Effect of Waste Plastic Oil on Engine Performance and Durability

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ABSTRACT

Thailand has had the policies supporting the production and uses of renewable and alternative energies in order to reduce the imports of the fuels from other countries. Producing the fuels from plastic wastes can lower the pollution and energy problems in the country in order to ensure that the fuels can actually be the alternatives. The purpose of this research study is to compare the effects of using the diesel fuel from the plastic wastes on the single cylinder engines by comparing the performances and wears of the engines with the commercial diesel fuel and waste plastic oil. There were two tests: 1) the engine performance test and 2) the engine wear test. According to the results of the engine performance test, it was found that the waste plastic oil resulted in the torque and brake power lower than those of the commercial diesel fuel for about 3% at 2,200 revolutions per minute. However, the waste plastic oil had the lower fuel consumption rate than that of the commercial diesel fuel. As a result, the waste plastic oil had the specific fuel consumption that was lower than that of the commercial diesel fuel for about 2%. Regarding the engine wears, it was found that the waste plastic oil caused slightly more wears than the commercial diesel fuel. It was concluded that the waste plastic oil was an alternative energy that had the potentials of the commercial diesel fuel without modifying the engines.

Index Terms
Waste Plastic Oil, Diesel Engine, Engine Performance, Wearing

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Introduction

Thailand had to mainly rely on importing energies from other country. It was found that 60 percent of the demands for commercial energies were initially from the imports. According to the data in 2019, it was found that the percentage of the imported crude oil was high (87 percent) by comparing it to that of the local crude oil. It also tended to rise because the volume of the petroleum production could not meet the demands [1].

The serious developments of the renewable and alternative energies would reduce relying and importing the fuels. Therefore, the government had policies promoting the renewable and alternative energies produced in the country. The energies include wind power, solar energy, water power, biomass, wastes, biogases and bio fuels. The goals were to lower the percentages of the renewable and alternative energies in the forms of electric power, heat and bio fuels of the final uses of energies to raise because the volum of the petroleum production could not meet the demands [1].

The properties of the waste plastic oil were similar. The properties of the waste plastic oil were similar to that of the diesel fuel [11]. Nonetheless, although this oil could be a commercially renewable fuel, the qualities were diversely dependent on various factors such as technologies, production systems and raw materials. Thus, it was necessary to have supporting data about the properties of the waste plastic oil (WPO).

Research Objectives

The purpose of this research study is to compare the effects of using the diesel fuel from the plastic wastes on the single cylinder engines by comparing the performances and wears of the engines with the commercial diesel fuel (CDF) and waste plastic oil (WPO).
Research Methods

A. Fuels

The tested diesel fuel was commercial according to the standard of the Department of Energy Business [14]. By comparing it to the diesel fuel produced from 100% plastic wastes through pyrolysis from the waste plastic oil refinery of Suranaree University of Technology, the properties of most oil were consistent with the announcements of the department. This excepted the refinery values (Table I). The oil was classified as high speed diesel (HSD).

Table I The properties of the refined diesel oil compared to the properties of the diesel oil in the announcement of the Department of Energy Business

| Fuel Properties | Test Method | WPO | Commercial Diesel Fuel Limit | HSD | LSD |
|-----------------|-------------|-----|-----------------------------|-----|-----|
| Density at 15ºC (kg/m³) | ASTM D 1298 | 0.8111 | Min 0.81 | Max 0.87 | 0.92 |
| Kinematic Viscosity at 40 ºC (cSt) | ASTM D 445 | 3.103 | Min 1.8 | Max 1.8 | 8 |
| Cetane Number | ASTM D 613 | 60 | Min 50 | Max 50 | 45 |
| Cetane Index | ASTM D 976 | 67 | Min 50 | Max 50 | 45 |
| Flash Point (ºC) | ASTM D 93 | 50.5 | Min 52 | Max 52 | 52 |
| Cloud Point (ºC) | ASTM D 97 | 15 | Min 10 | Max 10 | 16 |
| Oxidation Stability (g/m³) | ASTM D 2274 | 17.8 | Max 25 | Max 25 | - |
| Sulfur Content (% w/w) | ASTM D 2622 | 0 | Max 0.005 | Max 0.005 | 1.5 |
| Ash Content (% w/w) | ASTM D 482 | 0.005 | Max 0.01 | Max 0.01 | 0.02 |
| 90% (V/V) Distillation (ºC) | ASTM D 86 | 371.9 | Max 357 | Max 357 | - |
| Polyaromatic Hydrocarbons (% w/w) | ASTM D 2425 | 3.1 | Max 11 | Max 11 | - |
| Water Content (% w/w) | ASTM D 2709 | 0 | Max 0.05 | Max 0.05 | 0.3 |
| Lubricity Corrected (µm) | CEC F-06-96 | 350 | Max 460 | Max 460 | - |

B. Experimental Setup

The test diesel engine was a new single cylinder engine of HONMAR. Its model was DH850E. It was ready to use. The diesel engine performance and wear test kit was of ESSOM. Its model was MT502HD (Fig. 1). The technical data of the diesel engine are shown in Table II. The test kit and measuring tools for the engine performances and durability are presented in Fig. 2.

![Fig. 1 Experimental setup for engine testing](image)

Table II Test engine specifications

| Specifications | Honmar Model DH850E |
|----------------|---------------------|
| Horse Power (hp) | 6.7 at 3,600 rpm |
| Engine Type | Single-cylinder, 4-stroke |
| Cooling System | Air Cooled Type |
| Combustion System | Direct Injection |
| Cylinder Bore x Stroke (mm x mm) | 78x62 |
| Cylinder Volume (cm³) | 296 |
| Engine Start System | Recoil |
| Fuel Capacity (liter) | 3.5 |
| Fuel Type | Diesel |
| Engine Oil Capacity (liter) | 1.1 |
| Engine Dimension (mm) | 427x383x450 |

C. Standards and Test

The test was divided into two parts. The first part was the engine performance test according to the ISO 1550:2016 Internal Combustion Engine–Determination and Method for the Measurement of Engine Power–General Requirements, which was used as the reference for specifying the load of the engine during the engine durability test. The performances consisted of 1) engine break power, 2) engine break torque and 3) specific fuel consumption. The test started from warming the engine at 1,000 revolutions per minute (rpm) until the operating engine temperature was stable at 70 ºC, and the initial speed of the engine was set to 2,700 rpm. Then, the engine load was increased with the dynamometer until the speed of the engine was decreased. The value was recorded every 100 rpm until the speed of the engine was reduced to 1,700 rpm. Then, the test was over. The data were presented and analyzed in the form of the engine performance graph according to the international standards. The second part of the test was the engine durability test referring to the 200-hr Screening Test for Alternative Fuels or EMA 200-hr Test [16], which was the durability test standard for engines using alternative or renewable energies. In the test, the load was specified as the duty cycle as shown in Table III. The test was repeated for 18 hours (six cycles) and stopped for six hours in order to ensure that the temperature of the engine was equal to the ambient temperature. The test was repeated until it was tested for 200 hours. The durability of the engine was evaluated by measuring the properties of the engine oil.
every 50 hours. The examined properties including viscosity, density, alkalinity and contaminated water quantity in order to study the effects of the waste plastic oil on the lubrication system of the engine and to measure the wears of other components of the engine. The metal and non-metal contaminants such as iron (Fe), aluminium (Al), copper (Cu) and chromium (Cr) were identified in order to find the wears of the other components after using the waste plastic oil because the different components were made of the different materials. Therefore, the contaminants found in the engine oil could be used as the guidelines for identifying the wears of the components.

Table III The cycle of the EMA 200-hours durability test

| Cycle Step | Engine Speed (rpm) | Torque | Power | Time (min) |
|------------|--------------------|--------|-------|------------|
| 1          | Rated              | –      | Rated | 60         |
| 2          | 85%                | Maximum| 95%   | 60         |
| 3          | 90%                | 28%    | 25%   | 30         |
| 4          | Idle               | 0      | 0     | 30         |

Results

A. Performance Test

According to the results of the engine break torque test, it was found that the torque of the WPO was slightly lower than that of the CDF (Fig. 3). Especially for the speeds of 2,000 - 2,600 rpm that were the normal speeds of the engine, the highest torque of the engine was 2,200 rpm. The WPO had the highest torque of 11.0 N-m, while that of the CDF was 12.2 N-m. That is, the torque of the WPO was lower than that of the CDF for about 3%.

By calculating the engine brake power, it was found that the brake power tended to increase according to the speed. Additionally, both types of the diesel fuel had the similar results (Fig. 4). The highest power of the engine was at the speed of 2,500 rpm. The CDF had the highest power of 2.93 kW, while the CDF had the highest power of 2.83 kW. However, the power from the WPO was averagely lower than that of the CDF for 7% at the speeds of 1,700 - 2,300 rpm.

Regarding the specific fuel consumption (SFC), it was found that the engine using the WPO had the lowest average SFC of 0.44 g/kW-hr. Similarly, the CDF had the average SFC of 0.41 g/kW-hr. The average SFCs were calculated at the speeds of 2,000 - 2,600 rpm as shown in Fig. 5.

B. Durability Test

The properties of the engine oil during the durability test of the CDF and the WPO were shown in Table IV and Table V, respectively. The properties of the engine oil were changed according to the time. The viscosity and density tended to increase, while the alkalinity was decreased. By analyzing the metal and non-metal contaminants; it was found that the amounts of Fe, Pb, Cr, Cu, Al and Si increased during the test.

Table IV The properties of the engine oil during the durability test of the commercial diesel fuel

| Properties                | Operating Hours (hr) |
|---------------------------|----------------------|
| Viscosity at 100 °C (cSt) | 15.00 16.20 17.40 17.70 |
| Density at 100 °C (kg/m³) | 851.60 853.00 854.50 856.00 |
| Alkalinity (gKOH/g)       | 10.80 10.20 10.50 9.80 |
| Fe (ppm)                  | 22.33 23.10 25.33 25.68 |
| Pb (ppm)                  | 1.44 2.64 9.12 15.84 |
| Cr (ppm)                  | 0.90 1.60 2.60 3.90 |
| Cu (ppm)                  | 0.93 1.74 3.45 4.20 |
| Al (ppm)                  | 4.25 5.60 8.25 14.90 |
| Si (ppm)                  | 4.65 4.86 6.38 7.53 |
The properties of the engine oil during the durability test of the waste plastic oil are shown in Table V. By testing the durability of the engine using the waste plastic oil, it was found that the performance of the engine was slightly affected since the brake power was decreased for about 6%. The specific fuel consumptions of the waste plastic oil and the commercial diesel fuel were very similar. Therefore, the break thermal efficiency of the engine using the waste plastic oil was lower than that of the commercial diesel fuel for only 1.6 – 3.0%. For the wears of the engine, it was found that the waste plastic oil insignificantly resulted in more wears than the commercial diesel fuel.

## Discussions

In this study, the performance and durability of the single cylinder diesel engine using the commercial diesel fuel and the waste plastic oil were identified. By testing the performance of the engine at the different speeds, it was found that the graphs of the brake torque, brake power and specific fuel consumption changed in the same directions. The torque and brake power of the engine using the waste plastic oil were lower than that of the commercial diesel fuel. Nevertheless, the specific fuel consumptions of the waste plastic oil and the commercial diesel fuel were very similar. By testing the durability of the engine, it was found that the viscosity and density were increased. The alkalinity was decreased. The metal and non-metal contaminants were increased during the test. The engine consisted of many components including static components and dynamic components. Generally the dynamic components were made of metals that had frictions on the static components. The mentioned movements resulted in wears. Hence, the engine must have the lubricant that not only lubricate the components, but also cleaned the metal components. Normally, lubricants have reactions with oxygen in the air. Then, it results in acidic substances and gum. These reactions occur at high temperatures that degrade the lubricants with increased acidity and viscosity. If the acidity of lubricants is increased, then the metal components of machines were eroded [17]. It is found that Fe has the highest amount since Fe is a main component of the parts of engines. In overall, the commercial diesel oil had the amount of Fe slightly lower than that of the other oil. Possibly, it was because the commercial diesel fuel had additives such as biodiesel in order to improve the lubrication. Thus, the test results could confirm that the waste plastic oil had the potentials for being used in engines and its qualities could be improved and equivalent to that of the commercial diesel fuel.

## Recommendations

### A. Recommendations for Practices

Since the properties and test results of the waste plastic oil were similar to that of the commercial diesel fuel, we can use the waste plastic oil without modifying engines. For modified engines with adjusted fuel injection angles and other modifications, the waste plastic oil may improve the performance of the engines and completely replace the commercial diesel fuel.

### B. Recommendations for Further Research

1. Further studies should be conducted, or the qualities of the oil should be improved in order to be equivalent to that of the commercial diesel fuel.
2. Further studies about the pollution caused by engines should be conducted.
3. Field studies about the wears of engines should be conducted.

## Conclusion

This study presented the effects of the waste plastic oil on the diesel engine. By comparing the performance and wears of the engine using the waste plastic oil and the commercial diesel fuel, it was found that the performance was slightly affected since the brake power was decreased for about 6%. The specific fuel consumptions of the waste plastic oil and the commercial diesel fuel were very similar. Therefore, the break thermal efficiency of the engine using the waste plastic oil was lower than that of the commercial diesel fuel for only 1.6 – 3.0%. For the wears of the engine, it was found that the waste plastic oil insignificantly resulted in more wears than the commercial diesel fuel.

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