CHAPTER 5

ENGINE PERFORMANCE

In this chapter, performances of the tested small diesel engine with emulsified oil as fuel in terms of output torque, engine power, specific fuel consumption and emissions were carried out.

5.1 Test engine preparation

Figure 5.1 shows a tested small diesel engine (Yanmar TF 75-LM) of which the main components and engine specifications are shown in Figure 5.2 and Table 5.1, respectively. The engine was operated 20 hr. before testing for each condition and after that the piston, piston ring and nozzle injection, lubricant oil were changed.

Figure 5.1 The engine test bed.

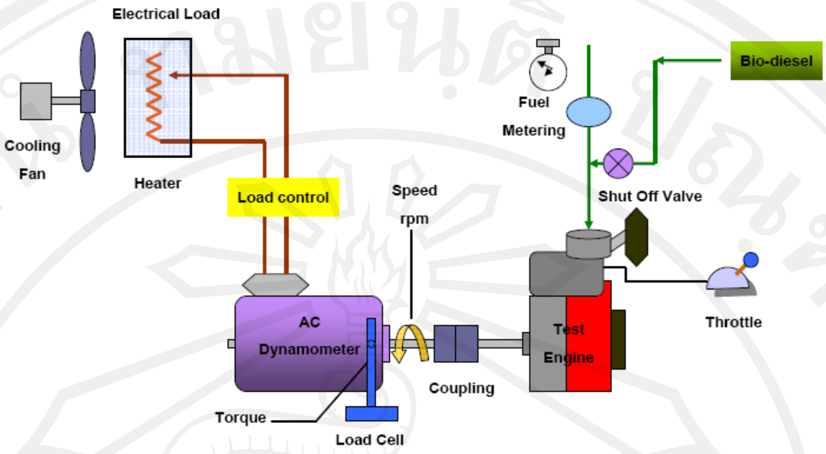


Figure 5.2 Schematic of the engine test bed.

Table 5.1 Specifications of the Yanmar TF 75-LM diesel engine.

Item	**Specification**
Engine Model	Yanmar TF 75-LM
Engine Type	Four strokes, water-cooled
Aspiration Type	Natural Aspiration
Injection Type	Indirect injection
Number of cylinder	1
Bore x Stroke	80 x 87 mm
Displacement	437 cc
Compression ratio	23.0 : 1
Max. Power	5.52 kW at 2200 rpm
Max. Torque	26.48 N m /1600 rpm.

The test engine was operated at room temperature and conducted at engine speeds of 1,000 - 2,000 rpm under full engine loads. The fuel was supplied to the engine by an external tank of 1 L capacity, which could be easily drained with the help of a three way stop valve. A glass burette of 20 mL was also attached in parallel to this tank and it was used for fuel flow rate measurement.

Test Procedure

1. Check the water coolant, lubricant oil and control equipment.
2. Start the engine at idle speed 1000 rpm on 30 min.
3. Adjust the load heater for test engine performance.
4. Read the Torque, fuel consumption and emission.
5. Adjust the engine speed step of 200 rpm until the speed reaches 2000 rpm.
6. Monitor and record the engine power and torque.
7. Change other fuels and repeat step 1-6.

5.2 Engine Performances

The engine power and the specific fuel consumption could be evaluated as follows:

The engine torque (N m) could be calculated from

$$T = F \cdot r \tag{5.1}$$

F is force (N) which could be read directly from the load cell and r is the radius arm of the load cell (m).

The engine power, P (kW), could be calculated by

$$P = \frac{2 \cdot \pi \cdot T \cdot N}{60 \times 1000} \tag{5.2}$$

Where N is engine speed (rpm).

The specific fuel consumption (g/kW hr) could be calculated by

$$sfc = \frac{m_f^{'}}{P} \tag{5.3}$$

m_f' is mass rate of fuel consumption (g/hr).

5.3 Gas Emissions Analysis

The engine gas emission could be read directly from a flue gas analyzer TESTO 350 XL as shown in Figure 5.3 of which CO (ppm), NOx (ppm) were main items in this study. The details of the emissions and the measuring range of the instrument are shown in Table 5.2

Figure 5.3 Flue Gas Analyzer TESTO 350 XL.

Table 5.2 Details of emissions and their measuring range of Testo 350 XL.

Sensor	Measurement Range	Accuracy	Resolution
O_2	0 to 25 vol. %	< 0.2% of m.v.	0.1 vol. %
CO	0 to 10,000 ppm.	< 5ppm (0 to 99 ppm) < 5% of m.v. (100 to 2,000 ppm) < 10% of m.v. (2,001 to 3,000 ppm)	1 ppm
CO_2	0 to CO_2 max.	± 0.3%vol.+1% of m.v. (0-25%vol.) ± 0.5%vol.+1.5% of m.v.(>25-50%)	0.01%vol (0-25% vol.) 0.01%vol (>25% vol.)
NO	0 to 3,000 ppm.	< 5ppm (0 to 99 ppm) < 5% of m.v. (100 to 2,000 ppm) < 10% of m.v. (2,001 to 3,000 ppm)	1 ppm
NO_2	0 to 500 ppm.	< 5 ppm (0 to 99 ppm) < 5% of m.v. (500 ppm)	0.1 ppm
SO_2	0 to 5,000 ppm.	< 5ppm (0 to 99 ppm) < 5% of m.v. (100 to 2,000 ppm) < 10% of m.v. (2,001 to 5,000 ppm)	1 ppm
H_2	0 to 300 ppm.	< 2 ppm (0 to 39.9 ppm) < 5% of m.v. (40 to 300 ppm)	0.1 ppm
C_xH_y	0 to 4 Vol. %	< 400 ppm (100 to 4,000 ppm) < 10% of m.v. (> 4,000 ppm)	0.1 ppm
Temperature	-40 to 1,200 ^oC	± 0.9 °F (-40 to+212 °F) ± 0.5% m.v.(+212 to+2,192°F)	

Black smoke could be read directly with a Hermann DO 285 Opacity Meter.

The tested engine speed was varied from1000 rpm up to 2000 rpm with a step change of 200 rpm. At each step, the engine was maintained steadily before data measurement. Each experiment was performed 5 times and the average value was undertaken.

5.4 Experimental Results

Figure 5.4 and Figure 5.5 show the engine torques and engine powers when different types of fuels are used at various engine speeds. For diesel oil, when 5 % of water was mixed with (95/0/5), the engine torque and the engine power were slightly lower than those without water (100 % diesel oil) at low engine speed. But when the engine speed was over 1400 rpm, the performances were less than those of diesel oil significantly due to the lower heating value with the amount of water mixing. Similar results were found with the emulsions of diesel/CPO/water. For diesel/CPO/water at 90/5/5, the engine performances were close to those of diesel/water at 95/0/5. The engine torques and the engine performances dropped with the percentages of CPO or water in the emulsions. It could be noted that the engine could run steadily when the percentages of CPO and water were not over 10 and 10 %, respectively.

Figure 5.6 shows the specific fuel consumption of the engine with the tested fuels which generally increases with the engine speed. The engine with 100 % diesel oil showed the best performance due to its highest heating value. For diesel/CPO/water at 90/5/5, the specific fuel consumption was close to the diesel mixed with 5 % water at low engine speed but when the speed was higher than 1400 rpm, more specific fuel consumption was higher due to its lower heating value. Again, when the percentages of CPO and water were higher in the emulsion, higher specific fuel consumptions were needed.

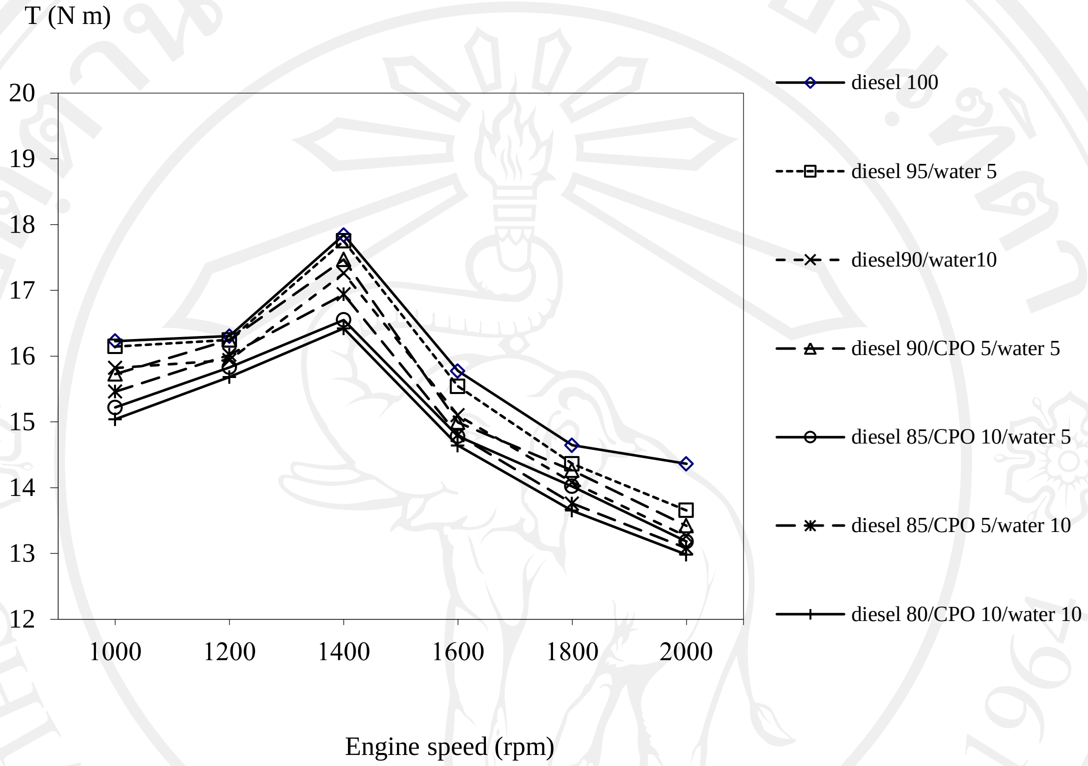


Figure 5.4 Engine torque at different engine speeds.

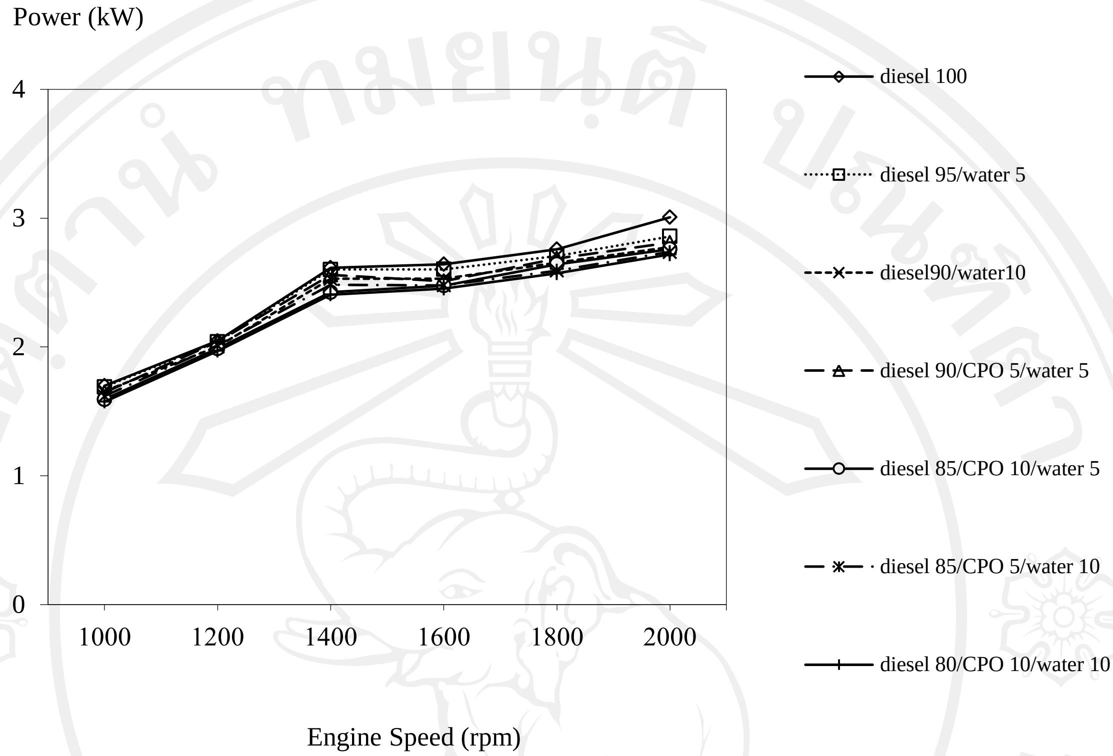


Figure 5.5 Engine power at different engine speeds.

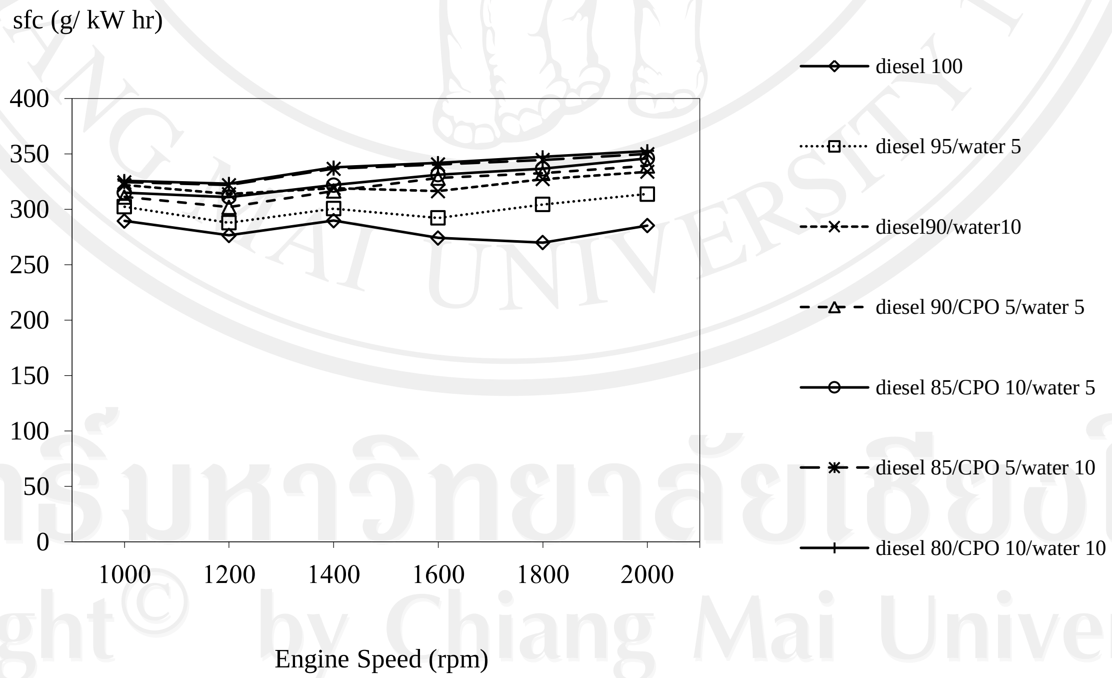


Figure 5.6 Specific fuel consumption at different engine speeds.

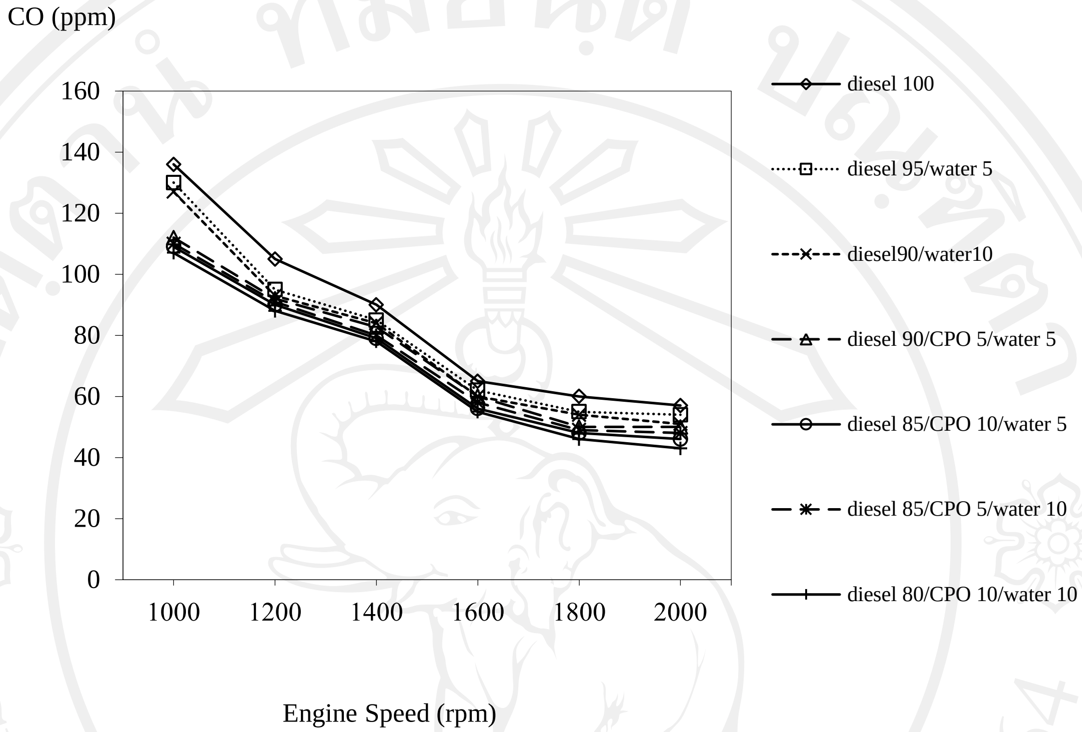


Figure 5.7 CO emission at different engine speeds.

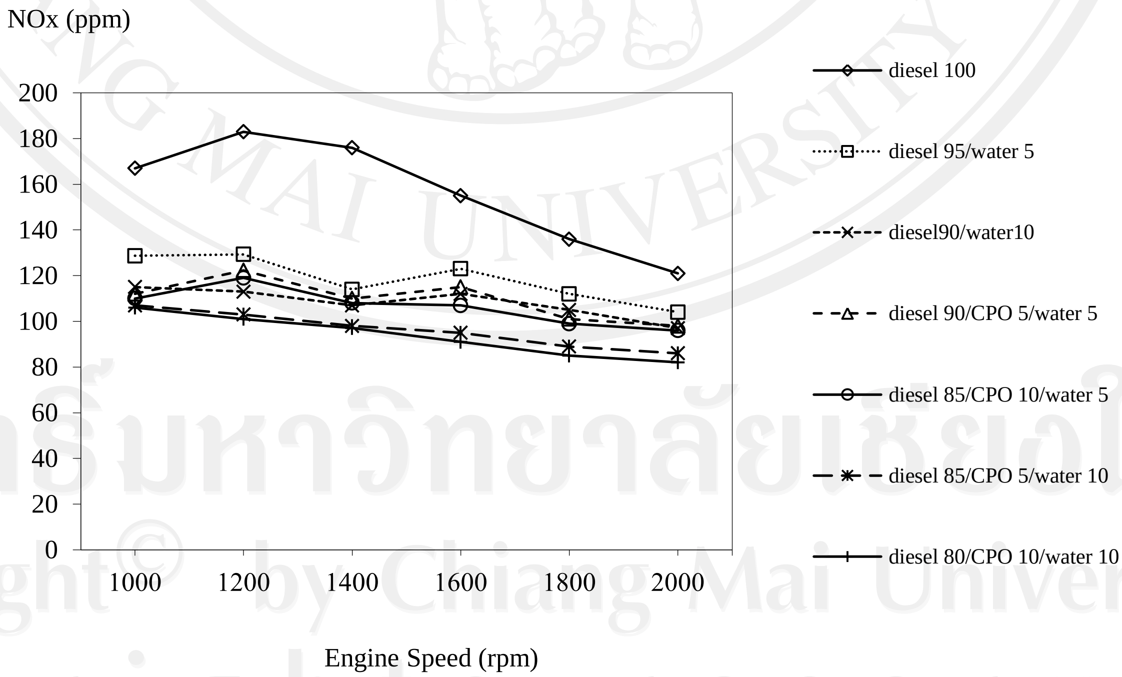


Figure 5.8 NOx emission at different engine speeds.

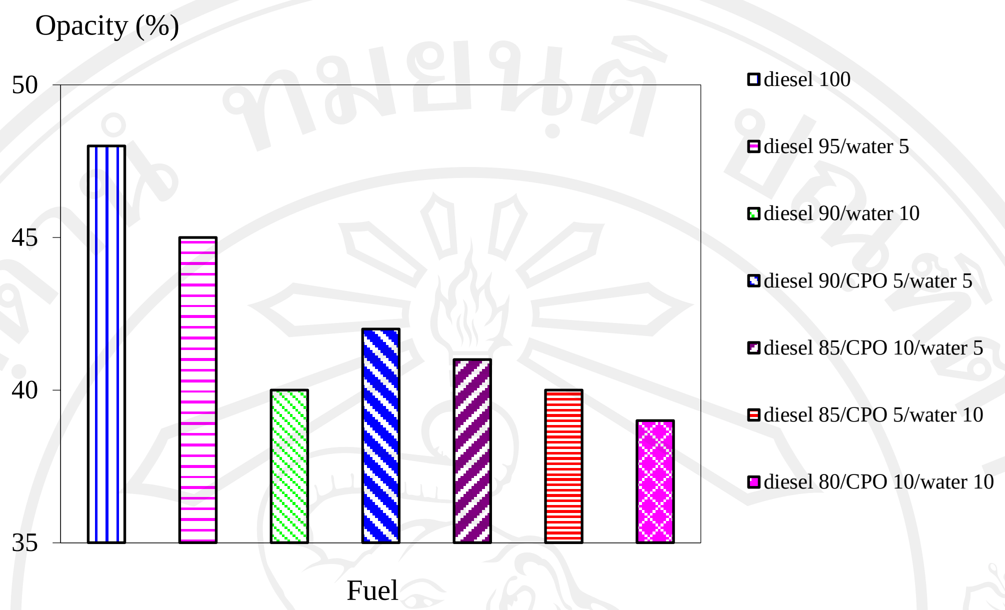


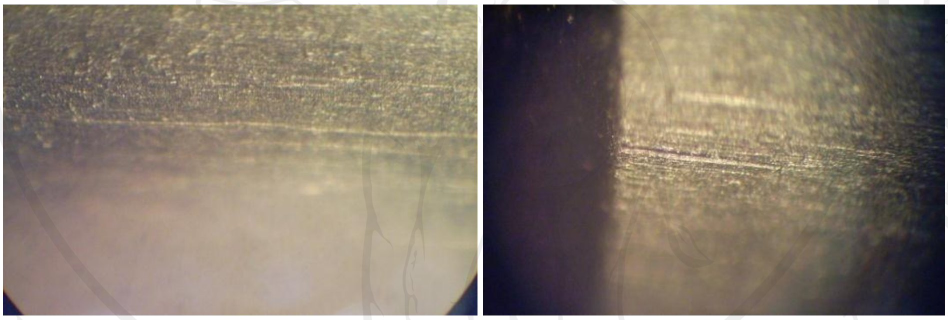
Figure 5.9 Black smoke of engine with different oil compositions.

Figure 5.7 and Figure 5.8 show CO and NOx emissions of the engine with different tested fuels. It could be seen that the diesel/CPO/water emulsion gave lowest emissions followed by the diesel/water emulsion. Figure 5.9 shows the results of the black smoke from the engine. The opacity of the black smoke from diesel oil was 48 % while those from diesel/water emulsion and diesel/CPO/water emulsion were 40-45 % and 38-42 %, respectively. Therefore, it could be noted that the emulsion could reduce the emissions of the engine significantly but higher specific fuel consumptions were needed.

Figures 5.10 – 5.12 show the wear effects on some engine parts when the fuel is diesel/CPO/water at 90/5/5 composition. The engine operation was 200 h and the considered engine parts were engine piston, needle injection and piston of fuel oil pump. It could be seen that the wears of this components were similar to those of diesel oil and the engine piston was cleaner from that with the diesel oil.

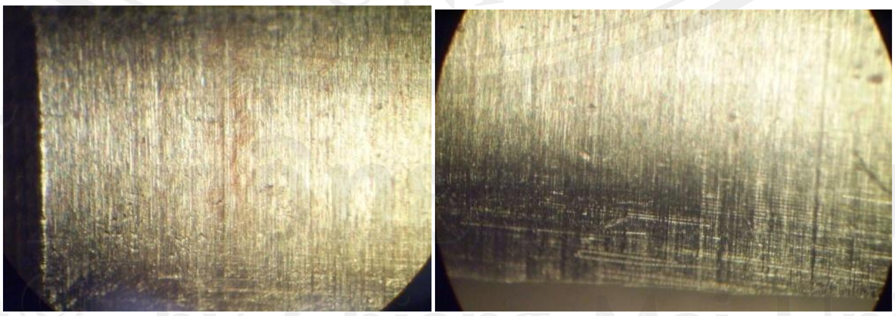
DieselPalm-Diesel Emulsion

Figure 5.10 Wear at the engine piston for the fuel oil and the emulsified Diesel/CPO/water of 90/5/5 after 200 h operation.



Diesel **Palm-Diesel Emulsion**

Figure5.11 Wear at the needle injection of fuel pump for the fuel oil and the emulsified Diesel/CPO/water of 90/5/5 after 200 h operation.



Diesel **Palm-Diesel Emulsion**

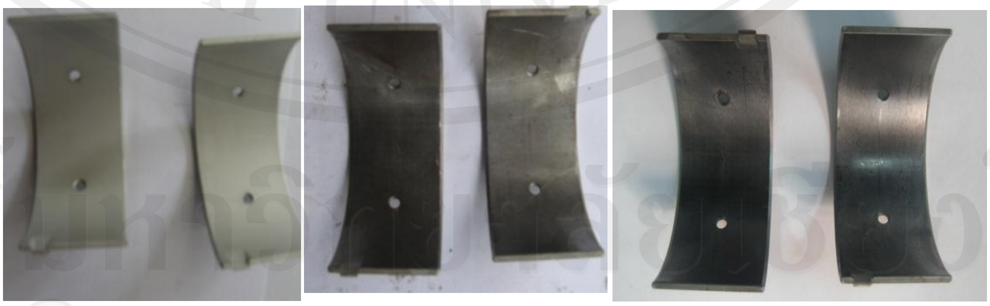
Figure 5.12 Wear at the piston of oil pump for the fuel oil and the emulsified Diesel/CPO/water of 90/5/5 after 200 h operation.

Before Tested **Diesel** **Palm-Diesel Emulsion**

Figure5.13 Wear at the piston ring for the fuel oil and the emulsified Diesel/CPO/water of 90/5/5 after 200 h operation.

Before Tested **Diesel** **Palm-Diesel Emulsion**

Figure 5.14 Wear at the intake valve and exhaust valve for the fuel oil and the emulsified Diesel/CPO/water of 90/5/5 after 200 h operation.



Before Tested **Diesel** **Palm-Diesel Emulsion**

Figure 5.15 Wear at the crank shaft bearing for the fuel oil and the emulsified Diesel/CPO/water of 90/5/5 after 200 h operation.

Figures 5.13 – 5.15 show the wears on some engine parts when the fuel is diesel/CPO/water at 90/5/5 composition. The engine operation was 200 h and the considered engine parts were piston ring, intake valve, exhaust valve and crank shaft bearing with diesel/CPO/water at 90/5/5 composition . It could be seen that the wears of this components were similar to those of diesel oil.

Table 5.3 Measurement of wear at the cylinder bore.

Fuel	At100 hour		At 200 hr	
	X-axis (mm.)	Y-axis (mm.)	X-axis (mm.)	Y-axis (mm.)
Diesel	80.003	80.002	80.005	80.003
Diesel/CPO/water (90/5/5)	80.004	80.002	80.007	80.004

Standard: 80.000-80.030 mm.

Table 5.4 Measurement of wear at the piston ring gap.

Piston ring	Fuel	At100 hour	At 200 hr
Piston ring number 1	Diesel	0.32	0.46
	Diesel/CPO/water (90/5/5)	0.34	0.44
Piston ring number 2	Diesel	0.34	0.38
	Diesel/CPO/water (90/5/5)	0.33	0.40
Piston ring number 3	Diesel	0.33	0.37
	Diesel/CPO/water (90/5/5)	0.34	0.38
Piston oil ring	Diesel	0.35	0.42
	Diesel/CPO/water (90/5/5)	0.35	0.43

Standard: 0.20 - 0.40 mm.

Table 5.5Measurement of wear at the intake valve and exhaust valve.

Piston ring	Fuel	At100 hour	At 200 hr
Intake Valve	Diesel	0.645	0.645
	Diesel/CPO/water (90/5/5)	0.645	0.645
Exhaust Valve	Diesel	0.645	0.645
	Diesel/CPO/water (90/5/5)	0.645	0.645

Standard: 0.645 - 0.960 mm.

Table 5.6 Measurement of wear at the crank shaft bearing.

Part	Fuel	At100 hour	At 200 hr
Crank shaft bearing	Diesel	0.036	0.044
	Diesel/CPO/water (90/5/5)	0.035	0.043

Standard: 0.028 - 0.086 mm.

Table 5.3 – 5.6 show the wears on the engine parts when the fuel is diesel/CPO/water at 90/5/5 composition. The engine operations were 100 h and 200 h. The considered engine parts were cylinder bore, piston ring gap, intake valve, exhaust valve and crank shaft bearing with diesel/CPO/water at 90/5/5 composition . It could be seen that the wear of the cylinder bore was 0.002 mm. The piston ring gap was 0.02 mm. The wears at intake valve and exhaust valve were not different from those of diesel. The gap between the crank shaft and the bearing was 0.001 mm. which was still in an acceptable range.