CHAPTER IV

RESULTS AND DISCUSSIONS

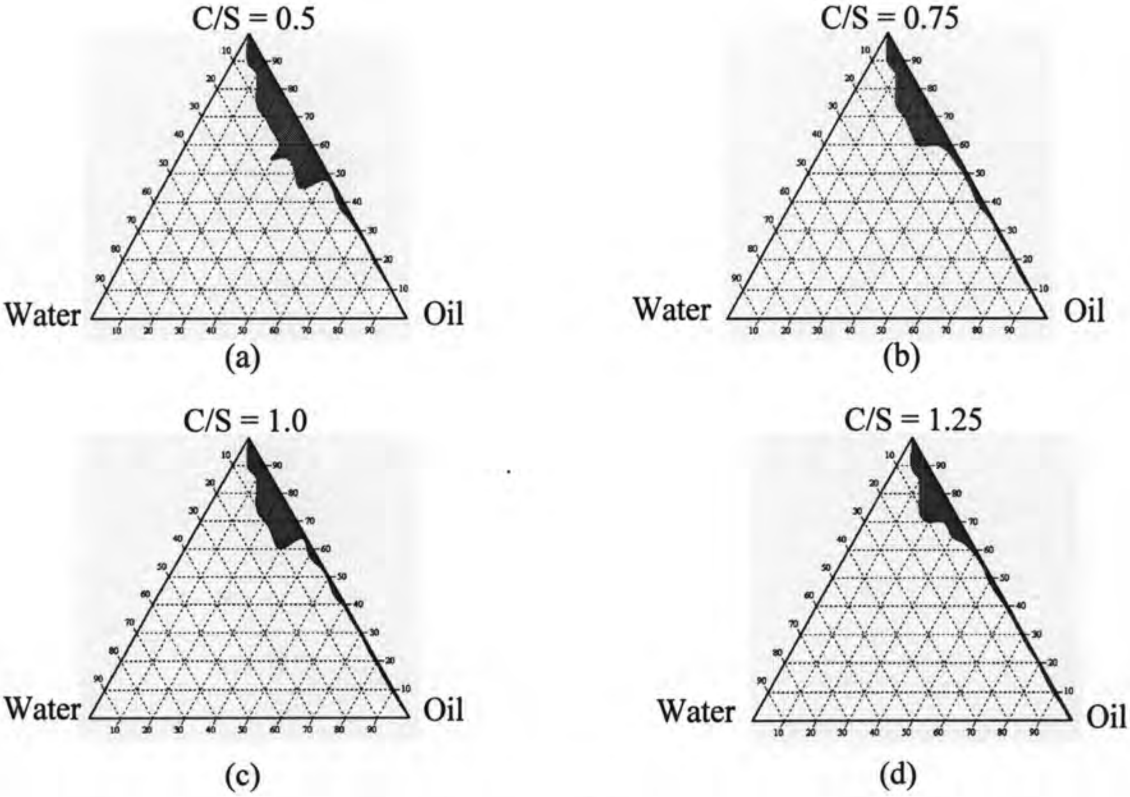
4.1 Microemulsion Area in the Pseudo-Ternary Diagram

Since this study aims to investigate the system combining palm oil, surfactant, alcohol and water that able to form microemulsion biofuel and to study their phase behavior of those systems by preparing pseudo-ternary diagrams at different compositions. Palm oil was selected as a material to produce microemulsion biofuel since palm oil is an agriculture product that widely used for transesterification biodiesel production due to its high production plant. In addition, ethanol alcohol was selected as cosurfactant for this work due to it is less toxic and can be obtained from agricultural product. The surfactant that used in this work is nonionic surfactant; coconut fatty acid diethanolamine (comperlan KD) following the previous study by Dantas et al. (2001) was used comperlan SDC as nonionic surfactant to produce microemulsion biofuel with the different types of vegetable. The result indicated that nonionic surfactants produced from coconut fatty acid may have been suitable and possible to form microemulsion biofuel with vegetable oil.

In order to form a microemulsion solution, it is necessary to determine the optimum proportions of cosurfactant/surfactant ratio that provides for maximum water solubilization. The cosurfactant/surfactant ratios (C/S ratios) of 0.5, 0.75, 1.0, and 1.25 were used. Four pseudo-ternary diagrams were drawn according to the observed results in the phase study. The diagrams indicate the ratios that produced the transparent homogeneous microemulsion phase, as shown in Figure.4.1. It was found that the cosurfactant/surfactant ratios influenced the formation of the transparent homogeneous microemulsion area: the higher the C/S ratio, the smaller the area of the microemulsion phase in the pseudo-ternary diagram.

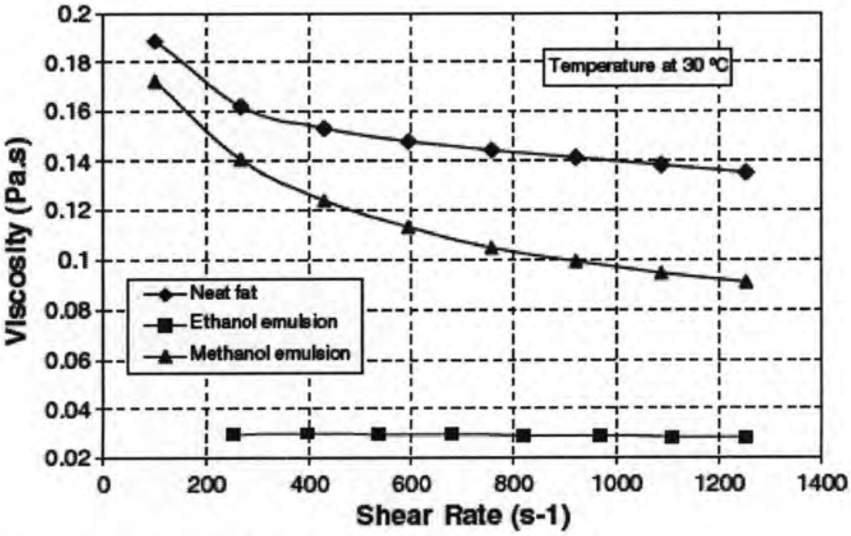
The results in the diagram support a previous study by Dantas et al. (2001) that they also used microemulsion technique to produce biofuel. The diagrams revealed the influence of the cosurfactant/surfactant ratios on the microemulsion area, and the maximum solubilization was found at the cosurfactant/surfactant ratio of 0.5. (The data were shown in the Appendix B). To obtain high solubilization, a high concentration of surfactant is needed to facilitate the water content in the system. Even though ethanol plays a role as the cosurfactant in this study, it is much more hydrophilic than diethanolamine; as such, too high ratio of ethanol may lead to unsuitable conditions for the palm oil, and hence, prevent microemulsion. Corresponds to Kerihuel et al. (2006) is observed for all the C/S ratios tested reported the C/S ratio influences the formation of microemulsion, because it gave the different microemulsion area. High ethanol concentrations in the system also led to unstable emulsion formation. The addition of alcohol can solve the problem by drastically reducing the viscosity of the emulsion (mainly with ethanol). Ethanol has the advantage of complete miscibility with fat at ambient temperature. So, it is more suitable than methanol for viscosity reduction as presented in Figure 4.2 (Kerihuel et al., 2006). Moreover, ethanol is a renewable fuel that can be obtained by fermenting agricultural waste containing sugar; hence, it should be noted that for fuel production, surfactant and ethanol alcohol are considered good additives (Rosen, 2004). On the other hand, when the C/S ratio is too low (i.e. C/S = 0.25), the low ethanol amount may not yield high solubilization of water in oil either since the amount of ethanol may not be enough to facilitate the water molecule in the inverse micelle.

In this work, the microemulsion solution of C/S = 0.5 was selected for further study as microemulsion biofuel (MB100) and blended biofuel (MB20 and MB5) because this ratio (C/S = 0.5) generated a larger microemulsion area which is easy to select one composition in microemulsion shade area for producing microemulsion biofuel. The microemulsion solution was composed of the following ratio: refined palm oil 95% weight, the cosurfactant/surfactant at a 0.5 ratio 4.95% weight, and water 0.05% by weight. These values and components were selected based on their combined contributions to on water content standard, fuel performance, and the oil yield for biofuel production.



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

Figure 4.1 Ternary Phase Diagram of the Systems Consisting of Coconut Fatty Acid Diethanolamine/Absolute Ethanol (Cosurfactant/ Surfactant: C/S), Water, and Refined Palm Oil at Different Ratios of C/S; (a) C/S = 0.5; (b) C/S = 0.75; (c) C/S = 1.0; and (d) C/S = 1.25



Note: Shear rate is flow of liquid

Figure 4.2 Viscosity Variations with the Shear Rates for Neat Fat, Methanol and Ethanol Emulsion.

4.2 Properties of the Microemulsion Biofuel and Its Blends

To use microemulsion biofuel as a fuel, its properties is required to be in a suitable range in order to ensure for both its running performance and maintain engine in the long run (less effect on engine). The parameters selected for this study included both fuel performance and engine maintenance. The properties of MB100, MB5 and MB20 were compared to the standard properties of transesterification biodiesel and petroleum diesel, as shown in Table 4.1.

Flash point

The flash point is the lowest temperature, at which a fuel will ignite when expose to an ignition source. The flash point for biodiesel production is used as the mechanism to limit the level of unreacted alcohol remaining in the finish fuel. It can be observed that the flash points of MB100, MB20 and MB5 were close to that of petroleum diesel, but different from that of transesterification biodiesel. This may be explained by the fact that our products and its blends contain ethanol, which has a very low flash point and hence reduce the fuel to get lower flash point as compared to transesterification biodiesel. The result shows that MB100 had the lowest flash point value dues to it contained highest ethanol in its composition as compared to the others. Alcohol directly influences the flash point of microemulsion biofuel to be low as compared to the flash point of vegetable oil which is the main composition of microemulsion biofuel. Thus, the flash points of MB100, MB20, and MB5 were found to be close to the flash point of diesohol (Kwanchareon et al., 2007) and not similar to the flash point of biodiesel prepared by the transesterification technique. Due to its low flash point, microemulsion biodiesel must be carefully handled and transported.

Cloud point

Cloud point is an important parameter because it defines the temperature at which a cloud or haze of crystals appears in the fuel; it generally relates to the temperature at which crystals begin to precipitate from the fuel. The presence of solidified waxes or crystals influence the flow behavior of the fluid, the tendency for foul fuel filters or injectors, the accumulation of wax on cold surfaces (e.g. the pipeline or heat exchanger fouling), and the characteristics of emulsion with water. The cloud point of biodiesel and its impact on the cold flow properties of the resulting blend should be monitored. The cloud point is an indication of the tendency of the oil to plug filters or small orifices at cold operating temperatures. From this study the cloud point of all of microemulsion biofuel production; MB100, MB20, and MB5, show relatively high cloud point value as compared to those of commercial diesel and tranesterification biodiesel (see Table 4.1). However, if we consider the average temperature of the whole year in Thailand, the cloud point of 4.3 °C of MB100 should not be any problem to operate with the diesel engine in Thailand.

Table 4.1 The Fuel Properties of Microemulsion Biofuel and Its Blends

Parameters	**M100**	**M20**	**M5**	**Diesel** [a]	**Biodiesel** [b]	**Diesel**[c]	**Biodiesel**[d]
Flash point (°C)	35	42	58	52	130	72	160
Cloud point (°C)	4.3	5.3	4.7	No report	No report	-15	-5
Carbon residue (%mass)	0.44	0.12	0.03	0.35 max	0.05 max	-	-
Gross heat combustion	38.9	44.3	45.5	No report	No report	43.0	37.2
Acid number (mg KOH/mg)	0.24	0.08	0.05	No report	0.5 max	-	-
Kinematic viscosity (cst or mm^2/sec)	35.44	4.99	3.52	1.9-4.1	1.9-6.0	3.16	4.151
Copper strip corrosion	1b	1b	1b	No. 3 max	No. 3 max	-	-

Note

[a] : Standard of diesel fuel grade NO. 2 following ASTM D975

[b]: Standard of biodiesel fuel (B100) following ASTM D6751

[c]: Physical-chemical properties of commercial diesel (Murillo et al., 2007)

[d]: Physical-chemical properties of commercial biodiesel (Murillo et al., 2007)

Carbon residue

This parameter is to determine the amount of carbon residue formed after the evaporation and pyrolysis of petroleum materials under certain conditions. It provided an indication of the relative coke forming tendency of such materials (ASTM, 2006). The standard value of carbon residue for petroleum diesel fuel and biodiesel are limited at 0.35 % wt. and 0.05 % wt., respectively. Carbon residue values of MB5 and MB20 were found to be within the standard level of petroleum diesel, but over the standard level for biodiesel. An examination of MB100 showed that it produced higher carbon residue than both petroleum diesel and biodiesel standard level. This is due to the fact that carbon residue content in engine oil produces unburned hydrocarbon and ash; since MB100 has the highest ratio of triglyceride, which can yield higher residue due to its bulky molecular structure as compared to conventional hydrocarbon or methyl ester (transesterification biodiesel). As a result, the MB1000 gave the highest carbon residue content after burning than MB20, MB5, petroleum diesel and biodiesel. In addition, more oxygen consumption is required for complete combustion when using MB100 fuel. This problem can be reduced by increasing the temperature of the mixture of gas and air when the fuel is injected.

Kinematic viscosity

Kinematic viscosity of liquid petroleum products, both transparent and opaque, is determined by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer (ASTM, 2006). For some engines, it may be advantageous to specify a minimum viscosity because of power loss due to injection pump and injector leakage. The MB100 microemulsion biofuel shows much higher values as compared to both the standard value of petroleum diesel and transesterification biodiesel. While its blends, MB20 and MB5, has much lower viscosities and meet the standard value of kinematic viscosity for biodiesel, but was a little bit higher than that of petroleum diesel. This is attributed to the fact that MB100 has a higher density than regular diesel. It is well recognized that the higher density leads to the higher flow resistance of fuel oil. As a result, the higher viscosity can bring about inferior fuel injection and incomplete combustion, and thus, decrease the efficiency of the engine. In addition, in this study, the cosurfactant (alcohol) had an effect on oil viscosity reduction. The viscosity of refined palm oil is 40.9 cst at 40°C, while the microemulsion biofuel, MB100, contains a cosurfactant in the system that would reduce the viscosity of the fuel to 35.44 cst, as mentioned in Table 4.1.

Gross heat combustion

The gross heat combustion or the heat of combustion is one of the most important fuel properties that indicate the fuel performance on running with an engine. The heat of combustion is a measurement of the energy available from a fuel. This value is essential when considering the thermal efficiency of the equipment for producing either power or heat (ASTM, 2006). The result showed that the heat of combustion of the microemulsion biofuel increased when less ethanol was added. It is well recognized that ethanol has a lower heating value than those of vegetable oil and petroleum diesel; therefore, the more petroleum in the composition, the higher the gross heat value. The result of this work corresponded to findings on the heating value of diesohol in relation to its ethanol content (Kwanchareon et al., 2007).

Acid number

This parameter refers to the level of fatty acids or processing acids that presents in biodiesel. Biodiesel with a high acid number has been shown to increase fueling system deposits and affect the corrosion of engines; it is also used as an indicator of the storage stability of biodiesel (Lin et al., 2006). This fuel property indicates a quality of fuel in terms of engine maintenance (i.e. storage) and engine performance (i.e. corrosion). The result of all products from this study, MB100, MB20, and MB5, were found to be within the standard value. This implies that our products are acceptable for using with diesel engine in term of engine maintenance.

Copper strip corrosion

The copper strip corrosion is a parameter indicating the corrosivity of sulfur compounds in hydrocarbon fluids. A copper strip corrosion test is performed by immersing a strip of cleaned, polished copper in a hydrocarbon fluid at a specified temperature for a predetermined time, and then comparing the results with the copper strip corrosion standard value. Our products were found to meet the standard value. This parameter also confirm that the microemulsion biofuel obtained from this present study will not affect and result on engine corrosivity.

Some of the properties of the products from this study were found close to the properties of diesohol that reported by Cheenkachorn et al. (2004). They studied fuel properties of diesohol that used biodiesel as an emulsified additive. Diesohol production utilizing with the following composition: conventional diesel, ethanol (5% water), and palm oil biodiesel at 95%, 5%, and 5% by volume, respectively. Diesohol emulsion exhibited good emulsion stability; they are capable of being stored for 6 months at room temperature. For properties of diesohol emulsion, the weight of carbon residue increases when the amount of biodiesel is increased. The diesohol emulsion had high carbon residue ratio than diesel fuel due to it had palm-oil biodiesel as an emulsifier as same as the carbon residue value of MB100 also had the highest carbon residue because it had the high triglyceride molecules in the structure. The carbon residue is considered as one properties needed to be concerned as it indicates diesel engine maintenance in the long run. Moreover, the viscosity of diesohol emulsion increases as biodiesel content increases. Heating value of diesohol decreases when more biodiesel is added; this same trend is also observed when ethanol is added. In addition, diesohol emulsion was found to have a lower cetane value than diesel fuel when increasing the amount of alcohol added (Kwanchareon et al., 2007). Therefore, it would be mentioned that the microemulsion biofuel, MB100, can be assumed to have higher cetane value as compared to MB20 MB5, and diesel fuel. Since the lower cetane index indicates the poorer the ignition, it can be expected that MB 100 will exhibit the better ignition as compared to MB5 and MB20.

For the overall properties of microemulsion biofuel production; MB100, MB20, and MB5, were close to both of conventional diesel standard and biodiesel standard, only flash point value and kinematic viscosity that show slightly different value to meet standard. To make sure that microemulsion biofuel can be applied as an alternative fuel, the further study on stability, performance and exhausted emission should be studied.

4.3 The Stability of the Microemulsion Biofuel

The preparation of stable water-in-oil microemulsion is essential for the production of a stable microemulsion biofuel. The effects of several process variables on the stability of microemulsion formation were investigated. The variables included the emulsifier dosage, the ratio of water to oil, the stirring intensity, the mixing time, the emulsifying temperature surfactant dosage, and so on (Fingas et al., 1994 and Jerzy et al., 1990). Temperature often affects emulsification through its effects on the interfacial tension, adsorption of the emulsifier, and viscosity of oil. Oil viscosity decreases as temperature increases; therefore, a higher temperature is favorable for emulsification (Chen et al., 2005).

So, in this study the effect of temperature on the stability of a microemulsion biofuel was researched. The stability results of MB100, which was the selected microemulsion biofuel, are shown in Tables 4.2-4.5. MB100 was kept at constant temperature, 30 °C in incubator for 6 months, the results are as shown in

Appendix B. Besides that, the stability was also tested at varied temperatures from 20°C to 70 °C.

The results showed that the microemulsion biofuel, MB100, which maintained homogeneous phase after being kept at 30 °C, exhibited good microemulsion stability. No agglomeration of liquid droplets and no sediment layer occurred physically. The homogeneity was due to the fact that the surfactant acts as an amphiphile (a surface-active agent) and forms micelles that have non-polar tails and polar heads. These molecules are attracted together by liquid/liquid interfacial film. When water was in the continuous phase, the polar head in a surfactant molecule oriented itself to the ethanol, and the non-polar tail oriented itself to the vegetable oil. This stability result corresponds to the diesohol emulsion stability results of Cheenkachorn et al. (2004). They kept a diesohol emulsion for 6 months at temperature room, and the diesohol emulsion showed good stability.

However, for the study of stability of MB100 at various temperatures, the results showed that for some composition ratios of microemulsion biofuel, at high temperatures MB100 turn to be turbid solution which is considered as instability for being biofuel. From the results in Table 4.2- 4.5, it was found that for MB100 at the composition of palm oil (95% by weight), a C/S ratio of 0.5 (4.95% by weight), and water (0.05% by weight) and for some other composition exhibit their stability in this range of temperature. However, for further study for performance of MB100, due to the limitation of water content of fuel to operate with real engine, only MB100 form the composition at C/S equal 0.5 and water content at 0.05% was selected. Besides from this selected composition of MB100, MB20 and MB5 which were the blends of the selected MB100 with diesel fuel at 80% and 95% by volume were also studied for their stability in the same temperature range. The result is as shown in Table 4.6. It was quite surprising that MB20 and MB5 are turbid or cloudy at the temperature higher than 60 °C. In addition, the phase separation at the normal temperature in Thailand (30-40 °C) was not found for our microemulsion biofuel. From the stability of our products indicate that the selected microemulsion biofuels MB100, MB20, and MB5 are promising to be used as biofuels. These results are similar to those of Kwanchareon et al. (2007); they also studied the stability of a diesel-biodiesel-ethanol blend, called *diesohol emulsion*, at temperature room 30-40 °C. They found that the diesohol emulsion can be used as a liquid fuel without the problem of phase separation.

Table 4.2 Stability of the Microemulsion Biofuel at a C/S ratio of 0.5

Characteristics	20 °C	25 °C	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	65 °C	70 °C
Palm oil 95%, C/S 4.95%, water 0.05%	-	-	-	-	-	-	-	-	-	-	-
Palm oil 95%, C/S 4.9%, water 0.1%	-	-	-	-	-	-	-	-	-	-	-
Palm oil 90%, C/S 9.95%, water 0.05%	*	*	*	-	-	-	-	-	-	-	-
Palm oil 90%, C/S 9.9%, water 0.1%	-	-	-	-	-	-	-	-	-	-	-
Palm oil 85%, C/S 14.95%, water 0.05%	-	-	-	-	-	-	-	-	-	-	-
Palm oil 85%, C/S 14.9%, water 0.1%	-	-	-	-	-	-	-	-	-	-	-

Table 4.3 Stability of the Microemulsion Biofuel at a C/S ratio of 0.75

Characteristics	20 °C	25 °C	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	65 °C	70 °C
Palm oil 95%, C/S 4.95%, water 0.05%	-	-	-	-	-	**	-	**	**	**	***
Palm oil 95%, C/S 4.9%, water 0.1%	-	**	**	**	-	-	**	**	-	-	-
Palm oil 90%, C/S 9.95%, water 0.05%	-	-	-	-	-	-	-	-	-	**	*
Palm oil 90%, C/S 9.9%, water 0.1%	-	-	-	-	-	-	-	-	-	*	*
Palm oil 85%, C/S 14.95%, water 0.05%	-	-	-	-	-	-	-	-	-	-	-
Palm oil 85%, C/S 14.9%, water 0.1%	-	-	-	-	-	-	-	*	-	-	-

Table 4.4 Stability of the Microemulsion Biofuel at a C/S ratio of 1.0

Characteristics	20 °C	25 °C	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	65 °C	70 °C
Palm oil 95%, C/S 4.95%, water 0.05%	-	-	-	-	-	-	-	-	-	*	**
Palm oil 95%, C/S 4.9%, water 0.1%	-	-	-	-	-	-	-	**	**	**	***
Palm oil 90%, C/S 9.95%, water 0.05%	-	-	-	-	-	-	-	-	-	-	*
Palm oil 90%, C/S 9.9%, water 0.1%	-	-	-	-	-	-	-	-	-	-	*
Palm oil 85%, C/S 14.95%, water 0.05%	-	-	-	-	-	-	-	**	**	-	-
Palm oil 85%, C/S 14.9%, water 0.1%	-	-	-	-	-	-	-	-	-	***	***

Table 4.5 Stability of the Microemulsion Biofuel at the C/S ratio of 1.25

Characteristics	20 °C	25 °C	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	65 °C	70 °C
Palm oil 95%, C/S 4.95%, water 0.05%	-	-	-	-	-	-	-	-	**	**	***
Palm oil 95%, C/S 4.9%, water 0.1%	**	**	**	-	-	**	-	-	**	**	***
Palm oil 90%, C/S 9.95%, water 0.05%	-	-	-	-	-	-	-	-	-	-	-
Palm oil 90%, C/S 9.9%, water 0.1%	-	-	-	-	-	-	**	***	-	-	*
Palm oil 85%, C/S 14.95%, water 0.05%	-	-	-	-	-	-	-	-	-	-	-
Palm oil 85%, C/S 14.9%, water 0.1%	-	-	-	-	-	-	-	-	-	-	-

Table 4.6 Stability of the Microemulsion Biofuel-Diesel Blends

Characteristics	20 °C	25 °C	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	65 °C	70 °C
Microemulsion 20%, diesel 80% (M20)	-	-	-	-	-	-	-	-	-	**	**
Microemulsion 5%, diesel 95% (M5)	-	-	-	-	-	-	-	-	-	**	**

Note: * Precipitation occurred

** Solution turns turbid

*** Solution turns turbid and precipitates later on

4.4 The Performance on Diesel Engine Operation

According to the Kyoto Protocol, which has enforced regulations on the emissions of greenhouse gases since 2005, biodiesel can be used to replace petroleum diesel in transportation fuel to reduce pollutant emissions. Biodiesel can also be mixed with petroleum diesel in any proportion for engine fuel.

Generally, biodiesel has lower exhaust emissions of carbon monoxide, unburned hydrocarbons, and particulate emission than regular diesel fuel. Unfortunately, most emissions tests have shown a slightly increase in nitrogen oxides (Gerpen, 2005). Vegetable oils have been proposed as diesel fuel, but their high viscosity has been found to be problematic. Piston and injector deposits and crankcase oil dilution are problems caused by high viscosity. Consequently, conversions of vegetable oil to other forms have been performed to reduce the viscosity and to produce a fuel with properties that are similar to those of petroleum fuel.

This section of the study was separated into two parts: (1) a comparison of the performance of the microemulsion biofuels (MB100, MB20, and MB5) in a single-cylinder engine with that of conventional diesel fuel and (2) a comparison of the exhaust emissions of the microemulsion biofuels with that of conventional diesel fuel. All the data of performance and emission of the microemulsion biofuel are shown in Appendix C.

4.4.1 The Operation Performance

The results of the fuel performance tests found that microemulsion biofuel MB100 provided higher power and torque than the others fuels (i.e., MB20, MB5, and the conventional diesel) as shown in Figure 4.3-4.4. From this results, it can be assumed that the higher viscosity of MB100 made it more suitable for this type of engine operation in term of oil injection, ignition, and combustion; thus than the others. However, this may require further investigation to support or being an evident for this reason. In addition, the torque increased as the water content increased. It can be clearly seen from the Figure 4.5. The addition of water in the form of an emulsion had a positive effect on combustion behavior (Lif et al., 2006). When ignition occurred in the cylinder, the water turned to steam with the high pressure. And hence this may increase torque of the engine.

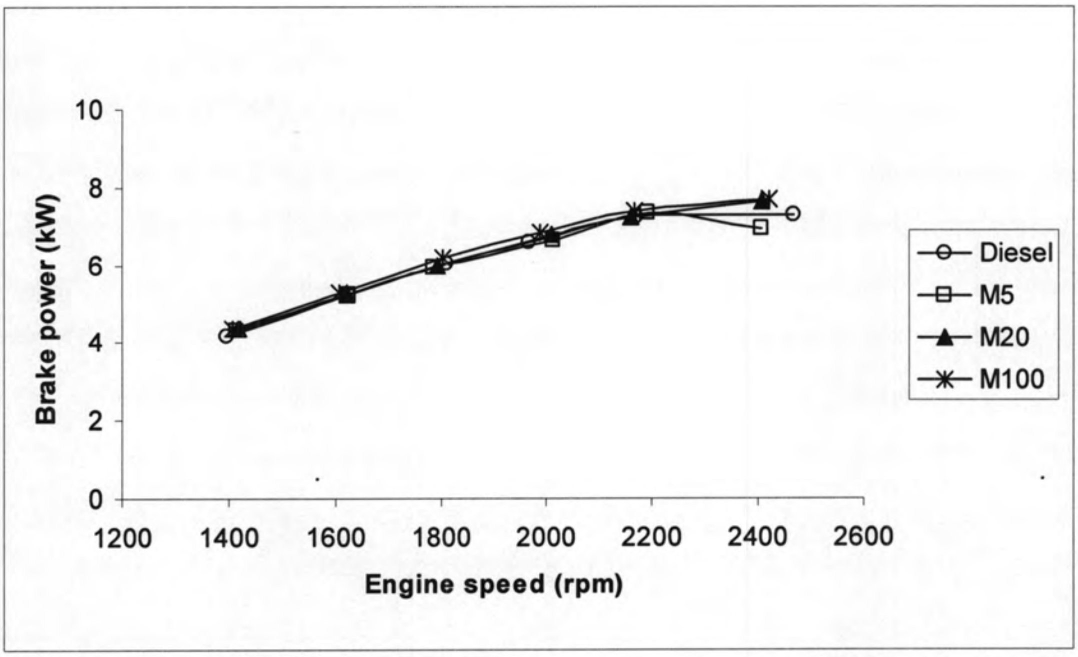


Figure 4.3 Brake Power of the Tested Fuels at Various Engine Speeds (rpm)

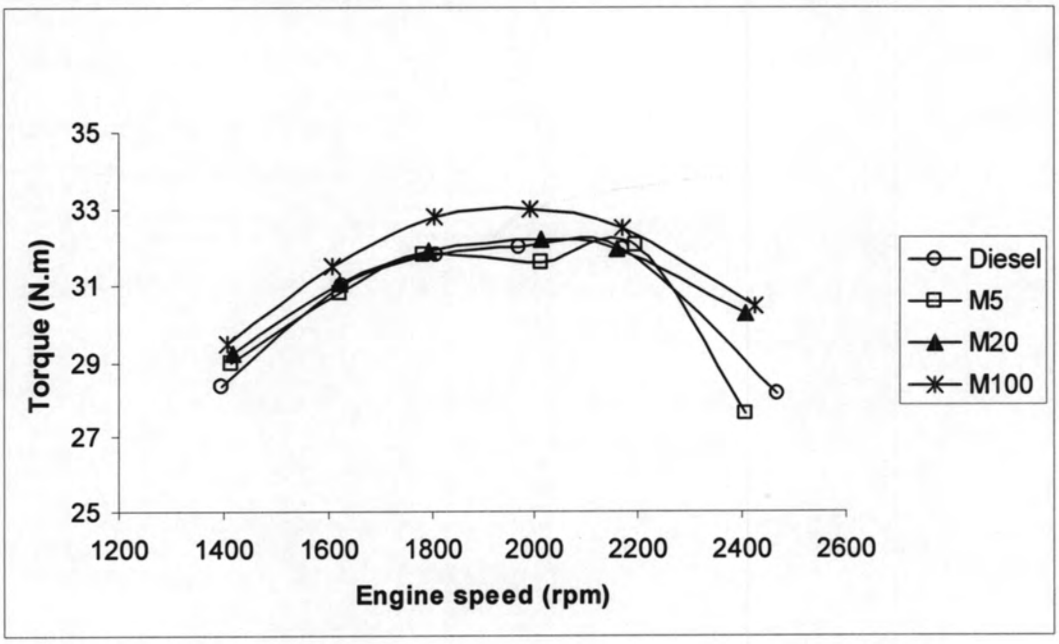


Figure 4.4 Torque of the Tested Fuels at Various Engine Speeds (rpm)

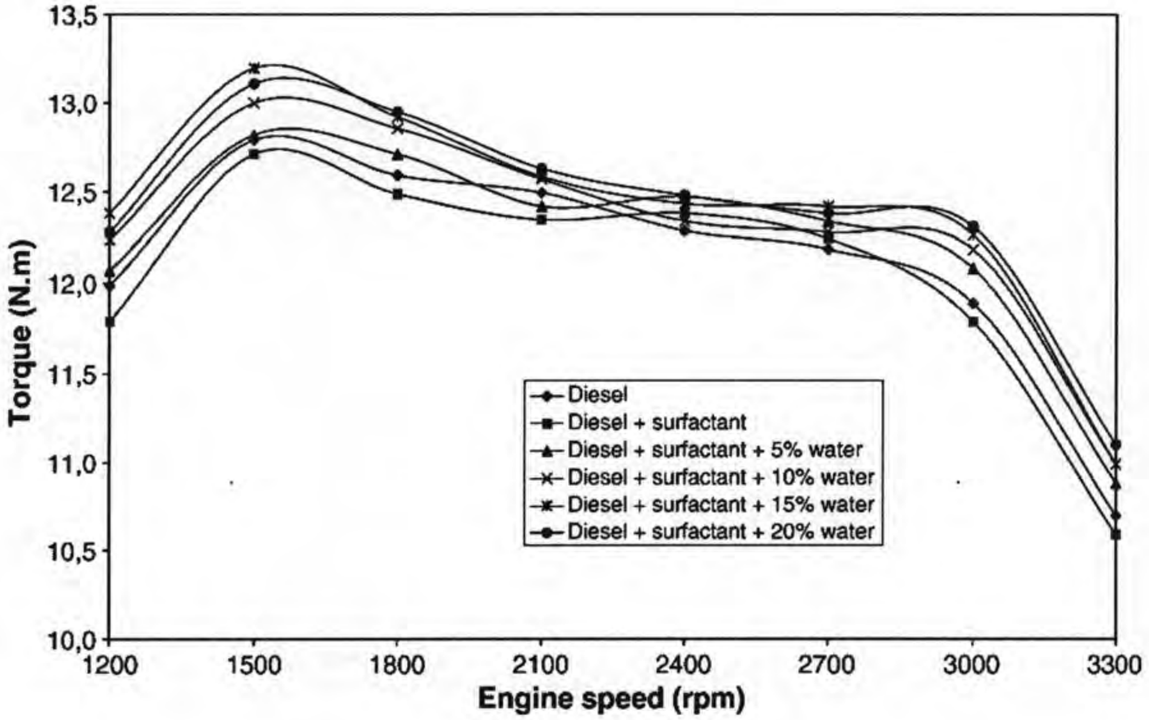


Figure 4.5 Engine Torque Output Versus Engine Speed Using Water-in-Diesel Emulsions as Fuel. (From Lif et al., 2006)

Another likely reason for the higher torque of MB100's was that the presence of water in the fuel was in form of water in oil microemulsion. The presence of an oil–water interface with very low interfacial tension led to a finer atomization of the fuel during injection. In this study, MB100 had higher water content than MB20, MB5 and the diesel fuel; thus, it exhibits the highest torque as can be seen in Figure 4.4. The fuel giving high torque indicates the high quality of oil. Therefore, our microemulsion biofuel can be considered as high performance fuel for single-cylinder engine in term of power.

Figure 4.6 shows fuel consumption as a function of engine speed for the tested fuels. As can be seen from the figure, fuel consumption decreases as engine speed increases. The higher consumption at low engine speeds is believed to be due to heat loss in the combustion chamber (Lif et al., 2006) and higher load applied to engine. When MB100 was compared with MB20 and MB5, MB100 was found to consume the most fuel because it had the lowest value of heat. This result corresponds with the results of a previous study by Lin et al. (2007). They also studied the characteristics of various fuels in comparison to conventional diesel fuel. They found that the diesel fuel had a slightly lower fuel consumption rate because it had the largest heating value of the tested fuels. In contrast, the biodiesel emulsions had slightly higher fuel-feeding rates and the lowest heating values. However, the different in fuel consumption among petroleum diesel, MB100 and MB5 are not significantly different for the whole range of engine speed. For MB20, the fuel consumption for different speed is quite fluctuate but in most cases show lower fuel consumption. It may need for more details study to clarify this finding.

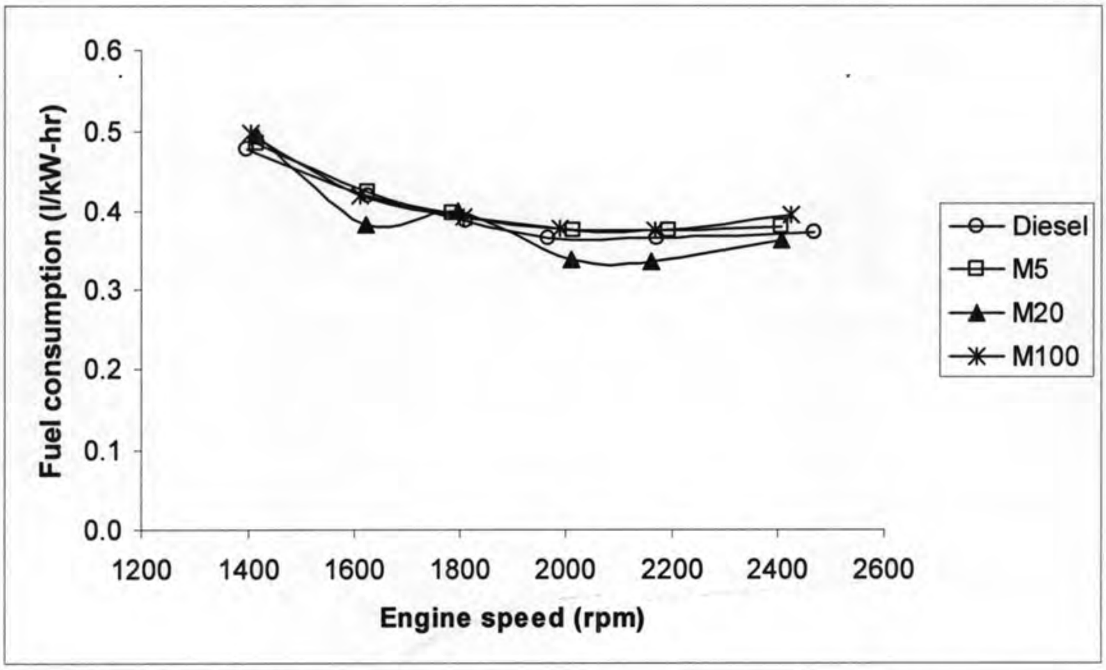


Figure 4.6 Fuel Consumptions of the Tested Fuels at Various Engine Speeds (rpm)

4.4.2 The Exhaust Emissions of the Diesel engine Operation

The black smoke emissions resulting from the combustion of the microemulsion biofuels, MB100, MB20, MB5, were compared with those of petroleum diesel and plotted in Figure 4.7. The examination was also conducted at various speed of engine operation. Overall figure shows that the smoke levels of all 4 types of fuel are slightly different. However, if we consider in the range speed from 2000 to 2500 rpm, MB100 and MB20 seem to emit the lower black smoke level. This may be because of the higher presence of oxygen that came from the higher ethanol and the water content in compositions of the fuels. The reduced smoke at high loads (low speed engine) of MB20 in range speed from 1400 to 2000 can be explained that this fuel had suitable of viscosity for this type engine and had enough amount of oxygen for combustion. In other hand, the viscosity of MB100 was too high to be in the suitable range for combustion. Diesel fuel and MB5, both of these fuels lack of oxygen for combustion so that at lower speed (high load), they emitted more black smoke. It can be clearly seen from structure formulas of diesel and palmatic acid that the main fatty acid composition in palm oil; diesel chemical formula in rang $C_{10}H_{20}$ to $C_{15}H_{28}$, palmatic acid: CH_3-$(CH_2)_{14}$-COOH. In addition, water emulsion formation in fuel is able to reduce the maximum total amount of soot yielded in the flame. It is an oxidizer that effectively introduced into the fuel-rich regions, it suppresses soot formation in the combustion chamber (Kumar et al., 2006). This is mainly due to the decrease in volume of the sooting region. There was a study by Kadota and co-workers indicates how the cooling effect of water evaporation results in the lowering of temperature within a droplet, so that the extent of the cracking reactions and subsequent solid formations are reduced (Kadota et al., 2002). They also predicted that water emulsification results in the reduction of a droplet's temperature, and creates the potential for a corresponding reduction in soot production. From the literature, an optimum water content value for the maximum reduction of soot emission concentrations is 5%. The emulsion spray flame appears to approach complete combustion more than the diesel spray flame. The microemulsion biofuels in this study had water contents much lower than 5%; therefore, the microemulsion biofuels may not be able to lower soot formation at significant level.

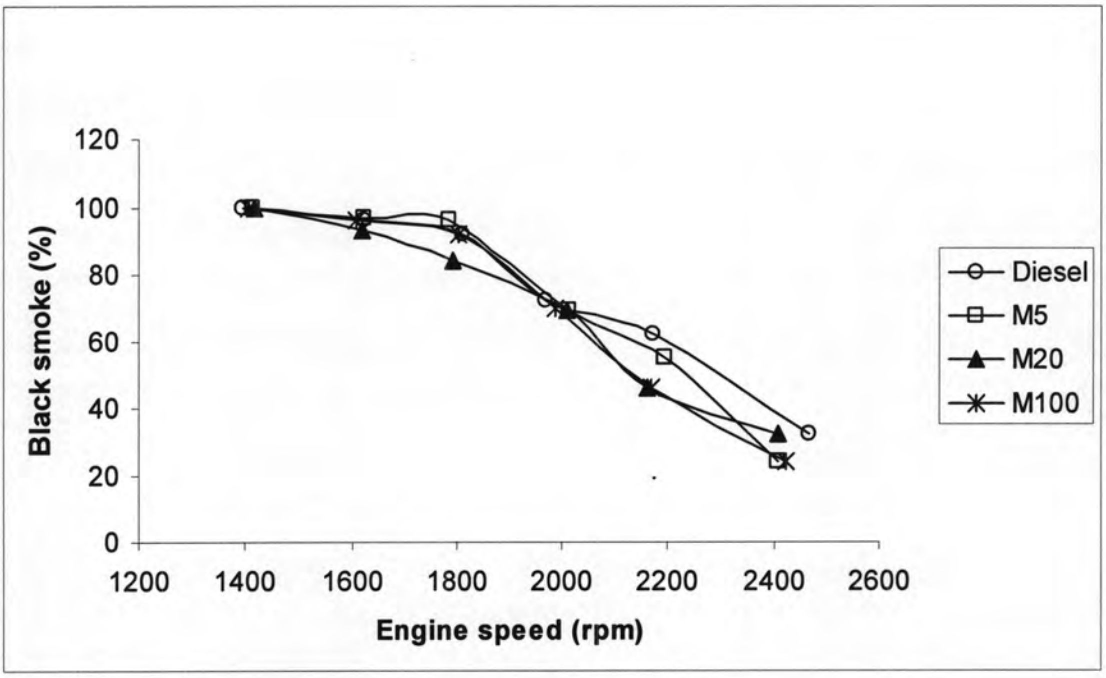


Figure 4.7 Black Smoke of the Tested Fuels at Various Engine Speeds (rpm)

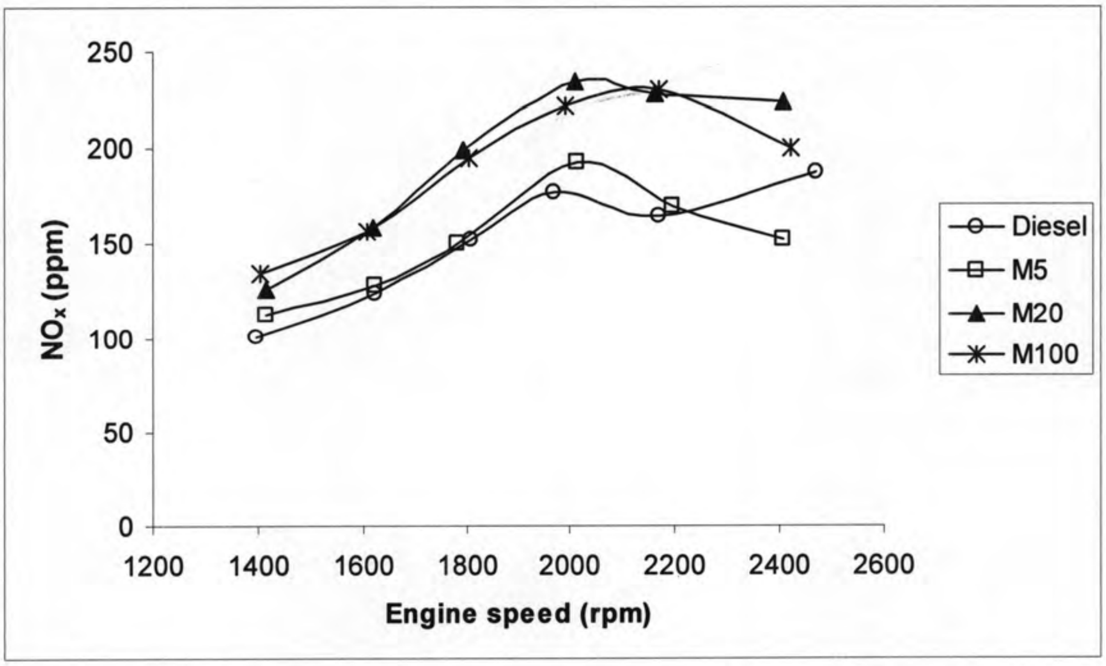


Figure 4.8 Nitrogen Oxides of the Tested Fuels at Various Engine Speeds (rpm)

Most of biodiesel are found to generate higher amounts of NO_x than the conventional diesel. It has been proposed that certain injection systems suffer an unexpected advance fuel injection timing due to the higher bulk modulus of compressibility in fuel blends contain biodiesel. To increase speed, cause a faster transference of the pressure wave from the injection pump to the nozzle, whereby advancing the needle lift. It is well known that advancing injection timing causes an increase in NO_x emissions (Murillo et al., 2007). From Figure 4.8, it can be observed that from low speed 1,400 up to 2,500 rpm all types of microemulsion biofuel show the same pattern of NO_x emission that climb up to the peak at 2,000 rpm and climb down to lower emission while for the petroleum diesel, the NO_x emission tend to be higher at rpm is getting higher than 2,200. In addition, the fuel that has shorter ignition delay (higher cetane value), nitrogen oxides (NO_x) emission is likely to be increased (Energy System Engineering, 2007) because of the temperature and pressure in combustion chamber increase that cause effect to increase NO_x emission. Moreover the running fuel with diesel engine that had nitrogen and oxygen from the air can be generated the NO_x emission. In addition, the microemulsion biofuel had NO_x emission because of had oxygen from the palm oil structure. Therefore the higher NO_x emission of MB100 and MB20 may be explained by these reasons.

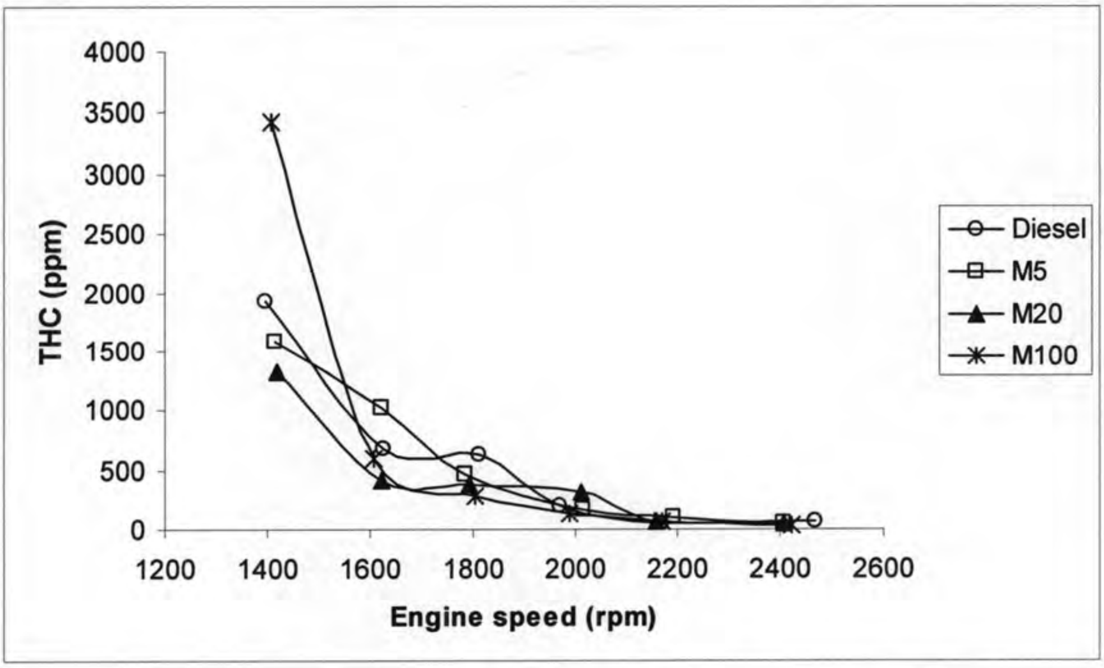


Figure 4.9 Total Hydrocarbons of the Tested Fuels at Various Engine Speeds (rpm)

Even though in this study our oil has not been determined for cetane number due to limitation of equipment and cost, the cetane number of palm oil and biodiesel usually has higher cetene value than petroleum diesel. The Almeida et al.

(2002) report the cetane value of petroleum diesel is 45-50 min while palm oil is 45-55 min those of. These results support the results in a previous study by Kwanchareon et al. (2007) that found the higher NO_x was emitted from the fuel blends than the diesel at low, medium, and high loads. The NO_x behavior of the biodiesel blends is complex and not yet conclusive. Some studies indicated that oxygenated fuel blends can cause an increase in NO_x emissions (Caro et al., 2001 and Ozer et al., 2004). In addition, the literature review indicated that NO_x levels were significantly reduced at water contents between 15-45%, but an increase in CO and hydrocarbon emissions with increasing water content (Lif et al., 2006). The reason for the reduction of NO_x emission may due to the decreasing temperature of the combustion as a result of vaporization of the liquid water in fuel and the consequent dilution of the gas phase species. However the amount of water is not significant to affect the combustion temperature. The microemulsion biofuels in this study had water contents of less than 15%; hence, the microemulsion biofuels could not reduce NOx emissions.

Hydrocarbon emissions from the microemulsion biofuels and the conventional diesel are shown in Figure 4.9. The maximum hydrocarbon emission was found for MB100 at a very low engine speed or high load because of incomplete fuel atomization, however it dramatically decreased from almost 3,500 ppm to 500 ppm at engine speed getting higher to 1,600 rpm and become lower THC than other fuels at speed 1,800 rpm to 2,400 rpm. This result corresponds with the one reported by Kumar et al., (2006) that hydrocarbon emission from the emulsion of animal fat showed higher emissions at low speeds. The hydrocarbon emission tended to increase because of the quench layers of unburned fuel present in the combustion chamber at low speeds. A high HC emission means that there is some unburned fuel emitted in exhausted gas due to the reduction of temperature in the combustion chamber that cause incomplete combustion to be occurred. Therefore, MB100 had higher hydrocarbon emissions at the low speed by this reason. Thereby, MB20 exhibits lower hydrocarbon emissions at lower speed than MB100. MB20 may be considered more suitable than MB100 in this perspective.

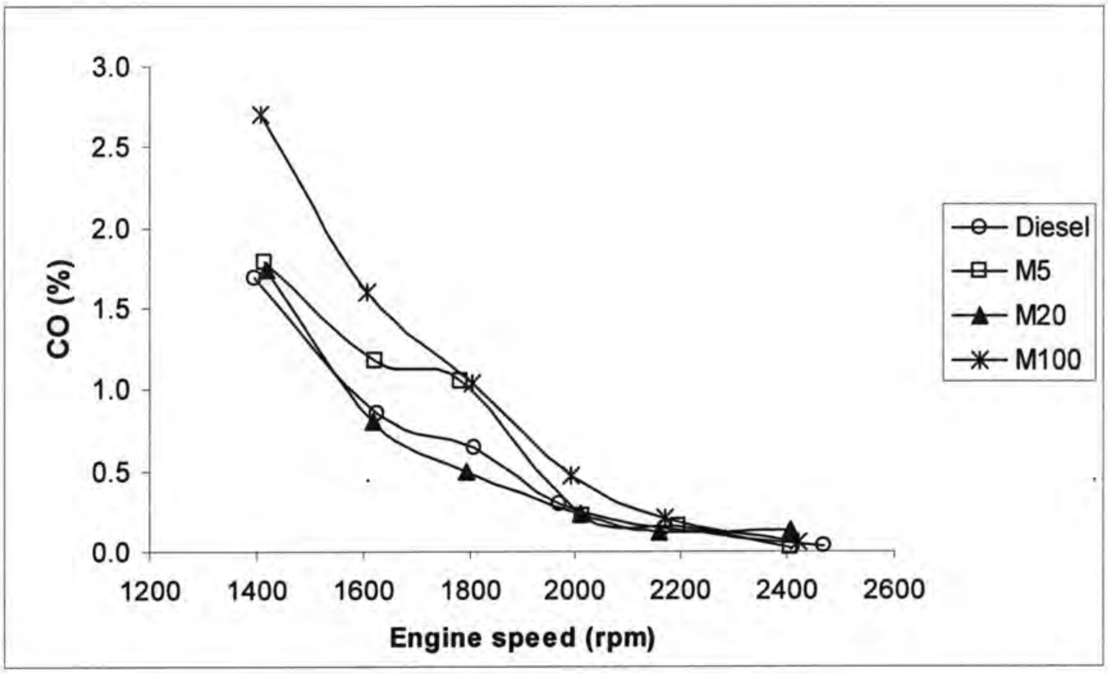


Figure 4.10 Carbon Monoxides produced by the Tested Fuels at Various Engine Speeds (rpm)

The trends of the carbon monoxide (CO) emissions in relation to engine speed of the microemulsion biofuels, MB100, MB20, and MB5, and conventional diesel fuel, are shown in Figure 4.10. The CO emissions from the microemulsion biofuels and diesel fuel appear to decrease as engine speed increases or load decrease. Owing to the fact that the lower burning gas temperature that occurred at the lower engine speed caused the lower conversion rate of CO to CO_2. Large CO emissions at lower engine speeds were observed even though the extent of the mixing between the atomized fuel particles and the surrounding ones was enhanced at higher speeds. In addition, the burning gas temperature inside the combustion chamber also increased (Lin et al, 2007). This resulted in the large conversion rate of CO to CO_2 emissions, and lower CO emission as can seen in Figure 4.10 and Figure 4.11. MB100 had the highest amounts of carbon monoxide emissions at low speeds or high load due to its high fuel consumption at this range and this made the engine chamber have not enough oxygen to generate complete combustion. Moreover, because of its high viscosity, MB100 may be injected as large droplets of fuel into the chamber, hence that cause incomplete combustion to be occurred. Consequently, CO, HC and black smoke emissions were high at the low speed engine or high load running. However at high speeds, the CO emissions from the microemulsion biofuels were not significantly different from the CO emissions from the diesel fuel. Our results differed from a previous studied by Kwanchareon et al. (2007). They reported that the CO emissions of different diesel compositions (diesel-biodiesel-ethanol) at various engine loads (engine speeds) was not much different from that of the conventional diesel, but at low speeds, the CO emissions of the blends decreased significantly when compared with that of the conventional diesel fuel. Because of the diesel-biodiesel-ethanol had the enrichment of oxygen in from the ethanol and biodiesel addition, in which an increase in the proportion of oxygen will promote the further oxidation of CO during the engine exhaust process. ·

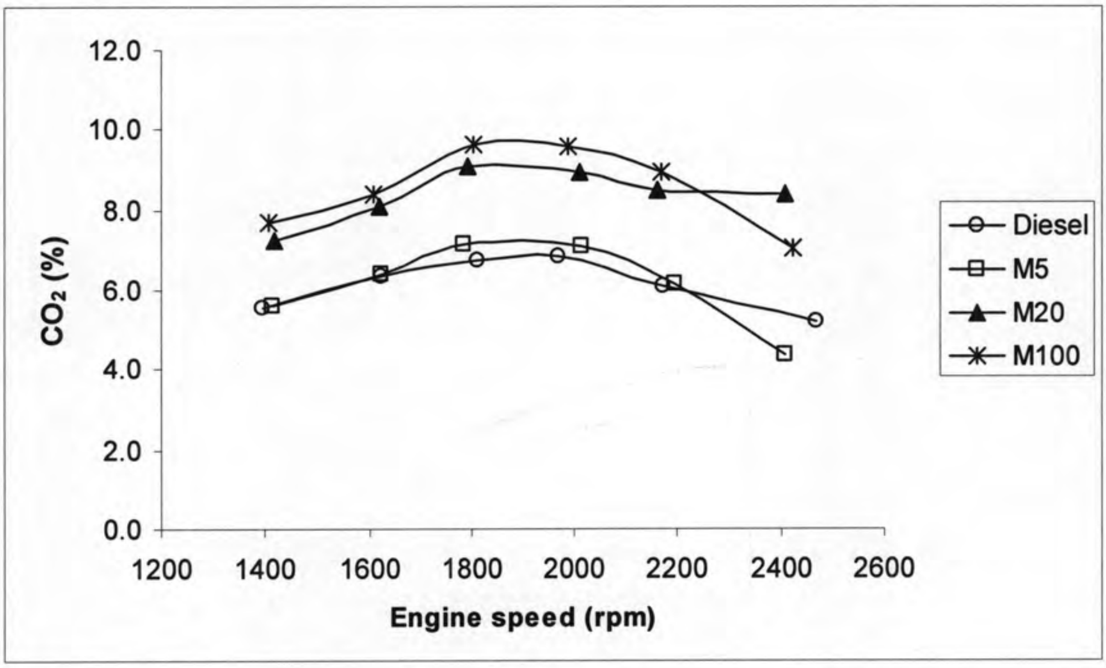


Figure 4.11 Carbon Dioxide Emissions of the Tested Fuels at Various Engine Speeds (rpm)

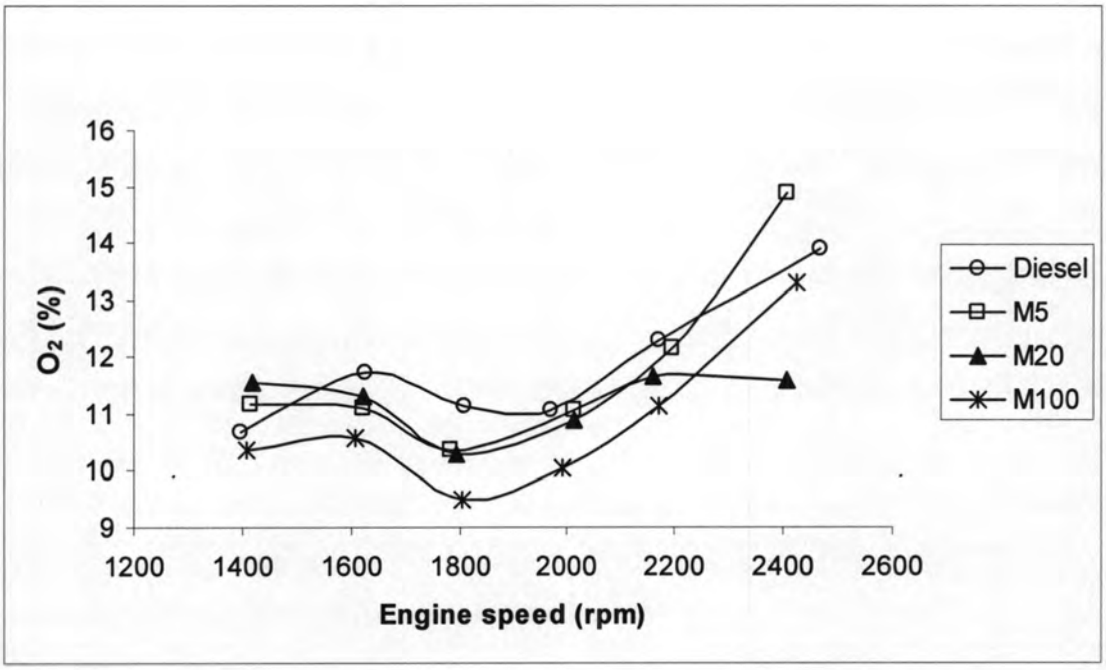


Figure 4.12 Oxygen of Various Tested Fuels at Various Engine Speeds (rpm)

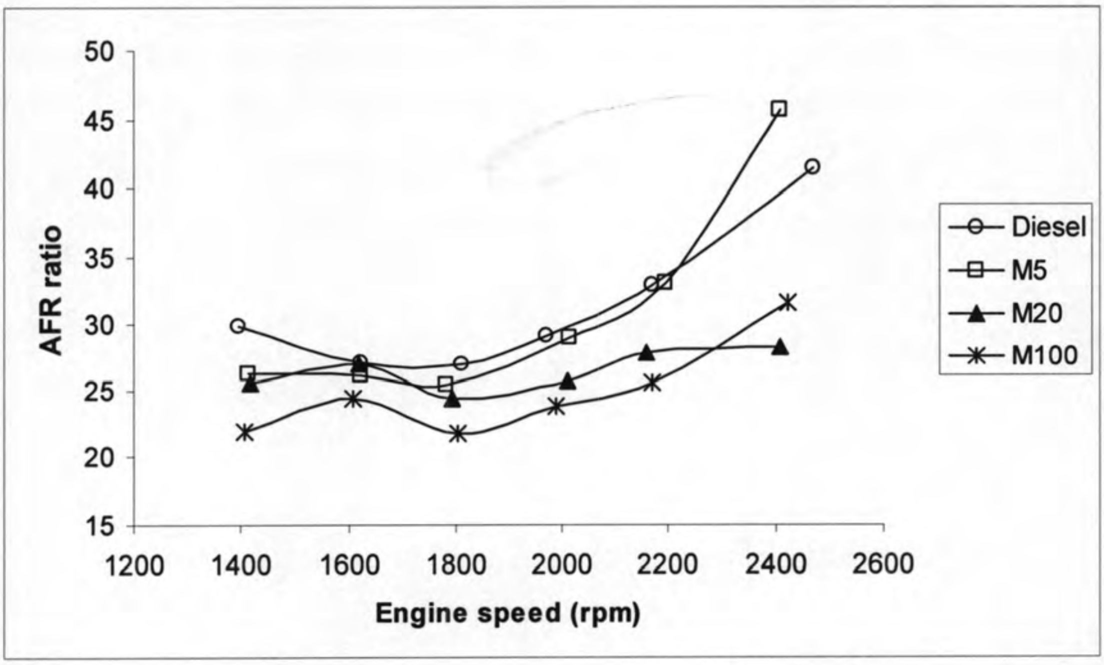


Figure 4.13 Airs to Fuel Ratios of the Tested Fuels at Various Engine Speeds (rpm)

The air to fuel ratio (AFR) is the mass of air to the fuel present during combustion. When all the fuel has been combined with all the free oxygen, typically within a vehicle's combustion chamber, the mixture becomes chemically balanced. The AFR is an important measure for anti-pollution and performance tuning reason. In fuel, the air/fuel mixture is approximately 14.7 times. Any mixture less than 14.7

to 1 is considered to be a "rich mixture". Any mixture more than 14.7 to 1 is a "lean mixture".

Normally for the petroleum fuel, rich mixtures produce cooler combustion gases due to the excessive amount of carbon, which oxidizes to form carbon monoxide (CO) rather than carbon dioxide (CO_2). Lean mixtures produce cooler gases due to the excessive dilution by unconsumed oxygen from air and its associated nitrogen. The engine designed for lean burning can employ higher compression ratios, and thus, provide better performance and lower exhaust emissions than those found in conventional diesel. The main drawback of lean burning is the large amounts of NO_x generated.

The air to fuel ratios of the microemulsion biofuels (MB100, MB20, and MB5) and the conventional diesel are shown in Figure 4.13. From the graph, all of the fuels were run with lean burning for all speeds. The increasing AFR at higher speed indicates the less consumption of the fuel but more air is consumed. This result corresponds to the result of fuel consumption rate and oxygen emission at different engine speed (see Figures 4.6 and 4.12). The suitable air to fuel ratio is 14.7 to 1 in terms of engine combustion; hence, when the fuel consumption decreases, oxygen increases due to the equivalence mass of the air to fuel ratio. Therefore, as the engine speed increases, the AFR increases, and oxygen emissions also increase; whereas, fuel consumption decreases.

The microemulsion biofuels produced lean mixture AFR ratios. Since the microemulsion biofuels formed lean mixtures, they produced CO_2, rather than CO. It can be seen in Figures 4.10 and 4.11 that the microemulsion biofuels exhibited complete exhaust gas emissions.

4.5 Microemulsion Biofuel Application

On account of overall properties, performance and emissions studies of the microemulsion biofuels, it can be concluded that microemulsion biofuels; MB100, MB20 and MB5, could be used as alternative fuels. The microemulsion biofuels exhibit performances close to those of the conventional diesel. In particular, MB20, exhibited less fuel consumption than diesel at increased engine speeds. In addition, the microemulsion biofuels--particularity MB20--also reduced some exhaust emissions for example black smoke, total hydrocarbon, carbon monoxide on other hand emission increase in term of NO_x and CO than the conventional diesel.

For using biofuel as an alternative; both transesterification biodiesel and microemulsion biofuel should be considered on water content in fuel. Although the standard of water allows in biodiesel and diesel is not higher than 0.05% by volume. To induce water to be in form of water in oil emulsion was found to promote a fuel to reduce particulate matter, nitrogen oxides (NO_x) and soot emission during the performing experiment on internal combustion engines by lowering the combustion temperature as reported by the studies of Zaid (2004) and Washington State University Extension Energy Program (2007). Moreover Zaid (2004) reveals than the addition of water in the form of emulsion could be improved the combustion behavior in diesel engine, hence the performance of the engine in term of engine torque, engine power, and brake thermal efficiency increase by water percentage in the emulsion fuel increase up to 20% by volume. On the other hand, negative effect of water presence in fuel have to be considered since it can be promote growth of microorganism in the fuel as water may create suitable environment to them. Moreover, another important concern of having high water in fuel is that corrosion of steel material can be occurred. However the fuel retained water and formed emulsions should be more studied in term of microbial contamination when used these fuel form as an alternative (Chung et al., 2000).