# 400-hour Durability Tests of Direct-Injection Engine Using Neat Palm Biodiesel

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***Abstract***

The objective of this study is to systematically investigate a long-term effect of using palm biodiesel in a compression ignition engine. A four-cylinder direct injection diesel engine, commonly employed in small farm trucks, was operated continuously on an engine dynamometer for a total of 400 hours using a modified driving cycle based on the EMA (Engine Manufacturers Association, USA) screening test. The tested engine was fueled only by neat palm biodiesel throughout the study. After each 50-hour test interval, various parameters such as power, torque, fuel consumption rate, cylinder pressure and exhaust emissions of CO, $CO_2$, $NO_x$, and THC were measured at various engine speeds of full load operation in order to determine any differences in the engine performance. The results revealed that this farm truck engine can be fueled with biodiesel for 400-hour operation without any significant effect on both engine performance and emissions.

***Keywords**:* Biodiesel, Durability, Performance, Emissions, Diesel engine

## 1. Introduction

Biodiesel can be derived from renewable sources such as animal fat and vegetable oil to produce a renewable fuel which has properties closer to diesel. The use of biodiesel could also reduce harmful emissions, such as hydrocarbon, carbon monoxide, particulate matters, and smoke opacity [1-2]. Many countries are promoting the use of biodiesel as an alternative fuel in order to reduce fossil fuel demands. Moreover, biodiesel can be blended with commercial diesel and use in diesel engine without major modification.

In Thailand, due to the consideration of the environmental sustainability and the holding down of labor costs, a wide range of local communities around the country have been supported to produce biodiesel as well as use neat biodiesel in diesel engines especially in agricultural applications [3]. Since palm tree was a common feedstock for biodiesel production, palm biodiesel has been mainly focused as an alternative fuel.

Even though the current government policy is driving toward increasing biodiesel production and usage within the country, in the view of motor vehicle supplier, the long term use of neat biodiesel may cause adverse effects on engine parts. Some authors have studied this consequence under durability testing. For example, Hsi-Hsien Yang et al. [4] investigated the hydrocarbons emissions from the use of B20, blended biodiesel derived from waste cooking oil. The test engines were installed on an engine dynamometer and performed for 80,000 km. following the FTP (Federal Test Procedure, USA) transient cycle. Their results indicated that particulate polycyclic aromatic hydrocarbons emissions increased as engine mileage increased. Yusuf Ali et al. [5] studied the effects of biodiesel from tallow oil on the diesel engine. The objective was mainly focused on the engine performance, exhaust emissions, and the lubrication characteristic. After the 200-hour test was performed following EMA (Engine Manufacturers Association, USA) test procedure [6], the obtained results did not show any increase in exhaust emissions or deterioration of engine performance as well as significant change in engine wear.

In spite of these studies, there are a few reports that focus on the durability test of biodiesel derived from palm oil and a few studies focus on a diesel engine used in agricultural applications. Hence, this study is aimed to perform a long-term engine test with neat palm biodiesel. A four-cylinder direct injection diesel, commonly employed in farm trucks, was operated continuously on an engine dynamometer following a modified EMA test cycle. Engine performance, injection pressure, and exhaust emissions were investigated and recorded, periodically, until reaching the total of 400-hour operation.

## 2. Materials and methods

### 2.1 Test Engine

Since in-line pump diesel engines were typically used in farm trucks for agricultural purposes, a YUNNEI model 4100QB-2, four-cylinder direct injection diesel engine, was employed as the test engine (Engine specification was shown in Table 1). The engine was coupled to a 150-kW eddy current dynamometer from Tokyo plant, and operated continuously following the modified test cycle.

Prior to the test, the engine was verified to ensure that it was in a normal condition. For that reason, engine parts specification, such as valve clearance, sealing bands range, cylinder head, piston rings, fuel pump, and injection pressure were determined.

After each 50-hour test interval, the engine performance was determined at full load operation. While the throttle was fully opened, engine torque, power, and fuel consumption at various speeds were determined through Tokyo plant data acquisition system, P.Drive. Pressure transducer type 6052C, attached to the fourth cylinder, provided cylinder pressure at various crank angle positions. Exhaust emissions, CO, $CO_2$, $NO_x$ and THC were evaluated using Horriba gas analyzer, MEXA-1600D.

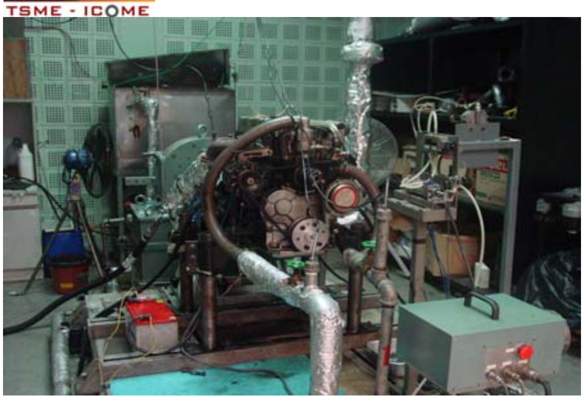

Fig. 1 YUNNEI model 4100QB-2

Table 1 Engine specifications

| | |
|---|---|
| Type | 4-stroke, vertical engine |
| Bore x Stroke | 100 x 115 mm. |
| Number of Cylinder | 4 |
| Cylinder Type | Waterish type |
| Combustion Type | Direct injection ω type |
| Displacement | 3.612 liters |
| Idle Speed | 800 rpm |
| Compression Ratio | 17.5:1 |
| Firing Order | 1-3-4-2 |
| Rated Power | 66.2/3200 kW-hr |
| Max Torque | 230/2200 N.m/rpm |
| Fuel Consumption | $\leq$238 g/kW-h |
| Net weight | 320 kg |
| Injection timing/pressure | 12°/19.1±0.49MPa |

Table 2 Properties of tested biodiesel

| Properties | Methods | Results | Units |
|---|---|---|---|
| 1.Water Content | ASTM D 6304 | 315.6 | ppm |
| 2.Acid Value | ASTM D 664 | 0.17 | mg KOH/g |
| 3.Oxidation Stability | EN 14112 | 16.39 | Hour |
| 4.Carbon Residue | ASTM D 4530 | 0.01 | %wt |
| 5.Gross Heat | ASTM D 240 | 38.20 | MJ/kg |
| 6.Density | ASTM D 4052 | 0.87 | g/cm$^3$ |
| 7.ASTM Color | ASTM D 1500/156 | 0.8 | - |
| 8.Pour Point | ASTM D 97 | 12 | ºC |
| 9.Flash Point | ASTM D 93 | 162 | ºC |
| 10.Cloud Point | ASTM D 2500 | 15.8 | ºC |
| 11.Kinematic viscosity at 40ºC | ASTM D 445 | 4.45 | mm$^2$/sec |

## 2.2 Test Fuel

Commercial grade biodiesel from Pathum Vegetable Oil Co., Ltd., originally derived from palm olein, was used for 400-hour test. The fuel properties were determined and presented, along with the specification and method of ASTM standard, as shown in Table 2.

## 2.3 Testing procedure and load cycle

The test engine was operated on an engine dynamometer continuously for 9 hours per day (3 cycles), following the modified test cycle. In order to accommodate the schedule of staffs at the engine laboratory, the experiment was conducted only on day time. After that it was shut down for 15 hours. During this time, the engine was allowed to reach ambient temperature. Engine oil and fuel filter were regularly replaced every 100-hour interval and after 50-hour test interval had been reached, the changes of engine performance and exhaust emissions were evaluated. The experiment lasted until the total of 400-hour operating time was met.

The engine speeds and loads applied in this study were modified from the EMA's 200-hour screening test. To simulate actual driving conditions in local agricultural applications, a single test cycle comprised of four different modes, as shown in Table 3.

Table 3 Engine test cycle

| Mode | Speed (rpm) | Torque (N.m) | Duration |
|---|---|---|---|
| Rated Condition | 2,200 | 117.5 | 60 min. |
| High Power | 1,600 | 124 | 60 min. |
| High Idle | 1,980 | 47 | 30 min. |
| Low Idle | 800 | No Load | 30 min. |

At rated condition mode, in practice, the agricultural truck engine was mostly operated on regular road and smooth farmland while carrying regular load, such as crane, fertilizer system, and agricultural products. Therefore, the engine speed at this condition was set at 2,200 rpm whereas the engine torque was set at 117.5 N.m, which was 60% of maximum torque. The operating condition maintained for 60 minutes.

At high power mode, the highest power among all test modes was set so that to simulate the performance of the engine when running on a rough, dirt farmland path and containing full of agricultural goods in the container. The engine speed was not so high but much higher engine torque was necessary. Therefore, the engine speed was set at 1,600 rpm and engine torque was set at 90% of maximum torque of 124 N.m. This mode was maintained for 60 minutes.

At high idle mode, the engine was operated at high speed with small load applied. The engine speed was set at 90% of rated speed, which was 1,980 rpm, and the applied load was set at 25% of maximum load, which was 47 N.m. This was to simulate the running of the farm truck on road without any product in its container. This condition was maintained for 30 minutes.

At low idle mode, the engine was set to idle, i.e., the applied load was set to zero and the engine speed was set at 800 rpm. This was maintained for 30 minutes.

## 3. Results and discussions

### 3.1 Engine performance

Full load performance of the engine fueled with neat palm derived biodiesel was examined. The obtained results of engine power, engine torque, and fuel consumption of prior and after 400-hour test were presented and plotted against engine speed. When the durability test was completed, the overall findings were almost identical (Fig.2 and Fig.3). The results indicated that the maximum engine power was still approximately 50 kW at the engine speed of 2800 rpm, as shown in Fig.2 and the maximum brake torque was still nearly 200 N.m at the engine speed of 2200 rpm, as shown in Fig.3. To focus more clearly how the engine performance deviated from the 0-hour test, the changes of the maximum brake torque of the engine at 2200 rpm of each 100-hour test were calculated relatively to the first test run and presented instead of actual values. The obtained data confirmed that the engine torque stayed fairly constant throughout 400-hour test interval, as shown in Fig.4.

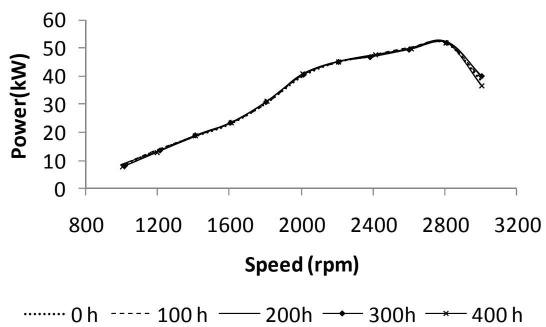


Fig.2 Engine power at various engine speeds

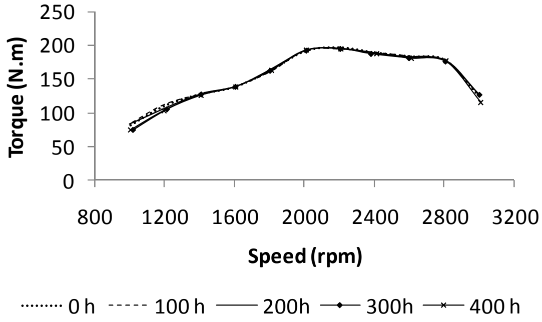


Fig.3 Engine torque at various engine speeds

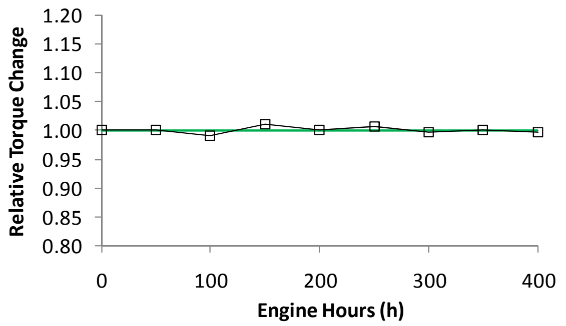


Fig.4 Maximum engine torque change relative to prior condition at 0 hour

Fig. 5 represents specific fuel consumption, SFC, at full load condition plotted against various engine speeds. The results of all experimental periods, 0 to 400 hours, generally showed that the maximum SFC was at the lowest speed of 1000 rpm as well as at the highest speed of 3000 rpm. As the speed increased from 1000 to approximately 1500 rpm the SFC gradually dropped until it reached the minimal point at about 2000-2200 rpm then the value started to increase again. Considering the SFC at the engine speed range between 1000 and 1200 rpm, it was observed that SFC of 400-hour test was noticeably higher than those of other test intervals even though the power output at the same engine speed was merely dropped (in Fig.2). These SFC results show that the 400-hour engine performance differed from the 0-hour. However, this can be the normal effect of long-term engine usage which can be occurred from diesel as well as biodiesel fuel. Similar to the maximum engine torque at 2200 rpm, the SFC results were calculated relatively to the result of 0-hour test and shown in Fig.6. According to the minimal point of SFC, at 2200 rpm, the changes of SFC were insignificant.

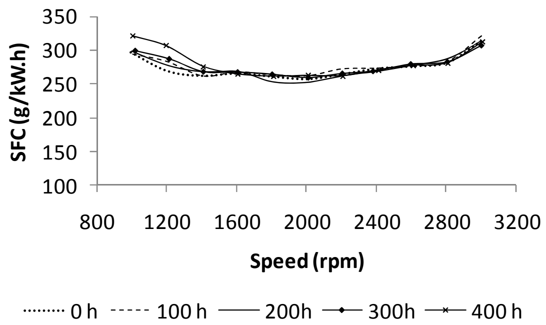


Fig.5 Fuel consumption at various engine speeds

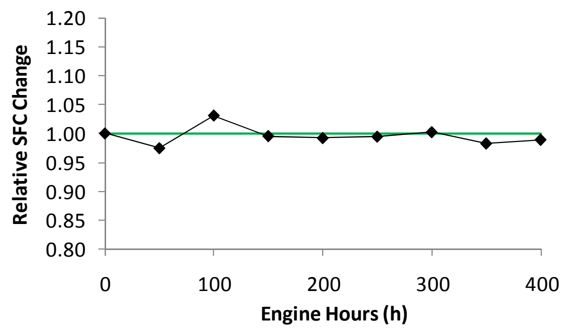


Fig.6 Optimal specific consumption change relative to prior condition at 0 hour

Although a pattern of the obtained performance and SFC were normal, the maximum torque, power, and fuel consumption were different from the manufacturer specification (see Table 1). This is because of the difference of fuel and test environment. Moreover, the test engine was not brand new. Before starting this test, it has been used for more than 100 hours.

### 3.2 Combustion behavior

Beside the performance test, at each 100-hour test interval, the cylinder pressure under full load condition was determined. Fig. 7 shows the initial values of cylinder pressure at 0 hour plotted against crank angle for the engine speeds of 1000, 1600, 2000 and 2200 rpm. The obtained results indicated that the value of cylinder pressure varied with engine torque. Therefore, the highest peak, approximately 70 bar, was found at the maximum torque condition, which was 2200 rpm of speed. However, maximum cylinder pressure of each engine speed occurred at different crank angle position. This depended on the amount of injected fuel and flame propagation.

Regarding the long-term experiment, the maximum cylinder pressure, which again was observed at the engine speed of 2200 rpm, of each test interval was presented, as shown in Fig. 8. From the obtained results, there was no significant change in terms of magnitude as well as configuration of cylinder pressure.

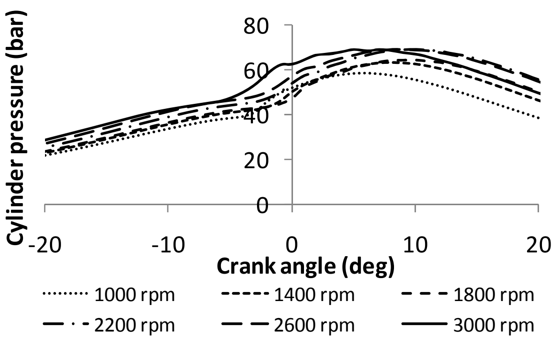


Fig.7 Cylinder pressure at various speed at 0 hour

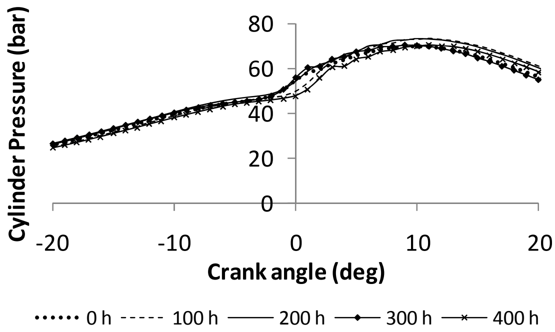


Fig.8 Cylinder pressure at 2200 rpm at various engine hours

### 3.3 Exhaust emissions

Prior to the 400-hour durability test, various exhaust emissions from the use of palm olein biodiesel, such as carbon monoxide (CO), carbon dioxide ($CO_2$), oxide of nitrogen ($NO_x$), total hydrocarbon (THC), and oxygen ($O_2$) were evaluated at full load test conditions. From the initial results, shown in Fig. 9, the correlation between $CO_2$ and CO emissions suggested that the most complete combustion was achieved when the engine was operated at approximately 2000 to 2200 rpm. At this stage, the combustion temperature was high resulted in the enhancement of $NO_x$ formation. When the engine speed was increased beyond 2200, CO emission tended to increase. In additions, the rise of CO agreed with an increase of THC emission. Therefore, a problem of incomplete combustion from unburned hydrocarbon could be occurred at this period.

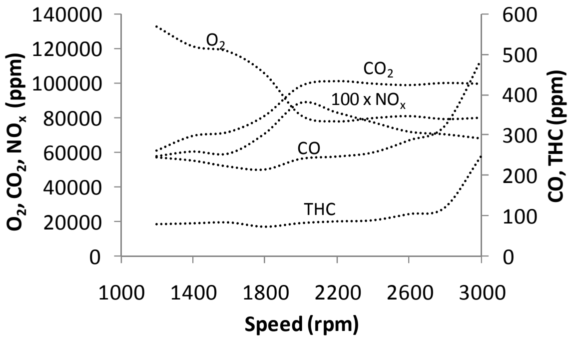


Fig.9 Exhaust emissions at the beginning of the test (0 hour)

During the 400-hour durability test, the emissions were also measured. Fig. 10-14 showed the amount of various emissions detected at various engine speeds when the engine was operated with wide opened throttle and full load condition. Surprisingly, after using neat biodiesel for hundreds of hours, the combustion seems more completed as can be seen from the trend of CO, $CO_2$ and THC in Fig 10, 11 and 13. The amount of CO and THC were less while $CO_2$ was more at 400 hour. $NO_x$ was also produced more due to the higher temperature during combustion (Fig.12). So, if considering emission results, it can be concluded that after 400 hours of using neat biodiesel, there was no adverse effect on the engine.

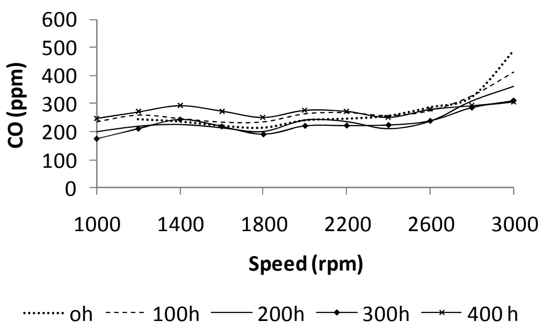


Fig.10 CO emission at various engine speeds

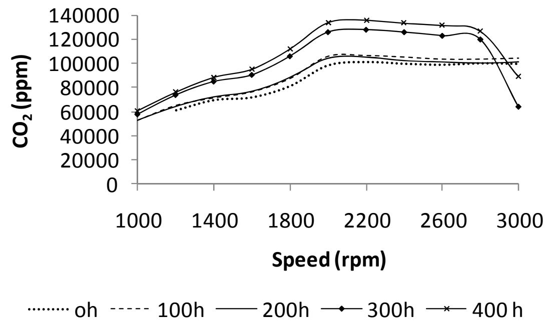


Fig.11 $CO_2$ emission at various engine speeds

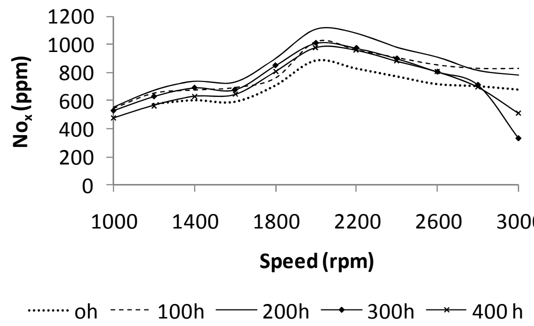


Fig.12 $NO_x$ emission at various engine speeds

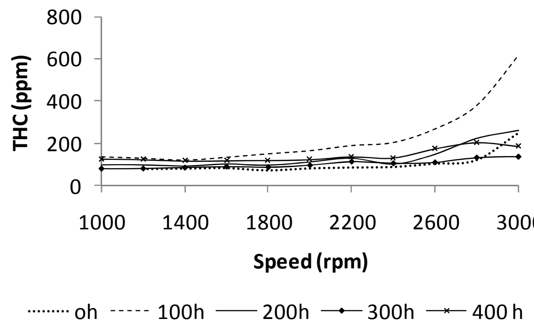


Fig.13 THC emission at various engine speeds

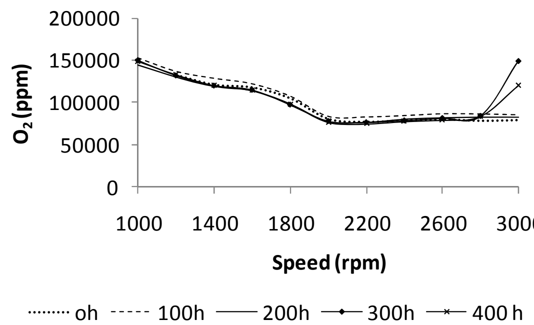


Fig.14 $O_2$ at various engine speeds

## 4. Conclusions

In this study, the 400-hour durability test of a farm truck's four-cylinder direct injection diesel engine using neat palm olein biodiesel was investigated. The engine was installed on the engine dynamometer and tested for 400 hours using a modified test cycle from the standard 200-h durability test of the Engine Manufacturers Association (EMA). At the same time, engine performance and exhaust emissions were determined periodically until reaching 400-hour of operation.

The results of this study can be summarised that, without any engine modification, the test engine was successfully operated with neat palm olein biodiesel on the test bench for 400 hours without any significant or adverse effects on both engine performance and emissions. Thus, palm olein biodiesel was compatible with this type of engine. However, authors wish to complete 1,000-hour durability test to firmly ensure the well-match of palm biodiesel and this agricultural engine. Thus, the bench test and engine investigation will be carried on. Moreover, engine oil, engine wear, and injector coking will be determined and analysed in the further study.

## 5. Acknowledgements

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