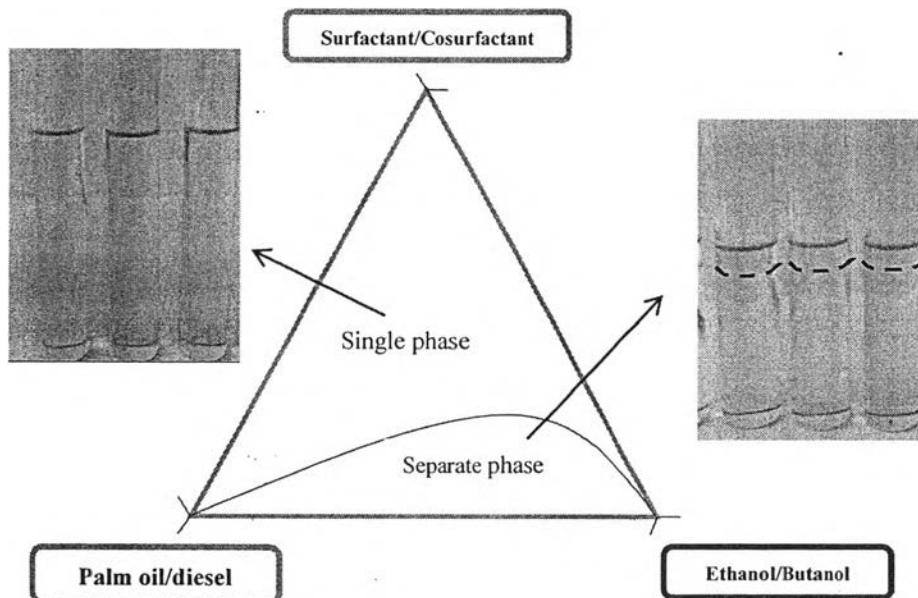


## CHAPTER IV RESULTS AND DISCUSSION

### 4.1 Phase Behavior Study of Microemulsion Biofuels

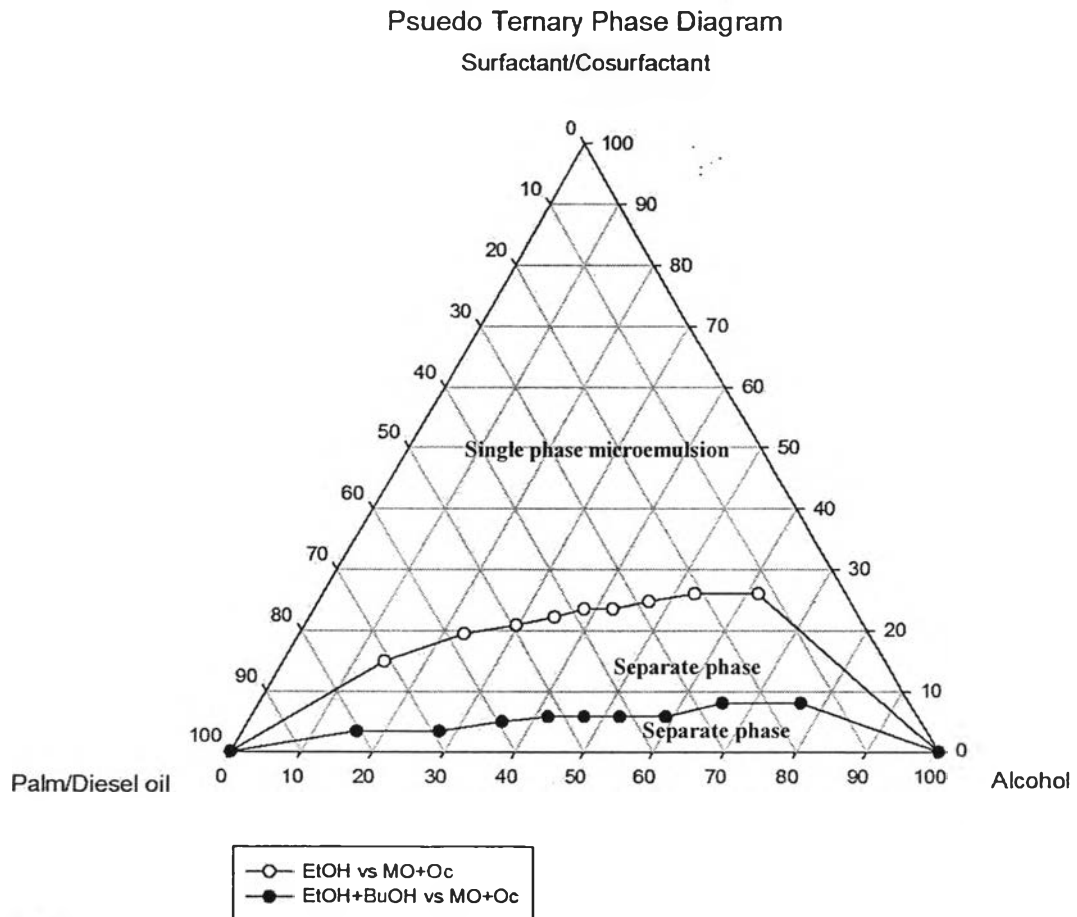
This study aims to minimize the amount of surfactant used while maintaining the fuel properties of microemulsion biofuel. A pseudo ternary phase diagram represents the phase behavior of microemulsion biofuel with varying surfactant concentration. The phase diagram is divided into three main components: oil phase, surfactant phase, and alcohol phase; the top to the left bottom is the percentage of oil in the mixture, the left to the right is the percentage of alcohol, and the right bottom to the top is the percentage of surfactant as shown in Figure 4.1. The miscibility curve indicates the lowest composition for formulating a single phase microemulsion. The upper area of the miscibility curve is the single phase composition and the area lower is the separate phase composition.



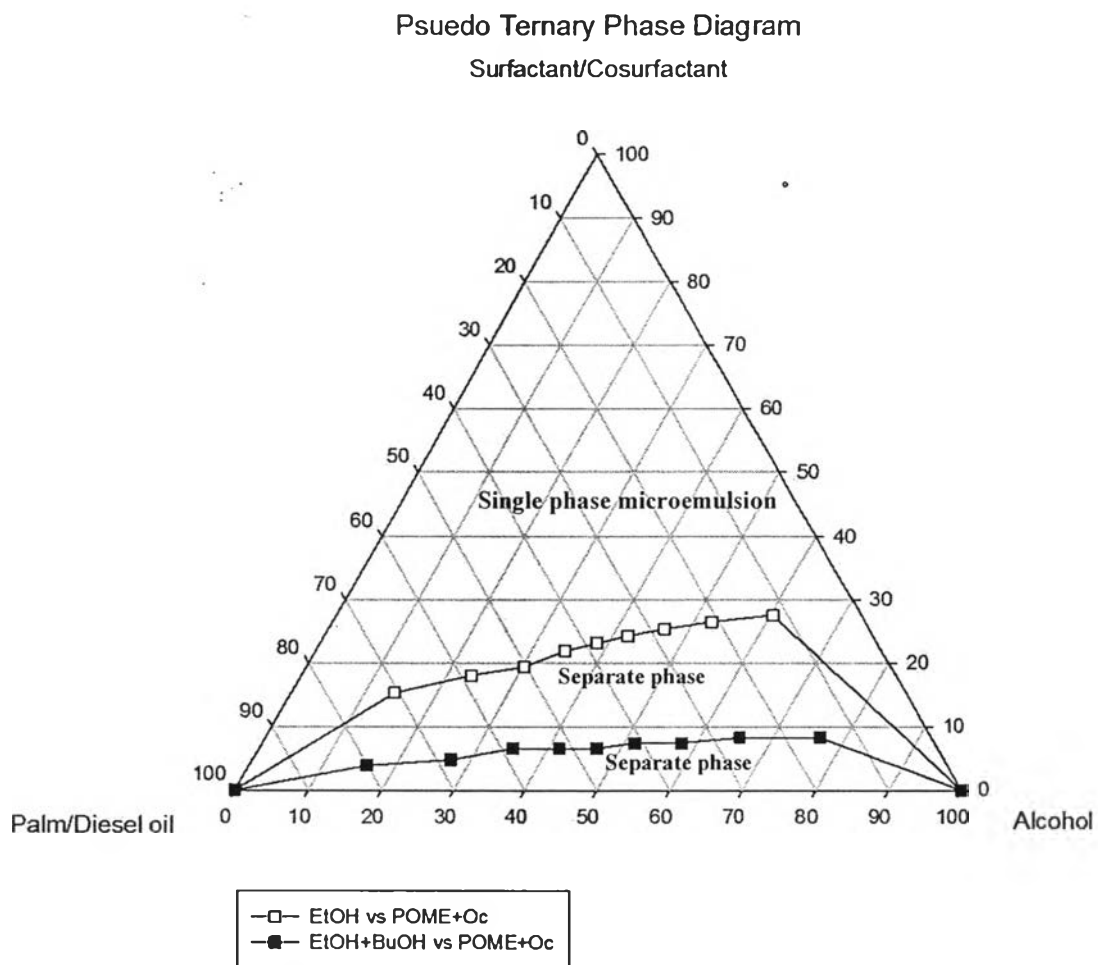
**Figure 4.1** Pseudo ternary phase diagram with single phase and separate phase example.

#### 4.1.1 Comparisons of the System with Single and Mixed Alcohol System

Figure 4.2 and Figure 4.3 show pseudo ternary phase diagrams of microemulsion biofuel systems with three main components consisting of palm oil/diesel oil as an oil phase (palm oil/diesel oil blend at a ratio of 1:1 (v/v)), methyl oleate (MO) or palm oil methyl ester (POME or biodiesel) as a surfactant and 1-octanol as a cosurfactant (surfactant/cosurfactant at a molar ratio of 1:8), and ethanol and butanol blend at a ratio of 1:1 (v/v) as a polar phase. The experiment was done at room temperature ( $25 \pm 2$  °C). The amounts of each component with the minimum amount of surfactant required to form a single phase microemulsion were plotted as shown in the Figure 4.2 and 4.3. It can be seen that the single phase microemulsion regions (above the immiscible curve) is larger with the addition of butanol compared with that of ethanol alone. This can be implied that the microemulsion biofuel system with butanol in the blend requires lower amount of surfactant to formulate the single phase microemulsion. Since butanol has less hydrophilic property than ethanol, the microemulsion tends to be more hydrophobic system which requires lower amount of surfactant used to be able to solubilize polar phase (i.e., ethanol in this case) into the hydrophobic oil phase. This can be concluded that the presence of butanol in the mixed liquid fuel of microemulsion biofuel remarkably gains a benefit in terms of reducing surfactant used.



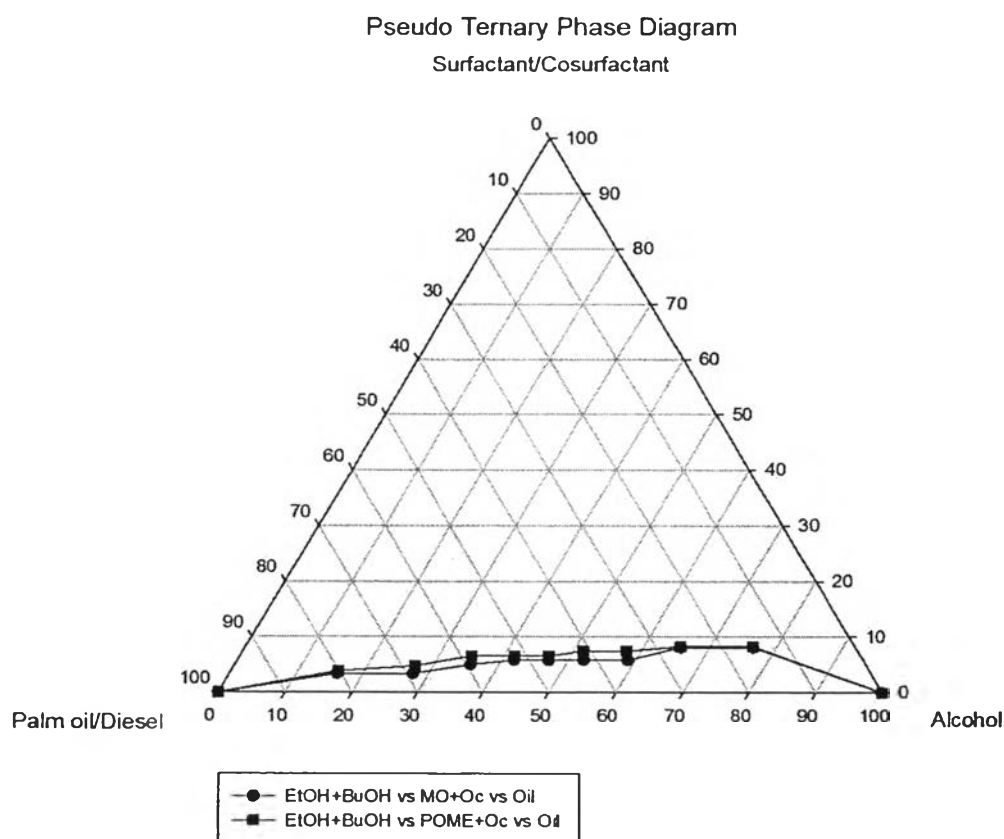
**Figure 4.2** Comparison of microemulsion biofuel systems of methyl oleate (MO) surfactant at room temperature ( $25 \pm 2$  °C) with palm oil/diesel oil ratio at 1:1 (v/v) with 1-octanol as a cosurfactant and a single and mixed ethanol-butanol blend system as a polar phase.



**Figure 4.3** Comparison of microemulsion biofuel systems of biodiesel (POME) as a surfactant at room temperature ( $25 \pm 2$  °C) with palm oil/diesel oil blend ratio at 1:1 (v/v), 1-octanol as a cosurfactant and a single and mixed ethanol-butanol blend system as a polar phase.

#### 4.1.2 Comparisons of the System with Different Types of Surfactant

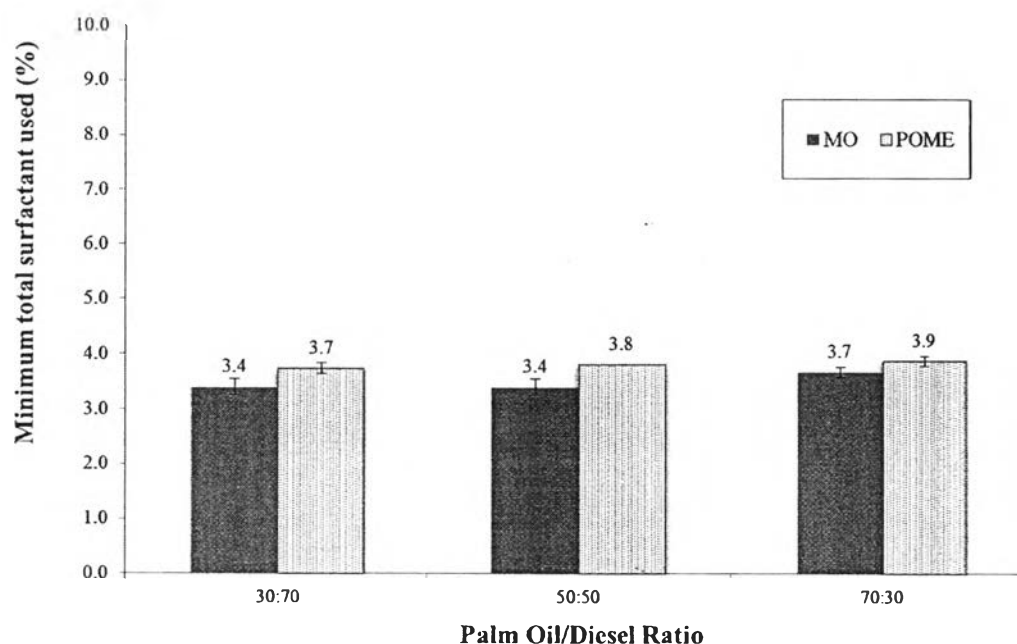
Figure 4.4 shows the comparison of the microemulsion biofuel system with different types of surfactant and 1-octanol as cosurfactant. Black circles and black squares represent methyl oleate (MO) and palm oil methyl ester (POME), respectively. The amount of surfactant required to formulate ME have almost similar result, because hydrophilic-lipophilic balance (HLB) values of MO and POME are 4.0 and 4.2, respectively.



**Figure 4.4** Comparison of the systems with methyl oleate (MO) and biodiesel (POME) at room temperature ( $25 \pm 2$  °C) with palm oil/diesel oil ratio at 1:1(v/v) with EtOH/BuOH.

## 4.2 Palm Oil/Diesel Ratio Study

After the phase behavior study, the minimum surfactant concentration was obtained and used for palm oil/diesel ratio study. Alcohols (ethanol/butanol at a ratio of 1:1(v/v)) were fixed at 20 % of the mixture by volume and surfactant/cosurfactant was mixed at a molar ratio of 1:8. At low percentage of alcohols (20 %), the result showed that palm oil/diesel ratios did not significantly affect to minimum total surfactant concentration required to form single phase microemulsion (Figure 4.5). The result is consistent with Attaphong and coworkers (2012), at high percentage of alcohol (more than 30 %), the amount of surfactant content increased with increasing of vegetable oil. While, at low percentage of alcohol, the amount of surfactant content were similar for different ratio of vegetable oil/diesel. Moreover, both types of surfactant, MO and POME, presented in similar results because of their similar HLB as mentioned in the section 4.1.2.

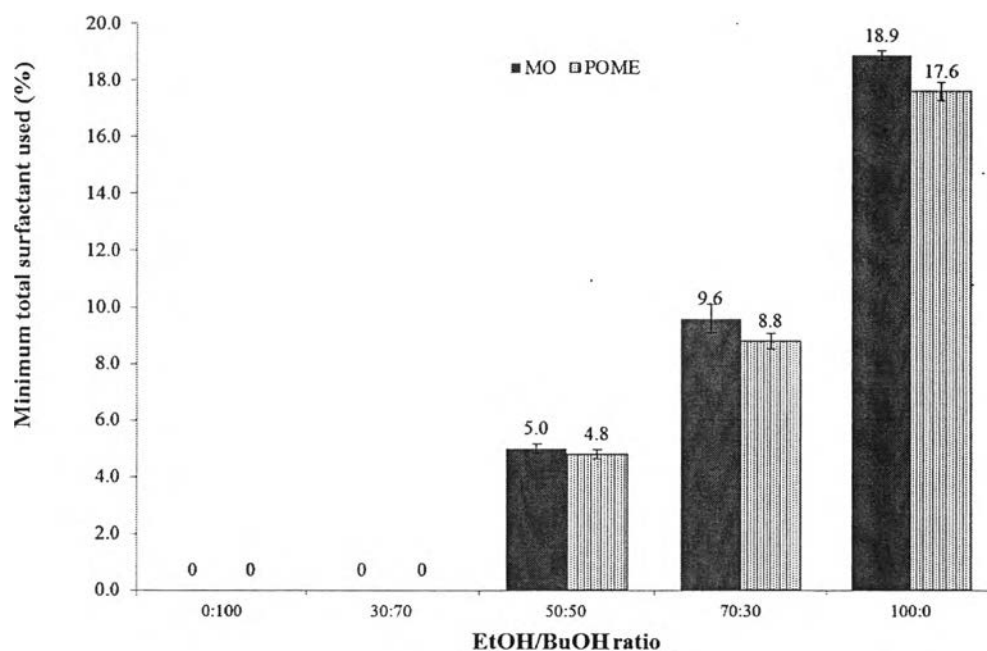


**Figure 4.5** Minimum total surfactant concentration to formulate single phase microemulsion (%) versus palm oil/diesel ratio (v/v) compared with methyl oleate and POME (biodiesel) as surfactants and 1-octanol as a cosurfactant at a molar ratio of 1:8 by 20 vol.% of EtOH/BuOH at a ratio of 1:1(v/v).

### 4.3 EtOH/BuOH Ratio Study

#### 4.3.1 Comparisons Minimum Total Surfactant Concentration to Formulate Single Phase Microemulsion over Effect of EtOH/BuOH Ratios of the System with Different Types of Surfactant

Figure 4.6 shows the minimum total surfactant concentration to formulate single phase microemulsion at five different EtOH/BuOH ratios. Both EtOH/BuOH ratios by percent volume of 0:100 and 30:70 in alcohol fraction do not need surfactant to formulate single phase microemulsion because at this range butanol can dissolve in all component. For EtOH/BuOH ratio of 50:50 or 1:1, the surfactant concentration was at the fraction of 5 % and 4.8 % for MO and POME surfactant, respectively. The similar results were observed for both type of surfactants, MO and POME (biodiesel) as mentioned in the section 4.1.2. At the EtOH/BuOH ratio of 70:30, this system required higher amount of surfactant than that of the EtOH/BuOH ratio of 50:50. The comparison of five different EtOH/BuOH ratios, showed that amount of surfactant concentration to formulate single phase microemulsion increased when the composition of butanol decrease because butanol has less hydrophilic property than ethanol as mentioned in section 4.1.1. Therefore, the presence of butanol can decrease the usability of surfactant to formulate single phase microemulsion.



**Figure 4.6** Minimum total surfactant concentration (%) versus EtOH/BuOH ratio (v/v) of ME with MO and POME as surfactants, 1-octanol as a cosurfactant at a molar ratio of 1:8 and palm oil/diesel ratio at 1:1 (v/v) in 20 vol.% of EtOH/BuOH.

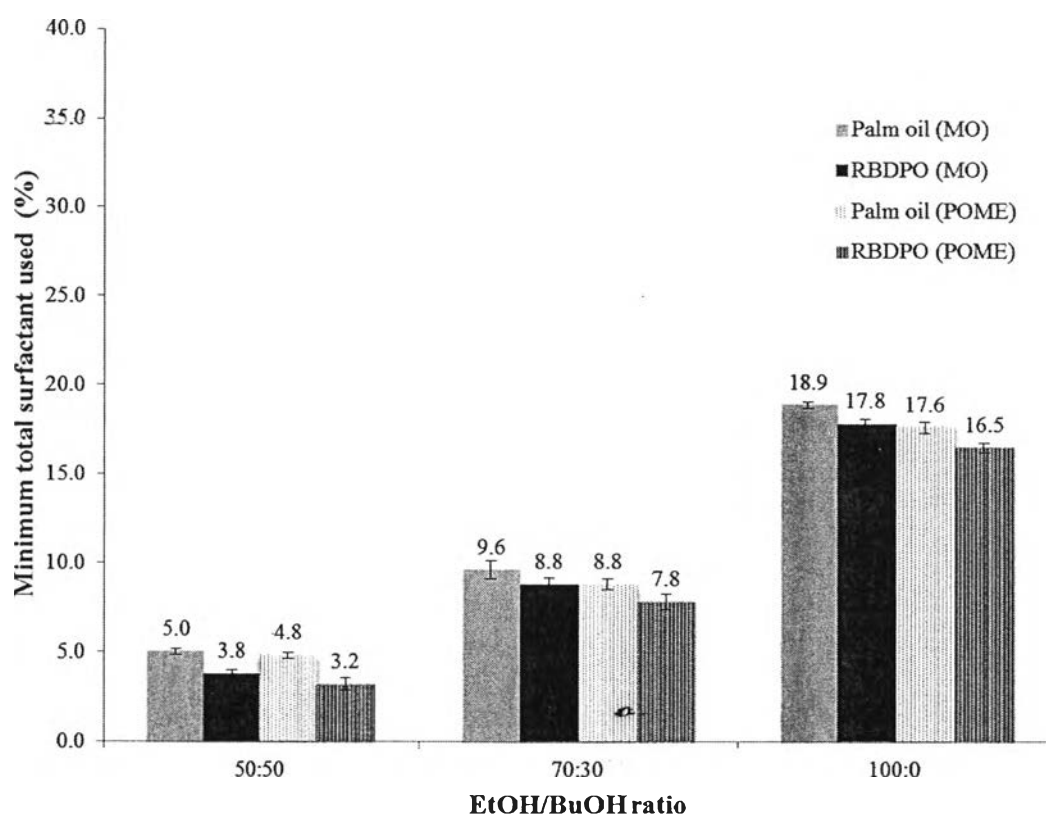
#### 4.3.2 Comparisons of Minimum Total Surfactant Concentration to Formulate Single Phase Microemulsion over Effect of EtOH/BuOH Ratios of the System with Different Types of Palm Oil

For this study food-grade palm oil (palm olein) and refined bleached deodorized palm oil (RBDPO) were selected to investigate as different types of palm oil. Because RBDPO has a benefit in terms of economic and environmental aspects, so it is selected.

Figure 4.7 shows the minimum surfactant concentration to form single phase microemulsion with varying three different EtOH/BuOH ratios. The result showed that amount of surfactant required increased significantly with decreasing the presence of butanol in systems for both type of palm oil as discussed in the section 4.1.1. For comparison amount of surfactant required with different types of palm oil, the results showed that RBDPO systems required slightly lower



surfactant concentration to form single phase microemulsion than that of palm olein system. Because the fatty acids in RBDPO (palmitic acid, C16:0) can facilitate the surfactant to form a single phase microemulsion. Palmitic acid was major type fatty acid in RBDPO at amount of 46.30 % was higher than that of palm olein at amount of 41.54 % as shown in Table 4.1.



**Figure 4.7** Minimum total surfactant concentration (%) versus EtOH/BuOH ratio (v/v) of microemulsion biofuel with MO and POME as surfactants with palm oil and RBDPO as oil phase, 1-octanol as a cosurfactant at molar ratio of 1:8 and palm oil/diesel ratio at 1:1 (v/v) in 20 vol.% of EtOH/BuOH.

**Table 4.1** Fatty acid composition of palm oil and refined bleach deodorized palm oil (RBDPO)

Fatty Acid Composition	Fatty Acid Composition (%)	
	Palm Oil	RBDPO
Saturated Composition		
Myristic acid (C14:0)	0.89	0.92
Palmitic acid (C16:0)	41.54	46.30
Stearic acid (C18:0)	3.51	3.52
Total	45.94	50.74
Unsaturated Composition		
Oleic acid (C18:1)	43.63	39.58
Linoleic acid (C18:2)	10.43	9.68
Total	54.06	49.26

(Che Man *et al.*, 1999).

#### 4.4 Fuel Properties Determination

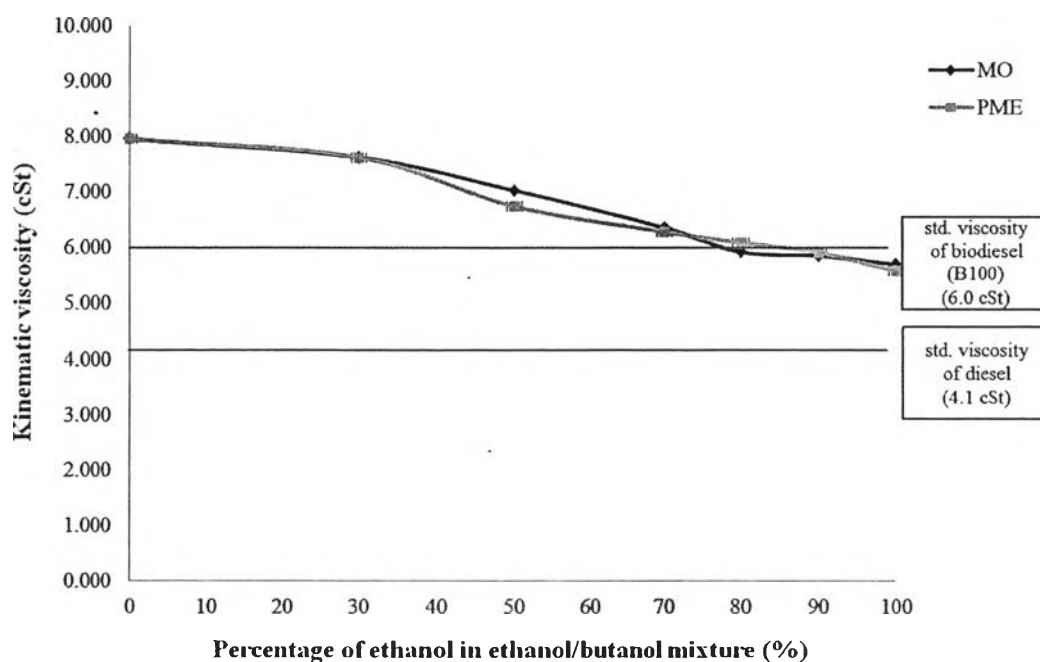
Fuel properties of microemulsion biofuels are the key factor to evaluate their performance close to those of diesel and biodiesel (B100) standard. For this part, we interested in the effects of surfactant's structure and type of palm oil and ratio of butanol in ethanol and butanol mixtures on their fuel properties, including kinematic viscosity, droplet size, cloud point, density, and heat of combustion. Microemulsion biofuels in this study were palm oil/diesel and RBDPO/diesel blends with 20 vol.% of alcohols (ethanol/butanol) and the appropriate surfactant concentration was selected at 5 vol.% of above the miscibility curve.

#### 4.4.1 Kinematic Viscosity Determination

In this research, the kinematic viscosity of microemulsion biofuels was measured by Cannon-Fenske viscometer followed the ASTM D445. The results were compared to neat diesel fuel and biodiesel (B100). Kinematic viscometer were measured at 40 °C, the standard kinematic viscosity of No.2 diesel has been reported at 4.1 cSt (Arpornpong *et al.*, 2014) while kinematic viscosity of B100 has been reported at 6.0 cSt (Jan *et al.*, 2010).

##### 4.4.1.1 *Effect of Surfactant Structures*

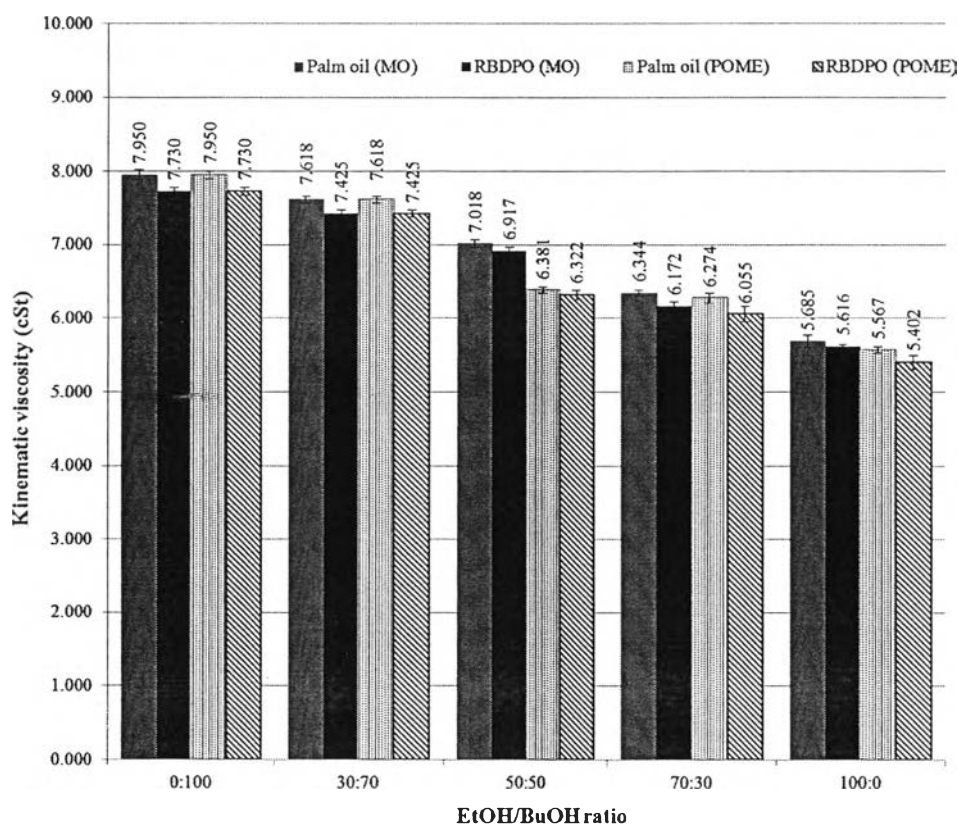
Methyl oleate (MO) and palm oil methyl ester (POME) or known as biodiesel were selected as a surfactant mixed with 1-octanol as a cosurfactant at a constant molar ratio of 1:8. Figure 4.8 shows the kinematic viscosity of palm oil/diesel blend at a ratio of 1:1 (v/v) with 20 vol.% of alcohol at different blending ratios of ethanol and butanol mixture. For kinematic viscosity of both surfactants (MO and POME) showed the similar trends, decreased with decreasing of butanol fraction. This is because of their similar kinematic viscosity, 4.68 and 4.76 cSt for MO and POME, respectively. The kinematic viscosities of microemulsion biofuels with MO and POME gradually increase with increasing of butanol fraction in the ethanol and butanol mixture because the kinematic viscosity of butanol are higher than that of ethanol, 3.64 and 1.20 for butanol and ethanol, respectively (Rakhi *et al.*, 2012). The result showed that the microemulsion systems with butanol alone presented the highest kinematic viscosity at 8 cSt. While kinematic viscosity of the microemulsion systems contained ethanol alone was about 5.5 cSt. At high percentage of ethanol fraction (70 % and 100 %) in ethanol and butanol mixture, the viscosity of microemulsion biofuels was close to that of the biodiesel (B100) standard ranging from 1.9 to 6.0 cSt (Jan *et al.*, 2010).



**Figure 4.8** Kinematic viscosities (cSt) at 40°C of the microemulsion biofuels using MO and POME with 1-octanol at a molar ratio of 1:8 as surfactant systems with palm oil/diesel blend at a ratio of 1:1 (v/v) with varying butanol contained in ethanol and butanol blends at 20 vol.% of alcohol.

#### 4.4.1.2 Effect of Different Types of Palm Oil

For this study, palm oil/diesel and RBDPO/diesel blended at a ratio of 1:1 (v/v) using MO and POME as a surfactant mixed with 1-octanol as a cosurfactant at a constant molar ratio of 1:8 with five different ethanol/butanol ratio (20 vol.% of ethanol and butanol mixture). The results in Figure 4.9 showed that the kinematic viscosities decrease with decreasing of butanol in ethanol and butanol mixture that is consistent with section 4.4.1.1. For effect of different types of palm oil, kinematic viscosities of RBDPO/diesel systems were slightly less than those of palm oil/diesel systems because RBDPO has kinematic viscosity lower than that of palm oil, 45.34 cSt (Bernat *et al.*, 2012) and 37.95 cSt (Yusnida *et al.*, 2013) for neat palm oil and RBDPO, respectively.

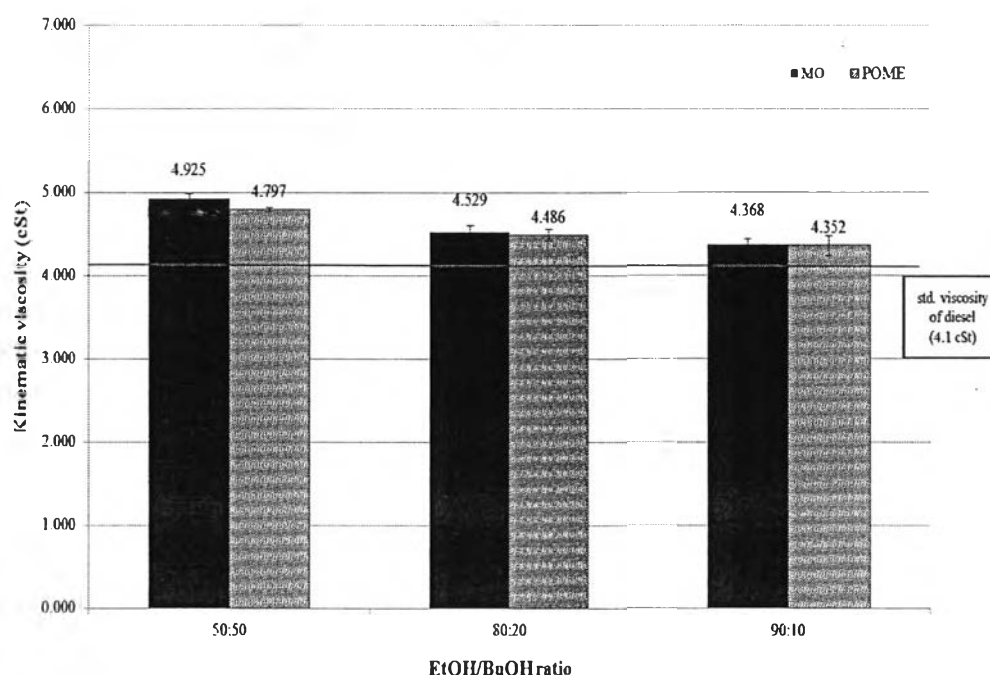


**Figure 4.9** Kinematic viscosity (cSt) at 40 °C versus EtOH/BuOH ratio compared with palm oil and RBDPO as different palm oil with palm oil/diesel ratio at 1:1 (v/v) with MO and POME as surfactants with 1-octanol as a cosurfactant at a molar ratio of 1:8 with 20 vol.% of EtOH/BuOH mixture.

#### 4.4.1.2 Effect of Adjustment Palm Oil/Diesel Ratio

Figure 4.10 represents the kinematic viscosity of palm oil/diesel blend at ratio of 30:70 (v/v) using MO and POME as a surfactant and mixed with 1-octanol as a cosurfactant at constant molar ratio of 1:8 with three different EtOH/BuOH ratios (20 vol.% of ethanol and butanol mixture). For the palm oil/diesel oil at ratio of 50:50 (v/v), the kinematic viscosity was not approach to standard viscosity of diesel. To reduce high viscosity of the microemulsion biofuels, palm oil/diesel ratios were adjusted to ratio of 30:70 (v/v). Result of adjusting

palm oil/diesel ratios showed that the kinematic viscosities of palm oil/diesel blend (30:70) systems at three different ratios of ethanol and butanol mixture can be maintained to the kinematic viscosity standard of diesel.



**Figure 4.10** Kinematic viscosity (cSt) of palm oil/diesel blend at a ratio of 30:70 (v/v) systems at 40°C versus EtOH/BuOH ratio with MO and POME as surfactants and 1-octanol as a cosurfactant at molar ratio of 1:8 with 20 vol.% of EtOH/BuOH mixture.

#### 4.4.2 Droplet Size Determination

Microemulsion biofuel droplet sizes and size distributions were measured by Zetasizer Nano apparatus (Model ZEN 3600, Malvern Instruments) with Dynamic Light Scattering technique (DLS). DLS technique measured the diffusion of particles moving undergo random motion known as Brownian motion, and converts this to size and a size distribution using the Stokes-Einstein equation (Noel et al., 1970). The sample were analyzed at room temperature ( $25 \pm 2$  °C). The aim of microemulsion biofuel droplet size determination is to find the correlation of droplet size and kinematic viscosity of microemulsion biofuels. This study investigated the

effect of surfactant structures and ethanol/butanol ratios on relation between droplet size and kinematic viscosity.

#### 4.4.2.1 Effect of Surfactant Structures

Table 4.2 shows droplet sizes of microemulsion biofuels with palm oil/diesel blends at a ratio of 1:1 (v/v) using two types of surfactant, MO and POME mixed with 1-octanol as a cosurfactant at molar ratio of 1:8 at three different ratio of EtOH/BuOH. The result showed that the droplet sizes of microemulsion biofuel had no difference for MO and POME surfactants. The droplet size of microemulsion biofuels of MO systems ranged from 475.3-5,461 nm at monodispersion (100 % intensity). Similar figures were found for POME systems, the droplet size ranged from 475.3-5,560 nm. The droplet size of MO and POME systems were similar because both types of surfactant has methyl ester group at their hydrophilic ends. For effect of ethanol/butanol ratio, the droplet sizes increased with decreasing of butanol in ethanol and butanol blends because of the stronger binding affinity between longer chain of butanol and surfactant structures than that of ethanol.

**Table 4.2** Comparison of the droplet size and distribution of microemulsion biofuels with palm oil/diesel blend (1:1 v/v) with MO and POME as surfactants at room temperature (25±2 °C)

Sample	Size Distribution (nm)			
	MO/1-octanol		POME/1-octanol	
	D <sub>1 mean</sub> (%intensity)	D <sub>2 mean</sub> (%intensity)	D <sub>1 mean</sub> (%intensity)	D <sub>2 mean</sub> (%intensity)
EtOH:BuOH (0:100)	475.3 (100%)	- (0%)	475.3 (100%)	- (0%)
EtOH:BuOH (50:50)	5,361 (100%)	- (0%)	5,413 (100%)	- (0%)
EtOH:BuOH (100:0)	5,461 (100%)	- (0%)	5,560 (100%)	- (0%)

#### 4.4.2.2 Relation between Droplet Size and Kinematic Viscosity of Microemulsion Biofuels

To describe the relationship between droplet size and kinematic viscosity of microemulsion biofuels, Stokes-Einstein's equation (Equation 4.1) was used in this calculation. For Stokes-Einstein's equation, microemulsion biofuel droplet size is explained in terms of  $D_h$  which is inversely proportion to kinematic viscosity ( $\eta$ ).

$$D_h = \frac{k_B T}{3\pi\eta D_t} \quad (4.1)$$

From Table 4.3, the kinematic viscosities of microemulsion biofuels system using MO as a surfactant were slightly higher than those of POME. While microemulsion droplet size using the MO system were less than those of POME system. So, we can conclude that these results were followed the Stokes-Einstein's equation and consistent with Arpornpong and coworkers (2014).



**Table 4.3** Kinematic viscosity and droplet size of palm oil/diesel blends at a ratio of 1:1 with 20 vol.% ethanol and butanol mixture with MO and POME as surfactants mixed with 1-octanol as a cosurfactant at a molar ratio of 1:8

Sample		Kinematic Viscosity (cSt)	Size Distribution $D_{1, mean}$ (nm)
MO/1-Octanol Palm oil/Diesel oil)	EtOH:BuOH (0:100)	7.982	475.3
	EtOH:BuOH (50:50)	7.018	5,361
	EtOH:BuOH (100:0)	5.685	5,461
POME/1-Octanol (Palm oil/Diesel oil)	EtOH:BuOH (0:100)	7.982	475.3
	EtOH:BuOH (50:50)	6.381	5,413
	EtOH:BuOH (100:0)	5.567	5,560

#### 4.4.3 Cloud Point Determination

Cloud point is the temperature that fuel becomes to form cloudy solution. When the temperature of fuel reaches to the cloud point, these wax crystals flowing with the fuel coat the filter element and suddenly decrease the fuel flow, making trouble the engine (Mittelbach, 2004). In this work, the cloud point of microemulsion biofuels were determined using temperature controlled water bath following to ASTM D 2500. Effect of ethanol/butanol ratios on the cloud points was investigated with palm oil/diesel blended at ratio of 1:1 (v/v) with 20 vol.% of ethanol and butanol mixture. The turbidness of the microemulsion biofuel is observed when the temperature is decreased every 1 °C.

The cloud points of microemulsion biofuel using MO and POME as a surfactant at the same ethanol/butanol ratio turned to be turbidness at the same temperature. This could be due to their similar functional group of surfactant as



#### 4.4.4 Density Determination

Density of all sample were measured at room temperature ( $25 \pm 2$  °C). Table 4.5 shows density of microemulsion biofuels, varying in range of 0.829-0.852 g/mL. the density of microemulsion biofuels were higher than diesel (0.828 g/mL) and less than biodiesel (B100) (0.876 g/mL).

**Table 4.5** Density of microemulsion biofuels

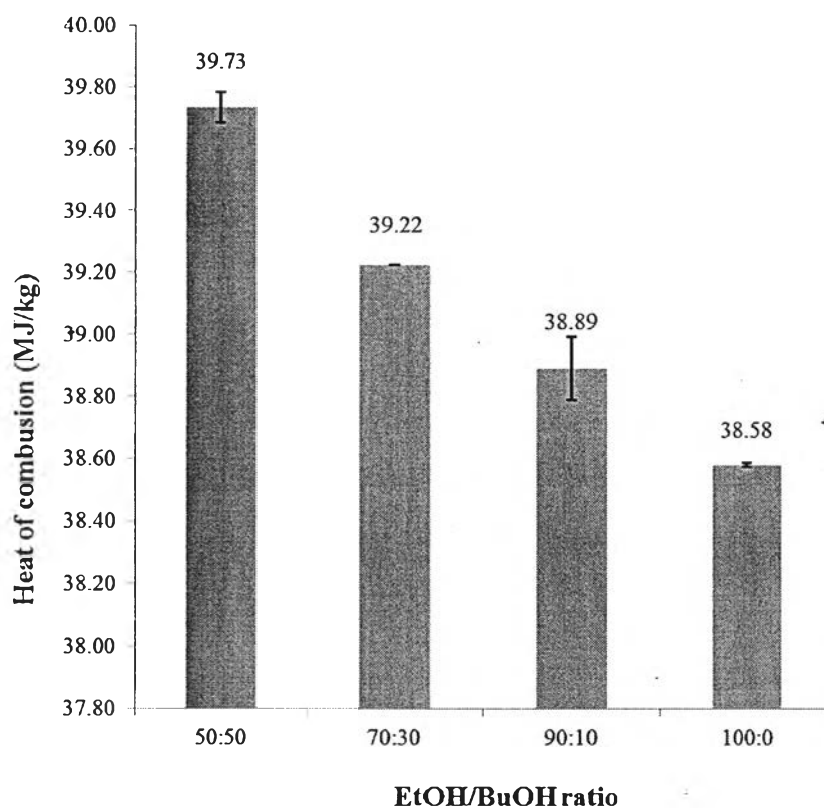
Sample (Ethanol/Butanol Ratio)	Density (g/mL)	
	MO/1-octanol	POME/1-octanol
0:100	0.852	0.852
30:70	0.851	0.851
50:50	0.848	0.845
70:30	0.841	0.840
100:0	0.833	0.829
Diesel <sup>a</sup>	0.828	
Biodiesel (B100) <sup>a</sup>	0.876	

<sup>a</sup>The data form Bernat *et al.*, 2012

#### 4.4.5 Heat of Combustion

Heat of combustion is an important property of a fuel, describing the amount of energy released in terms of heat when ending of combustion of the fuels. The heat of combustion is commonly measured with a bomb calorimeter. For this study, heat of combustion was followed by ASTM D 240. Figure 4.11 shows the heat of combustion of palm oil/diesel blends at a ratio of 1:1 (v/v) with POME as surfactant mixed with 1-octanol at a molar ratio of 1:8 with different ratios of

ethanol/butanol. The result indicated that the heating value decreased with amount of ethanol increased in the mixture of EtOH/BuOH blends. Microemulsion biofuel system contained high amount of ethanol, had high heating value vice versa that the lower amount of butanol had low heat of combustion. Microemulsion biofuels contained ethanol alone system had heat of combustion of 38.58 MJ/kg, while the system with ethanol/butanol at a ratio of 50:50 (v/v) had heat of combustion of 39.73 MJ/kg which higher than that of system with ethanol alone. Due to the fact that heat of combustion of butanol is originally higher than ethanol, accounting for 33 MJ/kg and 26.8 MJ/kg, respectively. However, heat of combustion of the microemulsion biofuels was slightly lower than diesel (43 MJ/kg) (Evangelos *et al.*, 2013).



**Figure 4.11** Heat of combustion of microemulsion biofuels with various EtOH/BuOH ratio using POME as a surfactant and 1-octanol as a cosurfactant at molar ratio of 1:8 with palm oil/diesel at ratio of 1:1 (v/v).

#### 4.5 Summarized Results

This research aims to formulate single phase reverse micelle microemulsion consisting of palm oil/diesel blend for stabilizing alcohols in oil phase. Nonionic surfactants and cosurfactant were used for formulation of reverse micelle microemulsion biofuel. The fuel properties of microemulsion biofuels were investigated and their performances were compared with diesel and biodiesel standard.

Microemulsion biofuels formation, palm oil and RBDPO were selected and blend with diesel as an oil phase and ethanol and butanol blends were used as a polar phase or viscosity reducer. Butanol was selected to improve the property of microemulsion biofuel. Nonionic surfactants, methyl oleate (MO) and palm oil methyl ester (POME or biodiesel), and 1-octanol as a cosurfactant were selected as an emulsifier to stabilize single phase microemulsion at a constant surfactant/cosurfactant molar ratio of 1:8. Since MO and POME have similar structure, they were used to study the effect of types of surfactant and the effect of ethanol/butanol ratios were investigated on phase behavior, kinematic viscosity, droplet size, cloud point, density, and heat of combustion to optimize the formulation of microemulsion biofuel.

In phase behavior study of microemulsion biofuel systems, the pseudo ternary phase diagram was used to determine a single phase microemulsion formation. The minimum surfactant concentration to formulate the single phase was depicted by the miscibility curve. The single phase is located above the miscibility curve while the separate phase is located below the curve. In this study, palm oil/diesel and EtOH/BuOH blended at a ratio of 1:1 (v/v). The results of phase behavior can be summarized that butanol contained system can be decreased the amount of surfactant used to formulate single phase microemulsion when compared to that of ethanol alone system. Because butanol has less hydrophilic property than ethanol, the microemulsion tends to be more hydrophobic system which requires lower amount of surfactant used to be able to solubilize polar phase (i.e., ethanol in this case) into the hydrophobic oil phase. Therefore, the use of butanol provides the

benefit in case of minimizing the surfactant used. Moreover, different types of surfactant were not significantly to amount of surfactant used because HLB values of two types of surfactant were not different. For palm oil/diesel blending ratio at 20 % of alcohols study, the results showed that palm oil/diesel ratio did not affect to amount of surfactant used to formulate single phase microemulsion. This is consistent with previous literature (Attphong *et al.*, 2012).

Butanol was selected as a cosolvent, the comparison of five different EtOH/BuOH ratios was investigated. The amount of surfactant used to formulate single phase microemulsion increased when the composition of butanol decreased. Therefore, the presence of butanol can decrease the surfactant used to formulate single phase microemulsion. Moreover, the similar results were observed for both types of surfactant, MO and POME because of their similar HLB. The use of palm olein and RBDPO as an oil phase showed that RBDPO systems required lower surfactant concentration to formulate a single phase microemulsion than that of palm olein systems because of the difference in fatty acid compositions.

Fuel properties of microemulsion biofuels were observed. The effects of surfactant structure, type of palm oil and ratio of butanol in ethanol and butanol mixtures were investigated on their fuel properties, including kinematic viscosity, droplet size, cloud point, density, and heat of combustion. The appropriate microemulsion biofuels in this study were palm oil/diesel and RBDPO/diesel blends with 20 vol.% of alcohols (ethanol/butanol) and the appropriate surfactant concentration of each system was selected at 5 vol.% of above the miscibility curve.

Microemulsion biofuel properties were compared to those of diesel and biodiesel (B100). For kinematic viscosity study, the kinematic viscosities of microemulsion biofuels with MO and POME gradually increased with increasing of butanol fraction in the ethanol and butanol mixture because the kinematic viscosity of butanol is higher than ethanol. At high percentage of ethanol fraction in ethanol and butanol mixture, the viscosity of microemulsion biofuels was close to the kinematic viscosity standard of biodiesel (B100). For the effect of types of palm oil, the kinematic viscosities of RBDPO/diesel systems were slightly less than those of

palm olein/diesel systems because RBDPO has kinematic viscosity relatively lower than palm olein.

For the palm oil/diesel blended at ratio of 50:50 (v/v), the kinematic viscosity did not approach to the viscosity of diesel. To reduce high viscosity, palm oil/diesel blending ratios were adjusted to the ratio of 30:70 (v/v). The kinematic viscosities of palm oil/diesel blend at ratio of 30:70 (v/v) systems at three different ratios of ethanol and butanol mixture approached to standard of kinematic viscosity of diesel.

In droplet size determination, this study investigated the effect of surfactant structures on the relation between droplet size and kinematic viscosity. The result showed that the droplet sizes of microemulsion biofuel had no difference for MO and POME surfactants because both of surfactant has methyl ester group contained in their hydrophilic group. From the result of kinematic viscosity and droplet size of microemulsion biofuel, it can be concluded that the results were followed for Stokes-Einstein's equation.

When compared the cloud point of microemulsion biofuels to that of diesel, the cloud point of microemulsion biofuels were higher than that of diesel (-15 °C) because the cloud point of neat palm oil is naturally high (13 °C). However, the cloud point of microemulsion biofuel was similar to that of B100. The density of microemulsion biofuels were varied in range of 0.829-0.852 g/mL.

The heating value results indicated that the heating value decreased with amount of ethanol increased in the mixture of EtOH/BuOH blends. Microemulsion biofuel systems contained low amount of butanol has relatively low heat of combustion.

Based on this findings, it can be summarized that the use of butanol in microemulsion biofuels presents a benefit in terms of amount of surfactant used for formulate single phase microemulsion and heating value. While it causes high kinematic viscosity of microemulsion biofuels as a limitation. Therefore, using of butanol needs formula adjustment to optimize kinematic viscosity of system. In addition, the use of MO and POME for formulating microemulsion biofuel showed the similar results. According to the practical utilization in terms of economic and

environment consideration, POME can be used as a surfactant instead of commercialized nonionic surfactant.