase in acid number, peroxide number and viscosity.

The chemical structure of triglycerides varies greatly from that of hydrocarbons of the crude oil origin. Fatty acids which build triglycerides consist of 14 to 24 carbon atoms, essentially 18 carbon atoms in .To further illustrate, the myristic acid ($C_{14:0}$), the palmitic acid ($C_{16:0}$), the stearic acid ($C_{18:0}$), the oleic acid ($C_{18:1}$), the linoleic acid ($C_{18:2}$), the linolenic acid ($C_{18:3}$), the arachidic acid ($C_{20:0}$), the behenic acid ($C_{22:0}$), the erucic acid ($C_{22:1}$), the lignocerin ($C_{24:0}$) can be found in fatty acid composition. The existence of relatively high levels of unsaturated fatty acid methyl esters contributes to the nature of biodiesel being very inclined towards oxidation as opposed to petroleum diesel fuel. In general, the number of double bonds and their position determines the rate of oxidation stability of fatty compounds. The position allylic to double bonds is where the oxidation chain reaction is usually initiated at. The oxidation stability may depend hydroxyl group (if present), ether and ester compounds as well as carbonyl group. The build-in oxygen atom assists to accelerate oxidation.

On the other hand, the presence of organic acids, alcohols, and metals from the production processes of FAME plays a role in accelerating the degradation processes.Furthermore, the highly hygroscopic nature of FAME can allow the growth of microorganisms and lead to reversible reaction of FAME to fatty acids and methanol due to the presence of free water.

Metals such as copper and copper alloy, iron, nickel and tin from tanks can also affect the oxidation and thermal stability of FAME can also be altered by the presence of metals such as copper and copper alloy, iron, nickel and tin from tanks storing the substances.The Oxidation process of FAME runs as the free-radical reaction in three stages:

- initiation - *initialisation of the reaction, free-radicals formation. Light, temperature, enzymes and metalic ions are instigators of the reaction,*

- propagation – *proceeding of the reaction, multiradical chain reactions,* formation of peroxide radicals,

- termination – *completion of the reaction, formation of non radical products.*

A huge variety of primary and secondary oxidation products such as hydroperoxides and peroxides and then aldehydes, aliphatic alcohols, formic acid ester, formic acid and short chain fatty acids are produced from the oxidation process. The acetic acid, the propionic acid and high molecular weight organic acids are also the by products of oxidation process.The stability of biodiesel is increased by the antioxidant additives. Moreover, the antioxidants assist to improve the stability by the presence of the free-radical chain's growth.In a nutshell, oxidation and thermal stability of FAME depends on:

- *fatty acids composition of the feedstock, i.e. triglycerides structure,*
- *technology of production, i.a. kind and quantity of the catalysts, methanol/catalyst molar ratio, etc.,*
- *external factors such as temperature, exposure to air and light,*
- *content of natural antioxidants or prooxidants (tocopherols and carotenes)*
- *presence of free water,*
- *hygroscopic nature,*
- *contaminants and metal present*
- *fungi and bacterial contaminants present.*

2.1 Analytical methods for oxidative and thermal stability testing

Thus far, several standard methods have been established in order to determine the oxidative and thermal stability of different products. The potential analytical methods for oxidative and thermal stability testing of FAME are taking over from fat and oil industry, petroleum diesel and diesel engine manufacturing fields. *Measurement of Thermal Stability – The Rancimat Method*

The length of time before the rapid acceleration of oxidation is the measurement of the hesitance to oxidation and is commonly referred to as the 'induction period' , or Oxidative Stability Index (OSI). The OSI test is the test in widely practiced in Europe where biodiesel fuels need to conform to the specification of an induction period (IP) of at least 6 hours when tested at 110 °C. The Metrohm Rancimat apparatus is widely utilized to measure OSI and the term 'Rancimat' and 'OSI' are often used hands in hands in the literature whilst reference is made to the test method. OSI, as commonly used in experiments, requires passing air through a heated sample of the fatty oil or ester. The air blown out of the sample is eventually passed through water contained in a tube fitted with a conductivity meter.

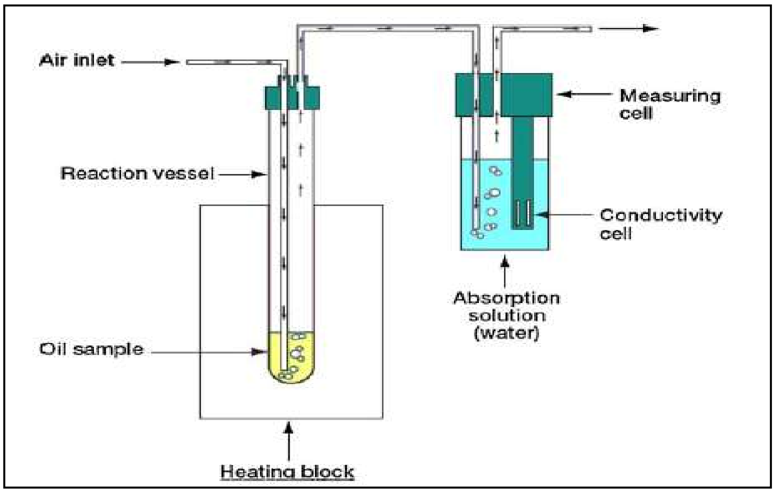


Figure 2.0: Simple Ranchimat Method

A sharp rise in conductivity is an indication of the formation of short chain, water soluble carboxylic acids, i.e., secondary oxidation products .Experiments have witnessed that the primary acidic families formed in the Rancimat OSI test is formic acid. An alternative approach has been reported where chemiluminescence is used to monitor the oxidation during the OSI test. Figure 2 illustrates that as the temperature of Rancimat test is increased periodically, the value of induction period decreases. The period whereby the conductivity suddenly increases is called the induction period (e.g.6 hr in this case). Various oils have different induction periods. Studies have portrayed that when the Rancimat test is carried out at different temperatures, the logarithm of the induction period (IP) will be a linear function of test temperature like plots of log (OSI IP) vs. T give straight lines.This confirmed that biodiesel stored at lower temperature is favorable for long-time storage of biodiesel omitting degradation. The Rancimat test has been used to measure the thermal stability by not employing an airflow but by measuring the polymer content in 8 g of biodiesel sample after 6 h at 200 °C [21]. The test is apparently suitable for practice in terms of repeating the experiments and ease to handle. [16] Found that the decrease in Rancimat induction period is faster at 20 8C than 40 8C with respect to time, though the difference between two temperatures is not significant. This might be due to high PV and AV at lower temperatures.

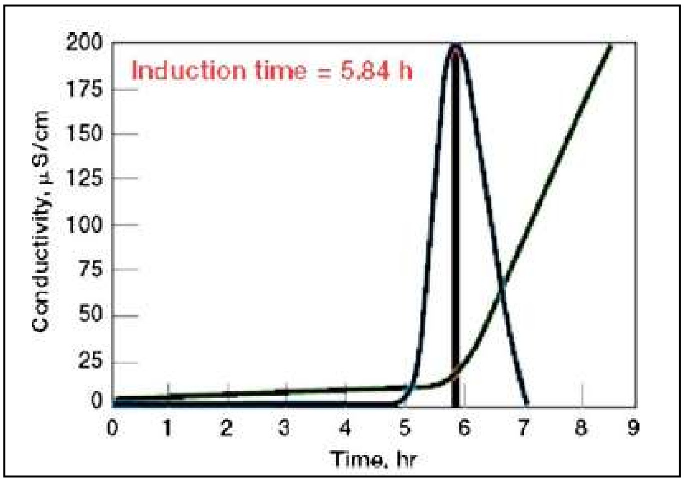


Figure 2.1: Graph conductivity versus time (16)

As an alternative, the Rancimat test can also be carried out manually using the Karl Fischer Coulometer make Metrohm (model no. 831 KF) as shown schematically in Fig. 3.An internal pump to suck the air is present. The air flow rate and the temperature of the oven can be adjusted according to precision desired. A well calibrated digital conductivity meter can be installed externally in the measuring cell. The apparatus can be utilized to check the oxidation as well as thermal stability. Air supply is closed at the time of measurement of thermal stability. However, the remaining part of the experimentation is similar to as that of Rancimat test.Therefore, it may be used as an alternative method as Rancimat test. Table 2.1 depict conditions, advantages and drawbacks as well as application of the Rancimat and bomb methods.

Table 2.1: Types of ASTM Methods

Methods	Description
ASTM D 2274	-Standard Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method) which the USA standard for biodiesel (ASTM D 6751-2003a - Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels) recommends for oxidation stability testing. This standard is equivalent to **PN-ISO 12205** – Petroleum products. -Determination of the oxidation stability of middle distillate fuels. This test method covers the measurement of inherent stability of distillate petroleum fuel under accelerated oxidizing condition. -The sample of fuel is aged at 95^{o}C for 16 hours while oxygen is bubbled through the sample. After aging the sample is cooled to room temperature and filtering to obtain the insolubles quantity.
ASTM D 6468	-Standard Test Method for High Temperature Stability of Distillate Fuels (DuPont F21). - Determination of filterable insolubles formation during aged of sample for 90 or 18 min. at 150^{o}C by measuring the light reflectance of the filter pad

ASTM D 4625	-Standard Method for Distillate Fuel Storage Stability at 110°F (43°C) – gravimetric measurement of filterable and adherent insolubles. Method of evaluating the storage stability of distillate fuels having flash points above 38°C. The sample of fuel is aged at 43°C for periods of 4 to 24 weeks. After aging the sample is cooled to room temperature and analysed for filterable and adherent insolubles.
ASTM D 525 / ISO 7536	-Standard Test Method for Oxidation Stability of Gasoline (Induction Period Method). -Induction period is the initial slow phase of a chemical reaction which accelerates. Induction periods are observed with radical reactions, but they may also occur in other systems (for example before steady-state concentration of the reactants is reached) [14].

Table 2.2: Comparison of Rancimat and bomb methods

Test method	***Temperature*** ***Sample Size***	***Test Condition***	***Advantages***	***Drawbacks***	***Application***
PN-EN 14112 ***Rancimat method***	110°C 3 g	Borosilicate glass vessel. Oxygen flow 10 l/h	Simple test employing conductivity drop for break point	The end of the induction period corresponds to the appearance of the secondary oxidation products volatile organic acids (formic acid)	**FAME specification**
ASTM **D 525** **Bomb method**	**100°C** **50 mL**	**Borosilicate glass container in pressure vessel.** **Oxygen pressure 100-102 psi.**	**Simple test employing pressure drop definition for break point**	**Important method for gasoline in which soluble gum is a function of autooxidation break point**	**Gasoline specification**

To conclude, the review done thus far has apparently shown that biodiesel is prone towards oxidation when exposed to higher temperature due to the formation of oxidation products such as aldehydes, alcohols, shorter chain carboxylic acids, and sediment in the biodiesel, which more often than not is responsible for various undesired incidents such as injector fouling, formation of deposits in engine combustion chamber and other components of the fuel system. Methods widely employed worldwide to investigate the thermal stability are Rancimat test, and ASTM Methods. Rancimat test has been proven to be an essential method to validate the thermal stability of fuels, mainly lipids. A significant number of studies were devoted to the thermal stability of various oils using these methods. However, no connection has been found in the literature between the results of various test methods. It is worth taking note that a great deal of effort is required in the arena of biodiesel namely, increase in the thermal/oxidation stability of biodiesel from non-edible oils. Next, the effect of thermal parameters on storage and oxidation stability is, therefore, are important R&D areas to further improve the stability of biofuel for use in existing to develop engines to replace the diesel petroleum.

A non-catalytic supercritical methanol method is an attractive process to convert various oils/fats efficiently into biodiesel. To evaluate oxidation stability of biodiesel, biodiesel produced by alkali-catalyzed method was exposed to supercritical methanol at several temperatures for 30 min. As a result, it was found that the tocopherol in biodiesel is not stable at a temperature higher than 300 °C. After the supercritical methanol treatment, hydroperoxides were greatly reduced for biodiesel with initially high in peroxide value, while the tocopherol slightly decreased in its content. As a result, the biodiesel prepared by the supercritical methanol method was enhanced for oxidation stability when compared with that prepared by alkali-catalyzed method from waste oil. Therefore, supercritical methanol method is useful especially for oils/fats having higher peroxide values.

Current commercial production for biodiesel involves the use of alkali-catalyzed method [2]. In this method, however, oils/fats that are high in free fatty acid and water contents are difficult to be utilized since the former reacts with alkaline catalyst to form undesirable saponified product and the latter hinders the complete conversion. Furthermore, purification process is necessary to remove catalyst and saponified products. In a previous study, thermal stability of biodiesel in supercritical methanol was investigated and it was found that biodiesel could be stable without decomposition or cis–trans isomerization under the condition of 300 °C/ 19 MPa or lower in temperature [8].

To enhance the oxidation stability, antioxidants were employed to prolong the stabilized time of biodiesel. Biodiesel is usually prepared from vegetable oil, various natural antioxidants originally in oils are important for oxidation stability of biodiesel. Main natural antioxidants in vegetable oils are tocopherols (a-tocopherol, b-tocopherol and c-tocopherol). However, these natural antioxidants may be denatured and/or decomposed when they are placed for a long time under air or high temperature. Since high temperature and high pressure are inevitable in supercritical methanol method, stability of natural antioxidant during supercritical methanol treatments is an important issue that should be studied.

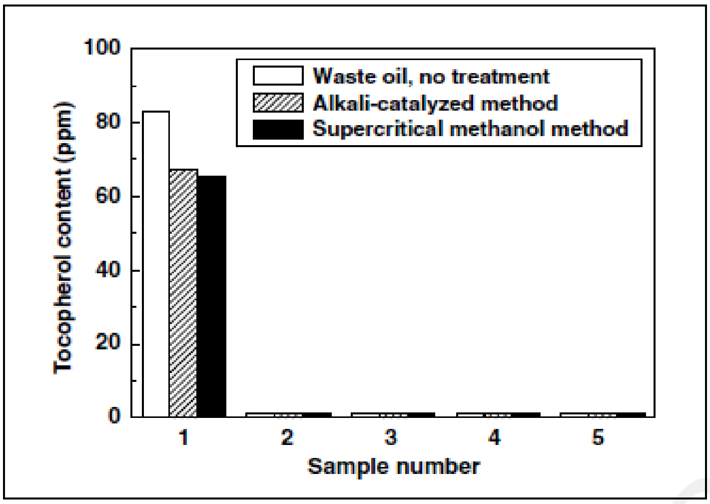


Figure 2.3: Tocopherol content of waste oils and biodiesels prepared by alkali-catalyzed method and supercritical methanol method (270ºC / 17 MPa for 60 min)(9)

During supercritical methanol exposure, most hydroperoxides was decomposed due to high temperature and high pressure, while tocopherol remained almost unchanged in its content for high unsaturated biodiesel (safflower and rapeseed biodiesel) but slightly decreased for low unsaturated biodiesel (palm biodiesel). Therefore, it was clarified that supercritical methanol method is useful especially for oils/fats that have higher peroxide values.

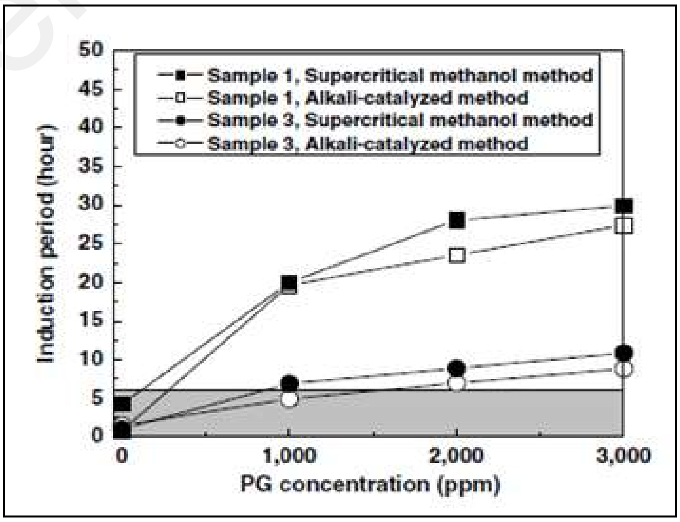


Figure 2.4: Comparison of oxidation stability of biodiesels prepared by an alkali-catalyzed method and supercritical methanol method(11)

Several articles report on the beneficial characteristics of biodiesel. It is non-toxic, free of sulphur and aromatics, readily biodegradable, safe to handle, enhances lubricity and its main physicochemical properties are comparable to those of conventional middle distillate fuels.The biodiesel stability generally depends on the fatty acid profile of the parent feedstock. Therefore, biodiesels with high contents of unsaturated fatty acids, such as linoleic and linolenic, are especially prone to oxidation . The relative oxidation rates for these unsaturated esters are linolenic > linoleic_oleic.(2)

Figure 2.5: Jacoba Oil (1)

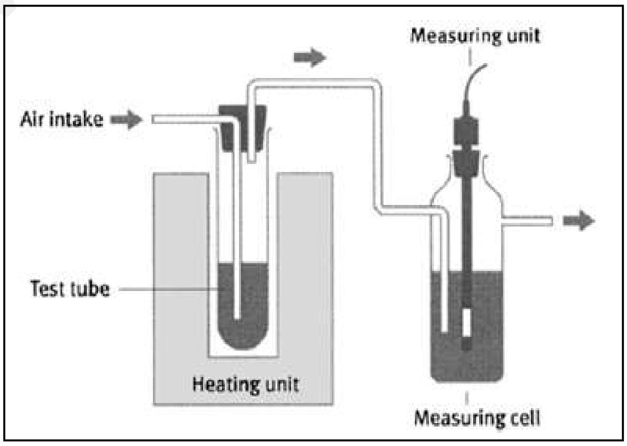


Figure 2.6: Principles of measurement of the Rancimat test method (EN-14112/IS-15607) (7)

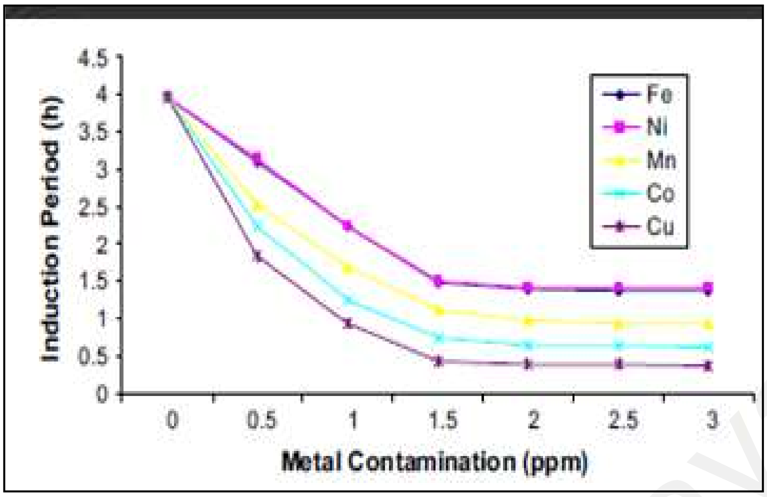


Figure 2.7: Influence of metal contamination on oxidation stability (15)

Copper has strongest catalytic effect and other metals such as iron, nickel, manganese and cobalt has negative influence on oxidation stability. Figure shows that the induction period become almost constant as concentration of metal increased.

Biodiesel derived fromfree fatty acids (FFAs),which has the advantage of not competing with the edible-oilmarket, exhibited poor oxidation stability. The induction period (IP) of the FFA-based biodiesel determined by the Rancimat method at 110 °Cwas 0.20 h. This study investigates the effectiveness of one natural and ten synthetic antioxidants, including α-tocopherol (α-T); butylated hydroxyanisole (BHA); butylated hydroxytoluene (BHT); 2,5-di tertbutylhydroquinone (DTBHQ); Ethanox 4740; Ethanox 4760E; 2,2′-methylene-bis-(4-methyl-6-tert-butylphenol) (MBMTBP); N,N′-di-sec-butyl-p-phenylenediamine (PDA); propyl gallate (PG); pyrogallol (PY); and tertbutylhydroquinone (TBHQ), at concentrations between 100 and 1000 ppm to improve the oxidation stability of the FFA-based biodiesel. The order of antioxidant effectiveness with respect to the oxidation stability of the FFA based biodiesel was. The

IP of the FFA-based biodiesel increased as the antioxidant concentration was increased and decreased at high test temperatures.(4)

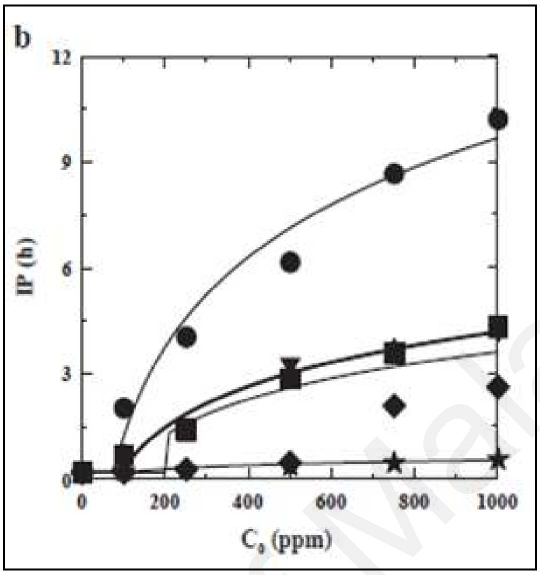


Figure 2.8: The variations of IP with C for FFA-based biodiesel at 110 ºC with the addition of various antioxidants (5).

The two reasons behind the biodiesel degradation process are 63 (i) its exposure to high temperatures (usually above 250–300 _C) 64 or (ii) the presence of an oxidant agent (usually air oxygen, but also 65 dissolved oxygen) in contact with the fuel during a sufficiently long 66 period of time. For instance, in Europe it is already approved an increase of the IP up to 8 h for the next version of the EN 14214 More saturated biodiesel fuels showed better stability, but the unsaturation degree alone was insufficient to explain the effect of the raw material. The previous use of the oil for frying processes reduced the stability of the final fuel, probably through the appeareance of contaminants and other compounds and the loss of natural anti-oxidants.(5)

Methanol is highly toxic, can be absorbed through the skin and is 100% miscible with water, so any kind of spill presents a serious problem. Ecological aspects are gaining a lot of recognition in our society. Bioethanol is derived from agricultural products; it is renewable and is biologically less objectionable in the environment Compared to methanol, ethanol is safer to handle because toxic effects to personal from exposure to fumes are reduced. It has been found that biodiesel, which is usually produced from food grade vegetable oils which are more expensive than diesel fuel, produced by transesterification of bioethanol and the oil extracted from the B. carinata seeds, kept in inert atmosphere displays physical–chemical properties suitable for use as diesel car fuel.(6)

One disadvantage associated with biodiesel is its poor oxidation stability. Oxidation can alter the physical and chemical properties of fuel and it can cause acidity and increasing viscosity due to formation of insoluble gums that can plug fuel filters. This disadvantage makes fuel unsuitable for use in engines because the resulting oxidation products can damage the motors of vehicles. Many of the plant-derived oils contain unsaturated fatty acid chains, such as oleic, linoleic and linolenic acids, which are the primary causes of instability in oils and biodiesel. The greater the level of unsaturation in fatty acid chains, the more susceptible they will be to oxidation.The combination of spectrofluorimetry and a PLS calibration model developed in this study was proven perfectly suitable as an analytical method to predict the oxidation stability of oils and biodiesel. The advantages of fluorescence spectroscopy, such as simplicity, quickness, low-cost, and facility for the implementation of on-line monitoring systems, suggested that this method can be a powerful analytical procedure for the research of the oxidation stability of oils and biodiesel.

The prediction of the oxidation stability showed a good agreement with the results obtained by the EN14112 reference method Rancimat. The models presented high correlation (0.99276 and 0.97951) between real and predicted values. The R2 values of 0.98557 and 0.95943 indicated the accuracy of the models to predict the oxidation stability of soy oil and soy biodiesel, respectively.(7)

Temperature and concentration affect the antioxidant stability of biodiesel. This paper suggested that biodiesel fuel should be stored at lower temperature is favorable for long time storage of biodiesel without degradation. Since the storage conditions could greatly affect stability of biodiesel.

Rancimat Method – Measurement of this method does not capture the impact of total glycerin on oxidation product formation. For the sample that been examined here, metal content had little effect on oxidation stability. (9)

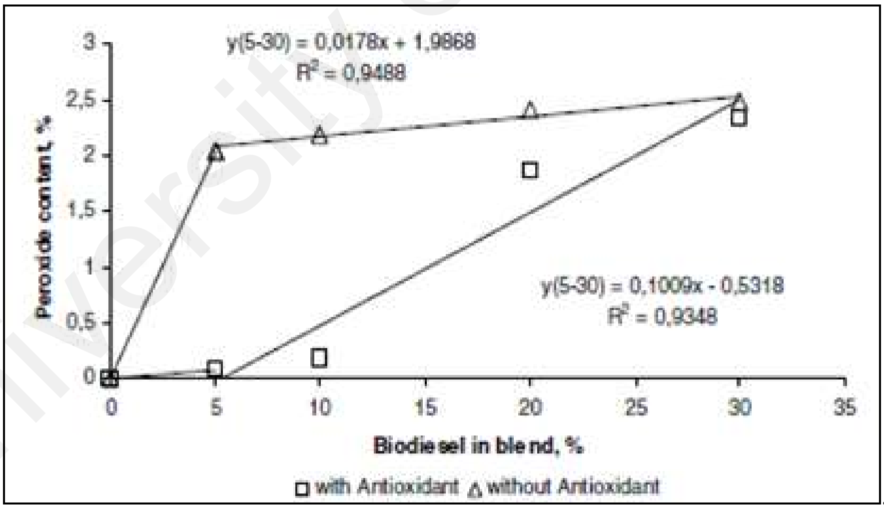


Figure 2.9: Antioxidant's effect over peroxide formation(10).

The addition of antioxidant to biodiesel blends led to reduction in insoluble formation. This reduction concerns filterable, adherent and iso-octane insoluble. The antioxidant increases blends' resistance toward secondary oxidation products decreases mostly for stabilized sample with the same concentration of biodiesel. (10) Antioxidant function is delaying not preventing it. There are two types of antioxidant that is auto and photo. The natural antioxidant in vegetable oil effected by refining process. Natural antioxidant such as vitamin E (tocopherols)

Several authors have performed long term storage tests on biodiesel quality and investigated the effect on the physical properties of the fuel with respect to time (10). It was reported that n, PV, AV,and density of biodiesel increased but the heat of combustion decreased when store for two years. From the experiment it was clear that as oxidation deterioration advances with respect to time, linoleic and linolenic acid methyl esters decreases and the fraction of oleic acid methyl become relatively high. (12).The significant decreases in the tocopherol content results in inevitably poor oxidation stability of biodiesel. Futhermore, it has been already confirmed that the poly-unsaturated fatty acid methyl esters are decomposed in supercritical methanol at the temperature higher than 300 celcius. (16)

The engine performance of the neat biodiesel and their blends was similar to diesel fuel with the same thermal efficiency, but higher fuel consumption. Compared with unoxidized neat biodiesel produced 15 and 16 % lower exhaust carbon monoxide and hydrocarbons respectively. None statically significant was found between oxides of nitrogen and smoke emissions from oxidized and unoxidized biodiesel. Most have concluded that vegetable oil in a diesel engine for extended periods of time may result in severe engine deposits, piston ring sticking, injector coking, and the thickening of the lubricating oil.These effects can be reduced through transesterification of the oil to form monoesters known as biodiesel. (17) The greater surface oxygen functionality in biodiesel the mean for more rapid oxidation and drastic structural transformation during the oxidation process.

The commission of Green paper "Towards an European strategy for the security of energy supply" sets the objective of 20% substitution of conventional fuels in the road transport sector by the year 2020. (21)The cetane index is an important index of the combustion characteristics of fuels, particularly diesel. Liquid fuels with a higher cetane index have a shorter ignitation delay, which leads to a shorter burning time, fewer occurrences of engine knocking and less nitrogen oxide formation. The cetane indices of the sample decreased with increasing storage time.(22)

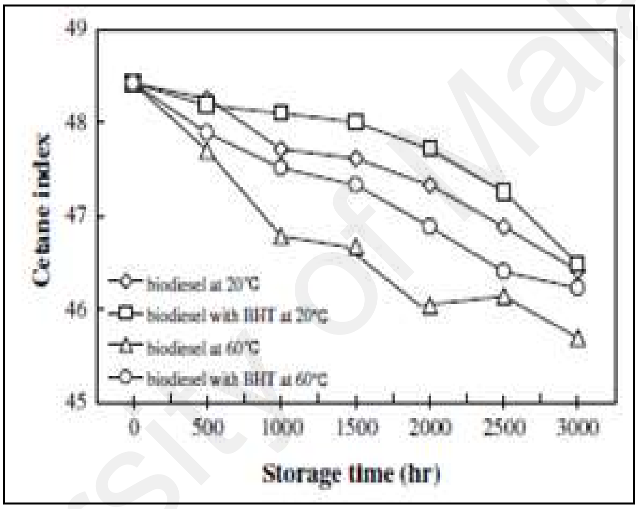


Figure 2.10: Comparison of the cetane index of palm-oil biodiesel at various storage temperatures and times and in the presence or absence of an antioxidant additive. (22)

The experimental results reveal that the palm oil biodiesel suffered greater oxidative degradation at higher storage temperatures and in the absences of an antioxidant, resulted in a faster decreases in the amount of heat released as the storage elapsed. The addition of the chain breaker antioxidant BHT effectively broke the peroxidation reaction and significantly retarded the decrease in heat release. The oxidative stability of the palm oil biodiesel was worst at a higher storage temperature, a longer storage time, and in the absence of an antioxidant, which caused the more extensive formation of sediments of oxidative products and hence a larger carbon residue after burning.

Among these properties, the oxidative stability of the blends show a negative anti synergistic effect, that is, all the blends have an induction period lower that the pure reference diesel and the pure castor FAME. On Contrary, the lubricity shows a positive synergistic effect, the wear scar of the blends being always lower than those of the pure components.The pattern of the oxidation process of castor oil FAME, using the Rancimat method, is similar to the oxidation pattern of the same sample oxidized using the PetroOXY method. (25) The oxidation stability decreased with the increase of the content of polyunsaturated methyl esters. Biodiesel of almond, olive, corn, rapeseed and high oleic sunflower oils had the global better properties because they have the greater monounsaturated content.(27)

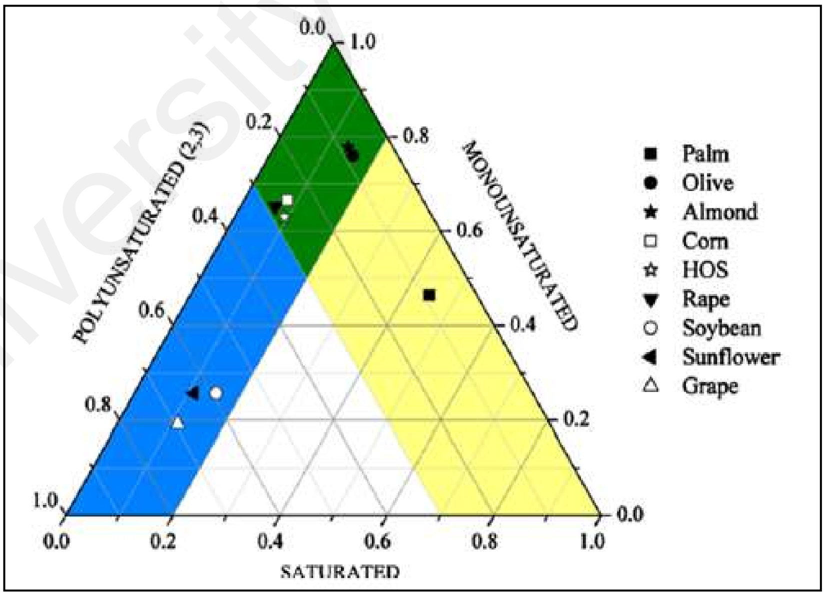


Figure 2.11: Biodiesels by monounsaturated , polyunsaturated and saturated methyl esters. Areas satisfying parameter of the European of Standard UNE-EN 14214: yellow (right), good cetane number and iodine value: blue (left), good CFPP: green (intersection), biodiesel that satisfied UNE-EN 14214(27)

Oxidative stability was significantly reduced upon extended storage and acid value as well as kinematic viscosity was increased by only small increments, with these effects more pronounced at elevated temperatures. Iodine value and low temperature were essentially unaffected by extended storage. (30)

The oxidative stability tests described enabled the comparison of synthetic lubricant samples and showed that their stability was lower than that petroleum-based oil. However, the physic-chemical properties, such pour point and viscosity index, were improved and potentially interesting for lubricant applications. The biodegradability experiments were carried out using a model of bio-kinetics. These studies proved that synthetic lubricant samples were easily degradable (similar to crude castor oil) and showed half –life significantly lower than those of mineral oil samples.(33)

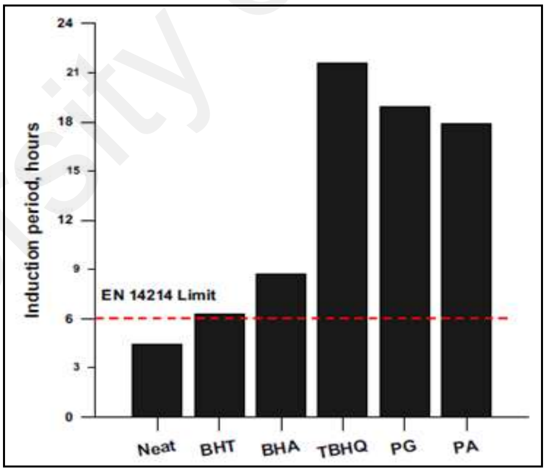


Figure 2.12: Oxidation stability measurements of the methyl ester sample treated with the various types of phenolic antioxidant (33)

The addition of antioxidant led to important differences in acid value and to limited effects in kinematics viscosity of the fuel blends. For all biodiesel blends, the acid value and to a lesser extent viscosity, tended to increase over storage time probably due to formation of antioxidant product such a peroxides and acids.(34)

Initiation: $RH + I \rightarrow R^{-} + IH$

Propagation: $R^{-} + O2 \rightarrow ROO^{-}$

$ROO^{-} + RH \rightarrow ROOH + R^{-}$

Termination: $R^{-} + R^{-} \rightarrow R \cdot R$

$ROO^{-} + ROO^{-} \rightarrow$ Stable Product

Figure 2.13: Typical oxidation reaction in biodiesel.(34)

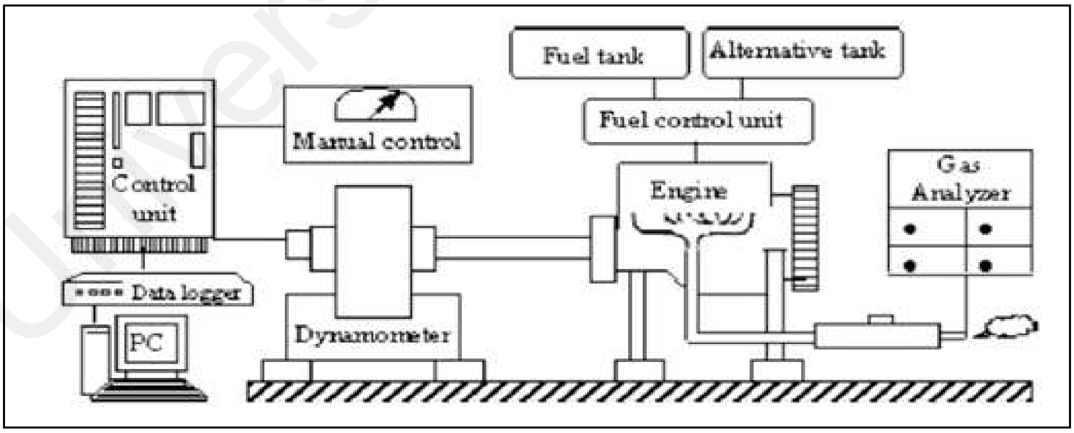


Figure 2.14: Engine test setup (35)

The properties of biodiesel produced from waste vegetable oil was measured based on ASTM standards. The experimental results revealed that blends of waste vegetable oil methyl ester with diesel fuel provide better engine performance and improved emission characteristics. Artificial Neural Network (ANN) modeling of a diesel engine using waste cooking biodiesel fuel to predict the brake power, torque, specific fuel consumption and exhaust emissions of the engine.(35)

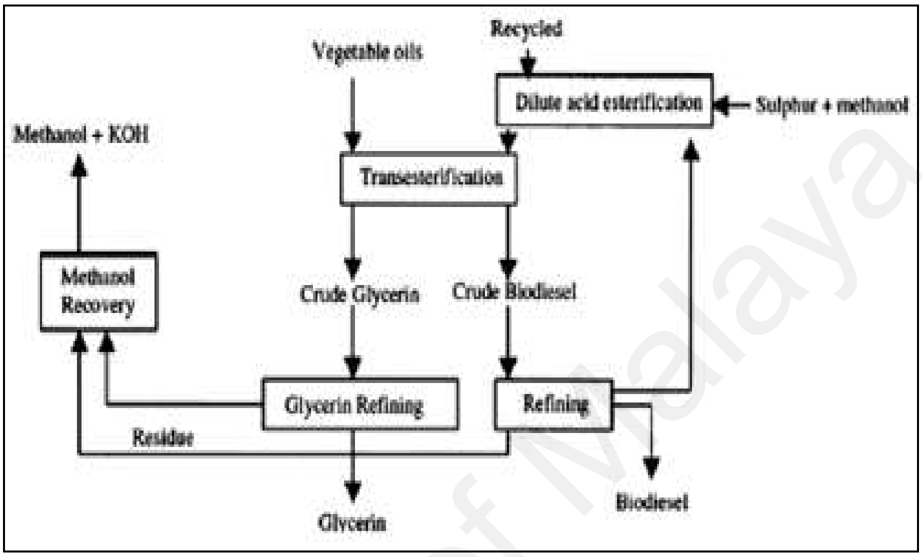


Figure 2.15: Basic scheme for biodiesel production (35)

Table 2.3: Instrumentation involved in characterization of biodiesel (40)

Feedstock	
Tobacco	High performance liquid chromatograph
Polango seed oil	High performance liquid chromatograph
Pongamia pinnata	(i)HPLC (Perkin-Elmer series 200) equipped with refractive index detector (shodex RI 71)
	(ii) H NMR Bruker DPX 300 spectrometer (Bruker, Rheinstetten, Germany)
	(iii) Gas chromotograph (for analysis of fatty acid composition of karanja oil)
Jatropha,Pongamia,sunflower	(i) GC (Model HR/GC/5300) (for fatty acid composition of vegetable oils)
Soybean,palm	(ii) Thin layer chromatography (TLC)
Pongamia pimata	Gas chromatography (Nucon, India) equipped with a FID detector
Waste cooking oil	Gas chromatography (GC) equipped with a capillary column (SPBTM-5, 30 m x 0.32mm x 0.25µm) and a FID
Neat and used frying oil	(i) HP 6890 series II Gas Chromatograph with a 3365/II GC-chermstation and a FID
	(i) Thin layer chromatography (TLC)
Sunflower oil	(ii) Gel permeation chromatography (GPC)
	(ii) Gas chromatography graph (GC), Nucon 5765, India
Microalgal chlorella protothеccoides	(i) Gas chromatography-mass spectrometric analysis
Soybean oil	(i) X-ray diffractometer
	(ii)GPC with an RI (refractive index) detector, (carrier: THF)
	(iii) Gas chromatography-mass spectrometer
Lipid extracted from the cell of R.glutinis	(i) Gas chromatography
Triolein	HPLC system (Hitachi, Ltd, Tokyo,Japan, D-7000 interface, L-7100
Sunflower oil	For FAME determination Agilent 6890 GC with a HP INNOwax capillary column
	For catalyst characterization
	(i) Balzer Prisma quadrupole mass spectrometer (QMS 200)
	(ii) Seifert 3000 XRD diffractometer (equipped with a PW goniometer)
	(iii) VG Escalab 200R spectrometer (equipped with an Hq-col-Te cryodetector)
Biopiles	Gas chromatography-mass spectrometer
Canola, corn, peanut, olivewaste vegetable	Gas chromatography
Castor oil	Size exclusion chromatography (SEC)

Higher composition of saturated fatty acids in feedstock will increase the oxidation stability of biodiesel but will lower its cloud and pour point. Whereas, higher composition of unsaturated fatty acids will enhance the cloud point and pour point of biodiesel but will have poor oxidation stability. Hence, a balance has to be maintained between the ratio of saturates and unsaturated for the oil to be used as a feedstock for biodiesel productions. (40)

Transesfericaton is the process successfully employed at present to reduce the viscosity and improve biodiesel characteristics. BHA showed very good physical adaption and was one of the most effective antioxidants screened. It is more volatile than TBHQ or PrG but should be suitable as long as storage temperatures are kept low. TBHQ showed good physical adaption for loadings up to 3000ppm before blending. PrG showed good physical adaption for loadings up to 1000ppm before blending and was among the most effective antioxidants screened. Its relatively poor stability in vegetable oil derivatives may decrease its suitability for blends with higher SME ratios. More soluble gallate esters may be used as an alternative. BHT showed relatively poor physical compability but was one of most effective antioxidant screened in this work. It may be more suitable when used in relatively small loadings (below 210 ppm after blending). A-Tocopherol showed very good physical compability in blends but was the least effective of the five antioxidants screened in this work. (45)By using frying oil it will increase the purity and decrease the viscosity of biodiesel oil.

Biodiesel as an alternative fuel for diesel engine is easier from the engineering point of view as it does not require extensive engine modification. Many engine problems are experienced while using raw vegetables oils as fuel, like coking of injectors and head of engine, excessive engine wear. Malaysia are respectively largest producers of palm oil in the world and contributes major contribution in world's palm oil. Waste edible oil is another source of biodiesel. Malaysia producers about 0.5 million tons of waste cooking oil every year. (19) The result suggested that high temperature, together with air exposure, greatly increase the biodiesel degradation rate. The temperature or air exposure alone, however, had little effect on biodiesel degradation. Water content in biodiesel will enhance biodiesel degradation due to its effect is much less than the above two factors.

Some of the articles stated that all of these particles emission characteristics varied significantly with engine condition. Biodiesel emissions were shown to be cleaner than petroleum diesel at higher engine load (100% and 75%) due to decrease in PM2.5 mass emission rate.(51)Emulsified palm-biodiesel with bio-solution can simultaneously save energy and reduce pollutants. Since more fine particles were generated when combustion is more complete, the size distributions of particles emitted from emulsified fuels deserve future investigation.(52)

In the current study a two-stage process, consisting of two reactions steps with glycerin separation and ethanol/catalyst addition in each of them was optimized for the production of ethyl esters, was implemented to increase the reaction conversion and thus achieve values required by the EN 14214. Several catalyst and reaction conditions were used for the optimization of the production process. (57)

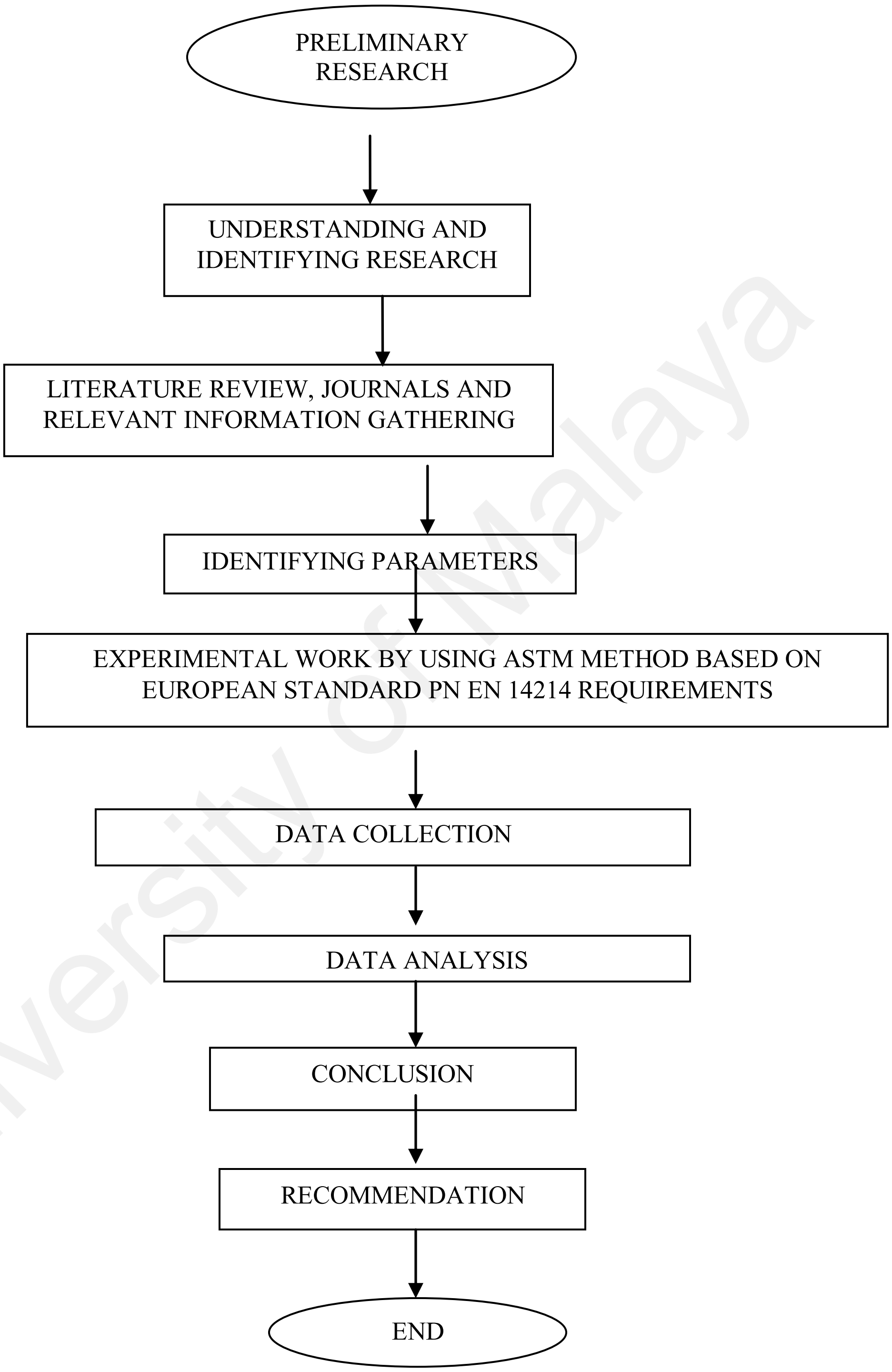
CHAPTER III

METHODOLOGY

3.0 Introductions

This chapter introduced the process required to achieve the objective of this project. It discuss mainly about the method and procedures to accomplish the study. It also includes a collection of theories, concepts or ideas as they relate to a particular discipline or field of inquiry. For this study,

3.1 Research Methodology Flow Chart



3.2 Methods and materials of the experimental studies

Table 3.1 : Characteristics of FAME in relation to European standard PN EN 14214 requirements (8)

Property **Unit**	Limits	**Testing method**
Fatty acids methyl esters content, *%(m/m)*	min. 96,5	PN EN 14103
Density at 15°C, kg/m^3	min. 860 max. 900	PN EN ISO 12185
Kinematic viscosity at 40 °C, mm^2/s	min.3,50 max. 5,00	PN EN ISO 3104
Flash point, °C	min. 120	PN EN ISO 3679
Sulphur content, mg/kg	max. 10	PN EN ISO 20846
Cetane number	min. 51,0	PN EN ISO 5165
Sulphated ash content, *%(m/m)*	max. 0,02	PN ISO 3987
Water content, mg/kg	max. 500	PN EN ISO 12937
Total contamination, mg/kg	max. 24	PN EN 12662
Copper strip corrosion (3h at 50°C)	1	PN EN ISO 2160
Oxidation stability at 110 °C, h	min. 6,0	PN EN 14112
Acid value, mg KOH/g	max. 0,50	PN EN 14104
Methanol content, *%(m/m)*	max. 0,20	PN EN 14110
Monoglyceride content, *%(m/m)*	max. 0,80	PN EN 14105
Diglyceride content, *%(m/m)*	max. 0,20	PN EN 14105
Triglyceride content, *%(m/m)*	max. 0,20	PN EN 14105
Free glycerol, *%(m/m)*	max. 0,02	PN EN 14105
Total glycerol, *%(m/m)*	max. 0,25	PN EN 14105
Group I metals (Na+K), mg/kg	max. 5,0	PN EN 14108 PN EN 14109
Group II metals (Ca+Mg), mg/kg	max. 5,0	PN EN 14538
Phosphorus content, mg/kg	max. 10,0	PN EN 14107

3.3 Experimental Procedures.

For this research report, six types of samples been used that consist of palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil. For the each experimental work that will be done, need to be stored in 12 weeks and each week the data need to be collected for the density, viscosity, flash point, total acid number and total base number. Then from the 12 weeks of data, the average value and the reaction the biodiesel will be studied, providing precise and more accurate result for this research report. The experimental work will be conducted in Tribology Laboratory in Faculty Of Engineering, University of Malaya.

3.3.1 PN EN ISO 12185

ASTM D4052-09 Standard Test Method for Density and Relative Density of Liquids by Digital Density Meter. PN-EN ISO 12185:2002 Crude petroleum and petroleum products -- Determination of density -- Oscillating U-tube method.

Figure 3.1: DMA4500 Digital density meter (71)

3.3.2 PN EN ISO 3104

ASTM D445-11 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity). PN-EN ISO 3104:2004 Petroleum products. Transparent and opaque liquids. Determination of kinematic viscosity and calculation of dynamic viscosity

Figure 3.2: AVS 440 and AVS450 viscometers with CT1450 thermostatic bath (71)

3.3.3 PN EN ISO 367

ASTM D3828-09 Standard Test Method for Flash-Point by Small Scale Closed Cup Tester. PN-EN ISO 3679:2007 Determination of flash point -Rapid equilibrium closed cup method

Figure 3.3: SETA FLASH Series 3+(71)

3.3.4 PN EN 14104

PN-EN 14104:2004 Fat and oil derivatives - Fatty Acid Methyl Esters (FAME) - Determination of sodium content by atomic absorption spectrometry.

Figure 3.4: PE 3030B AA Spectrometer (71)

3.3.5 ASTM D974-06

ASTM D974-06 Standard Test Method for Acid and Base Number by Color-Indicator Titration.PN-85/C-04066 Petroleum products. Determination of acid and base number by color-indicator titration.ASTM D3242-05 Standard Test Method for Acidity in Aviation Turbine Fuel.

CHAPTER IV

RESULTS

4.0 Introduction

The results of different type of biodiesel are being analyzed and investigated in this chapter. The experimental work is constructed based on the parameter of ASTM method. The model is being test in tribology laboratory at faculty of engineering.

To determine the best and most desirable biodiesel to be used in market, several aspect been taken into count such as the density, viscosity, flash point, total acid number and total base number to observe the output. The experiment will be conduct based on the American Standard Testing Method (ASTM) with six type of biodiesel that consist of palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil.

4.1 Obtaining Data and Graph of Several Type of Biodiesel

4.1.1 Introduction and Capabilities

Samples of FAME and FAME with six types of biodiesel sample were tested for oxidation stability using Rancimat and bomb methods. The ddensity, viscosity, flash point, total acid number and total base number were determined before and after ASTM test. Results of ASTM test are shown in Table as below and so on. All the data had been plotted in graph for each relationship which coincides with storage time for six type of biodiesel that consist of palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil.

4.1.2 Relationship between Density and Storage Time.

To determine the density factor, the perfect testing method been used is PN EN ISO 12185 and the result was tabulated as below from April 2011 to November 2011 (6 months).

Table 4.1: Mass Of 25ml Beaker (unit: gram)

	reading						
	1	2	3	4	5	6	average
mass of 25ml beaker	20.8174	20.8172	20.8175	20.8174	20.8174	20.8175	**20.8174**

For complete table of mass of 25ml samples can be referring to Appendix B.

Table 4.2: Mass Of 25ml Samples (unit: gram)

	week	15.4.11				30.4.11				30.11.11			
No.	samples	1	2	3	average	1	2	3	average	1	2	3	average
1	Palm oil	37.7164	37.7162	37.7162	37.7163	37.7234	37.7234	37.7235	37.7234	37.77	37.779	37.775	37.7747
2	Palm oil biodiesel	37.6123	37.6121	37.6121	37.6122	37.6137	37.6138	37.6137	37.6137	37.696	37.696	37.691	37.6943
3	Diesel	37.1537	37.1535	37.1537	37.1536	37.1551	37.1549	37.1549	37.1550	37.225	37.2248	37.2256	37.2251
4	Jatropha oil	38.1015	38.1015	38.1013	38.1014	38.1024	38.1021	38.1024	38.1023	38.1403	38.1408	38.1403	38.1405
5	Jatropha oil biodiesel	37.7699	37.7697	37.7693	37.7696	37.7731	37.7731	37.7731	37.7731	37.8089	37.8081	37.8082	37.8084
6	Coconut oil	37.6879	37.6882	37.6880	37.6880	37.6911	37.6912	37.6911	37.6911	37.9303	37.9301	37.931	37.9305

Table 4.3: Density of Biodiesel Sample (unit= kgm^{-3})

No.	samples	15.4.11	30.4.11	15.5.11	31.5.11	15.6.11	30.6.11	15.7.11	31.7.11	14.8.11	31.8.11	16.9.11	30.9.11	16.10.11	31.10.11	13.11.11	30.11.11
1	Palm oil	844.943	845.302	845.572	845.758	846.117	846.255	846.653	846.812	846.94	847.048	847.078	847.127	847.55	847.835	847.298	847.863
2	Palm oil biodiesel	839.738	839.817	840.135	840.25	840.727	840.647	841.627	841.76	842.07	842.157	842.227	843.385	843.657	843.632	843.663	843.847
3	Diesel	816.812	816.879	817.107	817.197	817.415	817.86	818.64	819.288	819.797	820.022	820.065	820.288	820.307	820.308	820.352	820.387
4	Jatropha oil	864.202	864.245	864.417	864.617	864.802	865.132	865.52	865.62	865.743	865.845	866.002	866.067	866.078	866.087	866.12	866.153
5	Jatropha oil biodiesel	847.612	847.785	848.137	848.458	848.688	849.012	848.257	848.633	849.015	849.077	849.413	849.483	849.483	849.495	849.515	849.55
6	Coconut oil	843.532	843.687	845.743	846.198	846.528	849.553	849.688	850.022	850.743	852.943	854.688	855.453	855.512	855.515	855.55	855.653

For analyzing purpose a scatter type graph had been plotted for graph of density versus storage time for palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil as in figure 4.1.

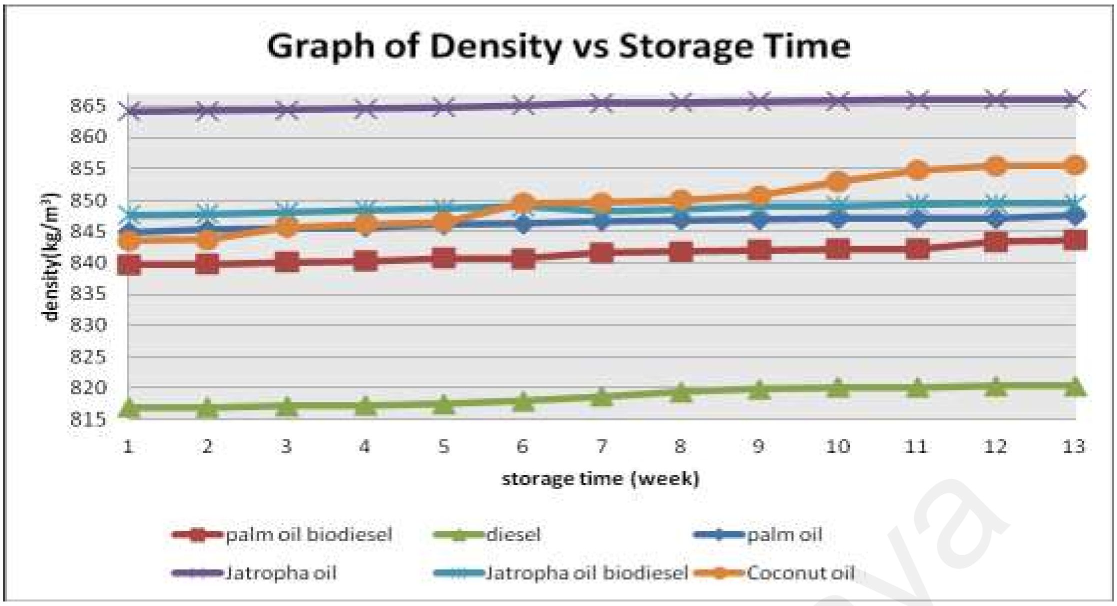


Figure 4.1: Graph of Density versus Storage Time

4.1.3 Relationship between Viscosity and Storage Time.

To determine the viscosity factor, the perfect testing method been used is PN EN ISO 3104 and the result was tabulated as below from April 2011 to November 2011 (6 months). For complete table of viscosity of biodiesel sample can be referring to Appendix C.

Table 4.4: Viscosity of Biodiesel Sample

sample	bath	sample number	15.4.11 time	15.4.11 viscosity	30.4.11 time	30.4.11 viscosity	13.11.11 time	13.11.11 viscosity	30.11.11 time	30.11.11 viscosity
palm oil	100°C	A1	6.33	5.433	4.2	5.477	10.11	7.76	9.21	8.02
		A2	5.12	5.672	7.129	6.03	7.69	8.117	5.33	8.319
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	5.56	5.399	5.502	5.597	6.31	7.667	5.04	7.814
	40°C	B1	7.45	3.676	8.35	3.681	8.09	6.027	7.63	6.11
		B2	4.56	3.521	9.77	3.75	6.11	6.03	4.98	6.12
		B3	1.03	3.074	3.56	3.09	3.97	5.223	3.01	5.276
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Palm oil biodiesel	100°C	A1	7.35	6.55	6.97	6.34	6.66	7.852	7.47	7.859
		A2	3.39	4.398	6.44	4.42	9.04	5.477	6.91	5.568
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	1.29	4.973	1.3	5.113	6.82	6.119	5.502	6.137
	40°C	B1	8.57	3.574	8.84	3.564	9.03	5.4	9.81	5.577
		B2	6.96	3.129	4.74	3.213	10	4.866	8.63	5.072
		B3	2.45	2.977	4.97	3.287	2.93	4.513	7.45	4.918
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Diesel	100°C	A1	17.98	3.944	11.83	3.949	10.92	5.167	4.92	5.173
		A2	10.08	1.129	9.11	1.188	8.91	2.397	9.92	2.719
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	1.47	1.021	1.09	1.039	1.05	1.412	1.07	1.437
	40°C	B1	15.77	2.976	6.89	3.028	4.689	4.027	7.63	4.033
		B2	9.76	2.643	6.82	2.703	4.56	2.997	6.96	3.163
		B3	2.93	1.765	7.99	1.769	5	2.571	3.97	2.623
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Jatropha oil	100°C	A1	11.07	1.227	11.3	1.33	8.09	1.811	9.71	1.833
		A2	6.73	1.926	6.98	2.04	8.11	2.65	7.86	2.712
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	1.27	1.463	4.92	1.469	7.92	2.824	6.59	3.3
	40°C	B1	16.78	3.017	11.24	3.148	8.09	3.901	10.11	3.92
		B2	8.5	2.76	6.11	2.819	4.56	3.468	7.33	3.573
		B3	2.93	3.794	3.97	4.021	11.94	5.526	3.01	5.537
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Jatropha oil biodiesel	100°C	A1	9.43	1.672	7.69	1.713	8.35	2.731	10.92	3.816
		A2	5.03	1.704	6.05	1.745	7.36	2.596	8.5	2.616
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	0.98	1.161	2	1.234	2.94	2.399	1.04	2.42
	40°C	B1	13.43	3.086	10.11	3.111	6.89	3.717	11.1	3.798
		B2	5.17	4.155	4.49	4.295	6.96	4.823	7.33	4.841
		B3	1.3	3.521	1.26	3.608	10.3	5.239	6.96	5.25
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Coconut oil	100°C	A1	16.42	8.23	17.69	8.297	9.07	8.899	8.09	8.911
		A2	15.59	8.67	6.44	8.738	3.97	9.807	11.38	9.93
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	6.04	7.156	7.49	7.247	8.92	7.943	1.05	7.962
	40°C	B1	12.69	7.175	5.73	7.218	4.92	8.589	9.43	8.609
		B2	11.41	7.317	4.56	7.333	1.26	7.644	3.01	7.807
		B3	14.21	6.941	1.27	7.221	11.54	7.669	6.96	7.633
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

For analyzing purpose a scatter type graph had been plotted for graph of viscosity at 40°C versus storage time for palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil as in figure 4.2.

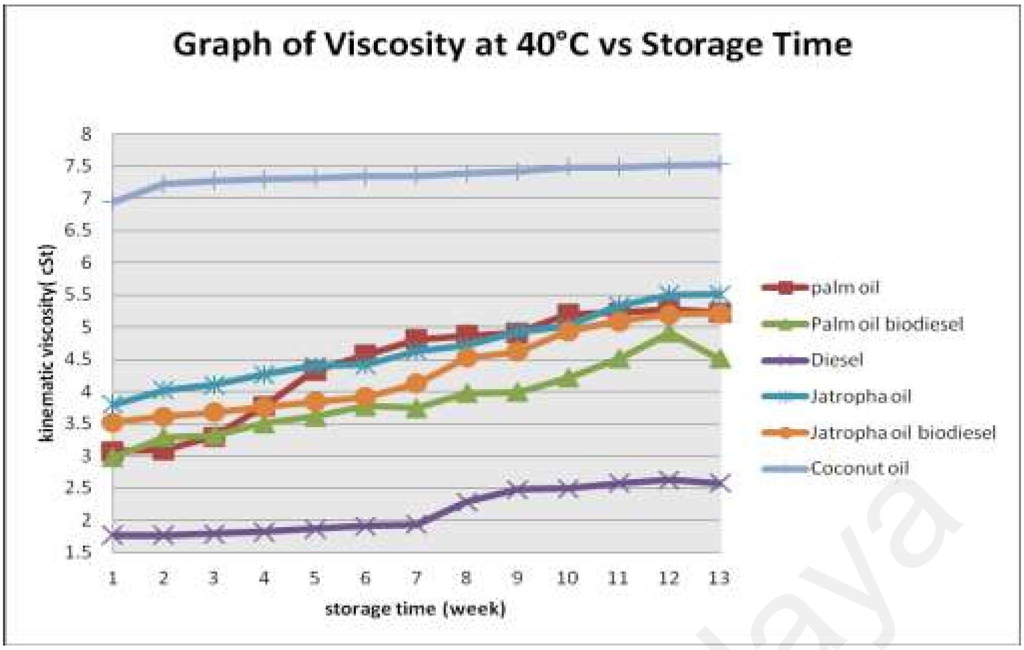


Figure 4.2: Graph of Viscosity at 40°C versus Storage Time

For analyzing purpose a scatter type graph had been plotted for graph of viscosity at 100°C versus storage time for palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil as in figure 4.3.

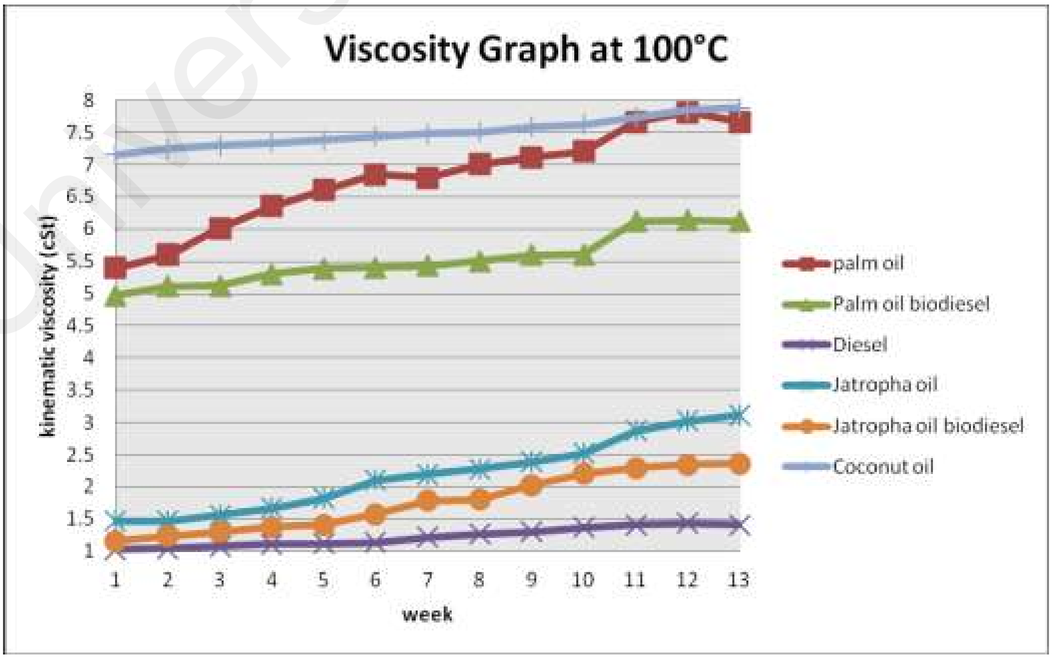


Figure 4.3: Graph of Viscosity at 100°C versus Storage Time

4.1.4 Relationship between Flash Point and Storage Time.

To determine the flash point factor, the perfect testing method been used is PN EN ISO 3679 and the result was tabulated as below from April 2011 to November 2011 (6 months).

Table 4.5: Flash Point of Biodiesel Sample

		flash point (°C)															
	samples	15.4.11	30.4.11	15.5.11	31.5.11	15.6.11	30.6.11	15.7.11	31.7.11	14.8.11	31.8.11	16.9.11	30.9.11	16.10.11	31.10.11	13.11.11	30.11.11
1	Palm oil	258	258	257	259	256	254	253	253	250	251	248	247	246	245	244	242
2	Palm oil biodiesel	194	186	184	186	183	185	177	178	173	174	171	170	169	169	167	166
3	Diesel	74	78	77	72	69	72	70	67	68	67	65	64	63	62	60	59
4	Jatropha oil	237	236	234	232	233	232	231	230	228	226	224	224	223	222	221	221
5	Jatropha oil biodiesel	205	204	204	203	202	201	198	196	195	191	187	188	186	184	182	181
6	Coconut oil	240	237	229	231	228	224	221	221	217	214	209	208	207	206	203	199

For analyzing purpose a scatter type graph had been plotted for graph of flash point versus storage time for palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil as in figure 4.4.

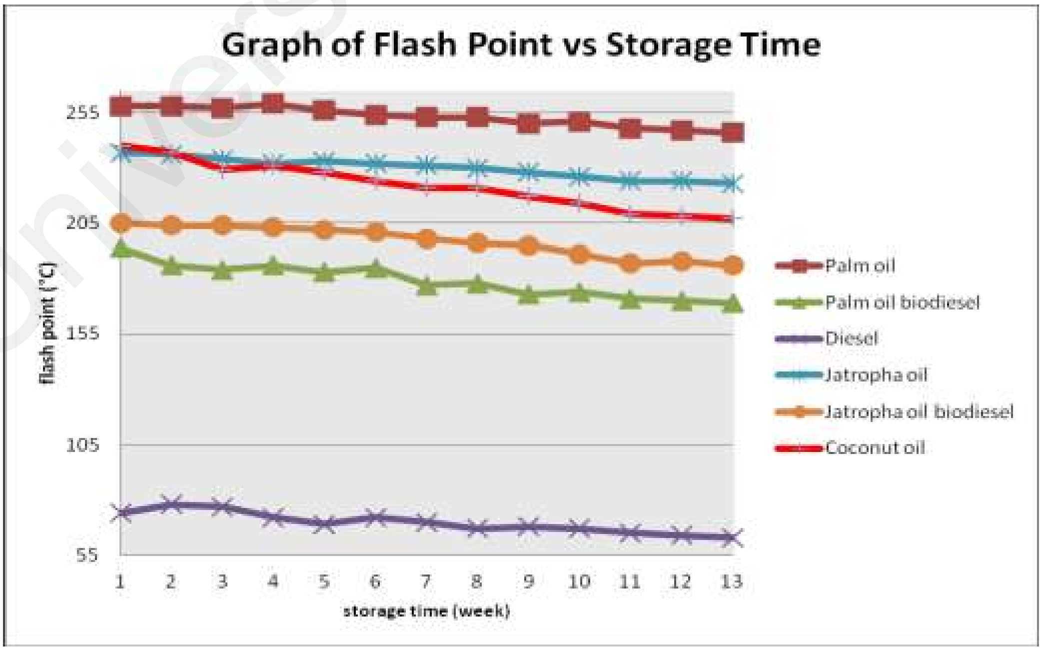


Figure 4.4: Graph of Flash Point versus Storage Time

4.1.5 Relationship between Total Acid Number (TAN) and Storage Time.

To determine the total acid number factor, the perfect testing method been used is PN EN 14104 and the result was tabulated as below from April 2011 to November 2011 (6 months). For complete table of total number of acid of biodiesel sample can be referring to Appendix D.

Table 4.6: Total Acid Number (TAN) of Biodiesel Sample

samples	15.4.11		30.4.11		30.11.11	
	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)
Palm oil	1.46	3.6325	1.46	3.4751	1.81	3.1463
Palm oil biodiesel	2.56	3.8836	2.57	3.4221	2.98	3.7016
Diesel	0.27	4.0428	0.28	3.972	0.67	4.2003
Jatropha oil	1.03	3.5613	1.03	3.0356	1.46	3.8063
Jatropha oil biodiesel	1.21	3.0441	1.23	3.7977	1.61	3.208
Coconut oil	4.05	3.0974	4.06	3.5824	4.77	3.1053

For analyzing purpose a scatter type graph had been plotted for graph of total number acid versus storage time for palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil as in figure 4.5.

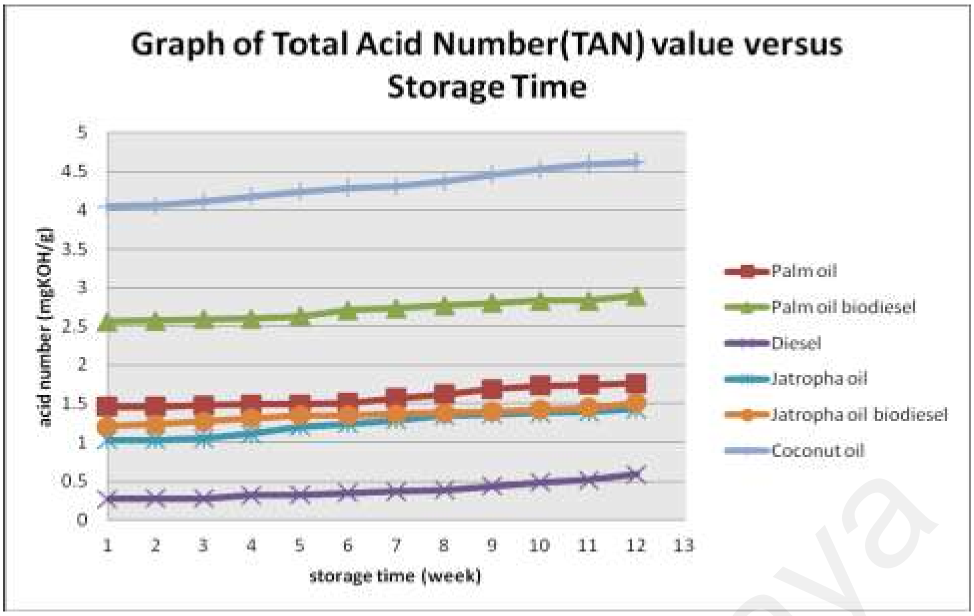


Figure 4.5: Graph of Total Acid Number (TAN) versus Storage Time

4.1.6 Relationship between Total Base Number (TBN) and Storage Time.

To determine the total base number factor, the perfect testing method been used is PN EN ISO 12937 and the result was tabulated as below from April 2011 to November 2011 (6 months). For complete table of total number of acid of biodiesel sample can be reefed to Appendix E.

Table 4.7: Total Base Number (TBN) of Biodiesel Sample

samples	15.4.11		30.4.11		30.11.11	
	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)
Palm oil	12.27	4.0356	12.27	3.7219	11.48	3.1511
Palm oil biodiesel	12.49	3.8251	12.48	3.9255	11.89	3.6429
Diesel	13.31	4.0217	13.29	4.112	12.95	3.9975
Jatropha oil	8.86	3.115	8.87	3.1081	8.25	3.6732
Jatropha oil biodiesel	11.94	3.9124	11.94	3.122	11.24	3.1426
Coconut oil	7.82	3.679	7.81	3.6434	6.52	3.1359

For analyzing purpose a scatter type graph had been plotted for graph of total number base versus storage time for palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil as in figure 4.6.

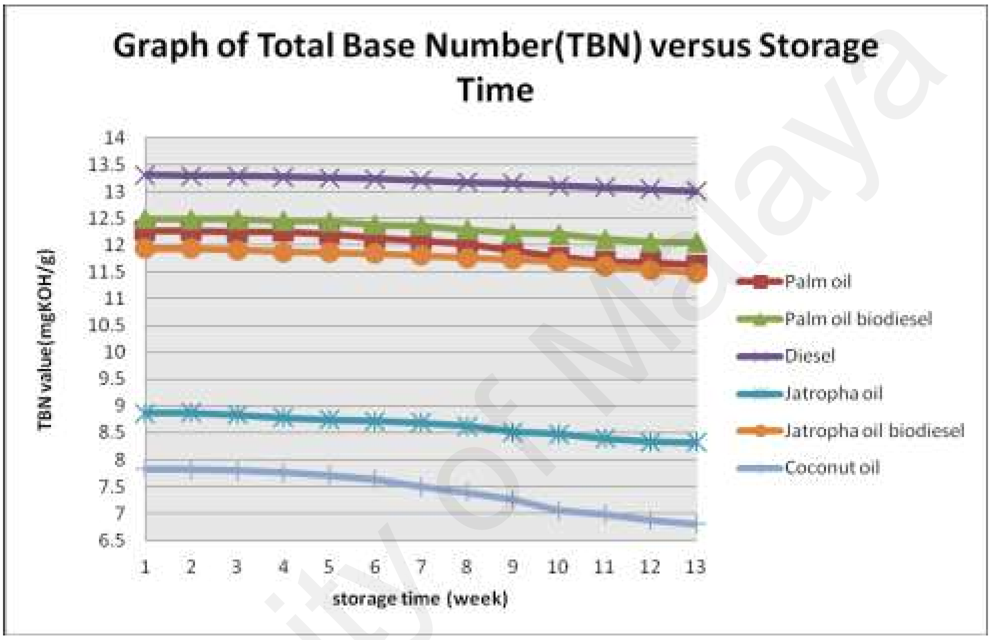


Figure 4.6: Graph of Total Base Number versus Storage Time

CHAPTER V

DISCUSSION

5.0 Introduction

This chapter will discuss more on the findings of the research project and the interpretation of results that had been obtained by application of American Standard Testing Method for six type of biodiesel that consist of palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil.

5.1 Discussion

From the graph density versus storage time, the highest density is jatropha oil and the lowest density is diesel. From graph viscosity at temperature 40°C the lowest are diesel and then followed by palm oil diesel and jatropha oil diesel. This shows that palm oil biodiesel has lowest oxidation rate. The coconut oil is not suitable to be used as engine oil because the oxidation rate is higher. But when the biodiesel sample was tested with 100°C, the graph viscosity at temperature 40°C shows for the most lowest is jatropha oil biodiesel diesel. This shows when the temperatures increases the jatropha oil can withstand higher temperature and can be best used as engine oil because the engine needs oil that can withstand higher temperature in engine during driving or cursing.

From the graph flash point versus storage time, the lowest flash point is biodiesel at 75°C that means the flash point of a volatile material is the lowest temperature at which it can vaporize to form an ignitable mixture in air. The flash point is not to be confused with the auto ignition temperature, which does not require an ignition source, or the fire point, the temperature at which the vapour continues to burn after being ignited. Neither the flash point nor the fire point is dependent on the temperature of the ignition source, which is much higher.

The lowest acid number was biodiesel and following by jatropha oil and pure palm oil. The highest acid number was coconut oil and following by palm oil with biodiesel. It shows that, higher acid value show that the biodiesel is easy to oxidize. The biofuel sample jatropha oil displayed the lowest degradation as its peroxide value and acid number showed the lowest growth and was also observed which indicated the highest growth of acidic products of degradation process.

Highest base number was diesel and following by palm oil diesel and jatropha with biodiesel. The lowest was coconut oil and jatropha oil. Total base number is a measure of reserve alkaline additives put into lubricants to neutralize acids, to retard oxidation and corrosion, enhance lubrication, improve viscosity characteristics and reduce the tendency of sludge build-up. Simply put, it is a test to measure the ability to neutralize corrosive acids that may be formed during normal operation Total base number is a measure of reserve alkaline additives put into lubricants to neutralize acids, to retard oxidation and corrosion, enhance lubricity, improve viscosity characteristic and reduce the tendency of sludge build up. Simply put, it is a test to measure the ability to neutralize corrosive acids that may be formed during normal operation.

CHAPTER VI

CONCLUSION

6.0 Introduction

This chapter covers the conclusion and recommendation for the overall study on American Standard Testing Method for six type of biodiesel that consist of palm oil, palm oil biodiesel, diesel, Jatropha oil, Jatropha oil biodiesel and coconut oil. The objective as well as the analysis results will be concluded. Thus, suitable suggestions and recommendations will be provided for further research purpose.

6.1 Conclusion

FAME is a product which needs a special protection against oxidation process especially at higher temperatures. The suitable biodiesel that can be used for consideration for alternative renewable energy would be jatropha biodiesel. Jatropha biodiesel good in thermal stability, can maintain fuel properties in higher temperature, low acid value, low density, has a higher total base number, low viscosity which indicates that jatropha biodiesel is thermally stable and has a longer period of oxidation rate. Palm oil with biodiesel also can be used as alternative but further studies required due to higher acid number.

Biodiesel is its poor oxidation stability. Oxidation can alter the physical and chemical properties of fuel such as it can cause acidity and increasing viscosity due to formation of insoluble gums that can plug fuel filters. Temperature and concentration affect the antioxidant stability of biodiesel. This research studies also suggested that biodiesel fuel should be stored at lower temperature is favorable for long time storage of biodiesel without degradation. Since the storage conditions could greatly affect stability of biodiesel. Hence, a balance has to be maintained between the ratio of saturates and unsaturated for the oil to be used as a feedstock for biodiesel productions.

Other than that, for palm oil, transesfericaton is the process successfully employed at present to reduce the viscosity and improve in biodiesel characteristics. By using frying oil it will increase the purity and decrease the viscosity of biodiesel oil.

This thesis applies the knowledge of mechanical engineering, energy efficiency, energy renewable, fuel technologies and some software skills such as European Standard Requirement and ASTM method which is very useful because it is a stepping stone to move forward in research involvement for either postgraduates or professional developments.

In future research, it should be used other type of oil such as soya bean oil, rapeseed oil, fried oil, waste oil to identify much more suitable type of oil to be used in engine that consume fuel. Waste oils should be taking into consideration to create a recycling environment and reduce green house effects. It will open a gateway to other research area related to the environmental and health analysis of the biodiesel fuel to environment.

This research also creates an opportunities to work together with Malaysian Biodiesel Power Plant such as in Sime Darby Biodiesel Plant and others company. Based on “1 Malaysia” and “Belilah Barangan Buatan Malaysia” slogan, this research paper can be used as a stepping stone in manufacturing a new solution and modification in existing biodiesel power plant which can compete with other develop country in market if a better biodiesel fuel been producing in future. Last not least, after this experiment, the studies should be continue in adding additives such as anti oxidant to increase thermal stability and lengthen the oxidation rate for further development.

APPENDIX A

Table of Density of Biodiesel Sample (unit= kgm^{-3})

	week	15.4.11				30.4.11				15.5.11				31.5.11			
No.	samples	1	2	3	average	1	2	3	average	1	2	3	average	1	2	3	average
1	Palm oil	37.7164	37.7162	37.7162	37.7163	37.7234	37.7234	37.7235	37.7234	37.7289	37.7287	37.7289	37.7288	37.7326	37.7326	37.7325	37.7326
2	Palm oil biodiesel	37.6123	37.6121	37.6121	37.6122	37.6137	37.6138	37.6137	37.6137	37.6201	37.62	37.6202	37.6201	37.6225	37.6223	37.6224	37.6224
3	Diesel	37.1537	37.1535	37.1537	37.1536	37.1551	37.1549	37.1549	37.1550	37.1596	37.1595	37.1595	37.1595	37.1613	37.1613	37.1614	37.1613
4	Jatropha oil	38.1015	38.1015	38.1013	38.1014	38.1024	38.1021	38.1024	38.1023	38.1058	38.1058	38.1056	38.1057	38.1098	38.1097	38.1097	38.1097
5	Jatropha oil biodiesel	37.7699	37.7697	37.7693	37.7696	37.7731	37.7731	37.7731	37.7731	37.7802	37.7801	37.7801	37.7801	37.7867	37.7865	37.7865	37.7866
6	Coconut oil	37.6879	37.6882	37.6880	37.6880	37.6911	37.6912	37.6911	37.6911	37.7324	37.7321	37.7323	37.7323	37.7414	37.7414	37.7413	37.7414

15.6.11				30.6.11				15.7.11				31.7.11				14.8.11				31.8.11			
1	2	3	average	1	2	3	average	1	2	3	average	1	2	3	average	1	2	3	average	1	2	3	average
37.7397	37.7397	37.7398	37.7397	37.7425	37.7425	37.7425	37.7425	37.7504	37.7505	37.7505	37.7505	37.7535	37.7537	37.7537	37.7536	37.7562	37.7562	37.7562	37.7562	37.7583	37.7584	37.7584	37.7584
37.6308	37.6309	37.6341	37.6319	37.641	37.609	37.641	37.6303	37.6499	37.6501	37.6498	37.6499	37.6526	37.6526	37.6526	37.6526	37.6588	37.6588	37.6588	37.6588	37.6604	37.6607	37.6605	37.6605
37.1657	37.1657	37.1657	37.1657	37.1746	37.1746	37.1746	37.1746	37.1901	37.1903	37.1902	37.1902	37.2031	37.2031	37.2033	37.2032	37.2134	37.2132	37.2134	37.2133	37.2178	37.2178	37.2179	37.2178
38.1134	38.1135	38.1134	38.1134	38.1201	38.12	38.12	38.1200	38.1278	38.1278	38.1278	38.1278	38.1299	38.1297	38.1298	38.1298	38.1322	38.1324	38.1322	38.1323	38.1343	38.1343	38.1343	38.1343
37.7913	37.7911	37.7911	37.7912	37.7977	37.7976	37.7976	37.7976	37.7825	37.7825	37.7826	37.7825	37.7901	37.79	37.7901	37.7901	37.7977	37.7977	37.7977	37.7977	37.7989	37.799	37.7989	37.7989
37.748	37.7479	37.748	37.7480	37.8085	37.8085	37.8084	37.8085	37.8111	37.8113	37.8111	37.8112	37.8179	37.8178	37.8178	37.8178	37.8324	37.8322	37.8322	37.8323	37.8799	37.8701	37.8788	37.8763

16.9.11				30.9.11				16.10.11				31.10.11				13.11.11				30.11.11			
1	2	3	average	1	2	3	average	1	2	3	average	1	2	3	average	1	2	3	average	1	2	3	average
37.7589	37.759	37.759	37.7590	37.7598	37.76	37.76	37.7599	37.7602	37.756	37.789	37.7684	37.7613	37.772	37.789	37.7741	37.763	37.763	37.7641	37.7634	37.77	37.779	37.775	37.7747
37.662	37.6619	37.6619	37.6619	37.685	37.6852	37.6851	37.6851	37.689	37.6923	37.6903	37.6905	37.691	37.69	37.6891	37.6900	37.693	37.689	37.69	37.6907	37.696	37.696	37.691	37.6943
37.2187	37.2187	37.2187	37.2187	37.2231	37.2233	37.2231	37.2232	37.2235	37.2235	37.2236	37.2235	37.2236	37.2235	37.2236	37.2236	37.2242	37.2245	37.2246	37.2244	37.225	37.2248	37.2256	37.2251
38.1374	38.1375	38.1374	38.1374	38.1387	38.1386	38.1389	38.1387	38.1389	38.1389	38.1391	38.1390	38.1391	38.1392	38.1391	38.1391	38.1399	38.1397	38.1398	38.1398	38.1403	38.1408	38.1403	38.1405
37.8057	37.8057	37.8056	37.8057	37.8069	37.8071	37.8072	37.8071	37.8071	37.8069	37.8072	37.8071	37.8073	37.8074	37.8072	37.8073	37.8079	37.808	37.8072	37.8077	37.8089	37.8081	37.8082	37.8084
37.9111	37.9112	37.9112	37.9112	37.9265	37.9265	37.9264	37.9265	37.9275	37.9278	37.9276	37.9276	37.9278	37.9276	37.9277	37.9277	37.9289	37.928	37.9283	37.9284	37.9303	37.9301	37.931	37.9305

APPENDIX B

Table of Flash Point of Biodiesel Sample

sample	bath	sample number	15.4.11		30.4.11		15.5.11		31.5.11		15.6.11		30.6.11	
			time	viscosity	time	viscosity	time	viscosity	time	viscosity	time	viscosity	time	viscosity
palm oil	100°C	A1	6.33	5.433	4.2	5.477	9.663	6.174	5.44	6.513	6.92	7.208	8.921	7.48
		A2	5.12	5.672	7.129	6.03	8.72	6.612	8.92	6.835	7.1	7.176	7.33	7.634
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	5.56	5.399	5.502	5.597	5.49	6.012	11.27	6.35	9.022	6.605	6.09	6.847
	40°C	B1	7.45	3.676	8.35	3.681	7.11	3.778	4.689	3.812	7.53	4.22	9.32	4.897
		B2	4.56	3.521	9.77	3.75	3.02	3.499	5.91	3.931	4.29	4.291	7.4	4.511
		B3	1.03	3.074	3.56	3.09	5.89	3.294	1.46	3.773	2.69	4.323	1	4.57
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Palm oil biodiesel	100°C	A1	7.35	6.55	6.97	6.34	7.04	7.113	16.78	7.129	10.32	7.197	6.89	7.254
		A2	3.39	4.398	6.44	4.42	8.11	4.76	6.81	4.88	6.96	5.104	4.88	4.911
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	1.29	4.973	1.3	5.113	1.07	5.121	2.39	5.304	6.97	5.393	2.01	5.406
	40°C	B1	8.57	3.574	8.84	3.564	4.92	3.602	5.68	3.717	8.09	3.815	7.09	4.18
		B2	6.96	3.129	4.74	3.213	7.69	3.251	4.56	3.418	7.33	3.5	8.72	3.611
		B3	2.45	2.977	4.97	3.287	5.93	3.317	10.91	3.503	4.92	3.613	2.93	3.774
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Diesel	100°C	A1	17.98	3.944	11.83	3.949	9.67	4.112	6.84	4.398	6.83	4.399	8.35	4.467
		A2	10.08	1.129	9.11	1.188	3.02	1.2	11.08	1.295	14.21	1.341	7.81	1.387
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	1.47	1.021	1.09	1.039	1.84	1.076	5.93	1.109	5.98	1.111	3.05	1.135
	40°C	B1	15.77	2.976	6.89	3.028	8.35	3.103	6.33	3.115	7.53	3.197	4.63	3.247
		B2	9.76	2.643	6.82	2.703	14.21	2.719	8.11	2.769	9	2.813	8.5	2.819
		B3	2.93	1.765	7.99	1.769	11.21	1.792	9.21	1.819	7.86	1.865	5.87	1.913
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Jatropha oil	100°C	A1	11.07	1.227	11.3	1.33	7.63	1.362	10.73	1.422	4.689	1.463	9.43	1.533
		A2	6.73	1.926	6.98	2.04	6.05	2.173	3.02	2.198	1.26	2.208	6.05	2.254
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	1.27	1.463	4.92	1.469	1.05	1.562	6.59	1.663	8.92	1.819	7.92	2.104
	40°C	B1	16.78	3.017	11.24	3.148	8.35	3.184	10.11	3.285	7.04	3.362	8.09	3.419
		B2	8.5	2.76	6.11	2.819	7.38	2.887	7.33	2.937	6.05	3.004	4.56	3.102
		B3	2.93	3.794	3.97	4.021	4.92	4.105	3.01	4.266	7.59	4.402	11.94	4.417
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Jatropha oil biodiesel	100°C	A1	9.43	1.672	7.69	1.713	8.85	1.765	10.92	1.822	8.85	1.923	8.35	1.976
		A2	5.03	1.704	6.05	1.745	8.72	1.827	8.5	1.947	6	2.137	7.36	2.201
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	0.98	1.161	2	1.234	3.2	1.296	1.04	1.377	5.502	1.409	2.94	1.573
	40°C	B1	13.43	3.086	10.11	3.111	4.63	3.168	11.1	3.273	6.73	3.289	6.89	3.316
		B2	5.17	4.155	4.49	4.295	6.11	4.381	7.33	4.469	4.56	4.492	6.96	4.513
		B3	1.3	3.521	1.26	3.608	8.5	3.677	6.96	3.757	11.9	3.842	10.3	3.918
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Coconut oil	100°C	A1	16.42	8.23	17.69	8.297	13.22	8.31	8.09	8.336	8.35	8.329	9.07	8.472
		A2	15.59	8.67	6.44	8.738	1.49	8.811	11.38	8.884	7.86	8.913	3.97	8.975
		A3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		A4	6.04	7.156	7.49	7.247	10.7	7.295	1.05	7.339	5.92	7.381	8.92	7.442
	40°C	B1	12.69	7.175	5.73	7.218	8.35	7.269	9.43	7.322	7.63	7.391	4.92	7.444
		B2	11.41	7.317	4.56	7.333	7.86	7.368	3.01	7.391	3.02	7.426	1.26	7.472
		B3	14.21	6.941	1.27	7.221	3.97	7.273	6.96	7.295	4.94	7.318	11.54	7.336
		B4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table of Flash Point of Biodiesel Sample

15.7.11		31.7.11		14.8.11		31.8.11		16.9.11		30.9.11		16.10.11		31.10.11		13.11.11		30.11.11	
time	viscosity	time	viscosity	time	viscosity	time	viscosity	time	viscosity	time	viscosity	time	viscosity	time	viscosity	time	viscosity	time	viscosity
6.97	7.603	11.75	7.573	12.97	7.61	8.57	7.74	10.11	7.76	9.21	8.02	10.11	7.76	9.21	8.02	10.11	7.76	9.21	8.02
5.93	7.713	8.57	7.881	11.69	8.062	9.1	8.113	7.69	8.117	5.33	8.319	7.69	8.117	5.33	8.319	7.69	8.117	5.33	8.319
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4.07	6.796	6.347	7.004	5.8	7.113	5.09	7.2	6.31	7.667	5.04	7.814	6.31	7.667	5.04	7.814	6.31	7.667	5.04	7.814
4.29	5.309	6.96	5.776	7.03	6.003	7.03	6.014	8.09	6.027	7.63	6.11	8.09	6.027	7.63	6.11	8.09	6.027	7.63	6.11
6.77	5.007	12.97	5.536	8.99	5.769	7.66	5.91	6.11	6.03	4.98	6.12	6.11	6.03	4.98	6.12	6.11	6.03	4.98	6.12
2.09	4.811	4.595	4.874	1.26	4.91	2.07	5.201	3.97	5.223	3.01	5.276	3.97	5.223	3.01	5.276	3.97	5.223	3.01	5.276
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4.63	7.284	9.03	7.499	7.04	7.69	4.92	7.732	6.66	7.852	7.47	7.859	6.66	7.852	7.47	7.859	6.66	7.852	7.47	7.859
14.21	5.13	6.75	5.218	6.96	5.398	7.86	5.412	9.04	5.477	6.91	5.568	9.04	5.477	6.91	5.568	9.04	5.477	6.91	5.568
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1.83	5.429	1.24	5.507	1.27	5.595	9.05	5.609	6.82	6.119	5.502	6.137	6.82	6.119	5.502	6.137	6.82	6.119	5.502	6.137
11.1	4.591	6.71	4.683	9.05	4.911	6.33	5.035	9.03	5.4	9.81	5.577	9.03	5.4	9.81	5.577	9.03	5.4	9.81	5.577
8.5	3.902	8.77	4.129	3.28	4.331	6.05	4.76	10	4.866	8.63	5.072	10	4.866	8.63	5.072	10	4.866	8.63	5.072
10.42	3.748	4.35	3.977	4.89	3.991	8.03	4.216	2.93	4.513	7.45	4.918	2.93	4.513	7.45	4.918	2.93	4.513	7.45	4.918
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6.11	4.491	8.13	4.52	7.04	4.721	9.43	5.023	10.92	5.167	4.92	5.173	10.92	5.167	4.92	5.173	10.92	5.167	4.92	5.173
3.02	1.51	1.26	1.53	2	1.763	6.44	1.93	8.91	2.397	9.92	2.719	8.91	2.397	9.92	2.719	8.91	2.397	9.92	2.719
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1.04	1.217	6.99	1.268	5.502	1.301	1.27	1.366	1.05	1.412	1.07	1.437	1.05	1.412	1.07	1.437	1.05	1.412	1.07	1.437
5.033	3.285	6.33	3.379	7.04	3.902	16.78	4.023	4.689	4.027	7.63	4.033	4.689	4.027	7.63	4.033	4.689	4.027	7.63	4.033
7.99	2.824	8.11	2.865	4.56	2.933	8.39	2.947	4.56	2.997	6.96	3.163	4.56	2.997	6.96	3.163	4.56	2.997	6.96	3.163
2.97	1.929	3.01	2.286	2.93	2.477	3.62	2.493	5	2.571	3.97	2.623	5	2.571	3.97	2.623	5	2.571	3.97	2.623
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13.22	1.571	6.89	1.609	10.11	1.654	5.84	1.736	8.09	1.811	9.71	1.833	8.09	1.811	9.71	1.833	8.09	1.811	9.71	1.833
1.26	2.301	7.33	2.384	8.72	2.484	14.21	2.513	8.11	2.65	7.86	2.712	8.11	2.65	7.86	2.712	8.11	2.65	7.86	2.712
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5.82	2.193	8.39	2.275	7.49	2.386	5.502	2.518	6.84	2.871	8.64	3.02	5.23	3.11	8.39	3.16	7.92	2.824	6.59	3.3
4.63	3.502	4.63	3.575	7.53	3.642	10.11	3.676	8.35	3.782	11.1	3.886	7.2	3.89	4.63	3.895	8.09	3.901	10.11	3.92
6.05	3.195	6.11	3.278	9.4	3.33	11.84	3.436	4.56	3.417	14.21	3.553	11.2	3.58	6.11	3.565	4.56	3.468	7.33	3.573
2.93	4.629	6.96	4.711	7.61	4.929	5.3	5.01	5.17	5.323	7.86	5.494	6.3	5.502	6.96	5.516	11.94	5.526	3.01	5.537
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4.689	2.103	8.35	2.175	8.09	2.291	7.63	2.364	2.19	2.841	7.52	3.47	2.3	3.53	8.35	3.62	8.35	2.731	10.92	3.816
7.33	2.294	4.56	2.318	3	2.376	3.02	2.419	2.93	2.483	6.44	2.516	2.4	2.53	4.56	2.58	7.36	2.596	8.5	2.616
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.04	1.786	5.03	1.804	9.4	2.03	4.63	2.206	1.27	2.291	1.05	2.347	1.28	2.36	5.03	2.383	2.94	2.399	1.04	2.42
12.4	3.391	11.75	3.473	9.43	3.526	6.59	3.623	4.689	3.717	4.92	3.798	4.702	3.717	11.75	3.798	6.89	3.717	11.1	3.798
14.21	4.572	3.02	4.637	3.01	4.643	8.5	4.691	6.11	4.762	3.02	4.799	4.36	4.806	3.02	4.818	6.96	4.823	7.33	4.841
5.84	4.123	10.71	4.531	8.22	4.615	1.26	4.935	9.81	5.088	7.84	5.192	4.3	5.206	10.71	5.22	10.3	5.239	6.96	5.25
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6.32	8.499	8.35	8.517	4.63	8.577	8.09	8.609	4.63	8.711	11.3	8.787	12	8.82	8.35	8.863	9.07	8.899	8.09	8.911
11	9.048	9.1	9.116	6.05	9.174	10.62	9.195	13	9.207	6.44	9.3	6.5	9.317	9.1	9.62	3.97	9.807	11.38	9.93
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7.91	7.476	6.95	7.508	5.502	7.585	1.05	7.621	4.72	7.743	6.04	7.848	6.3	7.883	6.95	7.903	8.92	7.943	1.05	7.962
7.04	7.503	8.35	7.827	12.96	7.917	12.81	8.39	10.11	8.402	16.78	8.509	11.2	8.518	8.35	8.559	4.92	8.589	9.43	8.609
6.11	7.499	7.33	7.517	8.5	7.519	6.11	7.532	6.73	7.546	8.72	7.553	8.2	7.591	7.33	7.613	1.26	7.644	3.01	7.807
6.96	7.349	10.71	7.387	13.9	7.414	7.66	7.479	2.93	7.48	9.01	7.501	4.6	7.526	10.71	7.586	11.54	7.669	6.96	7.633
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

APPENDIX C

Table of Total Acid Number (TAN) of Biodiesel Sample

samples	15.4.11		30.4.11		15.5.11		31.5.11		15.6.11		30.6.11	
	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)
Palm oil	1.46	3.6325	1.46	3.4751	1.48	3.3308	1.49	2.9987	1.49	3.7553	1.51	3.1689
Palm oil biodiesel	2.56	3.8836	2.57	3.4221	2.59	3.7591	2.6	3.9124	2.63	3.6234	2.71	3.7127
Diesel	0.27	4.0428	0.28	3.972	0.28	4.0166	0.32	4.4513	0.33	3.9875	0.35	3.8886
Jatropha oil	1.03	3.5613	1.03	3.0356	1.05	3.6549	1.11	3.1729	1.2	2.9947	1.24	3.8902
Jatropha oil biodiesel	1.21	3.0441	1.23	3.7977	1.27	3.8211	1.31	3.8233	1.35	3.6516	1.35	3.6732
Coconut oil	4.05	3.0974	4.06	3.5824	4.11	2.8967	4.18	3.0723	4.24	3.0211	4.29	3.7591

15.7.11		31.7.11		14.8.11		31.8.11		16.9.11	
TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)
1.57	3.6516	1.62	3.6219	1.69	3.0356	1.73	3.0716	1.74	3.1102
2.73	3.4241	2.77	3.4478	2.8	3.9255	2.83	3.2544	2.86	3.5613
0.37	3.9717	0.39	3.8613	0.44	4.0217	0.49	3.8917	0.52	4.1013
1.29	3.6981	1.34	3.1288	1.36	3.6746	1.38	3.2914	1.39	3.1012
1.37	2.4751	1.38	2.7429	1.4	3.9124	1.42	3.7127	1.45	3.2876
4.31	3.0592	4.37	2.9652	4.46	3.122	4.53	3.11	4.59	3.1689

30.9.11		16.10.11		31.10.11		13.11.11		30.11.11	
TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)	TAN value(mV)	mass of biodiesel(g)
1.76	3.1511	1.78	3.1869	1.79	3.2003	1.8	3.2693	1.81	3.1463
2.89	3.6429	2.92	3.5026	2.94	3.5801	2.96	3.6043	2.98	3.7016
0.56	3.9975	0.59	4.163	0.64	4.1131	0.66	4.278	0.67	4.2003
1.4	3.6732	1.425	3.3326	1.43	3.7106	1.44	3.3932	1.46	3.8063
1.48	3.1426	1.51	3.4302	1.54	3.2173	1.57	3.4901	1.61	3.208
4.62	3.1359	4.68	3.1152	4.71	3.2063	4.74	3.2207	4.77	3.1053

APPENDIX D

Table of Total Base Number (TBN) of Biodiesel Sample

samples	15.4.11		30.4.11		15.5.11		31.5.11		15.6.11	
	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)
Palm oil	12.27	4.0356	12.27	3.7219	12.24	3.099	12.25	3.9042	12.21	3.9831
Palm oil biodiesel	12.49	3.8251	12.48	3.9255	12.48	3.7219	12.45	3.7127	12.44	3.9245
Diesel	13.31	4.0217	13.29	4.112	13.29	3.905	13.27	3.0275	13.26	3.6234
Jatropha oil	8.86	3.115	8.87	3.1081	8.83	3.112	8.78	3.0981	8.74	3.1222
Jatropha oil biodiesel	11.94	3.9124	11.94	3.122	11.91	3.298	11.87	4.0746	11.86	3.8725
Coconut oil	7.82	3.679	7.81	3.6434	7.79	3.569	7.75	3.2105	7.71	3.9437

30.6.11		15.7.11		31.7.11		14.8.11		31.8.11	
TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)
12.13	3.1024	12.08	4.122	12.02	3.9284	11.89	3.832	11.78	3.2384
12.38	3.9457	12.36	3.712	12.29	3.8018	12.22	3.8317	12.2	3.5131
13.24	3.8993	13.21	3.8549	13.17	3.5748	13.15	3.8954	13.11	3.9021
8.71	3.7134	8.69	3.821	8.62	3.194	8.51	3.9122	8.47	3.8593
11.84	3.0872	11.81	3.5743	11.76	3.9638	11.73	3.2604	11.69	3.6457
7.63	3.7219	7.5	3.5821	7.39	3.0723	7.26	3.5913	7.05	3.902

16.9.11		30.9.11		16.10.11		31.10.11		13.11.11		30.11.11	
TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)	TBN value(mV)	mass of biodiesel(g)	TBN value(mV	ass of biodiesel(	TBN value(mV)	ass of biodiesel(	TBN value(mV)	mass of biodiesel(g)
11.7	3.4442	11.68	4.0611	11.63	3.4442	11.58	3.1102	11.51	3.0356	11.48	3.1511
12.11	3.8073	12.06	3.6199	12.05	3.8073	11.96	3.5613	11.93	3.9255	11.89	3.6429
13.08	3.9045	13.04	4.0127	13.01	3.9045	12.99	4.1013	12.97	4.0217	12.95	3.9975
8.39	3.6234	8.33	4.0135	8.32	3.6234	8.31	3.1012	8.28	3.6746	8.25	3.6732
11.61	3.7591	11.54	3.7127	11.48	3.7591	11.39	3.2876	11.31	3.9124	11.24	3.1426
6.99	3.8472	6.87	3.9145	6.8	3.8472	6.69	3.1689	6.58	3.122	6.52	3.1359

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