ORIGINAL ARTICLE

# Palm oil as a fuel for agricultural diesel engines: Comparative testing against diesel oil

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## Abstract

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**Due to unstable oil price situation in the world market, many countries have been looking for alternative energy sources to substitute for petroleum. Vegetable oil is one of the alternatives which can be used as fuel in automotive engines either in the form of straight vegetable oil, or in the form of ethyl or methyl ester. This paper presents a comparative performance testing of diesel engine using diesel oil and refined palm oil over 2,000 hours of continuous running time. Short-term performance testing was conducted for each fuel on the dynamometer engine test bed. Specific fuel consumption, exhaust temperature and black smoke density were determined and measured. Long-term performance testing (or endurance test) was also done by running the engines coupled with a generator in order to supply load (electricity) to a lightbulb board. For each 500 hours of engine run time, the engines were dissembled for engine wear inspection. It was found that the fuel pump and fuel valve weight losses from both engines showed insignificant differences either at the first 500 hours of running time or at the second 500 hours of running time but the inlet valve from the engine fueled by diesel oil had a higher weight loss than the engine fueled by refined palm oil at the first 500 hours and at the second 500 hours of running time. The compression rings from the engine fueled by refined palm oil showed a significant weight loss compared to the engine fueled by diesel oil both after 500 hours and after 1000 hours of running time.**

**Key words :** refined palm oil, diesel engine test, palm oil fuel substitute

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**บทคัดย่อ**

**กำพล ประทีปชัยกูร และ ธีรวัฒน์ อภิชาโต**

**การใช้น้ำมันปาล์มเป็นเชื้อเพลิงสำหรับเครื่องยนต์ดีเซลทางการเกษตร: การทดสอบเปรียบเทียบกับน้ำมันดีเซล**

**ว. สงขลานครินทร์ วทท. 2546 25(3) : 317-326**

จากสถานการณ์ราคาน้ำมันในตลาดโลกที่ผันผวนทำให้หลาย ๆ ประเทศแสวงหาแหล่งพลังงานทดแทนที่จะมาแทนน้ำมันปิโตรเลียม น้ำมันพืชเป็นตัวเลือกหนึ่งซึ่งสามารถนำมาใช้เป็นเชื้อเพลิงในเครื่องยนต์ได้ ทั้งในรูปของการใช้โดยตรงหรือการสังเคราะห์ให้เป็นเอธิลหรือเมธิลเอสเตอร์ บทความนี้เป็นการเสนอผลการทดสอบการใช้น้ำมันปาล์มกลั่นในเครื่องยนต์ดีเซล โดยเป็นการศึกษาเปรียบเทียบกับเครื่องยนต์ที่ใช้น้ำมันดีเซล การทดสอบเดินเครื่องยนต์ด้วยน้ำมันปาล์มใช้เวลาทั้งสิ้น 2000 ชั่วโมง สมรรถนะของเครื่องยนต์ เช่น อัตราการสิ้นเปลืองน้ำมันจำเพาะ อุณหภูมิไอเสีย ความหนาแน่นของควันจากไอเสีย ที่ใช้น้ำมันปาล์มและน้ำมันดีเซลได้ถูกวิเคราะห์โดยอาศัยแท่นทดสอบไดนาโมมิเตอร์ การทดสอบอายุการใช้งานของเครื่องยนต์เมื่อเดินเครื่องด้วยน้ำมันปาล์มได้ทดสอบโดยการเดินเครื่องยนต์ที่ต่อกับเครื่องกำเนิดไฟฟ้า โดยที่มีหลอดไฟทำหน้าที่เป็นภาระของเครื่องยนต์ ชิ้นส่วนของเครื่องยนต์ได้ถูกถอดออกเพื่อตรวจสอบการสึกหรอทุก ๆ 500 ชั่วโมงของการเดินเครื่อง ผลปรากฏว่าการสึกหรอของปั๊มน้ำมันและวาล์วน้ำมันจากการชั่งน้ำหนักที่สูญหายไปของเครื่องยนต์ทั้งสองที่ช่วงเวลา 500 ชั่วโมงแรก และ 500 ชั่วโมงที่สองของการเดินเครื่องมีความแตกต่างกันที่ไม่เด่นชัด ส่วนความสึกหรอของวาล์วไอดีของเครื่องยนต์ที่ใช้น้ำมันดีเซลมีค่ามากกว่าทั้งช่วงเวลา 500 ชั่วโมงแรก และ 500 ชั่วโมงที่สอง แหวนอัดของลูกสูบของเครื่องยนต์ที่ใช้น้ำมันปาล์มมีการสึกหรอสูงกว่าของเครื่องยนต์ที่ใช้น้ำมันดีเซลทั้งช่วงเวลา 500 ชั่วโมงแรก และ 500 ชั่วโมงที่สอง

ภาควิชาวิศวกรรมเครื่องกล คณะวิศวกรรมศาสตร์ มหาวิทยาลัยสงขลานครินทร์ อำเภอหาดใหญ่ จังหวัดสงขลา 90112

In 1999 energy consumption in Thailand was 47,699 ktoe (kilo ton of oil equivalent) which increased by 4.4% over the previous year. Petroleum products and other modern energies such as natural gas, condensate, coal and lignite increased by 4.3% [Department of Energy Development and Promotion,1999]. The total crude oil production was 1,694 ktoe and the total crude oil imported was 34,860 ktoe. Transportation sector consumed 18,991 ktoe. Diesel shared 54.1% while gasoline shared 27.1%. Due to the increasing oil price in the world market and in the country, the agricultural sector, which consumed 4.5% of the total energy consumption has suffered greatly because of the declined crop price and high fuel price. The thought of using vegetable oil as fuel substitute was spread throughout the country. Several formulae of blending vegetable oils by groups of farmers were used in diesel engines without any technical support so after some periods of time all formulae of blending vegetable oils were terminated because of engine failures. Providing the technical information to farmers or users is thus most important. A study of using refined palm oil as fuel substitute in agricultural engines has been conducted at the Department of Mechanical Engineering, Prince of Songkla University, Thailand.

Research on the use of vegetable oils as fuel substitutes in diesel engines have been done in many countries. Peter *et al*. (1982) used degummed soybean mixed with diesel oil at the ratio of 2:1 as a fuel in a diesel engine. After 600 hours of running it was found that the engine performance did not alter. Other researchers found that 95% vegetable oil blending with 5% diesel oil in a diesel engine gave no problems of carbon deposit on the engine parts or in the fuel injector. Adam *et al*. (1983) tested an agricultural machine with blended oil (soybean oil and diesel oil) and found that by using soybean blended with diesel oil in

**Table 1. Properties of diesel and refined palm oil**

| Fuel property | Specification | Diesel | Refined palm oil | Standard |
|---|---|---|---|---|
| Cetane Number | >47 | NA | 50 | ASTM D-613 |
| Specific gravity at 15.6ºC | >0.81, <0.87 | 0.84 | 0.92 | ASTM D-1298 |
| Viscosity at 40ºC (cSt) | >1.8, <4.1 | 3.1 | 40.9 | ASTM D-445 |
| Flash point (ºC) | >52 | 69 | >300 | ASTM D-93 |
| Water and sediment (%) | <0.05 | NA | Traces | ASTM D-2709 |
| Carbon residue (%) | <0.05 | <0.001 | 0.217 | ASTM D-4530 |
| Ash (%) | <0.01 | NA | 0.001 | ASTM D-482 |
| Distillation temp (ºC) | <357 | NA | 319 | ASTM D-86 |
| High heating value (MJ/kg) | - | 44.3 | 39.3 | ASTM D-240 |

**NA: Not Available**

the ratio of 2:1, the engine worked well. Kevin *et al*. (1999) concluded that by using semi-refined rapeseed oil (SRO) in a direct injection diesel engine, the power output reduced by 0.06% for every 1% increase in SRO inclusion rate and the brake specific fuel con-sumption increased by 0.14% per 1% increase in SRO inclusion rate. Chiyuki and Jun-ichi (1998) concluded that deacidified rapseed oil could be used in a single cylinder YANMAR IDI diesel engine but degummed and crude rapeseed oil were unsuitable for use as fuel due to the high level of incombustible materials in the oil. Suporn (1987) found that using 100% refined palm oil in a KUBOTA diesel engine model KND 5B resulted in the best power output and best emission while using 70% refined palm oil blended with 25% diesel resulted in the best specific fuel consumption.

## Materials and Methods

### Fuel preparation

Refined palm oil was used in the test. Characteristics of refined palm oil such as Cetane number, specific gravity, viscosity, gross heat of combustion, flash point, carbon residue were tested according to ASTM Standard by PTT Research and Technology Institute, PTT Public Company Limited. The characteristics of refined palm oil and diesel oil are shown in Table 1.

### Short-term engine testing equipment

Short-term engine performance tests were done according to JIS B8018 (1989): Small- size water-cooled diesel engines in land use with both 100% diesel oil and 100% refined palm oil for comparison. Figure 1 is the JIS B8018 (1989) profile test.

### Engine and dynamometer

Two KUBOTA Model ET80 single cylinder indirect injection diesel engines were used. The bore to stroke ratio is 84:84 mm. × mm. The maximum power is 5.88 kW at 2200 rpm. The compression ratio is 23:1. The engines were run with either diesel oil or refined palm oil for comparison. A PLINT & PARTNERS 12 horsepower

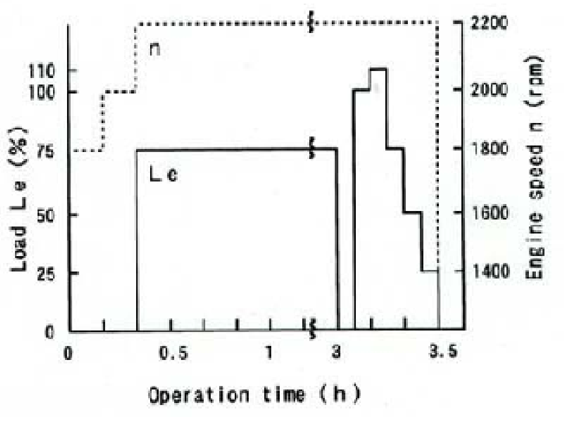


**Figure 1. JIS B8018 (1989) Standard profile test**

dynamometer coupled to the engine was used for determining the engine performance.

**Opacity meter**

A portable HESHBON Opacity meter model HBN-1500 was connected to the exhaust pipe of the engine to measure the smoke density of the exhaust gas. The exhaust gas was pumped into the meter in which a filter paper was inserted. Black particulates from the exhaust gas were trapped on the filter paper and then it was tested for the opacity compared with a standard filter paper. The meter provides an output reading between 0.00-100.00% with the resolution of 0.1%.

**Tachometer**

A DIGICON model DT-240P non-contact tachometer with the range from 5-100,000 rpm and the resolution of 1 rpm was used to measure the engine speed.

**Long -term engine testing equipment**

The long-term performance test was done to examine the effect of refined palm oil on engine durability comparing to diesel oil. One of the engines was run on diesel oil and the other was run on 100% refined palm oil. After every 500 hours of running, the engine was reconnected to the dynamometer for the short-term performance test to investigate the variations in its performance. Then the engine was dissembled to be visually checked for wear and weight loss of some parts of the engine such as piston rings, cylinder head, piston pump and inlet and exhaust valves. Samples of used lubricating oil were taken every 100 hours of 1000 hours for both engines and were sent to PTT Research and Technology Institute for wear test. Because of high expense in oil sample analysis, only 10 samples of each fuel were submitted for testing.

**Engine and generator**

For long term test, each engine was mounted on a stand and was coupled with a 7.5 kW, 230 Volts, 32.6 Amps, 50 Hertz, 80% efficiency electric generator. The electricity generated was supplied to a series of light bulbs for varying engine loads.

## Procedures

The purpose of short-term test was to determine the engine performances. Several load conditions were tested on each engine. Parameters of interest such as fuel consumption, torque, and exhaust temperature were recorded, and then the engine performances (specific fuel consumption, thermal efficiency) were determined. The engine components were then disassembled. The components such as piston rings, inlet and exhaust valves, fuel pump, fuel valve and bearing were weighed after the first 50 hours of running (run in time) and subsequently after every 500 hours of run time.

The purpose of the endurance test was to determine how long the engine fueled with 100% refined palm oil could be run.

**Start up procedures**

Two new KUBOTA Model ET80 engines were used in the test. It is assumed that both engines have the same characteristics. Both engines were run in for 50 hours according to the manufacturer's specification, and then the engines were disassembled. Fuel pumps, fuel valves, inlet valves, exhaust valves, piston rings and bearings were weighed against initial conditions of the engine components. After reassembling the engine, it was coupled with the dynamometer for performance test according to JIS standard B 8018 (1989): Small-size water-cooled diesel engines in land use. One engine was run on diesel oil while the other was run on refined palm oil.

After the short-term test, the engines were coupled with generators for the endurance test. For this endurance test, the engine operated at 2,200 rpm, 75% of maximum load. A lightbulb board was connected to the generator. The electricity gene-rated was supplied to the light bulbs. Lubricating oil was changed for every 100 hours and samples of used lubricating oil were collected. After 500 hours of running, the engines were moved from the dynamometer test bed and engine components were disassembled for inspection with the same procedures as mentioned above. Then the engines were reconnected to the dynamometer for the next 500 hours of the endurance test.

## Results

The results are divided into two parts. The first part is the result of the short-term performance tests (specific fuel consumption, thermal efficiency, exhaust temperature and smoke density) of the engines fueled with diesel oil and refined palm oil. The second part deals with the result of the used lubricating oil analysis.

### Results of the first part

#### Specific fuel consumption

Results from the test of the engines fueled by diesel oil and refined palm oil indicate that the specific fuel consumption of the engine fueled by diesel oil is 14.2-19.0% less than that fueled by refined palm oil at the first hour of running. The specific fuel consumption of the engine fueled by diesel oil is 19.3-25.8% less than the engine fueled by refined palm oil at 500 hours of running and 15.1-20.3% less at 1000 hours of running as shown in Figure 2. This is because the heating value of the refined palm oil is about 10% less than that of diesel oil causing a higher specific fuel consumption of the engine fueled by refined palm oil than the engine fueled by diesel oil.

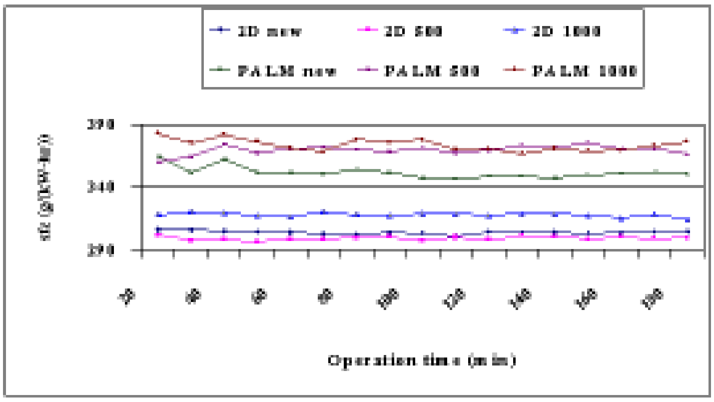


**Figure 2. The specific fuel consumption of the engines fueled by diesel and refined palm oil at the first hour (new), 500 hours and 1,000 hours of running time**

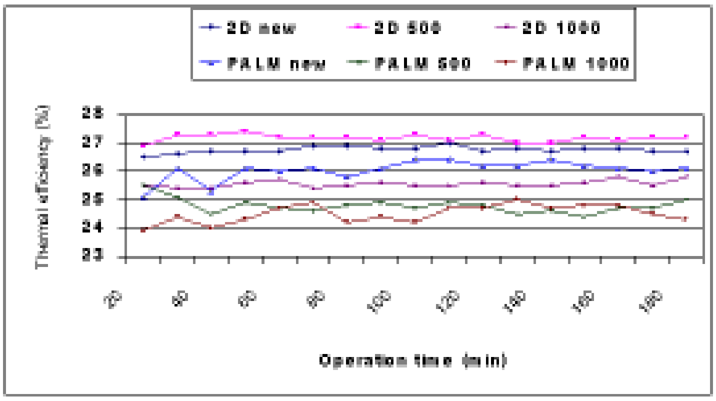


**Figure 3. Thermal efficiency of the engines fueled by diesel and refined palm oil at the first hour (new), 500 hours and 1,000 hours of running time**

**Thermal efficiency**

The thermal efficiency of the engine fueled by diesel oil was found to be 0.5-1.4% higher than the engine fueled by refined palm oil at the first hour of run-ning, then becomes 1.5-2.8% higher at 500 hours of running and finally becomes 0.5-1.6% higher at 1,000 hours of running as shown in Figure 3. This is because of the incomplete combustion of refined palm oil in the combustion chamber of the engine.

**Exhaust gas temperature**

The exhaust gas temperature of the engine fueled by refined palm oil was found to be higher than the engine fueled by diesel oil through out the test as shown in Figure 4. This is because of the incomplete combustion of refined palm oil in the combustion chamber of the engine, some of the unburned fuel escapes into the exhaust manifold where further combustion takes place causing the high exhaust temperature.

**Black smoke density**

The black smoke density from both engines was almost the same at the first hour and 1000 hours of running but the black smoke density from the engine fueled by refined palm oil was about 5% higher at 500 hours of running as shown in

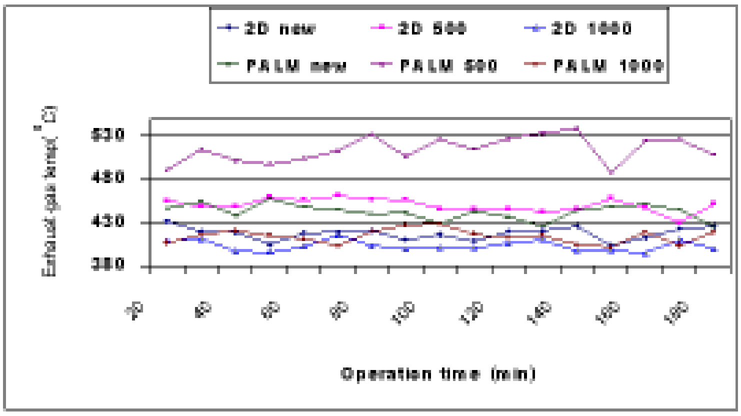


**Figure 4. The exhaust gas temperature of the engines fueled by diesel and refined palm oil at the first hour (new), 500 hours and 1,000 hours of running time**

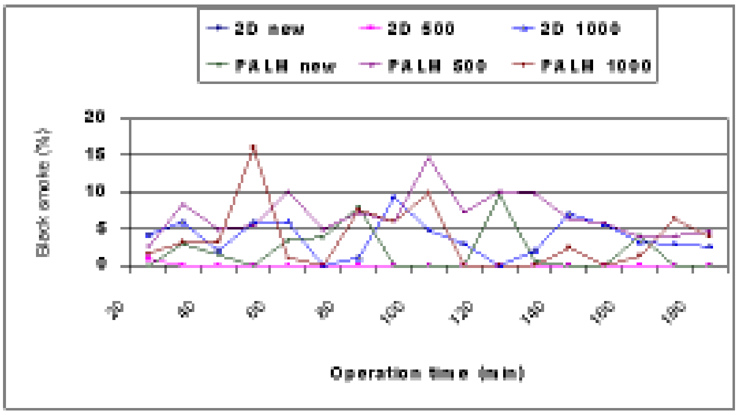


**Figure 5. The black smoke density of the engines fueled by diesel and refined palm oil at the first hour (new), 500 hours and 1,000 hours of running time**

Figure 5. This is because of the incomplete combustion of the refined palm oil in the combustion chamber caused more black smoke than the engine fueled by diesel oil.

**Results of the second part**

**Engine wear analyses**

Analyses of used lubricating oil from samples taken at every 100 hours of engine run time indicate that metal contents such as lead, chromium, aluminium, copper and silicon in the oil from the engine fueled by refined palm oil are higher than those from the engine fueled by diesel oil, but the ferrous content is almost the same, as shown in Figure 6 and Figure 7.

Weighing the components of the engine at the beginning of the test and after each 500 hours of running is a way to evaluate engine wear. It is found that the weight losses from fuel pump, fuel valve, inlet valve, exhaust valve and piston rod bearing are almost the same for both engines fueled with diesel and refined palm oil, as shown in Figure 8.

Compression ring from the engine fueled by refined palm oil has the most significant weight loss. At the first 500 hours of running, the com-

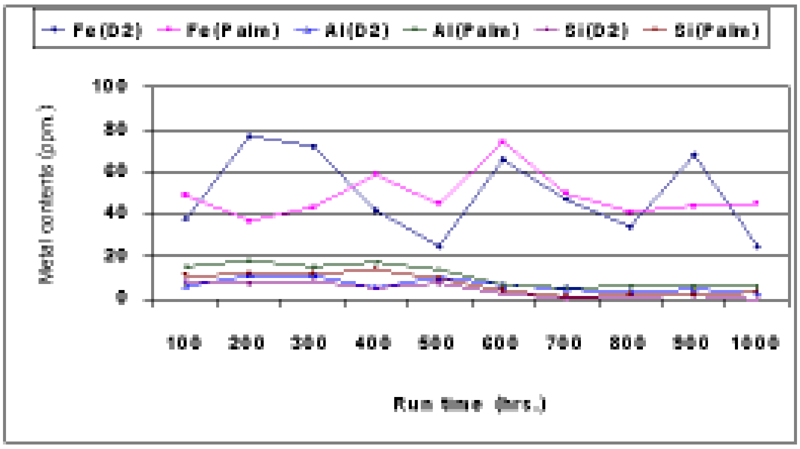


**Figure 6. Ferrous, aluminum and silicon content in used lubricating oil from the engines fueled by diesel and refined palm oil for every 100 hours of running**

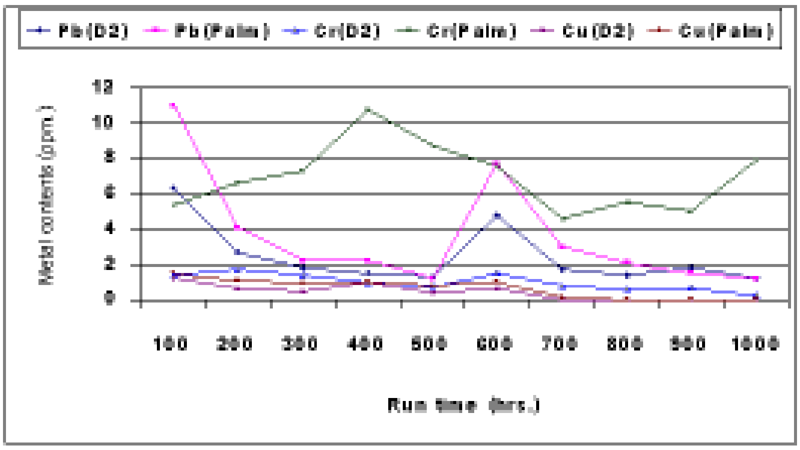


**Figure 7. Lead, chromium and copper content in used lubricating oil from the engines fueled by diesel and refined palm oil for every 100 hours of running time**

pression ring from the engine fueled by refined palm oil has 6.1 times the weight loss in the engine fueled by diesel oil and 4.4 times at the second 500 hours as shown in Figure 9. Figures 10 and 11 show the cumulative component wear at the first 1,000 hours of running time for both engines and the component wear at the second 1,000 hours of running time for the engine fueled by refined palm oil. The cumulative wear is 5.2 times higher for the engine fueled by refined palm oil which is in agreement with the increase in piston ring gap as shown in Table 2.

After 2,000 hours of running time, the piston rings wear was still high and caused an increase in ring gap. The exhaust valve stem clearance was increased, causing carbon and gum deposits on the valve covers.

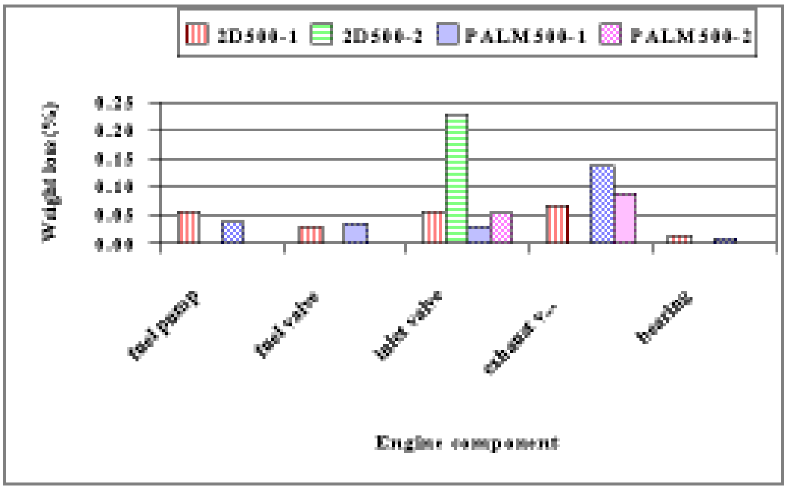


**Figure 8. Engine component wear from the engines fueled by diesel and refined palm oil at the first 500 and the second 500 hours of running time**

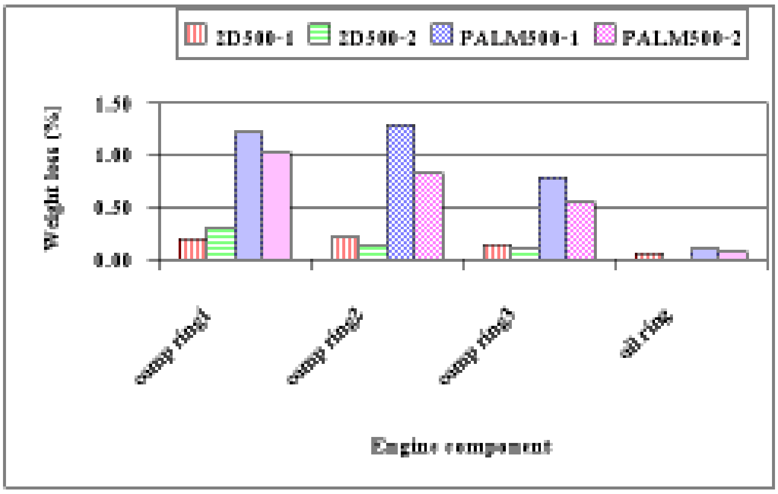


**Figure 9. Piston rings wear from the engine fueled by diesel and refined palm oil at the first 500 and the second 500 hours of running**

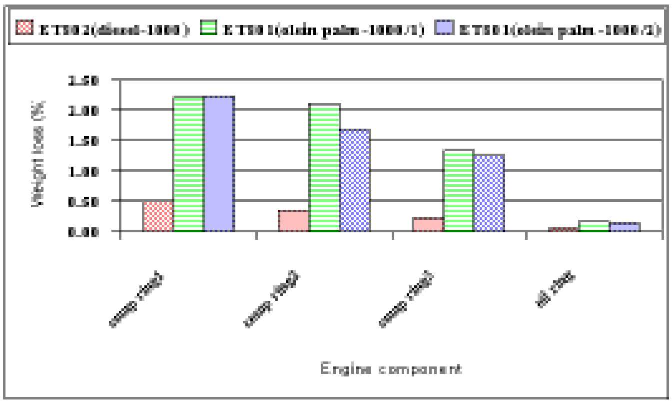


**Figure 10. Component wear from the engine fueled by diesel and refined palm oil at the first 1,000 hours and the second 1,000 hours of running from the engine fueled by refined palm oil**

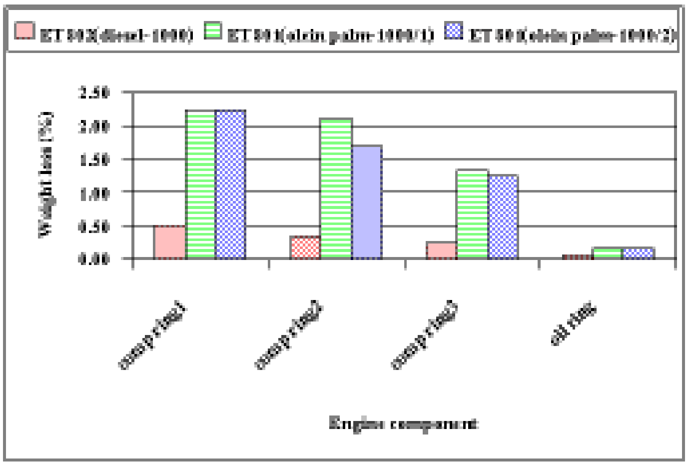


**Figure 11. Piston rings wear from the engine fueled by diesel and refined palm oil after the first 1,000 hours and the second 1,000 hours of running from the engine fueled by refined palm oil**

**Table 2. Comparison of piston ring gap of the engine fueled by diesel and refined palm oil after the first 1,000 hours of run time and the second 1,000 hours of run time from the engine fueled by refined palm oil**

| Piston ring | Standard new ring (mm) | Maximum allowable value (mm) | Diesel oil at 1000 hours (mm) | Refined palm oil at 1000 hours (mm) | Refined palm oil at 2000 hours (mm) |
|---|---|---|---|---|---|
| Compression ring #1 | 0.2-0.4 | 1.2 | 0.4 | 0.7 | 1.0 |
| Compression ring #2 | 0.2-0.4 | 1.2 | 0.5 | 0.7 | 1.2 |
| Compression ring #3 | 0.2-0.4 | 1.2 | 0.5 | 0.8 | 1.2 |
| Oil ring | 0.2-0.4 | 1.2 | 0.3 | 0.4 | 0.6 |

## Discussion

The results show that using 100% refined palm oil in a KUBOTA diesel engine and operating continuously at constant 75% maximum load and 2,200 rpm for 2,000 hours produce no serious problems. Starting the engine with refined palm oil is quite difficult because of its high viscosity and high flash point.

Specific fuel consumption and thermal efficiency of the engine fueled with refined palm oil are lower because of its low heating value.

Results of used lubricating oil analyses and components weighing indicate a similar trend, i.e. engine fueled by refined palm oil gives higher wear than that fueled by diesel oil. Because of incomplete combustion of refined palm oil, some of the unburned fuel adheres to the clearance between the cylinder liner and piston rings.

## Conclusion

Comparative tests of indirect injection agricultural engines fueled by diesel and refined palm oil and operating continuously at constant 75% maximum load and speed of 2,200 rpm indicate that for the first 1,000 hours of operation the specific fuel consumption of the engine fueled by refined palm oil is 15-20% higher. The black smoke density is not significantly different in the two cases. Wear in the engines fueled by refined palm oil and diesel oil is not significantly different but wear in the compression rings of the engine fueled by refined palm oil is significantly higher.

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