PRELIMINARY STUDY OF BIODIESEL PRODUCTION FROM CANTEEN'S TRAP GREASE

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ABSTRACT

The objective of this research was to produce biodiesel from trapped grease. Greased was collected from the grease trap of the central canteen of Mahidol University, Salaya Campus, and then passed through the extraction unit to extract the unwanted matters. This product was able to be transformed into ethyl ester, biodiesel, by using the transesterification reaction, in the present of acidic catalyst of concentrated sulfuric acid. The 100% access ethanol was involved to accomplish the reaction by the molecular ratio of 30:1 between ethanol and grease. At 90 ^{o}C for 90 minutes, the finished process provided the biodiesel of 95.17% by volume.

The results indicated that biodiesel had API gravity value at 15^{o}C of 0.90 g/cm^3, viscosity value at 40^{o}C of 8.69 mm^2/s, flash point value of 184^{o}C, and heat value of 9,685.35 Cal/g. After blending, to local diesel, the property test shown that there were no statistical differences between the blends and baseline diesel at the significant of 0.01 level.

With testing engine performance, the reported graph of torque and power exhibited that the blends' seemed to be slightly higher than diesel. Moreover, the entire results of correlation value of every samples' graph were in range of 0.97 – 0.99 which could be declared that the blends were replaceable to diesel in every ratio.

According to the results of those fuel specific properties and engine performance tests, it can statistically concluded that canteen's trap grease was able to be transformed to ethyl ester, biodiesel, and every ratio of diesel/biodiesel blend had the potentiality to substitute to diesel. Yet, there were little differences investigated among the blends which could be supported that the most suitable blend which had the best performance compared to diesel was B15.

KEY WORDS: TRAPPED GREASE/ BIODIESEL / TRANSESTERIFICATION

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การศึกษาเบื้องต้นเกี่ยวกับการผลิตน้ำมันดีเซลชีวภาพจากกากไขมันโรงอาหาร
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บทคัดย่อ

งานวิจัยนี้ มีวัตถุประสงค์เพื่อประเมินคุณภาพของน้ำมันดีเซลชีวภาพที่ผลิตจากกากไขมันของบ่อดักไขมันบริเวณโรงอาหาร โดยทำการเก็บรวบรวมกากไขมันดังกล่าวจากโรงอาหารกลางของมหาวิทยาลัยมหิดล วิทยาเขตศาลายา นำมาสกัดแยกของเสียอื่นที่ไม่ใช่ไขมันออกแล้วจึงผ่านปฏิกิริยาทรานส์เอสเทอริฟิเคชั่นภายใต้สภาวะความเป็นกรด โดยทำปฏิกิริยากับเอธานอลด้วยอัตราส่วนระหว่างเอธานอลต่อไขมัน เท่ากับ 30:1 ที่อุณหภูมิ 90 °ซ เป็นเวลา 90 นาที ได้สารเอธิลเอสเทอร์ร้อยละ 95.17 โดยปริมาตร นำเชื้อเพลิงดังกล่าวผสมเข้ากับน้ำมันดีเซลในอัตราส่วนผสมดีเซลชีวภาพร้อยละ 5, 10, 15 และ20 แล้วจึงนำไปผ่านกระบวนการทดสอบสมบัติต่างๆ พบว่า

ค่าที่ได้จากการทดสอบความถ่วงจำเพาะ, ความหนืด, จุดวาบไฟ และค่าความร้อนของเชื้อเพลิงผสมทุกชนิด ไม่มีความแตกต่างกับค่าเดียวกันที่ทดสอบกับน้ำมันดีเซล ที่ระดับนัยสำคัญ 0.01

เมื่อนำเชื้อเพลิงผสมทุกอัตราส่วนทดสอบการทำงานกับเครื่องยนต์ของรถยนต์ดีเซลขนาด 2,494 ซีซี, 4 สูบ, 90 แรงม้า เทียบกับน้ำมันดีเซลพบว่า ที่รอบการทำงานปกติ (1,500 – 3,000 rpm) ค่าแรงบิด และกำลังของเครื่องยนต์ของเชื้อเพลิงผสมมีค่าสูงกว่าของดีเซลเล็กน้อย แต่ในช่วงรอบการทำงานของเครื่องยนต์ที่ 3,100 – 3,900 rpm มีการตกลงของกราฟแสดงผลเมื่อเทียบกับดีเซล และกลับขึ้นมาเท่ากับดีเซลอีกครั้งที่ประมาณรอบการทำงานที่ 4,000 rpm เมื่อนำกราฟแสดงผลที่ได้จากเชื้อเพลิงทุกประเภทมาหาค่าสัมประสิทธิ์ความสัมพันธ์ระหว่างรอบการทำงานของเครื่องยนต์กับค่าแรงบิด และกำลังเครื่องยนต์พบว่ามีค่าอยู่ระหว่าง 0.97 – 0.99 ทั้งสิ้น ถือว่าเชื้อเพลิงผสมสามารถใช้ทดแทนน้ำมันดีเซลได้ทุกอัตราส่วน

จากผลการศึกษาสามารถสรุปได้ว่า กากไขมันจากบ่อดักไขมันโรงอาหาร สามารถผ่านปฏิกิริยาทรานส์เอสเทอริฟิเคชั่นได้สารเอธิลเอสเทอร์ เมื่อผสมเข้ากับน้ำมันดีเซลให้สมบัติความเป็นเชื้อเพลิงและการทำงานของเครื่องยนต์ไม่แตกต่างกับน้ำมันดีเซลในทุกอัตราส่วนผสม โดยอัตราส่วนที่ให้ผลการทดสอบที่ดีที่สุดคือเชื้อเพลิงผสมดีเซลชีวภาพร้อยละ 15

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CONTENTS

CONTENTS (Cont.)

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background and significance of problem

As a non-renewable resource, petroleum is now facing a quantity-decrease because of the world's raising demands. Since the majority of the nations do not have the natural oil resources themselves, whenever fluctuations in the world's oil prices occur, it always impacts on the world economies.

Inescapable, Thailand also receives such an effect. Since it mainly uses petroleum as the base of engine fuel in transportation activities, electricity generation, and in the industrial, commercial and agricultural sectors as well, seeking for substitutable diesel fuel would be an important way to solve the problem and stabilize the nation's currency and its deficits.

In the year 2000, following the King Bhumiphol's purpose of using palm oil instead of diesel, earnestly research throughout the government and private sectors were awoken. The Ministry of Science, Technology, and environment had set up a committee for the "Palm, and other Plant Oil to Biodiesel Project", a project whose had the purposes to gather information of biodiesel productivity and its utilization in foreign countries, and finding the quantity of diesel demand in the respective countries and including Thailand as well. The results would produce the guidelines on how to convert palm and other plant oil to biodiesel, and resolve ways of helping the devaluation of agriculture products.

Yet, there was a government policy, which warrants fresh palm prices to be not lower than 3 Baht/kilogram, and that 1-liter of palm oil is taken from no more than 5.88 kilograms of fresh palms. Hence, the lowest expense for every liter of purified palm oil is 17.64 Baht, which with the assemblage cost of converting it to biodiesel through synthetic procedures, increases the price of having purified palm oil biodiesel to 22.64 Baht/liter (1). This is higher than diesel's current price, and will therefore repel consumers of using such a fuel.

Since the biodiesel process is an ester conversion reaction, many of biodiesel research has shown that purified palm oil can be replaced by other material with lower costs, and still produce positive results. This material could be found in the form of used cooking oil, a cheap substance, which would therefore dramatically reduce the high cost of purified palm oil. Moreover, there is another matter with no cost which is feasible to use as a raw material of biodiesel production that is a trapped grease. Due to one kind of ester, such waste rather has a trend to be conversable to biodiesel.

According to the study report from the Department of Environmental Hygiene which tested the sewage of food services at the grease traps, found the following results:

The food services, such as restaurants, canteens, cafés and food shops, where the floor surfaces where less than 100 $m^{2,}$ contained an average of 129.49 milligrams of fat and oil per liter of outlet water. Food services between 100 to 200 m^2 in floor surface area resulted in 57.61 mL/liter, and 86.53 mL/liter for food services with more than 200 m^2 in floor surface area. Following the report of Bangkok Administration, there was an expectation that, Bangkok would produce 13.333 ton/day in year 2019 (2).

These oils and fats are pollutants to our water systems, and by extracting them from the greased waters and using them to produce biodiesel, not only produces a less expensive form of biodiesel, but will also help decrease water pollution and enhance our environment by utilizing the food waste.

1.2 Conceptual framework

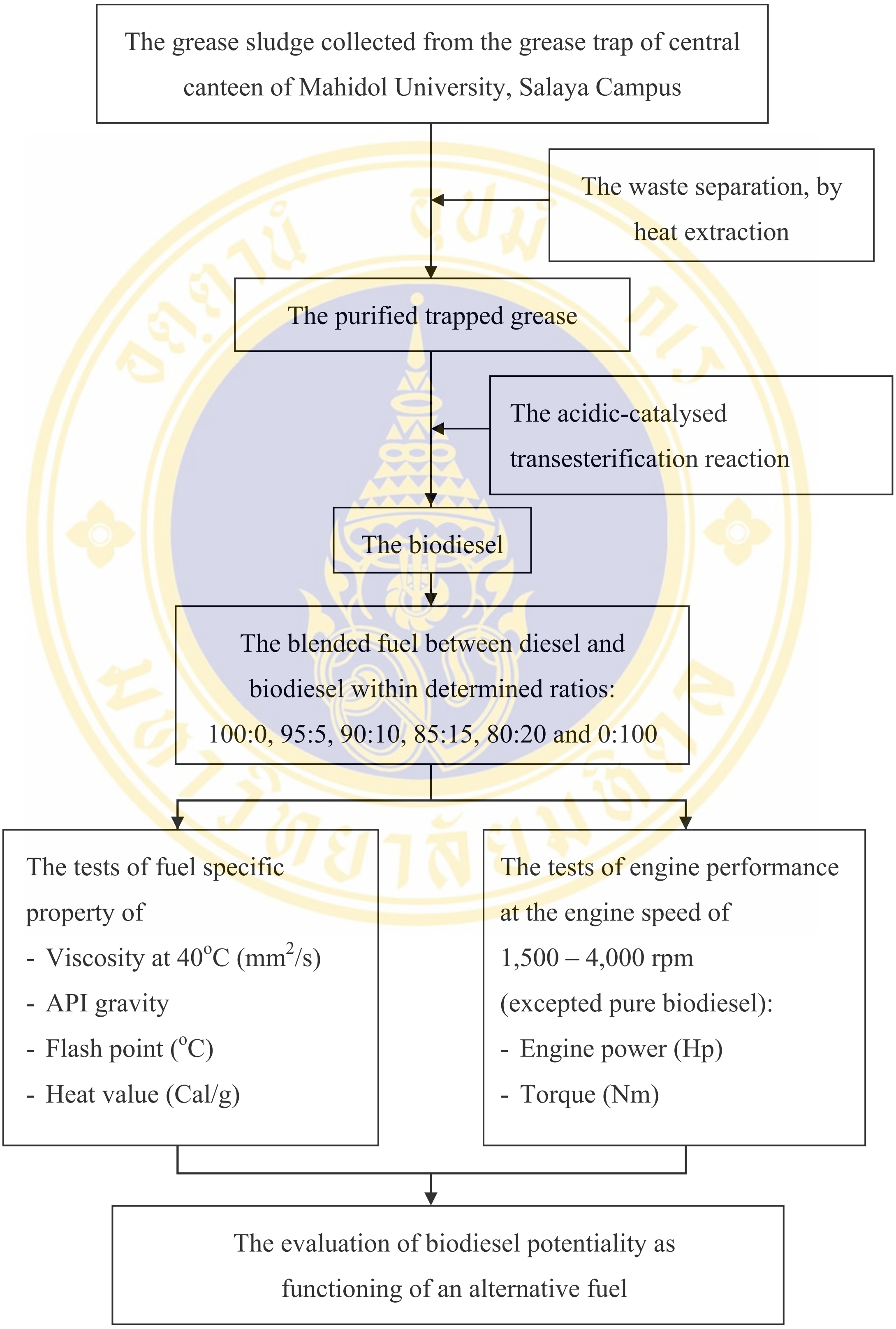


Figure 1-1 Conceptual Flame Work

1.3 Research Objectives

1.3.1 to produce the biodiesel of canteen's trapped grease collected from the trap of central canteen of Mahidol University, Salaya Campus.

1.3.2 to evaluate the potentiality of trapped grease biodiesel as an diesel fuel substitution.

1.4 Hypothesis

The biodiesel through the transerterificated process of the canteen's trapped grease has potentiality of being as diesel fuel.

1.5 Scope of the research

1.5.1 Trapped grease used in this study was collected from the grease trap of central canteen of Mahidol University, Salaya Campus.

1.5.2 The synthetic reaction was the transesterification, in the present of acidic catalyst.

1.5.3 The blended fuel had been determined in 4 proportions: B5 (the 5%-biodiesel blend), B10 (the 10%-biodiesel blend), B15 (the 15%-biodiesel blend), and B20 (the 20%-biodiesel blend).

1.6 Expected result

The results had a potential to be a guideline for waste utilization, particularly, in trapped grease recycling, one approaching of the environmental problem solutions.

CHAPTER 2

LITERATURE REVIEWS

This study occupied on the quality assessment of biodiesel fuel, a laboratory-synthesized substance, in functioning of diesel substitute fuel. The product was emerged by chemical reaction called "transesterification" which is a nucleophilic substitution chemical process. By using canteen's trap grease as a chemical base to provide the fatty acid molecules, the ester compound, known as biodiesel, will be created. All subjects of this chapter are follow;

2.1 Biodiesel
2.2 Transesterification
2.3 Feature of oil and fat
2.4 Petroleum
2.5 Properties of diesel
2.6 General knowledge of fat and oil in wastewater
2.7 Relevant research

Biomass, the renewable energy, has become the attractive fuel, as it is agricultural product and petroleum substitution. There are many effective ways to use such fuel. But in term of applying with diesel engine, the vegetable, one kind of biomass, is seemed to be unsuitable. As its high viscosity and low volatility, there are many studies showed that vegetable oil could be used in only short-term engine operation and presented worse performance than diesel (3),(4). With the improper characteristic, this fuel can cause many serious problems such as engine knocking, more pollutant providing, and injector cocking, etc, especially in the winter (5). To reduce its viscosity, the fuel needs to be blended with some microemulsions solvent, but some engine still performed a problem (20).

The most recently promising method of using vegetable oil is to have it conversed to the other molecular structure by reacting with alcohol. This process is intended to separated the viscous substance out of the vegetable oil and lessen its viscosity. This transformation process is the significant way to solve such problem and produce a Newtonian fluid.

2.1 Biodiesel

Biodiesel is name of an alternative fuel functioning as a diesel substitution. It is a substance in group of ester compound, which is generally derived from a chemical reaction between fat or oil and alcohol.

The American Society for Testing and Materials (ASTM) has defined the biodiesel as a monoalkyl ester of long chain fatty acids (21). The name of biodiesel is called and recognized in developed countries where plant oil is applied with diesel engines. This name of biodiesel is specifically refers to the ester which is derived from the chemical reaction. It differs from distilled crude plant oil used with the engine directly, which is in a group of fuel called "crude biodiesel". For example, the diesel mixed with coconut oil and kerosene, which is served in gas stations at Thabsakea tambon administration organization and Bangkhontee district of Samutsongkhram, is called "Coco-Diesel".

This kind of ester derivative can be derived from a chemical reaction between lipid feedstock, such as, vegetable oil or animal fat, and linear monoalkyl alcohol, such as, methanol or ethanol. This makes the biodiesel become an outstanding alternative fuel because it can be produced from renewable resource, the agricultural product. The former studies had exhibited that the biodiesel/diesel blend provided better performance than baseline diesel (6), (22).

There are many chemical reactions that can create the biodiesel: Soap pyrolysis product of vegetable oil, boron trifluoride-alcohol, acid halides, pyrolysis of vegetable oil, esterification, and transesterification (22), (23). But the most used procedures are these following three methods of producing biodiesel or to synthesize ester compound from plant or animal oil.

1. Using Transesterification reaction between oil and alcohol with acidic or basic catalyst.

2. Using Transesterification reaction between oil and alcohol without catalyst but high pressure. The biodiesel derived from this procedure will have good quality, high purity, and light color, but high cost.

3. Changing plant oil and animal fat to be fatty acid. Then, using such acid to react with alcohol to produce ester, this procedure might be called "transmethylation or transethylation" depending on the alcohol properties.

According to this study, transesterification will be the method used in the experimental process.

2.1.1 History of biodiesel researching and development

In the year 1846, there was a chemist tried to prepare the glycerol from castor oil via the ethanolysis reaction. After then, the alcoholysis spread over the world and it was studied in the reaction conditions and the factors that influence the reaction of deriving an alcohol from triglyceride of fish oil, tallow, rape, soybean, cottonseed, and linseed oil, etc (22).

Research and development of biodiesel began for a long time ago in many countries such as U.S.A., Australia, Germany, Italy, Nicaragua, Scheck Republic, and Malaysia, etc, since an affect of the petroleum energy crisis, the insufficiency in 1970 and Persia gulf war, which caused a hardly obstacle of oil transmission. The following results of those strait were the increasing of the oil price and the lack of oil.

In the same time, there was a problem of the agricultural activities, which always happens for all the time, that was the excessive quantity of the agriculture product made its price lower. Thus, this situation had motivated the inventible research of utilization of those products for an energy substitution of petroleum and also being as a clean energy as well, for saving the environment.

Therefore, the biodiesel research was seriously happened in the course of 15 years ago. In 1982, there was a report of the discovery of an animal ester compound in New Zealand. In the same year, Australia had found the methyl ester, which was produced from Rapeseed, and in 1989, the navigated project of bio-diesel was established and rapidly improved as the industrial purpose, especially, in 1990 – 2000. Till today, there are many products of such substance which is produced in an industry level and accepted from the industrial vehicle producer and general vehicle user. Since, the cleaner burning and lower sulfur emission, the biodiesel is able to reduce the toxic hoarding in environment(7).

In Thailand, the biodiesel scheme had been set up followed the King's intention at year 2000. This has wakened the country till now and researching has proceeded continuously. Following the project of biodiesel development and utilization encouragement of the Ministry of energy, the plan has determined to start at year 2005 with the initiated mission of community biodiesel the aim of local self-production. With the aim, the biodiesel operation base has been existed in some place such as The Chiang Mai province has proceeded the project of use oil biodiesel and now promoted to real use with the governmental vehicles and public transportation.

By the Ministry's project, the biodiesel had been regulated for real use over the country with in year 2007 in proportion of 5% blend till 2011 and rise up to 10% blend after then.

2.1.2 Utility of biodiesel

Plant oil using instead of fossil fuel in vehicle engine of Thailand had been accepted in past till today. After the publication of purify distillation palm oil used instead of diesel following the King's intention, the experimental research from government sector, even private sector, had been widely created in many patterns.

There are many ways to substitute plant oil to diesel, however; the concerning of this, is to reduce the viscosity of plant oil to be equal in the same rage of diesel which normally has the value under 4.2 cst at $40^{o}C$(8). Moreover, the cetane number, the value of viscosity, and the value of heat, etc, are also the considerations of using the plant oil.

The comparison between bio-diesel and plant oil gives the interested result that biodiesel gains closer properties of diesel fuel. Accordingly, using of such fuel would provide many profits to the environment as followings.

1. To the environment

To reduce the air pollutants produced from the engine ignition, The National Biodiesel Board, and the Environment Protection Agency of United States of America had tested in many ratios of biodiesel to the diesel engine and the result exposing that the using of B100 (100% of biodiesel) and B20 (20% of biodiesel: 80% of diesel) are able to lessen the after ignition released mass, significantly, compared with pure diesel. As a report of the shipyard department, Thailand Navy, the experimental result of biodiesel in diesel engine of 145 horsepower shown that the black smoke is reducible more than 40 %.

2. To the efficiency of engine

The proportion 1 – 2 % of bio-diesel blending with diesel oil is able to increase the index of lubrication to the oil. According to the test of the institution of researching and technology of Thailand's Petroleum Co., Ltd, the addition of biodiesel, produced from used cooking oil, or coconut oil, in proportion of 5% can increase the lubrication up to 2 times than diesel. Engine burning efficiency performs better because biodiesel has more oxygen molecules, which make a diffusion ratio between air and oil more consistent, causing higher complete burning. So, even it is about 10% lower of heating value, this defect of bio-diesel does not lessen the engine power.

3. To the economics

Biodiesel usage not only creates the job to the rural sides by supporting the surplus agricultural production to the fuel market, but also decreases some amount of imported oil, which loses the national currency more than 300,000 million baht/year.

Moreover, this can add value to the used cooking oil by modifying to biodiesel and resisting reuse of such oil that contain the carcinogenic substance.

4. To the domestic fuel producing

Thailand got a proportion of diesel use much higher than gasoline. Diesel market of Thailand has more value than gasoline about 2 times. In the future, it is trend that the refinery factories might not be able to provide enough oil to the domestic demand. Thus, to use biodiesel is to reduce the imbalance of oil supply that might happen. To blend biodiesel in ratio of 1 – 2 % is also up heave the lubrication of oil and lessen the amount of sulfur emission.

So, this is the important way to stabilize the interior economical and energy consumption.

2.1.3 Effect of biodiesel to the engine

As the international standard of properties of biodiesel can be compared with petroleum-diesel, this is considered that there is no negative effect to the engine, but in a case of long term used cars is necessary to change some of the adjoin seal rubbers.

There are normally use of biodiesel in many countries by mixing of vary ratio such as;

B2 (2% of biodiesel, 98% of diesel) is generally sold in Minnesota, U.S.A. and will be enforced to apply to all over the state in 2005.

B5 (5% of biodiesel, 95% of diesel) is normally sold in France.

B20 (20% of biodiesel, 80% of diesel) is popular in America following the act of alternative motor fuels (AMFT 1988), the oil is used widely particularly in private companies' and government's vehicles more than 147 units and also in the pollutant restricted area by using with school bus, omnibus, boat, or machinery in mine, for example. These are under certification of injector builder companies and engine builder companies.

B100 (100% of biodiesel) is used in Germany and Austria, and certified by the interior automobile companies.

2.2 Transesterification

The transesterification is the chemical reaction in kind of nucleophilic substitution reaction which proceeds by replacing lone pair electrons into the group of carboxylic acid derivative substances. This reaction combines with these two actions that are the addition and the elimination between ester and alcohol under an acidic or a basic catalysis to reconstruct a new ester and alcohol. This is called "Transesterification."

For this reaction of synthetic biodiesel, it is to add an alcohol in kind of methyl or ethyl into a triglyceride molecular of fat or oil for replaces an alkoxy group (-OR) and form the methyl ester or ethyl ester and glycerol as the picture below.

Figure 2-1 Chemical symbol of transesterification reaction

However, even both catalysts, the acidic and basic, are able to provide the same product, but the mechanisms of them are different from each other (23).

2.2.1 Acidic-catalysed mechanism

With the waste lipid, the acidic-catalysed reaction has more feasibility to complete the reaction because there is more fatty acid in such waste than neat vegetable oil. The acidic catalyst can possibly finish the complete reaction even there are a lot of free fatty acid molecule while the basic one cannot. The mechanisms of acidic-catalysed reaction are followings.

I. Acidic-catalysed transesterification

The acidic catalyst can converse the ester molecule to the other one as shown in the figure 2-2 below.

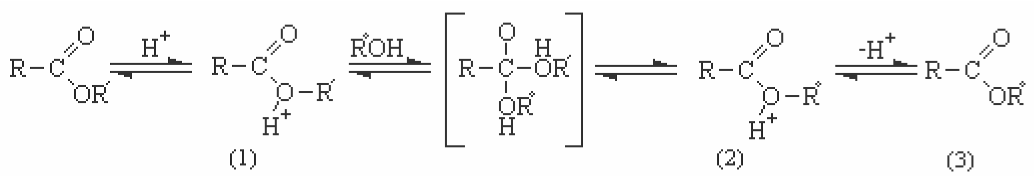


Figure 2-2 Mechanism of acidic-catalysed transesterification

(1) After the ester has been protonated by the catalyst, the substance is followed by addition of the exchanging alcohol to give the intermediate.

(2) The transition state is occurred after then.

(3) Therefore, the new ester has been created via the transition state.

II. Acidic-catalysed esterification

Within waste lipid, there are not only the ester molecule, but also the free fatty acid one, which can be conversed by this catalyst as shown in the figure 2-3 below.

Figure 2-3 Mechanism of acidic-catalysed esterification

(1) The acid protonates the fatty acid to construct an oxonium ion.

(2) At the intermediate, the molecule of the oxonium ion will be nucleophiled by the alcohol and the oxonium ion will be eliminated.

(3) For the stabilization, the proton will be dissociated and new ester will be then created.

2.2.2 Basic-catalysed transesterification

There is a difference path of basic catalyst to accomplish the transesterification. That is, the base can not esterify the waste lipid which has free fatty acid more than 10-15% (18). As the free fatty acid will be conversed into the form of carboxylate ion ($RCOO^-$) when it is in the basic solution, so; its molecule can not be attacked by the alcohol, since it has the same negative charge as followings.

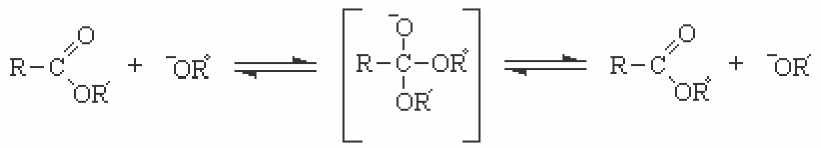


Figure 2-4 Mechanism of basic-catalysed transesterification

The ester reacting with the alcohol, which is in base form like alcoholate anion ($^-$OR") will be provide the intermediate that is reversible to the new product or even the same one. In case of there is any water in the reaction, the intermediate molecule can possibly be conversed to fatty acid. So, it is necessary to excrete it out before the process beginning.

That is one of the limitations of using the basic catalyst in waste lipid transforming reaction. Furthermore, the base probably reacts with the free fatty acid and produces the fatty acid salt as well. It possible to say that basic catalyst is not appropriated for using in production process of waste lipid biodiesel.

Consequently, this study had involved the acidic catalyst to achieve the grease biodiesel synthesis.

2.3 Feature of oil and fat

Plant oil, kind of ester compound substance, is originated from the reaction between glycerol which is alcohol compound and fatty acid to produce a compound product in the group of triglyceride that can be reversible to glycerol and fatty acid again when it is in the high temperature condition. The reaction can be exposed as the figure below.

(Glycerol) (Fatty acid) (Triglyceride) (Water)

Figure 2-5 Chemical symbol of triglyceride compound generation reaction

Fatty acid

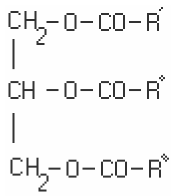
Fatty acid is carboxylic acid (R-COOH), connecting with hydrocarbon. The differences of each fatty acid can be considered from a number and the position of unsaturation of carbon atoms. In majority, the characteristic of natural fats is a single unit of hydrocarbon linking with the long straight chain of hydrocarbon as the figure below.

(Carboxylic Acid) (Hydrocarbon Chain)

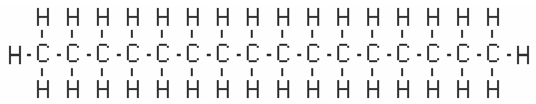
Figure 2-6 Chemical symbol of natural fat acid

Most of fatty acids found in natural have atom carbons in even number ranging between 4 – 30 atoms but they are mostly in range between 12 – 24, especially at 16 and 18 carbon atoms. The bonding among carbon atoms has two types: single and double. The acid having only single bonding is called "saturated fatty acid", found in high quantity in animal fat. The acid which has both single and double bonding is called "unsaturated fatty acid", found mostly in plant oil.

Plant oil is almost has the same characteristics as animal's for example non-soluble in water but in organic solvent, and energy providable. Since the heating value up to 90 – 95 % of diesel, higher than alcohol, and the value of cetane number is close to the lowest one of diesel, plant oil is able to be an alternative fuel, particularly instead of diesel. The unstable substance can be easily oxidized in the air and its polymerization can possibly occur in high temperature. The iodine number of it can be used to indicate the polymerization occurrence that is the higher iodine numbers is, the more possibility of polymerization occurs. Therefore, to the initial protection of polymerization of plant oil inside engine, the low iodine number oil is more suitable than the higher one to replace petroleum. The structure of plant oil and diesel can be shown as the figure below.



a. Plant oil



b. diesel

Figure 2-7 Structure of a. plant oil and b. diesel

Oil and fat are usually met in the sewage of food service, gas station, garage, and some factory; and generally extracted from the tissue of animal and plant, which is soluble in ether, chloroform, hexane, and high temperature alcohol but water. The main functions of such matters are the structure of tissue and energy storage. Oil will be in liquid state at room temperature while fat will be in the solid one.

Fat from plant and animal, which consists of the saturated fatty acid molecules and have a high molecular weight is solid and holds a high melting point, if it is a combination of the unsaturated fatty acid in an equal number of carbon atoms, the molecular will contain a low melting point called oil which is liquid. Oil is able to be strengthen by proceeding an unsaturated fatty acid in to the hydrogenation process to have the double bond broken into single, and if one of the fatty acid molecules is replaced by the phosphate group, it will be called phospholipid which is found in an animal tissue and principally in brain and nerve.

2.4 Petroleum

The oil and fat from petroleum means crude oil, natural gas, liquid natural gas, and other hydrocarbon compound which are natural matter and existing also solid, liquid, and gas state, as well.

Most of crude oil found is black or brown and instantly fuel odor; some may be have a mixed scent of sulphur, or hydrogen sulfide; for example while there are many differences of viscosity begin with liquidity until asphalt. For the specific gravity will remains in range between 0.08 – 0.97 at 15.6^{o}C (60^{o}F), which lighter than water, so; the oil will float over water when they are gathering. Liquid natural gas has the same physical slightly as gasoline and the dry one is colorless and scentless.

2.4.1 Production of instant oil from crude

As there are many kinds of hydrocarbon, different in structures and properties, in crude oil, the production of instant oil is so important to produce the appropriate oil for using in various utility purposes following the property of each fuel's kind.

2.4.1.1 Procedure of distillation

The petroleum distillation is the separation of oils which has many kinds mixing in crude by using the differences of boiling point, and melting point. The kinds of fuel that has smaller molecular structure will contain a lower boiling point and melting point than the bigger ones. Consequently, the fuel with smallest molecular structure will distill first in state of gas, which has the standard quality and can immediately be blended to be instant oil. The under-standard oil will be proceeded in quality improvement procedure in further. The table 2-1 (page 17) showed the differences of boiling point and utility of each kind of petroleum fuel.

2.4.1.2 Procedure of oil molecular conversion

Most of distilled oil is necessary to be standardized (9) following the commercial purposes supported to the various tasks which depend on the property of each type of oil molecular structure. This process may be involve the chemical treatment such as, catalytic addition, sulfur elimination by hydro-treating process, heating dissociation process, and polymerization process, etc, for the purpose that to adjust molecular size, or number of carbon atoms in the oil molecules.

2.4.1.3 Treating process

This chemical addition process is to improve the oil quality, maybe a physical adjustment such as, solvent extraction, or chemical absorption, to bring out the unwanted matter from the oil. Most method of this step is chemical means for example, to excrete the hydrogen sulfide by alkaline dissolution, to reduce the rapidity of the reaction ability by changing the corrosive matter into the other substance, etc. So, this process is created to serve the purpose of elimination some matter out of the oil for the suitable quality to blend into the instant oil.

2.4.1.4 Blending process

This process is to have the oil - produced from all of those steps - mixed with the necessary chemical addition for improving the oil quality to be under the regulated standard for example, mixing with MTBE for increasing the octane number of gasoline, blending the high sticky bunker oil with the lighter one to reduce the oil viscosity, etc.

Table 2-1 the differences of boiling point and utility of each kind of petroleum fuel

Kind of petroleum	The number of carbon atoms	Boiling point (^oC)	The state at room temperature	The utilization
Petroleum gas	C1 – C4	< 30	Gas	Fuel, Synthetic Material, Chemical
Light naphtha	C5 – C6	0 – 65	Liquid	Gasoline
Heavy naphtha	C6 – C10	65 – 170	Liquid	Gasoline, Chemical
Kerosene	C10 – C14	170 – 250	Liquid	Jet fuel, Lamp fuel
Diesel	C14 – C19	250 – 340	Liquid	Diesel engine fuel
Lubricate	C19 – C35	340 – 500	Liquid	Lubricate Matter
Wax	C19 – C35	340 – 500	Solid	Candies, Cosmetic, Polish, Detergent
Bunker oil	> C35	> 500	Liquid	Machinery fuel
Bitumen	> C35	> 500	Solid	Impermeable material, Asphalt

2.4.2 Situation of fuel usage of Thailand

According to the Thailand's fuel report 2003 by the department of alternative energy and energy conservation, instant oil is imported for 998 million liters, more than 2002 in ratio of 1.7 % or 8,901 million baht in total. The most kind of oil used in the whole year of 2003 is the high-speed diesel which has proximately used value at 17,463 million liters, higher than last year 9.3 %. It was found that the most high speed diesel is used in the field of transportation, which is up to 71.8 % of all, and agriculture, industrial, and the other, respectively (10). From the statistic report of department of energy business, the usage of high-speed diesel is 45.97 % of all kinds of oil used in Thailand. Therefore, to invent the alternative energy of this kind of fuel is another way to relieve the national economic problems.

2.5 Properties of diesel

There are a lot of oil kind using now a day; and each kind have its own features, which are suitable for using in difference duties. Here are some properties of diesel

2.5.1 Density

Density, one of the most importance properties of diesel, means the mass of oil per one volume unit, which can be influenced by many factors such as, saponification value, iodine number, free fatty acid, water, and oil temperature, etc. As the normal measuring condition, this feature of diesel at 15^{o}C should be in the range of 0.81 – 0.87, which can support the engine to perform regularly. The oil that have the value lower than the common one is able to have the power of engine declined while the higher one can impossibly cause the problem of black smoke emission.

2.5.2 Cetane number

To inject the fuel into the ignition chamber, diesel needs a few moments to has itself vaporized and mix with the air before its flaming time. This course is called "the ignition delay" used for relate the burning ability of fuel. For the affect to the engine burning efficiency, the longer ignition delay is, the more unburned fuel in the chamber rest, which is able to be a problem causing a severe ignition. Therefore, this phenomenon should exist in the shortest time for serving the engine to perform regularly.

By using the cetane number to relate the ignition delay a flammable ability, the standard of cetane value is regulated by comparing the diesel to the normal cetane ($C_{16}H_{34}$) which is a hydrocarbon matter that can be easily burned and determined to contain a cetane value of 100. High-speed diesel, the fuel under standardization of the ministry of commercial, is ruled the lowest value to be at 47 and 45 for a kind of low-speed diesel (9).

2.5.3 Viscosity

As the influence of viscosity to the shape of oil dispersed out from the injector, the oil with high viscosity can cause improper injections which are the coarse oil particles spout, the long strip of the oil jet, the low mix ability to the air. These can make an incomplete burning and lessen the engine power. So, the low viscosity oil will carry a better performance because of fine oil particles grant and proper spout distance.

Yet, even the low viscosity oil carries a good performance providable, but too low viscosity one is not rather suitable, as the fact that; such matter is unable to long travel in the air and able to cause an over burning that can affect the engine a lessen of the power, also.

Regularly, the underling standard diesel should have the value in range between 1.8 – 4.1 cst at 40^{o}C.

2.6 General knowledge of fat and oil in wastewater

The fat and oil in wastewater means the fat, oil, wax, fatty acid, mineral soap, mineral oil, and the other group of non-volatile substance, which is water-soluble and hexane extractible; also have the low weigh molecular until the high weigh one. In the municipal sewage, the fat and oil will be carried at amount of 10% of all organic matter, which are from the vegetable oil, animal oil, butter, and margarine. For the practical reason of wastewater treatment process, such matter should be eliminated out before passing into procedure latter. Following the notice of ministry of science technology and environment by the subject of sewage control standardize regulation to some kind of building and magnitude, the wastewater that can be drained to water resource must contain fat and oil in amount of not over to 20 mg./liter (2).

The content mainly found in sewage are oil, fat, wax, and fatty acid which are roughly called “the grease.” Moreover, the liquid matter at room temperature from plant and animal can probably grant an ester or glycerol which always being in form of sediment, called “grease sludge”. This matter causes a problem sticking to the strainer and restraining the biological process to the aerobic and anaerobic microorganism. The sludge in high amount can obstruct the digester and produces the strainer a clog. Besides, these materials remaining in sewage is able to create a film to the surface that is become a blemish to the shore and a pipes block up.

2.6.1 The impact of grease to the environment

For leaking out of to the water resources, the grease can cause many natural processes of the physical, the chemical, and the biological in the same time. These are able to damage the environment and human's properties, as well. The environment impacts are shown as followings.

1. Physical impacts

When the oil pours into the environment especially to the water resources, this material will be film the area surfaces and causes the effects as followings.

As a water insoluble feature, grease can reduce the amount of oxygen in water since becoming a film between the water and the air, that is the affect to the water by blocking up the solvency of oxygen.

Not only the gas resistant, grease also be a problem to the light by obstructing the beam through surfaces which causes a further problems that is the water up-heating, since crude, bunker, or any opaque oil have a heat absorption ability, so; the heat transferable to water is happened. Some sinking grease, which drops down to the water base, is cause the contamination until composition of the water sediment that is the causality of grease restriction of water resources.

Moreover, the surface floating grease is still be a problem to the scenery of coastal area, stream, or any blemish places.

2. Biological impacts

Hydrocarbon, an organic compound mainly associated from hydrogen and carbon atoms, is able to dissolve in water and harm the natural creatures also the environment which takes a long-time restoration to bring it back at the normal state. Here are some of the grease impacts to biological processes.

2.1 The impact to planktons

As small floating lives, the variation of natural water compounds can effect to the planktons by increasing a death rate, disturbing an expanding ability, causing a abnormal growth.

2.2 The impact to mangrove forest

In a tropical zone, the mangrove remains generally at the coastal area and estuary. The plants growing at the area usually have the air roots for respiration. With the sticky characteristic, the grease can restrain plant's roots to respire so that, it is so hard to the plants to make itself grow as normal, especially the sprouts. To the living things at the area, which is a place to conceal and grow, many creatures have been killed that is the effect to the sea animals, a decreasing in amount.

2.3 The impact to coral and sea grass

As a high diversity, and attractive area, to contaminate by grease is not only make an scenery depress but also harm to the coral and sea grass by resisting the growth rate or making such living an malfunction. Moreover, the waste is still harm to the animal living in the area, as well.

3. Social economy impacts

Human has an ability to manage the natural resources in many various patterns and lives by profiting over the natural. Whenever the human's activities have the environment a toxic, the impact always affect to the human unavoidably

3.1 The impact to the coastal cultivated areas

As the hydrocarbon and the toxin in the grease combination can lessen the water quality, the animal living in the toxic areas with 11 – 3 mil/liter of contamination can be harmed with 96 hours so that it is feasible to make the coastal cultivated product declining in amount.

3.2 The impact to the economical status

Not only the inclination of a coastal cultivated product, to leaking out of grease also directly affect to the other sections such as the natural resources, the touring places, and the environmental management system. By focusing to the grease blemish elimination and environment restoration, the government has lost some more or less of budget to compile the resources of-money, peoples, and time-for wiping out such problems.

2.6.2 The elimination waste grease

Fat and oil, the grease, have a property of enwrapping. Without of waste primary treating, the grease released from food service to the municipal sewage treatment system can have the microorganisms, the biological waste remedy, wrapped, which is able to make an inability of air and nutriment absorption and to lessen the growth rate or to kill such living, finally.

Besides, the waste is also has a carrying ability to prop the microorganism, the sludge, up to the surface instead of drowning to the base of precipitation tank which causes the system malfunctioning. So that, to excrete the grease out before coming in the treatment system is so necessary to make the treatment effective.

There are many ways depending on the factors- of consistency, quantity, and kind- of grease to eliminate waste grease. The waste treatment methodologies used nowadays are able to separate as followings

1. The physical treatment

With the not too large size of operating material and the convenient simple operation, physical treatment is generally used to exterminate the grease. Here are the grease physical treatments.

1.1 The procedure of natural floatation

The method of this process is to use the property of specific gravity of grease that lower than water and the enough time of detention to have the grease separated out of the waste water to the surface. The procedure using the grease trap tank and grease interceptors is suitable for waste producing areas which produce a little amount of sewage: homes, food services, small hotels, for example.

1.2 The procedure of air addition under normal pressure condition

The process of blowing the air directly into sewage for propping up the grease onto surface is to pump the air into wastewater within the pressure tank. Until the waste is saturated by the air, the pressure will be reduced to the normal condition and the air with a bobble form will push the grease up onto surface. This procedure is suitable for dividing the grease which has trend of floating by itself. The bubbles are just to use for accelerating the floating time of the grease, especially the one that is unable to part out of the waste itself by the grease trap.

1.3 The procedure of vacuum floatation

This operation is to suck the air out of a confine tank to make the inside pressure lower than the outside atmosphere to let the air dissolving in waste float up to the top, by this time, the bubbles are able to boost the grease up as well. Such method is efficient to the small grease particles, but it takes much investment cost since the using of a big vacuum pump to have an enough ability to suck the air of and the specification design. This is good for the waste that contains high volume of grease.

1.4 The procedure of air pressing to the waste under high-pressure condition; or dissolved air floatation (DAF)

Beneath the gas dissolve ability, the process uses the air pump to mix air and waste together at the pressure of 40 – 50 lbs/Sq.inch in the pressure control tank. Within a few minutes detention for merging, the pressure will be reduced onto the normal condition to decrease the dissolve ability of the air and make the surplus air out of the mixing. The small particles of the air will effectively bring up the grease, which is colloid and emulsion matter, out of wastewater. The DAF is now extensively approved in the part of industries of slaughter house, canned fish, for examples. Such system can be group into 2 operations that are non-circulation system, and circulation system.

2. Chemical treatment

By the disability of the physical treatment to elimination of grease which is homogeneous with waste, so the chemical treatment is created to solve the problem and be a fore step of physical one. The chemicals always used within the process are both inorganic substances for instance sulfur, alum, and chlorine; and synthetic inorganic substances which are more effective. The most used matter is sulfur.

3. Biological treatment

The physical and chemical processes can just only separate the grease from waste not to transform the grease molecules. Thus, the grease from those processes needs to be proceeded in further elimination or utilization. With biological process using some strains of bacteria which are now developed to be in an instant form, the grease can be digested and transformed into carbon dioxide and water.

For all the processes of grease treatment, the most extensively used method is the physical treatment as the convenient uncomplicated operation, not too large size, and lower operation cost compared to another methods. With those features, the physical process that is recently used is the grease trap.

2.7 Relevant research

Nisakorn Dornkasin (2) studied the utilization of mixing scum (fat and grease) from a restaurant's grease trap with sawdust to produce briquette fuel in ratio between the sawdust and the scum of 1:1, 1:2, 1:3, and 1:4. The results had shown the interesting information that such briquette of waste mix exposed their heat value of 7,065, 6,915, 6,466, and 6,117 kcal/kg, correspondingly. In that order, the after – burned emission of CO was 302, 203, 275, and 217 ppm, NO was 11, 0.4, 7, and 7 ppm, and SO_2 was 3, 2, 3, and 4 ppm, respectively. Accordingly, the researcher had concluded that the most suitable briquette was at the ratio of 1:3, however it was unsuitable for real use because of its height volatility and incomplete burning.

Kanith Krisnangkul, and Rachdhaporn Simahanoph (11) studied the appropriated preparatory condition of methyl ester compound from palm oil's fatty acid lied in the organic solvent 1:1 by volume. By using the continuity chemical reaction of transesterification with sodium methanol catalytic at 70^{o}C, the reaction ratio between methanol and vegetable oil is set to 13:1 by mole which the complete trans-esterification emerges at 96% within 11 minutes. The complete reaction is able to reach to 99% within 15 minutes by adjust the ratio to the 17:1 by mole. In the case of decreasing the amount of methanol, the complete reaction will take a longer time or incomplete reaction will be occur if the methanol is too little. The experimental result has been shown the most suitable organic solvent that is the toluene because of the most methyl ester providable compared to the other solvents results.

Jirawal bualear (12) studied the extractor used to divide the methyl ester out of the triglyceride mixing, which is from passing a vegetable oil trough the trans-esterification reaction; and the suitable condition for methyl ester preparation. The research expose that the most effective catalyst of the study is sodium methoxide with the concentration at 0.5% and the most yield grant condition is to use the mole ratio between alcohol and vegetable oil at 10:1 which provides yield of methyl ester up to 94% within an hour.

Thibhodin sangsawang (3) studied the prediction of the engine efficiency under the theory of mass transmission. By using the blended fuel that is tested with a one-piston diesel engine, the crude palm oil is blended to diesel in the rates of 5%, 10%, and 15% by volume. The result of pollution measuring has been shown that the more ratio of palm oil blended is, the more pollutants increase emit; except, the amount of nitrogen oxide discharge which has no significantly change by the condition of blending variation.

Wachara loisamutra, and team (6) studied the used vegetable oil adjustment to be a diesel fuel. To proceed the oil into the chemical reaction of trans-esterification with involve a concentration of sulfuric catalytic at 90^{o}C for 1 hour, the product given was tested with a one piston diesel engine, 11 hp. Without any engine adjustment, the experimental result of the oil was compared to diesel and the comparisons shown that the specific fuel consumption of diesel is higher than the modified used oil, the thermal efficiency and the air-fuel ratio of diesel is lower than the oil.

Sittisak Klongdech (13) studied the quality improvement of used cooking oil proceeded into the reaction of trans-esterification for substitution of diesel. To progress the experiment, the used cooking oil brought from McDonald was passed into the synthesize reaction for blending the product with diesel in the rates: 20%, 30%, 40%, and 50%. By testing with the one piston diesel engine with 7.5 hp/ 2200 rmp, The result have been shown that the emission of carbon monoxide, nitrogen oxide, and black smoke trend to incline when the proportion of methyl ester increase. Beside, as the more boiling point and viscosity of the synthetic, it is so necessary to use the severe ignition. For conclusions, the most suitable proportion is the methyl ester blending of 20%.

Surachai jirachakrit (4) studied the prediction of burning of vegetable oil blended with diesel under the natural transfer state. To burn the 5-cm Diameter oil drop, the results have been displayed the rates of flammability from the highest to lowest: diesel, coconut oil, palm oil, rice bran oil, and soybean oil. Besides, the exhaust test shows that the carbon monoxide trend to increase when the vegetable oil is higher which can descend from the lowest as follows: soybean oil, coconut oil, palm oil, and rice bran oil. As the considering to the engine efficiency and exhaust emission from testing of each mixing at 5 –10%, the most effective to the least one can be descended as follows: coconut oil, palm oil, soybean oil, and rice bran oil.

Ayhan Demirbaş (20), reviewed the production process of biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other method. The paper showed the pyrolysis produces more biogasoline than biodiesel fuel. Soap pyrolysis products of vegetable oils can be used as alternative diesel engine fuel. Methyl ester and ethyl ester of vegetable oils have several outstanding advantages among other new renewable. The factors affecting transesterification are the molar ratio of glycerides to alcohol, catalyst, reaction temperature and pressure, reaction time and the contents of free fatty acids and water in oils. The commonly accepted molar ratios of alcohol to glycerides are 6:1 – 30:1.

Y. Zang and team (21) studied the production processes of bio-diesel from purify vegetable oil and cooked oil beneath the acidic and basic catalytic reactions. By focusing on the assessment of production processes and the limitations, the production process of bio-diesel under basic catalytic reaction with the purify oil provides the interested results those are the less-using of instruments, and amount of row material- than the acidic one, but take a higher cost. The under-acidic catalytic production with row material of cooked oil is easier and has more technical feasibility than the basic one. Moreover, the amount of ester, the bio-diesel, is found the trend to be increased when the proportion between oil and alcohol, temperature, acid concentration, and reaction time, are extended.

Charles Peterson (24) studied the optimization of a batch type ethyl ester process. The results indicated that conversion of rapeseed oil into ethyl ester for use as biodiesel fuel involves transesterification of the oil triglycerides to mono-ester of the component fatty acids. To accomplish this conversion, raw rapeseed oil is treated as a catalyst. During the process, the glycerol which is produced is insoluble in the ester product, and being heavier, settles out carrying most of the dissolved KOH catalyst with it.

Mohamad I. Al-widyan (25) researched the experimental evaluation of the transesterification of waste palm oil into biodiesel. After synthesis, the biodiesel was blended into diesel in several ratios. The entire blends, including 100% ester were run on a standard test rig of a single-cylinder, direct-injection diesel engine. Tests were conducted to compare these blends with the baseline local diesel fuel in terms of engine performance and exhaust emission. The results indicated that the blends burned more efficiently with less specific fuel consumption, and therefore, resulted in higher engine thermal efficiency. Furthermore, the blends produced less carbon monoxide and unburned hydrocarbons than diesel fuel. The 100% ester fuel and the blends of

75:25 ester/diesel gave the best performance while the 50:50 blend consistently resulted in the lowest amounts of emissions over the whole speed range tested.

Mohamad I. Al-widyan (22) studied the utilization of ethyl ester of waste vegetable oil as fuel in diesel engines. In this work, the waste palm oil was transesterified under various conditions. H_2SO_4 and different concentrations of HCL and ethanol at different excess levels were used. Higher catalyst concentrations (1.5-2.25 M) produced biodiesel with lower specific gravity in a much shorter reaction time than lower concentrations. The H_2SO_4 performed better than HCL at 2.25 M, as it resulted in lower specific gravity relative to lower excess levels. The best process combination was 2.25 M H_2SO_4 with 100% excess ethanol which reduced specific gravity from an initial value of 0.916 to a final value of 0.8737 in about 3 hours of reaction time. Biodiesel had the behavior of a Newtonian fluid.

According to all relevant documents, it can be concluded that biodiesel has, trend to release less emission than the petrodiesel, and potentiality to be the diesel substitute fuel. Additionally, to produce the biodiesel from the used lipid, it trend to be more feasible by proceeding under the acidic condition than the basic one. The paper also showed that there is no different between the competencies of the biodiesel produced from methanol and ethanol, but the ethanol is a renewable local resource and has less toxic. So, research had made a decision to produce the waste grease biodiesel via the acidic-catalysed transesterification in the present of ethanol.

CHAPTER 3

METHOD OF THE RESEARCH

The study of biodiesel synthesis was concentrate on the quality assessment to serve the objectives of diesel substitution. The methodologies of this research consist by the factors which are shown below.

3.1 Factors of the study
3.2 Biodiesel production process
3.3 Qualities measurement
3.4 Qualities assessment

3.1 Factors of the study

The factors that concerned to this study are shown as followed.

3.1.1 Sequences of the study

To assess of biodiesel, a waste synthetic fuel, had many steps to forward to the final stage as followed.

3.1.1.1 Grease sludge collection

With the chemical process to produce the biodiesel of this study, the grease of canteen's sewage needed to be involved by collecting from the canteen's grease trap of Mahidol University's center canteen.

3.1.1.2 Waste separation

To had such a raw material reacted into the chemical reaction, the grease, which was a require matter, needed to be purified by hexane extraction to separate the unwanted waste out of grease.

3.1.1.3 Grease transformation process

To synthesize the biodiesel, the one unit sampling trap grease had to be proceeded in the restructured processes by acidic-catalysed transesterification reaction for creating ethyl ester, the biodiesel, which had the fuel properties close to diesel.

3.1.1.4 Fuel qualities tests

This step was to expose the attribute of the synthetic fuel by the performances of the fuel properties, the serving of engine performances, and the after-burned exhaust emissions.

3.1.1.5 Test results analysis

By the statistic methodology, the results of testing were analyzed by comparing of the tests to regulated standard, and the results between each testing group which were the pure diesel, and the diesel blended with the biodiesel.

3.1.1.6 Assessment

The analysis results would provide the considerable information which would be necessary to use in the fuel quality assessment.

3.1.2 Studied locations

To progress the study, the processes had to be mainly allocated into the laboratory used to fuel synthesize, and fuel properties test as follows.

- The biodiesel synthesis was allocated at the chemical laboratory of the faculty of environment and resources studies, Mahidol University.
- The fuel properties analysis was undertaken at the division of fuel analysis of the faculty of science, Chulalongkorn University and the department of Mechanical Engineering, Royal Thai Air Force Academy.
- The engine test was proceeded at horse power measurement unit of the Power Lab, AAS Autoservice Co., Ltd..

3.1.3 Sample

By statistical reason, the whole grease, which was testing material of the study, was collected within one time from the grease trap that was central canteen's of Mahidol University, Salaya Campus.

3.1.4 Variable

As the experimental study, the study processes must be proceeded in various methodology for solving the study's hypothesis, so that, there were many variables containing in this study, which can be divided into 3 types as followings.

3.1.4.1 Independent Variables

To figured out the best proportion of blended fuel, the percentage ratios between diesel and biodiesel were determined in various ratios as followings. 100:0, 95:5, 90:10, 85:15, and 80:20.

3.1.4.2 Control Variables

- Tested engine of NISSON, TDG21-C43524, 2,494 c.c., 4 cylinders, and 90 Hp, with out modification.
- Engine work rounds: 1,500 - 4,000rpm.

3.1.4.3 Dependent Variables

3.1.4.3.1 Fuel Properties

- Viscosity at 40^{o}C (mm^{2}/s)
- API Gravity at 15^{o}C (g/cm^{3})
- Flash Point (^{o}C)
- Heat Valued (Cal/g)

3.1.4.3.1 Engine Test

- Engine Performances
- Engine Power (Hp)
- Torque (Nm)

3.1.5 Statistical analysis

After the conversion of fat to biodiesel, quality of the biodiesel had been examined by testing to the high-speed diesel engine with the mixing between biodiesel and diesel in 5 various proportions. The results were then computing in the statistical process.

1) The grease-extracted results were calculated their central tendency

2) The fuel specific properties were analyzed with the statistic of two-related samples tests of Wilcoxon singned-rank test.

3) The engine performances were conducted to compare their correlations value (R).

3.2 Biodiesel production process

Biodiesel, the organic compound which have the functional group of ester, is producible from the reaction between Methanol (or Ethanol) and fatty acid. To fulfill the reaction with heat and catalyst of strong acid such as Sulfuric, or strong base such as Sodium hydroxide, the products that are Methyl ester (or Ethyl ester), Glycerol, and organic substance, will be produced.

This study is to modify the sample that is grease collected from grease trap of the central canteen, Mahidol University, Saraya campus. The trapped grease will be proceeded in the extraction process for separating the grease out of mixed waste, then, the grease will be undergone in the trans-esterification reaction under the acidic condition to construct the methyl ester, the bio-diesel. So that the production process can be divided into 2 procedures:

3.2.1 Extraction of the grease from mixed waste sludge

The waste collected from canteen's grease trap is a one-time sampling in high amount for being a substitute matter of the grease from canteen. The extraction processes are the followed.

3.2.1.1 As a high amount sampling, the collected grease from trap can not be proceeded at a time, hence, the waste has to be acidified for structural maintaining before taking in chemical reaction processes by adding the 1-ml conc. HCl for every 80 grams of sample.

3.2.1.2 Divide 20 $\pm$ 0.5 grams from the waste in to the 150-mL beaker, then, decrease its pH to become 2 by adding 0.3-mL conc. HCl.

3.2.1.3 Heat the sample by the oven at 103^{o}C in 4 hr, for dehydrating. The sludge waste will become solid.

3.2.1.4 Grind the solid to make it fine and fill the round bottle flask with 100 g of such matter, then add 200 mL of solvent, the hexane.

3.2.1.5 Combine the flask to the instrument of refluxtion for extracting the grease out of the waste by heat it at 90^{o}C for 4 hr.

3.2.1.6 To obtain the grease without any waste, mixing matter in the flask has to be separated the liquid out of the solid by strainer for then evaporation.

3.2.1.7 Evaporate the solution by the evaporator at 85^{o}C for 15 min for separation the grease of the hexane.

3.2.2 Production processes of biodiesel

To produce the biodiesel by transesterification reaction, the grease extracted from mixing waste need to be identified the quantity of free fatty acid by titrating with sodium hydroxide, so that the amount of alcohol used to react with the grease in further process will be calculable. Thus, the production processes of biodiesel can be divided as followed.

3.2.2.1 Identification of free fatty acid composition

To proceed the conversion, the ratio of the alcohol and grease needed to be calculated for determine their volume used in the reaction. Therefore, the grease had to be passed in the fatty acid composition analysis of gas chromatography of methodology type Ce2-66, Ce 1-62 AOCS 1993.

3.2.2.2 Transesterification reaction

To produce the biodiesel, the grease needs to be reacted with alcohol. The processes can be exposed as followed.

- Fill 500-ml beaker with the grease gathered from the extraction process, then, heat the material up to 80^{o}C.

- Mix a half of ethanol, whose amount has been calculated already, with conc. H_2SO_4 for making this reactant's pH becomes 3.

- Stir the mixture and then let it mix for 1 hr.

- After that, let the mixture cool down and wash it with deionized water.

- Separate the water and the impurity out of the product then take it into the other round bottle flask.

- Add the flask with the rest of ethanol, which had been adjust the pH already. Combine the flask with the reflux, and then heat it up to 90^{o}C for 90 min.

- Pour the solution in the separatory funnel to make it divided into 2 layers which ethyl ester would be upper and the other products were below.

- Separate the unwanted, the lower liquid, out and then washed the biodiesel by shaking with deionized water to clean the impurity out of the product.

- Pour the product trough the Sodium Sulfite for eliminating the water.

3.3 Quality Measurement

The qualities of synthesized biodiesel as mentioned are evaluated step by step as followed.

3.3.1 Fuel properties test

There are many properties used to indicate the potential of fuel such as the viscosity, the density, and the flash point, etc. For this study, the biodiesel will be passed in the fuel test procedure to expose its properties in order to compare to diesel. The testing methods are shown below.

3.3.1.1 The Kinematics Viscosity, at 40°C; ASTM D-2270-93

The Cleaning Solution

- The chromic acid (potassium dichromate), or the sulfuric acid, with concentration at 34 g/L is used as a cleaning solution.
- The solvent used with this cleaning solution are kerosene, petroleum spirit, or naphtha.
- For the sample such as bunker oil, some kind of kerosene should be used with a stronger cleaning solution such as toluene, or xylene.
- The dry solvent should be acetone
- The water used for cleaning the test tube should be filtered before involvement.

The process of testing of kinematic viscosity with translucent liquid

- The viscometer tube needs to be calibrated before using. In case of impure sample, the material has to be strained before proceeding.
- The viscosity tube used in test should be proper with the value of oil viscosity
- The temperature of viscosity bath must be at the same value of the regulation.
- In case of testing of many tubes at a time, to move-even one of-testing tubes is able to make the test results inaccuracy to another.
- The differences of timing, temperature, and viscosity, of testing processes are effectible to the test results.
- To measure the high kinematic viscosity matter, the 30 minutes of testing time is enough for the result providing.
- Begin to investigate the viscosity value of sample when the both temperature of sample and testing bath are at the equivalent point.
- Adjust level of sample inside the viscosity tube to the point which is higher than the marked point for 7 mm before 0.1 second of time running. If the testing time is less than the regulated standard, the test needs to be restarted again.
- The acceptable testing time is at least twice then record the time of flowing.

- If the testing results of two-time test are in the acceptable range, so it is reportable.

3.3.1.2 The API Gravity, at 15°C; ASTM D-1298-99

This is the methodology of the measuring of density, or specific gravity, or API gravity, of crude, petroleum products, and blending petroleum, or the product which is not petroleum but liquid.

The value read from hydrometer at any temperature will be converted to be the density value at 15°C, and the API Gravity at 60°F, by using of the International Standard Table 5B (API Table 5B)

The instruments:

- Glass Hydrometer with scale of density unit, specific gravity unit, or API Gravity unit, depended on demand.
- The thermometer of ASTM 12F
- Hydrometer Cylinder which has a suitable height for the floatation of hydrometer in sample. The range between the top, and the bottle, of hydrometer and cylinder's must be at least 25 mm (2.5 cm.)

The test temperature:

For the API Gravity measurement by using of hydrometer, the most accurate result is from measuring at 15°C or 60°F. The temperature at the testing time should be in range of -18°C to +90°F depending on typing of matter or oil sample, and proper condition. For diesel, the suitable temperature should be in range of 77°F to 86°C.

Normally, the sample that has temperature higher than 95°F needs to be cooled down before measuring, that is the immediately value reading may be cause the missing value.

The methodology:

- Adjust the temperature of Hydrometer Cylinder, and Thermometer, to be at the temperature that is close to sample about 5°C, or 41°F.

- Pour the sample carefully into cleaned Hydrometer Cylinder and make sure that there are no splashing, or any foam in the sample. If there are any foam emerges, the filter paper will be used to break that one by let the cleaned filter paper touch to such foam.

- Stay the cylinder in vertical position where there is no wind. Beside, the temperature of surrounding can be fluctuated within only 2°C (5°F) since beginning till finishing.

- Use the 12F thermometer to stir the sample in cylinder till the samples' temperature are mixed and closed to 0.1°C as much as possible.

- Put the hydrometer into sample and prevent the hydrometer's handle, which is higher than the dropped part, from soaking with the sample. Then, let the meter float freely inside the cylinder without touching the cylinder' edge.

- To get the testing value, take a look at the cross area of sample and scale of the hydrometer. Beginning with take a sight at the lower of sample surface, the value will be detected by move up the sight till the surface level, then, read the scale.

- In case of measuring with opaque liquid, the area detected must be at a little higher of the sample's surface.

3.3.1.3 Flash Point; ASTM D-93-99a

The method testing with petroleum product covers the temperature at 40°C to 360°C by manual method of close system and automatic method of close system of Pensky-Martens.

The instrument:

- The apparatus
- The cover with the motor and dipping handle
- The Heater
- The Ignition Source
- The Air Bath
- The Thermometer

The methodology:

- Prepare a sample and a test cup in low-temperature condition, at least 18°C
- Fill the test cup with the sample, right at point of the cup' scale.
- Put the covered sample into the Air Bath.
- Insert thermometer to the hold of the cover
- Adjust the test flame to be 3.2 – 4.8 mm
- Begin to heat up by tuning the rate of temperature to 5-6°C/min increasing.
- Turn on a stirrer which is under speed control at 90-120 rpm.
- For the sample that has an 110°C flash point or lower, the measuring will be started when its temperature reach to 23 $\pm$ 5°C, lower than expected point.
- Put the tested flame in the cup-for every single of 1°C increasing- for 0.5 second a time, then, immerse in empty cup for 1 second.
- In case of flash point is higher than 110°C, the test flam has to be put in the cup with every 2°C higher.

3.3.1.4 Heat Value

The fuel heat value will be conducted with the bomb calorimeter. This instrument is about to measure the heat which releases from the fuel sample. By detecting the temperature of water after the fuel burned, the heat value will be calculated by the data of temperature.

Instruments:

- The bomb calorimeter with water bath, sample container, stirrer, thermometer, and explode bomb controller.
- Thermometer ASTM C 56 with range of 19-35°C, 2 decimal detectable and the magnifying glass.
- Oxygen tank along with injector.
- Stopwatch
- Cylinder with measure scale for fuel transfer.
- Exploder wire with 10-cm long.
- Benzoic acid
- Fuel sample

The methodology:

- Combine all instruments following the hand book
- Implicate the wire with the electrodes stick.
- Take the fuel container into bomb calorimeter then compose the it with its cover, tightly.
- Add the oxygen into bomb calorimeter.
- Pour in water to the water bath then put the bomb calorimeter onto the center of the instrument.
- Note the ambient temperature for 5 minute and then press the switch of bomb.
- Record the temperature by every single 10 second till the temperature is constant.
- Calculate the heat value with the temperature data received from the note above. By the formula of heat value which shown below

$$W\Delta t = Q \times g + e_1 + e_2 + e_3$$

3.3.2 Measurement of fuel performance

As a fuel property of ethyl ester is close to diesel, to use such substance instead of diesel is so feasible to be implemented in real use.

Consequently, this study did the test to that matter with a tested diesel engine in scope of the engine performances, and exhaust emissions. By blending the fuel with diesel in various proportions, the mixtures were undertaken in the testing process in same tested engine to have there results compared with one another and the pure diesel for an assessment. There were 2 tested processes holding in this course:

Test of the engine performances

To test of the engine performances, the sample had to take in the inertia dynamometer for measurements of torque, and power, value. These processes were all controlled under the computer system of private sector engine test laboratory.

3.4 Quality Assessment

After measurement processes of biodiesel as substitution fuel, the data received from the test was taken to the assessment as followed.

3.4.1 The assessment of fuel potential

The tested results of fuel properties were brought to compare with the diesel properties standard regulated by the Ministry of Commercial.

3.4.2 The quality assessment of biodiesel

By using the results of fuel performance test, the data were taken to assess the fuel quality in order to indicate the ability of such fuel with substitution of diesel. The methods are shown bellow.

- The analysis of the correlation value of the test of engine performance
- The comparison of the value obtained form of each sample to the standard from the Department of Pollution Control, the Ministry of Natural Resources and environment.

CHAPTER 4

RESULTS AND DISCUSSION

After all production processes and property measurements were run, all data received from those procedures were recorded for being the information of biodiesel evaluation, furthermore.

4.1 Results of the study

These results of the study were conducted into 2 categories that were biodiesel synthesis and biodiesel specific properties. All the outputs are shown as followed.

4.1.1 Biodiesel synthesis

The trapped grease collected from canteen's grease trap had characters of sticky liquid combination, gray color and severe smell like sewage of a bunch of organic waste. Not only a grease, the waste also had the other things inside such as tubes, elastics, food wastes, cigarettes, and some small creatures like fly worms, and cockroach cocoons. These were the obstacles of grease waste using and it needed to be prepared before reaction processes.

4.1.1.1 Preparation of grease

It was unable to have the raw trapped grease reacted in the synthetic reaction because there were a lot of unwanted contamination inside, moreover, the molecular structure of the grease had been changed by the cooking and washing processes. To make the grease usable, the trapped grease needs to be extracted for separating the grease out of the unwanted matter. Here are the extraction results.

4.1.1.1.1 Indication of the quantity of hydrochloric acid

By the statistical reason, the trapped grease had to be collected within one time in high amount, and need to be maintained by adding 1-ml of concentrate hydrochloric acid for every 80 g of dry weight of waste. So, the trapped grease must be dried in oven with temperature of 103°C to examine the dry weight. The results are shown bellow.

Table 4-1 The dry weight of trapped grease

Replication / Waste Weight (g)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	AVE.
Fresh	100	100	100	100	100	100	100	100	100	100	100
Dry	45.88	47.10	47.90	48.14	47.50	47.50	48.02	47.82	47.01	46.95	47.38

The results show that 100 g of fresh waste could provide 47.38 g of the dried one, which was 47.38% of the fresh weight.

Since there were 34 kg of trapped grease, so the whole amount of the acid used in maintaining the grease was 201.365 ml.

4.1.1.1.2 Quantity of the extracted grease

After getting dry, the sludge had to be proceeded by extracting with Hexane, the organic solution, to dissolve the grease out of waste. The results are shown bellow.

Table 4-2 The quantity of pure grease extracted from sludge

Weight (g) \ Replication	1	2	3	4	5	6	7	8
Sludge	600	600	600	600	600	600	600	600
Grease	325.25	325.22	326.25	325.23	325.45	324.02	325.16	325.18

Weight (g) \ Replication	9	10	11	12	13	14	15	AVE.
Sludge	600	600	600	600	600	600	600	600
Grease	325.40	324.25	324.64	325.05	325.33	325.34	326.23	325.27

The extraction results was shown that the 600 g of sludge could provide 325.27 g of grease, thus, the 100 g of sludge would provide 54.21 g of grease which mean there were 54.21% of grease in dry waste.

According to the results above, it was exposable that a hundred grams of trapped grease had 47.38 g of dry weight, which had 54.21% of grease that was 25.85 g. Accordingly, a hundred grams of waste obtained 25.85% of grease.

4.1.1.2 Biodiesel synthesis

4.1.1.2.1 Proportion between alcohol and grease

The quantity of alcohol was computable from the results of gas chromatography test as followed.

- Quality and quantity of fatty acid

After extraction the grease out of sludge, the grease was proceeded in the gas chromatography method to find out the fatty acid composition. The results were below.

Table 4-3 The chromatography test results

Fatty acid composition	% Quantity
Myristic acid	2.00
Palmitic acid	71.87
Stearic acid	16.16
Total Saturated fatty acid	**90.03**
Oleic acid	9.97
Total Unsaturated fatty acid	**9.97**
Total fatty acid	**100.00**

- Proportion between ethanol and grease

By using the test result of gas chromatography, the proportion between ethanol and grease could be calculated as shown in appendix C page 109. The result shown that the proportion of ethanol : grease was 4 : 1.

4.1.1.2.2 Result of the synthesis

After passed the grease into the transesterification reaction to converse to be an ester compound, the product got a quite dark red color, and reek smell. For more detail is demonstrated below.

Table 4-4 The results of the biodiesel synthesis

Time	Volume of grease (ml)	Volume of ester (ml)	pH	
			Unwashed	Washed
1	600	576	1.0	5.7
2	600	572	1.3	6.3
3	600	567	1.3	6.2
4	600	569	1.5	6.9
Total	**2,400**	**2,284**	**-**	**-**
Average	**600**	**571**	**1.3**	**6.3**

According to result, the grease with volume of 600 ml could converse to ethyl ester, the biodiesel, at 571 ml, which was 95.17% conversion. The pH of the product was 1.3 and being 6.3 after washing.

4.1.2 Synthesized biodiesel specific properties

After finishing all synthesized processes, the biodiesel was blended with diesel in percentage of 5, 10, 15, and 20 respectively. Then the blends were examined in the fuel specific test. The results are in the table below.

Table 4-5 The results of the fuel specific test

Parameter \ Samples	Base line diesel	Blended				B100	Standard
		B5	B10	B15	B20		
Viscosity (mm^2/s)	3.54	3.69	3.70	3.90	4.15	8.69	1.9-6.2
API Gravity (g/cm^3)	0.83	0.84	0.84	0.84	0.85	0.9	0.86-0.9
Flash Point (^oC)	68.5±1.5	74	76 ± 2	71	76	181 ± 1	Min.100

Source: Appendix B

Table 4-5 The results of fuel specific test (Continue)

Samples / Parameter	Base line diesel	Blended				B100
		B5	B10	B15	B20	
Heat Value (Cal/g)	10,389.11	10,505.36	11,803.64	12,669.16	11,587.26	9,685.35
Smoke feature	Dark black	Black	Black	Black	Black	Pale black

Source: Appendix B

The followings are the conclusion of the fuel specific test.

4.1.2.1 Viscosity at 40°C (mm^2/s); ASTM D445-88

According to the viscosity measurement, the results exposed that biodiesel fuel had the viscosity of 8.69 mm^2/s higher than the ASTM standard regulation.

After blended with diesel, each fuel were measured their viscosity. The results were then shown its relation of increasing in value when the biodiesel portion was higher respectively. The highest viscosity remained in B20 that was 4.16 mm^2/s and the lowest one was at B5 that was 3.69 mm^2/s.

Yet, all viscosity received from the blends were in the acceptable range, under ASTM regulation, that was 1.9 – 6.2 mm^2/s, as show in the figure 4-1 below.

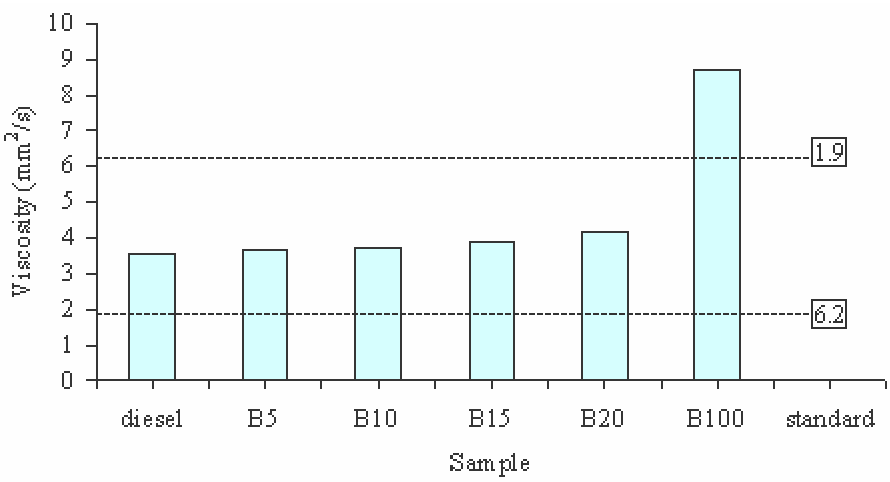


Figure 4-1 the results on viscosity test

After the values of each fuel were calculated in the statistical analysis, the results exposed that there were no difference of viscosity among the fuels with the significant at the 0.01 level.

4.1.2.2 API Gravity at 15°C (g/cm^3); ASTM D1298

As the results on API Gravity test, the pure biodiesel, B100, remained the value of 0.895 g/cm^3, which was in the regulated standard of ASTM.

With the test of the other fuels, the lowest value was detected at the baseline diesel that was 0.83 while the blends caught the higher value as its biodiesel proportion was increased. So, the highest API Gravity among the blends remained in the B20 that was 0.846 while the lowest one was at 0.837 from B5. All results were shown in the figure 4-2 below.

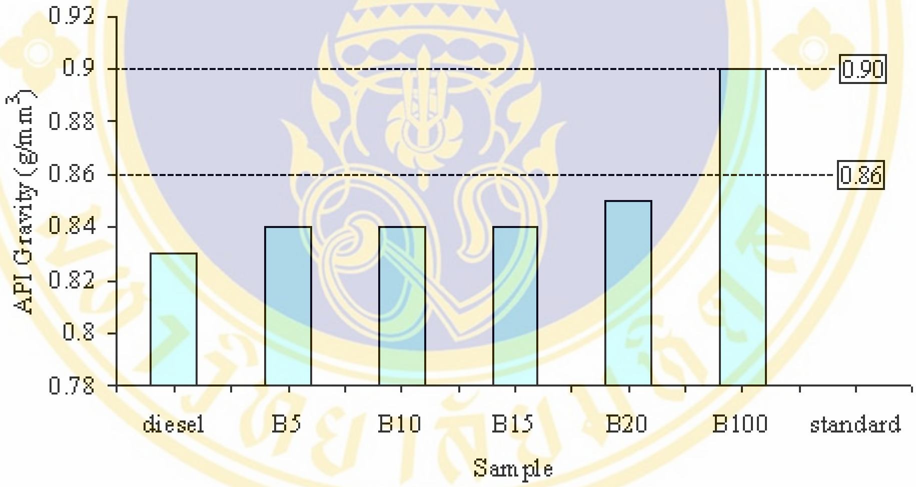


Figure 4-2 the results on API Gravity test

After the values of each fuel were calculated in the statistical analysis, the results exposed that there were no difference of API Gravity among the fuels with the significant at the 0.05 level.

4.1.2.3 Flash point (°C); ASTM D93, and ASTM D92

The highest flash point received from test was obtained from B100 that was 184°C. However, this still followed the regulation of ASTM, which is a minimum at 100 °C.

With the results of the other fuel, the lowest flash point was at the baseline diesel, which remained 68.5 °C while the entire blends had little higher flash point, but did not incline follow the proportion as in the other parameter. The closest flash point to baseline diesel was B15 that was 71 °C, All results were shown in the figure 4-3 below.

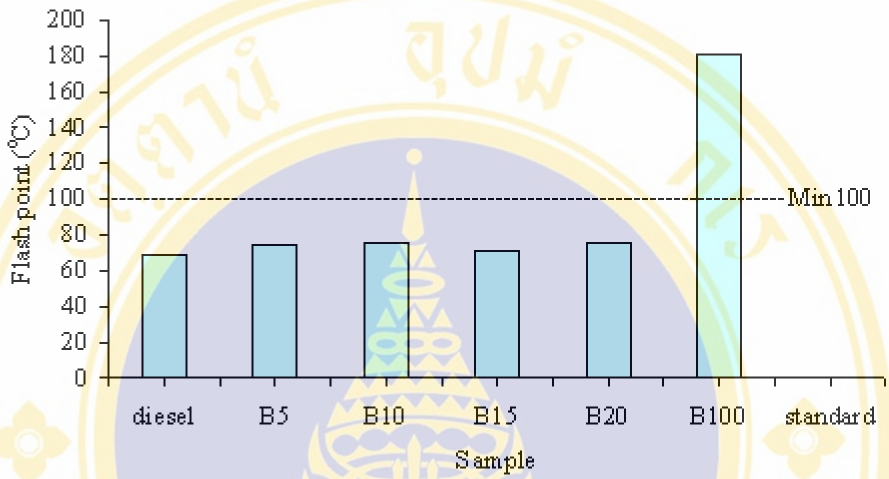


Figure 4-3 the results on flash point test

After the values of each fuel were calculated in the statistical analysis, the results exposed that there were no difference of flash point among the fuels with the significant at the 0.05 level.

4.1.2.4 Heat value (Cal/g)

Behind the heat value test, the results showed that baseline fuel had its value of 10,389.11 Cal/g while B100 had the lowest one of 9,685.35 Cal/g, less than diesel 6.77%.

For all blends, there were remarkable data of the test that is the highest heat value was in the B15, which was 12,669.16 Cal/g higher than baseline diesel 17.99%. In the meantime, the other blends performed the higher value as well, namely, the lowest one of among the blends was B5 which remained 10,505.36 Cal/g higher than baseline fuel 1.10% while B10 and B20 were also higher with the percentage of 11.98 and 10.34 respectively. All results were shown in the figure 4-4 below.

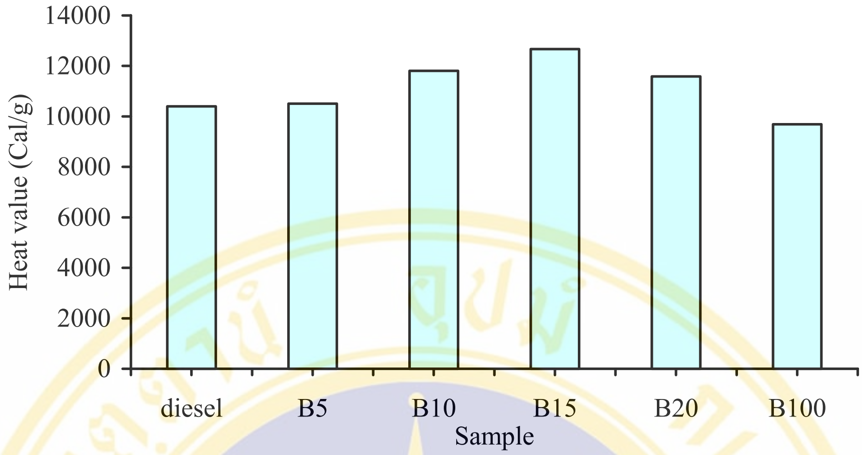


Figure 4-4 the results on heat value test

Moreover, after the test finishing, there were the smoke remain in the test unit which were a little different among the samples. Those were the highest smoke was detected from baseline diesel, which performed the darkest black smoke whereas the least one was caught from B100, which had the pale black one while the other sample showed the equalize black.

4.1.3 Engine performance

By test of engine performance of the entire blends along with the baseline diesel on the purpose of performance comparing, all fuel were run into the high speed diesel engine of NISSON type TDG21-C43524, 2,494 c.c., 4 cylinders, 90 Hp, without any modification.

The test of engine performance was measured in 2 parameters that were the engine torque and power. Every single value of those parameters were shown at the table in the appendix B. All results could be shown in brief as followings.

4.1.3.1 Torque measurement

When the fuel was undergone in test of torque, every sample had shown almost the same results as followings.

4.1.3.1.1 Test of Baseline diesel

After testing, the results had shown the curve of torque along with the engine speed. The range of torque was shown the highest value of 150.121 Nm at the engine speed of 1812.38 rpm whereas the lowest one was 122.558 Nm at 4191.88 rpm. All engine speed performed as showing below.

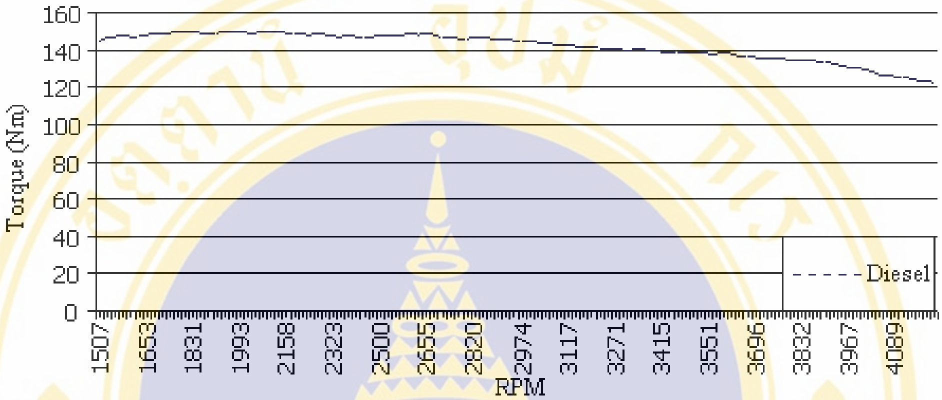


Figure 4-5 the results on torque of baseline diesel

The statistical analysis showed that the baseline diesel had the correlation value (R) of 0.99

4.1.3.1.2 Test of B5

The blended of B5 had its torque range which performed the highest value of 149.57 Nm at the engine speed of 2142.31 rpm while the lowest one was 122.789 Nm at 4187.73 rpm. All value of torque with each engine speed, compared with baseline diesel, was shown in the figure 4-6 below.

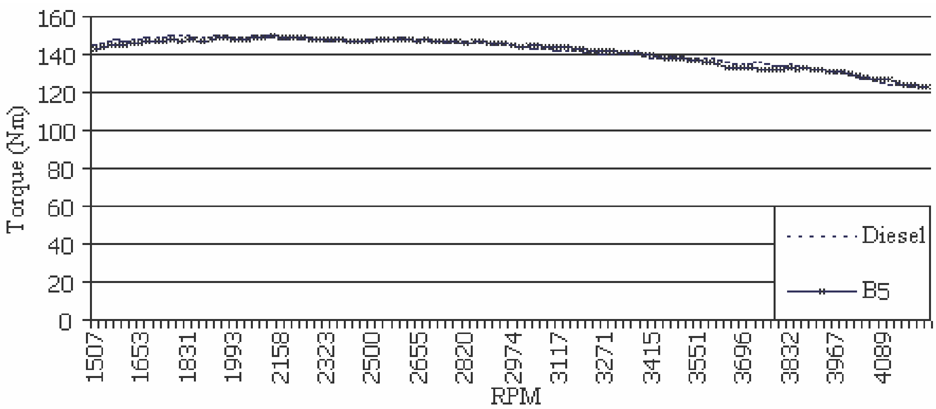


Figure 4-6 the results on torque of B5

After taking the graph into the statistical analysis of correlation, the results showed that B5 and baseline diesel had same correlation between engine speed and torque value by the equalize of R at 0.99.

4.1.3.1.3 Test of B10

The blended of B10 had its torque range which performed the highest value of 152.60 Nm at the engine speed of 1993.31 rpm while the lowest one was 122.668 Nm at 4193.97 rpm. All value of torque with each engine speed, compared with baseline diesel, was shown in the figure 4-7 below.

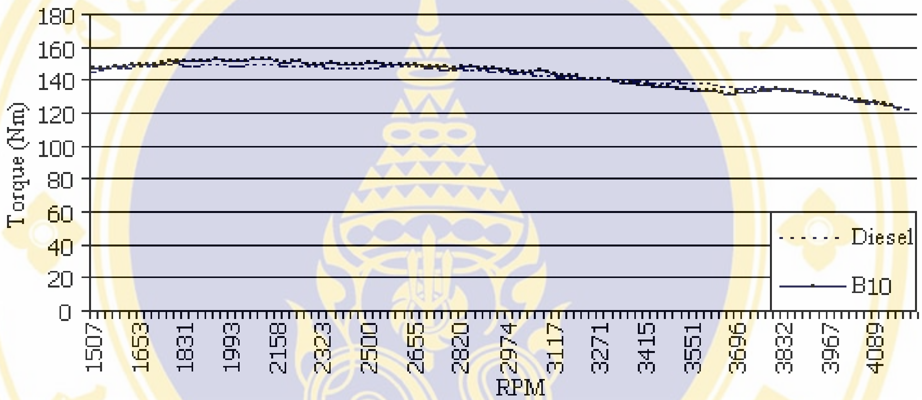


Figure 4-7 the results on torque of B10

After taking the graph into the statistical analysis of correlation, the results showed that B10 and baseline diesel had almost the same correlation between engine speed and torque value, namely, B10 had the value of R at 0.97 while Baseline diesel had 0.99.

4.1.3.1.4 Test of B15

The blended of B15 had its torque range which performed the highest value of 151.88 Nm at the engine speed of 2178.05 rpm while the lowest one was 120.703 Nm at 4190.04 rpm. All value of torque with each engine speed, compared with baseline diesel, was shown in the figure 4-8 below.

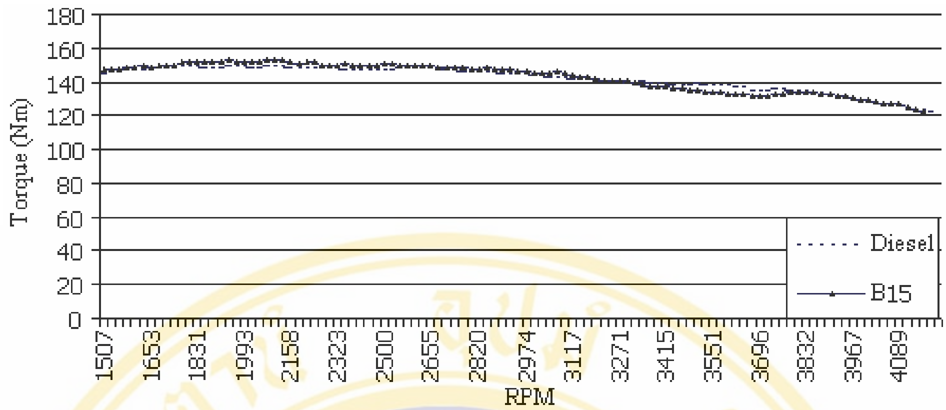


Figure 4-8 the results on torque of B15

After taking the graph into the statistical analysis of correlation, the results showed that B15 and baseline diesel had almost the same correlation between engine speed and torque value, namely, B15 had the value of R at 0.97 while Baseline diesel had 0.99.

4.1.3.1.5 Test of B20

The blended of B20 had its torque range which performed the highest value of 151.80 Nm at the engine speed of 1922.81 rpm while the lowest one was 121.866 Nm at 4197.08 rpm. All value of torque with each engine speed, compared with baseline diesel, was shown in the figure 4-9 below.

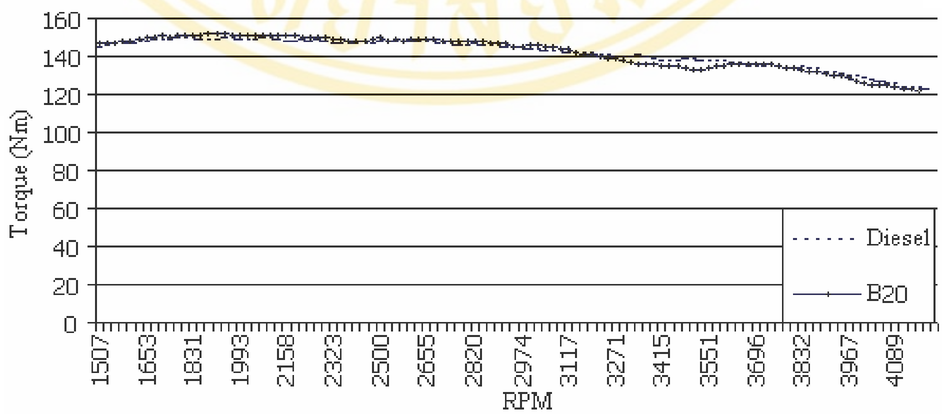


Figure 4-9 the results on torque of B20

After taking the graph into the statistical analysis of correlation, the results showed that B10 and baseline diesel had almost the same correlation between engine speed and torque value, namely, B20 had the value of R at 0.97 while Baseline diesel had 0.99.

Following the results on torque measurement above, it could mention that all fuel had the value of correlation between their engine speed and its torque close to the baseline diesel.

4.1.3.2 Power measurement

When the fuel was undergone in test of power, every sample had shown almost the same results as followings.

4.1.3.2.1 Test of Baseline diesel

After testing, the results had shown the curve of power along with the engine speed. The range of power was shown the highest value of 73.83 Hp at the engine speed of 3979.58 rpm whereas the lowest one was 31.05 Hp at 1506.50 rpm. All engine speed performed as showing below.

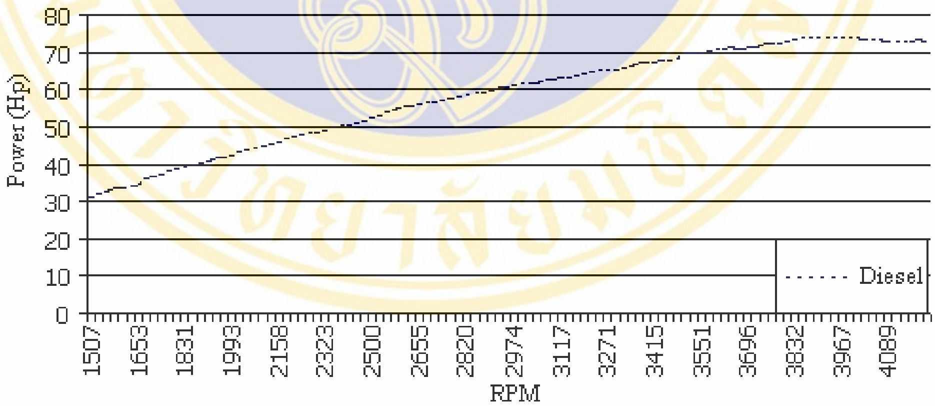


Figure 4-10 the results on power of baseline diesel

The statistical analysis showed that the baseline diesel had the correlation value (R) of 0.99

4.1.3.2.2 Test of B5

The blended of B5 had its power range which performed the highest value of 73.76 Hp at the engine speed of 3970.68 rpm while the lowest one was 30.76 Hp at 1510.95 rpm. All value of power with each engine speed, compared with baseline diesel, was shown in the figure 4-11 below.

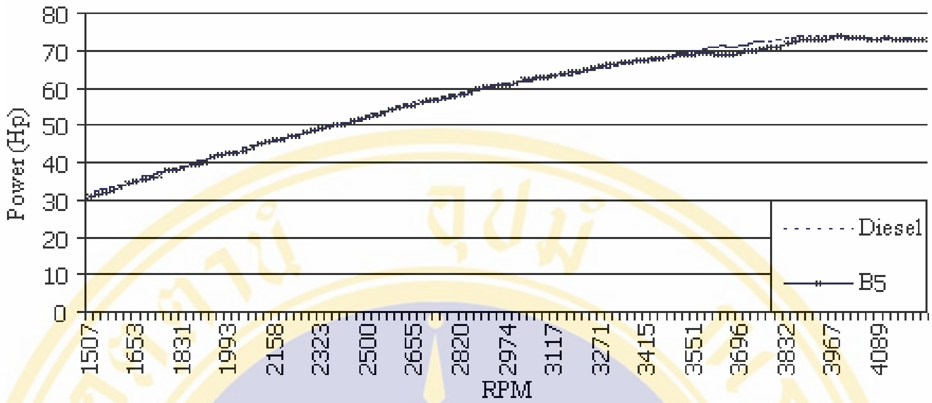


Figure 4-11 the results on power of B5

After taking the graph into the statistical analysis of correlation, the results showed that B5 and baseline diesel had same correlation between engine speed and power value by the equalize of R at 0.99.

4.1.3.2.3 Test of B10

The blended of B10 had its power range which performed the highest value of 174.47 Hp at the engine speed of 3982.89 rpm while the lowest one was 31.64 Hp at 1514.79 rpm. All value of power with each engine speed, compared with baseline diesel, was shown in the figure 4-12 below.

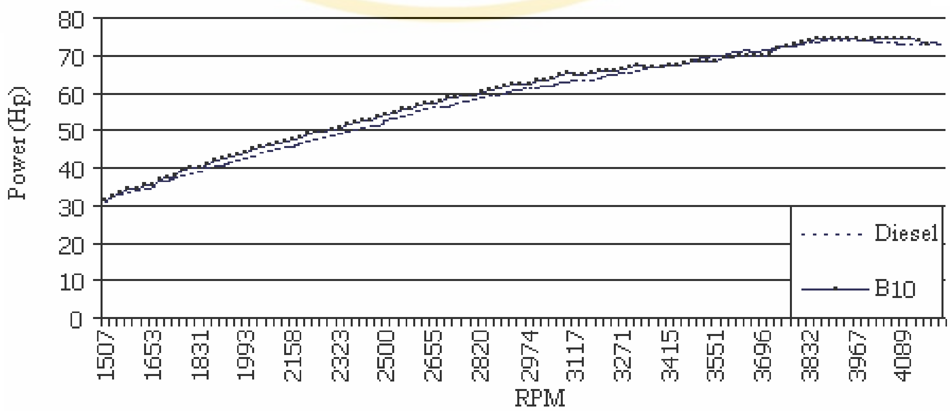


Figure 4-12 the results on power of B10

After taking the graph into the statistical analysis of correlation, the results showed that B10 and baseline diesel had the same correlation between engine speed and power that was R = 0.99.

4.1.3.2.4 Test of B15

The blended of B15 had its power range which performed the highest value of 73.51 Hp at the engine speed of 3893.83 rpm while the lowest one was 31.33 Hp at 1514.97 rpm. All value of power with each engine speed, compared with baseline diesel, was shown in the figure 4-13 below.

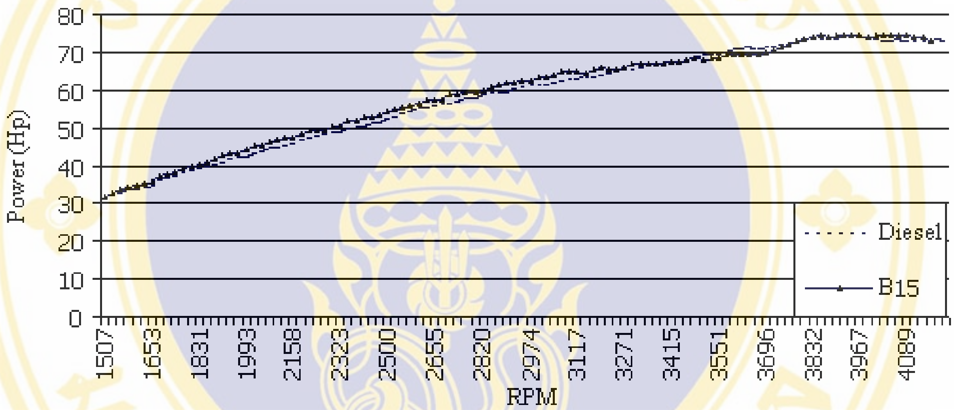


Figure 4-13 the results on power of B15

After taking the graph into the statistical analysis of correlation, the results showed that B15 and baseline diesel had the same correlation between engine speed and power that was R = 0.99.

4.1.3.2.5 Test of B20

The blended of B20 had its power range which performed the highest value of 73.66 Hp at the engine speed of 3932.90 rpm while the lowest one was 31.68 Hp at 1518.79 rpm. All value of power with each engine speed, compared with baseline diesel, was shown in the figure 4-14 below.

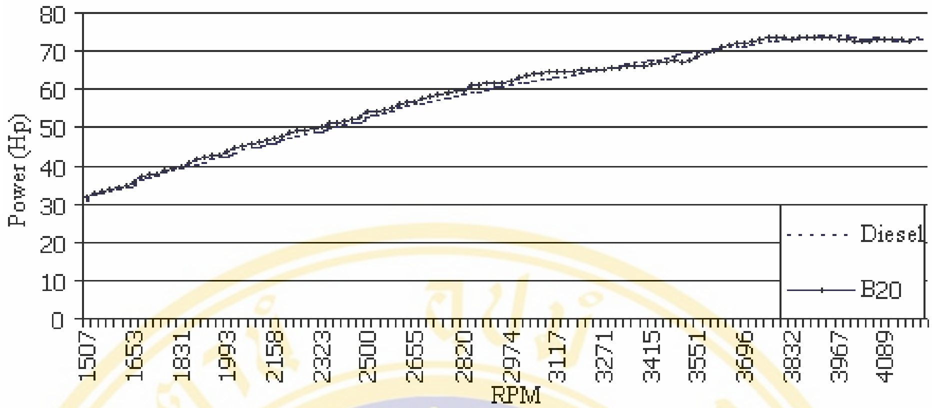


Figure 4-14 the results on power of B20

After taking the graph into the statistical analysis of correlation, the results showed that B20 and baseline diesel had the same correlation between engine speed and power that was R = 0.99.

Following the results on power measurement above, it could mention that all fuel had same value of correlation between its engine speed and their power.

4.2 Discussion

4.2.1 Biodiesel Production

4.2.1.1 Extraction of waste sludge

According to this study, the researcher had collected the waste sludge from the canteen's grease trap in a large amount within one time for avoiding the fluctuation, caused from various kind of food waste, that may occur in the final product. So, it was possible to say that such product, the biodiesel, was created from one sampling raw material. Therefore, the result might perform different if the samples were collected in more than once. To extract grease out of the mix waste sludge was slightly difficult for the reason of the hexane, which was the organic solvent, used in extracting was poisonous. However, as it had proper qualifications: well solute grease in sewage, least dissolve for other kinds of hydrocarbon, and had low boiling point. Hexane becomes the most promising solvent for extracting grease from waste sludge.

There are limitations of grease extraction at room temperature: taking long time extraction, and providing small amount of pure grease, so, it was necessary to use high temperature for extracting. Due to hexane's quality of low boiling point, when the solvent was heated up and partly became vapor. It could leak out of the extracting instrument. For this reason, it was shown that the extracting ability to dissolve grease in the sludge might decline. In the meantime, behind the hot extraction, the sludge partially absorbed the solution, causing some amount of grease remained in the sludge. Consequently, the quantity of the extracted grease might be less than it should be. Therefore, the researcher tried to squeeze the sludge so as to take the remaining hexane out as much as possible and it finally gained more hexane. However, the dry extracted sludge still performed waxy which meant that there was some grease hanging in it.

4.2.1.2 Biodiesel synthesis

The final synthesized product was the ester compound which had property of being a fuel because of its flammability. Not only grease which used as a raw material, but there were another two substances one accomplishing the reaction that were the linear monohydroxy alcohol of ethanol, and the acidic catalyst of concentrated sulfuric acid, which caused the vigorous agitation unnecessary as in the present of basic catalyst. This shown the same results as in the study of Y. Zhang (25) which concluded that the acidic-catalysed reaction had more technical feasibility of producing the used-oil biodiesel than the basic one. These made the products maintained a high acidity, and needed much volume of water to wash the catalyst, and the other impurity out of the expected product. This might lose some little amount of the product.

Yet, there must be had another theoretical products existing in the mixture that were the glycerol and small amount of organic salt as well. But there were not thing examined by sight, just only the two liquid layers remained. This was the effect from waste the grease, used as raw material of the reaction, had passed through many processes before laboratory procedure such as cooking, cleaning, and extracting. These made a change to the grease molecular from the normal structure, which was triglyceride, to free fatty acids, and their salt. Thus, there was not much tri-acyl form enough to transform into glycerol. Moreover, the amount of alcohol used in this study was theoretical 100% access by volume; so, this might caused all another products became homogenous with the alcohol. Therefore, it was only two homogenous layers observed.

4.2.2 Biodiesel specific property

Since the purpose of grease waste utilization by transforming to diesel substituted fuel. The product gained from final reaction was blended with local diesel for partially replacing with percentage of 5, 10, 15, and 20. Then all fuels were undergone in test of fuel specific property, and engine performance for comparing the results of blends with the baseline local diesel's.

Unexpectedly, the test results received from all fuel in the study were probably had a deviated value as same as it should be, since, the researcher noticed a little change of the baseline diesel color which showed a little darker. This might be from the improper way of keeping and the long stocking time before testing. There were a lot of interested points obtained from measurement as followings.

4.2.2.1 Fuel physical property

Subsequent to both fuels, biodiesel and diesel, which had been blended in various ratios, all blends were taken in every tests along with the baseline diesel, even the pure biodiesel, for evaluating there fuel ability compare to diesel. The test indicated that the values of all property had trend to be worsened when the biodiesel ratio was increased respectively. Nevertheless, after taken all value to the statistical analysis, the results showed that there were no differences between the blends and the baseline diesel, even pure biodiesel. But the unsteady performances had been found because there were only some properties of pure biodiesel met the ASTM regulation while some not. Here are the discussions of the entire physical property test.

The viscosity measured with baseline diesel was 3.54 mm^2/s while these values taken from blends were inclined when the percentage of biodiesel increased correspondingly. The most viscosity value was investigated from B20 which was 4.15 mm^2/s higher than baseline diesel at 14.7%. Even though the value were higher when the proportion increased, the value of each blends were in the acceptable range of ASTM that is 1.9 – 6.0, or it was able to mention that there was no difference between the blends and the baseline diesel, significantly.

In term of API gravity measurement, the baseline diesel had the value of 0.83 g/cm^3 while the blends got a little increasing value, namely, B5, B10, and B15, maintained the equivalent value of 0.84 g/cm^3, and the highest was caught from B20 that was 0.85 g/cm^3. Yet, there were no blends that met the standard, which has range of 0.86 – 0.90 g/cm^3, even baseline diesel. There was only the pure biodiesel which in the standard range, that was 0.90 g/cm^3. However, the statistical analysis had showed that there was no difference between the blends and the baseline diesel, significantly.

According to the flash point test, the dissimilarity was notably found between the pure biodiesel and the other fuel that was the pure biodiesel had the value of 184^{o}C while the baseline diesel got 68.5^{o}C. When the entire blends were run in the test, there was no relation among these values liked the other parameter, namely, the most flash point was obtained by B10, and B20 which was 76 ^{o}C higher than baseline diesel 9.86%, while the nearest flash point to baseline diesel was caught from B15 which was 71^{o}C higher than baseline diesel only 3.52%. In term of standard comparing, it was able to declare that all fuel had such value follow the standard, which was regulated for 52°C minimum.

4.2.2.2 Energy discharge ability

After taken the blends and the baseline diesel into the heat value test, and the engine performance test, which run in the real using high-speed diesel vehicle, the results had been shown some relation between its test value as followings.

- Heat value

The heat value was tested by the fuel bomb calorimeter to expose their heat ability. As a result, the test indicated that B100 obtained the lowest heat value of 9,685.35 Cal/g while baseline diesel got 10,389.11 Cal/g. The outstanding result was on the blends that were the entire blends presented the higher heat value with the average one of 11,626.32 Cal/g higher than diesel 10.64%. The most heat value obtained from B15 that was 12,669.16 Cal/g higher than diesel 17.99. In addition, the smoke ash of each fuel after burning had been shown that the most providing smoke ash was on baseline diesel that was darkest black while all blends had less black, particularly, B100 shown the pale black.

Following to these results, it was shown that the waste grease could be increased in value of heat by passing through the chemical transforming process. Since the study of Nisakorn (2) had reported that waste grease, that had been mixed with the sawdust, had heat value in range of 6,117 – 7,065 Cal/g. So, the conversion of trapped grease into biodiesel could rise up its heat value.

- Torque

This test showed that the torque value of every blend compared to diesel were not statistical difference. Roughly, the tested graph showed that at the normal engine speed of 1,500 – 3,000 rpm, the blends had little higher of torque than diesel. After that, at the 3,000 rpm the curve seem to be dropped, particularly at 3,500 rpm, and then it raised up until equal to baseline diesel at 4,000 rpm. The most promising curve compared to diesel was obtained from B15, since it presented the highest value at normal engine speed, and the nearest curve to the diesel at the course of dropping curve. Anyway, every blend showed statistically same in correlation value between engine speed and torque value.

- Power

The value of horse power shown in this study was not an engine break power, but it was a power received from the running engine, since the purpose of this step was just to compare the result on each sample, only. The results exposed that all blend presented a little higher power, at the course of normal engine speed, than baseline diesel, only B5 that had the same curve to diesel. Meanwhile, all blends were shown a power dropped at 3,500 – 3,000 rpm as well. After compared the whole test, the nearest power curve to diesel was obtained from B15 with a little higher at normal engine speed and a little drop at high engine speed.

However, the statistical analysis had shown that all fuel, including diesel, had the same correlation between engine speed and power, by the value of R = 0.99.

Even thought there were some document, such as the study of Ayhan Dermirbaş (20) shown that there was a similar competency between the methyl ester and the ethyl one, but some research had presented in different way. With the study of Mohamad I-Al Widyan (22), the results showed that ethyl ester produced from used vegetable oil had trend to perform with the engine better than diesel, while the paper of Sittisak Krongdech (13) exposed the performance of methyl ester of used oil in less potential of engine performance compared to diesel. Whether in this study, the results of the fuel, blended with ethyl ester, also performed slightly better than diesel. These might be able to declare that to create the mono-alkyl ester from waste lipid by using ethanol as raw material had trend to be more suitable than methanol.

According to the engine performance test, the character of all blend's curve was shown with the feature of dropped at high engine speed for both performance test. These might be the effect from the vehicle engine that had been used for long time. Moreover, at the course of dropped curve, it was an unusual engine speed. The high engine speed of old vehicle might be a factors that made the results fluctuated. Nevertheless, such effect was not occurred only with the blends, but baseline diesel was also the same, even though it was not as much as the blends.

Following of those energy tests, the results had exhibited that the blends had trend to release more energy than diesel. This was the effect of the oxygen atoms remaining in ethyl ester molecule which could have the blends exposed more energy than baseline diesel whose have no oxygen atom. Consequently, these could support the torque and power of the blends to higher than baseline diesel.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The conclusion of this study of biodiesel production from canteen's trap grease can be summarized as followed.

5.1.1 Biodiesel synthetic process

As a purpose of waste utilization, this study was initiated to evaluate the potential of trapped grease to produce ethyl ester, the alternative fuel, known as the biodiesel.

Trapped grease used in these processes was collected from grease trap of central canteen of Mahidol University, Salaya Campus, and then passed into the extraction unit for separating the unwanted matters out of grease. The results showed that a 100-g of waste sludge had its dry weight of 47.38 g, or 47.38% which provided a pure grease of 25.65 g, or 54.24% of dry weight. So, it could be mentioned that the fresh sludge of 100 g could be extracted, and provided pure grease of 25.65 g, or 25.65%. After taken it into the density measurement, the results showed that the grease had the value of 0.90 g/cm^3. This product was able to be transformed into ethyl ester, the biodiesel, by using the transesterification reaction, in the present of acidic catalyst of concentrated sulfuric acid. The 100% access ethanol was involved to accomplish the reaction by the molecular ratio of 30:1 between ethanol and grease. Depend on 90 ^{o}C within 90 min, the finished process provided the biodiesel of 95.17% by volume.

After that, the expected product, the biodiesel, had been blended with diesel in many different ratios, namely, B5 (a 5%-biodiesel blend), B10 (a 10%-biodiesel blend), B15 (a 15%-biodiesel blend), B20 (a 20%-biodiesel blend), and they were then taken to the testing processes, including diesel and biodiesel.

5.1.2 Biodiesel specific properties

The results indicated that biodiesel had API gravity value at 15^{o}C of 0.90 g/cm3, viscosity value at 40^{o}C of 8.69 mm^{2}/s, flash point value of 184^{o}C, and heat value of 9,685.35 Cal/g. For the results of blended fuel compared to baseline diesel, it seemed to be that the blends were worsen when the proportion of biodiesel inclined, but there were no statistical differences between the blends and the baseline diesel at the significant of 0.01 level. Consequently, it possible to say that the property of all blends was not different from those of diesel, especially in B15 which had higher heat value than diesel for 17.99%.

5.1.3 Engine performance

Not only the fuel specific property, but the engine performance of torque and power were also conducted to the study. By using the inertia dynamometer, the samples were run in the high-speed diesel engine of NISSON TDG21-C43524, 2,494 CC, 4 cylinders, and 90 Hp, to perform the fuel energy discharge ability.

With testing of engine performance, the reported graph of torque and power exhibited that; the blends' seemed to be slightly higher than diesel at normal engine speed of 1,500 – 3,000 rpm. After that they were a little dropped at 3,100 – 3,900 rpm and then rising up to the baseline graph again at 4,000 rpm. For the entire results of those measurements, the equation of each graphs were proceeded under the statistical analysis process to determine its relation between the engine speed and their performances compared with baseline diesel. The results showed that all the correlation value of those equations were in range of 0.97 – 0.99 which could be declared that the blends were replaceable to diesel in every ratio. Yet, little differences among the blends were investigated insignificantly. As there were the dropped curves of torque and power test in every blend at the engine speed of 3,100 – 3,900 rpm, the 15% biodiesel blend, B15, performed the least drop, which was the closest results to diesel, compared with the other blends.

According to the results of those fuel specific properties and engine performance test, it can statistically conclude that, the canteen's trap grease was able to transform to ethyl ester, the biodiesel, and every ratio of biodiesel/diesel blend had the potential to substitute to baseline diesel, since the indifferences result of the whole test. Particularly, the most suitable blend which had the best performance compared to diesel was B15.

5.2 Recommendation

By self-processing of the study, the researcher had met a lot of obstacles that caused this study uncompleted as it should be. Hence, there are many ways, which the researcher expects that it would be able to improve this document for raising the feasibility of real use of this transformed trapped grease in the future. Here are the recommendations of the study.

1) With the purpose to create a complete conversion, the researcher had spent all resources which are the factors that could make the reaction perfect such as the alcohol, and the energy, in maximum amount. So this might be an over action. To gain an optimum profit, the critical point of the process in spending less resources, while supplying a satisfied product, would be one of the important way to make the study more completed.

In addition, there were a lot of residual gained back after the production processes, for example, the extracted sludge, the hexane, the ethanol, and the waste water. While the hexane, and the ethanol, are reusable, the wastes received from the process are needed to be treated before elimination. So it is necessary to figured out the amount of all residual gained back from the production processes for being a supported data of the effective waste management, after all.

2) As same as every other goods, the product supposes to have a rational price, so that, it could be a competitive choice for consumer. This study was not support for such concern since it was just an initiation research and served for the objective on biodiesel quality assessment, thus, all resources were used in high volume, which could make the product not to suitable in term of economy. But the researcher still discern a possible chance for real using such fuel, since the price of world's petroleum have trend to raise up all the time, caused from the world's circumstances and the

lessening of the world's reserved oil. To clarify the biodiesel production cost, along with the trend of diesel price forecast, would be a benefit data for time prediction of suitable course for grease-biodiesel real implementation.

3) One of the problem found in this study was there were a lot of unwanted matters in the grease sludge such as small creatures and other waste like cigarette, elastic, and tube, etc, these cause the problem to the extraction process because the weight of mix waste was not the exact weight of grease sludge. Therefore, the extracted solution used in process was more than it should be. Moreover, it had to spend more extraction time than using pure grease sludge. To create the waste management system at the waste source for reducing the unwanted as least as it possible would be the approach to purify grease sludge and support the extraction process for more convenient, on the assumption that the less impurity of grease sludge would perform the more effective extraction with the higher product obtained.

Furthermore, this would be a constructive strategy for controlling a water pollution cause from municipal sewage as well.

4) The waste grease is a general pollutant produced in everywhere because it is a normal ingredient of many dishes. Seriously, there are several areas with no primary treatment system of such pollutant. This causes the environment problems of the producing the infected area, and the living place for carrier animal, etc. If there were an efficient sewage treatment unit, it would provide more purify grease, and more ability to collect the grease in large amount, and lessen the quantity of grease waste to the environment.

5) By the difficulty of measuring of exhaust emission, and long-term engine impact of the corrosion, and injector cocking, etc, this study could not provide all of those data. To research furthering more about such points would be a great benefit. Since a satisfied alternative fuel would be not only have just a rational price, or petroleum equivalent property, but also necessary to have a less emission, and long-term impact not to over than petroleum as well.

6) As an agricultural country, Thailand uses the most energy from diesel, since majority engine used in the agriculture process depend on it. Moreover, many interior activities need the diesel energy such as the industry, the transportation, and electricity generation, etc. These make the diesel become the most consumption fuel. To set up the research and development policy of grease biodiesel producing would be not only the approach to reduce such fuel import, but also the way to raise the agriculturist's chance to earn more income, as the ethanol is the material that could be produced from the agricultural product, and a row material of gasohol. These both fuels, the biodiesel and the gasohol, have their own research of less emission than petroleum, which perform more friendly to the environment.

As an initiator of this study, the researcher had found that it seem to be less earnestly concern from the government sector of these problems. The only policy established was just a long-term implementation and there was not thing that providable for the public, but the researching documents. Additionally, all departments who have their own research did not proceed its experiment themselves, but gather the data. Therefore, people who interesting, or having their own biodiesel can ask for not thing, but the papers. This is one of the serious problems that researcher think it have Thailand' biodiesel undeveloped. If there were the policy from the government for helping people to examine their biodiesel quality, it would be a useful way to add the feasibility chance of biodiesel for real use in the closer future.

These are all recommendations which researcher hope it would be a useful for the one who interesting in biodiesel, or anyone who had the inspiration for improving this study, and even any government sectors who may concern about the country alternative fuel development. Researcher hope that these would be the initiated tool for the grease waste transformation, the reduction of environmental pollution, the stabilization of nation monetary, and the public health supporting, in long term later.

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APPENDIX

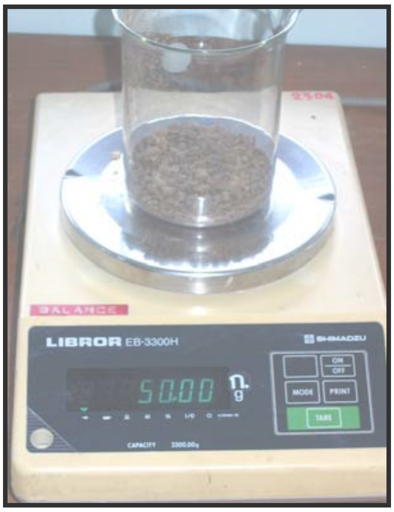
APPENDIX A

1. Procedure of grease extraction

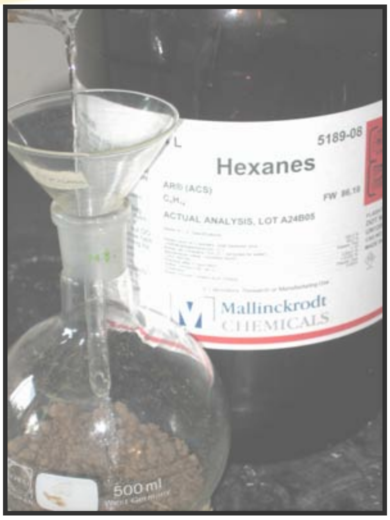
1.1 Trapped grease texture

1.2 Acidic preservation

1.3 Grease drying

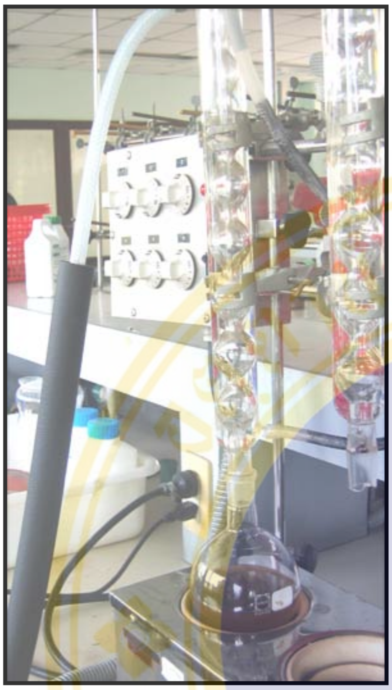


1.4 Grinning of dry grease



1.5 Addition of hexane, organic solution

1. Procedure of grease extraction (continued)



1.6 Heating extraction

1.7 Separation of extracted liquid

1.8 Evaporation

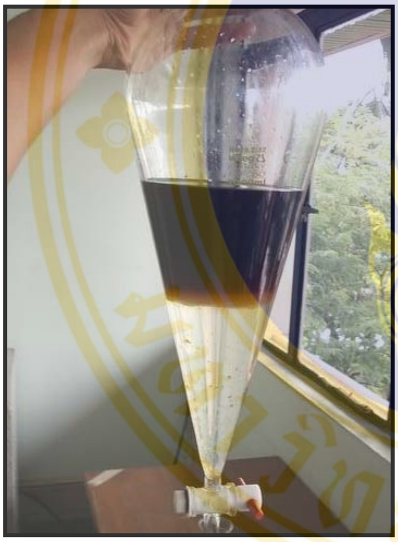
1.9 Purify trapped grease

1.10 Final product

2. Biodiesel Production

2.1 Reaction batch

2.2 Separation



2.3 Washing process

2.4 pH test

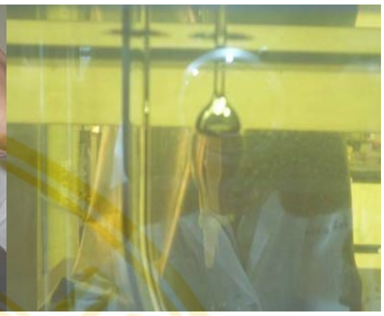
2.5 Water elimination

3. Fuel property test

3.1 Viscosity test

Hot bath

Test tube



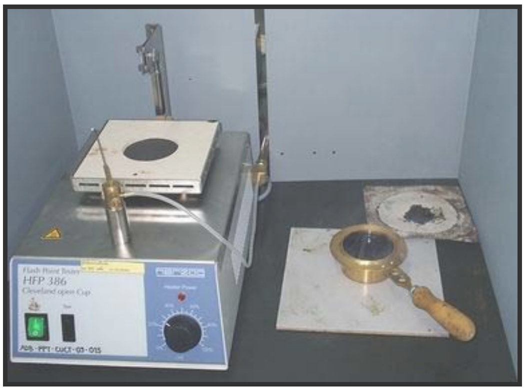
Experiment

3.2 AGI Gravity test

Cooling bath

3.3 Flash point test

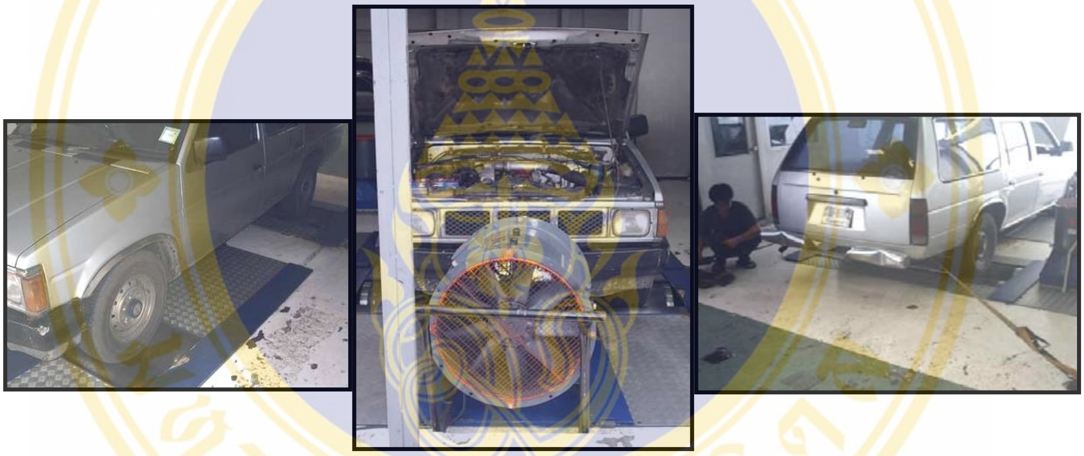
Close cup



Open cup

4. Engine performance

Tested engine



Chassis dynamometer

Computer recorder

APPENDIX B

Table B-1 Saponification value s of fatty compounds[a]

Acid	Saponification Value				
	Ester				
	TAG[b]	Methyl	Ethyl	Propyl	Butyl
Lauric	262.58	261.75	245.68	231.46	218.80
Myristic	232.10	231.46	218.80	207.45	197.22
Palmitic	207.97	207.45	197.22	187.95	179.52
Stearic	188.38	187.95	179.52	171.81	164.73
Oleic	189.66	189.23	180.68	172.88	165.71
Linoleic	190.96	190.53	121.87	173.96	166.71
Linolenic	192.28	191.84	183.06	175.05	167.71
Erucic	159.43	159.12	153.03	147.39	142.16

Source: Gerhard, 2002 (26)

[a]Computed from SV (sponification value) = 56,106/M.W.

[b]Triacylglyceryl

Table B-2 Biodiesel standard regulation

BioDiesel	Unit	Austrian Standard C1190 Feb. 91 [1)]	DIN 51606 Sept 1997	U.S. Quality Specification NBB/ASTM	Euro Standard EN 14214
Density at 15°C	g/cm3	0.86 - 0.90	0.875 - 0.90	-	0.86 - 0.90
Viscosity at 40°C	mm2/s	6.5 - 9.0 (20°C)	3.5 - 5.0	1.9 - 6.0	3.50 - 5.00
Flash point	°C (°F)	min. 55 (131)	min. 110 (230)	min. 100 (212)	min. 120 (248)
Total sulphur	mg/kg	max. 200	max. 100	max. 500	max. 10.0
Conradson (CCR) at 100% at 10%	% mass	max. 0.1 -	max. 0.05 -	max. 0.05 -	- max. 0.30
Cetane number	-	min. 48	min. 49	min. 40	min. 51
Sulfated ash content	% mass	max. 0.02	max. 0.03	max. 0.02	max. 0.02
Water content	mg/kg	free of deposited water	max. 300	-	max. 500
Water & sediment	vol. %	-	-	max. 0.05	-
Total contamination	mg/kg	-	max. 20	-	max. 24
Copper corrosion (3 hs, 50°C)	degree of Corrosion	-	1	No. 3b max.	1
Neutralisation value	mg	max. 1	max. 0.5	max. 0.8	max. 0.50
Oxidation stability	h	-	-	-	min. 6.0
Methanol content	% mass	max. 0.30	max. 0.3	max. 0.2	max. 0.20
Ester content	% mass	-	-	-	min 96.5
Monoglycerides	% mass	-	max. 0.8	-	max. 0.80
Diglycerides	% mass	-	max. 0.4	-	max. 0.20
Triglycerides	% mass	-	max. 0.4	-	max. 0.20
Free glycerine	% mass	max. 0.03	max. 0.02	max. 0.02	max. 0.02
Total glycerine	% mass	max. 0.25	max. 0.25	max. 0.24	max. 0.25
Iodine value		-	max. 115	-	max. 120

Source : Gerhard, 2002 (26)

Table B-3 Petroleum diesel property regulation of Ministry of Commercial, and Thai oil Co, Ltd.

Descriptions	**Units**	**Min/ Max**	**Limits**		**ASTM**
			High speed	**Low speed**	
Appearance: Visual	Bright and clear, free from haze and suspended matter				
Distillation: 50% v. Recovered at 100% v. Recovered at	 °C °C	 - max	 Report 357	 - -	 86 -
Flash Point, PMcc	°C	min	52	66	93
Relative Density (Specific Gravity) at 15.6/15.6 °C	- -	min max	0.81 0.87	- 0.920	1298 1288
Cetane Index or Catane Number	- -	min max	47 47	45 45	613 976
Viscosity, Kinematic at 40 °C	Cst Cst	min max	1.8 4.1	- 8.0	445 445
Pour point	°C	max	10	16	97
Color	ASTM	min max	- 4.0	4.5 7.5	1500
Sulphur Content	%wt	max	0.05	1.5	2622
Copper strip corrosion (3 hr at 100 °C)	-	max	No.1	-	130
Carbon Residue, Conradson	%wt	max	0.05	-	189
Ash	%wt	max	0.01	0.02	482
Water and Sediment Neutralization value	%v	max	0.50	0.3	2709
Strong Acid Number Total Acid Number Sediment	mg KOH/g mg KOH/g %wt	- max max	Nil 0.50 -	Nil - 0.02	974 473
Cleaning Detergent Additive			√	-	CEC
Lubrication tested by HFRR			≤ 460 µm	-	F-06-A-96

Source : Ministry of Commercial

สำนักวิจัยและพัฒนาวิทยาการหลังการเก็บเกี่ยวและแปรรูปผลิตผลเกษตร
กรมวิชาการเกษตร จตุจักร กทม.10900

กษ 0925/

รายงานผลการวิเคราะห์

โทร. : 0-2579-4111
0-29405468-9 โทรสาร.: 0-2940-5470

ผู้ส่งตัวอย่าง: นายกัปปพฤฒิ ธงอินเนตร	CP.No. 3203/48 OSL.No. 296/48
ที่อยู่: คณะสิ่งแวดล้อม มหาวิทยาลัยมหิดล 999 ถ.พุทธมณฑลสาย 4 ต.ศาลายา อ.พุทธมณฑล จ.นครปฐม 73170 โทรศัพท์ : 09-7830485 โทรสาร :	วันที่รับตัวอย่าง: 5 ตุลาคม 2548 วันที่ดำเนินงาน : 13 ตุลาคม 2548
ชนิดและลักษณะตัวอย่าง : กากน้ำมันพืชใช้แล้ว จำนวน 1 ตัวอย่าง	บรรจุภัณฑ์และสภาพตัวอย่าง : บิ๊กเกอร์ สภาพดี

รายงานผลวิเคราะห์ ดังนี้

รายการ	ผลวิเคราะห์	วิธีวิเคราะห์
Fatty acid composition (%)		Ce 2-66, Ce 1-62 AOCS 1993
C14:0 Myristic acid	2.00	
C16:0 Palmitic acid	71.87	
C18:0 Stearic acid	16.16	
Total Saturated fatty acid	90.03	
C18:1 Oleic acid	9.97	
Total Unsaturated fatty acid	9.97	

รายงานนี้รับรองผลเฉพาะตัวอย่างที่ได้ทดสอบเท่านั้น

....ผู้วิเคราะห์
(นางสาววิไลศรี ลิ้มปพยอม)

....รักษาราชการแทน
(นางสาววิไลศรี ลิ้มปพยอม) หัวหน้ากลุ่ม

....ผู้อำนวยการ

วันที่ 17 ต.ค. 48

ภาควิชาเคมีเทคนิค คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ถนนพญาไท แขวงวังใหม่ เขตปทุมวัน กรุงเทพฯ 10330
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7 ตุลาคม 2548

รายงานผลการวิเคราะห์และทดสอบ

เรื่อง รายงานผลการทดสอบหา Flash point, API Gravity และ Viscosity ของน้ำมัน

ชนิดตัวอย่าง : น้ำมัน Biodiesel

หน่วยงาน : คณะสิ่งแวดล้อมและทรัพยากรศาสตร์ มหาวิทยาลัยมหิดล

ผู้ส่งตัวอย่าง : คุณ กัปปพฤฒิ ธงอินเนตร

วิธีการเตรียมตัวอย่าง และทดสอบ :

Viscosity at 40 °C อ้างอิงตามมาตรฐาน ASTM D445-88

Flash point C° (close cup) อ้างอิงตามมาตรฐาน ASTM D93

Flash and fire point C°(open cup) อ้างอิงตามมาตรฐาน ASTM D92

API Gravity อ้างอิงตามมาตรฐาน ASTM D1298

Samples	Viscosity (mm^2/s)	Flash point C°		Fire point C°	API Gravity
		Close cup	Open cup	Open cup	
No. 1	3.69	74	-	-	0.84
No. 2	3.70	76± 2	-	-	0.84
No. 3	3.90	71	-	-	0.84
No. 4	4.15	76	-	-	0.85
No. 5	3.54	68.5±1.5	-	-	0.83
No. 6	8.69	-	181±1	193±1	0.90

(นางรัชนี แซ่อึ้ง)
นักวิทยาศาสตร์
ผู้วิเคราะห์

ขอรับรองผลการวิเคราะห์ถูกต้อง

(ศ.ดร.ภัทรพรรณ ประศาสน์สารกิจ)
หัวหน้าภาควิชาเคมีเทคนิค
7 ตุลาคม 2548

(ผศ.ดร. มะลิ หุ่นสม)
หัวหน้าห้องปฏิบัติการเชื้อเพลิง
7 ตุลาคม 2548

Table C-1 Results on viscosity at 40°C test

Sample	Timing of each replication (s)						Constant	Viscosity (mm^2/s^2)
	1	2	3	4	5	Ave.		
Diesel	3.546	3.546	3.551	3.541	3.543	3.545	0.08846	3.54
B5	3.696	3.677	3.695	3.696	3.690	3.691	0.1007	3.69
B10	3.702	3.707	3.706	3.702	3.702	3.704	0.1007	3.70
B15	3.904	3.908	3.907	3.911	3.901	3.907	0.08843	3.90
B20	4.155	4.155	4.157	4.153	4.157	4.156	0.1007	4.15
B100	8.692	8.687	8.693	8.693	8.693	8.692	0.08843	8.69

Table C-2 Results on APG gravity at 15°C test

Sample	Hydrometer test of each replication				API gravity (g/cm^3)
	1	2	3	Ave.	
Diesel	3.546	3.546	3.551	3.545	0.83
B5	3.696	3.677	3.695	3.691	0.84
B10	3.702	3.707	3.706	3.704	0.84
B15	3.904	3.908	3.907	3.907	0.84
B20	4.155	4.155	4.157	4.156	0.85
B100	8.692	8.687	8.693	8.692	0.90

Table C-3 Results on flash point test

Sample		Temperature			Flash point (°C)
		1	2	3	
Diesel		70	67	68.5	68.5±1.5
B5		74	74	74	74
B10		78	74	76	76±2
B15		71	71	71	71
B20		76	76	76	76
B100	Flash	180	181	182	181±1
	Fire	192	193	194	193±1

Results on engine performance test

Table C-4 Performance of baseline diesel

Vehicle: 8ฌฆ-9982			**Test: Baseline diesel**		
Duration: 13:00 – 15:00			**Date: 21/10/2005**		
Family : TDG21-C43524, 2,494 CC, 4 Cylinders, 90 Hp.					
RPM(1)	**Power (Hp)**	**Torque(Nm)**	**RPM(2)**	**Power (Hp)**	**Torque(Nm)**
1506.5	31.047	144.918	2076.89	44.0128	149.017
1551.02	32.2986	146.432	2093.5	44.5309	149.575
1572.82	32.8146	146.71	2109.81	44.9212	149.72
1594.76	33.5206	147.804	2141.82	45.4766	149.306
1610.21	33.686	147.108	2157.54	45.6986	148.941
1631.68	34.3143	147.881	2219.31	46.8068	148.307
1652.58	34.7906	148.037	2234.6	47.2102	148.562
1713.98	36.2378	148.671	2264.43	47.6911	148.099
1734.01	36.6983	148.822	2279.51	48.192	148.664
1753.95	37.2152	149.202	2308.62	48.593	148.011
1792.95	38.126	149.528	2323.18	48.934	148.115
1812.38	38.6917	150.121	2379.73	49.825	147.228
1831.23	39.0365	149.9	2390.93	50.2244	147.713
1886.5	39.8904	148.691	2418.33	50.5106	146.872
1904.81	40.3593	148.992	2445.81	51.1641	147.1
1922.73	40.7337	148.973	2459.27	51.3828	146.921
1958.27	41.6619	149.602	2499.75	52.4878	147.65
1975.67	42.0365	149.618	2526.09	52.9906	147.51
1992.9	42.3545	149.446	2552.52	53.7651	148.116
2043.62	43.2313	148.754	2578.51	54.3279	148.158

Table C-4 Performance of baseline diesel (continued)

RPM(3)	Power (Hp)	Torque(Nm)	RPM(4)	Power (Hp)	Torque(Nm)
2617.18	55.3277	148.655	3117.05	63.0731	142.289
2642.23	55.5962	147.961	3136.88	63.2328	141.748
2654.97	56.0233	148.382	3156.56	63.5365	141.54
2677.33	56.3302	147.949	3176.2	63.9636	141.611
2701.56	56.448	146.928	3224.26	64.6135	140.917
2726.01	57.0445	147.149	3243.23	64.9835	140.895
2773.34	57.6629	146.206	3271.24	65.2706	140.306
2796.77	58.0903	146.056	3288.34	65.3824	139.816
2820.29	58.8035	146.616	3306.94	65.815	139.949
2843.25	59.221	146.464	3325.59	66.4859	140.583
2854.51	59.2867	146.049	3370.75	67.0398	139.855
2877.03	59.5878	145.641	3388.69	67.2841	139.621
2930.62	60.5376	145.257	3415.2	67.514	139.011
2952.34	60.7661	144.733	3432.63	67.5934	138.468
2974.15	61.2531	144.823	3448.93	67.9165	138.472
2995.4	61.4289	144.208	3466.36	68.3453	138.646
3016.35	61.5674	143.529	3517.96	69.5864	139.093
3037.23	61.8682	143.239	3534.7	69.6051	138.471
3078.37	62.5997	142.996	3551.31	69.6417	137.896
3096.9	62.7636	142.512	3576.29	70.1026	137.839

Table C-4 Performance of baseline diesel (continued)

RPM(5)	Power (Hp)	Torque(Nm)	RPM(6)	Power (Hp)	Torque(Nm)
3593.06	70.7449	138.453	4058.47	73.1975	126.825
3616.38	70.9488	137.956	4071.36	73.3602	126.705
3656.64	71.2239	136.967	4089.46	73.0906	125.68
3672.32	71.0672	136.082	4108.15	72.9773	124.914
3695.86	71.2162	135.499	4120.34	72.7944	124.233
3711.38	71.398	135.276	4138.62	72.7198	123.557
3733.97	72.162	135.897	4174.33	73.3098	123.494
3749.4	72.4985	135.969	4191.88	73.0596	122.558
3794.74	72.5871	134.508			
3809.83	72.8546	134.469			
3832.26	73.3531	134.597			
3847.09	73.6424	134.607			
3868.1	73.6903	133.963			
3889.71	73.6807	133.201			
3925.18	73.8556	132.311			
3946.11	73.889	131.669			
3966.71	73.7996	130.827			
3979.58	73.8302	130.457			
3999.75	73.7468	129.653			
4019.62	73.5853	128.729			

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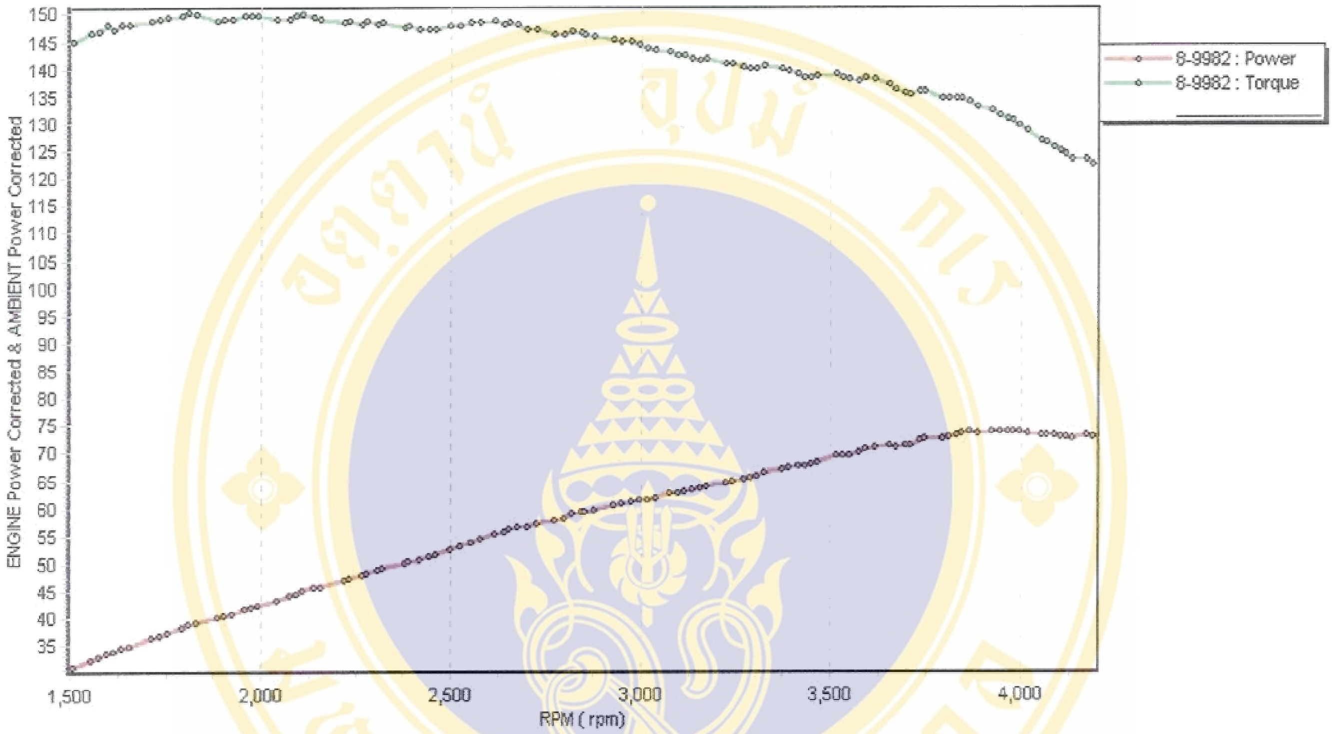

Vehicle : 8-9982
Test : Test2
Duration: 0:0:13.232
Date: 10/25/05
Ambient Correction : 2 %
for Diesel Normally
aspirated.

Speed : 109 km/h @ 4192 rpm
Power : 74 Hp @ 3946 rpm
Torque: 150 Nm @ 1812 rpm

Table C-5 Performance of 5%-biodiesel blend

Vehicle: 8ฒฌ-9982			**Test: B5**		
Duration: 13:00 – 15:00			**Date: 21/10/2005**		
Family : TDG21-C43524, 2,494 CC, 4 Cylinders, 90 Hp.					
RPM(1)	**Power (Hp)**	**Torque(Nm)**	**RPM(2)**	**Power (Hp)**	**Torque(Nm)**
1510.95	30.7583	143.148	2044.64	43.0173	147.944
1532.64	31.2842	143.535	2077.65	43.8837	148.526
1554.71	31.9502	144.509	2126.32	45.1712	149.384
1575.94	32.4094	144.612	2142.31	45.5676	149.57
1618.31	33.4789	145.473	2173.56	45.9986	148.814
1659.65	34.4901	146.133	2189.04	46.2556	148.587
1679.95	34.9586	146.329	2219.73	46.9724	148.804
1700.07	35.4443	146.606	2234.76	47.2141	148.564
1719.92	35.9174	146.848	2293.78	48.1463	147.599
1739.75	36.4825	147.458	2308.32	48.4465	147.584
1797.4	37.7464	147.673	2337.13	49.1227	147.799
1816.14	38.0934	147.493	2351.27	49.3825	147.687
1834.89	38.5661	147.797	2376.32	49.8827	147.61
1871.37	39.2812	147.603	2390.14	50.052	147.255
1889.25	39.5837	147.332	2444.95	51.1643	147.153
1907.26	40.0712	147.739	2471.95	51.8225	147.418
1960.2	41.4738	148.78	2485.16	52.0062	147.154
1977.42	41.7853	148.592	2511.82	52.7464	147.664
2011.25	42.2801	147.823	2537.97	53.2941	147.66
2028.18	42.7414	148.188	2576.73	54.0594	147.528

Table C-5 Performance of 5%-biodiesel blend (continued)

RPM(3)	Power (Hp)	Torque(Nm)	RPM(4)	Power (Hp)	Torque(Nm)
2602.31	54.5872	147.504	3094.39	63.2192	143.663
2627.58	55.1242	147.522	3124.78	63.9216	143.847
2640.05	55.336	147.39	3164.41	64.4535	143.227
2687.2	56.4171	147.632	3183.87	64.5354	142.533
2711.31	56.622	146.851	3212.89	64.921	142.089
2723.42	56.9035	146.925	3232.13	65.3925	142.269
2747.2	57.3074	146.687	3251.18	65.8122	142.343
2770.83	57.7809	146.638	3287.29	66.2958	141.814
2794.16	58.1831	146.426	3314.97	66.5328	141.133
2817.44	58.7379	146.601	3333.27	66.7905	140.901
2863.13	59.7024	146.63	3351.35	66.9846	140.549
2883.61	60.0196	146.362	3369.26	67.1409	140.128
2905.85	60.369	146.087	3387.27	67.563	140.259
2927.76	60.6315	145.624	3422.33	67.8642	139.441
2949.5	60.9106	145.217	3455.32	67.8413	138.063
2992.26	61.4645	144.443	3480.89	68.3724	138.122
3013.57	62.0688	144.832	3497.69	68.6143	137.945
3034.54	62.5041	144.84	3514.23	68.6536	137.374
3055.2	62.7523	144.432	3538.82	68.7531	136.617
3075.67	62.9488	143.92	3579.24	69.239	136.029

Table C-5 Performance of 5%-biodiesel blend (continued)

RPM(5)	Power (Hp)	Torque(Nm)	RPM(6)	Power (Hp)	Torque(Nm)
3594.26	69.4744	135.921	4023.27	73.1903	127.922
3609.8	69.1062	134.619	4041.76	73.0735	127.134
3632.91	68.7201	133.015	4054.49	73.0917	126.766
3648.38	68.9858	132.963	4080.02	73.6362	126.911
3671.38	69.5435	133.198	4098.37	73.1066	125.434
3693.97	69.7119	132.704	4116.62	72.7165	124.212
3730.2	70.0422	132.038	4152.29	73.0703	123.744
3744.96	70.2863	131.976	4170.04	73.0599	123.2
3767.08	70.8004	132.161	4187.73	73.125	122.789
3781.68	71.0641	132.141			
3803.75	71.7701	132.679			
3838.98	72.3258	132.48			
3860.61	72.83	132.656			
3874.71	72.8547	132.218			
3895.7	72.8834	131.557			
3909.64	72.9744	131.252			
3930.41	73.2229	131.003			
3970.68	73.7596	130.624			
3990.63	73.5105	129.533			
4003.72	73.2588	128.667			

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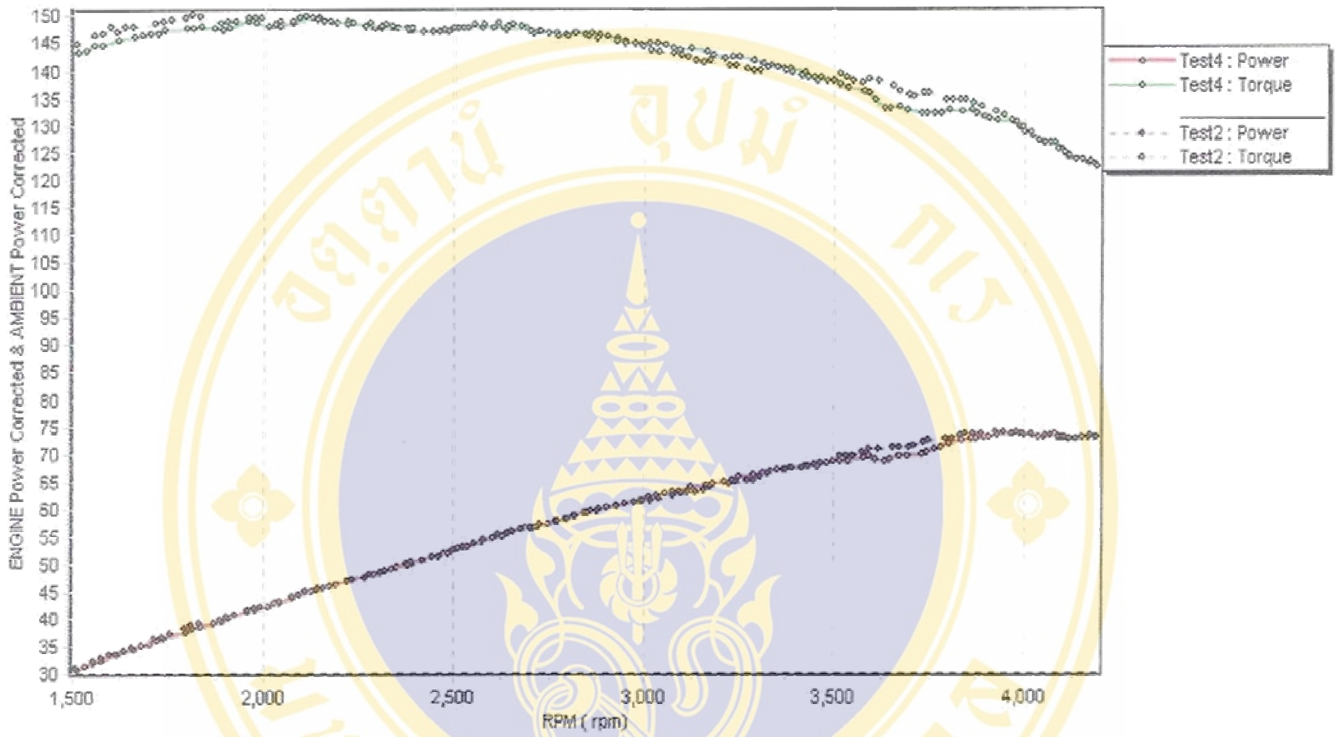

Vehicle: 8-9982

Test : Test4
Duration: 0:0:13.349
Date: 10/25/05
Ambient Correction : 3 %
for Diesel Normally aspirated.

Test : Test2
Duration: 0:0:13.349
Date: 10/25/05
Ambient Correction: 2 %
for Diesel Normally aspirated.

Speed : 109 km/h @ 4188 rpm
Power : 74 Hp @ 3971 rpm
Torque: 150 Nm @ 2142 rpm

Power : 74 Hp @ 3946 rpm
Torque: 150 Nm @ 1812 rpm

Table C-6 Performance of 10%-biodiesel blend

Vehicle: 8ฒ-9982			**Test: B10**		
Duration: 13:00 – 15:00			**Date: 21/10/2005**		
Family : TDG21-C43524, 2,494 CC, 4 Cylinders, 90 Hp.					
RPM(1)	**Power (Hp)**	**Torque(Nm)**	**RPM(2)**	**Power (Hp)**	**Torque(Nm)**
1514.79	31.6373	146.865	2108.07	45.3883	151.401
1559.55	32.5863	146.929	2125.07	46.1048	152.561
1603.32	33.6531	147.596	2157.7	46.8049	152.536
1624.9	34.2564	148.248	2173.91	47.1646	152.562
1645.9	34.6609	148.084	2205.54	47.5096	151.474
1667.33	35.4311	149.429	2236.69	48.0641	151.107
1682.48	35.6632	149.053	2282.98	49.2497	151.696
1748.7	37.1714	149.474	2298.06	49.4885	151.431
1768.81	37.7103	149.916	2327.36	49.5541	149.723
1788.51	38.199	150.187	2356.77	50.1755	149.708
1827.59	39.3529	151.415	2371.25	50.5132	149.796
1846.79	39.8869	151.874	2411.3	51.5898	150.447
1865.59	40.194	151.501	2439.3	51.9978	149.896
1902.9	40.9613	151.366	2467.2	52.6158	149.963
1939.58	41.8358	151.674	2480.9	52.826	149.73
1975.46	42.7237	152.08	2508.29	53.4426	149.824
1993.31	43.2583	152.604	2535.68	54.3223	150.645
2010.49	43.4013	151.8	2562.17	54.7472	150.254
2045.26	44.1517	151.8	2601.66	55.4946	149.993
2091.54	45.1065	151.651	2627.39	55.8136	149.378

Table C-6 Performance of 10%-biodiesel blend (continued)

RPM(3)	**Power (Hp)**	**Torque(Nm)**	**RPM(4)**	**Power (Hp)**	**Torque(Nm)**
2653.28	56.5804	149.953	3166.1	64.6854	143.666
2678.69	57.115	149.934	3185.83	64.5856	142.556
2691.1	57.2007	149.466	3234.75	65.5352	142.464
2725.73	57.5921	148.577	3253.94	65.7815	142.156
2774.63	58.7099	148.792	3272.58	65.5862	140.927
2786.48	58.8194	148.435	3291.19	65.5858	140.129
2810.21	59.206	148.149	3317.76	66.087	140.069
2833.57	59.4605	147.559	3354.5	66.8216	140.075
2857.05	60.0719	147.851	3381.57	67.129	139.593
2880.42	60.7964	148.421	3399.09	66.9652	138.535
2923.6	61.1888	147.172	3416.48	66.8747	137.643
2946.16	61.7283	147.333	3433.8	66.9541	137.111
2968.33	62.1128	147.143	3459.71	67.4319	137.056
2989.96	62.1598	146.19	3483.84	67.5736	136.393
3011.64	62.4544	145.825	3517.47	68.0619	136.065
3054.37	63.1457	145.376	3542.23	68.2349	135.457
3075.39	63.4863	145.161	3558.41	68.1512	134.676
3106.62	64.043	144.962	3574.65	68.3021	134.361
3127.66	64.8842	145.879	3598.7	68.4911	133.832
3146.38	65.0667	145.418	3637.48	69.3195	134.007

Table C-6 Performance of 10%-biodiesel blend (continued)

RPM(5)	Power (Hp)	Torque(Nm)	RPM(6)	Power (Hp)	Torque(Nm)
3652.93	69.2116	133.232	4095.3	74.311	127.597
3676.33	69.6746	133.27	4108.17	74.3432	127.252
3691.52	69.6401	132.656	4127.29	74.4305	126.811
3714.11	69.6313	131.832	4164.76	74.2134	125.304
3728.44	70.0035	132.027	4182.23	73.736	123.978
3750.95	70.3666	131.916	4193.97	73.1616	122.668
3796.03	71.6963	132.812			
3810.99	72.1796	133.183			
3833.4	72.8947	133.716			
3848.41	73.4566	134.221			
3869.6	73.7568	134.032			
3906.08	74.2387	133.647			
3927.47	74.2017	132.853			
3941.68	74.2764	132.508			
3962.86	74.4566	132.119			
3982.89	74.4697	131.478			
3996.5	74.2776	130.692			
4023.57	74.1708	129.626			
4056.91	74.3369	128.849			
4075.85	74.3141	128.211			

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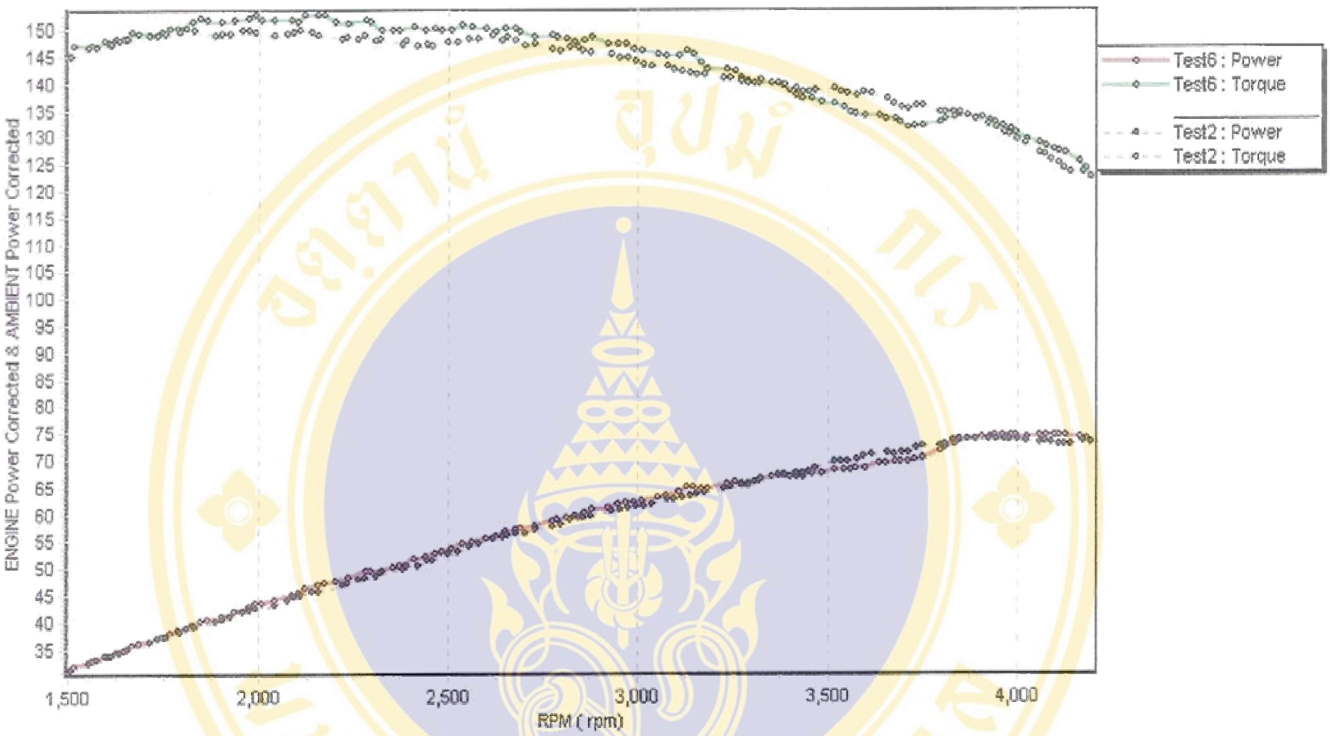

Vehicle: 8-9982

Test : Test6
Duration: 0:0:13.31
Date: 10/25/05
Ambient Correction : 3 %
for Diesel Normally
aspirated.

Speed : 109 km/h @ 4194 rpm
Power : 74 Hp @ 3983 rpm
Torque: 153 Nm @ 1993 rpm

Test : Test2
Duration: 0:0:13.31
Date: 10/25/05
Ambient Correction: 2 %
for Diesel Normally
aspirated.

Power : 74 Hp @ 3946 rpm
Torque: 150 Nm @ 1812 rpm

Table C-7 Performance of 15%-biodiesel blend

Vehicle: 8ฒม-9982			**Test: B15**		
Duration: 13:00 – 15:00			**Date: 21/10/2005**		
Family : TDG21-C43524, 2,494 CC, 4 Cylinders, 90 Hp.					
RPM(1)	**Power (Hp)**	**Torque(Nm)**	**RPM(2)**	**Power (Hp)**	**Torque(Nm)**
1514.97	31.3342	145.441	2112.55	45.4031	151.13
1559.62	32.3856	146.018	2129.17	45.8249	151.344
1581.77	33.059	146.967	2145.66	46.2979	151.73
1625.53	34.4098	148.854	2178.05	47.0445	151.884
1646.46	34.7912	148.59	2194.06	47.3762	151.839
1673.03	35.4054	148.811	2225.62	47.9669	151.552
1693.42	35.5985	147.822	2271.84	48.7327	150.839
1729.06	36.6234	148.943	2301.97	49.2516	150.45
1769.12	37.7498	150.048	2316.86	49.4929	150.215
1788.97	38.3082	150.577	2346.35	50.0741	150.069
1808.32	38.6484	150.289	2374.98	50.3243	149.001
1827.59	39.0336	150.187	2414.88	51.2932	149.361
1846.78	39.5074	150.431	2443.31	52.1404	150.061
1902.72	40.7247	150.506	2457.13	52.3144	149.715
1939.44	41.7148	151.247	2484.71	52.7229	149.209
1957.5	42.1766	151.51	2512.09	53.3459	149.326
1975.31	42.5485	151.468	2525.59	53.6358	149.336
2010.62	43.3097	151.47	2552.7	54.5254	150.201
2027.8	43.5259	150.937	2605.12	55.15	148.864
2079.21	44.7708	151.415	2631.23	55.8839	149.348

Table C-7 Performance of 15%-biodiesel blend (continued)

RPM(3)	Power (Hp)	Torque(Nm)	RPM(4)	Power (Hp)	Torque(Nm)
2656.9	56.5111	149.565	3248.84	65.8206	142.464
2669.65	56.7909	149.587	3296.48	66.2089	141.233
2692.5	57.2258	149.454	3322.95	66.4129	140.54
2741.92	57.9649	148.656	3341.28	66.4991	139.951
2766.41	58.4615	148.602	3359.54	66.6639	139.535
2790.47	58.8301	148.25	3404.08	66.7827	137.954
2849.01	59.4442	146.72	3421.67	66.8755	137.436
2872.06	59.8388	146.508	3447.82	67.2276	137.112
2895.26	60.6001	147.183	3489.67	68.0283	137.081
2938.81	61.7184	147.677	3506.54	68.0653	136.496
2961.3	62.1787	147.649	3523.25	68.0958	135.909
2983.43	62.4532	147.201	3548.36	68.5704	135.888
3005.15	62.5589	146.384	3573.42	69.3603	136.489
3026.67	62.7428	145.771	3621.4	69.9494	135.825
3079.72	63.4608	144.899	3645.45	70.0675	135.156
3100.66	63.9012	144.92	3661.16	69.9572	134.365
3131.51	64.3876	144.584	3692.4	70.109	133.517
3150.03	64.3823	143.722	3715.55	70.4392	133.31
3209.86	65.25	142.944	3760.48	71.2879	133.304
3229.49	65.6218	142.885	3783.32	71.8362	133.519

Table C-7 Performance of 15%-biodiesel blend (continued)

RPM(5)	Power (Hp)	Torque(Nm)	RPM(6)	Power (Hp)	Torque(Nm)
3798.6	72.3769	133.982			
3835.93	72.8366	133.521			
3858.27	73.2706	133.539			
3872.04	73.3867	133.275			
3893.83	73.5084	132.749			
3943.47	73.2578	130.631			
3957.37	73.1937	130.058			
3977.06	72.9692	129.017			
4010.66	72.8426	127.715			
4030.32	72.572	126.62			
4049.72	72.3479	125.624			
4087.03	72.0252	123.922			
4105.78	72.084	123.457			
4124.41	72.2845	123.241			
4160.96	72.2336	122.072			
4172.25	72.0509	121.434			
4190.04	71.9224	120.703			

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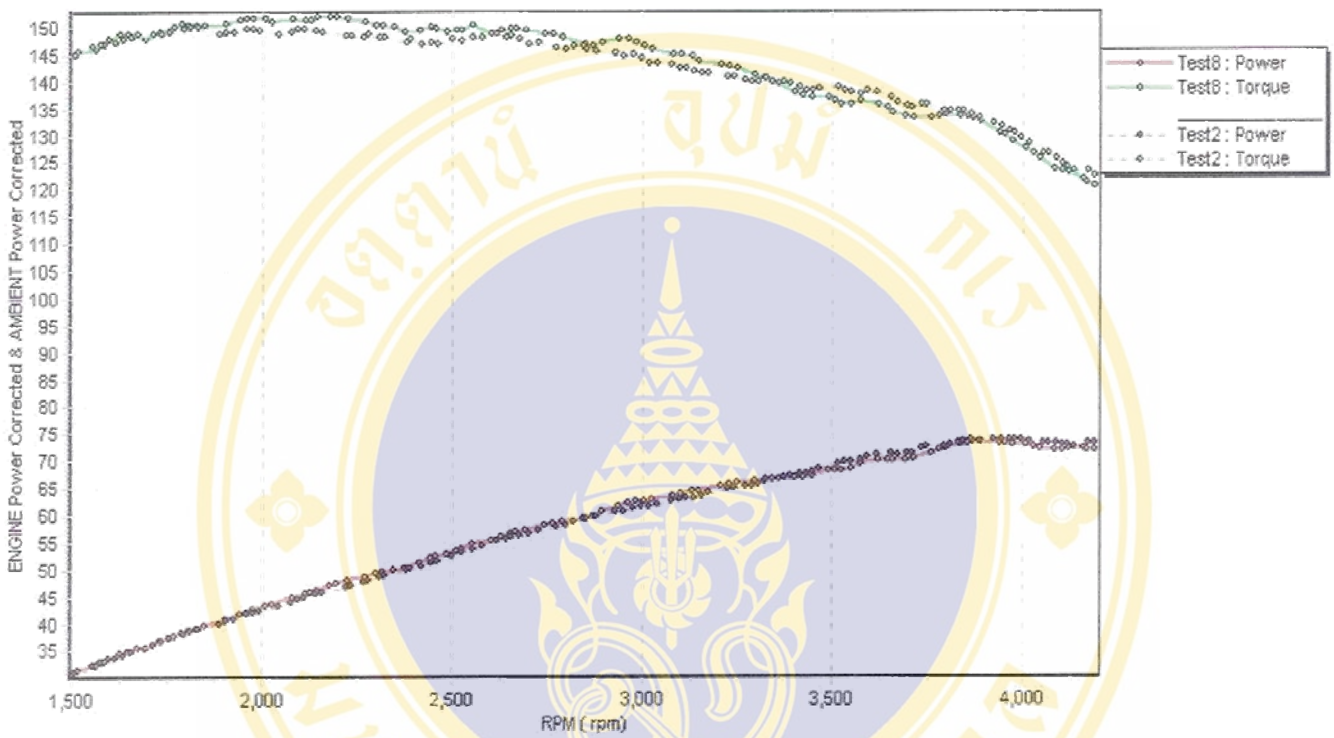

Vehicle: 8-9982

Test : Test8	Test : Test2
Duration: 0:0:12.970	Duration: 0:0:12.970
Date: 10/25/05	Date: 10/25/05
Ambient Correction : 3 % for Diesel Normally aspirated.	Ambient Correction: 2 % for Diesel Normally aspirated.

Speed : 109 km/h @ 4190 rpm
Power : 74 Hp @ 3894 rpm
Torque: 152 Nm @ 2178 rpm

Power : 74 Hp @ 3946 rpm
Torque: 150 Nm @ 1812 rpm

Table C-8 Performance of 20%-biodiesel blend

Vehicle: 8ฒ-9982			**Test: B20**		
Duration: 13:00 – 15:00			**Date: 21/10/2005**		
Family : TDG21-C43524, 2,494 CC, 4 Cylinders, 90 Hp.					
RPM(1)	**Power (Hp)**	**Torque(Nm)**	**RPM(2)**	**Power (Hp)**	**Torque(Nm)**
1518.79	31.6798	146.675	2097.97	45.1681	151.393
1563.56	32.6268	146.734	2114.65	45.5148	151.351
1585.61	33.1814	147.154	2147.52	46.1461	151.102
1607.35	33.7276	147.552	2163.85	46.5522	151.281
1629.02	34.3797	148.404	2196.02	47.3007	151.462
1650.45	34.9494	148.905	2227.37	47.7333	150.696
1671.71	35.5545	149.557	2273.74	48.5831	150.25
1733.98	37.1066	150.48	2289.04	48.9785	150.461
1754.29	37.5519	150.523	2318.77	49.3213	149.571
1769.06	37.8254	150.353	2333.73	49.6803	149.694
1808.88	38.9043	151.237	2362.81	50.1294	149.189
1828.2	39.3041	151.177	2416.76	51.0672	148.587
1847.58	39.8012	151.483	2430.69	51.2429	148.243
1885.44	40.5441	151.212	2458.63	51.88	148.381
1922.81	41.5091	151.803	2472.45	52.1914	148.437
1959.18	42.2528	151.654	2499.99	52.913	148.832
1977.16	42.6576	151.714	2527.75	54.0487	150.356
1994.6	42.8098	150.924	2580.43	54.3721	148.169
2029.7	43.5871	151.007	2593.85	54.8423	148.676
2081.14	44.8085	151.402	2619.57	55.1092	147.933

Table C-8 Performance of 20%-biodiesel blend (continued)

RPM(3)	Power (Hp)	Torque(Nm)	RPM(4)	Power (Hp)	Torque(Nm)
2645.47	55.9152	148.627	3163.42	64.6512	143.711
2671.14	56.639	149.104	3203.11	64.8047	142.268
2683.64	56.7529	148.708	3232.2	64.7887	140.953
2731.35	57.8056	148.821	3251.48	65.1057	140.802
2755.68	58.0468	148.123	3270.25	65.0694	139.916
2780.13	58.5906	148.195	3288.94	65.1701	139.336
2804.38	59.2162	148.483	3307.49	65.3044	138.84
2827.94	59.4344	147.788	3351.63	65.5609	137.55
2851.52	59.8592	147.613	3369.34	65.514	136.729
2898.24	61.0015	148.006	3395.95	65.875	136.405
2920.81	61.1412	147.198	3413.3	65.914	135.792
2941.7	61.6795	147.44	3430.7	66.1998	135.689
2963.92	61.829	146.689	3447.9	66.4212	135.464
2985.53	61.6384	145.178	3497.61	67.0233	134.749
3007.39	61.9705	144.9	3514.35	67.276	134.613
3050.85	63.2684	145.827	3530.85	67.4135	134.258
3072.08	63.5806	145.534	3555.13	67.3082	133.132
3093.18	63.8835	145.23	3571.57	67.7447	133.379
3113.99	64.0978	144.743	3588.03	68.3842	134.021
3143.16	64.4105	144.1	3635.48	69.663	134.745

Table C-86 Performance of 20%-biodiesel blend (continued)

RPM(5)	Power (Hp)	Torque(Nm)	RPM(6)	Power (Hp)	Torque(Nm)
3651.59	70.1309	135.051	4092.48	72.7329	124.973
3675.77	70.9268	135.686	4111.58	72.8875	124.657
3691.83	71.365	135.93	4142.81	72.8482	123.651
3715.76	71.8815	136.032	4161.44	73	123.353
3731.62	72.2151	136.082	4179.64	72.817	122.508
3754.22	72.5213	135.837	4197.08	72.7372	121.866
3793.34	73.2551	135.796			
3816.45	73.5196	135.461			
3838.97	73.3809	134.412			
3853.84	73.3179	133.779			
3874.92	73.0694	132.6			
3911.5	73.6212	132.352			
3932.9	73.6616	131.704			
3947.02	73.5921	131.109			
3968.02	73.5451	130.332			
3980.93	73.3394	129.546			
4001.44	73.2899	128.795			
4041.45	72.9241	126.883			
4061.01	72.6938	125.873			
4080.42	72.72	125.32			

PowerLab

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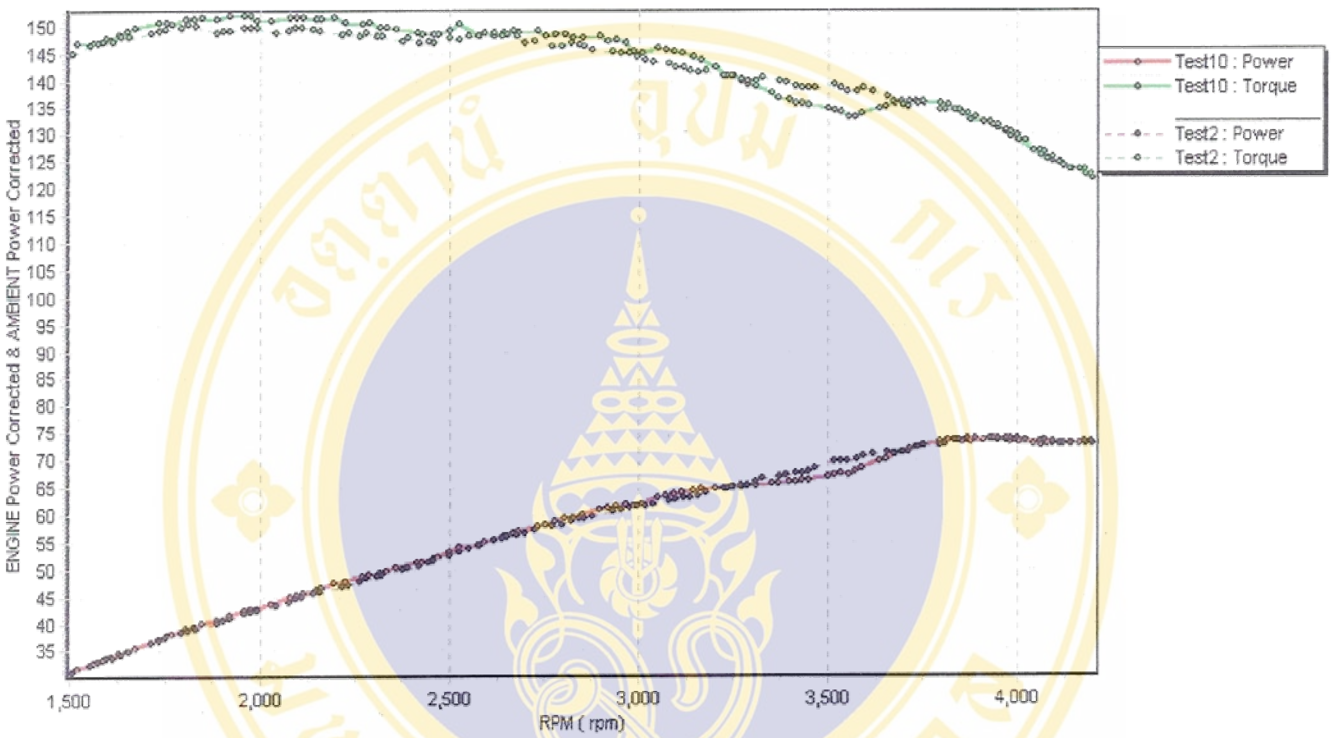

Vehicle: 8-9982

Test : Test10
Duration: 0:0:12.926
Date: 10/25/05
Ambient Correction : 3 %
for Diesel Normally aspirated.

Test : Test2
Duration:
Date:
Ambient Correction: 2 %
for Diesel Normally aspirated.

Speed : 109 km/h @ 4197 rpm
Power : 74 Hp @ 3933 rpm
Torque: 152 Nm @ 1923 rpm

Power : 74 Hp @ 3946 rpm
Torque: 150 Nm @ 1812 rpm

Calculation of the proportion between ethanol and grease

After extraction the grease out of sludge, the grease was proceeded in the gas chromatography method to find out the fatty acid composition. The results were exhibited below.

Table C-9 The chromatography analysis results

Fatty acid composition	**% Quantity**
Myristic acid	2.00
Palmitic acid	71.87
Stearic acid	16.16
Total Saturated fatty acid	**90.03**
Oleic acid	9.97
Total Unsaturated fatty acid	**9.97**
Total fatty acid	**100.00**

1 Saponification value of the fatty acid, and the ethyl ester

By using the test result of gas chromatography, the saponification value could be calculated as followings.

Table C-10 Sponification value of the ethyl ester

Fatty acid	**SN**	**%X**	**SN_x**
Myristic	218.80	2.00	4.38
Palmitic	197.22	71.87	141.74
Stearic	179.52	16.16	29.01
Oleic	180.68	9.97	18.014
Total	**-**	**100**	**193.14**

When:

SN is the saponification value of the fatty acid at table b-1 (appendix B)

SN_x is the saponification value of ethyl ester of each fatty acid from SN x %X.

2 Molecular weight of the alcohol, and grease

By the saponification value, the molecular weight of ethyl ester could be calculated. This was necessary for being a data of further calculation of alcohol molecular weight. The ethyl ester molecular weight calculation is shown below.

$$\text{Molecular weight} = \frac{56x1,000}{\sum SNx}$$

Since the SN_x was 193.14, so, the ethyl ester molecular weight was 289.94

As Transesterification Reaction can provide 3 molecules of ethyl ester from 1 molecule of triglyceride, so, the molecular weight of the grease is 289.94 x 3 equal 869.82

3 Quantity of alcohol used in the reaction

The alcohol used in the reaction got a proportion of 30:1 by mole with the grease. So the volume of those matters could be computed as followings.

- Volume of the alcohol

Since the molecular weight of the Ethyl Alcohol is 46.07 and the density is 0.719 g/cm^3, so, the volume of it could be calculated by the following formula.

$$Volume(ml) = \frac{Molecular\ \ Mass}{Density\ \ (g/ml)}$$

As the use of alcohol in this study was 30 times of molecular weight of grease, so, the molecular weight of alcohol was 30 x 46.07 = 1382.1. When took the value into the formula, the result was shown bellow.

$$v = \frac{1382.1}{0.719} = 1922.25 \quad \text{ml.}$$

By the percentage of 95 of alcohol solution, the volume of the ethyl alcohol used in the study must be $\frac{1922.25}{95} \times 100 =$ 2023.42 ml.

- Volume of the grease

Since the molecular weight of grease was 869.83 and density was 0.904 g/ml, the volume of grease that had been used in the study was calculated in the same way of alcohol as following.

$$Volume(ml) = \frac{Molecular\ \ Mass}{Density\ \ (g/ml)}$$

Which was $v = \frac{869.83}{0.904} = 962.20$ ml.

Consequently, the proportion by volume of ethanol and grease theoretically used in the reaction was 2023.42 : 962.20 or 2.1 : 1. With 100% excess of ethanol, the real used proportion was therefore 4046.84 : 962.20 or approximately 4 : 1 for having a quality product, the biodiesel.

Statistical analysis of two-related samples test

Table C-11 Descriptive Statistics

samples	N	Mean	Std. Deviation	Minimum	Maximum
VIS0	5	3.545840	.0037045	.05416	3.5513
API0	3	.834800	.0000000	.8348	.8348
FL0	3	68.5000	1.50000	67.00	70.00
VIS1	5	3.691480	.0081481	3.6776	3.6967
VIS2	5	3.704540	.0025442	3.7027	3.7078
VIS3	5	3.907380	.0031052	3.6042	3.9113
VIS4	5	4.156300	.0016733	4.1539	4.1579
VIS5	5	8.692180	.0027004	.86874	8.6936
API1	3	.837800	.0000000	.8378	.8378
API2	3	.841300	.0000000	.8413	.8413
API3	3	.843300	.0000000	.8433	.8433
API4	3	.846300	.0000000	.8463	.8463
API5	3	.895000	.0000000	.8950	.8950
FL1	3	74.0000	.00000	74.00	74.00
FL2	3	76.0000	2.00000	74.00	78.00
FL3	3	71.0000	.00000	71.00	71.00
FL4	3	76.0000	.00000	76.00	76.00
FL5	3	181.0000	1.00000	180.00	182.00

Table C-12 Test Statistics of two-related samples test (b)

	VIS1-VIS0	VIS2-VIS0	VIS3-VIS0	VIS4-VIS0	VIS5-VIS0
Z	-2.023(a)	-2.023(a)	-2.023(a)	-2.023(a)	-2.023(a)
Asymp.Sig.(2-tailed)	.043	.043	.043	.043	.043

	API1-API0	API2-API0	API3-API0	API4-API0	API5-API0
Z	-1.732(a)	-1.732(a)	-1.732(a)	-1.732(a)	-1.732(a)
Asymp.Sig.(2-tailed)	.083	.083	.083	.083	.083

	FL1-FL0	FL2-FL0	FL3-FL0	FL4-FL0	FL5-FL0
Z	-1.604(a)	-1.604(a)	-1.604(a)	-1.604(a)	-1.604(a)
Asymp.Sig.(2-tailed)	.109	.109	.109	.109	.109

BIOGRAPHY

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