BIODIESOHOL PRODUCTION FROM JATROPHA OIL USING MICROEMULSION TECHNIQUE

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การผลิตไบโอดีโซฮอลล์จากน้ำมันสบู่ดำโดยใช้เทคนิคไมโครอีมัลชัน

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วรางคณา ประภาติกุล :การผลิตไบโอดีโซฮอลล์จากน้ำมันสบู่ดำโดยใช้เทคนิคไมโครอีมัลชัน. (BIODIESOHOL PRODUCTION FROM JATROPHA OIL USING MICROEMULSION TECHNIQUE) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : จันทรา ทองคำเภา, อ. ที่ปรึกษาวิทยานิพนธ์ร่วม : สุบงกช โตไพบูลย์, 132 หน้า.

น้ำมันสบู่ดำเป็นน้ำมันพืชที่ได้รับความสนใจในการนำมาใช้เป็นวัตถุดิบเพื่อผลิตน้ำมันทางเลือก เนื่องจากเป็นน้ำมันที่ไม่ได้มาจากพืชอาหาร แต่เนื่องด้วยน้ำมันสบู่ดำมีความหนืดสูง จึงจำเป็นต้องลดความหนืดก่อนจะนำไปใช้กับเครื่องยนต์ดีเซล กระบวนการทรานเอสเทอริฟิเคชัน เป็นกระบวนการที่นิยมใช้ในการเปลี่ยนน้ำมันพืชให้เป็นน้ำมันไบโอดีเซล ได้กลีเซอรอลเป็นผลพลอยได้และมีน้ำเสียปริมาณมากจากกระบวนการผลิต ในงานวิจัยนี้ได้นำเสนอกระบวนการผลิตเชื้อเพลิงชีวภาพด้วยวิธีการอื่นคือกระบวนการไมโครอีมัลซิฟิเคชัน ผลผลิตที่ได้เรียกว่า “น้ำมันไมโครอีมัลชันไบโอดีโซฮอลล์ หรือ เอ็มบี” กระบวนการนี้เป็นเป็นมิตรกับสิ่งแวดล้อม เนื่องจากไม่ก่อให้เกิดของเสียและผลพลอยได้จากกระบวนการผลิต สิ่งที่สำคัญที่สุดสำหรับการผลิตน้ำมันเอ็มบีนี้คือสัดส่วนที่เหมาะสม-ขององค์ประกอบทั้งหมดในน้ำมัน ดังนั้นการศึกษาในช่วงแรกของงานวิจัยนี้คือการเตรียมซูโดเทอนารีเฟสไดอะแกรม สามองค์ประกอบหลักคือ น้ำมันสบู่ดำ, เอทานอล และสารลดแรงตึงผิวถูกผสมเข้าด้วยกัน ซึ่งเอทานอลและสารลดแรงตึงผิวถูกผสมให้เป็นสารประกอบเดียวกันเรียกว่า “สารลดแรงตึงผิวร่วมต่อสารลดแรงตึงผิว” ผลการทดลองจากซูโดเทอนารีเฟสไดอะแกรมและการทดสอบบางพารามิเตอร์พบว่าองค์ประกอบที่เหมาะสมของน้ำมันไมโครอีมัลชันคือ น้ำมันสบู่ดำ 95 เปอร์เซ็นต์ และสารละลายของสารลดแรงตึงผิวร่วมต่อสารลดแรงตึงผิว 5 เปอร์เซ็นต์ ซึ่งอัตราส่วนของสารลดแรงตึงผิวร่วมต่อสารลดแรงตึงผิวคือ 0.5 โดยใช้สารลดแรงตึงผิวชนิดเดียว สูตรของน้ำมันไมโครอีมัลชันที่ได้จากการเตรียมทั้งจากการใช้สารลดแรงตึงผิวชนิดเดียวและสารลดแรงตึงผิวผสมมีทั้งหมดแปดสูตรด้วยกัน ซึ่งทั้งหมดถูกทดสอบคุณสมบัติของน้ำมันคือ ค่าความหนืด, ค่าความเป็นกรด และค่าความเสถียรภาพต่อการเกิดปฏิกิริยาออกซิเดชั่น ระบบของสารลดแรงตึงผิวชนิดเดียวถูกเลือกเพื่อใช้สำหรับการผลิตน้ำมันเอ็มบี เนื่องจากน้ำมันไมโครอีมัลชั่นมีความหนืดสูงจึงถูกผสมกับน้ำมันดีเซลในสัดส่วน 5:95, 10:90 และ 20:80 โดยปริมาตร ซึ่งเรียกว่า “เอ็มบี5, เอ็มบี10 และเอ็มบี20” ตามลำดับ นอกจากนี้น้ำมันไบโอดีเซลและน้ำมันดีเซลถูกทดสอบเพื่อเปรียบเทียบสมรรถนะของเครื่องยนต์และไอเสีย คุณสมบัติของน้ำมันทุกชนิดถูกวิเคราะห์ตามมาตรฐานของ ASTM 6751 ผลการทดลองพบว่าน้ำมันเอ็มบีอยู่ในเกณฑ์มาตรฐานของน้ำมันไบโอดีเซล และจากการทดสอบสมรรถนะของเครื่องยนต์และปริมาณไอเสียพบว่า น้ำมันเอ็มบีโดยเฉพาะเอ็มบี20 และเอ็มบี10 มีศักยภาพใกล้เคียงและสามารถแข่งขันกับน้ำมันไบโอดีเซลและน้ำมันดีเซลได้อีกด้วย ดังนั้นการเปลี่ยนรูปของน้ำมันพืชโดยกระบวนการไมโครอีมัลชัน สามารถเป็นอีกเทคนิคหนึ่งเพื่อใช้ผลิตน้ำมันทางเลือก

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต

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WARANGKANA PRAPATIGUL: BIODIESOHOL PRODUCTION FROM JATROPHA OIL USING MICROEMULSION TECHNIQUE. ADVISOR : CHANTRA TONGCUMPOU, CO-ADVISOR : SUBONGKOJ TOPAIBOUL, 132 pp.

Jatropha oil has drawn an attention for being developed as an alternative fuel since it comes from non-edible plant. It is classified as a high viscous fuel and that its viscosity is necessary to be reduced before using in Compression Ignition (CI) engines. Transesterification process is the major widely used for alternating vegetable oils to methyl ester (so-called biodiesel), which obtaining glycerol as by-product and a large volume of waste water from the process. In this research, another approach for preparation of biofuel is introduced by using microemulsification process and the products known as "*microemulsion biodiesohol or MB*" . This process is environmentally friendly the fact that no waste and by-product are generated. The most important for producing this MB was the most suitable proportion of all components in the product. So, the first phase of this study was to prepare psuedo-ternary phase diagram. The three main components were jatropha oil, ethanol and surfactants. In this study, ethanol and surfactant(s) were mixed and considered as one component called co-surfactant/surfactant (C/S). The results from psuedo-ternary phase diagram and some properties testing indicated that the optimum compositions of microemulsion oil (MO) were 95% jatropha oil and 5% C/S solution which the C/S ratio was 0.5 in the single surfactant system. Eight formulations of MO prepared from both single and mixed surfactant were selected for evaluation for their properties, viscosity, free fatty acid and induction time. The formulation of single surfactant was selected for being MB production for further properties evaluation and performance testing. Due to its high viscosity of the MO, to test their performance with CI engine (Kubota RT 100), the MO was blended with conventional diesel in the proportion of 5/95, 10/90 and 20/80 (V/V%) and subsequently called as *MB5*, *MB10*, and *MB20*, respectively. In addition, biodiesel prepared from jatropha oil as well as neat diesel were also tested for their performance and emission for comparison. The properties of all fuels were evaluated according to ASTM 6751. The results show that most of parameters indicated the MBs properties were met the biodiesel standard. For engine performance and emission measurements, the results of the MBs fuel, especially MB20 and MB10 have high potential for application and were reasonably competative with biodiesl and neat diesel. In conclusion, the transfiguration of jatropha oil by microemulsion process can be a promising technique for producing an alternative fuel.

Field of Study: Environmental Management Student's Signature:………………………...
Academic Year: 2008 Advisor's Signature:………………………...
Co-Advisor's Signature:…………………….

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LIST OF ABBREVIATIONS

AFR	Air to fuel ratio
AOT	Sodium bis (2-ethlhexyl) sulfosuccinate
ASTM	American Standard Testing Method
BDF	Biodiesel via transesterification process
BFC	Brake fuel consumption
CI engine	Compression-ignition engine
CJO	Crude jatropha oil
CO	Carbon monoxides
CO_2	Carbon dioxides
cSt	Centistokes
C/S ratio	Co-surfactant to surfactant ratio
C/S solution	Co-surfactant to surfactant solution
DF	Conventional diesel fuel
DI system	Direct injection system
g	Gram
IDI system	Indirect injection system
JPO	Jatropha oil
KOH	Potassium hydroxide
MB5	Microemulsion biodiesohol contained 5% microemulsion oil and 95% diesel fuel
MB10	Microemulsion biodiesohol contained 10% microemulsion oil and 90% diesel fuel

MB20	Microemulsion biodiesohol contained 20% microemulsion oil and 80% diesel fuel
MB100	microemulsion oil or microemulsion biodiesohol 100% (not blend with diesel fuel)
MBs	Microemulsion biodiesohol including MB5, MB10 and MB20
mg	Milligram
MO	Microemulsion oil
MSFS	Mixed surfactant system
NO_x	Nitrogen oxides
O_2	Oxygen
SSFS	Single surfactant system
W/O microemulsion	Water-in-oil microemulsion
µm	Micrometer
^oC	Degree celcius
% wt	Percentage weight by weight

CHAPTER I

INTRODUCTION

1.1 Introduction

Oil demand is rapidly rising all over the world, which has led to increasing investigations for alternative fuels from renewable resources. Furthermore, due to the higher prices of fossil fuels (e.g., petroleum fuel) and problem on global warming, biofuel become more attractive more commercial application. Biofuel can be produced from any biological carbon source, especially photosynthetic plants. The basic feedstocks for biofuel production include seeds or grains of vegetable oils that can be chemically processed to produce fuels such as biodiesel.

Biodiesel can be produced from vegetable oils, animal fats, or used cooking oils via transesterification process (Sheehan et al., 1998). Generally, biodiesel can be used in compression ignition (CI) engine either with pure biodiesel or blended with neat diesel fuel with little or no modification of the engine (Banapurmath et al., 2008). In addition, biodiesel posesses properties of excellent biodegradability and lubricity and thus almost no emissions of sulfur oxides, polycyclic aromatic hydrocarbons (PAH), and nitrated polycyclic aromatic hydrocarbons (nPAH) will be generated from biodiesel combustion. Furthermore, its combustion produces lower emissions of carbon dioxide (CO_2), particulate matter (PM), unburned hydrocarbon (HC), and carbon monoxide (CO). The high oxygen content in biodiesel results in its high combustion efficiency; however, it produces higher levels of NO_x emissions (Lin and Lin, 2007). As mentioned, not only is pure biodiesel an attractive fuel alternative, but also the blends B2 and B5, which have already been used as fuels in common diesel engines. B2 consists of 2% biodiesel and 98% diesel fuel, whereas B5 has a 5% biodiesel and 95% diesel fuel composition.

Vegetable oils such as rapeseed, soybean, palm, coconut, sunflower and jatropha oil have been used as raw materials for biodiesel production. Among these seeds, jatropha oil is a more attractive one because it grows in marginal land, and production starts within the first year of planting (Srisomboon et al., 2005). Another important reason, jatropha oil is non-edible, and therefore, it is not put into the food-or-fuel discussion. Even though the productivity of jatropha is relatively low because of asynchronous ripening, the stability and quality of its productivity has been increased (Hambali, 2008). At present, the Thai government encourages farmers to grow high energy plants, especially *Jatropha curcas* L. Although the costs of biodiesel from this energy-plant are higher than that of conventional diesel, the plantation can promote domestic energy production and increase the country's annual income (Foidl et al., 1996).

Like other vegetable oils, jatropha oil is more viscous than diesel. This can cause problems for the engine, from poor atomization in the combustion chamber. To reduce this problem, vegetable oil is not used directly as biofuel, and four methods are widely used to modify the oil to be more suitable for engines namely; trans-esterification, dilution (blending) with conventional diesel fuel or other suitable hydrocarbons, microemulsification (co-solvency), and pyrolysis (Knothe et al., 1996). The method of altering vegetable oil into methyl ester via transesterification to obtain a so called "biodiesel" is popular and very commonly used. However, the transesterification process does not only produce biodiesel but also glycerol as by-products as well as a large volume of wastewater (Waitayakarn, 2006).

In this work, a microemulsion technique was introduced to modify vegetable oil properties by mixing jatropha oil with a surfactant and alcohol to allow a homogeneous microemulsion phase to be formed. Once a microemulsion is formed, it is expected that the molecules of the oil are in the process of rearranging themselves and, hence, the viscosity is decreased (Reddy, 2006). This technique has been reported to be a simple process with low energy consumption and no waste production or by-products (Ploysrimongkol, 2008). Additionally, microemulsion fuel has been found to reduce air pollution in the forms of smoke, nitrogen oxide (NO_x), and carbon monoxide (CO); to decrease the amount of fuel oil consumed; to lower the temperature of the exhaust gas; and to improve the combustion efficiency (Zhou and Zhang, 2002; Dai and Long, 1997, cited in Zhao et al., 2006). For this study, jatropha oil was used as the raw material; it was mixed with a surfactant to undergo a microemulsion reaction. Pseudo-ternary diagrams of the two-phase water-in-oil (W/O) emulsion were studied to select the optimum volume fraction for forming microemulsion. Pseudo-components consist of two- or three-phase systems; however, three-phase oil-in-water-in-oil (O/W/O) emulsions are generally applied in the fields of food, medicine, and cosmetics (Jager-Lezer et al., 1997, cited in Lin and Lin, 2007).

In order to obtain the most suitable proportion of each system component for forming a homogeneous phase microemulsion, pseudo-ternary phase diagrams were prepared. The homogenous phase product obtained from this study was named microemulsion oil. Single surfactant systems and mixed surfactant systems (used for microemulsification) were studied in comparison. Then the most suitable microemulsion oil was identified and mixed with different ratios of diesel fuel that were called microemulsion biodiesohol (MB) and labeled MBx according to their ratio. Finally, fuel properties, performances, and emissions were tested and compared with conventional diesel fuel and biodiesel from transesterification process.

1.2 Objectives

This research was focused on innovating the jatropha oil microemulsion biodiesohol production process by using a microemulsion technique. The specific objectives are as follows:

1. To determine the optimum cosurfactant to surfactant ratio (C/S ratio) for producing microemulsion oil from pseudo-ternary phase diagrams by mixing the surfactant, the cosurfactant, jatropha oil, and water to form a transparent solution.
2. To consider the optimum proportion of microemulsion oil by comparing single and mixed surfactant systems.
3. To investigate the properties, performances, and emissions of the microemulsion biodiesohols (MBs).

1.3 Hypotheses

1. Microemulsion biodiesohols produced from jatropha oil by microemulsion have properties and performances similar to those of biodiesel and can be used as fuel in a single-cylinder diesel engine.

2. The application of a mixed surfactant in the production process provides more stability to the biodiesohol compared to a single surfactant.

1.4 Scopes of the Study

This research is divided into the following four parts:

Part 1: Pseudo-ternary phase diagram preparation

The co-surfactant to surfactant ratios (C/S ratios) were 0.25, 0.50, 0.75, 1.00, and 1.25. The microemulsion area in the pseudo-ternary phase diagram was considered for each C/S ratio. The proportion of jatropha oil, C/S solution, and water that gave the largest microemulsion area was selected for further experiments.

Part 2: Microemulsion biodiesohol preparation

The optimum C/S ratio from the previous part was selected for preparing the microemulsion biodiesohols (MBs). MB was blended with conventional diesel fuel in three proportions: MB5, MB10, and MB20, which contained 5 percent, 10 percent, and 20 percent of MB and 95 percent, 90 percent, and 80 percent of conventional diesel, respectively. Finally, each microemulsion biodiesohol was tested for its fuel properties, performance, and exhaust gas emissions.

Part 3: The properties of microemulsion biodiesohol

The parameters of the microemulsion biodiesohol chosen from Part 2 were investigated according to American Standard Test Method 6751 (ASTM 6751). The examined parameters were acid number, carbon residue, cloud point, flash point, gross heat of combustion, and kinematic viscosity. In addition, a comparison of microemulsion biodiesohol and its blends was performed.

Part 4: Microemulsion biodiesohol performance and emissions

The microemulsion biodiesohol and its blends, which comply with the standard for biodiesel, were evaluated for their performances in a single-cylinder engine at the National Metal and Materials Technology Center (MTEC). Moreover, the exhaust gas emissions (i.e., carbon monoxide, CO; carbon dioxide, CO_2; hydrocarbon, HC; nitrogen oxides, NO_x; and oxygen, O_2) were examined.

CHAPTER II

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Vegetable Oil

Vegetable oils are lipids derived from plants, which are composed of triglycerides. These oils may be edible or non-edible, and it is the non-edible variety that is commonly used as fuel. In addition, vegetable oils are mixtures of organic compounds ranging from simple straight-chain to complex structures of proteins and fat-soluble vitamins. On the other hand, petroleum diesel fuel consists of saturated non-branched molecules with carbon atoms ranging between 12 and 18 (Kumar, 2007) and contains only carbon and hydrogen atoms. Fats and oils are water-insoluble or hydrophobic substances. When they contain three fatty acids linked to a glycerol molecule with ester linkages, they are known as a *triglyceride* (Figure 2.1). Fatty acids vary in carbon chain lengths and in the number of unsaturated bonds as listed in Table 2.1. The properties of vegetable oils are different from petroleum-based diesel fuel due to the large size of vegetable oil molecules and the presence of oxygen in the molecules (Ali and Hanna, 1994).

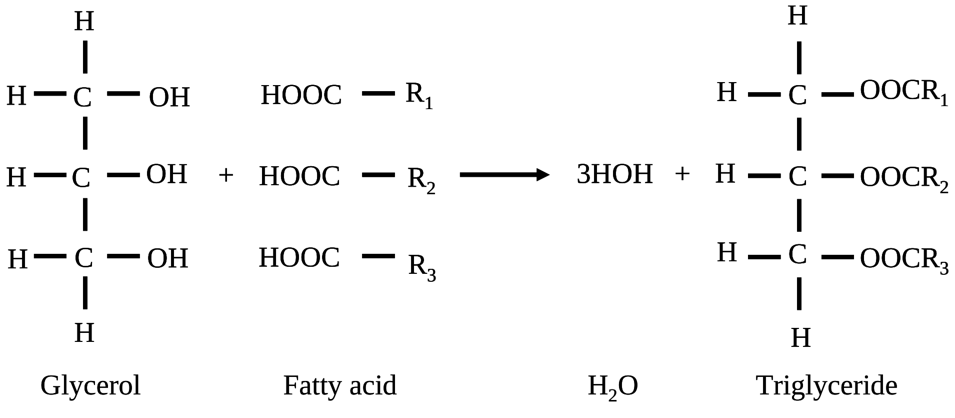


Figure 2.1 Chemical Structure of Vegetable Oil (Ali and Hanna, 1994)

The low volatility of vegetable oils is derived from the large molecules and high molecular weights present. Consequently, vegetable oils tend to accumulate and remain as charred deposits when they come in contact with engine cylinder walls (Ali and Hanna, 1994).

The advantages-disadvantages of using vegetable oils as fuels are listed as follows.

Advantages:

- They are liquid fuels from renewable sources.
- They are eco-friendly due to cleaner emission spectra. After combustion, they produce less carbon dioxide; moreover, they contain low contents of sulfur and aromatics (Reddy, 2006).
- They have the potential to make marginal land productive by inducing nitrogen fixation into the soil.
- Their production requires lesser energy input.
- The current prices of vegetable oils in world are nearly competitive with petroleum fuel prices.
- They require simpler processing technology.

Disadvantages:

- Vegetable oils have high viscosity, and some of them may freeze at low temperatures (Reddy, 2006).
- Vegetable oils have low volatility because of their chemical and physical properties, so they accumulate and remain as charred deposits when they come in contact with engine cylinder walls (Ali and Hanna, 1994).
- Vegetable oils are not economically feasible yet.
- Vegetable oils need further R&D work for the development of on-farm processing technology.

Table 2.1 Chemical Structure of Common Fatty Acid

Fatty acid	Systematic name	Structure[a]	Formula
Lauric	Dodecanoic	12:0	$C_{12}H_{24}O_2$
Myristic	Tetradecanoic	14:0	$C_{14}H_{24}O_2$
Palmitic	Hexadecanoic	16:0	$C_{16}H_{32}O_2$
Stearic	Octadecanoic	18:0	$C_{18}H_{36}O_2$
Arachidic	Eicosanoic	20:0	$C_{20}H_{40}O_2$
Behenic	Docosanoic	22:0	$C_{22}H_{24}O_2$
Lignoceric	Tetracosanoic	24:0	$C_{24}H_{48}O_2$
Oleic	Cis-9-Octadecenoic	18:1	$C_{18}H_{34}O_2$
Linoleic	Cis-9, cis-12-Octadecadienoic	18:2	$C_{18}H_{32}O_2$
Linolenic	Cis-9, cis-12, cis-15-Octadecatrienoic	18:3	$C_{18}H_{30}O_2$
Erucic	Cis-13-Docosenoic	22:1	$C_{22}H_{42}O_2$

[a] xx:y indicates xx carbons in the fatty acid chain with y double bonds.

Source: Kumar (2007)

2.2 Jatropha Oil

Jatropha curcas L. or the physic nut is a bush or small tree (up to 5 m in height) and belongs to the euphorbia family. The genus *jatropha* contains approximately 170 known species. The genus name *jatropha* is derived from the Greek words *jatrós* (doctor) and *trophé* (food), which implies medicinal uses. *Curcas* is the common name for the physic nut in Malabar, India (Henning, 2002). Moreover, jatropha is a tropical plant that can be grown in low to high rainfall areas (Kumar and Sharma, 2008) of between 250 and 3,000 mm annual rainfall (Foidl et al., 1996); besides, it is easy to establish, grows relatively quickly and is a long-lived oil plant. It is widely grown in Mexico, Nicaragua, Thailand, and India (Openshaw, 2000).

In addition, jatropha oil is non-edible, and its seed kernel contains about 48.5% of oil. In India, yields of jatropha were 5-6 kg per plant and 2,500 plants can be grown per hectare. *Jatropha curcas* cannot be used for nutritional purposes without detoxification; therefore, it is becoming a very attractive energy source for fuel production (Gubitz et al., 1999). Generally, the yield of jatropha oil is 1 liter per 4 kg of jatropha seeds (Koedkla, 2007). In order to use jatropha oil as fuel for transportation, the oil has to be transesterified with methanol or ethanol. The fatty acid composition of jatropha oil is illustrated in Table 2.2.

Table 2.2 Fatty Acid Composition of Jatropha Oil

Fatty acid	**Jatropha oil**
Palmitic (C_{16}/0)	14.2
Palmitoleic (C_{16}/1)	1.4
Stearic (C_{18}/0)	6.9
Oleic (C_{18}/1)	43.1
Linoleic (C_{18}/2)	34.4
Total Saturates	21.1
Total Unsaturates	78.9

Source: Sarin et al. (2007)

2.2.1 The Utilization of the Jatropha Oil

Jatropha oil can be tested directly in single cylinder diesel engines, water-cooled open combustion chamber diesel engines, older diesel engines or new big motors running at a constant speed (i.e., stationary engines) such as pumps and generators (Schrimpff, 2002 and Pramanik, 2003). The oil has been blended with neat diesel fuel, transesterified into jatropha methyl esters or jatropha ethyl esters, and then use as fuel in conventional diesel engines or diesel engines with adapted parameters (Kumar, 2007). Besides being used as energy source, jatropha oil has been used in soap, illumination, candles, the adulteration of olive oil, and making Turkey red oil (Henning, 2002). Moreover, the jatropha plant can be used as a living fence around gardens and fields since it is not consumed by animals (Schrimpff, 2002).

2.3 Biofuel

Biofuel is defined as any solid, liquid, or gaseous fuel that can be produced from any biological carbon source; nevertheless, the raw materials can be produced from photosynthetic plants. Biofuel is different from fossil fuel because it is derived from recently dead biological material; on the other hand, fossil fuel is derived from very long dead biological material. Moreover, biofuels are commonly used to power vehicles, home heater, and cooking stoves. They have more advantages than other fuel types since they are biodegradable; i.e., if spilled, no harm would come to the environment. The most common biofuel in Europe is biodiesel. Biofuel can be distinguished as being a part of one of three generations.

2.3.1 First generation biofuel is made from vegetable oil, animal fats, sugar, or starch using the conventional technology. Since the raw material of first generation biofuel is a part of the animal or human food chain, it competes with the needs of global populations, which are continuing to rise. As a result, this generation of biofuel has been criticized.

2.3.2 Second generation biofuel can be produced from a variety of non-food crops including waste biomass; the stalks of wheat and corn; wood; and special-energy-or-biomass crops such as Miscanthus. Some of the second generation biofuels under development are biohydrogen, biomethanol, DMF, Bio-DMF, Fischer-Tropsch diesel, biohydrogen diesel, mixed alcohols, and wood diesel.

2.3.3 Third generation biofuel is produced from algae; hence, it is also called *algae fuel* or *oilgae*. Algal oil, however, is hard to extract. Therefore, second and third generation biofuels are identified as the “advanced biofuels.”

2.4 Biodiesel

Biodiesel is a renewable diesel fuel substitute (Knothe et al., 1996; Sheehan et al., 1998). It can be chemically produced by processing vegetable oils, animal fats, or cooking waste with ethyl alcohol or methyl alcohol via transesterification to transform it into alcohol ester (Ali and Hanna, 1994). Biodiesel is an “oxygenated fuel” because the oxygen content can play a role in making fatty compounds suitable as diesel fuel (Knothe et al., 1996). Additionally, it is a liquid similar in composition to petroleum fuel, so it can be used in any diesel engine when mixed with fossil diesel. However, the majority of vehicle manufacturers limit their recommendations to 15% biodiesel blended with petroleum diesel.

Biodiesel can be produced domestically from agriculture oils and from cooking waste oils to reduce the import of petroleum oil. In addition, it is an oxygenated fuel, which contains a reduced amount of carbon and higher hydrogen and oxygen contents than fossil diesel. Therefore, it can improve the combustion of diesel fuel and reduce the particulate emissions from un-burnt carbon. Moreover, it can play a role in reducing greenhouse gas emission from the transportation sector and reducing emissions of carbon monoxide (CO), hydrocarbons (HC), sulfur oxides (SO_x) and air toxics (Sheehan et al., 1998). Its use, however, increases the emissions of nitrogen oxides (NO_x) (Knothe et al., 1996). The properties and qualities of biodiesel are illustrated in Table 2.3. In addition, a comparison of biodiesel and pure vegetable oil as fuel is shown in Table 2. 4

Table 2.3 Properties and Qualities of Biodiesel, 2007

No.	Properties	Limits	Method
1	Methyl Ester (%wt)	96.5 min.	EN 14103
2	Density at 15 °C (kg/m^3)	860-900	ASTM D1298
3	Kinematic Viscosity at 40 °C (cSt)	3.5 – 5.0	ASTM D445
4	Flash Point (°C)	120 min.	ASTM D93
5	Sulphur (% wt)	0.0010 max.	ASTM D2622
6	Carbon Residue (%wt)	0.3 max.	ASTM D4530
7	Cetane Number	51 min.	ASTM D613
8	Sulfated Ash (%wt)	0.02 max.	ASTM D874
9	Water (%wt)	0.050 max.	EN ISO 12937
10	Copper Strip Corrosion	No.1 max.	ASTM D130
11	Oxidation Stability at 110 °C (hrs)	6 min.	EN 14112
12	Acid Value (mg KOH/g)	0.50 max.	ASTM D664
13	Free Glycerol	0.02 max.	EN 14105
14	Total Glycerol	0.25 max.	EN 14105

Source: Department of Energy Business (2007)

Table 2.4 Comparison of Biodiesel and Pure Vegetable Oil as Fuel

	Biodiesel	**Vegetable oil**
1. Physical Characteristics:		
Physical Density	0.88	0.90 – 0.92
Viscosity	7-8	60 – 80
Flash Point	135	> 220
2) Chemical Characteristics:		
Phosphate mg/kg	< 15	< 15
Sulphur mg/kg	< 10	< 10
Chemical Reaction	hygroscopic, fast reaction	neutral, very low
3) Production:		
Principle	central, big industrial units	decentralized small oil expellers
Chemical Compounds Needed	methanol, potassium hydroxyl	-
Energy Input	29 %	12 %
4) Transport / Storage	small risk	no risk
5) Environment		
Biological Degradation	delayed	very fast
Danger of Water Pollution	small	No
Human Toxicity	toxic	regularly no or small
Circuit of Matter	difficult to realize	complete
6) Social Acceptability		
Strategy	big, central	small, decentralized
Logistics	complex	simple
Transportation	long distances	short distances
Vulnerability	higher	small
Regional Income Generation	low	high

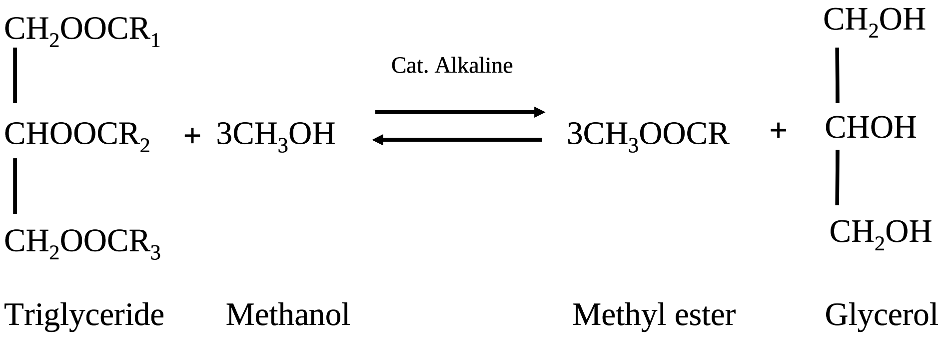
Source: Schrimpff (2002)

2.5 Biodiesel Preparation

Biodiesel usually refers to biofuel that has been prepared by the transesterification of vegetable oil, animal oil, or used oil. However, there are other methods to prepare biofuel used for diesel engines such as blending, pyrolysis, and microemulsion (Ma and Hanna, 1999). These methods yield biodiesel with different properties. Details of the mentioned biodiesel preparation methods are as follows:

2.5.1 Transesterification

The transesterification of vegetable oils with ethyl alcohol or methyl alcohol does not only produce ethyl ester and methyl ester (i.e., fatty acid methyl ester, FAME) but also glycerol. Glycerol is a by-product from the process, which can be used as feedstock in the cosmetic industry (Achten et al., 2008). Generally, methanol has been most commonly used in larger-scale production (Foidl et al., 1996). The important components of this process are the raw materials (i.e., vegetable oil, alcohol, and catalyst). Temperature is also an important factor affecting the process by way of the reaction time. The chemical reaction of transesterification is shown in Figure 2.2.



$$\begin{array}{l} CH_2OOCR_1 \\ | \\ CHOOCR_2 \\ | \\ CH_2OOCR_3 \end{array} + 3CH_3OH \xrightleftharpoons{\text{Cat. Alkaline}} 3CH_3OOCR + \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

Figure 2.2 Chemical Reaction of Transesterification

R_1, R_2, and R_3 in Figure 2.2 illustrate long carbon chains, which cannot be shown to scale in the figure because they are too long. Generally, biodiesel production uses a strong alkali (e.g., NaOH or KOH) as a catalyst, rather than an acidic one, since it helps the reaction to proceed more quickly. The base-catalyzed technique requires low temperature and pressure, and it is the most economic process, providing more than a 98%-product yield. However, in some cases when the raw material is highly acidic, it requires an acid-catalyzed reaction, which is slower. A catalyst is used to improve the reaction rate and yield because the reaction is reversible, and the excess alcohol is used to shift the equilibrium to the products side (Ma and Hanna, 1999).

2.5.2 Dilution or Blending

The blending of vegetable oils and diesel fuel in different compositions can reduce viscosity; however, it is not suggested for long-term use in direct injection diesel engines due to injector nozzle coking and sticking (Ziejewski et al., 1984 cited in Ali and Hanna, 1994). In practice, a proportion of 20% vegetable oil and 80% diesel fuel is blended. A blend of 50% vegetable oil and 50% diesel fuel had been used in a short-term experiment. The problem derived from this technique was the lubricating oil contamination that caused viscosity to increase due to the polymerization of polyunsaturated vegetable oils. It could have been caused by oxidation during storage or by a complex oxidative and thermal polymerization. Therefore, this method has been considered unsatisfactory and impractical for both direct and indirect diesel engines (Ma and Hanna, 1999).

2.5.3 Pyrolysis or Thermal cracking

Pyrolysis refers to a chemical change using heat in the presence of a catalyst (Agarwal, 2007) but in the absence of air or oxygen. The long chains are reduced into fragment mixtures of various sizes by cracking at a high temperature that causes a reduction in viscosity (Ali and Hanna, 1994). Furthermore, this reaction often occurs spontaneously at high temperatures. The pyrolyzed material can be vegetable oils, animal fats, and methyl ester of fatty acids (Ma and Hanna, 1999). In addition, this method is generally used by industries.

2.5.4 Microemulsion

Microemulsions are transparent and thermodynamically stable colloidal dispersions of two immiscible liquids containing appropriate amounts of surfactants and co-surfactants. The diameter of the dispersed-phase particles is less than onefourth the wavelength of the visible light (Knothe et al., 1996). Furthermore, microemulsification is a technique of mixing vegetable oil, surfactant, water, and alcohol (e.g., methanol, ethanol, or 1-butanol) to produce a homogenous transparent solution. This technique can solve the problem of the high viscosity of vegetable oils (Ma and Hanna, 1999), and it can improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles (Agarwal, 2007).

Rough dimensions of micelles, micellar solutions (i.e., microemulsions), and macroemulsions are as follows: (1) Micelles have radii of less than 5 nm, scatter little light, and are transparent. (2) Micellar solutions have radii between 5–50 nm (for transparent solutions, 5–10 nm; translucent, 10–50 nm), and (3) macroemulsions have radii higher than 50 nm and are opaque and milky in appearance (Tadros, 2005).

2.6 Surfactants

Surfactant is a contraction of the term *SURFace ACTive AgeNT*. Surfactants reduce the surface tension of water by adsorbing at the liquid-gas interface; they reduce the interfacial tension between oil and water by adsorbing at the liquid-liquid interface. Surfactants are usually organic compounds that are amphiphilic, meaning they contain both hydrophilic groups (the head) and hydrophobic groups (the tail) as illustrated in Figure 2.3. Therefore, they are soluble in both water and organic solvents (Rosen, 2004).

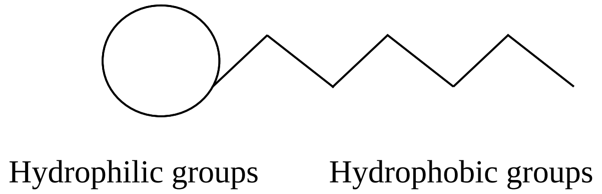


Figure 2.3 Representation of Surfactant Structure (monomer)

Surfactants are classified into four primary groups. Nonionic surfactants have no charged groups at their hydrophilic head. The head of an ionic surfactant carries a net charge. When the charge is negative, the surfactant is called an *anionic surfactant*; if the charge is positive, it is termed a *cationic surfactant*. If a surfactant contains a head with two oppositely charged groups--both positive and negative charges--it is called a *zwitterionic* (Rosen, 2004).

Many surfactants can assemble into aggregates in the bulk solution, and some of these aggregates are known as micelles. The concentration at which surfactants begin to form micelles is known as the *critical micelles concentration* or CMC. When micelles are formed in water or an aqueous medium, they are known as *normal micelles*, their hydrocarbon tails form a core that can encapsulate an oil droplet. Moreover, the polar heads groups form an outer shell that maintains favorable contact with water, a so-called oil-in-water microemulsion (O/W microemulsion). When surfactants assemble in oil or nonpolar media, the aggregate is referred to as a *reverse micelle*. In a reverse micelle, the polar head groups are in the core and the hydrocarbon tails maintain favorable contact with oil. It can solubilize water to form water-in-oil microemulsion (W/O microemulsion) (Tadros, 2005). The W/O and O/W types can be inverted from one type to the other, which can be achieved by adding an excess of one phase or by changing the emulsifier (Reddy, 2006). Pictures of O/W microemulsion and W/O microemulsion are shown in Figure 2.4.

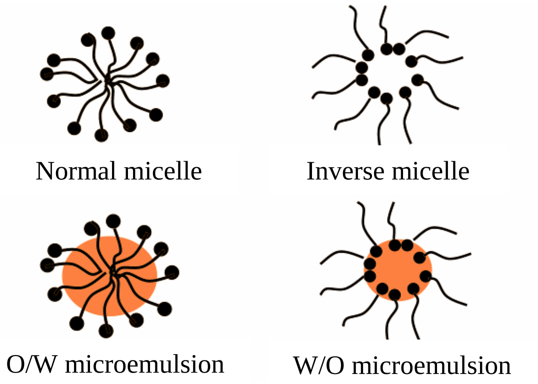


Figure 2.4 Representation of Microemulsions.

Two mutually insoluble liquids (usually water and hydrocarbons) can be converted into an optically transparent and thermodynamically stable emulsion by adding an appropriate surfactant or a mixture of surfactants. A decrease of micellar size depends on a decrease of solubilization capacity (Mackey, 1987 cited in Lim et al., 2005). Adding medium chain alcohols, which are termed as *co-surfactants* further increases the stability of microemulsions. A microemulsion consists of two phases as explained in Figure 2.5. The phase in which the water is broken into fine droplets (the dispersed phase) and the liquid surrounding the droplets (the dispersant or continuous medium) are dependent on the proportion of components and the hydrophile-lipophile balance (HLB) of the surfactant used (Lin and Lin, 2007).

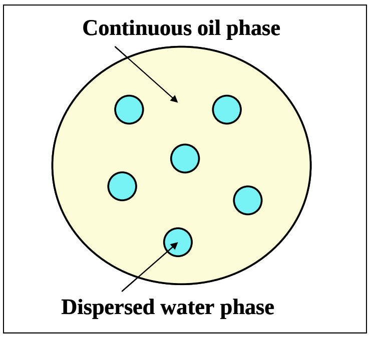
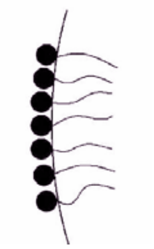


Figure 2.5 Illustration of Two-phase of Microemulsion

Microemulsion and emulsion are very similar; however, their main differences are drawn from the size difference of their dispersed components, as shown in Table 2.5.

Table 2.5 Characteristic Differences between Microemulsions and Emulsions

Microemulsion	Emulsion
• Thermodynamically stable • Small aggregates (~10 nm) • Highly dynamic system • High internal surface, high amount of surfactant needed • The oil/water interfacial film can be highly curved 	• Unstable, will eventually separate • Relatively large droplets (1-10mm) • Relatively static system • Moderately large internal surface, moderate amount of surfactant • Small oil/water curvature 

Source: Holmberg et al. (2003)

2.6.1 Phase Behavior of Surfactant Systems

Surfactants tend to aggregate in dilute solutions to form micelles with aggregation numbers in the region of 50 to 100. These micelles are spherical units in most cases, producing an isotropic solution with low viscosity. However, these micelles may grow, forming cylindrical micelles that are anisotropic and show features of structures on a macroscopic scale. Even in this case, the solution appears as a single phase. At much higher surfactant concentrations, a series of mesomorphic phases, referred to as liquid crystalline phases appear, whose structure depends on the surfactant’s nature and concentration. In general, one can distinguish between three types of behavior for a surfactant or polar lipid as the concentration is increased (Krog, and Riisom, 1985 cited in Tadros, 2005). (1) In surfactants with high solubility in water, the physicochemical properties such as viscosity and light scattering vary smoothly from the critical micelle concentration region up to saturation. In this case, the micelles remain small and generally are spherical in shape. (2) For surfactants with high water solubility, as their concentration increases they show dramatic changes in their physicochemical properties such as viscosity and flow birefringence. In this case, there are marked changes in self-assembly, e.g., the formation of liquid crystalline structures. (3) Surfactants with low water solubility show phase separation at low concentrations, e.g., separation of the solid hydrated phase (Tadros, 2005).

2.6.2 Choice of Surfactant

The surfactant is a very important constituent of hybrid fuel. It increases the solubility of diesel or vegetable oil blends with diesel in water and co-surfactant to form a homogeneous mixture that consists of a single phase. Compared to ionic surfactants, non-ionic surfactants may be required in very small quantities, because non-ionic surfactants have a more hydrophobic character. Therefore, non-ionic surfactants may be prepared for the production of hybrid fuels (Reddy, 2006). Furthermore, the addition of small quantities of anionic surfactants can be markedly increase the cloud point of most nonionics; in other words, the solution becomes cloudy because the temperature of the solution has gradually been raised (Tadros, 2005).

2.6.3 Choice of Co-surfactant

Short chain alcohols are non-ionic amphiphile molecule that can associate with surfactants, are called *co-surfactants*. They increase stability by decreasing the interfacial tension between oil and water to a level low enough for the almost spontaneous formation of the microemulsion systems (Reddy, 2006). Common co-surfactants are 1-decanol, ethanol, n-butanol, and 1-pentanol (Lim et al., 2005). N-butanol is the most suitable alcohol for microemulsion because it is more stable and lower in viscosity than the other alcohols (Knothe et al., 1996). Alcohol burns cleaner than conventional gasoline and produces less carbon monoxide (CO), hydrocarbon (HC), and oxides of nitrogen (NO_x) (Kim and Dale, 2005). Furthermore, alcohol has higher vaporization heat; thus, it reduces the peak temperature inside the combustion chamber leading to decreased NO_x emissions and increased engine power (Kumar, 2007).

Ethanol is an attractive alternative fuel because it is a 100% renewable product and it can be produced within the country (Foidl et al., 1996). Furthermore, it has the potential to reduce particulate emissions in compression-ignition (CI) engines (Kumar, 2007). The application of ethanol as a supplementary CI engine fuel may reduce environmental pollution, strengthen the agricultural economy, create job opportunities, and reduce diesel fuel requirements (Kumar, 2007). For countries with large agricultural areas, the use of ethanol is favored (Gubitz et al., 1999). Thailand is an agricultural country that can produce ethanol for consumption within the country. As a consequence, ethanol was selected to be the co-surfactant in this research.

2.7 Properties of Fuel

2.7.1 Acid Number

The *acid number* indicates the amount of free acid present in a substance, equal to the number of milligrams of potassium hydroxide needed to neutralize the free fatty acids present in one gram of fat or oil. A high acid number may indicate the future corrosion of the engine and increased fueling system deposits.

2.7.2 Carbon Residue

The *carbon residue* of a fuel is the tendency to form carbon deposits under high temperature conditions in an inert atmosphere (Tongcher et al., 2008). In diesel fuel, the presence of alkyl nitrates (such as amyl nitrate, hexyl nitrate, or octyl nitrate) causes a higher carbon residue value than they do in untreated fuel, which may lead to an incorrect carbon residue value (ASTM D4530 – 07).

2.7.3 Cloud Point

The *cloud point* is the temperature at which the fuel becomes cloudy due to the formation of crystals, which can clog fuel filters and supply lines. The testing method is slightly decrease temperature under concerned condition and ASTM D2500. This value emphasizes to the efficiency and utilization of fuel at low temperature (Tongcher et al., 2008). It is recommended by engine manufacturers that the cloud point should be below the temperature of use and not more than 6°C above the pour point (Knothe et al., 1996). Generally, the cloud point of vegetable oil is higher than that of petroleum diesel fuel (Ali and Hanna, 1994).

2.7.4 Flash Point

The *flash point* is the lowest temperature at which, when exposed to an ignition source, an ignitable mixture of air and fuel will ignite (Kwanchareon et al., 2007). High flash points indicate lower volatility characteristics. This results in high carbon deposit formation, injector coking, piston ring sticking, lubrication oil dilution, and oil degradation. High flash points result in safer handling and storage (Knothe et al., 1996). Therefore, the higher flash point of biodiesel indicates that the handling and storage of biodiesel is safer than that of diesel fuel (Bajpai and Tyagi, 2006). Furthermore, flash points of vegetable oils are higher than diesel fuel due to their non-volatile nature (Ali and Hanna, 1994).

2.7.5 Gross Heat Combustion

Gross heat combustion is one of the most important fuel properties that is specified as the energy of fuels per fuel mass (MJ/kg) (Ploysrimongkol, 2008). It is the amount of heat released during combustion and can be measured with a bomb calorimeter. In general, the gross heat combustion of vegetable oils is fairly consistent (Ali and Hanna, 1994).

2.7.6 Kinematic Viscosity

Viscosity is a very important property of fuel. Vegetable oils are characterized as having high viscosity, which leads to poor fuel atomization and inefficient mixing with air, causing incomplete combustion (Kumar, 2007). Vegetable oil is more susceptible to oxidative and thermal polymerization reactions since its structure is more unsaturated. This can cause deposition on the injector, forming a film that can interfere with the reactions in the combustion chamber. In addition, the viscosity of hydrocarbons depends on the length of the carbon chain (Ali and Hanna, 1994). Four methods for reducing viscosity have been identified and evaluated. The most commonly applied method is transesterification by the preparation of methyl esters. The three others are microemulsification or co-solvency, pyrolysis, and dilution or blending with conventional diesel.

2.7.7 Oxidation Stability

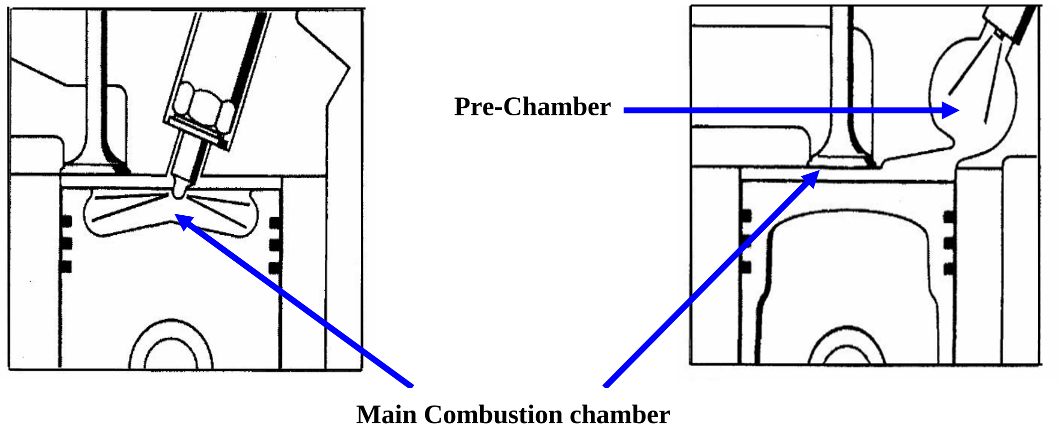
Oxidation stability can determine fuel storage characteristics. The number and location of double bonds in biodiesel fuel affect their stability. This problem can be solved by adding hydrogen or alcohol into biodiesel fuel to reduce the number of double bonds and, as a result, saturate the fatty acid chains (Bajpai and Tyagi, 2006).

2.7.8 Water Content

Water content is the quantity of water contained in fuel; its value can be analyzed by using Karl-Ficher tritration. In case, the water content is high, the combustion temperature can be reduced. As a result, nitrogen oxide (NO_x) and particulate matter (PM) decrease; on the other hand, the amount of carbon monoxide (CO) and hydrocarbon (HC) increase (Holmberg et al., 2003).

2.8 Diesel Engine

Diesel engine, which is widely used of many applications such as trucks and power generations, can be categorized into two types of engine, which according to their combustion chamber design, including a direct-injection engines (DI engines) and an indirect-injection engines (IDI engines) as illustrated in Figure 2.6. DI engines have only combustion chamber, which fuel is directly injected into its. IDI engines have an auxiliary combustion chamber or prechamber, which is separated from the main combustion chamber. Fuel is injected into prechamber, which highly turbulent and rapidly swirling flow. Air is induced into the main combustion chamber, which toward to mix with fuel in the prechamber at the end of compression process, it cause spontaneous ignition occurs. Combustion starts in the prechamber, after that fluid back into the main chamber. IDI engines are designed to use in the smallest engine size (Heywood, 1988). So, IDI engine was used for engine performance and emission investigation in this study.



(a) (b)

Figure 2.6 Diesel Engine: (a) Direct Injection Engine and (b) Indirect Injection Engine (http://www.dpchip.com/pumpinfo.html)

2.9 Emissions

Emissions from diesel engine are the consequence of the preceding combustion within in the engine; in addition, the combustion process also relates to the properties of the fuel. The combustion in automobile engine is more complete when ethanol is blended in the petroleum fuels, which contain no oxygen in their molecular structure, effect of increasing oxygen in their molecular structure (Kumar, 2007). Ideally, carbon dioxide (CO_2) and water are the products of complete combustion of hydrocarbons according to the Equation (1). Otherwise, carbon monoxide (CO), other oxygenated species (aldehydes, etc.), and hydrocarbons are produced in the incomplete combustion (Knothe et al., 1996). In addition, CO can convert to CO_2 following the Equation (2), and nitrogen can react with oxygen become nitrogen oxide according to Equation (3).

$$C_nH_{2n+2} + (1.5n + 0.5)O_2 \longrightarrow nCO_2 + (n+1)H_2O \qquad (1)$$

$$2CO + O_2 \longrightarrow 2CO_2 \qquad (2)$$

$$N_2 + O_2 \longrightarrow 2NO \qquad (3)$$

Moreover, a characteristic feature of biodiesel is non sulfur-containing emissions because biodiesel lacks sulfur in the composition (Knothe et al., 1996). Hence, it can reduce the problem of acid rain formation from transportation sector. Furthermore, biodiesel is free from aromatic hydrocarbons; thus, it can reduce unregulated emissions of pollutants such as ketone and benzene (Agarwal, 2007). The effects of these emissions on human health and environment were listed in Table 2.6.

Table 2.6 Effects of Emissions on Human Health and Environment

Emission	Health Impact	Environmental Impact
NO_x	• Cause respiratory problems: asthma, emphysema & bronchitis • Aggravates existing heart disease • Damage to lung tissue • Premature death	• Contributes to acid rain • Combines with particles to reduce visibility • Being a greenhouse gas
CO	• Fatigue • Headache • Dizziness • Nausea • Vomiting • Disorientation • Loss of consciousness	• Contributes to Global warming • Component of smog
PM	• Inflammation of lung tissue • Asthma attacks • Emphysema • Stroke • High blood pressure • Atherosclerosis • Heart attacks • Premature Death	• Contributes to smog • Reduce visibility • Absorbs sunlight causing global climate forcing • May affect local climate changes • Contributes to Global warming

Emission	• **Health Impact**	• **Environmental Impact**
CO_2	• Asphyxiation • Frostbite (from dry ice; solid carbon) • Kidney damage or coma	• Greenhouse effect • Global warming
HC	• Acute respiratory symptoms • Headache • Dizziness • Vomiting • Reduce cardiovascular function • Arrhythmia • Brain damage • Coma • Premature Death	• Precursor to ground-level ozone • Major component of smog

2.10 Literature Reviews

Yusuf and Hanna (1994) reviewed the use of vegetable oils and animal fats with diesel fuel and discussed fuel preparation by transesterification, pyrolysis, dilution, and microemulsion. In addition, the properties of the variously processed oils, the performance of diesel engines on vegetable oil, and the exhaust gases from engines operated were analyzed.

Foidl et al. (1996) discussed the development of *Jatropha curcas* L. as a possible energy crop in Nicaragua. Moreover, they described the production process of the methyl and ethyl esters from seed oil through the transesterification process. It was found that the seed of jatropha could not be used for nutritional purposes because it contains various poisonous compounds. However, it has been used with diesel fuel in various blends. Both methyl and ethyl esters are suitable for transesterification depending on the purpose. From an ecological standpoint, ethanol has more advantages than methanol because it is a 100% renewable product. In addition, it could be produced within the country. On the other hand, methanol is preferred in a large-scale production.

Gubitz et al. (1999) studied whether vegetable oils made from sunflower seeds, rapeseeds, soybeans, and jatropha seeds could be used as fuel substitutes. These oils were evaluated for their performance with direct and indirect injection diesel engines. Fuel conversion efficiency, specific consumption, as well as exhaust gas emissions were compared. It was found that jatropha oil led to the lowest exhaust gas emissions. Moreover, a long-term durability test was conducted in a water pump driven by a modified direct injection diesel engine for a 1,000 hr test run. Good behavior as fuel and no wear in the engine were found.

Lin and Wang (2003) studied fuel properties of three-phase emulsions (i.e., oil-in-water-in-oil or O/W/O emulsion) as an alternative fuel for diesel engines. This multi-phase emulsion was prepared by adjusting the optimum of hydrophilic–lipophilic balances (HLB) of liphophilic surfactant Span 80 (HLB 4.3) and hydrophilic surfactant Tween 80 (HLB 15). The results showed that with water content being equal, the viscosity of O/W/O emulsion was greater than that of W/O emulsion.

Cheenkachorn et al. (2004) studied biodiesel produced from palm oil as an emulsifier and exhibit additive for diesohol by constructing a three-phase diagram to establish an appropriate composition of the emulsion. Furthermore, the stability of diesohol emulsion and its fuel properties (such as carbon residue, viscosity, higher heating value, initial boiling point, cetane index, pour point, and flash point) were investigated. The results indicated that all prepared diesohol emulsions exhibited good emulsion stability after being put in storage for six months. Moreover, biodiesel was shown to be a suitable emulsifier for diesohol. Almost all fuel properties of diesohol emulsions were below standard limits, except for the flash point, which was lower than that of neat diesel fuel. The percentage by weight of carbon residue increased due to increasing ratios of ethanol and biodiesel. Therefore, it may be used as an alternative to low-speed diesel fuel. The appropriate diesohol emulsion for diesel engines should be 95% diesel and 5% biodiesel by volume.

Lif and Holmberg (2006) reported that a regular diesel engine already contains water-in-diesel emulsions. This fuel emulsions reduced emissions of health hazardous nitrogen oxides (NO_x) and particulate matter (PM); moreover, better burning efficiency decreased fuel consumption. The study focused on the influence of water on emissions and combustion efficiency. It was revealed that increasing water content in the emulsion resulted in a reduction of nitrogen oxides (NO_x) and particulate matter (PM). However, hydrocarbons (HC) and carbon monoxide (CO) in exhaust emission increased. In terms of combustion efficiency, it was found that the water content reduced the peak temperature in the cylinder, resulting in a lower level of NO_x formed. This is consistent with results obtained from Banapurmath et al. (2008), who found that NO_x formation strongly depends on peak temperature. Furthermore, microexplosions occurred, which enhanced the atomization of the fuel.

The performance and emissions of neat jatropha oil were evaluated in a single-cylinder direct injection diesel engine at a constant speed (Reddy and Ramesh, 2006). A comparison of jatropha and conventional diesel fuel was carried out. The results indicated a higher ignition delay from the jatropha oil; however, its emissions of HC, NO, and smoke were lower than those of diesel fuel. HC, NO, and smoke emissions of neat jatropha oil were 532 ppm, 1,162.5 ppm, and 2 BSU, respectively. After increasing the injector opening pressure (IOP) to 220 bars, the performance and emissions of jatropha oil were improved because of better spray formation.

Zhao et al. (2006) reported that microemulsion fuel could reduce air pollution and improve combustion efficiency, which was in agreement with previous studies. In addition, the microemulsion technique was simple and of low cost. Of interest to them were the factors affecting the preparation of diesel microemulsion. It was found that the quantity of solubilized water is maximal when the molar ratio of aqua ammonia and oleic acid is 1.66. Alcohols added to the system affected solubilized water. N-butanol was the best co-surfactant when its mass fraction of the solubilized water was up to 18.42% and its mass fraction was 1.0%. The effect of salt concentration on solubilized water was also studied; an optimum inorganic salt concentration of 0.28 mol/L was found to best increase the amount of water to be solubilized. The mixed surfactant exhibited superior water solubilization compared to the single surfactant. Furthermore, the amount of solubilized water could be increased greatly by adding a small amount of the cationic surfactant into the anionic surfactant.

Agarwal (2007) studied the applications of biofuels (alcohol and biodiesel) as fuels for internal combustion engines. The results revealed that the heating value of biodiesel was lower than that of diesel fuel because biodiesel contained a substantial amount of oxygen in the fuel. Carbon deposits of biodiesel in the cylinder head, piston top, and injector tip of diesel engine could not be observed. When biodiesel was blended with diesel fuel, its exhaust gas temperature and lubricating oil temperature were lower than those of neat diesel fuel. Moreover, CO and NO_x emissions were significantly reduced. Proportions of blended biodiesel up to 20% could be used in a constant speed CI engine without any modification.

Kumar (2007) discussed the properties and specifications of ethanol blended with diesel and gasoline fuel. Ethanol is an attractive alternative fuel because it is a renewable bio-based resource and it is oxygenated, thereby providing the potential to reduce particulate emissions in compression-ignition (CI) engines. Furthermore, this review focused on the performance and emissions of biodiesel in CI engines, combustion analysis, wear performance on long-term engine usage, and economic feasibility. The results show that PM and CO emissions become significantly reduced when 10% ethanol is added to gasoline. For some of the vehicles tested, CO_2 emissions were significantly reduced as well; although, it was not significant at a 95% confidence level.

Kwanchareon et al. (2007) studied phase diagrams of diesel-biodiesel-ethanol blends at different purities of ethanol and different temperatures. The phase diagram of diesel, biodiesel (palm oil methyl ester), and 99.9% ethanol at room temperature could be mixed to a homogenous solution at any ratio. In this study 99.5% ethanol was selected for further fuel property studies and emission testing because the mixture of 99.5% ethanol, biodiesel (as an additive), and diesel appeared as a single liquid phase. Moreover, 99.5% ethanol is cheaper than 99.9% ethanol and it is produced in Thailand. The blend of diesel-biodiesel-99.5% ethanol was a single liquid phase fuel at temperatures of $30^{o}C$ to $40^{o}C$. Therefore, this diesohol can be used as liquid fuel in

Thailand with its ambient temperature around 30-40^{o}C. The fuel properties (density, cetane index, heat of combustion, and pour point) were found to be close to the standard limits for diesel fuel. It was noted that the heating values of the blends that contained more than 10% ethanol were vastly different from that of neat diesel fuel. However, the flash point of diesohol was different from that of regular diesel and was found to be very low, in the range of 12-17^{o}C. The emissions from the blends were carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxide (NO_x). CO and HC were reduced significantly at a high engine load; however, NO_x emissions were higher for the blended fuels than they were for the conventional diesel. The most suitable blend for diesohol production was 80% diesel, 15% biodiesel, and 5% ethanol.

Lin and Lin (2007) postulated that the high oxygen content of biodiesel produces more nitrogen oxides (NO_x). An effective way to reduce NO_x emission was considered by using fuel emulsification and NO_x inhibitor agents in fuel. The study investigated biodiesel produced from soybean oil by peroxidation. The biodiesel was emulsified to a three-phase oil-droplets-in-water-droplets-in-oil (i.e., O/W/O) biodiesel emulsion. Moreover, aqueous ammonia, which is a NO_x inhibitor agent, was added into the O/W/O biodiesel emulsion. The results show that increasing engine speed causes the CO_2 emissions, equivalence ratio, exhaust gas temperature, fuel consumption rate, and brake specific fuel consumption to increase; however, it also caused NO_x emissions to decrease. Furthermore, the O/W/O biodiesel emulsion with aqueous ammonia produced the lowest NO_x emissions among the four fuels tested.

Banapurmath et al. (2008) investigated the performance and emission characteristics of honge, jatropha, and sesame oil methyl esters on a single-cylinder, four-stroke, direct-injection, and CI engine. The results showed that the performance of methyl esters of jatropha oil was poor, and its emissions were high when it was compared with those of conventional diesel fuel. HC and CO emissions of biodiesel from jatropha oil were found to be slightly more than those produced by the diesel operation, and their smoke emissions were also slightly higher than those of diesel fuel. However, the operation of the engine was observed to run smoothly with biodiesel from jatropha oil.

Kumar and Sharma (2008) explored the possibilities of plant exploitation in various applications. An overview covering the biology, chemistry, toxicity of seeds and their detoxification, and various industrial uses was given, with an emphasis on the benefits for rural and urban economies.

Ploysrimongkol (2008) studied the production of biodiesel by investigating the phase behavior of microemulsion systems in pseudo-ternary diagrams at different compositions of cosurfactant/surfactant ratios (C/S ratios), water, and oil. This study used refined palm oil as the raw material. The C/S ratios used in this study were 0.5, 0.75, 1.0 and 1.25. The results show that the C/S ratio of 0.5 was able to generate the largest microemulsion area and maximum solubilization. Moreover, the properties, performance, and exhaust gas emission of microemulsion biodiesel (pure product, MB100) and its blends with neat diesel (MB5 and MB20) were investigated. The results show that the microemulsion biodiesels produced from this study demonstrated possible use as biofuels.

Ramesh and Sampathrajan (2008) looked into how to reduce the viscosity of conventional jatropha oil produced biodiesel through the transesterification process. Jatropha oil biodiesel blended with diesel fuel was investigated. The blends were B_{20}, B_{40}, B_{60}, B_{80} and B_{100}. It was revealed that increasing kinematic viscosity results from increasing the amount of biodiesel. The viscosity of B_{20} blended biodiesel was close to the viscosity of diesel fuel. The flash point and carbon residue of the blended fuels were increased by increasing the amount of biodiesel in the fuels. The fuel properties of the blended fuels met the diesel fuel and biodiesel standards.

The works of previous researcher have been taken into consideration, and in this research, the principal objective is to produce biodiesohol from jatropha oil via the microemulsion technique, which is a simple and low cost method. In the first stage, the microemulsion biodiesohol was prepared in five co-surfactant to surfactant ratios, (0.25, 0.5, 0.75, 1.0, and 1.25). Due to its composition (jatropha oil, a surfactant, and ethanol) and its purpose of being used in a single cylinder diesel engine, the product from this work is called *microemulsion oil* (MO). The optimum composition from the phase stage was selected for further study by blending it with 5 %, 10%, and 20% microemulsion oil and 95 %, 90%, and 80% conventional diesel, called *MB5*, *MB10*, and *MB20*, respectively. Finally, the properties, performances, and exhaust gas emissions of microemulsion biodiesohol; the blends, MB5, MB10, and MB20; methyl esters of jatropha oil; and neat diesel fuel were investigated.

CHAPTER III

METHODOLOGY

The experimental procedure was divided into four parts. First, pseudo-ternary phase diagrams were generated and studied. Jatropha oil was used as raw material, and it was mixed with co-surfactant to surfactant solution (C/S solution) at different co-surfactant to surfactant ratios (C/S ratio). The compositions, which were plotted in the diagram, were perceived from homogenous and transparent solutions. The microemulsion area was generated by drawing a pseudo-ternary diagram, and the ratio that generated the largest microemulsion area was selected for further investigation. Second, microemulsion oil (MO) was prepared by mixing jatropha oil and C/S solution, which was obtained from a previous experiment. Additionally, the proportion of MO was indicated within the microemulsion area. Microemulsion oils were studied the optimal compositions by comparing between single surfactant systems and mixed surfactant systems at the same C/S ratio, and analyzing the principle fuel properties. After that, 5%, 10%, and 20% microemulsion oil were blended with 95%, 90%, and 80% diesel fuel by volume, respectively, and were respectively named *MB5*, *MB10*, and *MB20*. Third, the properties of MBs and its blends were evaluated following ASTM 6751. Finally, the performances and emissions of MBs and its blends in a single-cylinder engine were studied. For over all procedures were described in the flow diagram in Figure 3.1.

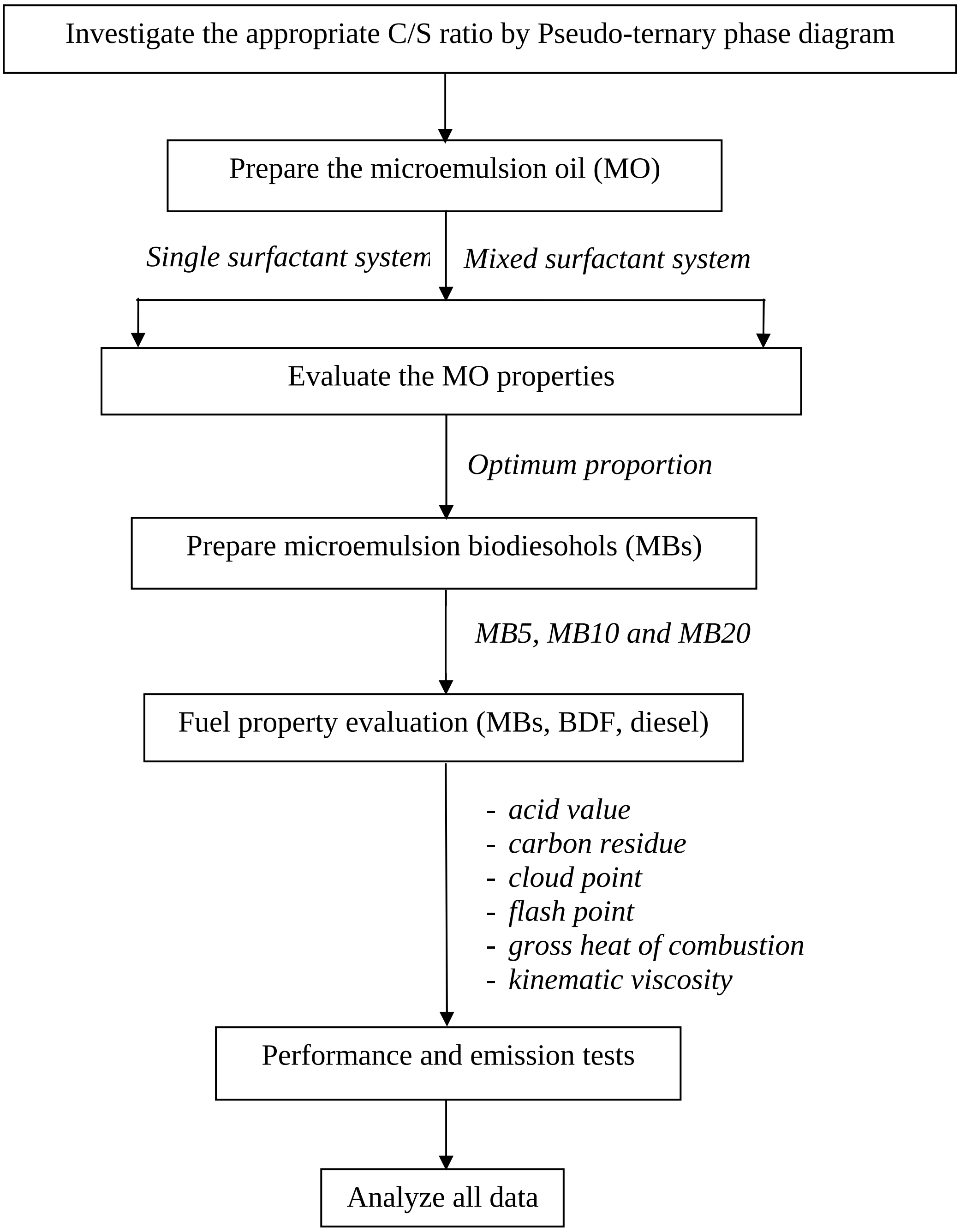


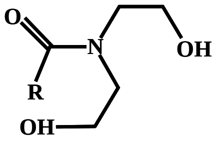
Figure 3.1 Experimental Procedure

3.1 Chemicals and Materials

3.1.1 Nonionic Surfactant

Coconut fatty acid diethanolamine (comperlan KD) of 99.7% active strength, purchased from Cognis Thailand Ltd., was used as the surfactant in this research. The physical and chemical properties are shown in Table 3.1.

Table 3.1 Physical and Chemical Properties of Comperlan KD

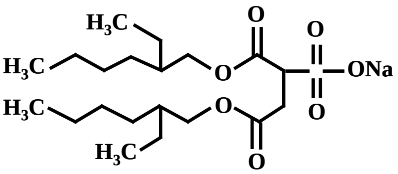
Properties	**Characteristics**
CAS No.	68603-42-9
Formula	$CH_3(CH_2)_nC(=O)N(CH_2CH_2OH)_2$
Chemical Structure	
Molecular Weight	280-290
Physical State	Liquid
Appearance	Yellow transparent liquid
Odor	Mild
Odor Threshold	Not determined
Melting Point	Not determined
Boiling Point	Not determined
Specific Gravity	0.98-1.00
Solubility in Water	Negligible (<0.1%)
Percent Volatiles (by Wt.)	Not determined
Stability	Normally stable
Hazardous Polymerization	Will not occur

Source: http://www.gmzinc.com/uploads/docs/MSDS_Comperlan_KD.pdf

3.1.2 Anionic Surfactant

Sodium bis (2-ethlhexyl) sulfosuccinate (AOT) of more than 96% anionic active, purchased from Fluka, was used as mixed surfactant with comperlan KD in this investigation. The physical and chemical properties are listed in Table 3.2.

Table 3.2 Physical and Chemical Properties of Sodium Bis (2-ethlhexyl) Sulfosuccinate (AOT)

Properties	**Characteristics**
CAS No.	577-11-7
Formula	$C_{20}H_{37}NaO_7S$
Chemical Structure	
Molecular Weight	444.57
Appearance	White solid, often supplied as an aqueous solution
Melting Point	173 - 179 °C
Boiling Point	Not determined
Solubility in Water	Appreciable
Stability	Stable, combustible, incompatible with strong oxidizing agents

Source: http://msds.chem.ox.ac.uk/DI/dioctyl_sulfosuccinate_sodium.html

3.1.3 Jatropha Oil and Its Methyl Ester (Biodiesel)

Crude jatropha oil, purchased from Thai Jatropha Oil Co., Ltd, was used in this study. In order to compare the properties and performance, the crude jatropha oil was also prepared as biodiesel via transesterification. The method of transesterification is described in Appendix B. The fatty acid composition of jatropha oil and its biodiesel are illustrated in Table 3.3.

3.1.4 Distilled Water

Distilled water was used in this analysis to generate microemulsion phase diagram.

Table 3.3 Fatty Acid Composition of Biodiesel from Jatropha Oil and Jatropha Oil

Fatty acid	**Biodiesel**[a]	**Jatropha oil**[b]
Myristic ($C_{14}/0$)	0.1	-
Palmitic ($C_{16}/0$)	14.5	14.2
Palmitoleic ($C_{16}/1$)	0.8	1.4
Stearic ($C_{18}/0$)	5.3	6.9
Oleic ($C_{18}/1$)	37.4	43.1
Linoleic ($C_{18}/2$)	41.6	34.4
Linolenic ($C_{18}/3$)	0.2	-
Arachidic ($C_{20}/0$)	0.1	-
Total Saturated	20.0	21.1
Total unsaturated	80.0	78.9

Note

[a] : The fatty acid composition of biodiesel was analyzed by GC at Biofuel Testing Laboratory of the National Metal and Materials Technology Center (MTEC)

[b] : The fatty acid composition of jatropha oil was got from Sarin et al. (2007)

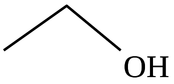
3.1.5 Conventional Diesel Fuel

The conventional diesel fuel or petroleum diesel that was blended with a microemulsion biodiesohol in this study is also called *diesel v-power* and was purchased from The Shell Company of Thailand Limited.

3.1.6 Co-Surfactant

Absolute ethanol alcohol at 99.8% strength purchased from Lab-Scan Analytical Sciences was used as the co-surfactant in this research. Its physical and chemical properties are shown in Table 3.4

Table 3.4 Physical and Chemical Properties of Ethanol

Properties	Characteristics
CAS No.	64-17-5
Formula	C_2H_6O
Chemical Structure	
Molecular Weight	46.07
Appearance	Colorless liquid
Melting Point	-144 °C
Boiling Point	78 °C
Flash Point	14 °C (closed cup)
Solubility in Water	Miscible in all proportions
Stability	Stable; substances to be avoided include strong oxidizing agents, peroxides, acids, acid chlorides, acid anhydrides, alkali metals, ammonia, moisture; Forms explosive mixtures with air

Source: http://msds.chem.ox.ac.uk/ET/ethyl_alcohol.html

3.2 Instruments

3.2.1 A Tirando Automatic Potentiometric Titratior, as shown in Figure 3.2 (a), was used for analyzing acid value.

3.2.2 An ACR-M3 Micro Carbon Residue Tester, as shown in Figure 3.2 (b), was used for analyzing carbon residues.

3.2.3 An ISL CPP 5Gs Cloud & Pour Point Tester, as shown in Figure 3.2 (c), was used for analyzing the cloud point and pour point.

3.2.4 An APM-7 Pensky-Martens Closed Cup Tester, as shown in Figure 3.2 (d), was used for analyzing the flash point.

3.2.5 An AC-350 Automatic Calorimeter, as shown in Figure 3.2 (e), was used for analyzing the gross heat of combustion.

3.2.6 A Cannon Mini-AV Automated Kinematic Viscometer, as shown in Figure 3.2 (f), was used for analyzing kinematic viscosity at 40 ^{o}C.

3.2.7 A Rancimat, as shown in Figure 3.2 (g), was used for investigating oxidation stability.

3.2.8 A Karl Ficher Tritratior, as shown in Figure 3.2 (h), was used for analyzing the water content.

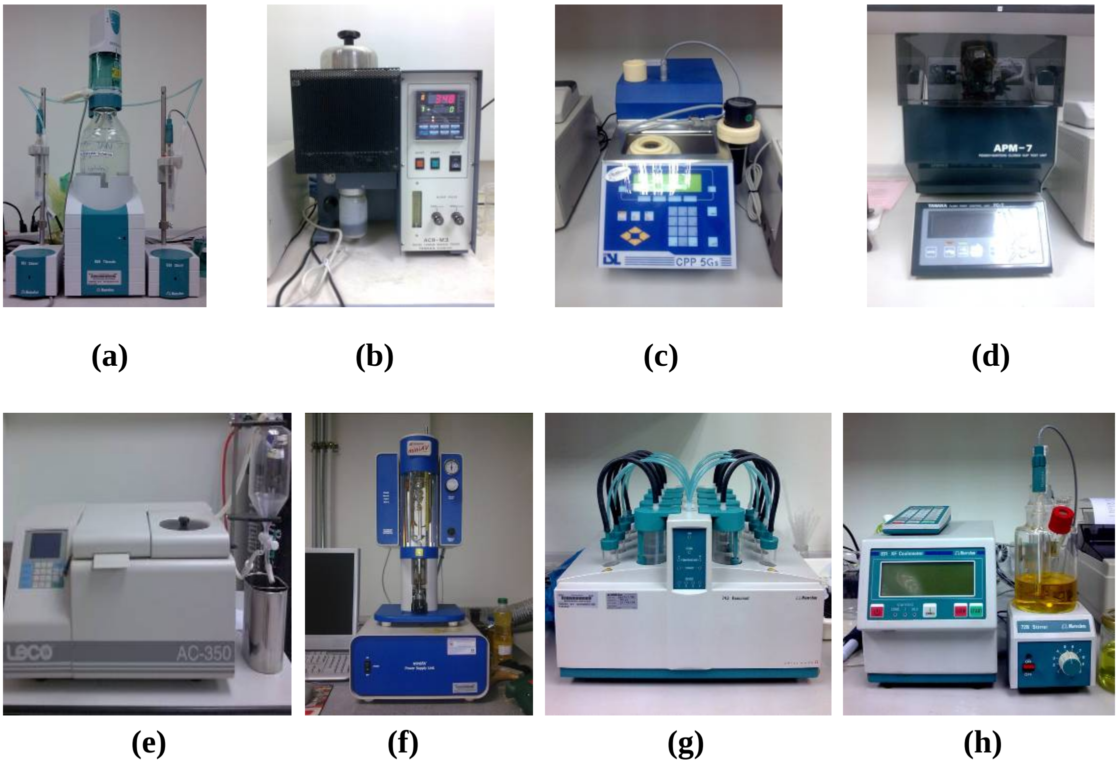
3.2.9 A Single Cylinder Diesel Engine, Model RT-100, 10 horsepower, from Siam Kubota, as shown in Figure 3.3, was used.

3.2.10 A Performance Test Set, as shown in Figure 3.4, consisting of a 10 kW generator; a series of halogen lamps; a fuel consumption meter; and an engine oil temperature, an exhaust temperature, and a humidity meter was used.

3.2.11 A Digital Tachometer produced by Technology Instruments CO., LTD., Daiichi DT-534P, as shown in Figure 3.5, was used.

3.2.12 A Model 495/01 Opacity Meter from Technotest connected to a display screen from Star gas global diagnostic system model 898 according to the EEC method, as shown in Figure 3.6, was used for analyzing black smoke.

3.2.13 An Exhaust Gas Analyzer, model HORIBA, MEXA-1600D, as shown in Figure 3.7, was used for indicating exhaust gas emissions.



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 3.2 Instruments for Analyzing Fuel Properties: (a) a Tirando Automatic Potentiometric Titratior, (b) an ACR-M3 Micro Carbon Residue Tester, (c) an ISL CPP 5Gs Cloud & Pour Point Tester, (d) an APM-7 Pensky-Martens Closed Cup Tester, (e) an AC-350 Automatic Calorimeter, (f) a Cannon Mini-AV Automated Kinematic Viscometer, (g) Rancimat and (h) a Karl Ficher Tritration.

Figure 3.3 Single Cylinder Diesel Engine Connected with Generator

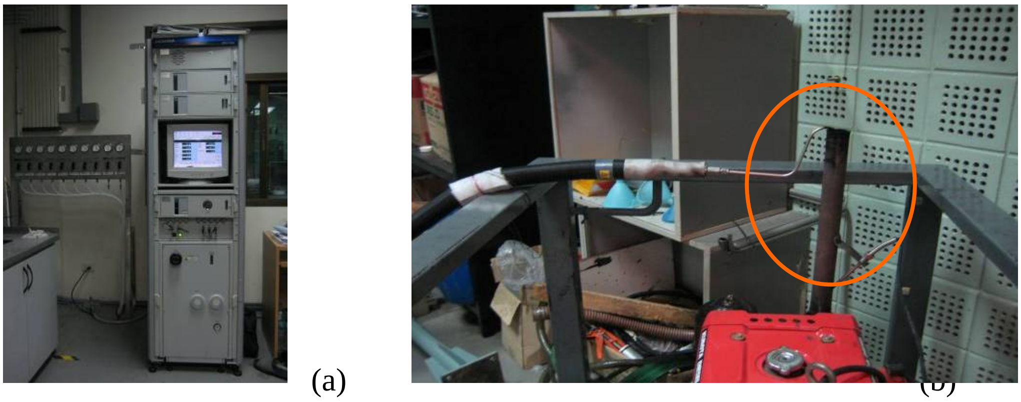
(a) (b) (c)

Figure 3.4 Performance Test Set: (a) Temperature Meter, (b) a Series of Halogen Lamps and (c) Fuel Consumption Meter

Figure 3.5 Digital Tachometer

(a) (b)

Figure 3.6 Black Smoke Meter: (a) the Display Screen and (b) the Opacity Meter



(a) (b)

Figure 3.7 Exhaust Gas Analyzer: (a) HORIBA and (b) Connected Probe with an Engine

3.3 Experimental Section

3.3.1 Studying the Pseudo-ternary Phase Diagram

The experimental procedure for constructing the pseudo-ternary phase diagram was started by preparing the co-surfactant and the surfactant solution (C/S solution). The co-surfactant and the surfactant were mixed at ratios of 0.25, 0.5, 0.75, 1.0, and 1.25. Each ratio represented one phase in the pseudo-ternary phase diagram. For example, the C/S ratio of 0.5 was prepared by mixing the co-surfactant and the surfactant at a ratio of 1:2 by weight, respectively. The surfactant mixture was prepared by using a magnetic stirrer at 600-800 rpm for 1 hour until a homogenous solution was obtained. Then, jatropha oil and C/S solution were weighted in a 10 ml vial and mixed by using a vertex to form a homogenous solution. Then, a little amount of water was added into the solution and vertexed again until feculence could be observed. The weight of the last drop of water added before feculence occurred was recorded. Furthermore, the jatropha oil and C/S solution proportions were varied from 0% to 100% to obtain one phase of the pseudo-ternary phase diagram**.** Finally, the total weight of jatropha oil, C/S solution, and water combined in the solution was calculated into 100% for all components. The obtained data was used to draw the microemulsion area in the pseudo-ternary diagram, as shown in Figure 3.8.

The optimum C/S ratio for producing microemulsion oil was obtained from the C/S ratio that generated the largest microemulsion area. The component of microemulsion oil could be obtained from the proportions where homogeneous phase exists and it was used for further experiment.

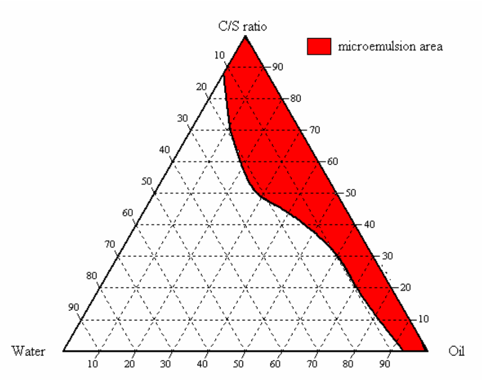


Figure 3.8 Determination of the Microemulsion Area by Pseudo-Ternary Diagram

3.3.2 Microemulsion Biodiesohol Preparation

In the previous part, the appropriate C/S ratio and the properties for obtaining a microemulsion were also identified to prepare the microemulsion oil. In this study the ratios of jatropha oil and C/S solution of 95:5 and 90:10 by weight, respectively, were investigated. For the purpose of comparison with a single surfactant system, the same jatropha oil and C/S ratio was prepared for a mixed surfactant system (e.g., by mixing 95% comperlan KD and 5% AOT together). The active concentrations of both the single and mixed surfactant systems were equal. Then, all compositions were analyzed for their properties including acid number, kinematic viscosity, and oxidation stability in order to choose the best composition for microemulsion oil.

After the appropriate conditions for microemulsion oil formation were examined, the microemulsion oil was blended with conventional diesel fuel at respective concentrations of 5%, 10%, and 20% microemulsion oil and 95%, 90%, and 80% diesel fuel by volume, called *MB5*, *MB10*, and *MB20*, respectively. The obtained solutions of the different mixing ratios were then analyzed for their fuel properties, performances, and emissions.

The word of *Microemulsion biodiesohol* or *MB* comes from the mixing with jatropha oil, which was received from plant, so it called "*bio*". It contains a small amount of ethanol in the composition of microemulsion oil (MO), and this MO is mixed with conventional diesel fuel at the latter, so it called "diesohol". Furthermore, this fuel was obtained via microemulsion technique.

3.3.3 Properties of the Microemulsion Biodiesohols

The following properties of MB5, MB10, and MB20 were determined: acid number, carbon residue, cloud point, flash point, gross heat of combustion, and kinematic viscosity. The methods used for determination of these parameters were followed American Standard Testing Methods (ASTMs): ASTM D664, D4530, D2500, D93, D240, and D445, respectively. These parameters were examined to demonstrate the long-term effects on the engine; however, the gross heat of combustion was tested to examine the performance of the fuel. In addition, the above-mentioned parameters were also examined for conventional diesel fuel (i.e., diesel v-power) and biodiesel, which was produced from jatropha oil via a transesterification process as mentioned earlier. These parameters were analyzed at the Biofuel Testing Laboratory of the National Metal and Materials Technology Center (MTEC). The details for each parameter and its testing method are given in Table 3.5.

Table 3.5 Parameters and Testing Methods of the Microemulsion Biodiesohols

Properties	**Instruments**	**Standard Testing Methods**[a]
Acid Value (mg KOH/g)	Tirando Automatic Potentiometric Titratior	ASTM D664
Carbon Residue, 100% sample	ACR-M3 Micro Carbon Residue Tester	ASTM D4530
Cloud Point (^{o}C)	ISL CPP 5Gs Cloud & Pour Point Tester	ASTM D2500

Properties	Instruments	Standard Testing Methods[a]
Flash Point (^{o}C)	APM-7 Pensky-Martens Closed Cup Tester	ASTM D93
Gross Heat of Combustion (MJ/kg)	AC-350 Automatic Calorimeter	ASTM D240
Kinematic Viscosity, 40^{o}C	Cannon mini-AV Automated Kinematic Viscometer	ASTM D445
Oxidation Stability	Rancimat	EN 14112
Water Content (%)	Karl fischer tritration	ASTM D6304

[a]: American Standard Testing Method (ASTM international)

3.3.4 Performances and Emissions Study of Microemulsion Biodiesohols

The performance and emissions of all three microemulsion biodiesohol ratios, MB5, MB10, and MB20, were evaluated and were compared with those of petroleum diesel fuel and biodiesel. All fuels were run through the Kubota IDI diesel engine model RT 100, which is a single-cylinder engine, and they were tested at partial load operation. An AC electric generator via pulleys and V-shape belts connected with the engine was used to convert the mechanical power from the engine to electricity to supply to a series of halogen lamps. Engine load was controlled by switching on the halogen lamps at different electric current. The engine speeds at 1,500 rpm, which is commonly used for the real operation, and 2,400 rpm, which is the rated speed from the company, were tested. All of these parameters were also examined at the Automotive & Alternative Fuel Laboratory of the National Metal and Materials Technology Center (MTEC). The performance parameters are shown in Table 3.6.

Table 3.6 Performance Parameters and Procedures for Fuel

Performance Parameters	Procedure
Power	Engine performance test via electrical generator
Fuel Consumption	Measuring fuel volume flow supplied to the engine
Engine Oil Temperature	Measuring the temperature of the lubricant oil in the engine
Exhaust Gas Temperature	Measuring the temperature at exhaust pipe
Humidity	Measuring the humidity in the testing area
Black Smoke	Using a smoke meter
Exhaust Gas	Using an exhaust gas analyzer

The emissions of all fuels were indicated through the exhaust gas analyzer, HORIBA, which connected with the single cylinder engine. The examination were conducted at difference engine loads, and were tested at the speeds of 1,500 rpm and 2,400 rpm as same as their performances study. The emissions parameters are shown in the Table 3.7.

Table 3.7 Types of Exhaust Gases Examination

Exhaust Gas	Units
Carbon Monoxide (CO)	ppm
Carbon Dioxide (CO_2)	%
Nitrogen Oxide (NO_x)	ppm
Oxygen (O_2)	%
Total Hydrocarbons (THC)	ppm
Ratio of Air and Fuel (AFR)	-
The Relative Air to Fuel Ratio (λ)	-

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Pseudo-ternary Phase Diagram Preparation

The microemulsion phase-- homogeneous transparent mixture-- was obtained in pseudo-ternary phase diagram at different C/S ratio as seen in the shade area on the right hand-side of diagrams of Figure 4.1. At each side of triangle represents proportion of each component; jatropha oil, C/S solution and water. The amount of water in the system as indicated in the diagram was calculated from the combination of water in ethanol, surfactant and added water. The maximum solubilization of water which provide the largest microemulsion area was considered as the optimum C/S ratio to be selected for further study.

The pseudo-ternary phase diagrams in Figure 4.1 show that the microemulsion area of the systems at C/S ratio of 0.25 and 0.5 were larger than the systems at C/S ratio of 0.75, 1.0 and 1.25. This may be explained by the fact that the lower C/S ratio, the lower the ethanol proportion and the higher the surfactant proportion in the system as a result. As a consequence, a system with the higher proportion of surfactant tends to provide higher solubilization. In addition, ethanol which plays a role as co-surfactant; however, since it is hydrophilic and miscible with water, it may result to space limitation for water to be solubilized. Subsequently, the higher the C/S ratio, the smaller the microemulsion area can be observed as shown in Figure 4.1. Furthermore, at a C/S ratio of 0.5 the largest microemulsion area was obtained. This finding agreed with the previous work for palm oil reported by Ploysrimongkol (2008).

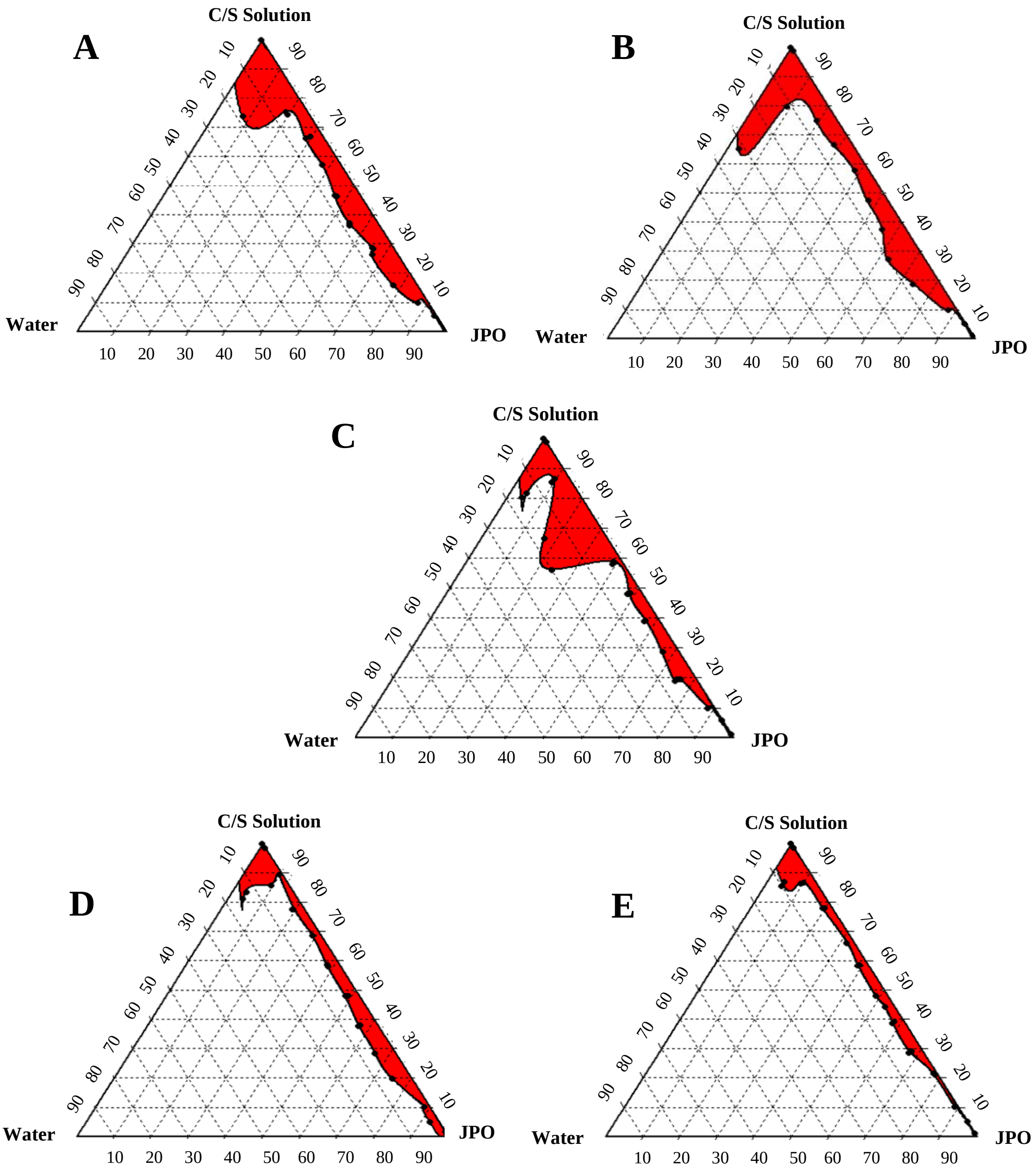


Figure 4.1 Microemulsion Area (A) at C/S Ratio of 0.25, (B) at C/S Ratio of 0.5, (C) at C/S Ratio of 0.75, (D) at C/S Ratio of 1.0, and (E) at C/S Ratio of 1.25

Therefore, from this part of the study the C/S ratios selected for preparation of microemulsion biodiesohol (MB) were the C/S ratio of 0.25 and 0.5 due to the larger area of microemulsion in the phase diagram. Additional reason for selection of these two ratios of C/S is that the limitation of water content in fuel according to standard limit of water in biodiesel. This is because high water content would be a problem for engine run. The formation of microdroplets or microemulsion product is known as water-in-oil (w/o) microemulsion or a so called reverse microemulsion (Reddy, 2006). This w/o microemulsion, water is solubilized into micelle or microdroplet that usually having size around 100 Å (Rosen, 2004). Even though, microemulsion may not alter structure of the oil, it is expected that micelle formation would modify and rearrange the molecule of oil and hence affect on some of its properties. Subsequently, in order to prove this, a larger volume of MBs was prepared using the formula from the selected systems of the two C/S ratio both for single and mixed surfactants systems.

4.2 Properties of the Alternative Fuels

In this study, the properties of test fuels are described in two main parts: (1) the properties of microemulsion oil, which was evaluated at different compositions, so that the optimum proportion of microemulsion oil was selected before blending with diesel fuel becoming microemulsion biodiesohols (MBs) as a result. The mentioned properties of microemulsion oil include kinematic viscosity, oxidation stability and acid number. (2) The properties of microemulsion biodiesohols, being blended at different proportions between optimized microemulsion oil and conventional diesel fuel. The properties of microemulsion biodiesohols consist of acid number, carbon residue, cloud point, flash point, gross heat of combustion and kinematic viscosity. Moreover, the stated properties of MBs were also compared with those of conventional diesel fuel and methyl ester of jatropha oil.

4.2.1 Properties of the Microemulsion Oil

For the first part, the kinematic viscosity, oxidation stability and acid number were examined. Crude jatropha oil (CJO) blended with C/S ratio of 0.25 and 0.5 were evaluated. Different surfactant as explained earlier (i.e., single and mixed surfactants) were applied to make four C/S solutions that contained different C/S ratio and different surfactant systems. Subsequently, each C/S solutions were mixed with crude jatropha oil at 5 and 10% by weight to make microemulsion oil, so there were totally eight formulations (see Tables 4.1 and 4.2), which were different in compositions, to be evaluated for their properties. Base on the properties of the oil, it was intended to select a suitable microemulsion oil to produce biodiesohol and test with a single cylinder engine (Kubota RT100) in the further experiment.

Table 4.1 Compositions (wt%) of Each Components in Microemulsion Oil Using Single Surfactant in C/S Component

Compositions in MO*	**Systems with C/S ratio 0.25**		**Systems with C/S ratio 0.50**	
	95: 5 of CJO: C/S	**90: 10 of CJO: C/S**	**95: 5 of CJO: C/S**	**90: 10 of CJO: C/S**
Jatropha Oil	95	90	95	90
Ethanol	1.0	2	1.7	3.3
Comperlan KD	4.0	8	3.3	6.7

Note * The compositions of MO also have a small amount of water that has been contained in the ethanol and Comperlan KD; however, it is insignificant.

Table 4.2 Compositions (wt%) of Each Components in Microemulsion Oil Using Mixed Surfactant in C/S Component

Composition in MO*	**Systems with C/S ratio 0.25**		**Systems with C/S ratio 0.50**	
	95: 5 of CJO: C/S	**90: 10 of CJO: C/S**	**95: 5 of CJO: C/S**	**90: 10 of CJO: C/S**
Jatropha Oil	95	90	95	90
Ethanol	1.0	2	1.7	3.3
AOT	0.2	0.4	0.165	0.335
Comperlan KD	3.8	7.6	3.135	6.365

Note * The compositions of MO also have a small amount of water that has been contained in the ethanol and Comperlan KD; however, it is insignificant.

From the results, the viscosity of CJO was 33.84 cSt, which was much higher than neat diesel. Compare to the Standard of biodiesel at 3.5-5.0 cSt (Department of Energy Business, 2007), its viscosity is almost ten times higher than those of the standard biodiesel. Therefore, it is necessary to reduce the viscosity before being used as an alternative fuel in an engine. To prepare as microemulsion oil by the formulations with C/S as describe in Tables 4.1 and 4.2, the viscosity was slightly decreased for both the oil mixed with the single surfactant and mixed surfactant systems (See Figures 4.2 and 4.3). However, at C/S ratio of 0.25 for both systems, the viscosity was found insignificantly different from the crude jatropha oil. While for the microemulsion oil prepared by mixing with C/S ratio of 0.50 exhibited significantly lower viscosity at about 2-3 sCt as compared with CJO. This may indicate that C/S ratio has more influence on viscosity of the products than only amount of ethanol. It can be explained that at suitable ratio of surfactant(s) and cosurfactant (ethanol), they were synergized to form microemulsion, and hence reducing viscosity of the products. As compared between single surfactant and mixed surfactant systems, it seems that type of surfactant may not significantly affect to viscosity due to only small amount of anionic surfactant (AOT) was mixed with Comperlan KD, suggesting that its effect would not be significant. Nevertheless, the viscosity of all microemulsion oils were still much higher that the neat diesel or biodiesel. This result suggests that when using this microemulsion oil in diesel engine, blending with diesel fuel at least the ratio of 1:10 is necessary to reduce the viscosity down to meet the upper limit of biodiesel standard.

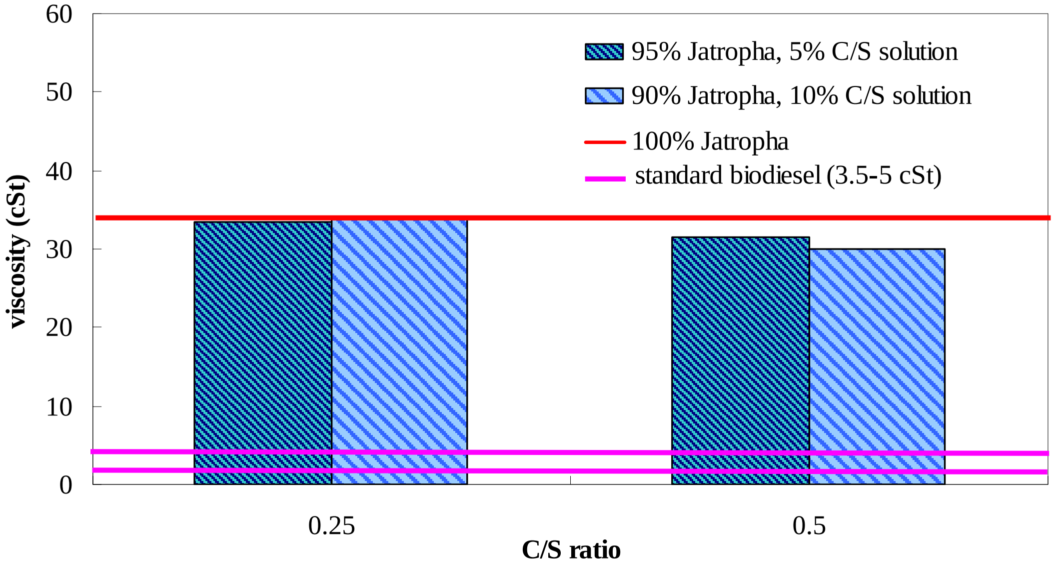


Figure 4.2 Kinematic Viscosity of Microemulsion Oil at C/S Ratios of 0.25 and 0.5 Using a Single Surfactant System

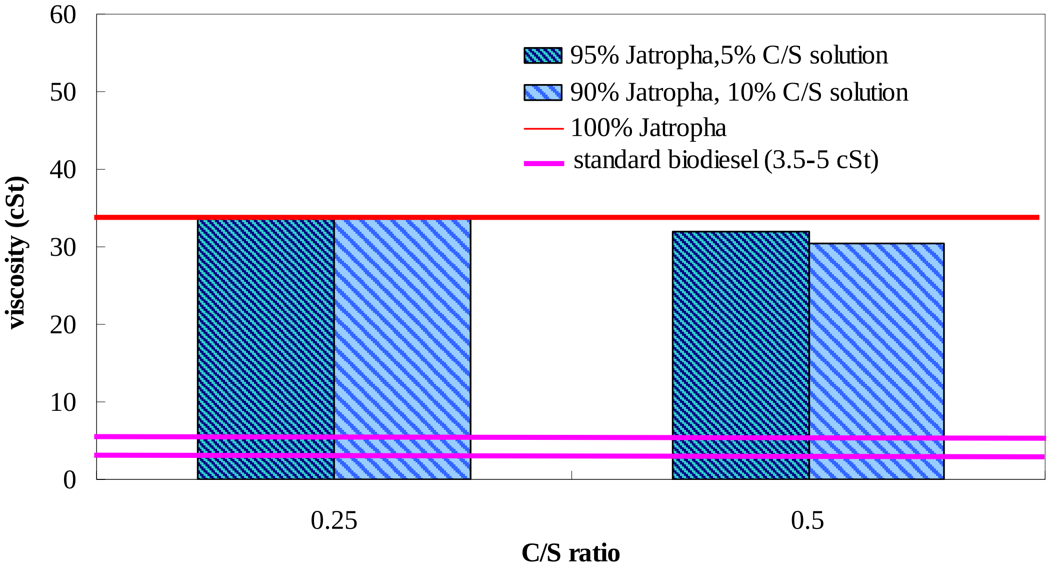


Figure 4.3 Kinematic Viscosity of Microemulsion Oil at C/S Ratios of 0.25 and 0.5 Using a Mixed Surfactant System

In addition, the oxidation stability was evaluated by using Rancimat and reported as induction time, which implies the time that the test sample can maintain its oxidation stability at a certain level. From the European Standard, the minimum induction time for biodiesel is set at 6 hours (Department of Energy Business, 2007). The results show that induction time of CJO was 9.46 hours, and it was increased when C/S solution was added. More C/S solution, higher induction time was detected.

For the MO contained a single surfactant in C/S component, induction time at C/S ratio of 0.5 was higher than that of C/S ratio of 0.25 in all proportions as shown in Figure 4.4, suggesting that the amount of ethanol in the C/S solution responded for this result. This ethanol plays a role as a co-surfactant; adding more ethanol can also enhance the stability of microemulsion (Reddy, 2006). For the MO contains mixed surfactants in C/S component, the improvement of the oxidation stability was found in the similar trend; however, their effect was much stronger than those found in the single surfactant (see Figure 4.5). The induction times of the mixed surfactant detected during the experiment were more than thrice of those of the single surfactant systems. This may be resulted from the stronger interaction of mixed anionic and nonionic surfactant which leads to higher stability to resist an oxidation and hence increases an induction time. Compared to CJO, both products prepared by both single and mixed surfactant show significantly improvement of oxidation stability. This indicates that C/S solution can play a role as antioxidant for the oil.

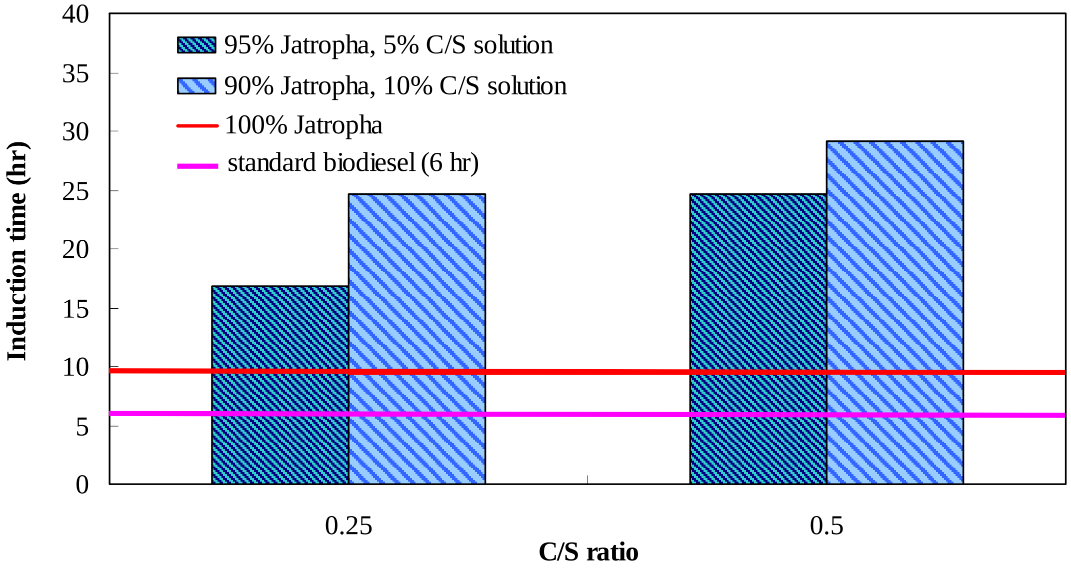


Figure 4.4 Oxidation Stability of Microemulsion Oil at C/S Ratios of 0.25 and 0.5 Using a Single Surfactant System

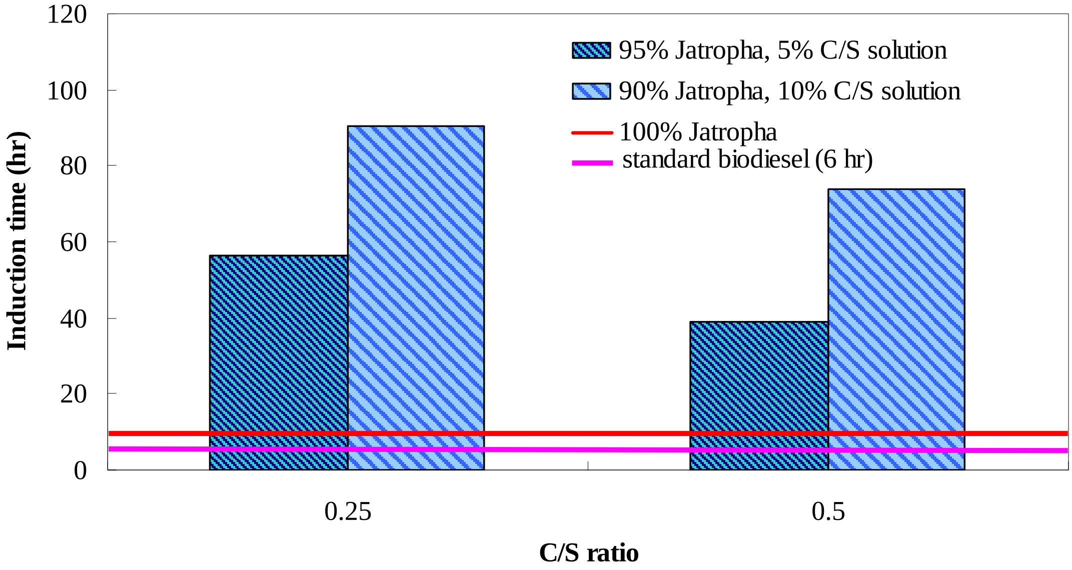


Figure 4.5 Oxidation Stability of Microemulsion Oil at C/S Ratio of 0.25 and 0.5 Using Mixed Surfactant System

The acid number is a measure of the amount of fatty acid converted from triglycerides that occur in vegetable oil. Thus the longer time, the lower acid number can be expected for biodiesel. The results showed that acid value of CJO was 2.48 mg KOH/g at the first day of measurement, which was higher than the upper limit of 0.5 mg KOH/g of ASTM D6751 standard (Department of Energy Business, 2007). For the MOs that C/S solutions were added into CJO, their acid values were still close to the acid value of CJO. So, addition of the C/S solutions cannot immediately reduce the acid value.

In order to evaluate the properties of MOs by the acid value, the mornitoring measurement for fatty acid was carried out for every two days for total two weeks. It was found that the acid values of CJO and MOs were rather constant. The result from induction time evaluations suggests that CJO itself and MOs have high oxidation stability, in other words, long shelflife. This results agree very well with a rather unchanged acid value detected. Nevertheless, for the cases of adding C/S solution, the acid values tended to decrease over time and strongly depended on amount and type of C/S solution used, especially for the composition of CJO:C/S solution of 90:10 at the C/S ratio of 0.5 in both single and mixed surfactant systems as seen in Figures 4.6 and 4.7. Even though the mechanism may not yet be clearly explained here, it may be caused from the microemulsion formation occured in MOs created some interaction with fatty acid. Therfore, it decreased the amount of proton in the solution and reduced the acid values. However, the acid value of MOs increased at the fourteenth day. Normally, when vegetable oil expose to the air, oxidation will occurr and higher acid value will be detected. To obtain a clearer picture, and ensure the stability of the oil, all samples should be kept for longer time investigation.

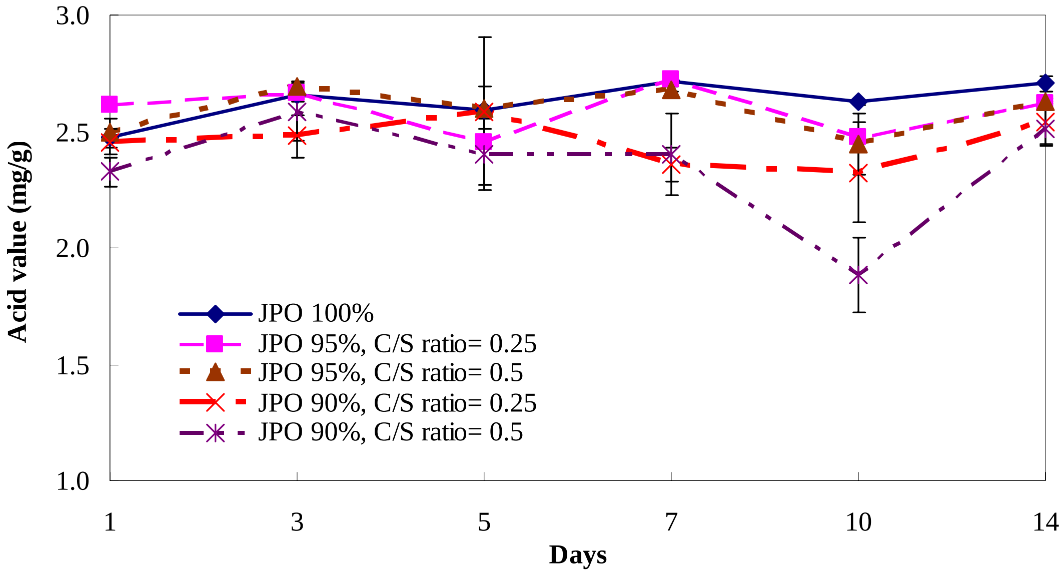


Figure 4.6 Acid Number of Microemulsion Oil at C/S Ratio of 0.25 and 0.5 Using Single Surfactant System

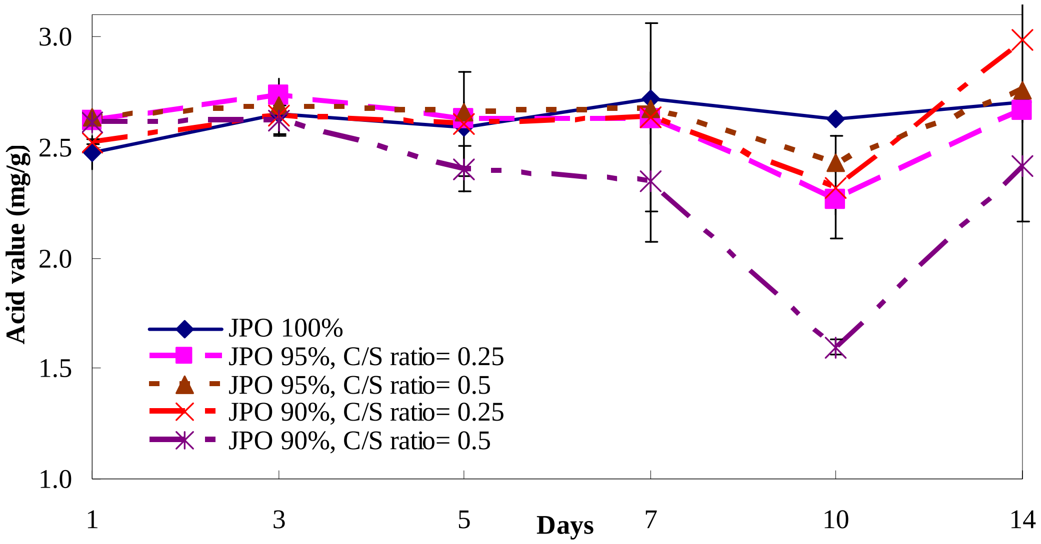


Figure 4.7 Acid Number of Microemulsion Oil at C/S Ratio of 0.25 and 0.5 Using Mixed Surfactant System

The criteria for selecting the optimum proportion of microemulsion oil (MO) for further experiment is as follows:

(1) Adding the C/S solution could reduce the viscosity of MOs while the types of surfactants did not affect anything. The results showed that the viscosity of MOs at the C/S ratio of 0.5 was decreased whereas the viscosity of MOs was closed to that of crude jatropha oil (CJO) when the C/S ratio was equaled to 0.25 for both surfactant systems.

(2) Although the induction time of MOs in a single surfactant system was shorter than that of the MOs in mixed surfactant system, it was still longer than the standard time limitation at 6 hrs. Moreover, the preparation time and difficulty of the single surfactant system were shorter and lesser than those of another system, so the single surfactant system was more appropriated system.

(3) Less amount of additive was required to add into conventional diesel fuel. In addition, according to the mixed fuel properties of crude jatropha oil and C/S solution were insignificantly different between the mixing ratio of 95:5 and 90:10, so performance and emission outcomes may not be affected when these fuels was taken into the experiment. In this case, the composition of CJO and C/S solution at the ratio of 95:5 was recommended for MBs preparation.

4.2.2 Properties of the Microemulsion Biodiesohols, Diesel and Biodiesel

From the previous part, the optimum composition of microemulsion oil was 95% of jatropha oil and 5% of C/S solution at the C/S ratio of 0.5 in the single surfactant system. However, the viscosity of the appropriated microemulsion oil was higher than biodiesel standard. Before it was used as fuel in the diesel engine, it must be mixed with diesel fuel in various ratios for reducing the viscosity values. So that, the blends from our selected formula microemulsion with petroleum diesel at volumetric ratio 5:95, 10:90 and 20:80 were prepared and called as MB5, MB10 and MB20, respectively. For all of these mentioned blends including neat diesel and biodiesel were examined for their properites as the result shown in Table 4.3.

According to the Table 4.1, it showed that the kinematic viscosity of each fuel can meet the biodiesel standard also.

The kinematic viscosities of MB5, MB10 and MB20 were 3.524, 3.952 and 4.991 cSt, respectively. The viscosity values increased following the percentage of microemulsion oil (MO) being blended according to the mixing rule that the viscosity of the blend is proportion of the each component in the mixture. This result agreed with the result of Cheenkachorn et al., (2004) in that the kinematic viscosity of blended diesel can be increased as the enhancement of proportion of biodiesel content. In this research, biodiesel--methyl ester of jatropha oil-- was also analyzed for comparison with other fuels and its viscosity was 4.293 cSt. The kinematic viscosity of both MBs and biodiesel were met the biodiesel standard values (i.e., 3.5-5 cSt).

As mentioned earlier that viscosity is the crucial parameters for engine operation. As a consequence, pure microemulsion oil or MO was not recommended since a high viscous fuel would result poor fuel atomization leading to inefficient fuel to air mixing can be generated in a combustion chamber (Reddy and Ramesh, 2006; Kumar, 2007). Because of this, using high viscous fuel can cause incomplete combustion and lead to high emission of hydrocarbon (HC) and carbon monoxide (CO). Therefore, in the next step on engine performance testing, reducing the kinematic viscosity of the fuel is needed. Thus, to blend with petroleum diesel was introduced before our microemulsion oil being used as an alternative fuel.

The second parameter was acid value, which is normally specified for only biodiesel since free acids are not found in petroleum diesel. The result is as expected, the higher proportion of petroleum diesel, the lower acid value of the blend. The acid value of MO, which obtained from the previous part, was 2.49 mg KOH/g, and for those of MB5, MB10 and MB20 were 0.35, 0.40 and 0.66 mg KOH/g, respectively (Table 4.3). Their acid values of MBs were significantly decreased from the original MO due to high proportion of diesel in the blends. However, the acid value of all blends (MBs) was still higher than the one of biodiesel, 0.15 mg KOH/g. This may be explained that the transesterification process for producing biodiesel from Jatropha oil used base (KOH) as a catalyst and thus some free acid may be already neutralized. From these results illustrated that the acid values of MB5, MB10 and biodiesel were less than the biodiesel standard of 0.5 mg KOH/g of ASTM D664 standard (Department of Energy Business, 2007). There was only MB20 that having acid value slightly exceeds the standard for biodiesel. Although, all of mentioned values were under the biodiesel standard, the other properties should also be considered before using them as an alternative fuel. On the other hand, the acid value of MB20 was higher than the ASTM D664 standard value; therefore, it may cause the corrosion of engines for a long-term operation and build up in fuel system.

Table 4.3 Properties of MBs, Diesel and Biodiesel Fuel

Sample	**Properties**						
	Acid Value (mg/g)	**Carbon Residue (%)**	**Cloud Point (^oC)**	**Flash Point (^oC)**	**Gross Heat of Combustion (MJ/kg)**	**Viscosity (cSt)**	**Water Content (%)**
MB20	0.66	0.0726	6.3	42	44.1	4.991	0.026
MB10	0.40	0.0465	6.2	48	45.0	3.952	0.014
MB5	0.35	0.0166	6	56	45.2	3.524	0.009
DF	-	0.0033	-5	64	45.5	3.078	-
Biodiesel	0.15	0.0396	4.7	191	39.5	4.293	0.057
Standard Biodiesel*	0.5max	0.3 max	N.A	120 min	N.A	3.5-5	0.05 max

* Source: Department of Energy Business, 2007

The weight percentages of carbon residue can be indicated that how much the amount of remained carbon is after the combustion process under the certain condition, which is high temperature in an inert atmosphere conditions (Tongcher et al., 2008). From the results in Table 4.3, the measured value of carbon residue when diesel fuel is combusted was found the lowest at 0.0033 %wt, and the highest value was found for MB20 at 0.0726 %wt. In addition, the values of other fuels such as the MB5, MB10 and biodiesel were 0.0166, 0.0465 and 0.0396 %wt, respectively. MB5 gave a less amount of carbon residue comparing to biodiesel while MB10 and MB20 was found slightly higher but still in the same magnitude. The carbon residue of all tested fuels was under the standard of biodiesel at 0.3 %wt. Theoretically, the appearance of most carbon residue after burning biodiesel fuel is derived from unburnt glycerol content. In the production process of MBs, removing some glycerol from the jatropha oil did not perform as same as in the transesterification process; however, the capacity of carbon being determined after combustion process of MBs and biodiesel fuels were not much different.

Another important parameter is cloud point since the temperature can cause any fuels become cloudy in a form of crystals. The desired value of cloud point for fuel is below the temperature of use. From the results shown in Table 4.3, even though the cloud point of the MBs as well as the biodiesel were higher than that the neat diesel fuel almost 10 ^{o}C, they were still below the ambient air temperature of Thailand, where average temperature is around 18-34^{o}C. However, in winter that temperature below 4-6 ^{o}C may be a limitation of using MB5, MB10, MB20 and biodiesel. For the reason that the fuel filters and supply lines might be clogged up. The cloud points of MBs and biodiesel fuels, which made from vegetable oil, were usually found higher than that of petroleum diesel fuel as a consequence of longer chain in their structures (Benjumea, 2007). These results were also corresponding with the result of Ali and Hanna (1994).

Flash point is the lowest temperature that exposing fuels in the environment can ignite itself. Lower flash point fuels can easier ignite in combustion chambers, but the low flash point fuels storage and transportation must be taken into consideration cautiously. Because the average of the highest ambient temperature in Thailand since 1978 to 2007 was approximately 38 ^{o}C (www.tmd.go.th), the MB20 flash point of 42 ^{o}C must be carefully stored and transported.

Generally, the flash point of diesel fuel was 64 ^{o}C, but it can be decreased when diesel fuel was blended with microemulsion oil in different proportions. In the Table 4.3, it showed that the higher the microemulsion oil was blended with diesel, the lower the flash point temperature of MBs was appeared. This dues to an increase of ethanol in composition since ethanol has very low flash point. Furthermore, the flash point temperature of biodiesel was the highest, so it may cause difficult ignition in the combustion chamber.

Gross heat of combustion is another important parameter. It is specified as the energy of fuels per fuel mass (MJ/kg), which can be released in a combustion process. From the Table 4.3, the highest gross heat of combustion was found with the neat diesel fuel was at 45.5 MJ/kg, and the lowest one was found with biodiesel at 39.5 MJ/kg. This value of MB5, MB10 and MB20 were slightly decreased from diesel fuel on increasing the MBs blend in the content, and the results were 45.2, 45.0 and 44.1, respectively. MBs and biodiesel contain oxygen in the molecule structure resulting to lower gross heat of combustion as compared to diesel fuel (Cheenkachorn et al., 2004; Agarwal, 2007; Benjumea, 2007 and Kwanchareon et al., 2007).

In addition, the heating value of fuel get from total heating value subtract the heating value of vaporization of latent water vapor, so the amount of water content in the molecule is also affect lower heating value. From the results of water content, biodiesel had the highest water content in the molecule, and this value of MBs was increased on increasing the MBs blend. These results were corresponded to the heating value.

4.3 Engine Test of Microemulsion Biodiesohols

This research studied the engine performances and emissions when MBs, diesel and biodiesel fuels were used in a small single cylinder diesel engine. All analysis results are compared and discussed in this section. In the performance test, the Kubota IDI diesel engine model RT100 was selected. This type of engine is normally used for light load and stationary applications such as farm irrigation and small electrical generator. To measure the engine performance, it was connected to an AC electric generator via pulleys and V-shape belts. The generator was used to convert the mechanical power from the engine to electricity to supply to a series of halogen lamps which were utilized as engine loads. In addition, two engine speeds of 1,500 and 2,400 rpm were set since the former is the common speed used by farmer in practice while the latter is the engine rated speed specified by the engine manufacture.

The engine operation can be divided into two categories as full-load and partial load performance test. The full-load test is a method to measure the engine maximum torque and power. When the engine is running, its throttle is fixed at the widest position. Then, loads are applied to the engine causing the speed to drop. Engine performance, fuel consumption and emissions are measured at each speed. The full load test is commonly used in various research works. The results of engine performance when applying renewable fuels, which provides lower heating value, are slightly drop of engine performance and higher fuel consumption. Exhaust gas quality is improved when blending biofuel into diesel. Nevertheless, in this research, partial load test was focused due to the fact that this engine is normally used at the load condition lower than the maximum load (i.e., engine load at the widest throttle opening position). The various constant loads were charged to the tested engine and the engine throttle was varied to keep the running speed of 1,500 and 2,400 rpm. The engine loads were designed to vary from 0 kW to 9 kW at 1,500 rpm, but they were not varied above 4 kW in the case of 2,400 rpm since the highest speed of this diesel engine was limited at 2,500 rpm at the widest throttle position. Moreover, engine power, fuel consumption, oil temperature and exhaust gas temperature were also measured. Later, they will be discussed in this section.

4.3.1 Performances of Microemulsion Biodiesohols, Diesel and Biodiesel

As can be seen in Figure 4.8, the engine power of all fuels increase as the increment of engine loads; i.e., more lamps were turned on, for both lower and higher speeds. During the experiment, once the engine loads were raised, the fuel pump had to be adjusted manually to supply more fuel in order to maintain the engine speed. Hence, more fuel was combusted and higher power could be measured. The same reason could be applied to the higher speed of 2,400 rpm. However, the power output slope was different. At the same engine load, the power output at higher speed is higher than that at another speed. With a pulley ratio of 5:8 (engine to generator) and at the engine speed of 2,400 rpm, the generator was running at its rated speed of 1,500 rpm creating full output voltage of 220 volt. The higher voltage output from the generator at the engine speed of 2,400 rpm was across the load circuit, creating larger amount of current flowing through the loads. Hence, higher power could be obtained from this engine speed than the lower one. When looking at the power gained from different fuels, the power curves of all fuels appear to be nearly the same. This can be implied that all fuels can provide sufficient energy for the engine to overcome the applied load.

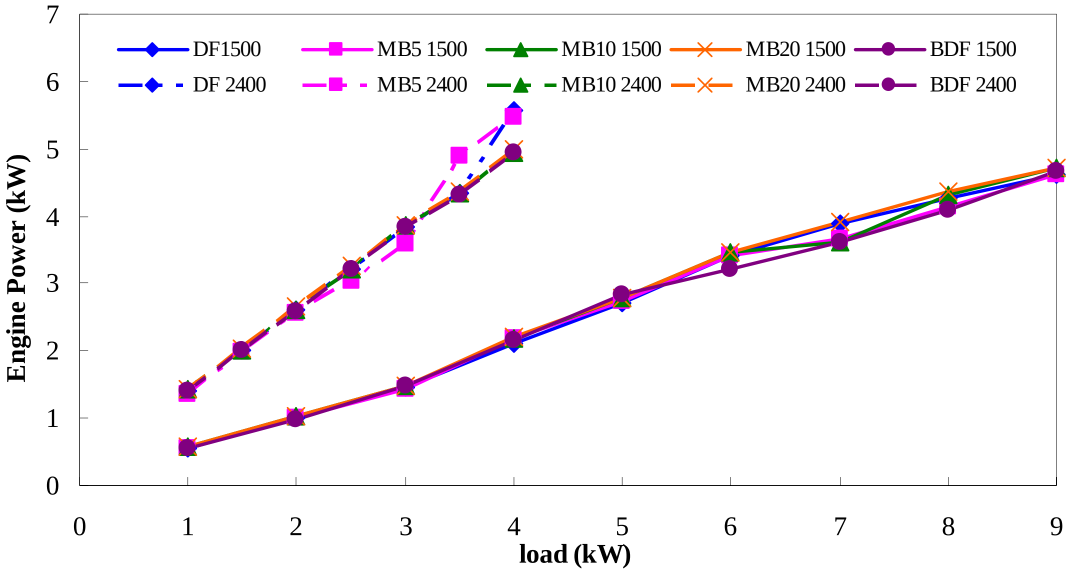


Figure 4.8 Engine Power (kW) at 1,500 rpm and 2,400 rpm

In this study, the brake fuel consumption (BFC) values were measured by mean of volume flow rate. It should be noted that the test results contain some error due to the change of volume to the temperature difference during the experiment. Each set of data could be affected directly from the various ambient temperature. In order to get the most accurate result, mass flow fuel consumption measurement should be used. From the experiment, the engine was controlled at constant speeds of 1,500 and 2,400 rpm and various loads were applied to the single cylinder diesel engine. The fuel consumptions of each case using different types of fuels and blends were recorded. Figure 4.9 shows the BFC changes in liter per hour (L/hr) when diesel, biodiesel and MBs were used. The results show that the brake fuel consumption is increased as the increment of engine loads for all fuels in both engine speeds, similar to the previous results in Figure 4.8. It can be seen that fuel consumption at high speed (2,400 rpm) was more than that at low speed (1,500 rpm). The slopes of all BFC curves at 2,400 rpm were also higher than those at the engine speed of 1,500 rpm. This is because the engine required power is higher at the higher speed. Thus the engine has to consume more fuel for producing that high power.

According to the Figure 4.9, the BFC in the unit of liter/hour (L/hr) of all tested fuels are almost similar at 1,500 rpm. The BFC of biodiesel is noticed as the highest because of its least gross heat of combustion comparing to other fuels mentioned in this study (Lin and Lin, 2007) while the BFC of MB10 is the lowest. The increments of BFC trends at the engine speed of 2,400 rpm are in the same way as the 1,500 rpm (the slope is almost equal), but with wider gab difference among all fuels. It can be noticed that the BFC curve of MB20 lines in the middle of other fuels both in the case of 1,500 and 2,400 rpm. According to the comparison data of MB20 and other fuels listed in Table 4.1, its heating value is also in between biodiesel and other tested fuels.

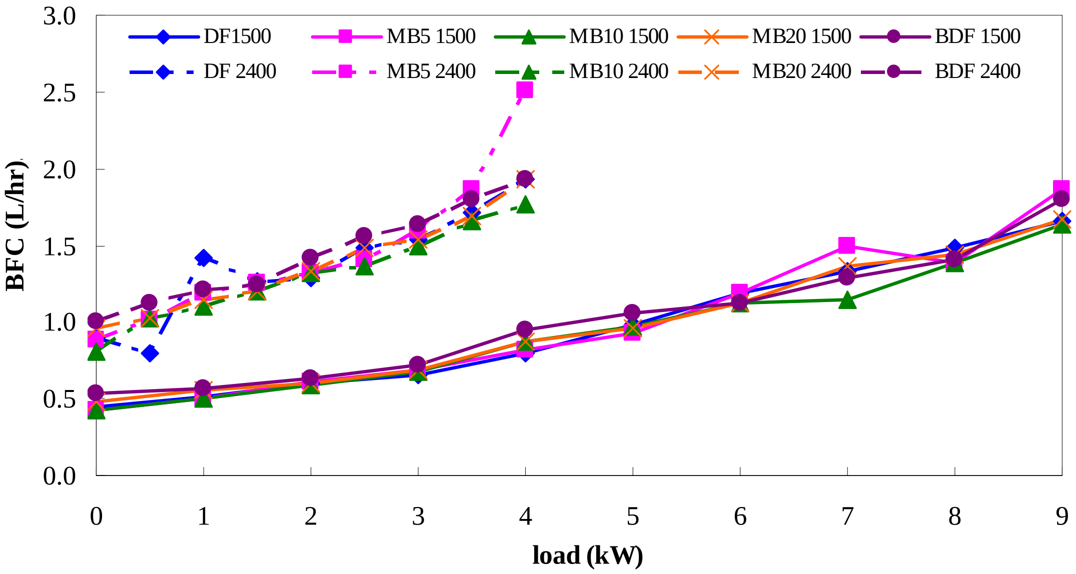


Figure 4.9 Brake Fuel Consumptions (L/hr) at 1,500 rpm and 2,400 rpm

Considering the fuel consumption comparing to the power output obtained from the engine, BFC in liter per kilowatt-hour (L/kW-hr) against engine load were plotted and shown in the Figure 4.10. In this case, it should be noted that all BFC (L/kW-hr) values were calculated from the measured fuel volume flow supplied to the engine in liter per power output in kW-hr, in other word, the proportion of input per output. These BFC values may give a figure of the engine fuel efficiency. However, this value is calculated by fuel mass flow and power output. If the data in Figure 4.10 are converted to the fuel efficiency, there will be some error as a result. The results show that the BFC values of both engine speeds are reduced as the increment of engine loads for all fuels even though the engine consumed more fuels at higher load and higher speed (see Figure 4.9). The higher engine power was also detected at that condition.

Among all fuels, the least BFC (L/kW-hr) was detected when MB10 was used for both engine speeds. This means that using MB10 fuel possibly yields the best engine fuel efficiency. As illustrated in Figures 4.10, the best fuel economy ranges are at the load of 5-9 kW and 3-4 kW at the speed of 1,500 and 2,400 rpm, respectively. These operation ranges are recommended for the farmer if the fuel economy is considered. Furthermore, when the BFC of both speed operations are compared at the engine loads varied from 1 to 4 kW, the BFC at 2,400 rpm engine speed are slightly lower than those of 1,500 rpm for all fuel types. This can be implied that better engine fuel efficiency could be achieved for the high engine speed. Furthermore, the least brake fuel consumption should be obtained at a general working range and this is usually designed by the engine manufacturer.

Although, the results imply that fuel conversion efficiency of 2,400 rpm is better than 1,500 rpm at partial load operation, the actual application should be considered before selecting the suitable engine speed. For instances, when energy saving is involved, the engine speed of 1,500 rpm will be more practical. On the other hand, the 2,400 rpm will be more suitable if more power is required and the engine efficiency is taken into consideration.

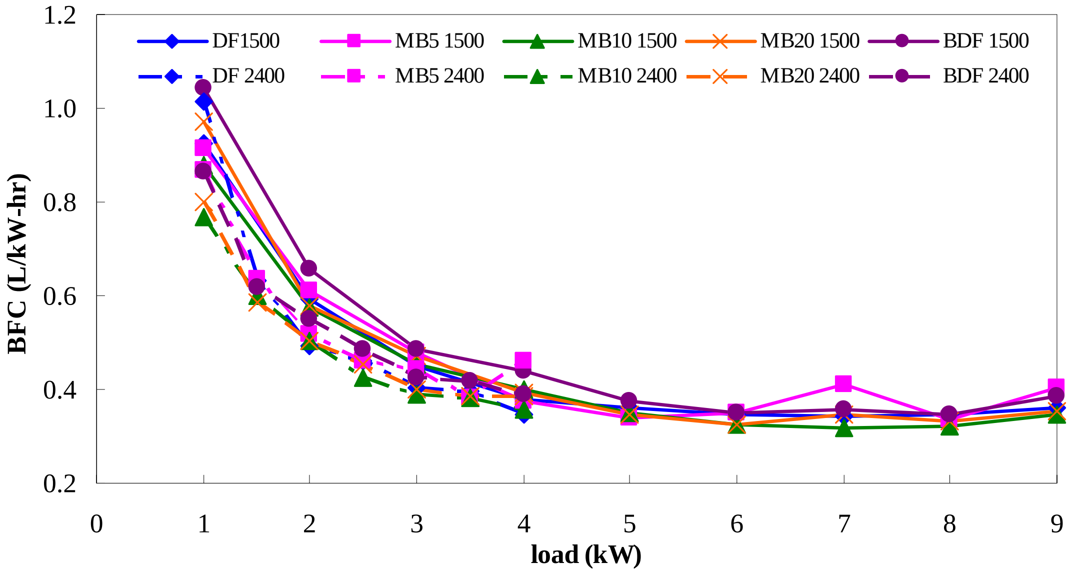


Figure 4.10 Brake Fuel Consumptions (L/kW-hr) at 1,500 rpm and 2,400 rpm

In this research, the engine oil temperature and exhaust gas temperature had also been measured during the engine testing. At constant speeds, the measured values are plotted versus various engine loads as can be seen in Figure 4.11 and Figure 4.12, respectively. Even though the engine oil temperatures were not started at the same point, these oil temperatures were in the operating temperature range, which is between 60 ^{o}C to 100 ^{o}C (Super Motards Forum, online, 2009). In accordance with the Figure 4.11, it can be seen that oil temperature increased as the increment of engine loads. It was also found that the range of oil temperature at the engine speed of 2,400 rpm was wider than that of 1,500 rpm; i.e., Figure 4.11 shows higher slope in case of high engine speed than that of the lower one. From the results, at the engine speed of 2,400 rpm, the slope of MB20 is the most precipitous while the slope of biodiesel is the steepest for another setting speed. At the high engine speed, higher heat generation from the combustion process was transferred to the engine oil more rapidly and caused higher rate of increasing oil temperature.

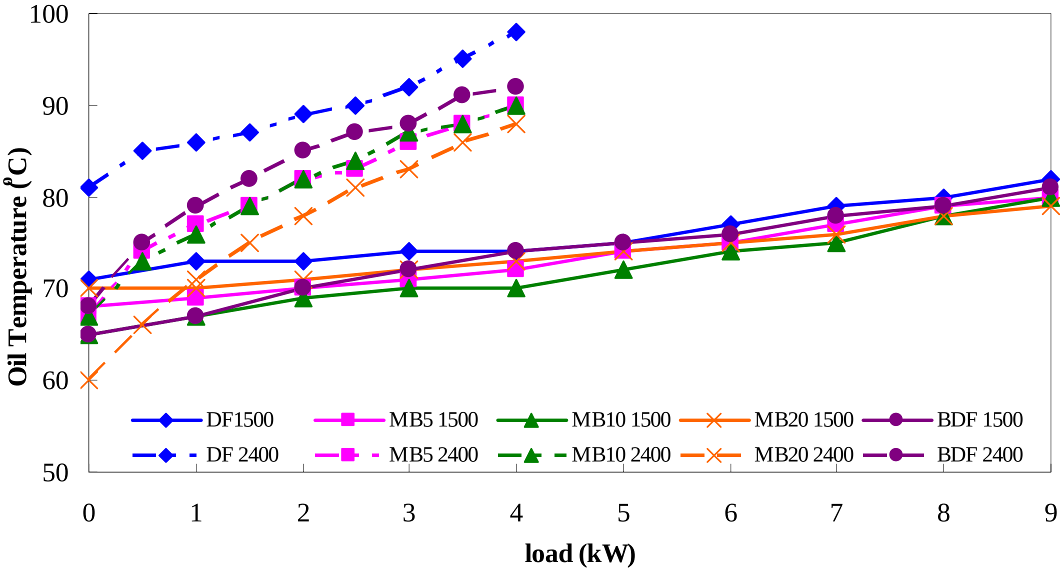


Figure 4.11 Oil Temperatures (^{o}C) at 1,500 rpm and 2,400 rpm

Focusing on the exhaust temperature, the data were recorded and shown in the Figure 4.12. The fuel that was stared to run on the engine at high initial oil temperature provided the higher start of exhaust gas temperature. At the engine speed of 1,500 rpm, the exhaust gas temperature was gradually increased as the load increased. On the contrary, it is dramatically increased at the engine speed of 2,400 rpm. Since more engine loads had been applied, more fuel must be injected to the combustion chamber for stabilizing the engine speed leading to the higher combustion heat. Consequently, oil temperature and exhaust gas temperature were rapidly rising.

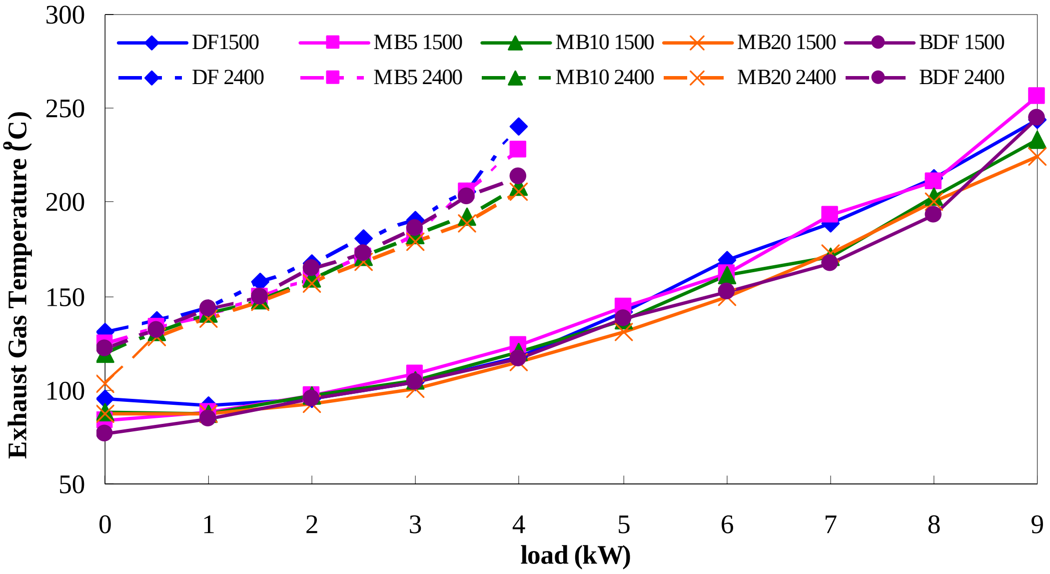


Figure 4.12 Exhaust Gas Temperatures (°C) at 1,500 rpm and 2,400 rpm

4.3.2 Emissions of Microemulsion Biodiesohols, Diesel and Biodiesel

While the single cylinder diesel engine had been running at two constant speeds and various loads; all exhausted emissions were also examined via an opacity meter and an exhaust gas analyzer. As illustrated in the Figure 4.13 and 4.14, the increment of engine loads affects the increment of black smoke formation for both engine speeds. In Comparison, the black smoke formed from the use of diesel fuel, MB5 and MB20 at the engine speed of 2,400 rpm were higher than those at the speed of 1,500 rpm. This can be explained that more fuel injected via a nozzle at high engine speed causes poor mixing between fuel and air and resulted in incomplete combustion. On the other hand, the black smoke values of MB10 are less at 2,400 rpm. These results are same as the smoke results at full-load performance test of previous research by Ploysrimongkol (2008). She reported that the black smoke emissions were lower at higher engine speed.

As can be seen in Figures 4.13, the black smoke of MB20 and biodiesel at the engine speed of 1,500 rpm are similar and they are lower than those of other test fuels. The oxygen molecule in microemulsion oil and biodiesel could cause the cleaner burning and resulted in less smoke emission. However, the black smoke trend of biodiesel at the engine speed of 2,400 was initially lower than the other fuels, and then it gradually increased since the engine load of 2 kW. Moreover, its trend becomes the highest among the other fuels after the 3-kW engine load (see Figure 4.14). This may be the disadvantage of biodiesel utilization on small diesel engine at high engine speed and load. The reason for high smoke emission form biodiesel is that its structure is normally more complicated than other fuels, especially neat diesel fuel, which can cause insufficient fuel atomization causing poor air-fuel mixture. Furthermore, biodiesel fuel contains the least gross heat of combustion, so it must be supplied more to the engine (higher BFC) than other fuels at the same load and speed. In addition, Banapurmath et al. (2008) also reported that the black smoke of biodiesel derived from jatropha oil was higher than that of diesel fuel because of its lower volatility and higher viscosity. These particular properties can also cause the partial combustion of fuel spray and intake air and hence higher black smoke emission was released through an exhaust pipe into the environment.

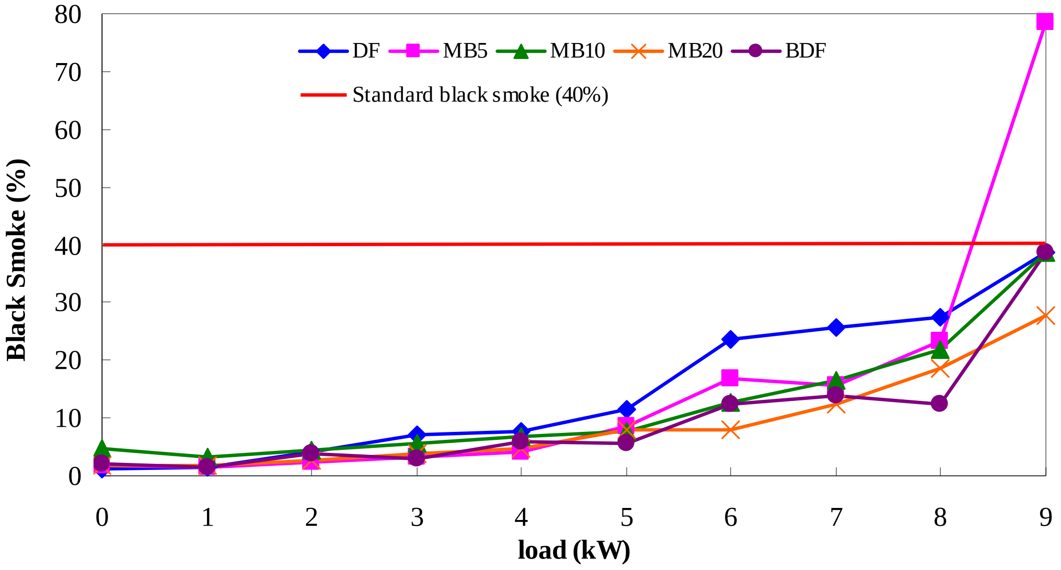


Figure 4.13 Black Smokes (%) at 1,500 rpm

The black smoke values of all tested fuels are mostly lower than the standard of black smoke emission at 40% (www.deqp.go.th). Nevertheless, the black smoke trend of MB5 fuel was dramatically increased in the range of 8 to 9 kW engine load at the engine speed of 1,500 rpm to become over the standard. This result is corresponding with the emission trends of carbon monoxide (CO) and total hydrocarbon (THC). The emissions also dramatically increase at the same range of engine loads. It can be implied that at the higher load such as 8 to 9 kW, incomplete combustion of MB5 fuel is occurred.

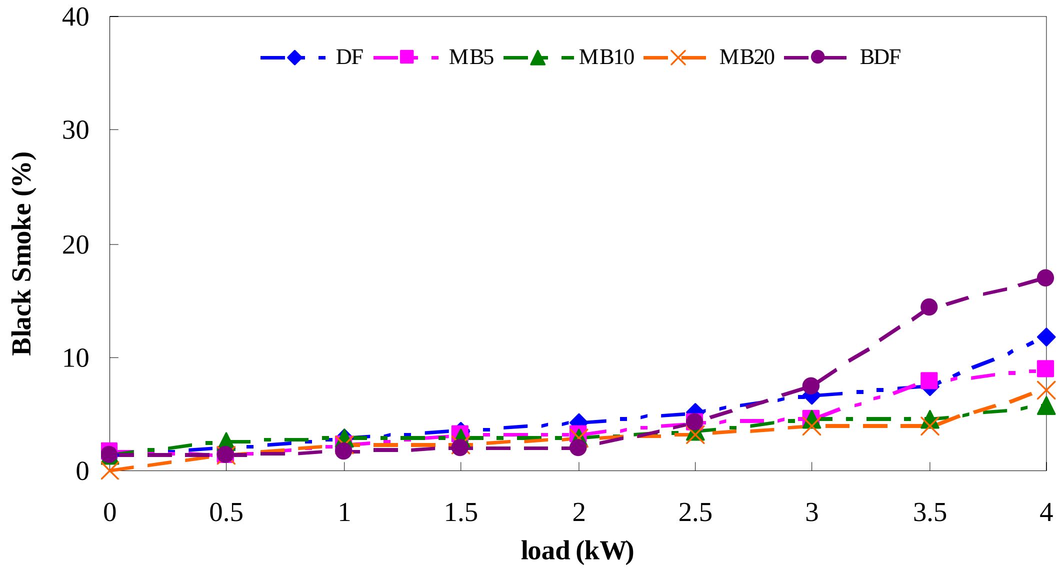


Figure 4.14 Black Smokes (%) at 2,400 rpm

Figure 4.15 demonstrates CO concentration (ppm) when running the engine at 1,500 rpm and applying 0 to 9 kW load. At a range of engine loads of 0 to 4 kW, CO trends of all fuels have decreased when increasing the engine loads. The combustion process was more complete as the CO emission values were very little. However, there are some differences among those trends between the load range of 5 kW and 9 kW. During this range, CO quantity has rapidly increased as the increment of engine load. The explanation of this should be that more fuel is supplied for overcoming some higher loads whereas compressed air in a cylinder almost constantly remains. So, air to fuel mixing characteristic tended to be poorer leading to incomplete combustion and thus higher CO emission attained. In this case, the CO trends of MB20 and biodiesel are much closed to each other and they are also located underneath the other fuel trends. The fuel that causes the highest CO concentration during 5 to 8 kW is diesel. Moreover, the CO trend of MB5 reaches the peak when applying the 9 kW engine load. It can also be noticed that the CO emission is minimal at the engine load of 4 kW, according to the graph. Thus, it can be recommended to use this type of engine at 1,500 rpm when light load is required to minimize the CO emission.

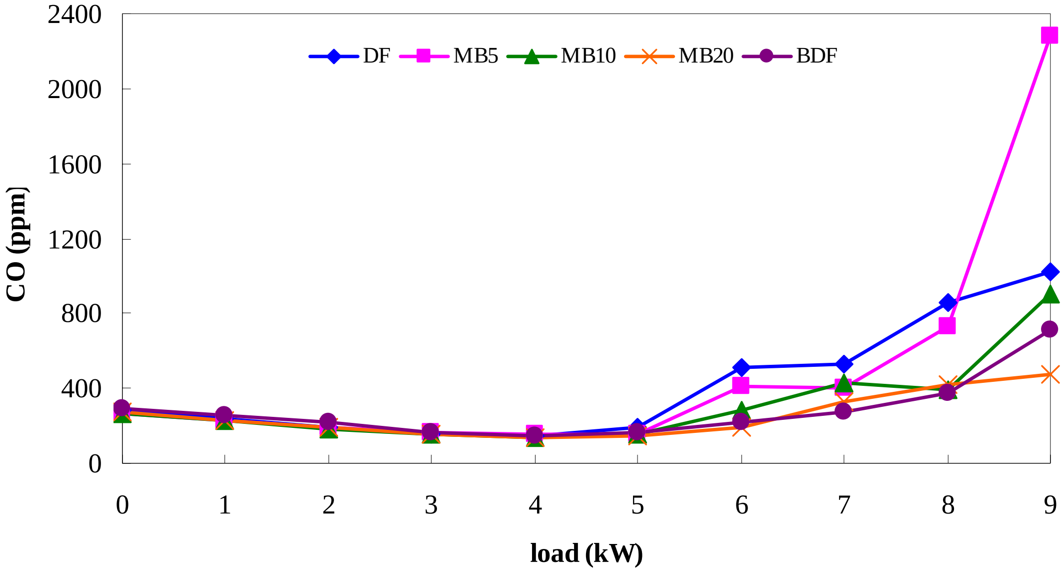


Figure 4.15 Carbon Monoxide (ppm) at 1,500 rpm

Figure 4.16 also illustrates the amount of CO emission when the engine loads were varied from 0 to 4 kW and the tested engine was operated at the engine speed of 2,400 rpm. The trends of CO emissions of all fuels are quite similar to those when the engine speed is 1,500 rpm but more variation gap between each fuel. The CO trends have continuously dropped then reach the lowest point at the 2.5 kW engine load. After that they start to increase. Less CO was detected when MB10, MB20 and biodiesel were fed into the engine. The oxygen molecule in these alternative fuel structures could enhance the combustion (Agarwal, 2007).

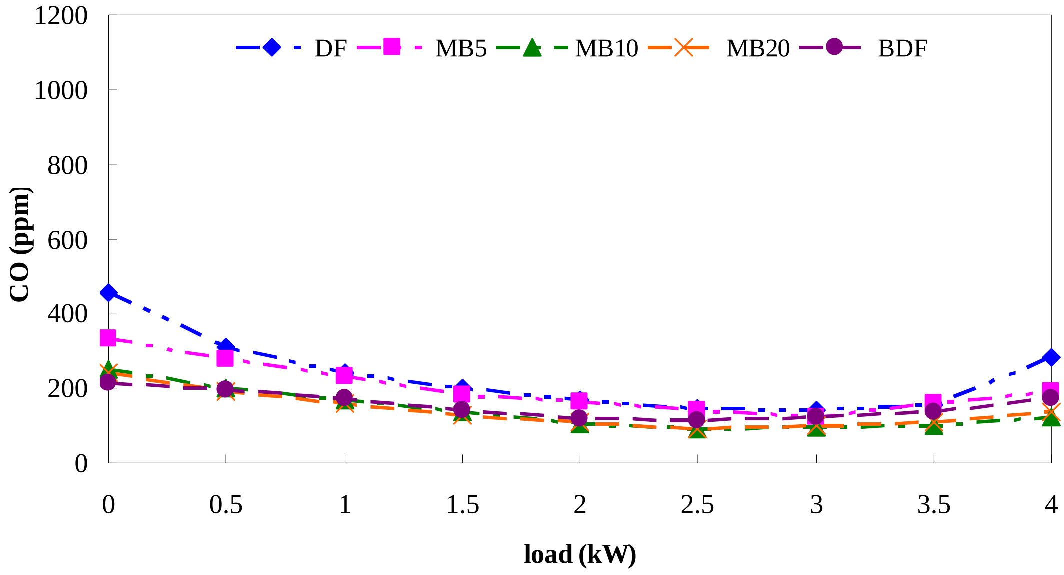


Figure 4.16 Carbon Monoxide (ppm) at 2,400 rpm

Commonly, the carbon dioxide (CO_2) emission is an outcome of any combustion process. Figure 4.17 demonstrates the amount of CO_2 versus various engine loads for the engine speed of 1,500 rpm and 2,400 rpm. The results show that the CO_2 increases with the increment of engine loads for both engine speeds. In comparison, the amount of CO_2 of the higher speed is higher than that of the lower speed. The reason is that because more fuel is injected into the combustion chamber at higher engine speed and loads. More fuel and more intake air were utilized for the combustion. Therefore, more CO_2 emission was created.

During the experiment, the least amount of CO_2 emission was found when biodiesel fuel was used for both engine speeds, but the highest amount of that gas was detected when the testing fuel was changed to the conventional diesel. The CO_2 concentration of MB20 was higher than biodiesel at the engine speed of 1,500 rpm, but it was closed to biodiesel at another engine speed. When the environmental effect from green house gas is taken into consideration, the fuels like biodiesel and MB20 can be used as an alternative fuel because it helps to reduce CO_2 emission in diesel engine.

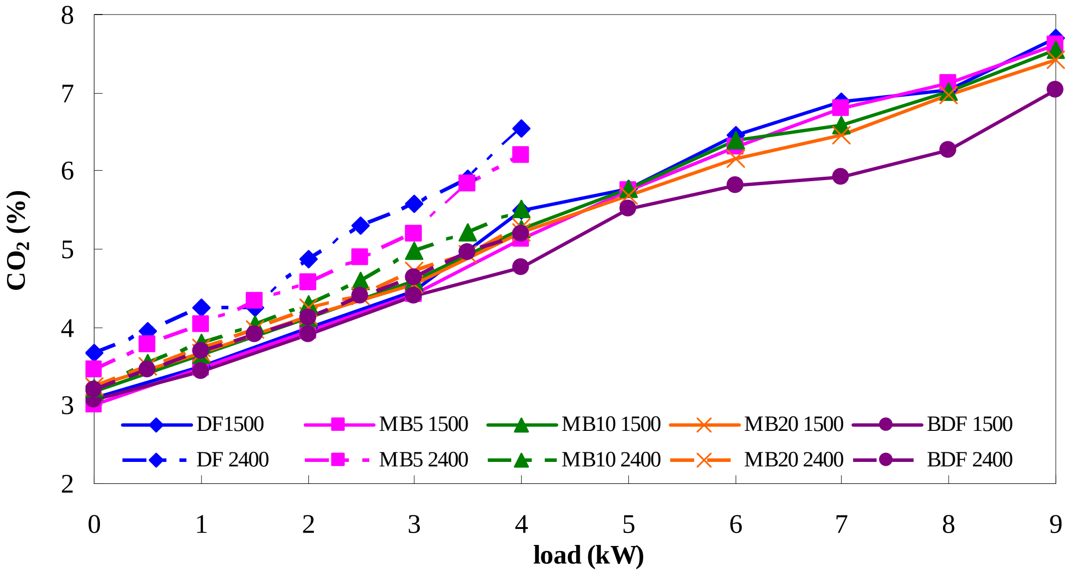


Figure 4.17 Carbon Dioxide (%) at 1,500 rpm and 2,400 rpm

Total hydrocarbon (THC) was measured via the exhaust gas analyzer. The THC is an unburned fuel emitted in exhaust gas emission, and it can imply the combustion inefficiency. In the case of imperfect combustion, some of CO and THC will be released to the surrounding through the tailpipe. THC emission values being derived from using all tested fuels were measured, and the data are recorded with designed engine loads at the engine speed of 1,500 rpm and 2,400 rpm as can be seen in Figures 4.18 and 4.19, respectively. The trends of THC emissions of all fuels in both engine speeds are similar to the trends of CO emissions. The amount of THC decreases as the increment of engine loads in the range of 0 kW to 5 kW, and 0 to 2.5 kW for the engine speed of 1,500 rpm and 2,400 rpm, respectively. On the other hand, their trends have become inversion that the THC trends have risen until the maximum engine for both engine speeds. When both engine speeds were compared, though the THC concentration of most fuels was higher when the speed was set at 2,400 rpm for no-load condition, it is gradually reduced through a range of engine loads (0-4 kW). This amount of THC becomes lower than the THC amount at 1,500 rpm afterward. The reason is that the combustion of the engine at higher engine speed is usually more severe conducting the higher burning temperature. So, the chains of hydrocarbon can be burnt easily and less amount of THC can be obtained as a result.

The amounts of THC of MB10, MB20 and biodiesel were less than those of MB5 and neat diesel fuel for both engine speeds. Since biodiesel and MBs had contained oxygen molecule to support a better combustion condition. This can result in THC emission reduction even though the structure of these alternative fuels was more complicated and their chains were also longer comparing to the structure and chain of diesel fuel. At high engine speed, the amounts of THC of MB10 and MB20 were similar and they were slightly lesser than the THC amount of biodiesel. In addition, it was found that the least THC emission was generated at the 5-kW and 2.5-kW load for the engine speed of 1,500 rpm and 2,400 rpm, respectively.

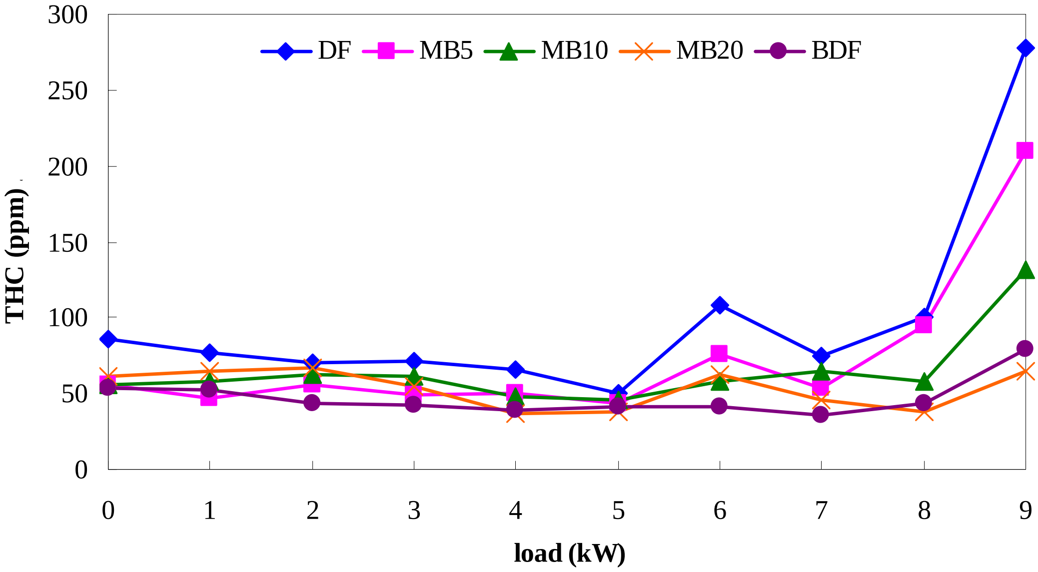


Figure 4.18 Total Hydrocarbon (ppm) at 1,500 rpm

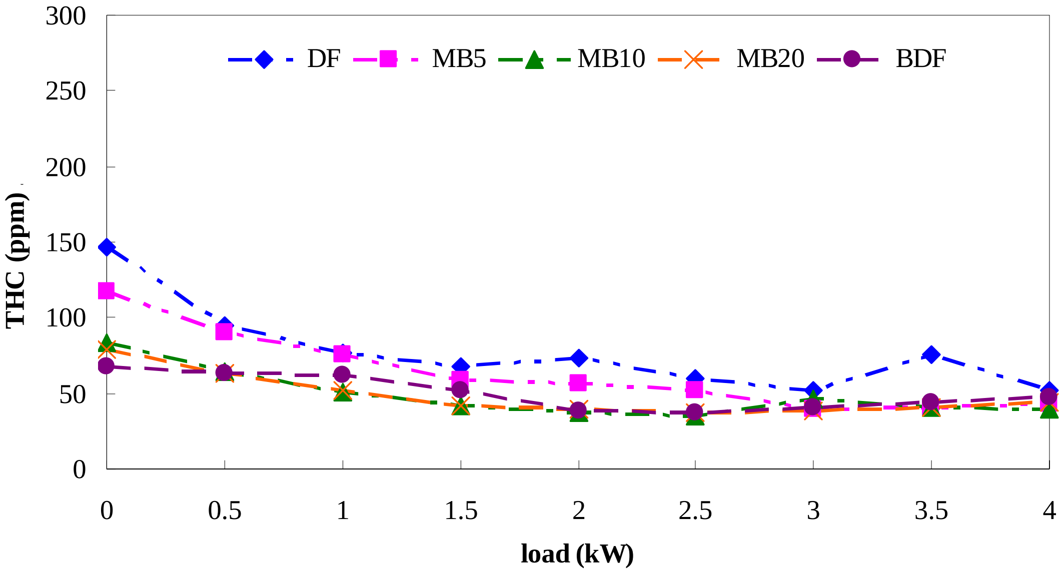


Figure 4.19 Total Hydrocarbon (ppm) at 2,400 rpm

NO_x emission is generally occurred at high combustion temperature (Agarwal, 2007 and Suetrong, 2003). Furthermore, high oxygen concentration during combustion can generate high NO_x emission (Heywood, 1988). Figure 4.20 and 4.21 demonstrate the amount of NO_x emissions against various engine loads at the engine speed of 1,500 rpm and 2,400 rpm, respectively. The Figure 4.20 shows that NO_x emission trends have increased since 0-kW engine load and reach the peak at 6 kW. Then, the NO_x emission has decreased until the load reaches maximum. Move on to the engine speed of 2,400 rpm, the NO_x emission output is still the same as Figure 4.20. The emission trends have continuously increased of engine loads since 0 kW to 4 kW. According to the previous results of CO and THC emissions, it is found that the NO_x trends move oppositely comparing to the trends of CO and THC for both constant speeds. While the NO_x trends increase, the trends of CO and THC tend to decrease at the same range of engine loads. The combustion temperature is normally higher at higher speed engine and loads because more fuel must be injected at that conditions leading to harsh burning of air-fuel mixture in the chamber and consequently, the higher temperature. The high temperature helps more complete combustion, which can reduce CO and THC emission, but NO_x emission usually occurred at high temperature can be easily generated (Agarwal, 2007).

MBs and diesel fuels produced NO_x emission more than biodiesel fuel for both engine speeds (1,500 rpm and 2,400 rpm). It would be explained that high temperature may be occurred in the combustion chamber when MBs and diesel were used. Since these fuels contain higher gross heat of combustion comparing to biodiesel. Furthermore, the combustion chamber contains plenty of air normally consisting of 78% of nitrogen, 20 % of oxygen and 1% of others (Heywood, 1988). So, reaction between nitrogen and oxygen in the induced air can also support the NO_x formation (Knothe et al., 1996). In addition, biodiesel contains the highest water content that can reduce the temperature in the chamber, so it produces the lowest of NO_x emission (Holmberg et al., 2003). Nonetheless, these results are different from the experiment outcomes reported by Ploysrimongkol (2008) and Kwanchareon et al., (2007) who have conducted the test on IDI and DI single-cylinder diesel engine with full load condition. They reported that NO_x emission amount of diesel fuel was the least comparing to those of MBs and biodiesel fuels because it lack of the oxygen content in the molecule.

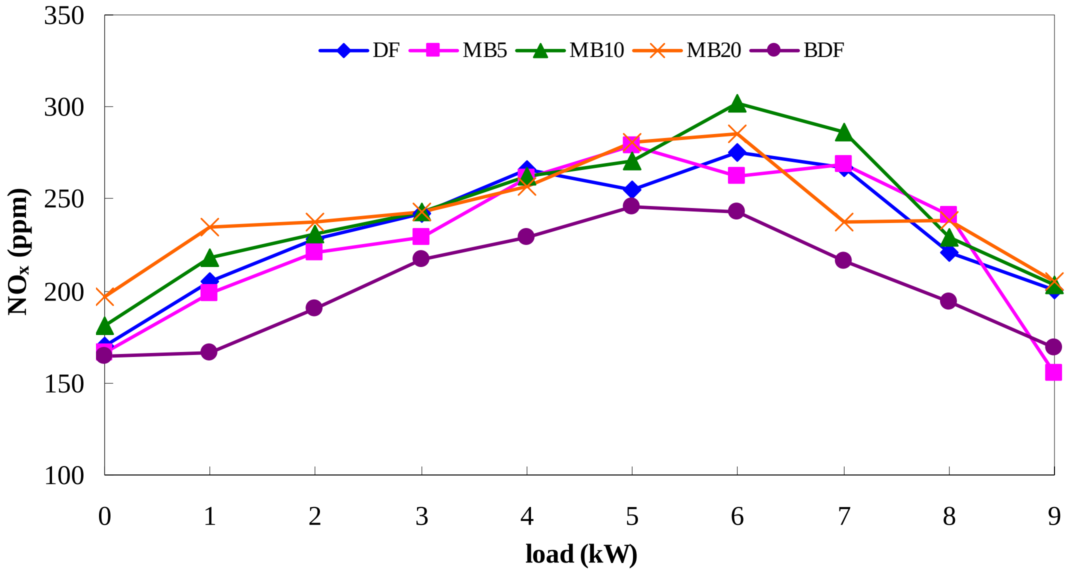


Figure 4.20 Nitrogen Oxide (ppm) at 1,500 rpm

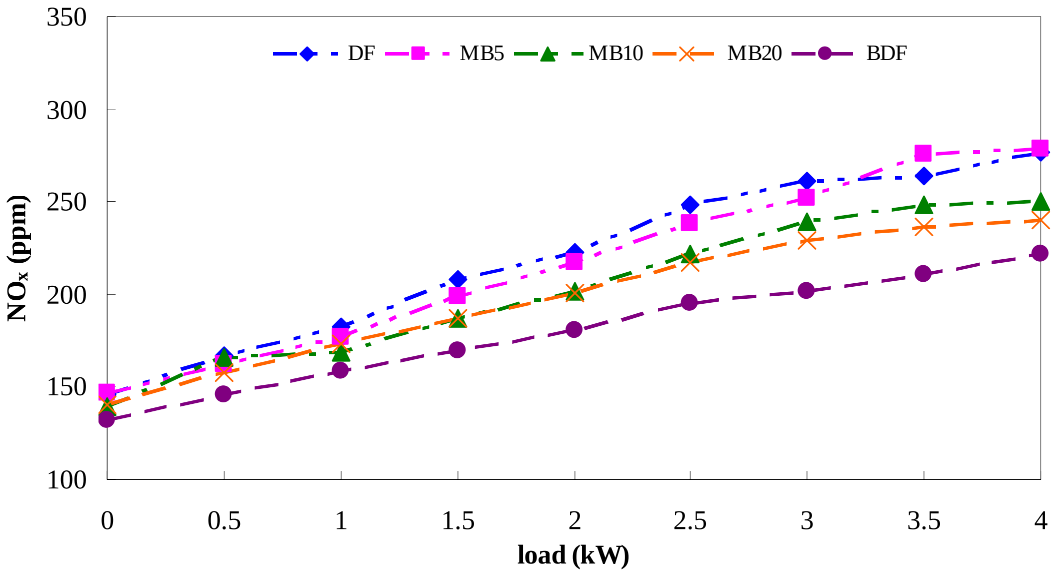


Figure 4.21 Nitrogen Oxide (ppm) at 2,400 rpm

The amount of oxygen, measured by the exhaust gas analyzer, can come from two sources: the oxygen content of alternative fuels and intake air. From the results, it can be described that oxygen, left in the exhaust gas, was decreased as the increment of engine load for both higher and lower speeds as presented in the Figure 4.22. When increasing the engine loads, more fuels were charged into the combustion chamber to overcome the engine loads. Nonetheless, intake air in the cylinder remained almost constant because a number of intake strokes per minute had not been changed since the engine speed was fixed. As a result, O_2 was more utilized in the combustion process so less amount of that gas was accordingly emitted to the surrounding.

From the Figure 4.22, MB10 and MB20 have higher amount of oxygen in the exhaust gas emission than other tested fuels for both engine speeds. This probably caused from both fuels contain microemulsion oil in which its components both jatropha oil and ethanol containing oxygen in their molecular structure. On the other hand, diesel fuel exhibited the lowest percentage of oxygen content in exhaust emission for both engine speeds since the neat diesel was only fuel that usually lacks of oxygen in its molecular structure.

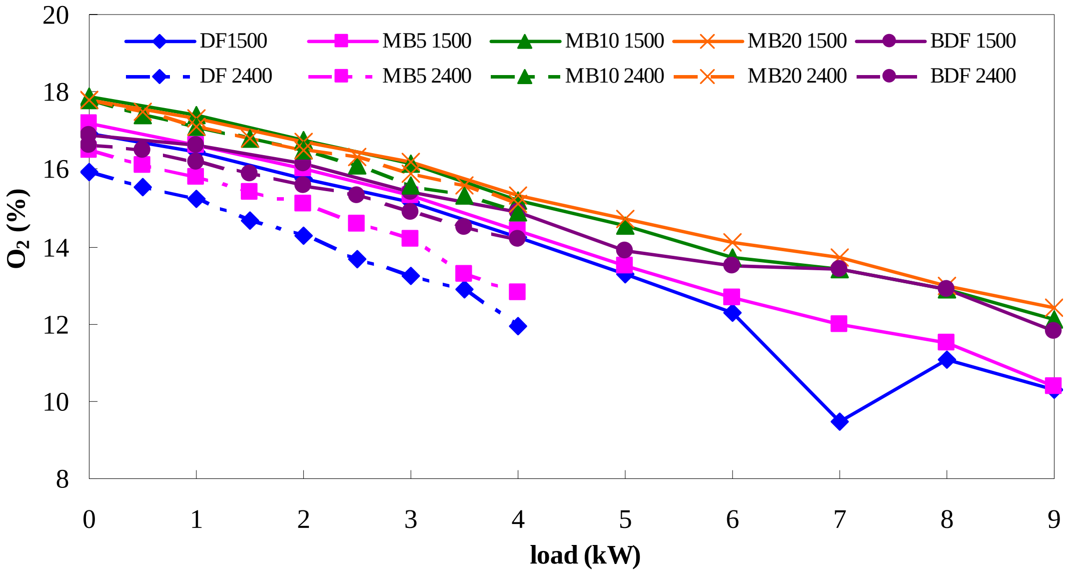


Figure 4.22 Oxygen (%) at 1,500 rpm and 2,400 rpm

The relations between the mass of each chemical reactant, which consist of fuel and air, and the composition of the products, which are CO_2 and H_2O, were considered in term of stoichiometric air to fuel ratio. The stoichiometric AFR can imply the enough oxygen content for conversion of all fuels to completely oxidized products (Heywood, 1988). The stoichiometric AFR of all tested fuels in this study are calculated from their mass composition as illustrated in Table 4.2. It can be seen that different compositions of fuels provide different stoichiometric AFR. From the results shown in the Table 4.2, the stoichiometric AFR values of MBs and biodiesel are less than that of diesel fuel, which may affect by some oxygen molecule in their structure. Hence, less air is required for complete combustion.

Table 4.4 Stoichiometric Air to Fuel Ratio for all Fuels

Fuel	Stoichiometric AFR
MB5	14.08
MB10	13.76
MB20	13.32
BDF	12.44
Diesel	14.51

According to the different stoichiometric AFR of each fuel, the *relative air/fuel ratio* (λ) is considered instead. The relative air/fuel ratio is the ratio of actual air/fuel ratio to the stoichiometric air/fuel ratio. For *rich mixture*, which the amount of fuel is over the requirement for the completion of combustion process, the relative air/fuel ratio is less than one. However, when the relative air/fuel ratio is more than one, the amount of compressed air is higher and less fuel is injected into the combustion process as known as *lean mixture*. Moreover, the relative air/fuel ratio is equal to one, it is named as the stoichiometric mixture (Heywood, 1988). As can be seen in the Figure 4.23, the relative air/fuel ratios of entire experimental fuels are higher than one, so they can be categorized as lean mixture.

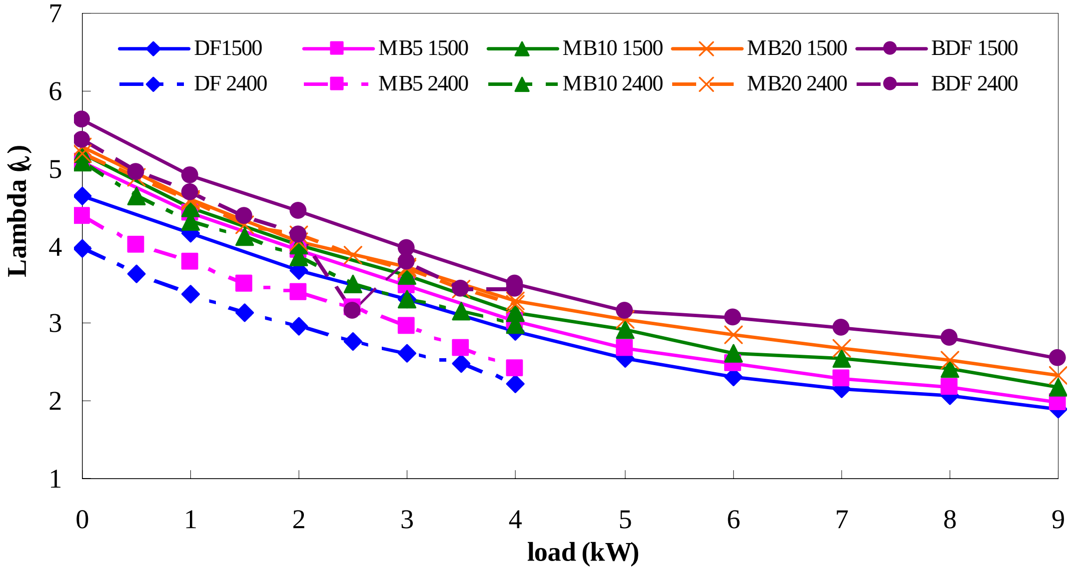


Figure 4.23 The Relative Air/Fuel Ratio (λ) at 1,500 rpm and 2,400 rpm

4.4 Preliminary Analysis for Microemulsion Biodiesohols Application

Due to the fact that Thailand has been importing petroleum oil from abroad approximately 90% (The Thainews, 2009), the petrol price of the country depends on the worldwide oil market. At present, the petrol price in Thailand and other countries has been increased since the Organization of the Petroleum Exporting Countries (OPEC) had reduced the crude oil producing and exporting (Department of Mineral Fuels, 2009). Alternative fuel such as biofuel can be a major contribution for reducing petroleum importing burden of the country.

The research has focused on producing and testing some alternative fuels in order to be an alternative fuel, especially for CI engine. Vegetable oils have received much interest as a raw material for an alternative fuel production because Thailand is an agricultural country where oil bearing crops can be grown and simply used. In this study jatropha oil was selected and used as raw material for making the fuels of microemulsion biodiesohols (MBs) and biodiesel. The benefit of using the non-edible energy plants is that it would promote domestic and local fuel producing.

Even though the properties and performance of the MBs are considered applicable for using with one barrel diesel engine, to promote the utilization of these fuels need to compete with conventional diesel in term of price. From this study at lab scale, the commercial diesel fuel used in our experiments, bought from the Shell Company of Thailand Limited was 44.84 baht/liter while the crude jatropha oil cost was 170 baht/liter (these prices in July 2008). Moreover, the low productivity of jatropha seeds, which is about 4 kilograms of seed generally yield approximately 1 liter of oil (Koedklai, 2007) is another concern for limitation supply.

With regards to the price competition at present, microemulsion biodiesohol (MB) being produced via microemulsification process cannot compete with conventional diesel; however, its intangible benefit in term of using raw material-jatropha seed-available in our country as well as reducing petroleum import should be considered. Moreover, there are several on-going researches carried out on increasing production of jatropha plantation as well as improvement of oil extraction efficiency. In addition, utilization of jatropha seed meal after oil extraction has been studied for added value, meanwhile the cost of petroleum diesel relied only on crude oil price that keep increasing continuously.

In comparison to other biofuel (i.e., biodiesel) the cost of transesterification process used for biodiesel production is normally higher than those for our MB products in term of waste management and complexity of biodiesel manufacturing. As a consequence, the trend of using jatropha oil as MBs for agricultural engine can be expected to be promising.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In conclusion, this research has been mostly focused on microemulsion biodiesohol (MB) production, being an environmentally friendly process and the outcomes can be summarized as follows:

From the pseudo-ternary phase diagram, it can be found that the microemulsion areas of 0.25 and 0.5 C/S ratios in the single surfactant system were larger than the areas being found in other C/S ratios. Moreover, the C/S ratio of 0.5 was the most appropriated for biodiesohol production when the microemulsion oil's properties were considered.

The C/S solution may be considered as an oxidation stability additive because the oxidation stability property of crude jatropha oil had been improved when the solution was added. Additionally, the single surfactant systems were more appropriated than mixed surfactant systems in microemulsion oil (MO) preparation for the reasons that the preparation time and difficulty of the single surfactant system were shorter and less than those of another system. Even though, the induction time of the single surfactant systems of 32.67 hr was shorter than that of another mentioned system (38.81 hr), it was still massively higher than the standard time (6 hr).

For making the MB fuels, the best microemulsion oil should be composed of 95% jatropha oil and 5% C/S solution at the solution ratio of 0.5 with the single surfactant system. Although the composition of 90% jatropha oil and 10% C/S solution of both surfactant systems had lower kinematic viscosity and higher induction time than the appropriated composition. The difference will be less when mixing MO with normal diesel fuel. Hence, only a small amount of C/S solution, which plays a role as additive, is sufficient for MB production for using as an alternative in diesel engine.

The various formulas of Microemulsion Biodiesohols (MBs), which have been declared in this study, can be decided as an alternative fuel for a small diesel engine because their investigated properties were mostly followed the biodiesel standard of

Thailand and their flash points were also closed to that of commercial diesel fuel. However, the flash points of MBs was clearly lower than that of biodiesel fuel. Storing and transporting the MB fuels must be carefully performed. According to the engine performances and emissions, all test results were nearly similar when biodiesel and MB fuels, especially MB10 and MB20, were utilized as mentioned earlier. However, the amount of NO_x in the exhaust gas of MBs was higher than biodiesel. Comparing to diesel fuel, the harmful emission effects had been reduced since the MBs and jatropha oil biodiesel are classified as an environmentally friendly fuel. In addition, in the fuel consumption section, biodiesel was consumed by the engine more than other experimental fuels because of its lowest heating value.

The engine performance and emission results being inspected were very similar when biodiesel, MB10 and MB20 fuels were applied to the small diesel engine. The procedure of producing MBs is uncomplicated comparing to biodiesel, which is produced from transesterification process. Additionally, the microemulsion technique is also environmentally friendly as there is no by-product, no waste water generated and releases less emissions from the process.

5.2 Recommendations

According to the limitation of working time and research budget, the technique of producing microemulsion biodiesohol (MB) using jatropha oil as a raw material should be more studied and investigated in order to promote the use of MB fuel in small agricultural diesel engines. Therefore, the following personal opinions have been provided as future revision plans.

1. Jatropha oil stability and quality improvement should be more concerned for the entire oil production including plantation area selection, jatropha growing, seed harvesting and choosing, oil extraction and oil storage and transportation.

2. In the engine performance and emission examination, the test environment including ambient temperature, pressure and humidity and the engine condition should be controlled as the same for each set of experiment for more accurate test result.

3. The long-term engine durability test using MBs should be conducted for engine and fuel compatibility assessment.

4. The properties, performances and emissions of crude jatropha oil that was directly blended with neat diesel fuel via dilution or blending technique should be analyzed for comparing with MBs.

APPENDICES

APPENDIX B

Biodiesel Production Via Transesterification Process

The biodiesel being used in this study was obtained from the traditional transesterification process, using jatropha oil as raw material, potassium hydroxide (KOH) as catalyst, and methanol as alcohol, since methanol and KOH were used as catalyst in low-temperature and low-pressure process (Foidl et al., 1996). This biodiesel was produced at the Biofuel Testing Laboratory, The National Metal and Materials Technology Center (MTEC). Subsequently, the fatty acid compositions of biodiesel were analyzed by gas chromatography which its fatty acid properties were similar to the fatty acid compositions of jatropha oil, reported by Sarin et al. (2007). The comparison of fatty acid values between biodiesel and jatropha oil is shown in the Table B-1. According to the table, the highest fatty acid value of biodiesel is linoleic acid (41.76%) being classed as unsaturated compound (80% unsaturated). Normally, fatty acid methyl ester (FAME) from transesterification process was achieved 85-90% in the first step and over 99% in the second step (Foidl et al., 1996). Nonetheless, in this study, it contained FAME up to 98.42% in the first step while 97.50% was achieved in the second step. So, biodiesel being compared with MBs was from the first step only.

About producing the biodiesel from jatropha oil, it took a plenty of time to separate glycerol from methyl ester which may be overnight for great separation especially in high productivity of biodiesel. For making a pure methyl ester, the water being around four to five times of the quantity of biodiesel product was applied to eliminate some excess methanol, remaining soaps and remaining glycerol. Therefore, a large volume of wastewater was drained in this step. After the washing step, the biodiesel was heated up for eliminating some water content. Furthermore, the biodiesel properties and engine performance and emissions when biodiesel was utilized as fuel were latterly evaluated comparing to the fuels of MB5, MB10, MB20 and neat diesel.

APPENDIX C

Table C-1: Acid Value (mg KOH/g) of Fuels

Sample	Acid Value (mg KOH/g)					
	Days					
	1	3	5	7	10	14
Jatropha Oil1	2.39	2.62	2.59	2.73	2.64	2.72
Jatropha Oil2	2.52	2.67	2.59	2.71	2.62	2.67
Jatropha Oil3	2.52	2.67	2.60	2.71	2.62	2.73
Mean	2.48	2.65	2.59	2.72	2.63	2.71
SD	0.08	0.03	0.01	0.01	0.01	0.03
SSFT 0.25, 95:5_1	2.58	2.64	2.44	2.74	2.46	2.62
SSFT 0.25, 95:5_2	2.62	2.70	2.45	2.70	2.47	2.61
SSFT 0.25, 95:5_3	2.63	2.66	2.46	2.73	2.49	2.63
Mean	2.61	2.67	2.45	2.72	2.47	2.62
SD	0.03	0.03	0.01	0.02	0.02	0.01
SSFT 0.5, 95:5_1	2.51	2.69	2.51	2.68	2.58	2.63
SSFT 0.5, 95:5_2	2.47	2.67	2.60	2.67	2.32	2.64
SSFT 0.5, 95:5_3	2.50	2.71	2.69	2.69	2.44	2.62
Mean	2.49	2.69	2.60	2.68	2.45	2.63
SD	0.02	0.02	0.09	0.01	0.13	0.01
SSFT 0.25, 90:10_1	2.44	2.40	2.92	2.30	2.56	2.57
SSFT 0.25, 90:10_2	2.44	2.46	2.55	2.44	2.14	2.61
SSFT 0.25, 90:10_3	2.48	2.58	2.29	2.34	2.27	2.43
Mean	2.45	2.48	2.59	2.36	2.32	2.54
SD	0.02	0.09	0.32	0.07	0.22	0.09
SSFT 0.5, 90:10_1	2.29	2.67	2.58	2.30	2.01	2.58
SSFT 0.5, 90:10_2	2.29	2.65	2.31	2.60	1.93	2.53
SSFT 0.5, 90:10_3	2.40	2.44	2.32	2.30	1.70	2.43
Mean	2.33	2.59	2.40	2.40	1.88	2.51
SD	0.06	0.13	0.15	0.17	0.16	0.08
MSFT 0.25, 95:5_1	2.63	2.69	2.69	2.64	2.19	2.62
MSFT 0.25, 95:5_2	2.63	2.82	2.65	2.59	2.27	2.66
MSFT 0.25, 95:5_3	2.60	2.69	2.54	2.65	2.32	2.73
Mean	2.62	2.73	2.63	2.63	2.26	2.67
SD	0.02	0.08	0.08	0.03	0.07	0.06
MSFT 0.5, 95:5_1	2.63	2.69	2.66	2.78	2.39	2.76
MSFT 0.5, 95:5_2	2.64	2.67	2.65	2.76	2.42	2.75
MSFT 0.5, 95:5_3	2.64	2.70	2.67	2.49	2.48	2.77
Mean	2.64	2.69	2.66	2.68	2.43	2.76
SD	0.01	0.02	0.01	0.16	0.05	0.01

Sample	Acid Value (mg KOH/g)					
	Days					
	1	3	5	7	10	14
MSFT 0.25, 90:10_1	2.53	2.68	2.72	2.65	2.50	3.32
MSFT 0.25, 90:10_2	2.53	2.71	2.76	3.05	2.06	2.95
MSFT 0.25, 90:10_3	2.51	2.54	2.33	2.20	2.40	2.68
Mean	2.52	2.64	2.60	2.63	2.32	2.98
SD	0.01	0.09	0.24	0.43	0.23	0.32
MSFT 0.5, 90:10_1	2.58	2.58	2.43	2.53	1.60	2.52
MSFT 0.5, 90:10_2	2.64	2.70	2.29	2.03	1.56	2.60
MSFT 0.5, 90:10_3	2.62	2.59	2.49	2.47	1.63	2.13
Mean	2.61	2.62	2.40	2.34	1.60	2.42
SD	0.03	0.07	0.10	0.27	0.04	0.25

Table C-2: Induction Time (hr) of Fuels

Sample	Induction Time (hr)
Jatropha Oil	9.46
SSFT 0.25, 95:5	16.77
SSFT 0.5, 95:5	32.67
SSFT 0.25, 90:10	24.63
SSFT 0.5, 90:10	29.16
MSFT 0.25, 95:5	56.27
MSFT 0.5, 95:5	38.81
MSFT 0.25, 90:10	90.32
MSFT 0.5, 90:10	74.09

Table C-3: Kinematic Viscosity (cSt) of Fuels

Sample	Kinematic Viscosity (cSt)
Jatropha Oil	33.84
SSFT 0.25, 95:5	33.56
SSFT 0.5, 95:5	31.54
SSFT 0.25, 90:10	33.90
SSFT 0.5, 90:10	29.95
MSFT 0.25, 95:5	33.82
MSFT 0.5, 95:5	31.88
MSFT 0.25, 90:10	33.99
MSFT 0.5, 90:10	30.36

Table C-4: Carbon Residue (%) of Fuels

Fuel	Initail Weight (g)				Final Weight (g)		%Carbon Residue		Average %Carbon Residue
	Cup		Sample		Cup+Sample				
	1	2	1	2	1	2	1	2	
Diesel	3.0049	2.9948	1.5042	1.5207	3.0049	2.9949	0.0000	0.0066	0.0033
MB5	3.0464	2.9959	1.5059	1.5018	3.0468	2.996	0.0266	0.0067	0.0166
MB10	2.9909	3.0095	1.4954	1.5127	2.9914	3.0104	0.0334	0.0595	0.0465
MB20	2.9774	3.0163	1.5184	1.5121	2.9782	3.0177	0.0527	0.0926	0.0726
Biodiesel	2.9909	2.9893	1.5198	1.5107	2.9916	2.9898	0.0461	0.0331	0.0396

APPENDIX E

According to the engine performances, the Kubota IDI diesel engine model RT100 was tested, which it was connected to an AC electric generator via pulleys and V-shape belts. The generator was used to convert the mechanical power, generated from the engine, to electrical power being then supplied to a series of halogen lamps. The generator efficiency is generally 80%. The specifications of Kubota IDI diesel engine were illustrated in TableE-1 and the calculation formulas of engine power and torque were shown in the equations (1), (2) and 3.

Table E-1: The Specifications of Kubota IDI Diesel Engine Model RT100

Engine Characteristic	A single cylinder diesel engine, four stoke, horizontal position, water cooled
Engine Model	RT 100
Bore x Stroke (mm. x mm.)	88 x 90
Rated Power (hp/rpm)	10/2,400
Continuous Power (hp/rpm)	9/2,400
Compression Ratio	22:1
Type of Cooling	Radiator
Type of Combustion System	Spherical combustion system (swirl chamber)

The calculation formulas of engine power and torque are as follows:

$$P_{Gen} = I \text{ x } V \qquad (1)$$

$$P_{Engine} = \frac{IxV}{\eta_{Gen}} \qquad (2)$$

$$\tau = \frac{P_{Engine}x60}{2\pi N} \qquad (3)$$

$$\lambda = \frac{AFR}{14.7} \qquad (4)$$

Where: P_{Gen} is the electrical generator power (Watt)
I is the electrical current (Ampere)
V is the electromotive force (Volt)
P_{Engine} is the engine power (Watt)
η_{Gen} is the efficiency of the generator
τ is the engine torque (Newton-meter)
N is the engine speed (round per minute)

λ is the relative air to fuel ratio

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Presentation:

Warangkana Prapatigul, Chantra Tongcumpou and Subongkoj Topaiboul. *Pseudo-ternary phase diagram for biodiesohol production from jatropha oil using microemulsion technique*. Pure and Applied Chemistry International Conference 2009 (PACCON 2009), Naresuan University, Phitsanulok, Thailand, January 14-16, 2009. Organization by Chemical Society of Thailand; Department of Chemistry, Faculty of Science, Naresuan University; Pibulsongkarm Rajaphat University and Rajamangala University of Technology Lanna.

Proceeding:

Warangkana Prapatigul, Chantra Tongcumpou and Subongkoj Topaiboul. Pseudo-ternary phase diagram for biodiesohol production from jatropha oil using microemulsion technique. PACCON (Pure and Applied Chemistry International Conference) (2009): 703-706.

Award:

"The Outstanding Oral Presentation Award", Pure and Applied Chemistry International Conference 2009, Naresuan University, Phitsanulok, Thailand, January 14-16, 2009.

APPENDIX A

Table A-1: Pseudo-Ternary Phase Diagram at C/S Ratio 0.25 in Single Surfactant System

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (2/5/08)	C/S ratio	J. oil	Water	Total	Note (6/5/08)
1.1	0.1013	2.0256	0.0168	2.1437	Initially Turbid	4.73	94.49	0.79	100	Homogenous Solution
1.2	0.1119	2.0010	0.0156	2.1285	Initially Turbid	5.26	94.01	0.73	100	Homogenous Solution
1.3	0.1001	2.0119	0.0147	2.1267	Initially Turbid	4.71	94.60	0.69	100	Homogenous Solution
Avg	0.1044	2.0128	0.0157	2.1330	-	4.90	94.37	0.74	100	-
2.1	0.2014	1.8024	0.0548	2.0587	Initially Turbid & More Bulk	9.78	87.55	2.67	100	Homogenous Solution
2.2	0.2013	1.8038	0.0498	2.0550	Initially Turbid	9.80	87.78	2.43	100	Homogenous Solution
2.3	0.2009	1.8084	0.0620	2.0714	Initially Turbid & More Bulk	9.70	87.30	3.00	100	Homogenous Solution
Avg	0.2012	1.8049	0.0555	2.0617	-	9.76	87.54	2.70	100	-
3.1	0.4006	1.6055	0.1578	2.1641	Initially Turbid & More Bulk	18.51	74.19	7.30	100	Homogenous Solution
3.2	0.4112	1.6070	0.1743	2.1927	Initially Turbid & More Bulk	18.75	73.29	7.96	100	Homogenous Solution
3.3	0.6331	1.6087	0.1625	2.4046	Initially Turbid & More Bulk	26.33	66.90	6.77	100	Homogenous Solution
Avg	0.4816	1.6071	0.1649	2.2538	-	21.20	71.46	7.34	100	-
4.1	0.6080	1.4006	0.1098	2.1186	Initially Turbid	28.70	66.11	5.19	100	Homogenous Solution
4.2	0.6119	1.4103	0.1243	2.1467	Initially Have Bulk	28.50	65.69	5.80	100	Homogenous Solution
4.3	0.6024	1.4010	0.1179	2.1215	Initially Turbid & Little Bulk	28.39	66.04	5.57	100	Homogenous Solution
Avg	0.6074	1.4040	0.1173	2.1290	-	28.53	65.95	5.52	100	-
5.1	0.8039	1.2499	0.1788	2.2329	Initially Turbid	36.00	55.98	8.02	100	Homogenous Solution
5.2	0.8244	1.2265	0.1681	2.2193	Initially Turbid	37.15	55.26	7.59	100	Homogenous Solution
5.3	0.8075	1.2415	0.1770	2.2263	Initially Turbid	36.27	55.76	7.96	100	Homogenous Solution
Avg	0.8119	1.2393	0.1746	2.2262	-	36.47	55.67	7.86	100	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (2/5/08)	C/S ratio	J. oil	Water	Total	Note (6/5/08)
6.1	1.0043	1.0215	0.1414	2.1676	Initially Turbid	46.33	47.13	6.54	100	Homogenous Solution
6.2	1.0026	1.0526	0.1434	2.1990	Initially Turbid	45.59	47.87	6.54	100	Homogenous Solution
6.3	0.9923	0.9970	0.1474	2.1371	Initially Turbid	46.43	46.65	6.92	100	Homogenous Solution
Avg	0.9997	1.0237	0.1441	2.1679	-	46.12	47.22	6.67	100	-
7.1	1.2028	0.8027	0.0997	2.1057	Little Small Bulk	57.12	38.12	4.76	100	Homogenous Solution
7.2	1.2041	0.8004	0.1043	2.1093	Little Small Bulk	57.09	37.95	4.97	100	Homogenous Solution
7.3	1.2082	0.8076	0.1067	2.1230	Little Small Bulk	56.91	38.04	5.05	100	Homogenous Solution
Avg	1.2050	0.8036	0.1036	2.1126	-	57.04	38.04	4.92	100	-
8.1	1.4127	0.6114	0.1073	2.1320	Initially Turbid	66.26	28.68	5.06	100	Homogenous Solution
8.2	1.4142	0.6154	0.0998	2.1300	Initially Turbid	66.40	28.89	4.71	100	Homogenous Solution
8.3	1.4120	0.6292	0.0700	2.1118	Initially Turbid	66.86	29.79	3.34	100	Homogenous Solution
Avg	1.4130	0.6187	0.0924	2.1246	-	66.51	29.12	4.37	100	-
9.1	1.6144	0.4188	0.1217	2.1555	Initially Turbid	74.90	19.43	5.68	100	Homogenous Solution
9.2	1.6090	0.4069	0.1256	2.1421	Initially Turbid	75.11	18.99	5.89	100	Homogenous Solution
9.3	1.6182	0.4348	0.1277	2.1813	Initially Turbid	74.18	19.93	5.88	100	Homogenous Solution
Avg	1.6139	0.4202	0.1250	2.1597	-	74.73	19.45	5.82	100	-
10.1	1.8069	0.2002	0.4490	2.4568	Initially Turbid	73.55	8.15	18.31	100	Homogenous Solution
10.2	1.8034	0.2169	0.4387	2.4597	Initially Turbid	73.32	8.82	17.86	100	Homogenous Solution
10.3	1.8165	0.2050	0.4450	2.4672	Initially Turbid	73.63	8.31	18.07	100	Homogenous Solution
Avg	1.8089	0.2074	0.4442	2.4613	-	73.50	8.43	18.08	100	-
11.1	0.0227	1.9810	0.0000	2.0037	Transparent	1.13	98.87	0.00	100	Homogenous Solution
11.2	0.0202	1.9840	0.0000	2.0042	Transparent	1.01	98.99	0.00	100	Homogenous Solution
11.3	0.0232	1.9850	0.0000	2.0082	Transparent	1.16	98.84	0.00	100	Homogenous Solution
Avg	0.0220	1.9833	0.0000	2.0054	-	1.10	98.90	0.00	100	-

Table A-2: Pseudo-Ternary Phase Diagram at C/S Ratio 0.50 in Single Surfactant System

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (28/4/08)	C/S ratio	J. oil	Water	Total	Note (29/4/08)
1.1	0.2075	1.8050	0.0388	2.0513	Initially Turbid	10.12	87.99	1.89	100	Homogenous Solution
1.2	0.2013	1.8026	0.0500	2.0539	Initially Turbid	9.80	87.76	2.43	100	Homogenous Solution
1.3	0.2019	1.8054	0.0455	2.0528	Initially Turbid	9.84	87.95	2.22	100	Homogenous Solution
Avg	0.2036	1.8043	0.0448	2.0527	-	9.92	87.90	2.18	-	-
2.1	0.4025	1.6034	0.1600	2.1659	Initially Turbid	18.58	74.03	7.39	100	Homogenous Solution
2.2	0.4018	1.6136	0.1579	2.1733	Initially Turbid	18.49	74.25	7.27	100	Homogenous Solution
2.3	0.4047	1.6063	0.1653	2.1763	Initially Turbid	18.60	73.81	7.60	100	Homogenous Solution
Avg	0.4030	1.6078	0.1611	2.1718	-	18.56	74.03	7.42	-	-
3.1	0.6001	1.4034	0.2200	2.2235	Initially Turbid	26.99	63.12	9.89	100	Homogenous Solution
3.2	0.6012	1.4031	0.2200	2.2243	Initially Turbid	27.03	63.08	9.89	100	Homogenous Solution
3.3	0.6028	1.4009	0.2169	2.2206	Initially Turbid	27.15	63.09	9.77	100	Homogenous Solution
Avg	0.6014	1.4025	0.2190	2.2228	-	27.05	63.09	9.85	-	-
4.1	0.8058	1.2043	0.1378	2.1479	Initially Turbid	37.52	56.07	6.42	100	Homogenous Solution
4.2	0.8081	1.2061	0.1400	2.1542	Initially Turbid	37.51	55.99	6.50	100	Homogenous Solution
4.3	0.8024	1.2134	0.1388	2.1546	Initially Turbid	37.24	56.32	6.44	100	Homogenous Solution
Avg	0.8054	1.2079	0.1389	2.1522	-	37.42	56.12	6.45	-	-
5.1	1.0059	1.0066	0.1156	2.1281	Initially Turbid	47.27	47.30	5.43	100	Homogenous Solution
5.2	1.0067	1.0070	0.1243	2.1380	Initially Turbid	47.09	47.10	5.81	100	Homogenous Solution
5.3	1.0061	1.0022	0.0969	2.1052	Initially Turbid	47.79	47.61	4.60	100	Homogenous Solution
Avg	1.0062	1.0053	0.1123	2.1238	-	47.38	47.34	5.28	-	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (28/4/08)	C/S ratio	J. oil	Water	Total	Note (29/4/08)
6.1	1.2013	0.8031	0.1015	2.1059	Initially Turbid	57.04	38.14	4.82	100	Homogenous Solution
6.2	1.2085	0.8171	0.0864	2.1120	Initially Turbid	57.22	38.69	4.09	100	Homogenous Solution
6.3	1.2166	0.8052	0.0583	2.0801	Initially Turbid	58.49	38.71	2.80	100	Homogenous Solution
Avg	1.2088	0.8085	0.0821	2.0993	-	57.58	38.51	3.90	-	-
7.1	1.4069	0.6016	0.1076	2.1161	Initially Turbid	66.49	28.43	5.08	100	Homogenous Solution
7.2	1.4067	0.6028	0.1100	2.1195	Initially Turbid	66.37	28.44	5.19	100	Homogenous Solution
7.3	1.4189	0.6002	0.1134	2.1325	Initially Turbid	66.54	28.15	5.32	100	Homogenous Solution
Avg	1.4108	0.6015	0.1103	2.1227	-	66.46	28.34	5.20	-	-
8.1	1.6068	0.4129	0.1226	2.1423	Initially Turbid	75.00	19.27	5.72	100	Homogenous Solution
8.2	1.6010	0.4211	0.1179	2.1400	Initially Turbid	74.81	19.68	5.51	100	Homogenous Solution
8.3	1.6076	0.4195	0.1200	2.1471	Initially Turbid	74.87	19.54	5.59	100	Homogenous Solution
Avg	1.6051	0.4178	0.1202	2.1431	-	74.90	19.50	5.61	-	-
9.1	1.8153	0.2090	0.2600	2.2843	Initially Turbid	79.47	9.15	11.38	100	Homogenous Solution
9.2	1.8160	0.2026	0.2245	2.2431	Initially Turbid	80.96	9.03	10.01	100	Homogenous Solution
9.3	1.8127	0.3317	0.2200	2.3644	Initially Turbid	76.67	14.03	9.30	100	Homogenous Solution
Avg	1.8147	0.2478	0.2348	2.2973	-	79.03	10.74	10.23	-	-
10.1	0.1038	2.0361	0.0056	2.1455	Initially Turbid	4.84	94.90	0.26	100	Homogenous Solution
10.2	0.1010	2.0128	0.0078	2.1216	Initially Turbid	4.76	94.87	0.37	100	Homogenous Solution
10.3	0.1022	2.0066	0.0029	2.1117	Initially Turbid	4.84	95.02	0.14	100	Homogenous Solution
Avg	0.1023	2.0185	0.0054	2.1263	-	4.81	94.93	0.26	-	-
11.1	2.0009	0.1015	0.9549	3.0573	Little Bulk	65.45	3.32	31.23	100	Homogenous Solution
11.2	2.0060	0.1102	1.0030	3.1192	Little Bulk	64.31	3.53	32.16	100	Homogenous Solution
11.3	2.0113	0.1056	0.9726	3.0895	Little Bulk	65.10	3.42	31.48	100	Homogenous Solution
Avg	2.0061	0.1058	0.9768	3.0887	-	64.95	3.42	31.62	-	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (28/4/08)	C/S ratio	J. oil	Water	Total	Note (29/4/08)
13.1	0.0196	1.9807	0.0000	2.0003	Transparent	0.98	99.02	0.00	100	Homogenous Solution
13.2	0.0214	1.9866	0.0000	2.0080	Transparent	1.07	98.93	0.00	100	Homogenous Solution
13.3	0.0267	1.9875	0.0000	2.0142	Transparent	1.33	98.67	0.00	100	Homogenous Solution
Avg	0.0226	1.9849	0.0000	2.0075	-	1.12	98.88	0.00	-	-

Table A-3: Pseudo-Ternary Phase Diagram at C/S Ratio 0.75 in Single Surfactant System

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (26/5/08)	C/S ratio	J. oil	Water	Total	Note (27/5/08)
1.1	0.1060	2.0214	0.0070	2.1344	Initially Turbid	4.97	94.71	0.33	100	Homogenous Solution
1.2	0.1052	2.0085	0.0050	2.1187	Initially Turbid	4.97	94.80	0.24	100	Homogenous Solution
1.3	0.1024	2.0248	0.0068	2.1340	Initially Turbid	4.80	94.88	0.32	100	Homogenous Solution
Avg	0.1045	2.0182	0.0063	2.1290	-	4.91	94.80	0.29	-	-
2.1	0.2052	1.8057	0.0096	2.0205	Initially Turbid	10.16	89.37	0.48	100	Homogenous Solution
2.2	0.2011	1.8037	0.0105	2.0153	Initially Turbid	9.98	89.50	0.52	100	Homogenous Solution
2.3	0.2001	1.8140	0.0087	2.0228	Initially Turbid	9.89	89.68	0.43	100	Homogenous Solution
Avg	0.2021	1.8078	0.0096	2.0195	-	10.01	89.52	0.48	-	-
3.1	0.4018	1.6168	0.0093	2.0279	Initially Turbid	19.81	79.73	0.46	100	Homogenous Solution
3.2	0.3999	1.6026	0.0085	2.0110	Initially Turbid	19.89	79.69	0.42	100	Homogenous Solution
3.3	0.4080	1.6058	0.0109	2.0247	Initially Turbid	20.15	79.31	0.54	100	Homogenous Solution
Avg	0.4032	1.6084	0.0096	2.0212	-	19.95	79.58	0.47	-	-
4.1	0.6021	1.4025	0.0080	2.0126	Initially Turbid	29.92	69.69	0.40	100	Homogenous Solution
4.2	0.6056	1.4008	0.0068	2.0132	Initially Turbid	30.08	69.58	0.34	100	Homogenous Solution
4.3	0.6009	1.4101	0.0074	2.0184	Initially Turbid	29.77	69.86	0.37	100	Homogenous Solution
Avg	0.6029	1.4045	0.0074	2.0147	-	29.92	69.71	0.37	-	-
5.1	0.8066	1.2189	0.0110	2.0365	Initially Turbid	39.61	59.85	0.54	100	Homogenous Solution
5.2	0.8102	1.2049	0.0087	2.0238	Initially Turbid	40.03	59.54	0.43	100	Homogenous Solution
5.3	0.8069	1.2184	0.0078	2.0331	Initially Turbid	39.69	59.93	0.38	100	Homogenous Solution
Avg	0.8079	1.2141	0.0092	2.0311	-	39.78	59.77	0.45	-	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (26/5/08)	C/S ratio	J. oil	Water	Total	Note (27/5/08)
6.1	1.0086	1.0102	0.0733	2.0921	Initially Turbid	48.21	48.29	3.50	100	Homogenous Solution
6.2	1.0016	1.0009	0.0781	2.0806	Initially Turbid	48.14	48.11	3.75	100	Homogenous Solution
6.3	1.0024	1.0100	0.0663	2.0787	Initially Turbid	48.22	48.59	3.19	100	Homogenous Solution
Avg	1.0042	1.0070	0.0726	2.0838	-	48.19	48.33	3.48	-	-
7.1	1.2011	0.8106	0.0594	2.0711	Initially Turbid	57.99	39.14	2.87	100	Homogenous Solution
7.2	1.2059	0.8094	0.0424	2.0577	Initially Turbid	58.60	39.34	2.06	100	Homogenous Solution
7.3	1.2060	0.7990	0.0458	2.0508	Initially Turbid	58.81	38.96	2.23	100	Homogenous Solution
Avg	1.2043	0.8063	0.0492	2.0599	-	58.47	39.14	2.39	-	-
8.1	1.4106	0.6148	0.0086	2.0340	Initially Turbid	69.35	30.23	0.42	100	Homogenous Solution
8.2	1.4002	0.6176	0.0097	2.0275	Initially Turbid	69.06	30.46	0.48	100	Homogenous Solution
8.3	1.4029	0.6138	0.0116	2.0283	Initially Turbid	69.17	30.26	0.57	100	Homogenous Solution
Avg	1.4046	0.6154	0.0100	2.0299	-	69.19	30.32	0.49	-	-
9.1	1.6071	0.4061	0.0245	2.0377	Initially Turbid	78.87	19.93	1.20	100	Homogenous Solution
9.2	1.6012	0.4081	0.0255	2.0348	Initially Turbid	78.69	20.06	1.25	100	Homogenous Solution
9.3	1.6109	0.4050	0.0195	2.0354	Initially Turbid	79.14	19.90	0.96	100	Homogenous Solution
Avg	1.6064	0.4064	0.0232	2.0360	-	78.90	19.96	1.14	-	-
10.1	1.8085	0.2051	0.1067	2.1203	Initially Turbid	85.29	9.67	5.03	100	Homogenous Solution
10.2	1.8027	0.2000	0.1088	2.1115	Initially Turbid	85.38	9.47	5.15	100	Homogenous Solution
10.3	1.8060	0.2027	0.0799	2.0886	Initially Turbid	86.47	9.71	3.83	100	Homogenous Solution
Avg	1.8057	0.2026	0.0985	2.1068	-	85.71	9.62	4.67	-	-
11.1	2.0148	0.1080	0.3578	2.4806	Initially Turbid	81.22	4.35	14.42	100	Homogenous Solution
11.2	2.0253	0.1029	0.3931	2.5213	Initially Turbid	80.33	4.08	15.59	100	Homogenous Solution
11.3	2.0039	0.1142	0.3384	2.4565	Initially Turbid	81.58	4.65	13.78	100	Homogenous Solution
Avg	2.0147	0.1084	0.3631	2.4861	-	81.04	4.36	14.60	-	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (26/5/08)	C/S ratio	J. oil	Water	Total	Note (27/5/08)
13.1	0.0217	1.9810	0.0000	2.0027	Transparent	1.08	98.92	0.00	100	Homogenous Solution
13.2	0.0203	1.9853	0.0000	2.0056	Transparent	1.01	98.99	0.00	100	Homogenous Solution
13.3	0.0200	1.9835	0.0000	2.0035	Transparent	1.00	99.00	0.00	100	Homogenous Solution
Avg	0.0207	1.9833	0.0000	2.0039	-	1.03	98.97	0.00	-	-

Table A-4: Pseudo-Ternary Phase Diagram at C/S Ratio 1.0 in Single Surfactant System

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (1/5/08)	C/S ratio	J. oil	Water	Total	Note (2/5/08)
1.1	0.0995	2.0028	0.0530	2.1553	Initially Turbid	4.62	92.92	2.46	100	Homogenous Solution
1.2	0.1203	2.0038	0.0460	2.1701	Initially Turbid	5.54	92.34	2.12	100	Homogenous Solution
1.3	0.1035	2.0033	0.0550	2.1618	Initially Turbid	4.79	92.67	2.54	100	Homogenous Solution
Avg	0.1078	2.0033	0.0513	2.1624	-	4.98	92.64	2.37	-	-
2.1	0.2052	1.8053	0.0280	2.0385	Initially Turbid	10.07	88.56	1.37	100	Homogenous Solution
2.2	0.2106	1.8070	0.0260	2.0436	Initially Turbid	10.31	88.42	1.27	100	Homogenous Solution
2.3	0.2030	1.8081	0.0301	2.0412	Initially Turbid	9.95	88.58	1.47	100	Homogenous Solution
Avg	0.2063	1.8068	0.0280	2.0411	-	10.11	88.52	1.37	-	-
3.1	0.4070	1.6012	0.1107	2.1189	Initially Turbid	19.21	75.57	5.22	100	Homogenous Solution
3.2	0.4006	1.6039	0.1211	2.1256	Initially Turbid	18.85	75.46	5.70	100	Homogenous Solution
3.3	0.4178	1.6018	0.1156	2.1352	Initially Turbid	19.57	75.02	5.41	100	Homogenous Solution
Avg	0.4085	1.6023	0.1158	2.1266	-	19.21	75.35	5.45	-	-
4.1	0.6054	1.4014	0.1203	2.1271	Initially Turbid	28.46	65.88	5.66	100	Homogenous Solution
4.2	0.6064	1.4069	0.1194	2.1327	Initially Turbid	28.43	65.97	5.60	100	Homogenous Solution
4.3	0.6023	1.4006	0.1066	2.1095	Initially Turbid	28.55	66.39	5.05	100	Homogenous Solution
Avg	0.6047	1.4030	0.1154	2.1231	-	28.48	66.08	5.44	-	-
5.1	0.8003	1.2442	0.1058	2.1503	Initially Turbid	37.22	57.86	4.92	100	Homogenous Solution
5.2	0.7988	1.2009	0.0965	2.0962	Initially Turbid	38.11	57.29	4.60	100	Homogenous Solution
5.3	0.8017	1.2108	0.1175	2.1300	Initially Turbid	37.64	56.85	5.52	100	Homogenous Solution
Avg	0.8003	1.2186	0.1066	2.1255	-	37.65	57.33	5.01	-	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (1/5/08)	C/S ratio	J. oil	Water	Total	Note (2/5/08)
6.1	1.0023	1.0278	0.0600	2.0901	Initially Turbid	47.95	49.17	2.87	100	Homogenous Solution
6.2	1.0106	0.9992	0.0733	2.0831	Initially Turbid	48.51	47.97	3.52	100	Homogenous Solution
6.3	1.0010	1.0040	0.0758	2.0808	Initially Turbid	48.11	48.25	3.64	100	Homogenous Solution
Avg	1.0046	1.0103	0.0697	2.0847	-	48.19	48.46	3.34	-	-
7.1	1.2037	0.8331	0.0679	2.1047	Initially Turbid	57.19	39.58	3.23	100	Homogenous Solution
7.2	1.1983	0.8012	0.0711	2.0706	Initially Turbid	57.87	38.69	3.43	100	Homogenous Solution
7.3	1.2560	0.8204	0.0732	2.1496	Initially Turbid	58.43	38.17	3.41	100	Homogenous Solution
Avg	1.2193	0.8182	0.0707	2.1083	-	57.83	38.81	3.36	-	-
8.1	1.4047	0.6093	0.0478	2.0618	Initially Turbid	68.13	29.55	2.32	100	Homogenous Solution
8.2	1.3956	0.6040	0.0502	2.0498	Initially Turbid	68.08	29.47	2.45	100	Homogenous Solution
8.3	1.4048	0.6004	0.0499	2.0551	Initially Turbid	68.36	29.22	2.43	100	Homogenous Solution
Avg	1.4017	0.6046	0.0493	2.0556	-	68.19	29.41	2.40	-	-
9.1	1.6026	0.4031	0.0589	2.0646	Initially Turbid	77.62	19.52	2.85	100	Homogenous Solution
9.2	1.6105	0.4040	0.0679	2.0824	Initially Turbid	77.34	19.40	3.26	100	Homogenous Solution
9.3	1.6065	0.4045	0.0641	2.0751	Initially Turbid	77.42	19.49	3.09	100	Homogenous Solution
Avg	1.6065	0.4039	0.0636	2.0740	-	77.46	19.47	3.07	-	-
10.1	1.8155	0.2027	0.0885	2.1067	Initially Turbid	86.18	9.62	4.20	100	Homogenous Solution
10.2	1.8033	0.2014	0.0902	2.0949	Initially Turbid	86.08	9.61	4.31	100	Homogenous Solution
10.3	1.7997	0.2006	0.1035	2.1038	Initially Turbid	85.55	9.54	4.92	100	Homogenous Solution
Avg	1.8062	0.2016	0.0941	2.1018	-	85.93	9.59	4.48	-	-
11.1	2.0105	0.0994	0.3657	2.4756	Initially Turbid	81.21	4.02	14.77	100	Homogenous Solution
11.2	1.9993	0.0998	0.3023	2.4014	Initially Turbid	83.26	4.16	12.59	100	Homogenous Solution
11.3	2.0030	0.1017	0.2989	2.4036	Initially Turbid	83.33	4.23	12.44	100	Homogenous Solution
Avg	2.0043	0.1003	0.3223	2.4269	-	82.60	4.13	13.27	-	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (1/5/08)	C/S ratio	J. oil	Water	Total	Note (2/5/08)
13.1	0.0197	1.9822	0.0000	2.0019	Transparent	0.98	99.02	0.00	100	Homogenous Solution
13.2	0.0306	1.9810	0.0000	2.0116	Transparent	1.52	98.48	0.00	100	Homogenous Solution
13.3	0.0201	1.9851	0.0000	2.0052	Transparent	1.00	99.00	0.00	100	Homogenous Solution
Avg	0.0235	1.9828	0.0000	2.0062	-	1.17	98.83	0.00	-	-

Table A-5: Pseudo-Ternary Phase Diagram at C/S Ratio 1.25 in Single Surfactant System

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (13/5/08)	C/S ratio	J. oil	Water	Total	Note (14/5/08)
1.1	0.1003	2.0050	0.0032	2.1085	Initially Turbid	4.76	95.09	0.15	100	Homogenous Solution
1.2	0.1002	2.0150	0.0028	2.1180	Initially Turbid	4.73	95.14	0.13	100	Homogenous Solution
1.3	0.1023	2.0052	0.0026	2.1101	Initially Turbid	4.85	95.03	0.12	100	Homogenous Solution
Avg	0.1009	2.0084	0.0029	2.1122	-	4.78	95.09	0.14	-	-
2.1	0.2018	1.8090	0.0136	2.0244	Initially Turbid	9.97	89.36	0.67	100	Homogenous Solution
2.2	0.2043	1.8018	0.0145	2.0206	Initially Turbid	10.11	89.17	0.72	100	Homogenous Solution
2.3	0.2033	1.8017	0.0163	2.0213	Initially Turbid	10.06	89.14	0.81	100	Homogenous Solution
Avg	0.2031	1.8042	0.0148	2.0221	-	10.05	89.22	0.73	-	-
3.1	0.6017	1.6055	0.0188	2.2260	Initially Turbid	27.03	72.12	0.84	100	Homogenous Solution
3.2	0.4406	1.6023	0.0191	2.0620	Initially Turbid	21.37	77.71	0.93	100	Homogenous Solution
3.3	0.4365	1.6085	0.0163	2.0613	Initially Turbid	21.18	78.03	0.79	100	Homogenous Solution
Avg	0.4929	1.6054	0.0181	2.1164	-	23.19	75.95	0.85	-	-
4.1	0.6024	1.4088	0.0634	2.0746	Initially Turbid	29.04	67.91	3.06	100	Homogenous Solution
4.2	0.6023	1.4038	0.0734	2.0795	Initially Turbid	28.96	67.51	3.53	100	Homogenous Solution
4.3	0.5999	1.4184	0.0833	2.1016	Initially Turbid	28.54	67.49	3.96	100	Homogenous Solution
Avg	0.6015	1.4103	0.0734	2.0852	-	28.85	67.64	3.52	-	-
5.1	0.8045	1.2051	0.0725	2.0821	Initially Turbid	38.64	57.88	3.48	100	Homogenous Solution
5.2	0.8102	1.2267	0.0658	2.1027	Initially Turbid	38.53	58.34	3.13	100	Homogenous Solution
5.3	0.8053	1.2029	0.0528	2.0610	Initially Turbid	39.07	58.36	2.56	100	Homogenous Solution
Avg	0.8067	1.2116	0.0637	2.0819	-	38.75	58.19	3.06	-	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (13/5/08)	C/S ratio	J. oil	Water	Total	Note (14/5/08)
6.1	1.0009	1.0162	0.0690	2.0861	Initially Turbid	47.98	48.71	3.31	100	Homogenous Solution
6.2	1.0053	1.0217	0.0598	2.0868	Initially Turbid	48.17	48.96	2.87	100	Homogenous Solution
6.3	1.0030	1.2029	0.0559	2.2618	Initially Turbid	44.35	53.18	2.47	100	Homogenous Solution
Avg	1.0031	1.0803	0.0616	2.1449	-	46.83	50.29	2.88	-	-
7.1	1.2054	0.8020	0.0502	2.0576	Initially Turbid	58.58	38.98	2.44	100	Homogenous Solution
7.2	1.2050	0.8049	0.0488	2.0587	Initially Turbid	58.53	39.10	2.37	100	Homogenous Solution
7.3	1.2115	0.8109	0.0476	2.0700	Initially Turbid	58.53	39.17	2.30	100	Homogenous Solution
Avg	1.2073	0.8059	0.0489	2.0621	-	58.55	39.08	2.37	-	-
8.1	1.4044	0.6054	0.0408	2.0506	Initially Turbid	68.49	29.52	1.99	100	Homogenous Solution
8.2	1.4101	0.6865	0.0431	2.1397	Initially Turbid	65.90	32.08	2.01	100	Homogenous Solution
8.3	1.4032	0.6080	0.0425	2.0537	Initially Turbid	68.33	29.61	2.07	100	Homogenous Solution
Avg	1.4059	0.6333	0.0421	2.0813	-	67.57	30.40	2.02	-	-
9.1	1.6116	0.3999	0.0502	2.0617	Initially Turbid	78.17	19.40	2.43	100	Homogenous Solution
9.2	1.6059	0.4096	0.0438	2.0593	Initially Turbid	77.98	19.89	2.13	100	Homogenous Solution
9.3	1.6021	0.4045	0.0506	2.0572	Initially Turbid	77.88	19.66	2.46	100	Homogenous Solution
Avg	1.6065	0.4047	0.0482	2.0594	-	78.01	19.65	2.34	-	-
10.1	1.8083	0.2125	0.0810	2.1018	Initially Turbid	86.04	10.11	3.85	100	Homogenous Solution
10.2	1.8035	0.1999	0.0901	2.0935	Initially Turbid	86.15	9.55	4.30	100	Homogenous Solution
10.3	1.8029	0.2101	0.0720	2.0850	Initially Turbid	86.47	10.08	3.45	100	Homogenous Solution
Avg	1.8049	0.2075	0.0810	2.0934	-	86.22	9.91	3.87	-	-
11.1	2.0006	0.1120	0.2257	2.3383	Initially Turbid	85.56	4.79	9.65	100	Homogenous Solution
11.2	2.0005	0.1006	0.2107	2.3118	Initially Turbid	86.53	4.35	9.11	100	Homogenous Solution
11.3	2.0009	0.1136	0.1937	2.3082	Initially Turbid	86.69	4.92	8.39	100	Homogenous Solution
Avg	2.0007	0.1087	0.2100	2.3194	-	86.26	4.69	9.05	-	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (13/5/08)	C/S ratio	J. oil	Water	Total	Note (14/5/08)
13.1	0.0195	1.9816	0.0000	2.0011	Transparent	0.97	99.03	0.00	100	Homogenous Solution
13.2	0.0237	1.9805	0.0000	2.0042	Transparent	1.18	98.82	0.00	100	Homogenous Solution
13.3	0.0200	1.9843	0.0000	2.0043	Transparent	1.00	99.00	0.00	100	Homogenous Solution
Avg	0.0211	1.9821	0.0000	2.0032	-	1.05	98.95	0.00	-	-

Table A-6: Pseudo-Ternary Phase Diagram at C/S Ratio 0.5 in Single Surfactant System for Comparison with Mixed Surfactant System

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (9/9/08)	C/S ratio	J. oil	Water	Total	Note (10/9/08)
1.1	0.0258	1.9819	0.0015	2.0093	Initially Turbid	1.28	98.64	0.08	100	Homogenous Solution
1.2	0.0290	1.9813	0.0016	2.0120	Initially Turbid	1.44	98.47	0.09	100	Homogenous Solution
1.3	0.0218	1.9820	0.0016	2.0055	Initially Turbid	1.09	98.83	0.08	100	Homogenous Solution
Avg	0.0255	1.9817	0.0016	2.0089	-	1.27	98.65	0.08	100	-
2.1	0.1038	2.0020	0.0051	2.1113	Initially Turbid	4.92	94.82	0.26	100	Homogenous Solution
2.2	0.1015	2.0056	0.0055	2.1130	Initially Turbid	4.80	94.92	0.28	100	Homogenous Solution
2.3	0.1284	2.0024	0.0048	2.1361	Initially Turbid	6.01	93.74	0.25	100	Homogenous Solution
Avg	0.1112	2.0033	0.0051	2.1201	-	5.24	94.49	0.26	100	-
3.1	0.2036	1.8059	0.0067	2.0170	Initially Turbid	10.09	89.53	0.37	100	Homogenous Solution
3.2	0.2096	1.8083	0.0062	2.0249	Initially Turbid	10.35	89.30	0.35	100	Homogenous Solution
3.3	0.2105	1.8034	0.0066	2.0213	Initially Turbid	10.41	89.22	0.37	100	Homogenous Solution
Avg	0.2079	1.8059	0.0065	2.0211	-	10.29	89.35	0.36	100	-
4.1	0.4012	1.6080	0.0113	2.0221	Initially Turbid	19.84	79.52	0.64	100	Homogenous Solution
4.2	0.4005	1.6044	0.0121	2.0186	Initially Turbid	19.84	79.48	0.68	100	Homogenous Solution
4.3	0.4018	1.6010	0.0120	2.0164	Initially Turbid	19.93	79.40	0.67	100	Homogenous Solution
Avg	0.4012	1.6045	0.0118	2.0190	-	19.87	79.47	0.66	100	-
5.1	0.6063	1.4088	0.0150	2.0325	Initially Turbid	29.83	69.31	0.86	100	Homogenous Solution
5.2	0.6016	1.4009	0.0151	2.0200	Initially Turbid	29.78	69.35	0.87	100	Homogenous Solution
5.3	0.6026	1.4006	0.0154	2.0210	Initially Turbid	29.82	69.30	0.88	100	Homogenous Solution
Avg	0.6035	1.4034	0.0152	2.0245	-	29.81	69.32	0.87	100	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (9/9/08)	C/S ratio	J. oil	Water	Total	Note (10/9/08)
6.1	0.8029	1.2059	0.0142	2.0262	Initially Turbid	39.63	59.52	0.86	100	Homogenous Solution
6.2	0.8037	1.2089	0.0137	2.0295	Initially Turbid	39.60	59.57	0.83	100	Homogenous Solution
6.3	0.8063	1.2021	0.0138	2.0254	Initially Turbid	39.81	59.35	0.84	100	Homogenous Solution
Avg	0.8043	1.2056	0.0139	2.0271	-	39.68	59.48	0.84	100	-
7.1	1.0104	1.0052	0.0110	2.0306	Initially Turbid	49.76	49.50	0.74	100	Homogenous Solution
7.2	1.0081	1.0029	0.0112	2.0262	Initially Turbid	49.75	49.50	0.75	100	Homogenous Solution
7.3	1.0099	1.0084	0.0108	2.0331	Initially Turbid	49.67	49.60	0.73	100	Homogenous Solution
Avg	1.0095	1.0055	0.0110	2.0300	-	49.73	49.53	0.74	100	-
8.1	1.2181	0.8168	0.0141	2.0539	Initially Turbid	59.31	39.77	0.92	100	Homogenous Solution
8.2	1.2055	0.8024	0.0136	2.0263	Initially Turbid	59.49	39.60	0.91	100	Homogenous Solution
8.3	1.2038	0.8097	0.0127	2.0310	Initially Turbid	59.27	39.87	0.86	100	Homogenous Solution
Avg	1.2091	0.8096	0.0135	2.0371	-	59.36	39.74	0.90	100	-
9.1	1.4022	0.6078	0.0202	2.0358	Initially Turbid	68.88	29.86	1.27	100	Homogenous Solution
9.2	1.4037	0.6139	0.0200	2.0432	Initially Turbid	68.70	30.05	1.25	100	Homogenous Solution
9.3	1.4045	0.6013	0.0201	2.0315	Initially Turbid	69.14	29.60	1.27	100	Homogenous Solution
Avg	1.4035	0.6077	0.0201	2.0368	-	68.90	29.83	1.26	100	-
10.1	1.6013	0.4103	0.0404	2.0584	Initially Turbid	77.79	19.93	2.27	100	Homogenous Solution
10.2	1.6006	0.4041	0.0405	2.0516	Initially Turbid	78.02	19.70	2.29	100	Homogenous Solution
10.3	1.6068	0.4017	0.0405	2.0554	Initially Turbid	78.17	19.54	2.28	100	Homogenous Solution
Avg	1.6029	0.4054	0.0405	2.0551	-	77.99	19.72	2.28	100	-
11.1	1.8016	0.2007	0.1095	2.1190	Initially Turbid	85.02	9.47	5.51	100	Homogenous Solution
11.2	1.8051	0.2085	0.1113	2.1321	Initially Turbid	84.66	9.78	5.56	100	Homogenous Solution
11.3	1.8013	0.2070	0.1098	2.1253	Initially Turbid	84.75	9.74	5.51	100	Homogenous Solution
Avg	1.8027	0.2054	0.1102	2.1255	-	84.81	9.66	5.52	100	-

Table A-7: Pseudo-Ternary Phase Diagram at C/S Ratio 0.5 in Mixed Surfactant System

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (12/9/08)	C/S ratio	J. oil	Water	Total	Note (15/9/08)
1.1	0.0205	1.9821	0.0017	2.0044	Initially Turbid	1.02	98.89	0.09	100	Homogenous Solution
1.2	0.0215	1.9825	0.0017	2.0058	Initially Turbid	1.07	98.84	0.09	100	Homogenous Solution
1.3	0.0255	1.9803	0.0015	2.0074	Initially Turbid	1.27	98.65	0.08	100	Homogenous Solution
Avg	0.0225	1.9816	0.0016	2.0059	-	1.12	98.79	0.09	100	-
2.1	0.1017	2.0018	0.0074	2.1114	Initially Turbid	4.82	94.81	0.37	100	Homogenous Solution
2.2	0.1037	2.0042	0.0070	2.1154	Initially Turbid	4.90	94.74	0.35	100	Homogenous Solution
2.3	0.1098	2.0008	0.0069	2.1180	Initially Turbid	5.18	94.47	0.35	100	Homogenous Solution
Avg	0.1051	2.0023	0.0071	2.1149	-	4.97	94.67	0.36	100	-
3.1	0.2007	1.8004	0.0102	2.0122	Initially Turbid	9.97	89.47	0.55	100	Homogenous Solution
3.2	0.2009	1.8006	0.0098	2.0122	Initially Turbid	9.98	89.48	0.53	100	Homogenous Solution
3.3	0.2024	1.8048	0.0100	2.0181	Initially Turbid	10.03	89.43	0.54	100	Homogenous Solution
Avg	0.2013	1.8019	0.0100	2.0142	-	10.00	89.46	0.54	100	-
4.1	0.4007	1.6048	0.0111	2.0184	Initially Turbid	19.85	79.51	0.64	100	Homogenous Solution
4.2	0.4062	1.6054	0.0115	2.0249	Initially Turbid	20.06	79.28	0.66	100	Homogenous Solution
4.3	0.4016	1.6012	0.0110	2.0156	Initially Turbid	19.92	79.44	0.64	100	Homogenous Solution
Avg	0.4028	1.6038	0.0112	2.0197	-	19.95	79.41	0.64	100	-
5.1	0.6007	1.4017	0.0109	2.0160	Initially Turbid	29.80	69.53	0.68	100	Homogenous Solution
5.2	0.6020	1.4051	0.0113	2.0211	Initially Turbid	29.79	69.52	0.69	100	Homogenous Solution
5.3	0.6010	1.4061	0.0114	2.0212	Initially Turbid	29.73	69.57	0.70	100	Homogenous Solution
Avg	0.6012	1.4043	0.0112	2.0195	-	29.77	69.54	0.69	100	-

Sample	Weight (g)				Observation	Weight (%)				Observation
	C/S ratio	J. oil	Water	Total	Note (12/9/08)	C/S ratio	J. oil	Water	Total	Note (15/9/08)
6.1	0.8024	1.2010	0.0097	2.0167	Initially Turbid	39.79	59.55	0.66	100	Homogenous Solution
6.2	0.8020	1.2055	0.0108	2.0219	Initially Turbid	39.67	59.62	0.71	100	Homogenous Solution
6.3	0.8011	1.2064	0.0102	2.0213	Initially Turbid	39.63	59.68	0.68	100	Homogenous Solution
Avg	0.8018	1.2043	0.0102	2.0200	-	39.69	59.62	0.69	100	-
7.1	1.0017	1.0070	0.0100	2.0232	Initially Turbid	49.51	49.77	0.72	100	Homogenous Solution
7.2	1.0040	1.0018	0.0097	2.0200	Initially Turbid	49.70	49.59	0.70	100	Homogenous Solution
7.3	1.0063	1.0036	0.0107	2.0251	Initially Turbid	49.69	49.56	0.75	100	Homogenous Solution
Avg	1.0040	1.0041	0.0101	2.0228	-	49.63	49.64	0.73	100	-
8.1	1.2045	0.8032	0.0090	2.0221	Initially Turbid	59.57	39.72	0.71	100	Homogenous Solution
8.2	1.2002	0.8026	0.0093	2.0175	Initially Turbid	59.49	39.78	0.73	100	Homogenous Solution
8.3	1.2020	0.8038	0.0086	2.0198	Initially Turbid	59.51	39.80	0.69	100	Homogenous Solution
Avg	1.2022	0.8032	0.0090	2.0198	-	59.52	39.77	0.71	100	-
9.1	1.4104	0.6013	0.0101	2.0282	Initially Turbid	69.54	29.65	0.81	100	Homogenous Solution
9.2	1.4024	0.6017	0.0099	2.0203	Initially Turbid	69.41	29.78	0.80	100	Homogenous Solution
9.3	1.4038	0.6099	0.0100	2.0300	Initially Turbid	69.15	30.04	0.81	100	Homogenous Solution
Avg	1.4055	0.6043	0.0100	2.0262	-	69.37	29.82	0.81	100	-
10.1	1.6009	0.4011	0.0340	2.0432	Initially Turbid	78.35	19.63	2.02	100	Homogenous Solution
10.2	1.6058	0.4010	0.0332	2.0473	Initially Turbid	78.44	19.59	1.98	100	Homogenous Solution
10.3	1.6029	0.4058	0.0346	2.0505	Initially Turbid	78.17	19.79	2.04	100	Homogenous Solution
Avg	1.6032	0.4026	0.0339	2.0470	-	78.32	19.67	2.01	100	-
11.1	1.8024	0.2048	0.1008	2.1161	Initially Turbid	85.17	9.68	5.15	100	Homogenous Solution
11.2	1.8012	0.2065	0.0999	2.1157	Initially Turbid	85.13	9.76	5.11	100	Homogenous Solution
11.3	1.8050	0.2010	0.0993	2.1135	Initially Turbid	85.40	9.51	5.08	100	Homogenous Solution
Avg	1.8029	0.2041	0.1000	2.1151	-	85.24	9.65	5.11	100	-

APPENDIX D

Table C-1: Performance of Diesel Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^{o}C)	
		min/30ml	L/hr						Exhaust Gas	Oil
0	1505	3.59	0.45	N.A	132	N.A	N.A	N.A	95	71
1	1508	3.30	0.51	0.92	135	3.3	0.56	0.0035	92	73
2	1502	3.01	0.60	0.59	134	6.0	1.01	0.0064	95	73
3	1507	2.44	0.66	0.45	136	8.6	1.46	0.0093	104	74
4	1510	2.15	0.80	0.38	138	12.2	2.10	0.0133	118	74
5	1507	1.50	0.98	0.36	135	16.1	2.72	0.0172	142	75
6	1507	1.31	1.19	0.35	135	20.2	3.41	0.0216	169	77
7	1505	1.21	1.33	0.34	135	23.0	3.88	0.0246	189	79
8	1508	1.13	1.48	0.35	135	25.3	4.27	0.0270	213	80
9	1504	1.05	1.66	0.36	135	27.4	4.62	0.0294	244	82

note: N.A = Not Available

Table C-2: Performance of Diesel Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^{o}C)	
		min/30ml	L/hr						Exhaust Gas	Oil
0.0	2406	2.00	0.90	N.A	244	N.A	N.A	N.A	131	85
0.5	2406	2.16	0.79	N.A	244	N.A	N.A	N.A	137	81
1.0	2404	1.16	1.42	1.01	244	4.6	1.40	0.0056	143	86
1.5	2402	1.25	1.27	0.63	244	6.6	2.01	0.0080	158	87
2.0	2404	1.24	1.29	0.49	243	8.6	2.61	0.0104	167	89
2.5	2406	1.13	1.48	0.46	243	10.6	3.22	0.0128	181	90
3.0	2404	1.10	1.54	0.40	243	12.6	3.83	0.0152	191	92
3.5	2404	1.03	1.71	0.39	243	14.3	4.34	0.0173	206	95
4.0	2402	0.56	1.93	0.35	243	18.3	5.56	0.0221	240	98

note: N.A = Not Available

Table C-3: Performance of MB5 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^{o}C)	
		min/30ml	L/hr						Exhaust Gas	Oil
0	1498	4.14	0.43	N.A	131	N.A	N.A	N.A	84	68
1	1502	3.37	0.50	0.91	132	3.3	0.54	0.0035	88	69
2	1500	2.57	0.61	0.61	133	6.0	1.00	0.0064	97	70
3	1502	2.37	0.69	0.48	134	8.6	1.44	0.0092	109	71
4	1500	2.12	0.82	0.38	135	12.9	2.18	0.0139	124	72
5	1500	1.57	0.92	0.34	135	16.2	2.73	0.0174	144	74
6	1500	1.37	1.19	0.35	134	20.3	3.40	0.0217	162	75
7	1500	1.27	1.50	0.41	133	22.0	3.66	0.0233	193	77
8	1500	1.18	1.38	0.33	134	24.7	4.14	0.0264	211	79
9	1502	0.58	1.86	0.40	134	27.6	4.62	0.0294	256	80

note: N.A = Not Available

Table C-4: Performance of MB5 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^{o}C)	
		min/30ml	L/hr						Exhaust Gas	Oil
0.0	2402	2.02	0.89	N.A	243	N.A	N.A	N.A	125	67
0.5	2404	1.46	1.02	N.A	243	N.A	N.A	N.A	134	74
1.0	2402	1.31	1.19	0.87	243	4.5	1.37	0.0054	140	77
1.5	2402	1.26	1.26	0.64	243	6.5	1.97	0.0079	150	79
2.0	2402	1.22	1.32	0.52	243	8.4	2.55	0.0101	159	82
2.5	2404	1.17	1.40	0.46	243	10.0	3.04	0.0121	171	83
3.0	2404	1.08	1.59	0.44	243	11.8	3.58	0.0142	183	86
3.5	2402	0.58	1.86	0.38	243	16.1	4.89	0.0195	206	88
4.0	2404	0.43	2.51	0.46	243	18.0	5.47	0.0217	228	90

note: N.A = Not Available

Table C-5: Performance of MB10 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^{o}C)	
		min/30ml	L/hr						Exhaust Gas	Oil
0	1500	2.49	0.43	N.A	132	N.A	N.A	N.A	88	65
1	1500	2.25	0.50	0.88	133	3.4	0.57	0.0036	87	67
2	1500	2.02	0.59	0.57	135	6.1	1.03	0.0066	97	69
3	1502	1.47	0.67	0.45	135	8.8	1.49	0.0094	105	70
4	1500	1.23	0.87	0.40	135	12.9	2.18	0.0139	120	70
5	1498	1.14	0.97	0.35	135	16.5	2.78	0.0178	137	72
6	1498	1.04	1.13	0.33	135	20.5	3.46	0.0221	161	74
7	1498	1.03	1.14	0.32	135	21.4	3.61	0.0230	171	75
8	1500	0.52	1.38	0.32	135	25.6	4.32	0.0275	203	78
9	1498	0.44	1.64	0.35	135	27.9	4.71	0.0300	233	80

note: N.A = Not Available

Table C-6: Performance of MB10 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^{o}C)	
		min/30ml	L/hr						Exhaust Gas	Oil
0.0	2402	2.14	0.81	N.A	244	N.A	N.A	N.A	119	67
0.5	2402	1.45	1.03	N.A	244	N.A	N.A	N.A	131	73
1.0	2402	1.38	1.10	0.77	244	4.7	1.43	0.0057	141	76
1.5	2398	1.30	1.20	0.60	243	6.6	2.00	0.0080	148	79
2.0	2400	1.22	1.32	0.50	243	8.6	2.61	0.0104	159	82
2.5	2398	1.19	1.37	0.42	243	10.6	3.22	0.0128	171	84
3.0	2400	1.12	1.50	0.39	243	12.7	3.86	0.0154	183	87
3.5	2400	1.05	1.66	0.38	243	14.3	4.34	0.0173	192	88
4.0	2402	1.01	1.77	0.36	243	16.3	4.95	0.0197	208	90

note: N.A = Not Available

Table C-7: Performance of MB20 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^{o}C)	
		min/30ml	L/hr						Exhaust Gas	Oil
0	1500	2.29	0.48	N.A	132	N.A	N.A	N.A	87	70
1	1502	2.10	0.55	0.97	134	3.4	0.57	0.0036	87	70
2	1502	2.01	0.60	0.58	135	6.1	1.03	0.0065	93	71
3	1498	1.44	0.69	0.47	135	8.7	1.47	0.0094	101	72
4	1500	1.23	0.87	0.39	136	13.0	2.21	0.0141	115	73
5	1500	1.15	0.96	0.34	135	16.5	2.78	0.0177	131	74
6	1498	1.04	1.13	0.33	135	20.5	3.46	0.0221	150	75
7	1500	0.53	1.36	0.35	135	23.2	3.92	0.0249	173	76
8	1498	0.50	1.44	0.33	135	25.8	4.35	0.0278	200	78
9	1498	0.43	1.67	0.35	134	28.2	4.72	0.0301	224	79

note: N.A = Not Available

Table C-8: Performance of MB20 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^{o}C)	
		min/30ml	L/hr						Exhaust Gas	Oil
0.0	2402	1.53	0.96	N.A	244	N.A	N.A	N.A	103	60
0.5	2400	1.45	1.03	N.A	244	N.A	N.A	N.A	128	66
1.0	2400	1.34	1.15	0.80	244	4.7	1.43	0.0057	138	71
1.5	2400	1.30	1.20	0.59	244	6.7	2.04	0.0081	147	75
2.0	2402	1.21	1.33	0.50	244	8.7	2.65	0.0106	157	78
2.5	2398	1.13	1.48	0.46	243	10.7	3.25	0.0129	168	81
3.0	2400	1.10	1.54	0.40	243	12.7	3.86	0.0154	179	83
3.5	2398	1.04	1.69	0.39	243	14.4	4.37	0.0174	189	86
4.0	2398	0.56	1.93	0.39	243	16.4	4.98	0.0198	206	88

note: N.A = Not Available

Table C-9: Performance of Biodiesel Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^oC)	
		min/30ml	L/hr						Exhaust Gas	Oil
0	1498	2.16	0.53	N.A	132	N.A	N.A	N.A	77	65
1	1500	2.06	0.57	1.04	133	3.3	0.55	0.0035	85	67
2	1498	1.53	0.64	0.66	134	5.8	0.97	0.0062	95	70
3	1502	1.40	0.72	0.49	136	8.7	1.48	0.0094	104	72
4	1500	1.16	0.95	0.44	135	12.8	2.16	0.0138	117	74
5	1502	1.08	1.06	0.37	137	16.5	2.83	0.0180	138	75
6	1500	1.04	1.13	0.35	135	19.1	3.22	0.0205	152	76
7	1500	0.56	1.29	0.36	134	21.6	3.62	0.0230	167	78
8	1502	0.51	1.41	0.35	135	24.2	4.08	0.0260	193	79
9	1500	0.40	1.80	0.39	135	27.6	4.66	0.0297	245	81

note: N.A = Not Available

Table C-10: Performance of Biodiesel Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Actual Speed (rpm)	Fuel Consumption		Brake Fuel Consumption (L/Kw-hr)	Electromotive Force (Volt)	Electric Current (Ampere)	Power Engine (kW)	Torque (N.m)	Temperature (^{o}C)	
		min/30ml	L/hr						Exhaust Gas	Oil
0.0	2400	1.48	1.00	N.A	244	N.A	N.A	N.A	122	68
0.5	2400	1.36	1.13	N.A	244	N.A	N.A	N.A	132	75
1.0	2400	1.29	1.21	0.86	244	4.6	1.40	0.0056	143	79
1.5	2402	1.27	1.24	0.62	244	6.6	2.01	0.0080	150	82
2.0	2402	1.16	1.42	0.55	243	8.5	2.58	0.0103	165	85
2.5	2400	1.09	1.57	0.49	243	10.6	3.22	0.0128	173	87
3.0	2404	1.06	1.64	0.43	244	12.6	3.84	0.0153	186	88
3.5	2398	1.00	1.80	0.42	243	14.2	4.31	0.0172	203	91
4.0	2400	0.56	1.93	0.39	243	16.3	4.95	0.0197	214	92

note: N.A = Not Available

Table C-11: Emissions of Diesel Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0	1.3	282	3.09	170	16.9	85.9	68.72	4.65
1	1.6	240	3.50	205	16.5	77.5	60.80	4.16
2	4.0	196	3.99	228	15.8	70.0	53.80	3.69
3	7.0	155	4.47	242	15.1	71.9	48.64	3.32
4	7.6	149	5.49	266	14.2	65.7	42.38	2.90
5	11.4	188	5.78	255	13.3	50.7	37.35	2.56
6	23.7	511	6.46	276	12.3	108.0	33.51	2.30
7	25.8	525	6.88	267	9.5	75.2	30.68	2.15
8	27.5	859	7.04	220	11.1	100.8	30.47	2.07
9	38.7	1024	7.70	201	10.3	278.0	27.73	1.90

Table C-12: Emissions of Diesel Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0.0	1.3	458	3.67	146	15.9	146.7	57.01	3.96
0.5	1.9	312	3.95	167	15.5	95.2	53.24	3.64
1.0	2.9	240	4.25	182	15.2	76.5	49.62	3.38
1.5	3.5	200	4.26	208	14.7	67.5	45.71	3.14
2.0	4.2	169	4.88	222	14.3	73.5	43.12	2.96
2.5	5.2	146	5.30	249	13.7	60.2	40.18	2.76
3.0	6.7	143	5.58	262	13.2	51.9	37.85	2.62
3.5	7.4	157	5.91	264	12.9	75.5	36.09	2.48
4.0	11.8	284	6.54	277	11.9	51.8	32.61	2.22

Table C-13: Emissions of MB5 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0	1.9	267	3.01	166	17.2	56.1	70.08	5.08
1	1.6	230	3.47	199	16.6	47.3	61.63	4.43
2	2.3	195	3.94	221	16.0	55.4	54.92	3.94
3	3.1	164	4.43	229	15.3	49.4	49.12	3.49
4	4.2	155	5.12	261	14.4	49.7	42.50	3.03
5	8.5	157	5.74	279	13.5	43.8	37.94	2.69
6	16.8	412	6.3	262	12.7	75.4	34.67	2.48
7	15.7	399	6.81	269	12.0	53.3	32.20	2.29
8	23.4	727	7.12	241	11.5	94.9	30.65	2.17
9	78.6	2280	7.62	155	10.4	210	27.83	1.98

Table C-14: Emissions of MB5 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0.0	1.6	332	3.46	147	16.5	117.0	62.21	4.39
0.5	1.3	279	3.77	162	16.1	90.5	56.57	4.02
1.0	2.2	234	4.03	177	15.8	75.9	53.49	3.8
1.5	3.2	184	4.33	199	15.4	58.2	50.01	3.52
2.0	3.2	163	4.57	217	15.1	56.7	47.51	3.39
2.5	4.2	143	4.89	238	14.6	51.8	44.39	3.21
3.0	4.5	123	5.19	252	14.2	39.9	41.78	2.97
3.5	7.8	160	5.84	276	13.3	40.8	37.10	2.67
4.0	8.9	192	6.21	279	12.8	43.4	35.14	2.41

Table C-15: Emissions of MB10 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0	4.8	264	3.18	181	17.9	55.9	70.06	5.18
1	3.2	224	3.64	218	17.4	58.0	61.70	4.48
2	4.5	182	4.12	231	16.8	62.5	55.15	4.02
3	5.7	155	4.59	243	16.1	61.4	49.40	3.62
4	6.7	134	5.25	262	15.2	48.5	43.51	3.14
5	7.6	153	5.77	271	14.6	45.6	39.70	2.93
6	12.8	281	6.39	302	13.7	58.0	36.15	2.61
7	16.4	428	6.59	286	13.4	64.5	34.83	2.55
8	21.9	391	7.02	229	12.9	58.3	33.38	2.41
9	38.7	899	7.55	203	12.1	132.0	30.00	2.18

Table C-16: Emissions of MB10 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0.0	1.3	249	3.23	139	17.8	83.2	68.49	5.07
0.5	2.5	202	3.55	166	17.4	64.2	63.92	4.65
1.0	2.9	170	3.81	169	17.1	50.2	58.75	4.32
1.5	2.9	135	4.03	187	16.8	42.1	54.98	4.11
2.0	2.9	107	4.3	202	16.5	37.4	53.50	3.85
2.5	3.5	91	4.59	222	16.1	34.8	49.65	3.52
3.0	4.5	98	4.97	239	15.6	46.1	46.26	3.31
3.5	4.5	102	5.22	248	15.3	40.8	44.20	3.16
4.0	5.8	125	5.51	250	14.9	39.1	40.82	2.98

Table C-17: Emissionse of MB20 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0	1.9	277	3.24	197	17.8	61.5	70.39	5.28
1	1.9	232	3.68	235	17.3	64.5	61.85	4.61
2	2.6	193	4.14	237	16.7	67.0	54.48	4.05
3	3.9	154	4.54	243	16.2	54.9	50.22	3.72
4	4.8	140	5.21	257	15.3	37.0	44.21	3.30
5	7.9	148	5.68	281	14.7	37.8	40.57	3.06
6	7.9	193	6.16	285	14.1	62.6	37.97	2.85
7	12.3	325	6.46	237	13.7	46.0	35.36	2.68
8	18.7	417	6.97	238	13.0	38.4	34.84	2.52
9	27.8	473	7.42	205	12.4	64.4	31.64	2.34

Table C-18: Emissions of MB20 Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0.0	0.0	240	3.25	140	17.8	78.4	68.22	5.19
0.5	1.3	193	3.49	158	17.5	63.0	64.30	4.89
1.0	2.3	160	3.73	173	17.1	51.8	60.16	4.58
1.5	2.3	126	3.97	187	16.8	41.8	56.46	4.27
2.0	2.9	108	4.24	201	16.5	39.3	54.96	4.14
2.5	3.2	92	4.41	217	16.3	37.1	50.54	3.89
3.0	3.9	98	4.72	229	15.9	38.1	48.54	3.71
3.5	3.9	111	4.94	236	15.6	40.3	44.94	3.45
4.0	7.1	138	5.28	240	15.1	43.9	43.41	3.24

Table C-19: Emissions of Biodiesel Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 1,500 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0	2.0	295	3.08	165	16.9	53.0	68.90	5.62
1	1.6	256	3.44	166	16.6	52.7	61.80	4.90
2	3.9	217	3.90	190	16.1	43.3	55.55	4.44
3	2.9	167	4.39	217	15.4	42.8	49.80	3.97
4	5.8	148	4.76	229	14.9	38.8	43.99	3.50
5	5.5	168	5.51	246	13.9	41.6	39.81	3.16
6	12.4	221	5.81	243	13.5	41.8	38.52	3.07
7	13.8	273	5.93	216	13.4	36.2	36.27	2.95
8	12.3	370	6.27	194	12.9	43.1	35.55	2.82
9	38.8	713	7.03	169	11.8	79.7	31.64	2.55

Table C-20: Emissions of Biodiesel Fuel Run Through the Kubota RT 100 Engine at the Engine Speed of 2,400 rpm with Partial Load Operation

Engine Load (Kw)	Black Smoke (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	O_2 (%)	THC (ppm)	AFR	Lambda (λ)
0.0	1.3	215	3.19	132	16.6	67.6	65.15	5.37
0.5	1.3	195	3.45	146	16.5	63.2	62.33	4.96
1.0	1.6	172	3.69	159	16.2	61.9	58.36	4.68
1.5	1.9	142	3.91	170	15.9	52.1	55.33	4.38
2.0	1.9	118	4.13	181	15.6	38.4	51.66	4.14
2.5	4.2	114	4.40	195	15.3	37.6	49.54	3.17
3.0	7.4	124	4.64	202	14.9	40.1	46.80	3.80
3.5	14.4	139	4.96	211	14.5	44.0	43.91	3.45
4.0	16.9	173	5.20	222	14.2	47.8	43.33	3.44

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