CHARACTERISTICS, PERFORMANCE, AND GREENHOUSE GAS EVALUATION OF
JATROPHA BIODIESOHOL FOR AGRICULTURAL MACHINERY

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ไมโครอิมัลชั่นเป็นเทคนิคที่ใช้สำหรับการผลิตเชื้อเพลิงชีวภาพที่เรียกว่าไบโอดีโซฮอล ซึ่งเป็นวิธีการที่ง่าย และต้นทุนต่ำ สำหรับการศึกษานี้ใช้น้ำมันดีเซลที่มีเอทานอลลดแรงตึงผิวและน้ำมันสบู่ดำ เป็นส่วนผสมโดยศึกษา พฤติกรรมวัฏภาคซึ่งเน้นที่การมีความเป็นเนื้อเดียวกันของน้ำมันเชื้อเพลิง สารลดแรงตึงผิวประเภทต่างๆ อัตราส่วน เอทานอลและสารลดแรงตึงผิว (E/S ratio) และปริมาณเอทานอลและสารลดแรงตึงผิว (E/S content) ได้ ทำการศึกษา และผลที่ได้แสดงให้เห็นว่าสารลดแรงตึงผิวชนิด LS1, E/S ratio เท่ากับ 3 และ E/S content ที่ร้อย ละ 5 โดยปริมาตร มีแนวโน้มที่เหมาะสมที่สุดสำหรับการเตรียมไบโอดีโซฮอลจากสบู่ดำ การประยุกต์ใช้โมเดลทาง คณิตศาสตร์ที่เรียกว่า mixture design ถูกนำมาใช้พยากรณ์หรือคาดการณ์ความหนืดอยู่ในช่วงที่ต้องการ พบว่า สมการชนิด {3,3} lattice augmented with interior points and centroid ให้ผลการทำนายที่ดีที่สุด จาก การศึกษาคุณสมบัติของไบโอดีโซฮอลจากสบู่ดำ แสดงให้เห็นว่าไบโอดีโซฮอลมีคุณสมบัติเทียบเคียงมาตรฐานไบโอ ดีเซล ยกเว้นค่าความเป็นกรด จุดวาบไฟ และความหนาแน่น การเติมสารเอทิลเฮกซิลไนเตรตเป็นสารเติมแต่งเพื่อ เพิ่มประสิทธิภาพการทำงานของเครื่องยนต์ จากผลการทดสอบสมรรถนะของเครื่องยนต์โดยใช้ไบโอดีโซฮอลจากสบู่ ดำที่มีน้ำมันสบู่ดำร้อยละ 20 (JBH20) และมีน้ำมันสบู่ดำร้อยละ 25 (JBH25) ไบโอดีเซลจากสบู่ดำ และน้ำมันดีเซล เป็นเชื้อเพลิง พบว่าการเกิดไมโครอิมัลชันของน้ำมันไบโอดีโซฮอลสามารถปรับปรุงแรงบิดและ อัตราการสิ้นเปลือง จำเพาะเบรก เมื่อเทียบกับน้ำมันดีเซล นอกจากนี้ยังปล่อยก๊าซไอเสียลดลงอีกด้วย สำหรับบัญชีรายการประเมิน วงจรชีวิตแบบตลอดวัฏจักรศึกษาที่สหกรณ์การเกษตรเวียงสา จังหวัดน่าน ซึ่งมีระบบสำหรับการผลิตไบโอดีเซลจาก สบู่ดำ พบว่าไบโอดีเซลจากสบู่ดำปล่อยก๊าซเรือนกระจก 329.42 กิโลกรัมคาร์บอนไดออกไซด์เทียบเท่าต่อกิกะจูล ซึ่งมากกว่าที่ JBH25 ปลดปล่อยประมาณ 2 เท่า โดยการจัดการของเสียเป็นปัจจัยสำคัญในการปล่อยก๊าซเรือน กระจกของไบโอดีเซล ในขณะที่การปล่อยก๊าซเรือนกระจกของ JBH25 โดยส่วนใหญ่มาจากกระบวนการเผาไหม้ ผล การศึกษาอัตราส่วนพลังงานสุทธิ (NER) พบว่ามีเพียงไบโอดีเซลจากสบู่ดำล้วน มีประสิทธิภาพการใช้พลังงานที่ เหมาะสมมากที่สุดเมื่อเทียบกับน้ำมันดีเซลที่ผสมกับน้ำมันไบโอดีเซลร้อยละ 25 โดยปริมาตร (JME25) และ JBH25 โดยพลังงานที่ได้จากผลิตภัณฑ์ร่วมและของเสียก่อให้เกิดการเพิ่มอัตราส่วนพลังงานสุทธิอย่างมีนัยสำคัญ

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MONGKOLCHAI ASSAWADITHALERD: CHARACTERISTICS, PERFORMANCE, AND GREENHOUSE GAS EVALUATION OFJATROPHA BIODIESOHOL FOR AGRICULTURAL MACHINERY. ADVISOR: ASST. PROF. CHANTRA TONGCUMPOU, Ph.D., CO-ADVISOR: NUWONG CHOLLACOOP, Ph.D., JITTI MUNGKALASIRI, Ph.D., 110 pp.

Microemulsion is a proposed technique for biofuel production with simple and low-cost preparation called biodiesohol. For this study, diesel based microemulsion with ethanol, surfactant, and Jatropha oil were studied for their phase behavior focusing on homogeneity of the fuel. Various types of surfactant, ethanol-surfactant ratio (E/S ratio) and ethanol-surfactant content (E/S content) had been investigated and the result showed that LS1, E/S ratio at 3 and E/S content at 5 tend to be the most appropriate for Jatropha biodiesohol preparation. The mixture design was effectively applied to predict or estimate kinematic viscosity in the desired range by {3,3} lattice augmented with interior points and centroid. The property results of biodiesohol showed compatible properties with biodiesel standard except for acid number, flash point, and density. The EHN (ethylhexyl nitrate) was added into biodiesohol as additive to increase the efficiency of engine performance. The engine performance testing using Jatropha biodiesohol (E/S:Jatropha oil:Diesel at 5:20:75 namely JBH20 and 5:25:70 namely JBH25), JME (Jatropha methylester), and diesel as fuel show that forming microemulsion can partially improve power, torque, and brake specific fuel consumption compared to diesel. In addition, exhaust gas emission also decreased. The cradle to gate life cycle inventory based on the Wiangsa agricultural cooperative at Nan Province, which existed the system for JME production show that JME emits 329.42 $kgCO_{2e}$/GJ. JME showed greater GHG emissions than that of JBH25 approximately 2 times. The waste handling was main emissions for JME, while the maximum emission of JBH25 was combustion process.The results of NER (Net energy ratio) showed that neat JME is the most suitable energy efficiency compared to JME25 (Jatropha biodiesel blended with diesel at 25 %v/v) and JBH25. The energy credits from co-products and wastes significantly cause on increase of NER.

Field of Study: Environmental Management	Student's Signature	---------------------------------
Academic Year: 2015	Advisor's Signature	---------------------------------
	Co-Advisor's Signature	---------------------------------
	Co-Advisor's Signature	---------------------------------

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LIST OF ABBREVIATIONS

CJO	Crude Jatropha oil
E	Ethanol
S	Surfactant
D	Diesel
GHG	Greenhouse gas
LCA	Life cycle assessment
NER	Net energy ratio
EO	Ethylene oxide
JME	Jatropha methylester
JBH	Jatropha biodiesohol
JBH20	Jatropha biodiesohol (E/S:CJO:D = 5:20:75)
JBH20E	Jatropha biodiesohol (E/S:CJO:D = 5:20:75 added ethylhexyl nitrate 5% v/v)
JBH25	Jatropha biodiesohol (E/S:CJO:D = 5:25:70)
JBH25E	Jatropha biodiesohol (E/S:CJO:D = 5:25:70 added ethylhexyl nitrate 5% v/v)
JME25	Jatropha methylester blended with diesel at ratio of 25:75
KV	Kinematic Viscosity
CO	Carbon monoxide
CO_2	Carbon dioxide
NO_x	Oxide of nitrogen
BP	Brake power
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
PM	Particulate matter
HP	Horse power

CHAPTER 1

INTRODUCTION

1.1 Motivations

With the crisis of fossil fuel depletion, alternative fuels have been developed to replace the use of fossil fuel. Biofuel is one of those which has been researched in several aspects in order to compete with fossil fuel. These include the feasibility of biofuels production, their performance, economic aspects as well as environment impacts from their usage. In addition, The World Energy Council provided recommendations to achieve the development of energy supply from renewable and other low-carbon sources [1]. Several alternative fuels have been recently investigated. Among the vegetable oils, *Jatropha curcas* displays potential as a biofuel crop because it is a non-edible plant, avoiding controversial tradeoffs between food and fuel [2]. In general, vegetable oils possess a high viscosity because of the large molecular mass and chemical structure. Consequently, vegetable oil must be modified to be suitable for use in diesel engines [3, 4]. To improve this undesired property, several processes such as transesterification, pyrolysis, and microemulsions have been introduced to transformed vegetable oil to be other forms of renewable energy [5, 6]. The viscous oil leads to low atomization and inefficient combustion. Moreover, because the use of food crops as alternative fuels has been debated for food security reasons, non-edible plants such as Jatropha are more attractive and have the potential to serve as the feedstock for biofuel production [7].

The technology used to convert triglycerides to methylesters or biodiesel by transesterification is widely used to reduce viscosity. However, this process requires chemicals, energy, and water to purify the biodiesel, generating waste and wastewater

[8] that includes byproducts such as glycerol. Furthermore, transesterification requires a complicated system that demands a large initial investment in addition to the high operational and maintenance costs.

Microemulsification is an effective approach for producing biofuel that involves mixing two immiscible liquids (vegetable oil or diesel or biodiesel) and using alcohol to stabilize the mixture [9]. Compared to transesterification, the microemulsion technique is a simple and cheap process [10-12]. Microemulsions are thermodynamically stable, isotropic solutions of water and oil stabilized by the appropriate surfactant [13]. Microemulsions exhibit many unique properties, such as transparency and ultra-low interfacial tension as well as high solubilization. For microemulsion-based fuel production, 3 main components (oil-like, water-like, and a surfactant) are mixed to form a clear, transparent, and homogeneous solution. Thus, phase stability can be improved with this technique, and the high viscosity of vegetable oil can be reduced. In addition, it has been claimed that the phenomenon of micro-explosions in microemulsions leads to a significant increase in the burning rate and burning efficiency, thereby enhancing engine torque and performance [14]. Another advantage of microemulsion-based biofuels is that there is no need for engine modifications [15-17]. Furthermore, Zhao et al. [18] reported that microemulsion fuel could reduce air pollution and improve combustion efficiency.

The direct usage of vegetable oils for diesel engine fuel is possible by blending vegetable oils with conventional diesel fuels in a suitable ratio. Bioethanol is considered a biodegradable biofuel which acts as an oxygenate, accelerating the complete fuel combustion [19, 20]. However, an obstacle for ethanol-diesel blends is the immiscibility from the low solubility of ethanol in diesel [21, 22]. Therefore, a

surfactant is introduced to enhance the miscibility of a blend of vegetable oil, ethanol, and diesel by forming a microemulsion. In addition to the miscibility, the ethanol and surfactants are expected to reduce the kinematic viscosity of the blend.

To avoid corrosion and sulfur dioxide emission, the nonionic alcohol ethoxylate is an appropriate surfactant that does not contain sodium or sulfur; thus, ethoxylate was used in the biofuel produced in this study. The low HLB (Hydrophile-Lipophile Balance) surfactants with their low ethylene oxide group numbers suitably facilitates water in oil (w/o) microemulsions. Due to concerns regarding alcohol as a cetane reducer, ethylhexyl nitrate (EHN) is currently used as a major additive to diesel to improve ignition and boost the cetane number. The addition of 0.4% additive to diesel oil has been shown to increase the cetane number from 45 to 51 units [23]. Moreover, EHN has long been considered to present no particular risk to human health [24]. Ethers are also widely used and have been reported as effective cetane enhancers. The limitations of ethers as fuel additives are that they are not renewable and exhibit a high cancer risk [25].

The innovative micro-emulsification biofuel are defined as simple technique, low waste, and low energy production. Previous study showed that 24.3% CO_2e contributed from transesterification process [26]. In term of GHG accounting, carbon dioxide (CO_2) from combustion of biomass products such as vegetable oil and bioethanol is defined as biogenic carbon which was not taken into an account for CO_2 emission. The net energy ratio is a primary factor indicating efficiency of the biofuel production through evaluation energy input and energy output. Hassain and Davis [27] concluded from their study that the life-cycle net energy ratio (NER) of raw vegetable oil is approximately 6 times and 2–6 times higher than fossil diesel and biodiesel,

respectively. The Jatropha biodiesohol (JBH) in this study is comprised of bioethanol, plam oil-based alcohol ethoxylate surfactant, crude Jatropha oil, and commercial diesel that mechanical mixing to formulate a homogenous and clear microemulsion. The JBH contains fossil fuel and biofuel can promote with proper balance on environment and social.

Thailand is well known as an agricultural country that exports many kinds of agricultural products as the world kitchen. The export values of agricultural products was very costly. Due to this reason, the use of low carbon biofuels in agricultural sector can be promoted to the farmers for plant cultivation which are not only concern about global warming but also enhance export trading as low carbon agricultural products. In addition, using vegetable oil and bioethanol motivate not only farmer income and also imported diesel reduction.

1.2 Objectives:

1. To investigate phase behavior and microemulsion formation of Jatropha biodiesohol by pseudo-ternary phase diagram with various nonionic surfactant at different E/S ratio (ethanol/surfactant ratio)

2. To examine the significant characteristics of Jatropha biodiesohol compared to fuel standards for diesel engine.

3. To determine the performance of Jatropha biodiesohol by diesel engine test.

4. To determine the greenhouse gas emission and energy consumption of biodiesohol and compare to tranestered Jatropha biodiesel by life cycle assessment.

1.3 Hypotheses:

1. Microemulsification technique can be applied to produce Jatropha biodiesohol.

2. Jatropha biodiesohol is compatible to fuel standards for diesel engine and can be applied for being biofuel of agricultural machinery.

3. Jatropha biodiesohol production can reduce greenhouse gases emission compared to diesel and Jatropha biodiesel production.

1.4 Scopes of the Study:

This research can be divided into 4 parts, which are phase behavior study, fuel properties, performance and emission of engine, and life cycle analysis on GHG emission and energy efficiency. The scope of research summarizes the detail shown in Fig 1.1.

1. **Material Source:** Crude Jatropha oil was taken from Kasetsart University, Khampaengsan, Nakhonpathom Province. Nonionic fatty alcohol ethoxylate surfactant was produced by Thaiethoxylate Co. Ltd.,. Commercial Diesel was purchased from PTT station.

2. **Characteristic and performance:** Fuel properties and characteristics were conducted at King's Mongkut University of Technology North Bangkok (KMUT'NB). Jatropha biodiesohol was tested by two cylinder compress ignition engine.

3. **Emission:** Air pollutants such as CO_2, CO, and NO_x was analyzed in stage of combustion. Black smoke will be measured as unregulated air emission.

4. **Life cycle GHG emission**

    - Life cycle of each stage was determined in Jatropha biodiesel's model in small community in Nan province to scaled-up model of Jatropha biodiesohol production instead of biodiesel production.

    - Functional unit: GJ to determine the GHG performance of each systems.

- Scope and boundary: 5 main stages which are cultivation, transportation, production, use, and waste handling.

- Analysis focused on the three most important GHGs of bioenergy, i.e., carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which the global warming potential factors were accounted by IPCC 2013-100y method.

Phase behavior	• Pseudo-ternary phase diagram • Vary E/S ratio at 1,3, and 9 • Vary EO group of surfactant (LS1, LS3, and LS7)
Jatropha biodiesohol properties	• Kinematic viscosity @ 40 °C of E/S content 5%, 10%, and 20% with 20% and 25% of CJO • Addition 0.5% EHN as cetane enhancer • Other properties; density, flash point, acid value, and cloud point
Jatropha biodiesohol performances and emissions	• Two cylinder - CI engine • Torque , power, and specific fuel consumption • CO, CO_2, NOx, and black smokes
Environmental aspect	• Net energy ratio (NER) • GHGs emission

Figure 1.1 *Diagram of summarized overall experiment and assessment in this research.*

CHAPTER 2

BACKGROUND AND LITERATURE REVIEWS

2.1 Background for renewable energy situation in Thailand

Although, alternative fuels, such as biofuels, are projected to see significant growth (but from low levels), fossil fuels still remain the dominant source of energy in 2030 [28]. Thus, the reduction and substitution of fossil fuel consumption are required to be more sustainable. Thailand realized the importance of alternative fuels and gained more knowledge and information by the Ministry of Energy who improved strategies on development and promotion of the use biodiesel when a crisis of crude oil price reappeared in mid-2004. Levels of development and deployment of efficient and low-carbon and carbon free energy technologies are slower than expected to fulfil sustained energy demand growth, which remains positive under significant energy subsidies to support social and economic development [29].

For Thailand situation, Energy Policy and Planning Office reported that diesel consumption in 2014 was at an average of 57.8 million liters (ML)/day, an increase of 3.9%. To achieve 25% share of the renewable energy in the total energy consumption by 2021, by targeting the consumption of bioethanol (at 9 ML per day). The demand of ethanol in 2013 increased by 20%, and reach to 2.15 ML/day. Moreover, bioethanol was exported 139.28 ML in 2011 and 63.7 ML in 2013 (to Philippine, Japan, and United Kingdom). The reduction of export has been found due to the increase of internal use for producing gasohol. However, Thailand produced ethanol (by molasses, sugarcane juice, and cassava) in the beginning of 2016 at 3.2 ML, which was taken into the account for 76.2% of total capacity. This can be showed that diesel demand is still increasing,

and bioethanol is potentially produced that should be promoted as an alternative fuel in Thailand.

2.2 Theoretical background

2.2.1 Microemulsion

Early the 1959s, Schulman and Hoar introduced the term "microemulsion" for transparent solution in a model four component system. The transparent solutions consisted of water, hydrocarbon, surfactant and cosurfactant. In the later studies, Schulman and coworker has since been defined and indeed redefined on many occasions. However, the microemulsion definition provides as a system of water with or without electrolyte, oil and nonionic surfactant which are single isotropic and thermodynamically stable liquid solution. Microemulsions are thus defined as "a system of water, oil and ampliphile which is a single optically isotropic and thermodynamically stable liquid solution. The tendency toward a water-in-oil (w/o) or an oil-in-water (o/w) microemulsion is dependent on the properties of the oil and the surfactant, the water-to-oil ration and the temperature. For example, non-ionic surfactants are conveniently classified on an empirical scale known as hydrophilic-lipophilic balance (HLB) which runs from 1 to 20. Surfactant facilitates w/o microemulsion is nonionic surfactant to form reverse micelle as shown in Fig 2.1a.

Microemulsions are an approach for blending because they exhibit isotropic transparency and low viscosities with ultralow interfacial tensions and high solubilization properties [30-32]. This microemulsion-based biofuel (MBF) of either 'alcohol-diesel-surfactant system' or 'alcohol-vegetable oil–diesel-surfactant systems' have been previously studied [3, 10, 33-35]. The blending of vegetable oil, diesel, surfactant, and alcohol has been called as biodiesohol [33]. This Jatropha biodiesohol

(JBH) contains 3 primary compositions: the non-aqueous liquid (hydrophobic; crude Jatropha oil (CJO), diesel (D), and aqueous liquid (hydrophilic; bioethanol), and surfactant. In this study, the surfactant was nonionic surfactant which was alcohol ethoylate surfactant containing C12-14 tail and 1, 3, and 7 EO head as presented in Fig 2.1b. The advantages of biodiesohol are simply mixing technique without a high energy input and expensive equipment [36] and the compatibility of the diesel engine without requiring a major modification [37]. In addition, bioethanol is a cheaper and more environmentally friendly fuel than long-chain alcohols.
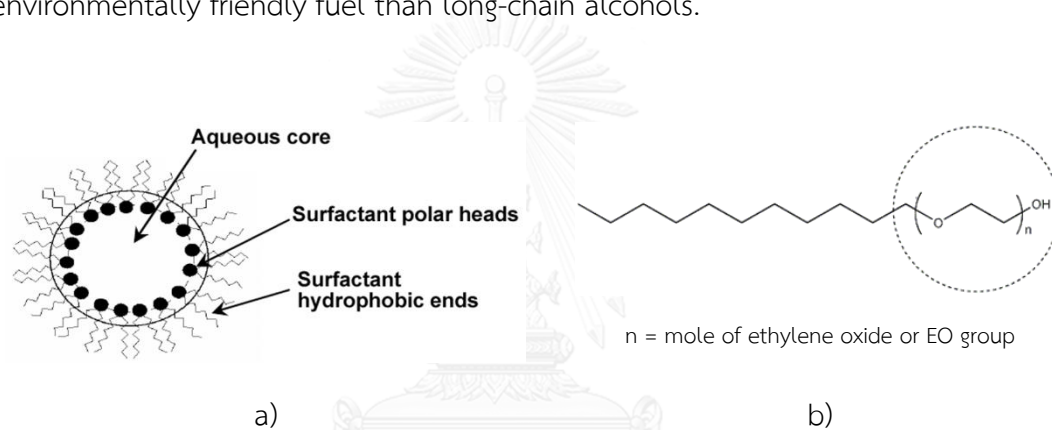
Figure 2.1 a) A schematic view of a reverse micelle structure [38] and b) the structure of studied surfactant.

- Jatropha oil

The advantages of non-edible vegetable oil as a diesel fuel are liquid nature portability, ready availability, renewability, higher heat content, lower sulphur content, lower aromatic content, and biodegradability. On the other hand, the disadvantage of non-edible vegetable oil as a diesel fuel are higher viscosity, lower volatility, the reactivity of unsaturated hydrocarbon chains, and higher percentage of carbon residue [39]. The properties of Jatropha oil presented by No [40] shown in Table 2.1.

The Jatropha (*J. curcas Linnaeus*) plant originated from Mexico and was spread to Asia and Africa by Portuguese traders as a hedge plant. *J. curcas* L. belongs to the family Euphorbiaceae, which is renowned of having species that contravene the Geneva conventions on chemical warfare. The genus name Jatropha derives from the Greek *jatros* (doctor), *trophe* (food), which implies medicinal uses, hence the plant is traditionally used for medicinal purposes. It is a hardy shrub that can grow on poor soils and areas of low rainfall (from 250 mm a year) hence its being promoted as the ideal plant for small farmers [41, 42].

The fact that the oil of *J. curcas* cannot be used for nutritional purposes without detoxification makes its use as an energy source for fuel production very attractive, therefore Jatropha is one plant that is wildly promoted and conducted the researches on neat and blends of Jatropha as biofuel. Other aspects such as agronomic trait, productivity, economic were studied, inclluding proterties as biofuel as shown in Table 1. However, the seed yield and seed oil yield varies widely which is logic for a crop that grows under many different conditions. Genetic and environmental factors have a significant on oil yield production factors. *J. curcas* is still a wild species and genetic identification of provenances and testing them in different locations and conditions still need to be done [43]

Table 2.1 Fuel properties of Jatropha [40]

Property	Jatropha oil
Density (kg/m^3, 40 °C)	901–940
Viscosity (mm2/s, 40 °C)	24.5–52.76
Flash point (°C)	180–280
Pour point (°C)	-3 to 5
Cloud point (°C)	8–10
Cetane number	33.7–51
Calorific value (MJ/kg)	38.20–42.15

There is also still a dearth of research about the influence of various cultivation-related factors and their interactions and influence on seed yield. Projections of seed yield and oil yield on plantations in many websites lack a sound scientific basis with wide variations and do not give description of conditions under which data were collected [44]. In fact, labor for Jatropha cultivation is required to prepare the land, set-up nurseries, planting, irrigate, fertilize, prune, harvest and process the seeds ready for the market, particularly in the early years. It is expected that labor for maintenance and harvest should increase to substantial levels in subsequent years. Otherwise minimum labor is only required only if *J. curcas* is grown for combating desertification and preventing soil erosion.

- **Diesel**

ASTM has classifies diesel fuel to 3 grades which normally are Diesel no.1, Diesel no. 2 and diesel no.4. Diesel no.2 has moderate volatilization which is lower than no.1 and higher than no.4. The unique properties of Diesel no.2 are high boiling point cloud point and flash point which is suitable for vehicular and machinery fuel in tropical weather since diesel is wax and paraffin base which is sensitive to temperature.

Table 2.2 Some of fuel properties of Thailand standards compared to ASTM specification.

Properties	Diesel No.2		Biodiesel		
	ASTM	Thailand[a]	ASTM	Thailand[b]	Thailand[c]
Specific gravity @ 15.6/15.6 °C	-	0.81-0.87	-	-	-
Viscosity @ 40 °C (cSt)	1.9-4.1	1.8 – 4.1	1.9-6.0	3.5 – 5.0	1.9-8.0
Pour point (°C)	-	≤ 10	-	-	-

Properties	Diesel No.2		Biodiesel		
	ASTM	Thailand[a]	ASTM	Thailand[b]	Thailand[c]
Oxidative stability (g/m3)	-	≤ 25	≥ 3 (hr @ 110 ℃)	≥ 10 (hr @ 110 ℃)	-
Cetane index	≥ 41	≥ 50	≥ 47 (cetane No.)	≥ 51 (cetane No.)	≥ 47 (cetane No.)
Flash point (℃)	> 52	> 52	> 103	> 120	> 120
Water and sediment (%vol)	< 0.05	< 0.05	< 0.05	< 0.05	≤ 0.2
Density @ 15℃ (kg/m3)	-	-	860 - 900	860 - 900	-
Methyl ester (%wt)	-	4.5 -5	-	≥ 96.5	-
Acid number (mg KOH/g)	-	-	≤ 0.50	≤ 0.5	≤ 0.8

[a]: Properties and qualities of high speed diesel (B.E. 2556)

[b]: Properties and qualities of biodiesel [45]

[c]: Properties and qualities of biodiesel for agicultural machinery [46]

In Jan-April 2013, Thailand imports crude oil approximately 900 KBD (kilo barrels/day). About 38% of crude oil is conventional diesel which can estimate to 54.4 million litres/day. As mentioned earlier, however, not only 5% biodiesel but also other additives are added to improve quality of each brand of fuel production in the market. Quality of diesel depends on standard, thus diesel's fuel properties are various in different country. As comparison data in Table 2.2, the quality shows that it is not much different in properties of each type of fuel.

- **Ethanol or bioethanol**

Ethanol is another alternative fuel and is considered a liquid biodegradable biofuel that reduces GHG emissions [47]. Bioethanol is one considered to use a

component blending with some alternative fuel. [48, 49]. Bioethanol is of particular interest because it can be produced by biomass fermentation [50]; thus, this biofuel could play an important role in reducing the use of fossil fuels. However, ethanol is hydrophilic, which limits its solubilization with diesel and causes it to be unstable or stable only for short-term use due to its chemical incompatibility and temperature instability. Therefore, a surfactant is required to improve this problem by facilitating microemulsion.

Currently, ethanol is promoted to be an alternative fuel. Ethanol has potential as a valuable replacement of gasoline in the transport fuel market. The government has encouraged production and use of bio-ethanol in order to reduce dependency on oil import, mitigate global warming impact and activate the grass root economy by stabilizing the income of farmers and generating employment in the local community. The Thai renewable energy policy promotes the use of gasohol, a 10% blend of bio-ethanol with 90% gasoline, for substitution of conventional gasoline with a target to increase the use of ethanol up to 3 million litres per day by 2011. Thailand has potential to produce bioethanol which is made from agricultural products including wastes. Currently, cane molasses and cassava are the two major raw materials for bio-ethanol production in Thailand.

- **Surfactant and additives**

Conventional surfactant molecules comprise a polar head group region and a non-polar tail region. When surfactants are incorporated into immiscible mixtures of oil and water, the surfactant molecule can locate at the oil/water interface which is thermodynamically very favorable. Nonionic Surfactants do not ionize in aqueous solution, because their hydrophilic group is of a non-dissociable type, such as alcohol,

phenol, ether, ester, or amide. As the lipophilic group has often the alkyl or alkylbenzene type, the former coming from fatty acids of natural origin such as vegetable oil (e.g. coconut oil and plam kernel oil). This polyether chain is used as the lipophilic group in the so-called polyEO. Surfactants will be used in this study produced from plam oil named dehydol LS1, dehydol LS3 and dehydol LS7. The utilization of cetane-improving additives is necessary to avoid difficulties in cold starting and other performance problems associated with low cetane numbers. Ignition promoters have traditionally been given to alkyl nitrates (e.g., amyl nitrate, hexyl nitrate, and octyl nitrate), but azo compounds and alkyl peroxides have also been proposed. The commercial market considers several factors when selecting and using cetane improvers; these include (a) efficacy toward improving ignition properties, (b) hazards associated with storage and transport, (c) additional costs associated with diluting cetane improvers to allow safe transport, and (d) nitrogen content.

The 2-ethyhexyl nitrate (2-EHN) is currently added to diesel oil to improve ignition and boost cetane number. The 2-Ethyhexyl nitrate (2-EHN), or the nitric acid ester of 2-ethyl-1-hexanol is currently added in significant amounts to diesel oil to improve ignition and boost cetane number. 2-EHN is a large-scale commodity, the worldwide production of which is estimated to be about 100,000 tons per year. It has long been considered as presenting no particular risk to human health [24]

2.2.2 Micro-explosion phenomenon

Micro-explosion is an important phenomenon in the secondary atomization process of water-in-oil emulsion fuels (Fig.2.2). Generally this phenomenon is affected by volatility of base fuel, type of emulsion, water content, diameter of the dispersed liquid (water), location of the dispersed liquid and ambient conditions like pressure

and temperature [51]. Fu et al. have stated that both water-in-oil and oil-in-water emulsions can microexplode at certain conditions. Furthermore, they have related the diameter of the dispersed liquid with the strength of the micro-explosion [52]. The droplet diameter of an emulsion in the combustion chamber is in the range of 20-30 micron and micro-explosion phenomenon wouldn't occur with this range of droplet sizes [53].
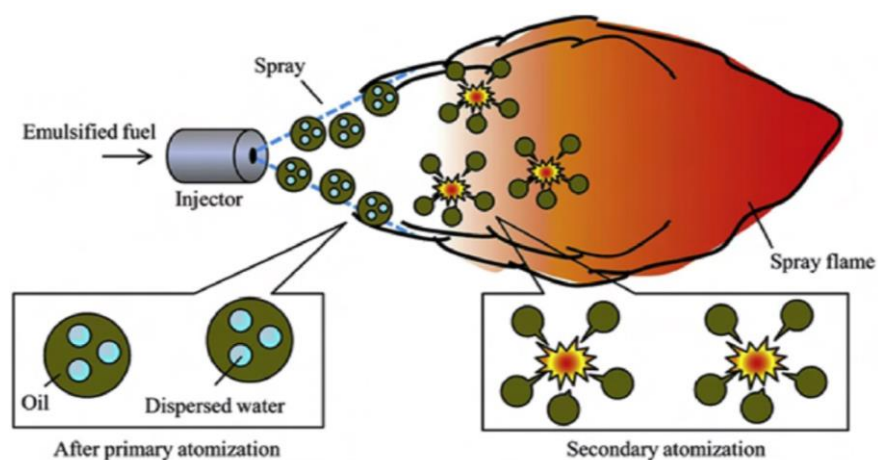
Figure 2.2 *Primary and secondary atomization in spray flame of emulsified fuel [51]*

2.2.3 Biodiesel from tranesterification

Biodiesel has been promoted as an alternative biofuel by transesterification process. The chemicals, electricity, and water are consumed to produce this biofuel, which also generates wastes and by-products that affected to natural resources and environmental quality. To increase the alternative fuel, biodiesel plantations in small scale were set up in rural areas to produce biodiesel served to community that followed by the national policy to reduce fossil fuel consumption in Thailand called "Alternative Energy Development Plan (AEDP) 2012-2021". Thailand has two standards of biodiesel that are biodiesel for commercial and biodiesel for community, which has been announced the up to date on 2014 and 2006, respectively. The interesting

pattern of agricultural distribution via agricultural cooperative is attractive not only for their products but also fuel supply chain.

Transesterification of a vegetable oil was conducted as early as 1853 by scientists E. Duffy and J. Patrick, many years before the first diesel engine became functional. Transesterification is a chemical reaction between triglyceride and alcohol in the presence of catalyst to form esters and glycerol shown in Fig 2.3.
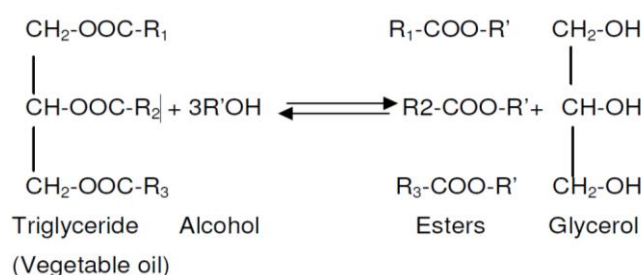
Figure 2.3 *Substrates and products of transesterification for biodiesel production*

Alkali-catalysed transesterification is much faster than acid-catalysed transesterification and is less corrosive to industrial equipment and therefore is the most often used commercially. Sodium hydroxide or potassium hydroxide is used as basic catalyst with methanol or ethanol as well as the vegetable oil. Sodium hydroxide is cheaper and is the widely used in large scale-processing. The alkaline catalyst concentration in the range of 0.5 - 1% by weight yield 94 - 99% conversion of most vegetable oils into esters [43].

2.3 Design of experiment

The design of experiment (DOE), which is an effective and powerful alternative approach for problem solving, statistical modelling and optimization, provided an estimate of the optimum composition of the microemulsion [54]. Several studies have applied a DOE to optimize the interfacial tension, dynamic viscosity, and drug delivery of a microemulsion [54-56]. The statistical experimental design saves both time and

cost and reduces the hazardous chemical wastes generated during the experiment [57]. The mixture design has been applied to investigate optimal microemulsion formulations, typically in pharmaceutical products [58-60]. This present work aims to use a pseudo ternary phase diagram and mixture design model to determine the optimal composition of JBH based on the optimum kinematic viscosity. In addition, the effect of the EO group and E/S ratio on the kinematic viscosity was evaluated during the experiment.

2.4 Fuel properties

Parameter and importance is decribed in Table 2.3 both in definition and importance. These properties related to engine performance which is very mandatory to verify that can be used effectively in CI engine.

Table 2.3 *Definition and importance of significant properties.*

Properties	Definition and importance
Density, kg/m^3	A fuel property which has direct effects on the engine performance characteristics. Because diesel fuel injection systems meter the fuel by volume, the change of the fuel density will influence the engine output power due to a different mass of injected fuel.
Viscosity at 40 $^{\circ}$C, cSt	Viscosity is a measure of a liquid's resistance to flow. High viscosity means the fuel is thick and does not flow easily. The viscosity has effects on the atomization quality, the size of fuel drop, the jet penetration and it influences the quality of combustion.

Properties	Definition and importance
Cloud Point, $^{\circ}C$	The temperature at which dissolved solids are no longer completely soluble, precipitating as a second phase giving the fluid a cloudy appearance. This term is relevant to several applications with different consequences.
Surface Tension, mN/m	An important parameter in the formation of droplets and fuel's combustion. A high surface tension makes the formation of droplets from the liquid fuel difficult.
Oxidation Stability, g/m^3	A chemical reaction that occurs with a combination of the oil and oxygen. The rate of oxidation is accelerated by high temperatures, water, acids and catalysts such as copper. The rate of oxidation increases with time. The service life of a lubricant is also reduced with increases in temperature.
Flash Point, $^{\circ}C$	The lowest temperature corrected to a barometric pressure of 101.3 kPa at which application of an ignition source causes the vapor above the sample to ignite under specified testing conditions. It gives an approximation of the temperature at which the vapor pressure reaches the lower flammable limit.
Heating value (or energy value or calorific value MJ/kg)	The heating value of a substance is the amount of heat released during the combustion of a specified amount of it. The energy value is a characteristic for each

Properties	Definition and importance
	substance. Heating value is commonly determined by use of a bomb calorimeter.
Cetane index	Cetane number is a measure of the ignition delay of a diesel fuel. The shorter the interval between the time the fuel is injected and the time it begins to burn, the higher is its cetane number.

2.5 Engine performances

- **Torque and Power**

The main purpose of running an engine is to obtain mechanical power. Power is defined as the rate of doing work and is equal to the product of force and linear velocity or the product of torque and angular velocity. Thus, the measurement of power involves the measurement of force (or torque) as well as speed. The force or torque is measured with the help of a dynamometer and the speed by a tachometer. The power developed by an engine and measured at the output shaft is called the brake power (bp).

- Brake Specific fuel consumption

Specific fuel consumption is the ratio that compares the fuel used by the engine to the amount of power the engine produces. Specific fuel consumption allows manufacturers to see which engine use the least fuel while still producing high amount of power. It allows engines of all different sizes to be compared to see which is the most fuel efficient.

- Brake thermal efficiency

In general, energy conversion efficiency is the ratio between the useful output of a device and the input, in energy terms. For thermal efficiency, the input, to the device is heat, or the heat-content of a fuel that is consumed. The desired output is mechanical work, or heat, or possibly both.

2.6 Emissions of combustion

- **Carbon monoxide**

Formation of CO is well established. Under some conditions, there is not enough O_2 available for complete oxidation and some of the carbon in the fuel ends up as CO. The amount of CO, for a range of fuel composition and C/H ratios, is a function of the relative air-fuel ratio.

- **Carbon dioxide**

CO_2 is a naturally occurring gas which emit mainly from burning fossil fuels and biomass for energy production and transportation. While not normally considered a pollutant, CO_2 contribute to the greenhouse effect. However, real combustion processes are not perfect and result in small amounts of partially oxidized and unoxidized carbon. Incomplete oxidation occurs due to inefficiencies in the combustion.

- **Hydrocarbon**

HC emissions result from the presence of unburned fuel in the engine exhaust. HC emissions are various compounds of hydrogen, carbon, and sometimes oxygen. They are burned or partially burned fuel and/or oil. HC emissions contribute to photochemical smog, ozone, and eye irritation. However, some of the exhaust hydrocarbons are not found in the fuel, but are hydrocarbons derived from the fuel

whose structure was altered do to chemical reaction that did not go to completion. For example: acetaldehyde, formaldehyde, 1,3 butadiene, and benzene all classified as toxic emissions.

- **Oxide of nitrogen**

NO_x is a generic term for the compounds nitric oxide (NO) and nitrogen dioxide (NO_2). Both are present to some degree in the exhaust, and NO oxidizes to NO_2 in the atmosphere. NO_x contributes to acid rain and photochemical smog; it is also thought to cause respiratory health problems at atmospheric concentrations found in some parts of the world. To understand NO_x formation, we must recognize several factors that affect NO_x equilibrium. Remember that all chemical reactions proceed toward equilibrium at some reaction rate. NO is only formed at high temperatures and the reaction rate is relatively slow.

- **Soot** Soot is a carbonaceous particulate matter and is produced during combustion of the rich fuel - air mixtures. Appearance of black smoke emissions in the exhaust indicates high concentration of soot in the exhaust gases. Soot is mostly produced in the diffusion combustion systems, but overly rich premixed combustion also produces soot. As the spark ignition engines generally operate close to stoichiometric air-fuel ratio, soot emissions from these engines are not significant. There is the discussion that particulate emissions only from the diesel engines as these are of major health concern and are more difficult to control. Soot emissions have been associated with respiratory problems and are thought to be carcinogenic in nature.

- **Greenhouse gas emission** CO_2 accounts for majority of GHG emissions from stationary combustion. When weighted by their Global Warming Potentials, CO_2 represents 99% of U.S. GHG emissions from all commercial, industrial, electrical

generation and industrial stationary combustion sources. CH_4 and N_2O emissions represent less than 1% of total CO_2 equivalent emissions from the same sources. Potential exceptions include CH_4 from open burning processes and N_2O from some engines equipped with catalytic NO_x emission controls. Despite the smaller emission contributions of CH_4 and N_2O, these gases have been included as part of standard emission inventory development efforts by most U.S. and international organizations.

2.7 Life cycle greenhouse gas and energy evaluation

Development of biofuels should be assessed in aspects of sustainability to be effective renewable energy. Sustainable development is understood as satisfying the needs of the present generation without compromising the needs of future generations. Sustainability takes into account three aspects which are economic, environmental and social aspects [61].

An energy metric such as the net energy ratio (NER) gives a monetary-independent analysis for the viability of an energy generation process. It is the relationship, calculated for the lifetime of the system, between the energy output and the energy content of all the materials with which the plant is constructed (their 'embodied energy') plus the energy needed for all the operations [62]. Thus for an energy generation system to be sustainable its net energy ratio should be greater than 1, and as high as possible. However, in economic aspect will be concerned for being the parameter to decide or select the technique or technology of production. Cost per net energy is one value that refers to money was spent to generate energy in one unit. Low price of energy becomes incentive to promote the project easily with sustainability.

Life-cycle assessment (LCA) of a product comprises the evaluation of the environmental effects produced during its entire life-cycle, from the extraction of the raw materials from which it is made, through the manufacturing, packaging and marketing processes, and the use, re-use and maintenance of the product, on to its eventual recycling or disposal as waste at the end of its useful life [63]. LCA does not necessarily need to be applied to the entire life-cycle of a product. In many cases, this kind of evaluation is applied to a single process such as a car assembly or to a service such as raw material transportation. LCA is not necessarily carried out in a single sequence. It is an iterative process in which subsequent rounds can achieve increasing levels of detail (from screening LCA to full LCA) or lead to changes in the first phase prompted by the results of the last phase. LCA consists of the following steps: goal and scope definition, inventory analysis, impact assessment, and interpretation.

2.8 Literature Reviews

2.8.1 Straight Jatropha oil as fuel

The advantages of vegetable oils as diesel fuel, apart from renewability, are the minimal sulfur and aromatic contents, the higher flash point (safely storage), the higher lubricity, and the higher biodegradability and non-toxicity. On the other hand, their disadvantages include the very high viscosity, the higher pour point, the lower cetane number, the lower calorific value and the lower volatility [64]. Their major problem is associated with highly increased viscosity, 10–20 times greater than normal diesel fuel.

The performance of neat Jatropha oil in the application to the single cylinder water-cooled direct injection diesel engine developing a power output of 3.7 kW at the rated speed of 1500 rpm at various output have been investigated as the basis for

comparison with the blending, biodiesel and dual fuel operation techniques by Kumar et al. [65]. Neat Jatropha oil resulted in a slightly reduced thermal efficiency as compared to diesel. The maximum smoke level with Jatropha oil was 4:4 BSU which was higher than that of diesel and methyl ester. The increase of Ignition delay and combustion duration and lower heat release rates with Jatropha oil were found. The performance and emissions of neat Jatropha oil were evaluated in a single-cylinder direct injection diesel engine at a constant speed [66]. 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.   The results on a single-cylinder direct-injection engine operating on neat Jatropha oil as well as blends of diesel and Jatropha oil were presented by Forson et al. [67] and Agarwal and Agarwal [68]. Their tests showed that Jatropha oil could be conveniently used as a diesel substitute in a diesel engine. However, Agarwal and Dhar [69] claimed that the application of neat vegetable oil to CI engines results in increased volumetric fuel consumption and brake specific fuel consumption. Emissions of CO and HC were found to be higher, whereas NO_x and PM emissions were lower compared to mineral diesel.

2.8.2 Blends of Jatropha oil or other biofuels with diesel

Since straight vegetable oils are not suitable as fuels for diesel engines, they have to be modified to bring their combustion related properties closer to diesel. This fuel modification is mainly aimed at reducing the viscosity to eliminate flow/atomization related problems. The techniques can be used to reduce the viscosity of vegetable oils; namely dilution/blending, transesterification, and micro-emulsion.

Application of Jatropha oil blends to CI engines were studied in properties and performances. Pramanik [70] reported the performance of the single cylinder CI engine using Jatropha oil blended with diesel fuel and compared the results with the performance obtained with neat Jatropha oil and diesel fuel. Among the various blends, the blends containing up to 30% (v/v) Jatropha oil have viscosity values close to that of diesel fuel at the range of 35–40 °C. They found that engine performance was significantly improved compared to that of neat Jatropha oil. The specific fuel consumption and the exhaust gas temperature of the blends were reduced due to decrease in viscosity of the vegetable oil.

Forson et al. [67] reported the results on tests on a single-cylinder direct-injection engine operating on diesel fuel, Jatropha oil, and blends of diesel and Jatropha oil in proportions of 97.4%/2.6%; 80%/20%; and 50%/50% by volume. The trend of carbon monoxide emissions was similar for the fuels but diesel fuel showed slightly lower emissions to the atmosphere. The test showed that Jatropha oil could be conveniently used as a diesel substitute in a diesel engine. The test showed increases in brake thermal efficiency, brake power and reduction of specific fuel consumption for Jatropha oil and its blends with diesel generally, but the most significant conclusion from the study is that the 97.4% diesel/2.6% Jatropha fuel blend produced maximum values of the brake power and brake thermal efficiency as well as minimum values of the specific fuel consumption.

Additionally, biodiesel or methyl (or ethyl) ester was introduced as biofuel. The feedstock is vegetable oils that can promote to farmers as it could enhance the benefits for rural and urban economies. The high viscosity of vegetable oils leads to problems in pumping and spray characteristics when used in combustion engines. The

best way to use the vegetable oils as fuel in compression ignition engines is to convert it into biodiesel. Biodiesel can be blended in various proportions with fossil diesel to create a biodiesel blend or can be used in its pure form. It can be used in compression ignition engines with very little or no engine modifications because it has properties similar to mineral diesel [71, 72]. Banapurmath et al. [71] 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.

Ramesh and Sampathrajan [73] 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 B20, B40, B60, B80 and B100. It was revealed that increasing kinematic viscosity results from increasing the amount of biodiesel. The viscosity of B20 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. Undoubtedly, transesterification is well accepted and best suited method of utilizing vegetable oils in CI engine without significant long-term operational and durability issues. However,

this adds extra cost of processing because of the transesterification reaction involving chemical and process heat inputs.

In rural and remote areas of developing countries, where grid power is not available, vegetable oils can play a vital role in decentralized power generation for irrigation and electrification. In these remote areas, different types of vegetable oils are grown/produced locally but it may not be possible to complicated process them in rural settings. In fact, the microemulsion technique is simple and of low cost production that can solve the problem of vegetable oil viscosity for producing biofuel. Microemulsion is isotropic, clear, or translucent thermodynamically stable dispersions of oil, water, surfactant, and often a small amphiphilic molecule, called co-surfactant [74]. Previous studies have reported microemulsion show considerable promise for providing low viscosity fuel blends containing substantial quantities of vegetable oil by microemulsification with short-chain alcohols, such as methanol or ethanol or butanol approach.

Lin and Wang [75] produced two-phase emulsions (w/o) and three-phase emulsions (o/w/o) to feed a diesel engine. They investigated the engine performance and emissions of these systems with various water contents and compared them to regular diesel oil. It was observed that a greater water content generated lower calorific values. They observed that emulsions had lower exhaust gas temperature, CO_2, CO, NO_x, and O_2 emissions and smoke opacity. The three-phase emulsions produced higher exhaust gas temperatures and lower CO and NO_x emissions as compared with two-phase emulsions with the same water proportion.

Cheenkachorn et al. [76] 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 [77] 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 25 of NO_x formed. This is consistent with results obtained from Banapurmath et al. [71] who found that NO_x formation strongly depends on peak temperature.

Dantas Neto et al. [78] Diesel - based microemulsions and a surfactant/diesel blend, using ethoxylated (5 EO) nonylphenol as surfactant, were prepared and tested

in a diesel engine to evaluate its performance and emissions. The following properties were evaluated: density, viscosity, cloud point and corrosiveness. Experimental results showed that density and viscosity were greater than those obtained for neat diesel. Cloud point and corrosiveness were not affected by water and surfactant. Specific fuel consumption of the microemulsion systems was greater than that of diesel, but the small droplets of water improved diesel combustion. Compared with diesel, an increase in carbon monoxide (CO) and nitrogen oxide (NO_x) emissions and a decrease in black smoke emissions were obtained.

Qi et al. [79] studied a single cylinder direct injection diesel engine was tested using neat biodiesel and the micro-emulsions as fuels under variable operating conditions. Studied microemulsion system were divided into ME1 and ME2 which contained 80:20:4:0.5 and 80:20:4:1.0 of Biodiesel (mL): Ethanol (mL): Span 80 (g): Water (mL), respectively. At low engine loads, those of the micro-emulsions are lower. The start of combustion is later for the micro-emulsions than for biodiesel. For the micro-emulsions, there is slightly higher brake specific fuel consumption (BSFC), while lower brake specific energy consumption (BSEC). Drastic reduction in smoke is observed with the micro-emulsions at high engine loads. Nitrogen oxide (NO_x) emissions are found slightly lower under all rang of engine load for the micro-emulsions. But carbon monoxide (CO) and hydrocarbon (HC) emissions are slightly higher for the micro-emulsions than that for biodiesel at low and medium engine loads.

Obviously, Most of engine experiments were conducted using a single cylinder CI engine, which is typically used for agriculture, irrigation and decentralised electricity generation. Microemulsion was used to lower the viscosity of Jatropha oil in order to eliminate various operational difficulties. The emissions of CO and HC from various

microemulsion-based fuels were significantly found in higher concentration than that of diesel due to incompleted combustion that should be concerned about the air pollutants, however NO_x and smoke were showed to decrease which these are the dominant advantage of microemulsion.

2.8.3 Greenhouse gas implication and energy efficiency of biodiesel

Life cycle assessment (LCA) is an environmental sustainability assessment tool which has been widely used to assess environmental performance of renewable technologies and also bioenergy systems such as bioethanol and biodiesel. The crucial advantage of a life cycle approach is that all burdens from raw material extraction through production, to use and disposal, will be accounted for. Even though focusing only on GHG emissions is not the complete LCA as described in the ISO standards, it is especially useful for evaluating the GHG performance of transportation biofuels by a fair comparison with conventional petroleum fuels because it focuses on the entire life cycle of the biofuels rather than just the combustion in vehicles. Even though a variety of research on LCA and GHG analysis of bioenergy and biofuels has been conducted, diverse results have been obtained even for the same kind of bioenergy.

Biodiesel production from Jatropha is one of the options being considered for partially substituting diesel fuel for transportation in Thailand. However, several issues such as food versus energy, energy and environmental benefits need to be addressed. This study aims to investigate the energy consumption and greenhouse gas (GHG) emissions from Jatropha Methyl Ester (JME) production in Thailand using a life cycle approach. Prueksakorn and Gheewala [26] reported that the main contributions came from the fertilizer production and use; diesel consumption for irrigation; and transesterification at 31, 26, and 24% respectively. Nazir and Setyaningsih [80]

concluded that the cultivation process contributed to the highest environmental impacts compared with other stages in the life cycle. Moreover, biodiesel production from palm oil consumes much higher fossil-based energy than Jatropha oil. The highest fossil-based energy consumption was in the transesterification process, followed by the plantation and oil extraction. However, Kaewcharoensombat et al. [81] studied the impact load by NETS method (the numerical eco-load total standardization method). The results of global warming load of biodiesel production stage (as NETS/kg biodiesel) was higher than that of agriculture and transportation stage approximately 1.61E+05, and 3.70E+03 times, respectively.

Focusing on Jatropha plantation, Prueksakorn et al. [82] studied energy chain of plantation system for biodiesel production in Thailand. Perennial and annual-harvesting cultivation were compared on NEB (net energy balance; the difference of energy output and energy input) and NER (net energy ratio; the ratio of energy output and energy input). Interestingly, the advantage of the perennial plantation is that fruit yield is low in the first 2 years but stabilizes after the second year; thus, the biodiesel production is maximized. On the other hand, the biodiesel yield for annual harvesting is low but substantial energy is gained from the wood which can be used for power production. An interesting hot spot of GHGs emission that Prueksakorn and Gheewala [26] reported is tranesterification process, which generated CO_2e approximately 24% of whole life cycle. Tranesterification consumes a lot of energy for phase separation and generates unpurified by-product (glycerol) and wastewater which have to pretreatment prior to utilization. Microemulsion based fuels are prepared by mixing and blending process which needs low energy, thus NER and GHGs emission of microemulsion or blending approach is very interested.

CHAPTER 3

METHODOLOGY

3.1 Materials

1. Crude Jatropha oil

Jatropha curcas seeds, pressed seeds and oil were supplied by Kasetsart University, Kamphaengsaen Campus, Nakhon Pathom, Thailand (WGS84 : 14.03403, 99.97032). The seeds were collected from mature *J. curcas* trees and were extracted for the oil by using a screw press. The oil was left to settle for 5 days prior to the separation by centrifugation at 2,750 G for 10 minutes to remove impurities and then was stored in opaque, sealed glass bottles storage at 25℃ in order to protect oxidation from light and maintain a certain range of temperature during the experiment.

2. Bioethanol

Bioethanol 99.5% (v/v) was provided by Mithrpol Co., Ltd.

3. Ethoxylate alcohol dehydol surfactant

Fatty alcohol ethoxylated nonionic surfactants from Thai Ethoxylate Co., Ltd. (Thailand) with different ethylene oxide groups: LS1, LS3 and LS7 (1, 3 and 7 moles of the EO group, respectively). The nonionic surfactant used in this study is a biodegradable product and sulfur-free surfactant, avoiding contributing SO_2 to the ambient air after combustion. Specification of these surfactants is shown in Table 3.1.

4. Commercial diesel

The commercial diesel used in this study (containing 7% of palm metylester as mandated) was purchased from PTT Plc.
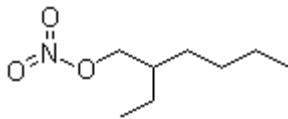
5. EHN

The cetane booster additive in this experiment was ethylhexyl nitrate (EHN), which was purchased from Sigma Aldrich, and its structure and properties are shown in Table 3.2.

Table 3.1 *Specification and certification of analysis of LS1, LS3 and LS7*

Test Item		Surfactants		
Item	Unit	LS 1	LS 3	LS 7
Color@40°C	APHA	2	2	2
Active substance	%m/m	99.95	99.95	99.91
Water Content	%m/m	0.05	0.05	0.09
pH (1% Aq) @25°C	-	6.3	6.1	6.2
Hydroxyl Value	mg KOH/g	239	175	115
Density@70°C	g/cm^3	0.837	0.891	0.949
Turbidity Titration Value	mL	8.2	15.2	-
HLB	-	3.6	7.9	12.1
Emulsifier type	-	W/O	O/W	O/W
EO mole	moles	0.90	2.89	-

Table 3.2 *Chemical properties of 2- Ethylhexyl nitrate (EHN)*

• Molecular structure of 2-Ethylhexyl nitrate ($C_8H_{17}NO_3$)	
• Vapor pressure at 20℃	27Pa
• Solubility in water at 20℃	12.6 mg L^{-1}
• Log $K_{o/w}$	5.24
• Liquid density	0.96

3.2 Methodology:

This experiment was separated into 3 parts as shown in Fig. 3.1 which are phase behavior, Jatropha biodiesohol properties, performances and emissions, and life cycle analysis for GHG accounting and energy efficiency analysis.
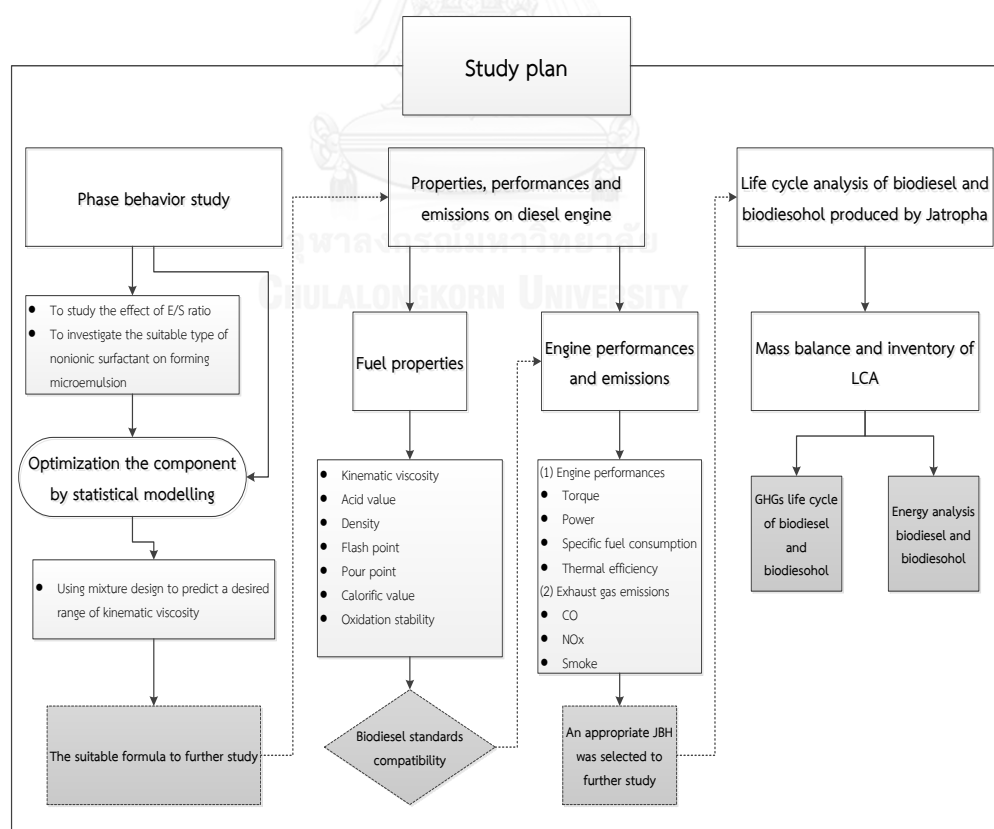
Figure 3.1 *Diagram of study plan in this research.*

3.2.1 Phase behavior study

In this experiment, four compositions included 99.5% (v/v) ethanol, fatty alcohol ethoxylated nonionic surfactant with different ethylene oxide group (EO group), jathopha oil, and diesel fuel were studied with pseudo-ternary phase diagram (Fig.3.2). Ethanol and surfactant were mixed with certain ratio called E/S ratio that was one phase of pseudo-ternary phase diagram and varied of each nonionic surfactants contained various mole of EO group. Homogeneous, clear and transparent emulsion solutions were selected and used further depending on expected suitable properties of biodiesel standard. Pseudo–ternary phase diagram providing wide area of homogeneous solution of each appropriate surfactant and E/S ratio was considered to focus on oil properties that will be studied in further step.
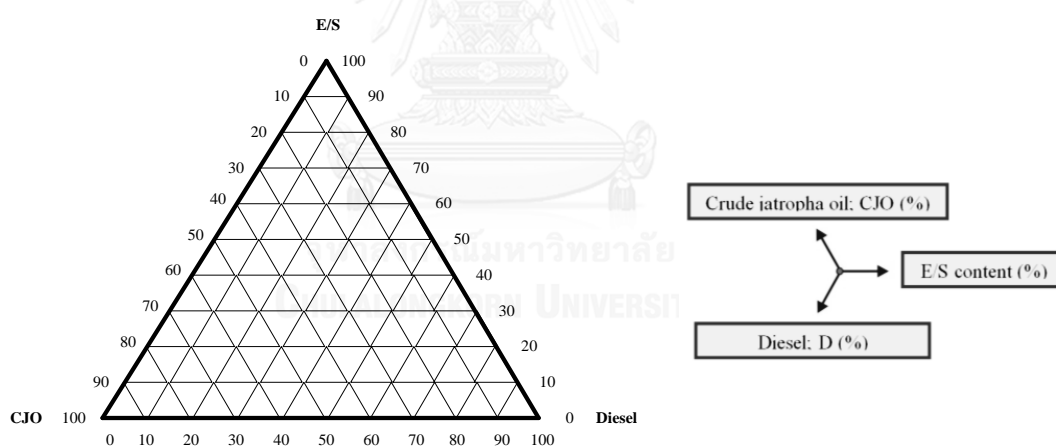
Figure 3.2 *A pseudo-ternary phase diagram for phase behavior study contained three phases of E/S ratio, crude Jatropha oil (CJO), and fossil diesel.*

3.2.1.1 Screening surfactant selection and E/S ratio optimization by phase stability

The three compositions of pseudo ternary phase diagram were ethanol and surfactant mixture (E/S mixture) with different surfactant (LS1, LS3, and LS7), CJO, and D were investigated to study the miscibility by 10% volume-scaled pseudo ternary phase diagram. The ethanol and surfactant (E/S) ratio used in phase miscibility study are 1, 3, and 9. Homogeneous, clear, and transparent microemulsions were evaluated at 25 °C by visual inspection. These three physical properties were the primary criteria for the selection of surfactant and E/S ratio for the further study on the effect of E/S ratio, CJO content, and EO group in surfactant.

3.2.1.2 Effect of EO group in fatty alcohol ethoxylate surfactant, E/S ratio, and E/S content on the kinematic viscosity

The effect of EO group of surfactant on viscosity was studied with the optimized compositions and E/S ratio. This study was focused on E/S ratio which conducted in low E/S ratio at 1, 2, and 3 of different surfactant in various EO groups of LS1, LS3, and LS7. In addition, 20% and 25% CJO were studied the effect of kinematic viscosity that was measured at 40°C by viscometer (ASTM D445) and statistically analyzed by ANOVA and Duncan's new multiple range test (DMRT) method. In all cases, $p < 0.05$ indicates significance.

3.2.1.3 Mixture design in DOE for screening and optimizing the kinematic viscosity

The mixture design were applied the mathematical models to determine the relationship of response variable (kinematic viscosity), and the three independent variables (percentage volume of CJO, mixture of E/S, and diesel. Mixture design in DOE was examined by the Statistica software program (Version 10.0). The simplex lattice

model was investigated by different number of factor levels and augmented interior and centroid points as shown in Fig. 3.3. The special cubic model was selected to analyze the contour phase diagram.

The statistical data was introduced to investigate the validation of model such as p value, R^2, and R^2 adjusted. The mean absolute percentage error (MAPE) was calculated in order to compare the error found in different model. The confirmative test was conducted by 4 formulas of Jatropha biodiesohol.

{3,2} simplex lattice   {3,3} simplex lattice   {3,3} simplex lattice augmented with
                                                          three interior points and the centroid
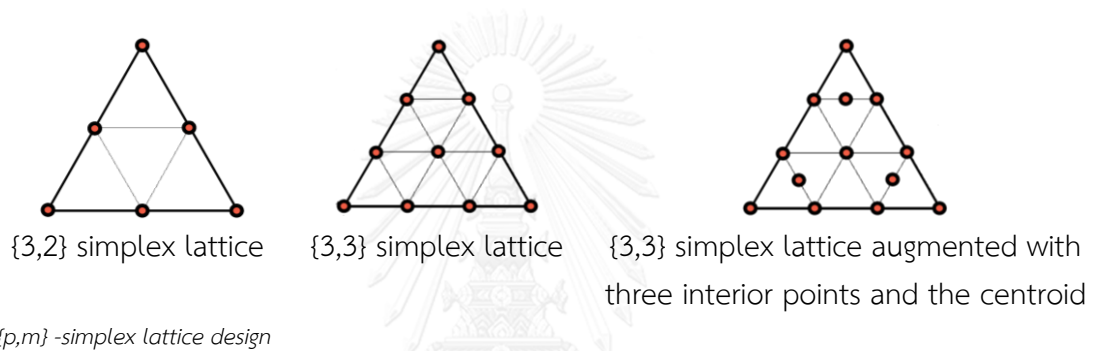
{p,m} -simplex lattice design
p = number of components, and m = number of factor levels

Figure 3.3 *The coordinate of each composition ratio for simplex lattice model of the mixture design used in this study.*

3.2.2 Fuel properties

ASTM (American Standard Testing Method) shown in Table 3.3 is used to determine the properties of Jatropha biodiesohol and Jatropha oil and performed by the specific equipment at Bioenergy laboratory, National metal and materials technology center (MTEC). EHN was added to Jatropha biodiesohol to study properties and performances compared to without EHN addition.

Table 3.3 *ASTM method and specific instrument for analysis of Jatropha biodiesohol properties.*

Properties	Instruments	Testing Methods
Acid value (mg KOH/g)	Tirando Automatic Potentiometric Titrator	ASTM D664
Cloud point (^{o}C)	ISL CPP 5Gs Cloud & Pour Point Tester	ASTM D2500
Density (kg/m^3)	Anton Paar DMA-4500 Digital Density Meter	ASTM D4052
Flash point (^{o}C)	APM-7 Pensky-Martens Closed Cup Tester	ASTM D93
Kinematic viscosity, 40°C	D445-E20L Kinematic Viscometer	ASTM D445
Oxidation stability	Rancimat	EN 14112

3.2.3 Engine performances and emissions

Jatropha biodiesohol is expected to be an alternative biofuel that use in agricultural machinery. Testing performances is required to assess the operational performances such as specific fuel consumption, torque, and brake power at various engine speed. In addition, the exhaust gas emission was measured by exhaust gas analyzer equipped with exhaust pipe in terms of concentration (ppm) of carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), and oxides of nitrogen (NO_x). Black smokes were investigated using smoke meter.

The brake power, brake-specific fuel consumption, and brake thermal efficiency were studied using Jatropha biodiesohol as fuel in a diesel engine to assess the

operational performances at various engine speeds (1,250-2,250 rpm) with a 50% engine load. The calculations for measuring performance were as follows:

$$\textbf{Brake power (bp)} = \frac{2\pi N\tau}{60} \qquad (1)$$

where τ = torque (N − m) and N = the rotational speed (rpm)

$$\textbf{Brake specific fuel consumption (BSFC)} \qquad (2)$$

$$= \frac{\text{Fuel consumption (kg/hr)}}{\text{bp (kW)}}$$

$$\textbf{Brake thermal efficiency (BTE)} = \frac{3.6}{\text{BSFC} \times \text{LHV}} \qquad (3)$$

where LHV = low heating value (MJ/kg).

This experiment studied the performance and emissions. Testing performances were studied using a 2-cylinder 4-stroke engine, horizontally positioned and water cooled. This system represented an agricultural machinery engine and was used to assess measures of operational performance of the fuels, including brake-specific fuel consumption, torque, brake power, and brake thermal efficiency, at various engine speeds (1,250-2,250 rpm) at a 50% engine load. The exhaust gas emissions of nitrogen oxides (NO_x), carbon dioxide (CO_2), carbon monoxide (CO), and black smoke were measured using an exhaust gas analyzer equipped with an exhaust pipe; NO_x was measured in ppm, whereas CO_2, CO and black smoke concentrations were measured as percentages. The diesel engine specifications of this study are shown in Table 3.4. The engine was set up as shown in Fig.3.4.

Table 3.4 *Specifications of the studied diesel engine.*

Type	Characteristics
Engine	2 cylinder, 4 stroke, indirect injection, and water cooled
Capacity	570 cc
Max. power at 2600 rpm.	14 PS / 10.3 kW
Starter system	Electric start 12 volts
Bore	72 x 70
Charge of air	Naturally aspirated
Dimensions (W x D x H)	388.5 x 504.5 x 520 mm

Engine parts

1) Cooling system
2) Diesel engine
3) Dynamometer
4) Dynamometer controller
5) Smoke analyzer
6) Exhaust gas emission analyzer
7) Fuel consumption balance
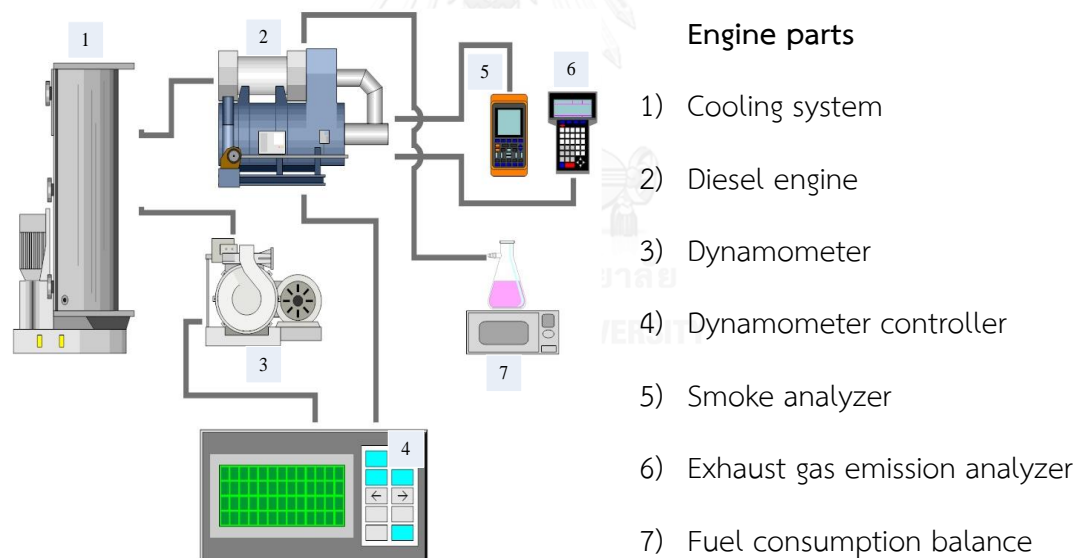
Figure 3.4 *Schematic layout of the engine's test installation.*

3.2.3 Scoring evaluation

The results of derived performances and emissions from diesel engine is difficult to compare together, thus the scoring is required to gain single score for making decision. All factors at all speeds was averaged, then each factors was divided in certain

level and this study had 5 levels, which each level was calculated by following equation;

$$L_i = Min + \left[(i-1)\frac{(Max - Min)}{L_t}\right]$$

Where, L_i = Level

L_t = Total level

Min = minimum value

Max = maximum value

3.2.4 Life cycle analysis

Experiment results were calculated NER by calorific valued or heating value. NER is defined as ratio of net energy output to net energy input. Goal of this LCA is to evaluate the environmental advantages and disadvantages, especially in greenhouse gas emissions and energy analysis of Jatropha biodiesohol compared to Jatropha biodiesel. The functional unit used in this case was energy basis. Scopes depended on existing reliable data that was defined. Boundary of this study was cradle to gate and cradle to grave. Primary data from small community in Nan province is observed. Secondary and surrogate data set may require in order to assess the life cycle inventory (LCI) that accounts inputs and outputs and proposes to identify sources of inputs and outputs which is useful for interpretation of the stages affected to environmental impacts.
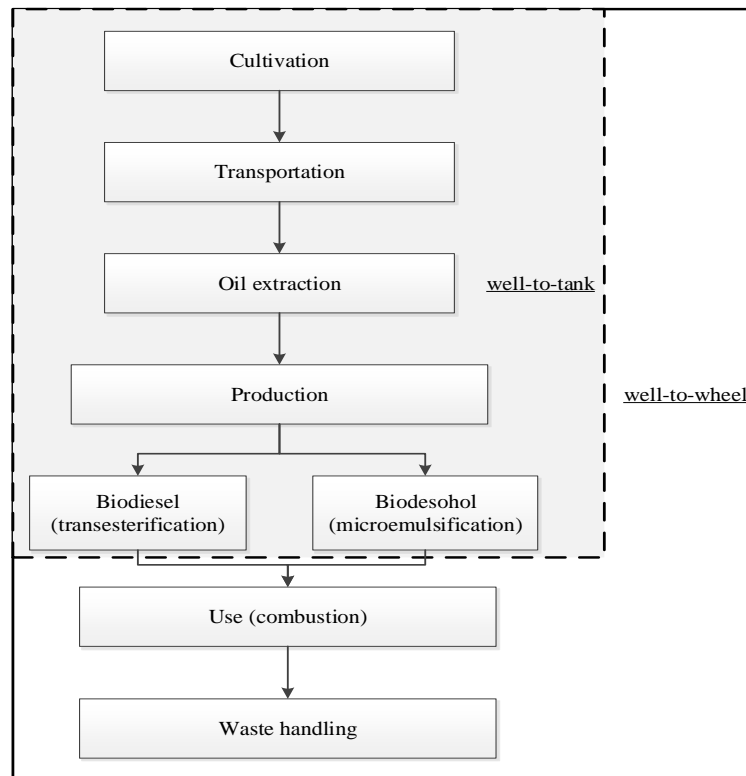
Figure 3.5 *Boundary of JBH and JME life cycle analysis*

The assessment presented in this study was performed in well to wheel life cycle analysis as shown in Fig.3.5. Among all processes, data was collected from the Wiang Sa agricultural cooperative at Wiang Sa District in Nan Province located in the northern Thailand (18.55222, 100.702827). The assumptions and supporting data are needed to achieve life cycle inventory shown in Table 3.5.

Table 3.5 *Data assumption for life cycle analysis*

Cultivation
1   0.8% reviving growth, Tree Density 400 tree/Rai
2   Productivity 800 kg fruit /Rai/year
3   Yielding 500 kg seed/Rai/year
4   Water consumption 50L/day for 8 months excepted for rain season
5   Density of diesel = 0.84 kg/L
Pump for water supply (Total head 24 m, 1HP (0.7457kw) , Q = 4,980L/h)

Transportation	
1	Distance from Cooperative to Jatropha cultivation site 35 km
2	Diesel is main fuel (assume that commercial diesel is totally from fossil diesel)
3	Type of vehicle is small truck
Extraction	
	1. Dehulling
1	capacity 110 kg JCL fruit/hr
2	seed fraction 0.625 kg JCL seed/kg JCL fruit
3	shell fraction 0.375 kg JCL shell/kg JCL fruit
4	capacity 68.75 kg JCL seed/hr
5	power supply 2 HP
6	Density of CJO = 0.91708 kg/L
	2. Milling
1	capacity 15 kg seed/hr
2	rate 3.7 L mixed CJO/hr
3	seed-oil ratio 4.054 kg seed/ L mixed CJO (oil and sediment)
4	seed-clear CJO ratio 4.2567 kg seed/ L CJO
5	oil-waste to CJO ratio 0.05 L oil-waste/ L CJO
6	oil extraction eff. 20-25 % mass
7	seed cake 0.7845 kg/ kg seed
8	power supply 2 HP
Production	
1	density JME 0.86495 kg/L
2	heating value 39.8 MJ/kg
3	conversion efficiency 0.85L JME/L CJO
Use (combustion)	
1	stationary engine
End of life	
1	Wood for 20 year life cycle
2	Biomass from leave for 20 year life cycle

Gaining 1GJ (as functional unit) of straight JME (B100), B25 (containing 25 vol % of JME), and JBH (containing 25 vol % of crude Jatropha oil) was observed in order to conduct the life cycle inventory analysis (LCIA). The goal of this study is to evaluate

and compare both GHG emission and energy efficiency analysis. The GHG calculations were calculated by Simapro program and Ecoinvent database. Detail of each stage could be focused the data for taking into the account by mass allocation. The study area of this research focused on the agricultural area, which has been set up the community biodiesel station. Energy efficiency was calculated by net energy ratio (NER), which is defined by the following equation;

$$NER = E\text{out}/E\text{in}$$

The case study was compared in three cases that are straight JME (B100), B25, and JBH. The B25 is no prejudice in order to compare to JBH composed of 25 % (v/v) Jatropha oil.

CHAPTER 4
RESULTS AND DISSCUSSION

Focusing on the development of biodiesohol, it must be considerd in all aspects, typically the feasibility on production, the practical use, and environmental friendly products. The study was covered phase behavior to find out the optimum ratio and a suitable surfactant, fuel properties and engine test to study the feasibility on practical use in diesel engine compared to commercial diesel and biodiesel. In addition, the environmental aspect was concerned about exhaust gas emission, GHG emission, and energy efficiency.

4.1 Phase behavior study and Jatropha biodiesohol preparation

A 10% volume pseudo-ternary phase diagram aims to study the phase separation and microemulsion formation, as shown in Fig. IV-1. Ethanol and vegetable oil are immiscible liquids that cause a phase separation that is unsuitable for forming a microemulsion for injection and combustion systems. Therefore, the purpose of this approach was to enhance the ethanol dispersion in the CJO and diesel and to form a reverse micelle of w/o microemulsion through the addition of the anionic surfactant. The results in Fig. 4.1 clearly indicate that the presence of ethanol in different ratios of CJO and diesel blends led to the occurrence of phase separations, which occurred in systems containing more than 20% ethanol. The presence of water in bioethanol, diesel or vegetable oil can critically reduce the solubility of ethanol in oil [83]. A concentration of 99.5% ethanol was used instead of absolute ethanol, which is costly, to produce the JBH; the presence of approximately 0.5% water dramatically encouraged phase separation due to greater hydrophilicity. This is the main reason that JBH without the addition of surfactant provided a larger area for phase separation,

as depicted in Fig. 4.1. The phase behavior can also change depending on the ambient temperature [15, 25].
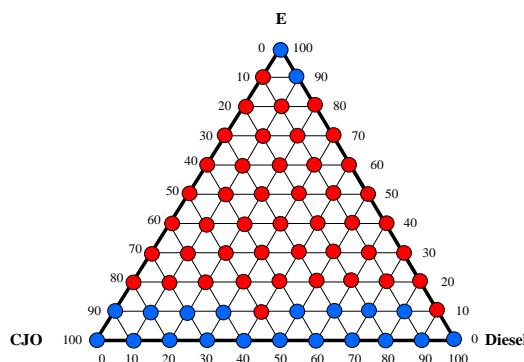
Figure 4.1 *A pseudo-ternary phase diagram of CJO, diesel and ethanol without surfactant (the blue circle is clear and heterogeneous, whereas the red circle is turbid or phase separated).*

For JBH preparation, ethanol and studied surfactant were mixed at a desired ratio such as 1:1, 3:1 and 9:1. This stock solution called E/S mixture that was added into 10 mL clear vial at a certain volume. Then, Crude Jatropha oil and diesel were added and blended, respectively with volume that was designated by pseudo-ternary diagram. Mixing by manual shake was required. The observation on phase and physical property was studied after 24 hr. for equilibrium occurring.

4.1.1 Phase stability for the surfactant selection and E/S ratio optimization

A pseudo-ternary diagram describes the different phases in the system under different compositions (Fig. 4.2). The E/S mixture was fixed at a ratio (E/S ratio) of 1, 3 and 9. The results showed that lower E/S ratios provide the larger transparency and homogeneity areas in the single-phase microemulsion. Macroemulsions were formed in the black area typically at an E/S ratio = 9, in which the turbid solutions were significantly found for high diesel content (>50%) and high E/S content (>50%). This result indicates that the higher EO group of the surfactant influence on miscibility of the system due to its higher hydrophilicity (see Fig. 4.2).

Surfactant	E/S ratio = 9	E/S ratio = 3	E/S ratio = 1
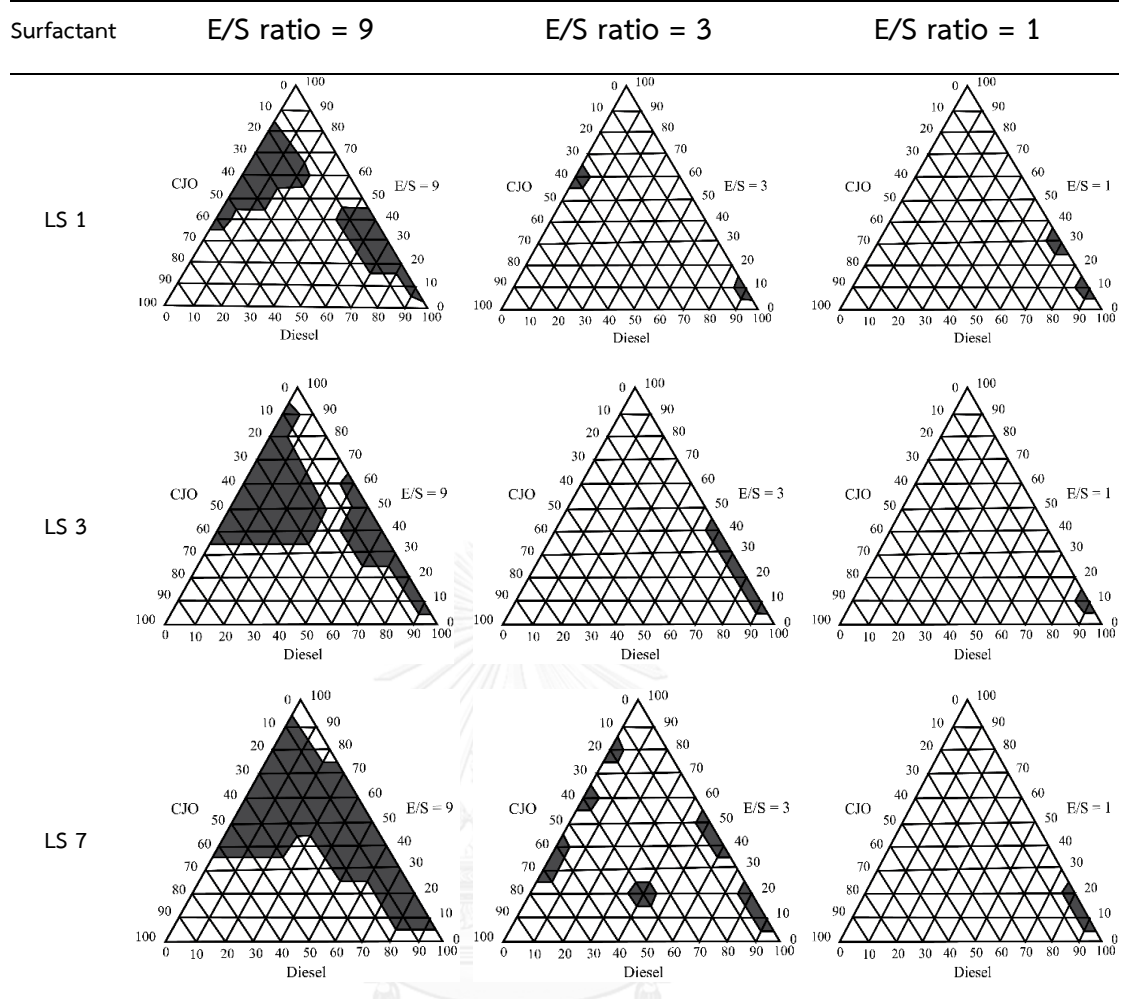
- Miscibility areas drawn in the pseudo-ternary phase diagram

  - Gray area: turbid solution (macroemulsion)

  - White area: transparent and homogenous solution (microemulsion)

Figure 4.2 *Pseudo-ternary phase diagram of the E/S ratio at 1, 3, and 9 using different surfactants*

However, for the system with LS7, larger the area of transparency and homogeneity were observed at the E/S ratio at 1. This can be explained by the Bancroft' Rule that states the increasing hydrophilicity of a surfactant increases the amount of the surfactant needed to obtain reverse micellar microemulsion [84].

This present work agreed with the previous work by Arpornpong et. al. [20] that the EO groups directly affect the hydrophobicity of the system. Diesel represents the hydrophobic portions that provide the low solubility in the ethanol (the polar portion). Excess polar and non-polar components display the essential effects required to form the macroemulsion. By providing 7% biodiesel as the oxygenated component in commercial diesel in Thailand can enhance the formation of microemulsions. Biodiesel has been reported to function as a surfactant because of its chemical structure displaying amphiphilic molecules containing non-polar tails and polar heads, forming micelles in the microemulsion system [22]. The JBH is a w/o microemulsion with a continuous hydrophobic phase of oil and a dispersed hydrophilic phase of water and ethanol. The average particle droplets size of 4.1 to 6.1 nm measured by a Nano Zetasizer 3600 (Malvern) confirmed that the microemulsification was occurred.

In general, a surfactant with a HLB higher than 7 tends to form o/w emulsions, whereas an HLB below 7 tends to form w/o emulsions [85]. This approach has been confirmed by Burguera and Burguera that some studies with the surfactant in a HLB range of 4-6 were able to form a w/o microemulsion [86]. LS3 and LS7 display HLBs higher than 7 but selected for the preliminary study because the system is composed of ethanol as the hydrophilic component. It is expected that hydrophilicity of LS3 and LS7 would facilitate the ethanol to be able to form w/o microemulsion with CJO and diesel. However, the performance of LS3 and LS7 on miscibility was not as good as of LS1 (see in Fig. 4.2). As the highest hydrophobic surfactant, LS1 is the most suitable for preparing Jatropha biodiesohol with a high stability.

4.1.2 Effect of the E/S content in the different EO group in the fatty alcohol ethoxylate surfactant, and the E/S ratio on the kinematic viscosity

Kinematic viscosity is an important fuel property for operating a diesel engine. Therefore, the effect of the EO group in the surfactant, E/S ratio, and E/S content on the kinematic viscosity of the products was evaluated. In this present work, the E/S content was evaluated at 5%, 10%, and 20% for all surfactants with 20% and 25% CJO because these compositions provide a single phase and clear solution (Fig. 1). In addition, the E/S ratio was varied at 1, 2, 3, and 4.

For statistical analysis, the results indicate that an increase of E/S content leads to significantly decrease the kinematic viscosity typically in LS1 and LS3 system as shown in Fig. 4.3. In the same composition and E/S ratio, the system with LS7 shows the higher kinematic viscosity since LS7 has the highest EO group in this study which generally has a higher critical micelle concentration (cmc) and tends to form a larger droplet size [87].

The kinematic viscosity tends to increase with an increase in the EO group of the surfactants and with an increase in the CJO proportion; however, an increase in the ethanol in the E/S ratio (a higher E/S) tends to reduce the kinematic viscosity of the JBH. This result can be explained by the fact that the kinematic viscosity of each individual component directly affects the kinematic viscosity of the product, i.e., ethanol has the lowest kinematic viscosity among all components, and therefore, an increase in the ethanol or E/S ratio will be lower the kinematic viscosity of the system. However, CJO has a much higher kinematic viscosity than diesel. Therefore, products with the identical E/S content but with a larger portion of CJO display a higher kinematic viscosity.
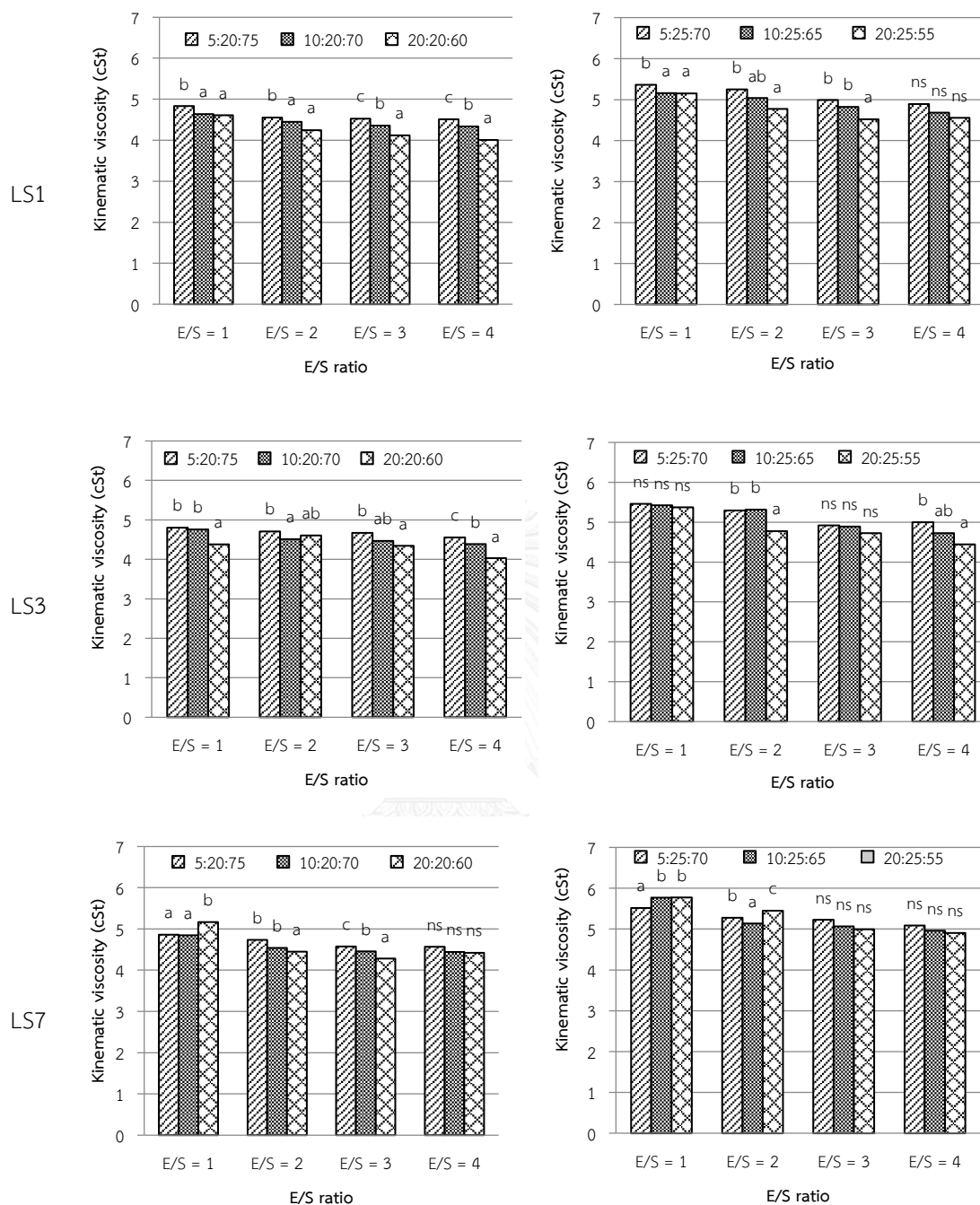
Figure 4.3 *Kinematic viscosities at 40°C of the different proportions of the E/S*

content: CJO: D at different E/S ratios for surfactants with different EO groups

(Different letters-a,b, and c refer to a significant difference of kinematic viscosity with

various proportions in each E/S ratio, while ns refers to no significance)

LS1 displayed a greater miscibility (Fig. 4.2) in the phase behavior study,

particularly at an E/S ratio of 1. In addition, LS1 yielded the lowest kinematic viscosity

compared to those of LS3 and LS7. Therefore, the LS1 surfactant is the most appropriate for this Jatropha biodiesohol investigation.

The most appropriate E/S ratio and E/S content of LS1 are at 4 and 20, respectively significantly reduce kinematic viscosity and achieve the desired kinematic viscosity; however, the difference in viscosity was insignificant when compared to an E/S ratio of 3 (Fig. 4.3). When considering the heating value and storage, a high content of ethanol would provide a low energy content and low flash point. Thus, an E/S ratio at 3 is considered the best ratio for Jatropha biodiesohol production in this present study. At this point, a kinematic viscosity of biodiesohol at the compositions of both 20% and 25% of CJO and E/S content at 5% and 10% with an E/S ratio of 3 satisfied the biodiesel standard (3.5-5 $mm^2 \cdot s^{-1}$ at 40°C).

4.1.3 Mixture design in DOE to screen and optimize the kinematic viscosity

This experiment focuses on a simplex lattice model that has been adopted to optimize the composition of microemulsions [59, 88, 89]. In addition, the multi-response optimization of the cost, yield, oxidation stability and cold filter plugging point determined by the simplex centroid mixture design has been studied for application in biodiesel production [90]. In this present study, with similar approach, the compositions of the product were investigated. The mixture design was introduced to determine the suitable composition of biodiesohol (CJO, E/S and diesel) based on the kinematic viscosities of the blends.

To determine the best fit model for this experiment, a statistical analysis (Table 4.1) is introduced to consider the appropriateness and ability to predict the response variable (kinematic viscosity) of the model. R^2 is the most commonly used value to judge the fit of a statistical model.

Table 4.1 ANOVA and statistical analysis of the studied model

Simplex lattice model	{3,2} lattice	{3,3} lattice	{3,3} lattice augmented with interior points and centroid
Fitting model	Linear	Quadratic	Full cubic
p value	0.128	0.009	0.010
R^2	0.746	0.986	0.998
R^2-adjusted	0.577	0.969	0.994
MAPE	123.3	16.19	5.031

The adjusted R^2 is generally the best indicator of the fit quality when comparing two models ({3,3} simplex lattice and {3,3} simplex lattice augmented with three interior points and the centroid) that are nested. The MAPE is also the most common measure of the forecast error (Eq. 1). The results of the MAPE examinations can be classified into four types: excellent (MAPE<10), good (MAPE 10–20), acceptable (MAPE 20–50), and unacceptable (MAPE > 50) [91].

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|X_{pi}-X_{oi}|}{X_{oi}} \times 100 \qquad \text{(Eq. 1)}$$

where X_p is the predicted kinematic viscosity, and X_o is the observed or measured kinematic viscosity.

The results from the ANOVA (see Table 4.1) show that the {3,3} simplex lattice augmented with interior points can be applied to screen for and optimize the kinematic viscosity of Jatropha biodiesohol because of the good fit to the full cubic model with

an excellent MAPE. In addition, MAPE and the scatter plot between the prediction and observation (Fig.4.4) show low residuals because of the low MAPE; this result is defined as an excellent equation to be used in the prediction of the viscosity. From Table 4.1, the {3,2} simplex lattice model is not sufficient to optimize for the viscosity because the MAPE is unacceptable and the p value for the model equation is not significant. The {3,3} simplex lattice without an interior point also shows relatively high R^2 and adjusted R^2; however, the high MAPE is defined only as a good model, which can still be applied for screening the viscosity in the microemulsion system.
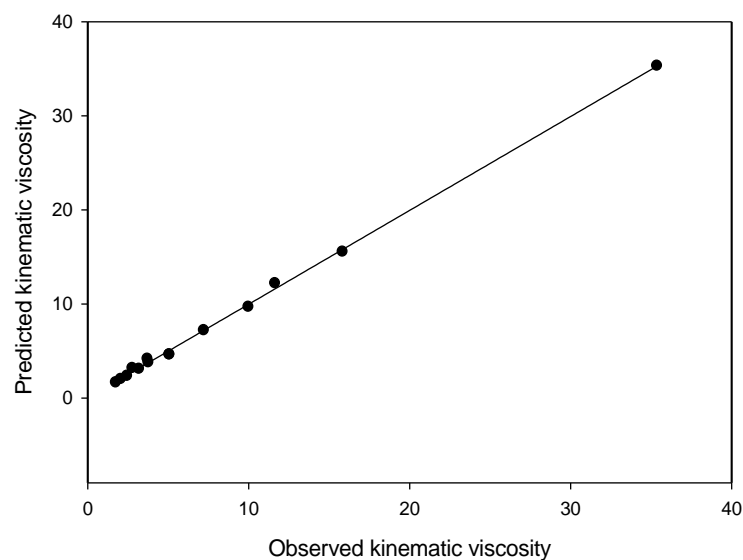
Figure 4.4 *Scatter plot of the predicted and measured kinematic viscosity*

The equation of the kinematic viscosity screening model can be used in two models: the {3,3}simplex lattice and the {3,3}simplex lattice augmented with interior points (Eq.2 and Eq.3, respectively). However, the full cubic model of the {3,3} lattice augmented with interior points and a centroid displayed the lowest residual and is the most appropriate for optimizing the kinematic viscosity (KV).

$$KV_{x,y,z} = 34.21X + 2.34Y + 3.35Z - 49.99XY - 30.80XZ - 1.53YZ \qquad \text{(Eq. 2)}$$

$$KV_{x,y,z} = 35.25X + 1.67Y + 3.19Z - 52.40XY - 34.36XZ - 0.77YZ + 24.64XYZ -$$
$$36.49XY(X-Y) - 14.04XZ(X-Z) + 0.77YZ(Y-Z) \qquad \text{(Eq. 3)}$$

Where X, Y, and Z are the volume of CJO, (3:1 v/v) E/S mixture, and diesel, respectively.

The standard error and p- value for the coefficients of each variable obtained from Eq. 3 are illustrated in Table 4.2.

Table 4.2 *The significant coefficients of the {3,3} lattice augmented with an interior point and centroid*

	Coeff.	Std.Err.	p value
X	35.250	0.67983	*0.000001*
Y	1.6675	0.67983	0.070226
Z	3.1855	0.67983	*0.009407*
XY	-52.399	3.03979	*0.000066*
XZ	-34.361	3.03979	*0.000349*
YZ	-0.7718	3.03979	0.812095
XYZ	24.641	17.3975	0.229614
XY(X-Y)	-36.488	5.82357	*0.003311*
XZ(X-Z)	-14.039	5.82357	0.073499
YZ(Y-Z)	0.7703	5.82357	0.901160

P-value can be implied which term in equation is significantly effect to kinematic viscosity. Five variables or interaction-variables were found to significantly affect the kinematic viscosity ($p < 0.05$). The statistical analysis confirms that the CJO is a major variable that significantly affects the kinematic viscosity, as shown by the surface response results in Fig. 4.5b. The binary mixture of CJO-E/S and CJO-D shows

that E/S content and D results in reduction the viscosity of the blend product. In addition, the coefficient of interactions of XY and XY(X-Y) were found significantly decrease the viscosity with $p < 0.05$. This significant viscosity reduction results from the positive effect (coefficient is minus) of the LS1 surfactant and bioethanol (or as the co-surfactant).
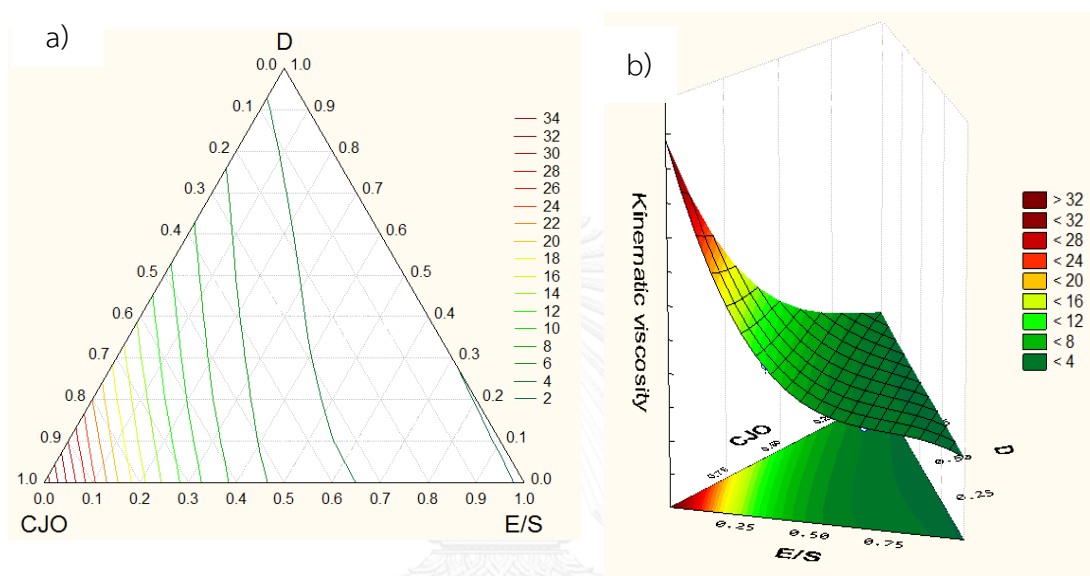
Figure 4.5 *Fitting contour plot of the kinematic viscosity (a) and a surface plot (b) of the simplex lattice mixture design for a {3,3} lattice augmented with three interior points and a centroid*

When compared to the kinematic viscosity standard for diesel and biodiesel (in the ranges of 2-4 mm^2s^{-1} and 3.5-5 mm^2s^{-1}, respectively), the contour plot (Fig.4.5a) shows that a large area for several proportions can be selected when maintaining the viscosity of the biodiesohol within the biodiesel standard. Furthermore, an increased kinematic viscosity standard for biodiesel in agriculture machinery in Thailand (up to 8 mm^2s^{-1}) implies that the proportion of the CJO in a blend of Jatropha biodiesohol can be up to 50%; this proportion is still able to form a single-phase and clear

microemulsion. However, other properties should still be investigated for full compatibility.

Table 4.3 Kinematic viscosity results of the confirmation experiment.

E/S:CJO:D	Kinematic viscosity at 40 °C (mm^2s^{-1})	
	Predicted (by Eq. 3)	Measured
• 5:20:75	5.08	4.53
• 10:20:70	4.76	4.36
• 5:25:70	5.64	4.99
• 10:25:65	5.25	4.83
• Jatropha methyl ester (JME)	-	4.56
• France (EU15412)	3.5-5	
• USA (ASTM424720)	1.9-6	
• Thailand for regular biodiesel	3.5-5	
• Thailand for agricultural biodiesel	1.9-8	

To confirm the application of the mixture design, 4 experimental candidates are shown in Table 4.3 and were established to evaluate the kinematic viscosity and other fuel properties such as the heating content, cloud point and density. This experiment was performed to study the feasibility of effective Jatropha biodiesohol. The results show that the calculated kinematic viscosity from Eq.3 is higher than the measured data by approximately 0.5 mm^2s^{-1} (or 10%).The MAPE from the model (5.03%) is lower than that found in a confirmative test because kinematic viscosity was calculated by 14 formulas, taking into account the ANOVA as shown in Table 4.4.

Table 4.4 *The kinematic viscosity of each coordinate of all experimental mixture designs*

CJO	3:1 (v/v) E/S	D	Kinematic viscosity (mm^2s^{-1})
1.0000	0.0000	0.0000	35.30 ± 0.100
0.0000	1.0000	0.0000	1.752 ± 0.000
0.0000	0.0000	1.0000	3.270 ± 0.111
0.3333	0.6667	0.0000	3.864 ± 0.137
0.3333	0.0000	0.6667	7.219 ± 0.005
0.0000	0.3333	0.6667	2.492 ± 0.064
0.6667	0.3333	0.0000	10.05 ± 0.096
0.6667	0.0000	0.3333	16.23 ± 0.563
0.0000	0.6667	0.3333	2.103 ± 0.061
0.3333	0.3333	0.3333	4.992 ± 0.107
0.6667	0.1667	0.1667	11.36 ± 0.010
0.1667	0.6667	0.1667	2.774 ± 0.001
0.1667	0.1667	0.6667	3.708 ± 0.007
0.3333	0.3333	0.3333	4.992 ± 0.107
0.0000	0.5000	0.5000	2.732 ± 0.080
0.5000	0.5000	0.0000	10.38 ± 0.104
0.5000	0.0000	0.5000	4.262 ± 0.067

The ranges of density and kinematic viscosity (860-900 $kg \cdot m^{-3}$ and 3.5-5.0 $mm^2 \cdot s^{-1}$, respectively) are within biodiesel specifications in the EU, USA, and Thailand. The heating value and cloud point are also reported but are not required in the

specifications. Compared to the JME in this study that was compatible with these standards, Jatropha biodiesohol shows a lower density because of the presence of ethanol in the blends. Moreover, an addition of oxygenated additives, such as ethanol, increases the volatility of the mixture fuel and produces a lower flash point at ambient temperatures [92]. However, a lower cloud point is found in Jatropha biodiesohol. The heating contents of Jatropha biodiesohol are higher than that of JME because of the diesel displaying a heating value of approximately 45.82 MJ·kg^{-1}. The use of statistical and mathematical models in the mixture design can be applied to other fuel properties to consider the desired and optimized proportion of each component.

4.2 Properties, performances and emissions on diesel engine

A microemulsion of JBH was investigated to compare to system of CJO-Diesel-Ethanol blend without surfactant using a pseudo-ternary phase diagram. It can be concluded that surfactant plays important role to formulate a clear and homogenous microemulsion. Due to the fact that, size of droplet affect to microexplosion enhancement [52] since this study was investigated the mean droplet size of microemulsion. Moreover, the previous researches reported that alcohol reduced cetane number of fuel, therefore adding the EHN was studied in order to improve this trouble so that Jatropha biodiesohol can be practically use for agricultural activity.

a) b)
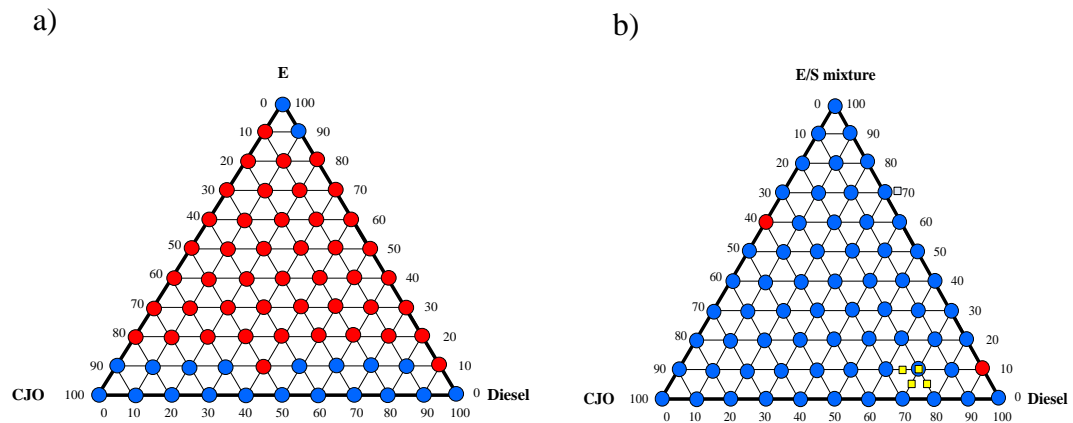
Figure 4.6 *A pseudo-ternary phase diagram of CJO, diesel and ethanol without surfactant (a) and with a ratio of 3:1 of ethanol-surfactant mixture (b) on microemulsion stability at 25°C (the blue circle is clear and heterogeneous, the whereas red circle is turbid or phase separated).*

In general, a microemulsion is an isotropic and thermodynamically stable system with a dispersed domain diameter varying from approximately 1 to 100 nm. Most mixture ratios of JBH were single phase, homogeneous, and clear solutions except for the E/S:CJO:D ratios of 60:40:0 and 10:0:90. To confirm microemulsification, the average mean size of the JBH was measured using dynamic light scattering. As shown in Fig. 4.6b (the yellow square in the pseudo-ternary phase diagram), 4 interesting formulas were previously observed based on proper surfactant and viscosity using a statistical model called mixture design [93]. The results indicated that the range of the average domain size was approximately 3.6-6.0 nm, as shown in Table 4.5. The size tended to increase with an increase in E/S and CJO content. The increased size of the ethanol fraction has been showed to be caused by an increased droplet radius [94].

Table 4.5 *The average size of Jatropha biodiesohol with and without the addition of EHN.*

E/S	CJO	D	EHN	Size (nm)
5	20	75	-	4.101
5	20	75	0.5	3.621
5	25	70	-	4.272
5	25	70	0.5	4.845
10	20	70	-	5.627
10	20	70	0.5	4.253
10	25	65	-	6.061
10	25	65	0.5	5.358

The phenomenon describing the effect of EHN addition is illustrated in Fig. 3. The repulsive forces of the O-atom (negative charge) both in CH_2-O-CH_2 and CH_2-O-H of surfactant head [95] resulted in larger sizes of the reverse micelles (Fig.4.7a). EHN, which was added as a cetane booster, acted as a surfactant or co-surfactant in the JBH system and thus increased the attractive force of the N-atom (positive charge) when it interacted with the EO head of LS1. This interaction resulted in a smaller size compared to those without EHN (Fig. 4.7b). The effect of increasing the CJO can be explained by the structure of the triglyceride of CJO. The polarity of the ester may have enhanced the attraction of the aqueous phase in the core of the micelle, leading to an increase in the micelle size. In addition, the H-bond in the C-chain may have caused the aggregation of larger micelles.
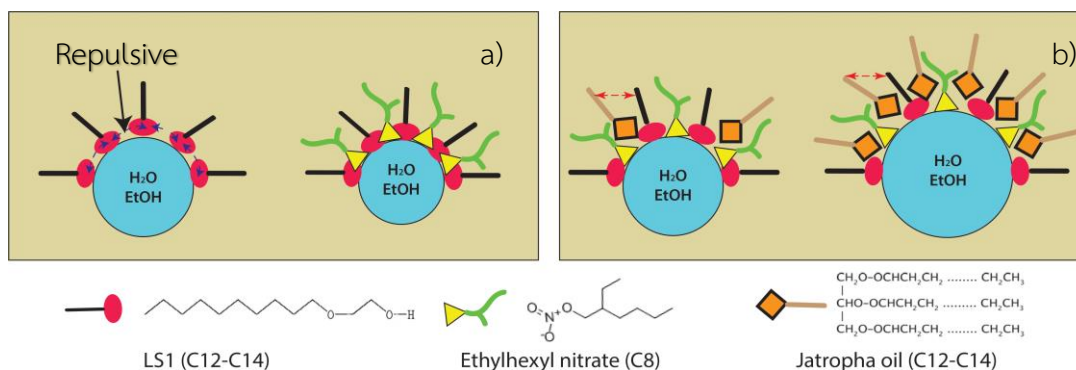
Figure 4.7 *Schematic interaction of a reverse micelle in the JBH system. a) The effect of the addition of EHN on the size of the droplet; b) the effect of increased CJO in the system.*

After being stored for as long as 6 months, the JBH was considered a microemulsion and was still clear and homogeneous. The JBH of E/S:CJO:D at the ratios of 5:20:75 and 5:25:70 with added EHN also formed a single-phase microemulsion. The EHN molecule was considered to have an amphiphilic structure, in which the nitrate terminus represents the hydrophilic part and the alkyl group (C8) represents the hydrophobic tail.

4.2.1 Fuel properties

The fuel properties were studied prior to testing the fuel performance to determine whether JHBs could be used as effective biofuels. The presence of ethanol facilitates the formation of a microemulsion, and the addition of 4% ethanol to diesel has been reported to increase the power output and efficiency [96]. Thus, in this work, 3.25% ethanol in a 5% E/S mixture was preferably studied for its effect on the properties and performance of the fuel. The JBHs, JBHs with added EHN, and the main components of Jatropha biodiesohol were compared to the biodiesel standard (ASTM standard); the results are shown in Table 4.6.

Table 4.6 *Properties of the main components of Jatropha biodiesohol with various proportions of Jatropha biodiesohol and the ASTM standard for biodiesel.*

E/S:CJO:D	Density (g/L)	Kinematic viscosity (cSt)	Calorific value (MJ/kg)	Cloud point (°C)	Flash point (°C)	Acid No. (mgKOH/g)	Oxidation stability (hr)
5:20:75 (JBH20)	836.64	4.53	43.2	10.9	17.50	3.07	23.03
5:25:70 (JBH25)	840.86	4.99	42.9	10.6	15.50	4.37	18.89
5:20:75+0.5%EHN (JBH20E)	835.87	4.50	42.1	11.7	13.5	2.51	22.18
5:25:70+0.5%EHN (JBH25E)	840.16	4.98	41.9	10.5	15	3.06	18.60
JME	864.95	4.53	39.8	13.1	171.5	0.28	13.46
CJO	917.08	35.3	39.4	2.1	260	12.3	13.14
EtOH (99.5%)	801.03	1.76	-	> -35	12.0	< 0.06	-
Diesel	830.00	3.27	44.6	9.70	61.0	0.07	-
Biodiesel STD	860-900	1.9-6.0	-	-	> 103	≤ 0.50	≥ 3

The additions of CJO and EHN to the fuel were investigated for their effects on the density, kinematic viscosity, calorific value, cloud point, flash point, acid number, and oxidation stability. The fuel properties can be described as followed;

4.2.1.1 Density

Fuel density also generally increases with increasing molecular weight of the component atoms of the fuel molecules. Density effects to the engine output power due to a different mass of injected fuel. Density of CJO shows the highest value compared to ethanol and diesel. However, the increase of density of JBHs resulted in the increase of JCO proportion. Jatropha biodiesohol with 20% and 25% of CJO had insignificant differences (835-840 g/L). Due to high amount of diesel, densities of jatropha biodiesohol are nearly value belonged to diesel. Existing 75-80% of other components can reduce density of 20 – 25% of CJO approximately 9%. Addition of EHN does not change the density since EHN was added in small amount which does not effect to density.

4.2.1.2 Kinematic viscosity

The viscosity of vegetable oil is approximately 10 times higher than that of diesel fuel. Therefore, the use of vegetable oil in direct injection diesel engines creates poor fuel atomization, incomplete combustion, carbon deposition on the injector, and fuel build up in the lubricant oils, resulting in serious engine fouling[92]. The possible technique can improve the oil viscosity include blening with a suitable solvent, emulsification, pyrolysis, and transesterification to obtain biodiesel. The E/S ratio at 3 and E/S content at 5% with 20% and 25% jatropha oil provided suitable properties on kinematic viscosity at 40 °C as shown in Table 2. The standard requirement of kinematic viscosity for biodiesel followed ASTM D445 is 1.9-6.0 cSt. The JHB20 was supposed to be greater atomization during the injection than JME and JHB25. All proportion of jatropha biodiesohol showed in range of biodiesel requirement. Diesel is main component in microemulsion system that showed a major role to reduce viscosity. The addition of ethanol to diesel fuel lowers fuel viscosity[97]. Wrage and Goering [98] found that blending 10% ethanol with different diesel fuels reduced their viscosity around 25% of the difference with respect to the ethanol viscosity.

4.2.1.3 Calorific value

The heating value of vegetable oils is lower than that of diesel fuel. Tranesterification increase the heating value of biodiesel. The calorific value of Jatropha biodiesel was lower than diesel which is believed due to the fact that the heating value decreases with increase in unsaturation that CJO contains 75% unsaturated fatty acid. The oleic acid (42.4–48.8%) and linoleic acid (28.8–34.6%) are the dominant fatty acids present in the Jatropha seed oil [99].The calorific value of ethanol is about 20 MJ/L, which lower than that of diesel approximately 50% that can

reduce the quality of fuel on performance. The range of calorific value that was found in the JBHs was 41.9-43.2 MJ/kg. E/S at ratio of 3:1 provided 29.5 MJ/kg contained 5% in the JBHs showed the effect to reduce the calorific value of The JBHs. CJO and JME showed lower calorific value than that of diesel that used in this study about 11%. The energy content or net calorific value of biodiesel is less than that of diesel fuel; also it has higher viscosity and density, than diesel fuel[100]. Adding EHN into the JHBs reduced calorific value according to its energy bond (C=C > C-H > C-C > N-O).

4.2.1.4 Cloud point

The cloud point of fatty acids is the temperature at which the clear fatty acid becomes cloudy due to the crystallization of higher melting components. For jatropha biodiesohol, the range of cloud point is about 10.6 -11.2 °C which should be noted that at lower 12°C can not maintain the solubility and phase stability of the JBHs. The higher percentage of CJO in the JBHs led to decrease the cloud point in which E/S:CJO:D at 5:20:75 and 5:25:70 showed 10.9 and 10.6°C, respectively. However, EHN addition had evidence to increase the cloud point. The solubility of surfactant decreases may begin to lose their surface active properties of surfactants above a transition temperature. The high CFPP of vegetable oil has been reported that it can be significantly reduced by blending vegetable oil with *alcohol* and diesel blend. Many researchers claim that CFPP point decreases with the length of the alcohol carbon chain increases [101],[102].

4.2.1.5 Flash point

The flash point is an indication of how easy a fuel may burn. Fuel with higher flash points is less flammable or hazardous than fuel with lower flash points. The flashpoint of the fuel affects the shipping and storage classification of fuels and the precautions

that should be used in handling and transporting the fuel[103]. Ethanol (99.5%) has flash point about 12 ℃ that mainly shows the influence on flash point of The JHBs. The flash point of a fuel is measured at the surface of the fuel that gives off enough vapour to be ignited (start burning). Thus, flash points of jatropha biodiesohol are closely to low flash point of ethanol due to its high volatilization of ethanol. The result showed that the JBHs of which EHN addition exhibited the increase of flash point, whereas the increase of CJO content can improve flash point due to its high flash point.

4.2.1.6 Acid number

The acid number in oil is the result of the degree of breakdown of oil, due to a chemical reaction called hydrolysis or lipolysis, in which free fatty acids are formed. The increase in acidity arising from oxidative process can cause corrosion of fuel system components. Oxidation is related to an increase in the acid value and viscosity of the fuel. The main cause of the autoxidation lies in the presence of double bonds in the chemical structure of fatty compounds[101]. The increase of acid number with EHN addition leads to reduce acid number as shown in Table 2. This can be implied that EHN exhibit the property as an antioxidant. The JBHs containing 25% CJO shows significantly the increase of acid number. The increase in the acid value did not result in an induction time by Rancimat, suggesting that the acid value was due to a nonvolatile acid [104].

4.2.1.7 Oxidation stability

Oxidative degradation of biofuel can lead to the formation of, acids, insoluble sediments, and varnish deposits[105]. Numerous physicochemical properties like induction period, viscosity, iodine value, peroxide value and acid value monitoring

have been applied to study oxidation stability [106]. The primary oxidation products of double bonds are allylic hydroperoxides. Peroxides formed in the initial stage of oxidation can decompose to form aldehydes, ketones, and acids.

The measurement of oxidation stability has performed to accelerate oxidation by increasing temperature and blowing oxygen to samples. The higher ratio of CJO caused to increase oxidation stability by decreasing induction time. The oxidation stability showed lower induction time of the JHBs with EHN addition. The 2% EHN was added into soy methyl ester has been reported regarding to the role as antioxidant [107].

4.2.2 Engine performances

Ethanol has limited solubility in diesel fuel, and the phase separation and water intolerance in ethanol–diesel blend fuels are crucial disadvantages [108]. Moreover, ethanol fuel has an extremely low cetane number, and fuels with high cetane numbers are preferred for use in diesel engines because auto-ignition is easier with higher cetane numbers. Thus, in this work, we studied the effects of a 5% E/S mixture and the addition of a cetane enhancer (EHN) to the JBHs on improving ignition performance and boosting the cetane number through the use of an oxygenated additive.

JBH20 and JBH25 were selected for the performance study due to their high calorific values, which are more favorable for engine performance. In addition, the effect of the cetane enhancer on the performance of a CI engine was evaluated using the addition of EHN to the selected JBHs. The power of the engine measured at the output shaft is called the brake power, which is given by Eq. 1. The brake-specific fuel consumption (BSFC) is the ratio of the fuel used by the engine to the amount of power the engine produces, which is given by Eq. 2. The brake thermal efficiency (BTE) is the

ratio of energy output (energy provided by the engine) to the energy input, which is shown in Eq. 3.

- **Power and torque**

The two main formulas of the JBHs with and without the addition of EHN were investigated with respect to the power and torque generated compared to those generated by commercial diesel and neat JME, as shown in Fig.4.8. The maximum brake power occurred at 1,750 rpm. The JBHs showed positive results in an increase both of brake power and torque, especially at high speeds, whereas JBH20 exhibited the lowest power and torque values. It can be concluded that a greater amount of CJO in the microemulsion system leads to increased power and torque. Vegetable oil enhances the lubricity of fuel [109], which can reduce the friction in an engine. For the torque performance, the JBH microemulsions with 0.5% EHN were considerably enhanced compared to diesel and JME. The addition of EHN obviously exhibited significant power boosting capabilities relative to JBH20, though an insignificant difference in the power and torque was observed with JBH25. It has been reported that the addition of 2% EHN into dimethylfuran (DMF)-diesel blends provides a shorter ignition delay and lower combustion noise [110].
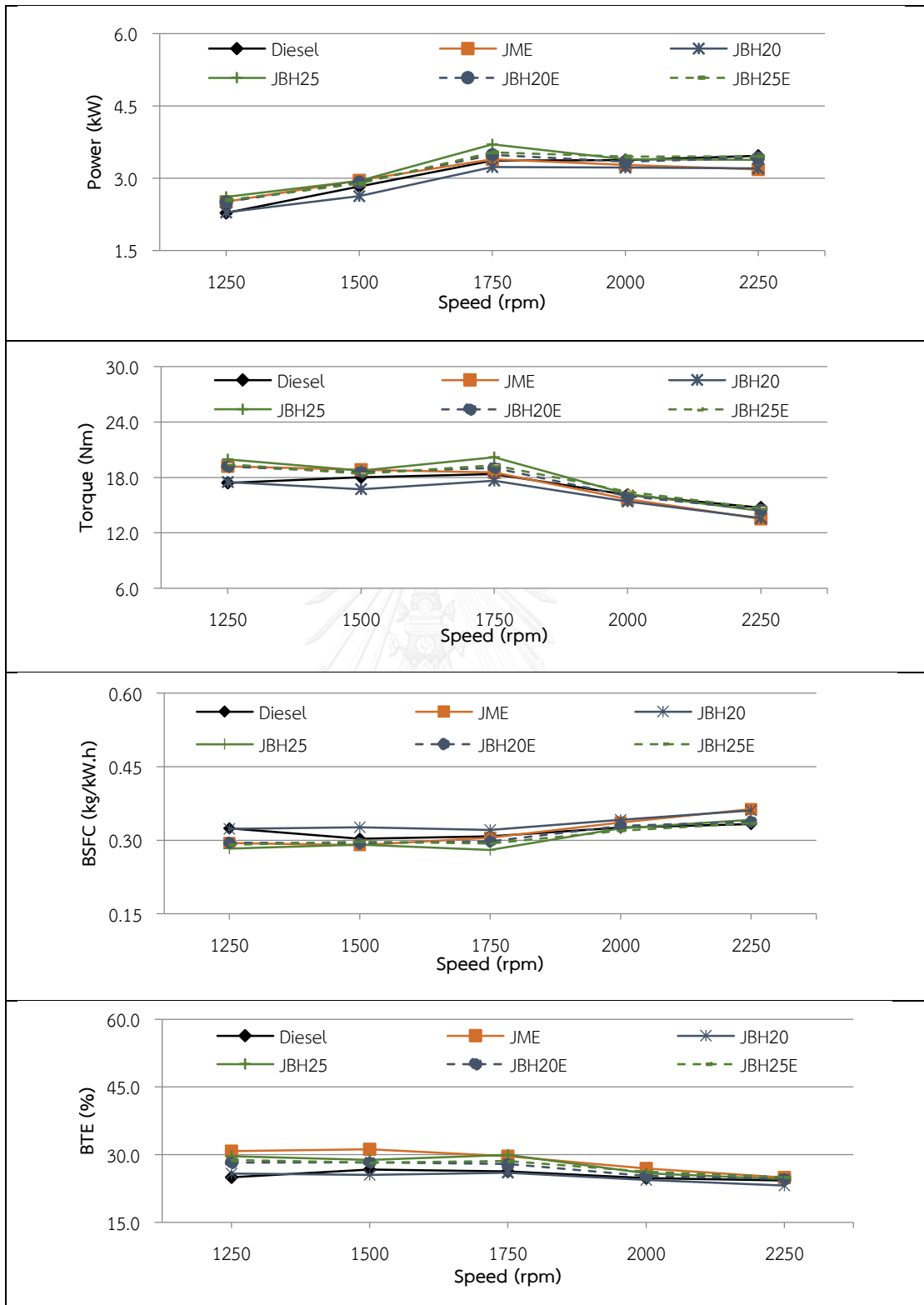
Figure 4.8 The engine performance test: power, torque, brake specific fuel consumption, and brake thermal efficiency of diesel, neat Jatropha biodiesel (JME), and Jatropha biodiesohol with and without the addition of ethylhexyl nitrate.

● **Brake specific fuel consumption (BSFC)**

The BSFC was lower at low speeds and increased slightly at high engine speeds, as indicated in Fig. 3. One explanation for this observation is that fuel consumption was required to overcome the engine friction. Among all the fuels assessed, the JBH20E, JBH25 and JBH25E at high speed showed considerably lower fuel consumption compared to diesel and JME. Thus, EHN addition improves BSFC. This improvement may have resulted from the occurrence of a well-premixed combustion phase and a diffusive combustion phase that resulted from improved oxygen enrichment [108]; some literature has shown that alcohol-diesel blends or diesohol exhibit greater fuel consumption at the same load because the heating value of alcohol is lower than that of neat diesel [111-113].

The JBH20 had the highest BSFC because power was generated in the lowest amount, as previously presented. Thus, the engine required a greater mass of fuel to provide the same power at 1 kWh. However, it should be noted that the microemulsion technique showed evidence of promoting micro-explosion atomization, which led to higher combustion efficiencies by mixing well with air. With respect to the mean diameters of the JBHs, the release of greater pressure from a smaller droplet enhanced the performance. The BSFC of the diesel engine depends on many factors, such as the relationships among the volumetric fuel injection system, fuel density, viscosity and lower heating value [114].

● **Brake thermal efficiency (BTE)**

The BTE calculation is simply an inverse of the BSFC and low heating value, which refers to the energy that the engine provides to the energy potential of the fuel. At low speeds, the BTE showed that the microemulsions, with the exception of JBH20,

provided significantly higher BTE values compared to diesel, whereas the JME showed greater BET values than the other fuels. However, no significant differences were observed in the BET values of all fuels at high engine speeds. The presence of alcohol has been reported to improve BTE due to well-premixed combustion as a result of the lower cetane number of alcohol [115]. The higher BTE values can be attributed to the increasing proportion of CJO in the microemulsion system, and adding EHN to the JBHs appeared to cause an inferior improvement in BTE.

4.2.3 Emission characteristics

An insignificant difference was observed in the CO_2 output of all the fuels due to the lean conditions during combustion. JBHs showed lower smoke output compared to diesel and JME due to the presence of fuel-bound oxygen, which promoted complete combustion by reducing CO, as shown in Fig.4.9.

According to Attia et al. [116], the greater HC and CO reduction results in finer microemulsion droplets. Ethanol acts as an oxygenator, accelerating fuel combustion [47, 117, 118]. The addition of a cetane enhancer provided better results for smoke output. Rakopoulos reported that smoke was reduced by the use of vegetable oil blends compared to neat diesel [64]. This is an advantage of using vegetable oil in a microemulsion biofuel.
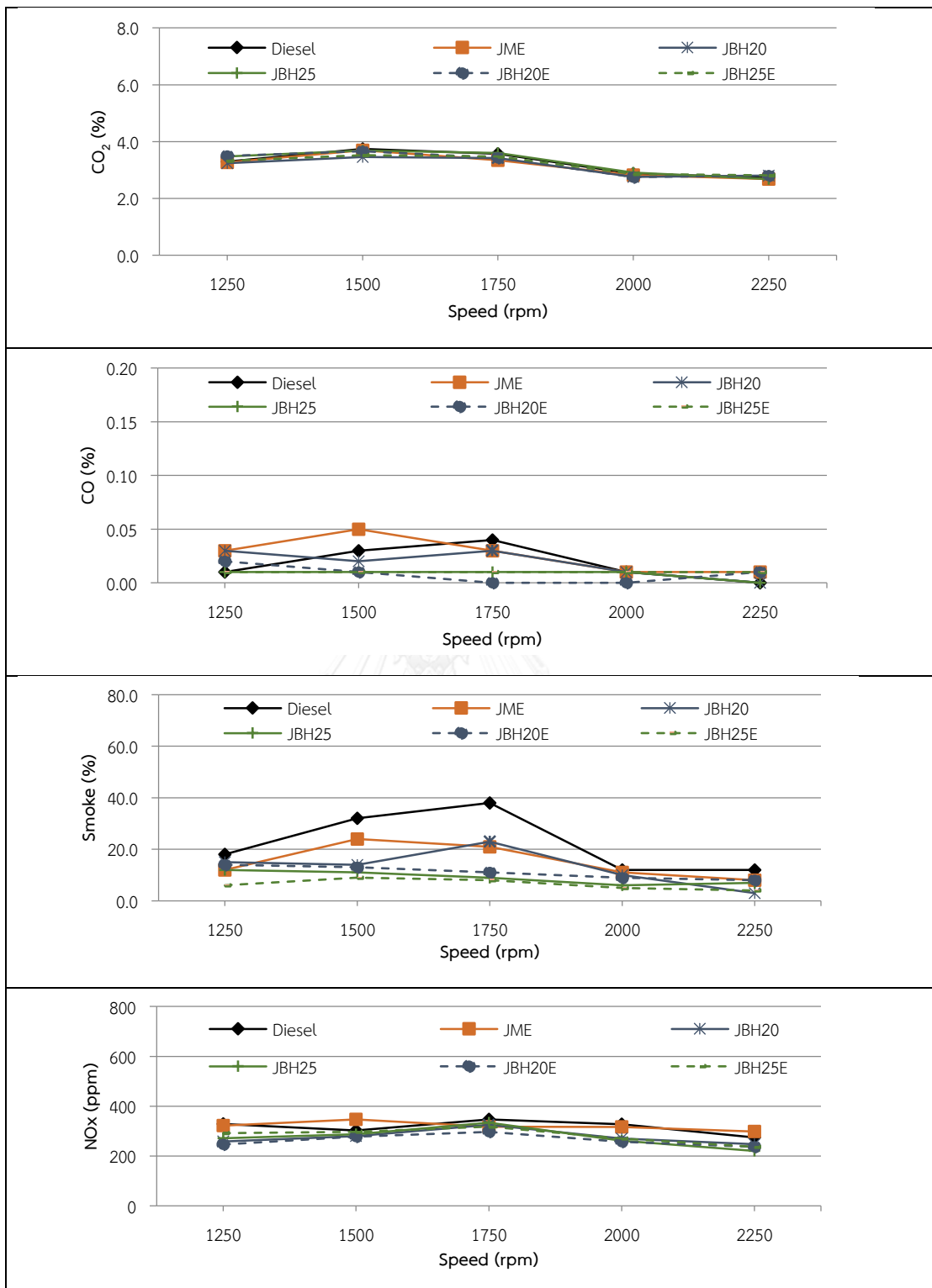
Figure 4.9 *The exhaust gas emissions. CO_2, CO, NO_x, and smoke values of diesel, neat Jatropha biodiesel (JME), and Jatropha biodiesohol with and without the addition of ethylhexyl nitrate.*

EHN can reduce smoke formation. In addition, the oxygen content in ethanol, surfactant, and vegetable oil improves CO and the emissions of smoke and soot [119]. Because ethanol has a lower calorific value and a higher latent heat of vaporization, the combustion temperature decreases, resulting in reduced thermal NO_x emissions. Furthermore, the oxygen content and cooling effect of ethanol increase the ignition delay period, resulting in the proper mixing of fuel with air, leading to complete combustion [120]. Therefore, ethanol in fuel has the potential to reduce both the NO and PM emissions [121]. Ribeiro et al. claimed that the use of ethanol with additives, such as a cetane enhancer, can sharply reduce particulate emissions [92]. The EHN additive can increase the cetane number of a fuel, accelerating the formation of radicals and thereby accelerating ignition. This consequent may result in shorter ignition delay times and decreased NO_x emissions.

4.3 Scoring evaluation

From performance and emission study, the results depended on type of fuel, and speed. To find out the suitable fuel, scoring is required to make decision for further study. JBH25 and JBH25E showed the larger area in radar chart (see Fig. 4.10) means that they can practically consume instead of both commercial diesel and biodiesel. The total score (Table 4.7) confirmed that JBH25 is the best for air pollution emission and engine performance. Additionally, EHN adding as additive will increase costs of microemulsion-base biofuel production, thus this showed that JBH25 is the most appropriate for further study in order to investigate GHG emission and energy analysis.
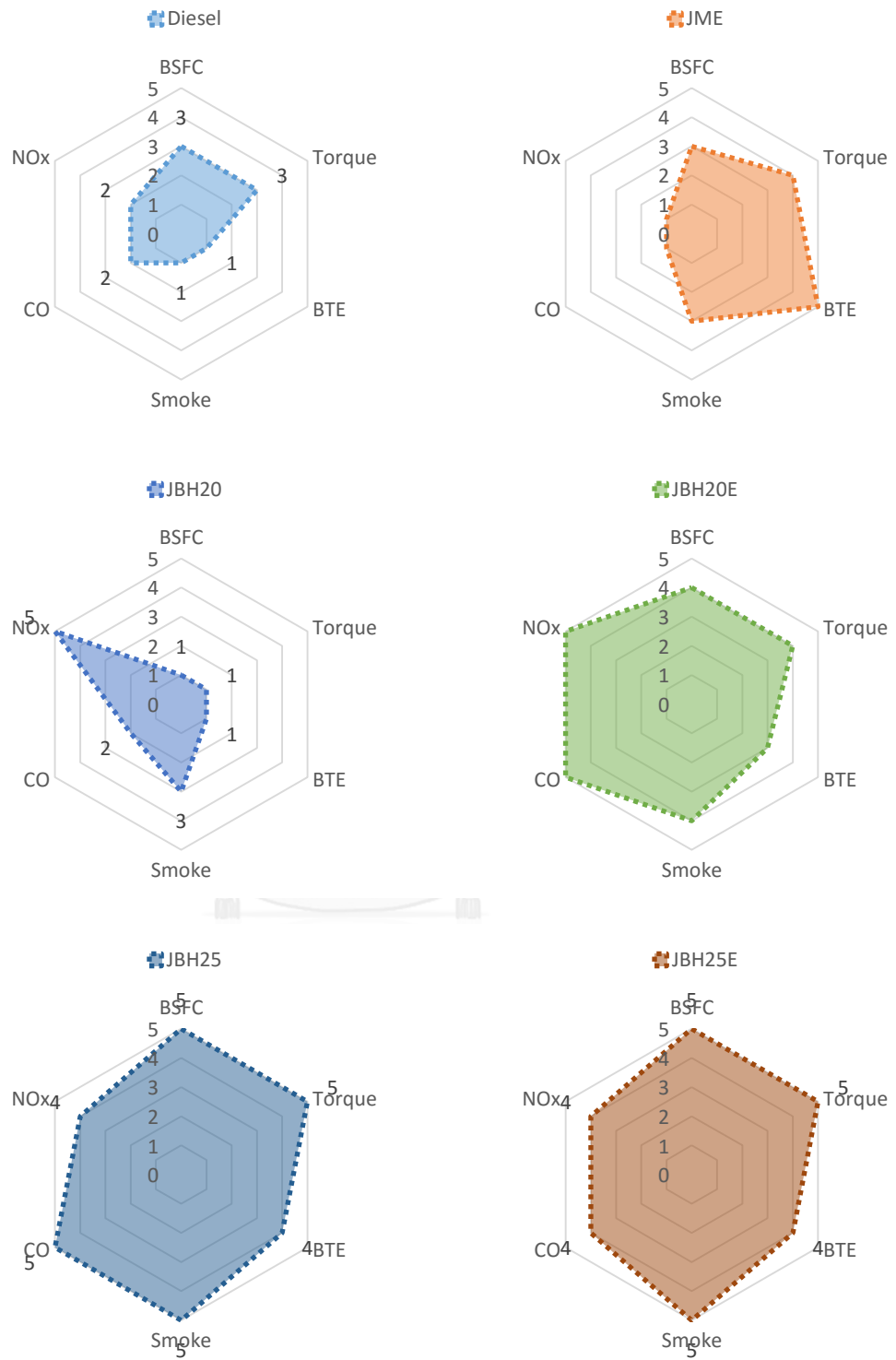
Figure 4.10 *Radar chart of scoring the performances and emissions of various fuels.*

Table 4.7 *Score of studied fuels on performances and emissions*

Fuels	Ranking						Total score
	BSFC	Torque	BTE	Smoke	CO	NO_x	
Diesel	3	3	1	1	2	2	12
JME	3	4	5	3	1	1	17
JBH20	1	1	1	3	2	5	13
JBH20E	4	4	3	4	5	5	25
JBH25	5	5	4	5	5	4	28
JBH25E	5	5	4	5	4	4	27

4.4 Life cycle analysis of biodiesel and biodiesohol produced by Jatropha

4.4.1 Biofuel productions

Life cycle of Jatropha cultivation can be harvested for about 20 years Jatropha seeds were transplanted in PE bag which are easily to grow in the field with higher survival rate. The germination rate was 80% in cultivation of Jatropha plantation. The distance between the 2 meters x 2 meters (density at 400 trees/Rai), the average annual yield of 800 kg of Jatropha fruit/Rai/yr. The 15-15-15 fertilizer is added at rate of 50 kg/ Rai with watering at an average rate of 50 L/d. In case of no insect infestation, pesticides are not applied. Diesel is used in the agricultural machinery for land preparation until harvest. Electricity is used for pump to spread water in plantations. During the rainy season, water will not be applied to the crops. However, the first year may not be harvested. Productivity depends on the care of crops and soil quality. Emission of nitrous oxide from the use of nitrogen fertilizer releases at rate of 0.01 kgN_2O/kgN.

The farmers purchase raw materials for the Jatropha cultivation from the Wiangsa agricultural cooperative and Jatropha fruits are sent to sell at the Wiangsa agricultural cooperative. The Sanna-Nhongmai subdistrict is the cultivation area that is

the maximum distance (35 km) to send to the Wiangsa agricultural cooperative for JME production. The Cooperative Wiangsa purchase raw materials to produce biodiesel from MuangNan District (35 km). For biodiesel distribution, the farmers that are member of the Wiangsa agricultural cooperative can buy biodiesel at the Wiangsa agricultural cooperative, thus transportation for distribution to farmer was not taken to the account.

The process of screw press extraction has two phases which are dehulling and milling. Jatropha shell will be removed by a 2 HP dehulling machine with capacity at 110 kg Jatropha fruit/h. The proportion of the Jatropha shell to Jatropha seed is about 37.5:62.5. A 2 HP milling machine is operated with capacity of 15 kg seed/h for providing 1L of turbid Jatropha oil using 4.05 kg of seed. The turbid Jatropha oil contains seed cake that is a main impurity which can be removed by settling for 3-5 days. The turbid Jatropha oil contains the 5 % (v/v) of oil waste and sediment and 95 %(v/v) of clear Jatropha oil, which its density is 0.917 g/mL is used to produce biofuels.

For traditional transesterifacation process, Triglyceride as carboxylic group reacts with alcohol using base catalyst (KOH) to produce JME in reactor. Additionally, the production process required heat and water to purify JME. The 100L of Jathopha oil will be reacted with 20L of methanol using 1.2 kg of KOH as catalyst to produce 85L of JME. To gain 85L JME, the 16.46 kWh of electricity requires for mixer, heater, and pump in biodiesel reactor system. Whereas JBH requires labor for 30 min mixing of the 4 raw materials, which are Jatropha oil from Nan province, 99.5 % vol bioethanol (E) from Mitrpol Co. Ltd. and LS1(S) from Thaiethoxylate Co. Ltd., commercial diesel (D) from PTT Co. Ltd., were simply blended by a ratio of CJO:E:S:D at 25:3.25:1.75:70.

4.4.2 Engine combustion and waste handling

Most of agricultural machine normally is compress ignition engine. Greenhouse gas evaluation was estimated by default emission factors of stationary combustion for agriculture activity from IPCC (2006) "Guidelines for National Greenhouse Gas Inventories" [122]. Transesterification by base catalyst is tradition method, which is shorten and basic process that is suitable for farmer communication. However the

disadvantages (such as generating large amount of wastewater from alkaline catalyst, high cost of refining jatropha oil as raw material and additional purification step is necessary to remove the alkaline catalyst) have motivated many researchers to find a better alternative method to produce biodiesel [123]. Biomass from Jatropha shell were composted as organic fertilizer. Jatropha seedcake and oil waste from extraction process were composted to be organic fertilizer due to its high major nutrients including biomass based on 20 year lifetime was substituted LPG, which the heating value is 49.2 MJ/kg. Polyethylene bag was proposed to be incinerated. Wastewater from biodiesel refinery process has been treated by anaerobic digestion process [124].

4.4.3 Life cycle Inventory analysis

The data were collected from both primary and secondary data presenting inventory in Table 4.8 and 4.9. Problems and obstacles of this research are expected to expand the scope to be *well-wheel life cycle* that included use and waste handling stage.

In case of stationary equipment, The results of GHG from combustion using estimation presented in Table 4.10 was calculated by IPCC (2006), which recommended the equation for fuel statistics and data on combustion technologies applied together with default emission factors to calculate the GHG emissions as follows;

$$\textbf{Emissions}_{\text{GHG gas, fuel}} = \textbf{Fuel Consumption}_{\text{fuel}} \times \textbf{Emission Factor}_{\text{GHG gas, fuel}}$$

where; $\text{Emissions}_{\text{GHG gas, fuel}}$ = emissions of a given GHG by type of fuel (kg GHG)

$\text{Fuel Consumption}_{\text{fuel}}$ = amount of fuel combusted (TJ)

$\text{Emission Factor}_{\text{GHG gas, fuel}}$ = emission factor of a given GHG by fuel (kg GHG/TJ)

(see appendix D; Table D-2)

Table 4.8 *Inventory data of JME providing 1GJ.*

Stage	Materials	Amount	unit
JME 1 GJ			
Cultivation	Seed	0.0182	kg
	PE bag	0.0727	kg
	Fertilizer	14.5472	kg
	Diesel (product) density= 0.83	1.5187	kg
	Water	3.4913	m3
	Electricity	0.5208	kWh
Transportation	Transportation (materials for cultivation)	70	tkm
	Transportation (Jatropha from growing site)	70	tkm
	Transportation (materials for production)	70	tkm
Extraction	Electricity	17.6196	kWh
Production JME	MeOH	5.4065	kg
	KOH	0.4101	kg
	Electricity	5.6252	kWh
	Water	0.1094	m^3
Combustion	CH_4	70.8	$kgCO_2e$
	CO_2	0.25	$kgCO_2e$
	N_2O	0.1788	$kgCO_2e$
End of life	Biomass from stem	29.09444	kg
	Shell	87.28333	kg shell
	Seed cake	114.1311	kg
	Oil waste and sediment	1.708744	L
	Wastewater	0.116195	m^3
	Glycerol (unpurified)	5.126232	L

Table 4.9 Inventory data of JBH25 providing 1GJ.

Stage	Materials	Amount	unit
JBH25 1 GJ			
Cultivation	Seed	0.0038	kg
	PE bag	0.0150	kg
	Fertilizer (product)	3.0093	kg
	Diesel (product) density= 0.83	0.1425	kg
	Water	0.7222	m^3
	Electricity	0.1077	kWh
Transportation	Transportation (materials for cultivation)	70	tkm
	Transportation (Jatropha from growing site)	70	tkm
	Transportation (materials for production)	70	tkm
Extraction	Electricity	3.6448	kWh
Production JBH	Diesel	16.4282	kg
	Ethanol	0.8494	kg
	Surfactant	0.2958	kg
Combustion	CH_4	79.6	$kgCO_2e$
	CO_2	0.25	$kgCO_2e$
	N_2O	0.1788	$kgCO_2e$
End of life	Biomass from stem	6.01858	kg
	Shell	18.05574	L
	Seed cake	23.60957	m^3
	Oil waste and sediment	0.353477	L

Table 4.10 The GHG emission estimation by IPCC (2006) method for stationary machine providing energy 1GJ.

Fuel type	CO_2	CH_4	N_2O	Total kgCO2e
	$kgCO_2$	$kgCO_2e$	$kgCO_2e$	
Diesel	74.1	0.25	0.1788	74.5288
JME	70.8	0.25	0.1788	71.2288
JBH25	79.6	0.25	0.1788	80.0288

4.4.4 GHG emissions

Among all stages, GHGs of JME and JBH25 were compared each other to observe the hot spot of each products presenting in Table 4.11. As the result of GHG emission evaluation, JME emitted higher GHG than JBH25 approximately 2 times. JME and JBH25 released GHG equal to 329.42 and 166.60, respectively. Focused on JME, the waste from biomass was managed by composting followed "*the 4/1000 Initiative Soils for Food Security and Climate*" A 4/1000 annual growth rate of the soil carbon stock intends to show that even a small increase in the soil carbon stock (agricultural soils, notably grasslands and pastures, and forest soils) is crucial to improve soil fertility and agricultural production and to contribute to achieving the long-term objective of limiting the temperature increase to +1,5/2°C. Crude glycerol is waste from JME production, which the Wiangsa agricultural cooperative can not recycle or utilize it due to its high impurity and mismanagement on collection process. Actually, It can be useful on cosmetic industry [125]. GHG of well to wheel is considered that JBH25 was confirmed that this microemulsion based biofuel can reruce GHG emission.

Table 4.11 GHG emissions from each stages in both JME and JBH25

Stages	JME	JBH25
	kgCO2e	kgCO2e
Cultivation	16.00	3.03
Extraction	12.20	2.31
Transportation	36.90	36.90
Production	8.10	9.22
Combustion	71.23	80.03
Waste handling	185.00	35.11
Total well to wheel	*329.42*	*166.60*
Total well to tank	*73.19*	*51.46*

JME @ GHG = 329.42 kgCO2e
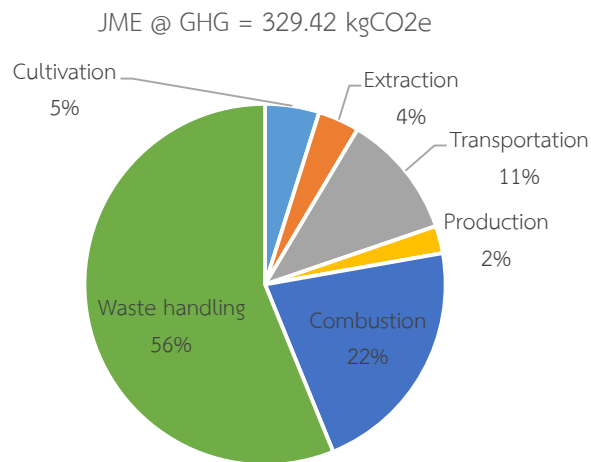
Figure 4.11 *Percentage of GHG emissions for whole life cycle of JME*

JBH25 @ GHG = 166.6 kgCO2e
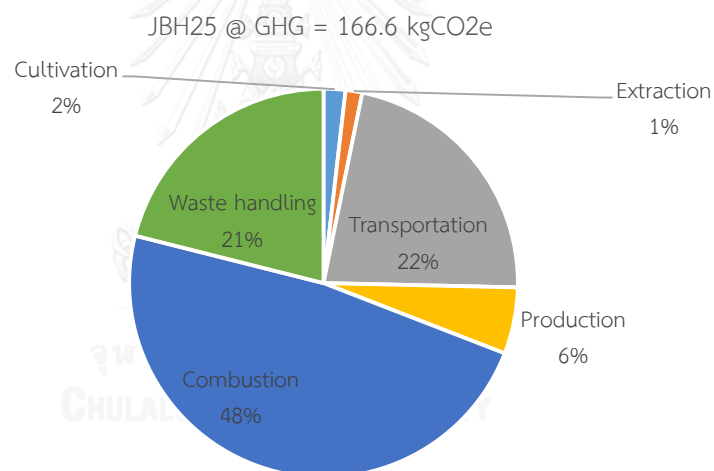
Figure 4.12 *Percentage of GHG emissions for whole life cycle of JBH25*

Whereas JBH25 showed the hot spot at combustion (use) process that emits 48% (Fig. 4.10) that might be improper method to estimate GHG emission. This study has investigated the GHG concentration at 1750 rpm 50% load, which the data presented in Table 4.12. This extra experiment was sampling the exhaust gas from end of pipe of diesel engine measured by GC analysis. Direct gas collection in air bag has limitation due to the fact that air samples have to send to laboratory for measurement that spent more time and CH_4 is unstable. However, the advantage of using JBH as biofuel can significantly reduce nitrous oxide.

Table 4.12 *Concentrations of GHG emission from exhaust gas emission of JME and JBH25*

Sample	Concentration (ppm) at 1750 rpm 50% load		
	CH4	CO2	N2O
JME-1	19.77	20,309.56	1.28
JME-2	54.84	23,800.96	1.51
JME-3	33.77	25,221.37	1.59
JBH25-1	13.35	13,614.64	0.81
JBH25-2	18.57	17,058.47	1.03
JBH25-3	27.05	16,689.21	1.11

4.4.5 Energy analysis

The efficiency of fuel was studied to evaluate that how many energy it consumes to produce itself for 1 GJ. NER (net energy ratio) is meaningful to describe the sustainability on energy production. The net energy value was calculated using energy factor (Table 4.13) multiplied by mass of material. The energy consumption was investigated in Fig.4.11, which indicates that JME 25 and JBH25 loose more energy in production stage due to using fossil diesel as material, which is the highest energy factor.
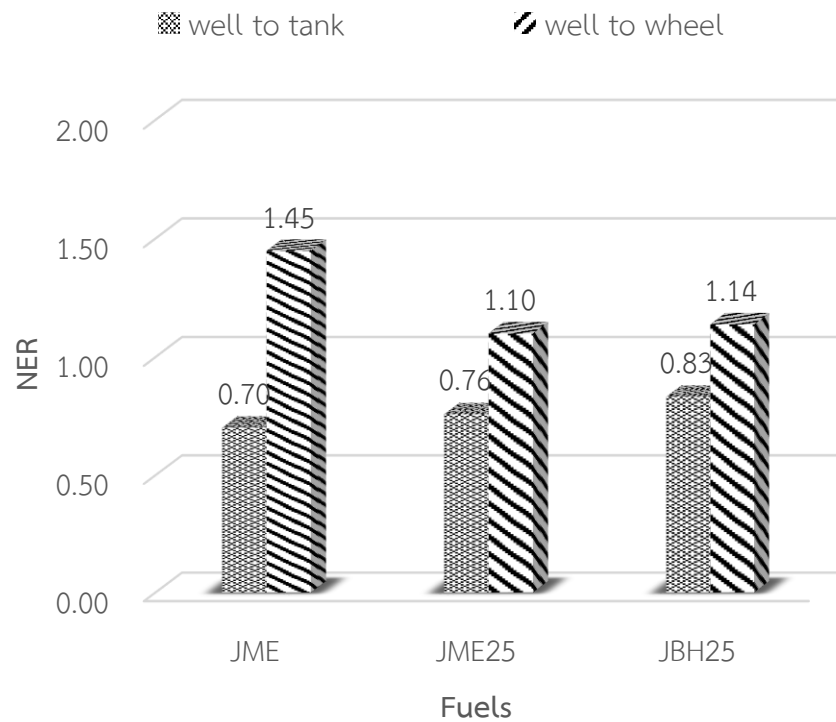
Figure 4.13 *The well to tank and well to wheel of net energy ratio of JME, JME25, and JBH25*

While, the cultivation stage is really low because they consume lower amount of fertilizers. The energy credits from wood wastes, oil sediment, and crude glycerol can be compensated for energy loss of neat JME. For NER, This term generally used to imply the sustainable fuel production. NER is higher than 1 means that the fuel provide more energy than requirement.

For NER calculation, it needs to study for all stages since heating value from wastes can compensate as gaining more energy. JME from well to wheel shows the highest NER, which is the most sustainable and efficient than the others. As show in Fig.4.11, if energy from wastes was not included, JBH25 shows the greatest NER (1.45) while, JME presents the lowest NER because it consume a lot of N fertilizer that is the highest impact to loose energy.

Table 4.13 *Energy factors for net energy ratio calculation*

Materials	Energy factor (MJ/kg)	References
Diesel	9.6	[82]
Bioethanol	8.80 MJ/L	[126]
Methanol	38.08	[82]
NaOH	19.87	[127]
JME	39.8	Result of this study
Electricity	36	[82]
N-fertilizer	87.9	[128]
P-fertilizer	26.4	[128]
K-fertilizer	10.5	[128]
Seed cake (as fertilizer)	6.22	Energy factor is computed assuming that 1 kg of seed cake ≈0.15 kg of N:P:K–40:20:10
Peel (air dry)	11.1-13.07	[82]
Crude glycerin	17.8	Result of this study
Wood (air dry)	16.54-15.5	[129]
Surfactant (LS1)	37.9	Result of this study

From this part, the results show that JBH is advantageous on performance, GHG emission, and energy efficiency. In addition, the hidden point of this result are as followed;

- The JBH is an alternative fuel that can promote use in rural area
- Jatropha is and effective non-food fuel that increase and promote income of community
- When the fossil oil price is decreasing, biodiesel mainly from palm oil is expensive, thus the JBH is an alternative for use in agricultural or other sectors

However, the GHG of biodiesel is much higher JBH. It can not deny that biodiesel is dominantly made from vegetable oil and replace diesel consumption than JHB. In addition, the studied area is agricultural area which can be avoided the study of land use change.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The production of Jatropha biodiesohol by micro-emulsion technique is uncomplicated which requires no specified tools or equipment. Additionally, electricity or water are not consume as feedstock compared to biodiesel from tranesterification. The derived Jatropha biodiesohol that is intended for use in agricultural machinery as well as diesel engines. However, the proper characteristic of this biofuel is transparent and homogenous regarding to the appearance of micro-emulsion. The Jatropha biodiesohol can prepare as follows:

- The studied surfactant is a non-ionic surfactant without salt and sulfur in their molecules. This experiment properly used Dehydol alcohol LS1, which is produced from palm oil containing an Ethoxylate group that governs to HLB equal to 3.6. This is the cause to form water in oil microemulsion.
- The suitable ratio of the mixture of ethanol to surfactant is at 3:1 providing a larger area of transparent and homogeneous microemulsion in pseudo ternary phase diagram.
- The study found that the Jatropha biodiesohol storage at 25-35 °C over six months still showed clear without separation phase.

The first property to be used as a main criteria for preparing JBH is kinematic viscosity, which affects to the injection system in diesel engines. The application of mathematical model to predict the optimal ratio or formula in the preparation of JBH showed that {3,3} lattice augmented with interior points and centroid is most appropriate to estimate desired kinematic viscosity. It is clearly seen that correlation coefficients (R^2) was the highest value with low residue. The kinematic viscosity of selected four formula has met biodiesel standard, which was E/S:CJO:D at 5:20:75, 5:25:70, 10:20:70, and 10:25:65 to study the fuel properties.

The fuel property testing of JBHs showed that acid value, density at 15 ° C, and flash point are not compatible with the standard for biodiesel. This is due to several issues. The Jatropha oil is an ingredient containing more than 75 percent of the polyunsaturated fatty acid that potentially convert to a free fatty acid that leads to

increase acid value. The density of diesel, which is a major component has very low causes the density of JBHs does not meet biodiesel standard. Additionally, the ethanol which is one component resulting in being low density and low flash point in JBHs. The higher ethanol also leads to reduce heating value and cetane number. From this reason, JBHs containing 10% E/S mixture are neglected to further study on engine performances.

Focusing on the development of biodiesohol, the results showed that JBH25 and JBH25E provide the advantages on power, torque and thermal efficiency. In addition, it can reduce the emission of nitrogen oxides and black smoke. It found that the score was not much different between both of JBH25 and JBH25E. Therefore, to reduce the use of additives, JBH25 used to estimate the greenhouse gas emissions in the further study.

The greenhouse gas emissions compared to the production of Jatropha biodiesel and Jatropha biodiesohol found that biodiesel and oil production of biodiesohol emit the greenhouse gas by 329.42 and 166.6 kilograms of carbon dioxide equivalent, respectively. The most source of greenhouse gas emissions for JME production is the process of cultivation since the acquisition of fertilizer release of N_2O from nitrogen fertilizers. While the the most emissions of JBH25 is combustion. Considering all stages of production, JBH emits less greenhouse gas than that of biodiesel.

The results of this overview. The consumption JBH can substitute fossil diesel up to 30 percent, which 5 percent belongs to bioethanol produced from cassava and sugarcane including palm oil based surfactant and the other 25 percent come from Jatropha oil, which does not interfere with food security, easy production, and suitable for use in agricultural areas.

5.2 Recommendations

From the knowledge gained from this research, the researcher suggests that there are many issues that should be studied further in order to fulfill the research to be more completed. To develop the biodiesohol on the adoption of sustainable production and to contribute to implementation, it should be provided as follows:

- Jatropha oil, eventhough it looks clear, there is natural gum that should be removed (degumming) prior to produce JBHs. The natural gum has eliminated

at this early stage may reduce the carbon residue that can cause engine problems in long term use.

- Some of the fuel properties should be improved such as temperature stability and flashpoint which these properties are affected by temperature in storage procedure. Some areas there may be a wide range of temperatures which affects the improper appearance such as macroemulsion formation and phase separation that provides inappropriate on engine performance including on safety both in the transport and storage.

- The relevant agency should scope and define a standard feature of microemulsion based biofuel. The guideline is required to use in comparison with the same technique to produce oil. In this report, the JBHs were compared to Jatropha methylester. This may not be appropriate in terms of comparison.

- Although, the engine test was studied in this research. In fact, there are many types and technologies of compressed ignition engine were not investigated. Therefore, it should be studied more in engine performance in different type of diesel engine, especially agricultural machinery. In addition, the long-term effects from the use of microemulsion based biofuel to the engine may be studied further to ensure that farmers can use this fuel in their farms.

- This kind of biofuel is lacking of promotion and encouragement to contribute to implementing. There should be reviewed the feasibility of using this fuel in rural area without complicated tool. The strategies to reach the recognition of farmers to use biodiesohol should be created.

- Life cycle assessment studies may need to cover not only the global warming but also other environmental impacts. The study of the land use change and biodiversity in case of studied area is not agricultural should be evaluated.

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APPENDICES

Appendix A Raw data and statistical analysis of kinematic viscosity for comparing the significance of EO group, E/S ratio, and E/S content.

Table A-1 Mean and SD from kinematic viscosity at different EO group, E/S ratio, and E/S content

code	time				K	K*t = Viscosity	mean	SD
	min	sec	subsec	tot sec	cSt/s	Cts		
L1_1-(0.5-2.5-7)-1	6	26	37	386.37	0.01407	5.4362		
L1_1-(0.5-2.5-7)-2	6	18	44	378.44	0.01407	5.3247	5.3618	0.064459
L1_1-(0.5-2.5-7)-3	6	18	43	378.43	0.01407	5.3245		
L1_1-(1-2.5-6.5)-1	6	9	8	369.08	0.01407	5.1930		
L1_1-(1-2.5-6.5)-2	6	8	6	368.06	0.01407	5.1786	5.1572	0.049989
L1_1-(1-2.5-6.5)-3	6	2	48	362.48	0.01407	5.1001		
L1_1-(2-2.5-5.5)-1	6	0	21	360.21	0.01407	5.0682		
L1_1-(2-2.5-5.5)-2	6	5	24	365.24	0.01407	5.1389	5.1520	0.091107
L1_1-(2-2.5-5.5)-3	6	13	6	373.06	0.01407	5.2490		
L1_2-(0.5-2.5-7)-1	6	23	73	383.73	0.01407	5.3991		
L1_2-(0.5-2.5-7)-2	5	59	42	359.42	0.01407	5.0570	5.2483	0.17456
L1_2-(0.5-2.5-7)-3	6	15	88	375.88	0.01407	5.2886		
L1_2-(1-2.5-6.5)-1	6	9	7	369.07	0.01407	5.1928		
L1_2-(1-2.5-6.5)-2	5	56	46	356.46	0.01407	5.0154	5.0377	0.145229
L1_2-(1-2.5-6.5)-3	5	48	61	348.61	0.01407	4.9049		
L1_2-(2-2.5-5.5)-1	5	29	28	329.28	0.01407	4.6330		
L1_2-(2-2.5-5.5)-2	5	33	88	333.88	0.01407	4.6977	4.7732	0.189698
L1_2-(2-2.5-5.5)-3	5	54	59	354.59	0.01407	4.9891		
L1_3-(0.5-2.5-7)-1	5	45	24	345.24	0.01407	4.8575		
L1_3-(0.5-2.5-7)-2	6	13	90	373.9	0.01407	5.2608	4.9931	0.231806
L1_3-(0.5-2.5-7)-3	5	45	49	345.49	0.01407	4.8610		
L1_3-(1-2.5-6.5)-1	5	39	22	339.22	0.01407	4.7728		
L1_3-(1-2.5-6.5)-2	5	40	97	340.97	0.01407	4.7974	4.8254	0.070817
L1_3-(1-2.5-6.5)-3	5	48	68	348.68	0.01407	4.9059		
L1_3-(2-2.5-5.5)-1	5	16	85	316.85	0.01407	4.4581		
L1_3-(2-2.5-5.5)-2	5	21	81	321.81	0.01407	4.5279	4.5184	0.056243
L1_3-(2-2.5-5.5)-3	5	24	76	324.76	0.01407	4.5694		
L1_4-(0.5-2.5-7)-1	5	42	73	342.73	0.01407	4.8222		
L1_4-(0.5-2.5-7)-2	5	40	23	340.23	0.01407	4.7870	4.8927	0.153566
L1_4-(0.5-2.5-7)-3	6	0	26	360.26	0.01407	5.0689		
L1_4-(1-2.5-6.5)-1	5	34	26	334.26	0.01407	4.7030		
L1_4-(1-2.5-6.5)-2	5	33	7	333.07	0.01407	4.6863	4.6816	0.024199
L1_4-(1-2.5-6.5)-3	5	30	87	330.87	0.01407	4.6553		
L1_4-(2-2.5-5.5)-1	5	10	14	310.14	0.01407	4.3637	4.5570	0.422191
L1_4-(2-2.5-5.5)-2	5	3	21	303.21	0.01407	4.2662		

code	time				K	K*t = Viscosity	mean	SD
	min	sec	subsec	tot sec	cSt/s	Cts		
L1_4-(2-2.5-5.5)-3	5	58	30	358.3	0.01407	5.0413		
L3_1-(0.5-2.5-7)-1	6	26	71	386.71	0.01431	5.5338	5.4616	0.064586
L3_1-(0.5-2.5-7)-2	6	18	2	378.02	0.01431	5.4095		
L3_1-(0.5-2.5-7)-3	6	20	25	380.25	0.01431	5.4414		
L3_1-(1-2.5-6.5)-1	6	19	78	379.78	0.01431	5.4347	5.4212	0.022397
L3_1-(1-2.5-6.5)-2	6	17	3	377.03	0.01431	5.3953		
L3_1-(1-2.5-6.5)-3	6	19	70	379.7	0.01431	5.4335		
L3_1-(2-2.5-5.5)-1	6	11	93	371.93	0.01431	5.3223	5.3714	0.065746
L3_1-(2-2.5-5.5)-2	6	13	57	373.57	0.01431	5.3458		
L3_1-(2-2.5-5.5)-3	6	20	58	380.58	0.01431	5.4461		
L3_2-(0.5-2.5-7)-1	6	2	35	362.35	0.01431	5.1852	5.2935	0.099864
L3_2-(0.5-2.5-7)-2	6	11	30	371.3	0.01431	5.3133		
L3_2-(0.5-2.5-7)-3	6	16	10	376.1	0.01431	5.3820		
L3_2-(1-2.5-6.5)-1	6	9	43	369.43	0.01431	5.2865	5.3176	0.124363
L3_2-(1-2.5-6.5)-2	6	21	17	381.17	0.01431	5.4545		
L3_2-(1-2.5-6.5)-3	6	4	20	364.2	0.01431	5.2117		
L3_2-(2-2.5-5.5)-1	5	30	97	330.97	0.01431	4.7362	4.7791	0.053209
L3_2-(2-2.5-5.5)-2	5	32	81	332.81	0.01431	4.7625		
L3_2-(2-2.5-5.5)-3	5	38	13	338.13	0.01431	4.8386		
L3_3-(0.5-2.5-7)-1	5	52	57	352.57	0.01431	5.0453	4.9179	0.362352
L3_3-(0.5-2.5-7)-2	6	3	34	363.34	0.01431	5.1994		
L3_3-(0.5-2.5-7)-3	5	15	10	315.1	0.01431	4.5091		
L3_3-(1-2.5-6.5)-1	5	52	36	352.36	0.01431	5.0423	4.8910	0.132893
L3_3-(1-2.5-6.5)-2	5	38	7	338.07	0.01431	4.8378		
L3_3-(1-2.5-6.5)-3	5	34	94	334.94	0.01431	4.7930		
L3_3-(2-2.5-5.5)-1	5	32	16	332.16	0.01431	4.7532	4.7257	0.177756
L3_3-(2-2.5-5.5)-2	5	16	97	316.97	0.01431	4.5358		
L3_3-(2-2.5-5.5)-3	5	41	59	341.59	0.01431	4.8882		
L3_4-(0.5-2.5-7)-1	5	45	30	345.3	0.01431	4.9412	5.0009	0.139287
L3_4-(0.5-2.5-7)-2	5	42	51	342.51	0.01431	4.9013		
L3_4-(0.5-2.5-7)-3	6	0	59	360.59	0.01431	5.1600		
L3_4-(1-2.5-6.5)-1	5	14	34	314.34	0.01431	4.4982	4.7287	0.204287
L3_4-(1-2.5-6.5)-2	5	35	48	335.48	0.01431	4.8007		
L3_4-(1-2.5-6.5)-3	5	41	53	341.53	0.01431	4.8873		
L3_4-(2-2.5-5.5)-1	5	8	97	308.97	0.01431	4.4214	4.4453	0.052626
L3_4-(2-2.5-5.5)-2	5	8	10	308.1	0.01431	4.4089		
L3_4-(2-2.5-5.5)-3	5	14	86	314.86	0.01431	4.5056		
L7_1-(0.5-2.5-7)-1	12	52	93	772.93	0.007196	5.5620	5.5144	0.055456
L7_1-(0.5-2.5-7)-2	12	37	85	757.85	0.007196	5.4535		
L7_1-(0.5-2.5-7)-3	12	48	15	768.15	0.007196	5.5276		
L7_1-(1-2.5-6.5)-1	13	26	9	806.09	0.007196	5.8006	5.7693	0.164554

code	time				K	K*t = Viscosity	mean	SD
	min	sec	subsec	tot sec	cSt/s	Cts		
L7_1-(1-2.5-6.5)-2	12	57	1	777.01	0.007196	5.5914		
L7_1-(1-2.5-6.5)-3	13	42	12	822.12	0.007196	5.9160		
L7_1-(2-2.5-5.5)-1	13	9	81	789.81	0.007196	5.6835		
L7_1-(2-2.5-5.5)-2	13	27	57	807.57	0.007196	5.8113	5.7743	0.079121
L7_1-(2-2.5-5.5)-3	13	29	92	809.92	0.007196	5.8282		
L7_2-(0.5-2.5-7)-1	12	17	1	737.01	0.007196	5.3035		
L7_2-(0.5-2.5-7)-2	12	3	89	723.89	0.007196	5.2091	5.2771	0.059354
L7_2-(0.5-2.5-7)-3	12	19	11	739.11	0.007196	5.3186		
L7_2-(1-2.5-6.5)-1	11	43	65	703.65	0.007196	5.0635		
L7_2-(1-2.5-6.5)-2	11	53	67	713.67	0.007196	5.1356	5.1348	0.070956
L7_2-(1-2.5-6.5)-3	12	3	37	723.37	0.007196	5.2054		
L7_2-(2-2.5-5.5)-1	12	31	27	751.27	0.007196	5.4061		
L7_2-(2-2.5-5.5)-2	12	42	85	762.85	0.007196	5.4895	5.4500	0.041836
L7_2-(2-2.5-5.5)-3	12	37	97	757.97	0.007196	5.4544		
L7_3-(0.5-2.5-7)-1	12	38	25	758.25	0.007196	5.4564		
L7_3-(0.5-2.5-7)-2	12	10	32	730.32	0.007196	5.2554	5.2257	0.246833
L7_3-(0.5-2.5-7)-3	11	30	2	690.02	0.007196	4.9654		
L7_3-(1-2.5-6.5)-1	12	0	0	720	0.007196	5.1811		
L7_3-(1-2.5-6.5)-2	11	44	54	704.54	0.007196	5.0699	5.0654	0.118042
L7_3-(1-2.5-6.5)-3	11	27	21	687.21	0.007196	4.9452		
L7_3-(2-2.5-5.5)-1	11	19	72	679.72	0.007196	4.8913		
L7_3-(2-2.5-5.5)-2	11	58	80	718.8	0.007196	5.1725	4.9954	0.15414
L7_3-(2-2.5-5.5)-3	11	24	6	684.06	0.007196	4.9225		
L7_4-(0.5-2.5-7)-1	11	33	89	693.89	0.007196	4.9932		
L7_4-(0.5-2.5-7)-2	11	53	28	713.28	0.007196	5.1328	5.0888	0.08287
L7_4-(0.5-2.5-7)-3	11	54	35	714.35	0.007196	5.1405		
L7_4-(1-2.5-6.5)-1	11	38	66	698.66	0.007196	5.0276		
L7_4-(1-2.5-6.5)-2	11	40	12	700.12	0.007196	5.0381	4.9621	0.122549
L7_4-(1-2.5-6.5)-3	11	9	92	669.92	0.007196	4.8207		
L7_4-(2-2.5-5.5)-1	11	29	96	689.96	0.007196	4.9650		
L7_4-(2-2.5-5.5)-2	11	18	79	678.79	0.007196	4.8846	4.9053	0.052485
L7_4-(2-2.5-5.5)-3	11	16	25	676.25	0.007196	4.8663		

Table A-2 The statistical analysis focused on comparison of significant difference between EO group of surfactant (Different letter-a,b, and c refers to a significant difference of kinematic viscosity with various surfactants in each proportion, while ns refers to no significance)

E/S	E/S:CJO:D	Kinematic viscosity (cSt)		
		LS1	LS3	LS7
1	5:20:75	*4.8304 ± 0.0756 ns*	*4.8052 ± 0.0632 ns*	*4.8622 ± 0.0326 ns*
	10:20:70	4.6394 ± 0.0255 a	4.7616 ± 0.0128 b	4.8444 ± 0.0700 b
	20:20:60	4.6077 ± 0.0709 b	4.3811 ± 0.0508 a	5.1686 ± 0.0366 c
2	5:20:75	4.5517 ± 0.0288 a	4.7109 ± 0.0494 b	4.7347 ± 0.0306 b
	10:20:70	4.4463 ± 0.0654 a	4.5113 ± 0.0310 ab	4.5380 ± 0.0241 b
	20:20:60	4.2433 ± 0.1163 a	4.6078 ± 0.1450 b	4.4474 ± 0.1174 ab
3	5:20:75	4.5273 ± 0.0407 ns	4.6707 ± 0.1248 ns	4.5715 ± 0.0248 ns
	10:20:70	4.3603 ± 0.0472 a	4.4660 ± 0.0133 b	4.4551 ± 0.0269 b
	20:20:60	4.1155 ± 0.0168 ns	4.3454 ± 0.2309 ns	4.2832 ± 0.0547 ns
4	5:20:75	4.5131 ± 0.0454 ns	4.5557 ± 0.0497 ns	4.5688 ± 0.0542 ns
	10:20:70	4.3388 ± 0.0599 ns	4.3894 ± 0.0875 ns	4.4409 ± 0.0504 ns
	20:20:60	4.0042 ± 0.0793 a	4.0279 ± 0.0927 a	4.4202 ± 0.1772 b
1	5:25:70	5.3618 ± 0.0645 a	5.4616 ± 0.0646 ab	5.5144 ± 0.0555 b
	10:25:65	5.1572 ± 0.0500 a	5.4212 ± 0.0224 b	5.7693 ± 0.1646 c
	20:25:55	5.1520 ± 0.0911 a	5.3714 ± 0.0657 b	5.7743 ± 0.0791 c
2	5:25:70	5.2483 ± 0.1746 ns	5.2935 ± 0.0999 ns	5.2771 ± 0.0594 ns
	10:25:65	5.0377 ± 0.1452 a	5.3176 ± 0.1244 b	5.1348 ± 0.071 ab
	20:25:55	4.7732 ± 0.1897 a	4.7791 ± 0.0532 a	5.4500 ± 0.0418 b
3	5:25:70	4.9931 ± 0.2318 ns	4.9179 ± 0.3624 ns	5.2257 ± 0.2468 ns
	10:25:65	4.8254 ± 0.0708 a	4.8910 ± 0.1329 ab	5.0654 ± 0.118 b
	20:25:55	4.5184 ± 0.0562 a	4.7257 ± 0.1778 ab	4.9954 ± 0.1541 b
4	5:25:70	4.8927 ± 0.1536 ns	5.0009 ± 0.1393 ns	5.0888 ± 0.0829 ns
	10:25:65	4.6816 ± 0.0242 ns	4.7287 ± 0.2043 ns	4.9621 ± 0.1225 ns
	20:25:55	4.5570 ± 0.4222 ns	4.4453 ± 0.0526 ns	4.9053 ± 0.0525 ns

Table A-3 The statistical analysis focused on comparison of significant difference between E/S ratio of system (Different letter-a,b, and c refers to a significant difference of kinematic viscosity with various E/S ratio in each proportion, while ns refers to no significance)

Surfactant	E/S	Kinematic viscosity (cSt)		
E/S:CJO:D		5:20:75	10:20:70	20:20:60
LS1	1	4.8304 ± 0.0756 b	4.6394 ± 0.0255 c	4.6077 ± 0.0709 c
	2	4.5517 ± 0.0288 a	4.4463 ± 0.0654 b	4.2433 ± 0.1163 b
	3	4.5273 ± 0.0407 a	4.3603 ± 0.0472 ab	4.1155 ± 0.0168 ab
	4	4.5131 ± 0.0454 a	4.3388 ± 0.0599 a	4.0042 ± 0.0793 a
LS3	1	4.8052 ± 0.0632 b	4.7616 ± 0.0128 c	4.3811 ± 0.0508 b
	2	4.7109 ± 0.0494 b	4.5113 ± 0.0310 b	4.6078 ± 0.1450 b
	3	4.6707 ± 0.1248 ab	4.4660 ± 0.0133 ab	4.3454 ± 0.2309 b
	4	4.5557 ± 0.0497 a	4.3894 ± 0.0875 a	4.0279 ± 0.0927 a
LS7	1	4.8622 ± 0.0326 c	4.8444 ± 0.0700 c	5.1686 ± 0.0366 b
	2	4.7347 ± 0.0306 b	4.5380 ± 0.0241 b	4.4474 ± 0.1174 a
	3	4.5715 ± 0.0248 a	4.4551 ± 0.0269 ab	4.2832 ± 0.0547 a
	4	4.5688 ± 0.0542 a	4.4409 ± 0.0504 a	4.4202 ± 0.1772 a
E/S:CJO:D		5:25:70	10:25:65	20:25:55
LS1	1	5.3618 ± 0.0645 b	5.1572 ± 0.0500 b	5.1520 ± 0.0911 b
	2	5.2483 ± 0.1746 b	5.0377 ± 0.1452 b	4.7732 ± 0.1897 ab
	3	4.9931 ± 0.2318 a	4.8254 ± 0.0708 a	4.5184 ± 0.0562 a
	4	4.8927 ± 0.1536 a	4.6816 ± 0.0242 a	4.5570 ± 0.4222 a
LS3	1	5.4616 ± 0.0646 b	5.4212 ± 0.0224 b	5.3714 ± 0.0657 c
	2	5.2935 ± 0.0999 ab	5.3176 ± 0.1244 b	4.7791 ± 0.0532 b
	3	4.9179 ± 0.3624 a	4.8910 ± 0.1329 a	4.7257 ± 0.1778 b
	4	5.0009 ± 0.1393 a	4.7287 ± 0.2043 a	4.4453 ± 0.0526 a
LS7	1	5.5144 ± 0.0555 b	5.7693 ± 0.1646 b	5.7743 ± 0.0791 c
	2	5.2771 ± 0.0594 ab	5.1348 ± 0.0710 a	5.4500 ± 0.0418 b
	3	5.2257 ± 0.2468 a	5.0654 ± 0.118 a	4.9954 ± 0.1541 a
	4	5.0888 ± 0.0829 a	4.9621 ± 0.1225 a	4.9053 ± 0.0525 a

Appendix B Average data of performances and emissions of various fuels at different engine speed

Table B-1 Data for performance calculation and exhaust gas emission analysis with different fuels and speed of engine

Fuel	Speed	Density	weight	BSFC	Torque	Power	Calorific value	BTE	Smoke	CO2	CO	O2	NOₓ
	rpm	g/mL	kg	kg/kw.hr	N-m	kw	MJ/kg		%	%	%	%	ppm
Diesel	1250	0.830	0.026	0.324	17.416	2.279	44.500	24.941	18.000	3.300	0.010	16.360	328.000
	1500	0.830	0.032	0.303	18.005	2.827	44.500	26.672	32.000	3.740	0.030	15.600	303.000
	1750	0.830	0.043	0.308	18.375	3.366	44.500	26.266	38.000	3.570	0.040	15.980	347.000
	2000	0.830	0.034	0.326	16.122	3.375	44.500	24.811	12.000	2.870	0.010	16.880	327.000
	2250	0.830	0.038	0.333	14.717	3.466	44.500	24.280	12.000	2.730	0.000	17.200	275.000
JME	1250	0.865	0.041	0.294	19.196	2.511	39.800	30.737	12.000	3.270	0.030	16.280	322.000
	1500	0.865	0.049	0.290	18.820	2.955	39.800	31.172	24.000	3.690	0.050	15.780	347.000
	1750	0.865	0.047	0.305	18.534	3.395	39.800	29.622	21.000	3.340	0.030	16.140	318.000
	2000	0.865	0.056	0.336	15.642	3.274	39.800	26.916	11.000	2.820	0.010	17.070	317.000
	2250	0.865	0.038	0.363	13.502	3.180	39.800	24.907	8.000	2.680	0.010	17.290	298.000
JD20	1250	0.838	0.034	0.302	18.690	2.445	44.200	26.947	13.000	3.240	0.010	16.370	279.000
	1500	0.838	0.042	0.301	18.118	2.845	44.200	27.022	13.000	3.740	0.010	15.590	324.000
	1750	0.838	0.034	0.277	20.412	3.739	44.200	29.376	11.000	3.590	0.000	15.860	395.000
	2000	0.838	0.035	0.295	17.844	3.735	44.200	27.648	9.000	2.870	0.000	16.900	312.000
	2250	0.838	0.035	0.379	12.922	3.043	44.200	21.464	6.000	2.680	0.000	17.320	265.000
JD25	1250	0.842	0.036	0.293	19.292	2.524	43.700	28.134	12.000	3.340	0.010	16.150	313.000
	1500	0.842	0.040	0.286	19.080	2.996	43.700	28.782	23.000	3.950	0.020	15.440	368.000
	1750	0.842	0.035	0.290	19.498	3.571	43.700	28.381	20.000	3.650	0.020	15.870	384.000
	2000	0.842	0.040	0.291	18.034	3.775	43.700	28.263	14.000	2.730	0.000	17.260	285.000
	2250	0.842	0.035	0.365	13.452	3.168	43.700	22.600	6.000	2.730	0.010	17.190	304.000
JBH20	1250	0.837	0.036	0.323	17.490	2.288	43.200	25.801	15.000	3.240	0.030	16.330	258.000
	1500	0.837	0.029	0.327	16.726	2.626	43.200	25.523	14.000	3.460	0.020	16.020	280.000
	1750	0.837	0.035	0.321	17.644	3.232	43.200	25.980	23.000	3.420	0.030	15.960	325.000
	2000	0.837	0.035	0.342	15.384	3.220	43.200	24.389	10.000	2.760	0.010	17.020	270.000
	2250	0.837	0.037	0.360	13.604	3.204	43.200	23.120	3.000	2.800	0.000	17.060	248.000
JBH20E	1250	0.837	0.041	0.295	19.174	2.509	43.300	28.220	14.000	3.490	0.020	16.090	247.000
	1500	0.837	0.028	0.294	18.572	2.916	43.300	28.274	13.000	3.660	0.010	15.780	278.000
	1750	0.837	0.036	0.297	19.024	3.485	43.300	27.947	11.000	3.430	0.000	16.240	297.000
	2000	0.837	0.040	0.329	15.972	3.343	43.300	25.262	9.000	2.750	0.000	16.950	257.000
	2250	0.837	0.038	0.338	14.518	3.419	43.300	24.616	8.000	2.800	0.010	17.020	237.000
JBH25	1250	0.841	0.031	0.283	19.960	2.611	42.900	29.650	12.000	3.480	0.010	15.970	271.000
	1500	0.841	0.024	0.291	18.748	2.943	42.900	28.808	11.000	3.680	0.010	15.720	287.000
	1750	0.841	0.037	0.280	20.198	3.700	42.900	29.948	9.000	3.600	0.010	15.880	334.000
	2000	0.841	0.037	0.324	16.202	3.392	42.900	25.865	6.000	2.910	0.010	16.850	262.000
	2250	0.841	0.040	0.341	14.362	3.382	42.900	24.579	7.000	2.680	0.000	17.200	221.000
JBH25E	1250	0.841	0.038	0.291	19.434	2.543	43.000	28.802	6.000	3.320	0.010	16.200	292.000

Fuel	Speed	Density	weight	BSFC	Torque	Power	Calorific value	BTE	Smoke	CO2	CO	O2	NOx
	rpm	g/mL	kg	kg/kw.hr	N-m	kw	MJ/kg		%	%	%	%	ppm
	1500	0.841	0.027	0.297	18.392	2.888	43.000	28.196	9.000	3.520	0.010	15.960	297.000
	1750	0.841	0.028	0.293	19.306	3.536	43.000	28.559	8.000	3.480	0.010	16.070	318.000
	2000	0.841	0.039	0.319	16.462	3.446	43.000	26.219	5.000	2.860	0.010	16.830	270.000
	2250	0.841	0.040	0.335	14.652	3.451	43.000	25.017	4.000	2.810	0.010	17.010	237.000

Appendix C Data for scoreing analysis

Table C-1 Average BSFC, Torque, BTE, Smoke, CO, and NO$_x$ at all speeds and their range of ranking

Factors		BSFC		Torque		BTE		Smoke		CO		NO$_x$	
Fuels	Unit	kg/kw.hr	Ranking	N-m	Ranking		Ranking	%	Ranking	%	Ranking	ppm	Ranking
Diesel	Average	0.3190	3	16.9269	3	25.3940	1	22.4	1	0.0180	2	316.00	2
JME	Average	0.3178	3	17.1388	4	28.6704	5	15.2	3	0.0260	1	320.40	1
JBH20	Average	0.3345	1	16.1696	1	24.9624	1	13.0	3	0.0180	2	276.20	5
JBH20E	Average	0.3106	4	17.4520	4	26.8639	3	11.0	4	0.0080	5	263.20	5
JBH25	Average	0.3041	5	17.8940	5	27.7702	4	9.0	5	0.0080	5	275.00	4
JBH25E	Average	0.3069	5	17.6492	5	27.3585	4	6.4	5	0.0100	4	282.80	4
Min		0.3041		16.1696		24.9624		6.4000		0.0040		263.2000	
Max		0.3345		17.8940		28.6704		22.4000		0.0260		330.8000	
Max-Min		0.0304		1.7244		3.7081		16.0000		0.0220		67.6000	
Lt		5.0000		5.0000		5.0000		5.0000		5.0000		5.0000	
(Max-Min)/Lt		0.0061		0.3449		0.7416		3.2000		0.0044		13.5200	
L1	L5	0.3041	0.3102	16.1696	16.5145	24.9624	25.7040	6.4	9.6	0.0040	0.0084	263.20	276.72
L2	L4	0.3102	0.3162	16.5145	16.8594	25.7040	26.4456	9.6	12.8	0.0084	0.0128	276.72	290.24
L3	L3	0.3162	0.3223	16.8594	17.2042	26.4456	27.1872	12.8	16.0	0.0128	0.0172	290.24	303.76
L4	L2	0.3223	0.3284	17.2042	17.5491	27.1872	27.9288	16.0	19.2	0.0172	0.0216	303.76	317.28
L5	L1	0.3284	0.3345	17.5491	17.8940	27.9288	28.6704	19.2	22.4	0.0216	0.0260	317.28	330.80

Appendix D Data for GHG emissions

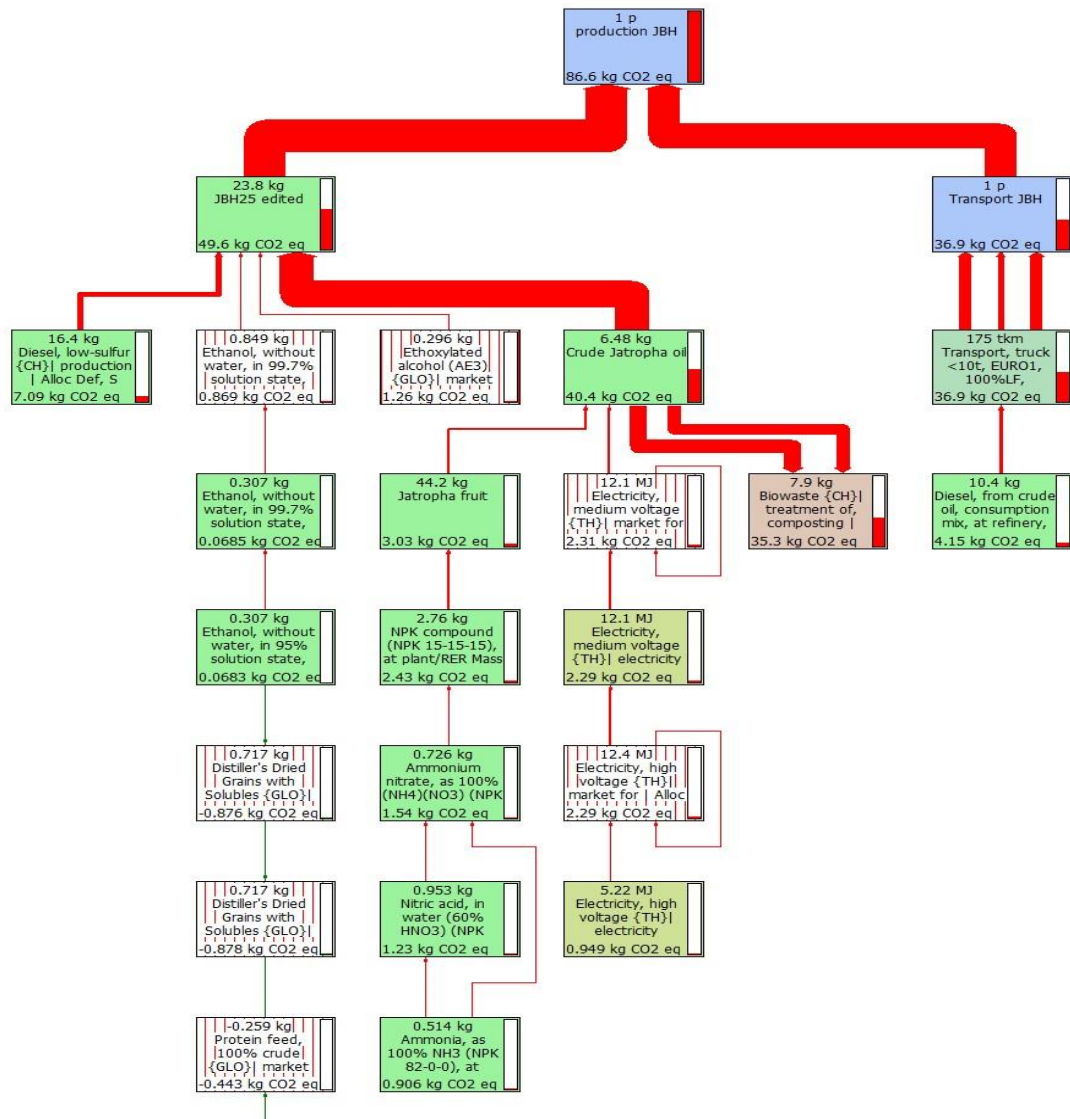Figure D-1 Main sources of GHG emissions of JME

Figure D-2 Main sources of GHG emissions of JBH25

Table D-1 DEFAULT EMISSION FACTORS FOR STATIONARY COMBUSTION IN THE <u>RESIDENTIAL AND AGRICULTURE/FORESTRY/FISHING/FISHINGFARMS</u> CATEGORIES (kg of greenhouse gas per TJ on a Net Calorific Basis)

Fuel		CO_2			CH			N_2		
		Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper
Crude Oil		73 300	71	75	10	3	30	0.6	0.2	2
Orimulsion		r 77 000	69	85	10	3	30	0.6	0.2	2
Natural Gas Liquids		r 64 200	58	70	10	3	30	0.6	0.2	2
Gasoline	Motor Gasoline	r 69 300	67	73	10	3	30	0.6	0.2	2
	Aviation	r 70 000	67	73	10	3	30	0.6	0.2	2
	Jet Gasoline	r 70 000	67	73	10	3	30	0.6	0.2	2
Jet Kerosene		r 71 500	69	74	10	3	30	0.6	0.2	2
Other Kerosene		71 900	70	73	10	3	30	0.6	0.2	2
Shale Oil		73 300	67	79	10	3	30	0.6	0.2	2
Gas/Diesel Oil		*74 100*	*72*	*74*	*10*	*3*	*3*	*0.6*	*0.2*	*2*
Residual Fuel Oil		77 400	75	78	10	3	30	0.6	0.2	2
Liquefied Petroleum		63 100	61	65	5	1.5	15	0.1	0.03	0.3
Ethane		61 600	56	68	5	1.5	15	0.1	0.03	0.3
Naphtha		73 300	69	76	10	3	30	0.6	0.2	2
Bitumen		80 700	73	89	10	3	30	0.6	0.2	2
Lubricants		73 300	71	75	10	3	30	0.6	0.2	2
Petroleum Coke		r 97 500	82	115	10	3	30	0.6	0.2	2
Refinery Feedstocks		73 300	68	76	10	3	30	0.6	0.2	2
Other Oil	Refinery Gas	n 57 600	48	69	5	1.5	15	0.1	0.03	0.3
	Paraffin Waxes	73 300	72	74	10	3	30	0.6	0.2	2
	White Spirit and SBP	73 300	72 200	74 400	10	3	30	0.6	0.2	3
	Other Petroleum Products	73 300	72 200	74 400	10	3	30	0.6	0.2	2
Anthracite		98 300	94	101	300	10	900	1.5	0.5	5
Coking Coal		94 600	87	101	300	10	900	1.5	0.5	5
Other Bituminous		94 600	89	99	300	10	900	1.5	0.5	5
Sub-Bituminous Coal		96 100	92	100	300	10	900	1.5	0.5	5
Lignite		101 000	90	115	300	10	900	1.5	0.5	5
Oil Shale and Tar		107 000	90	125	300	100	900	1.5	0.5	5
Brown Coal Briquettes		n 97 500	87	109	n 300	10	900	n 1.5	0.5	5
Patent Fuel		97 500	87	109	300	10	900	1.5	0.5	5

Fuel		CO₂			CH₄			N₂O		
		Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper
Natural Gas		56 100	54 300	58	5	1.5	15	0.1	0.03	0.3
Municipal Wastes (non-		n 91 700	73 300	121 000	300	100	900	4	1.5	15
Industrial Wastes		n 143 000	110	183	300	100	900	4	1.5	15
Waste Oils		n 73 300	72 200	74	300	100	900	4	1.5	15
Peat		106 000	100	108	n 300	100	900	n 1.4	0.5	5
Solid Biofuels	Wood / Wood	n 112 000	95 000	132	300	100	900	4	1.5	15
	Sulphite lyes (Black Liquor)[a]	n 95 300	80 700	110 000	n 3	1	18	n 2	1	21
	Other Primary Solid Biomass	n 100 000	84 700	117 000	300	100	900	4	1.5	15
	Charcoal	n 112 000	95 000	132	200	70	600	1	0.3	3
Liquid	Biogasoline	n 70 800	59 800	84	10	3	30	0.6	0.2	2
	Biodiesels	n 70 800	59 800	84	10	3	30	0.6	0.2	2
	Other Liquid	r 79 600	67 100	95 300	10	3	30	0.6	0.2	2
Gas Biomass	Landfill Gas	n 54 600	46 200	66	5	1.5	15	0.1	0.03	0.3
	Sludge Gas	n 54 600	46 200	66	5	1.5	15	0.1	0.03	0.3
	Other Biogas	n 54 600	46 200	66	5	1.5	15	0.1	0.03	0.3
Other	Municipal Wastes (biomass fraction)	n 100 000	84 700	117 000	300	100	900	4	1.5	15

(a) Includes the biomass-derived CO2 emitted from the black liquor combustion unit and the biomass-derived CO2 emitted from the kraft mill lime kiln.

n   indicates a new emission factor which was not present in the 1996 IPCC Guidelines.

r   indicates an emission factor that has been revised since the 1996I PCC Guidelines.

Appendix E Data for energy analysis

Table E-1 Energy analysis of JME

Fuel	Process	Material	Handling	Energy factor		Amount (kg)	Energy	
				Gain	loss		Gain	loss
JME 1 GJ	Cultivation	N Fertilizer			87.90	4.85	0.00	426.23
		P Fertilizer			26.40	4.85	0.00	128.02
		K Fertilizer			10.50	4.85	0.00	50.92
		Diesel			43.10	1.52	0.00	65.46
		Electricity			10.00	0.52	0.00	5.21
	Transportation	Diesel			43.10	7.00	0.00	301.70
	Extraction	Electricity			10.00	17.62	0.00	176.20
	Transesterification	JME		39.80		25.13	1000.00	0.00
		MeOH			38.08	5.41	0.00	205.88
		KOH			19.87	0.41	0.00	8.15
		Electricity			10.00	5.63	0.00	56.25
	End of life	stem	Subsituted LPG	16.54		29.09	481.22	0.00
		Oil sediment	Subsituted Bunker oil	22.30		1.71	38.10	0.00
		Shell	Composting	6.22		87.28	542.90	0.00
		Seedcake	Composting	6.22		114.13	709.90	0.00
		Crude glycerol	Subsituted Bunker oil	17.80		5.13	91.25	0.00
						Total	2062.23	1424.00
						NEB	638.23	
						NER	1.45	

Table E-2 Energy analysis of JME25

Fuel	Process	Material	Handling	Energy factor		Amount (kg)	Energy	
				Gain	loss		Gain	loss
JME25 1GJ	Cultivation	N Fertilizer			87.90	1.21	0.00	106.56
		P Fertilizer			26.40	1.21	0.00	32.00
		K Fertilizer			10.50	1.21	0.00	12.73
		Diesel			43.10	0.38	0.00	16.36
		Electricity			10.00	0.13	0.00	1.30
	Transportation	Diesel			43.10	7.00	0.00	301.70
	Extraction	Electricity			10.00	3.64	0.00	36.45
	Blending	JME25		41.30		1000.00	1000.00	0.00
		Diesel			43.10	17.60	0.00	758.72
		MeOH			38.08	1.35	0.00	51.47
		KOH			19.87	0.10	0.00	2.04
		Electricity			10.00	1.41	0.00	14.06
	End of life	stem	Subsituted LPG	16.54		7.27	120.31	0.00
		Oil sediment	Subsituted Bunker oil	22.30		0.43	9.53	0.00
		Shell	Composting	6.22		21.82	135.73	0.00
		Seedcake	Composting	6.22		28.53	177.47	0.00
		Crude glycerol	Subsituted Bunker oil	17.80		1.28	22.81	0.00
						Total	1465.84	1333.39
						NEB	132.45	
						NER	1.10	

Table E-3 Energy analysis of JBH25

Fuel	Process	Material	Handling	Energy factor		Amount (kg)	Energy	
				Gain	loss		Gain	loss
JBH25 1GJ	Cultivation	N Fertilizer			87.90	1.00	0.00	88.17
		P Fertilizer			26.40	1.00	0.00	26.48
		K Fertilizer			10.50	1.00	0.00	10.53
		Diesel			43.10	0.14	0.00	6.14
		Electricity			10.00	0.11	0.00	1.08
	Transportation	Diesel			43.10	7.00	0.00	301.70
	Extraction	Electricity			10.00	3.64	0.00	36.45
	Microemulsification	JBH25		42.90		1000.00	1000.00	0.00
		Diesel			43.10	16.43	0.00	708.05
		bioEthanol			12.94	0.85	0.00	10.99
		Surfactant			37.90	0.30	0.00	11.21
	End of life	stem	Subsituted LPG	16.54		6.02	99.55	0.00
		Oil sediment	Subsituted Bunker oil	22.30		0.35	7.88	0.00
		Shell	Composting	6.22		18.06	112.31	0.00
		Seedcake	Composting	6.22		23.61	146.85	0.00
						Total	1366.59	1200.81
						NEB	165.78	
						NER	1.14	

VITA

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