Effect of injection timing on performance and emissions characteristics of a single cylinder diesel engine fuelled with waste plastic oil

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Abstract. This research was aimed to study the effect of injection timing on performance and emissions characteristics of a single cylinder diesel engine using waste plastic oil as an alternative fuel. The injection timing was set up to 15°, 20° (factory default) and 25° CA bTDC position by directly adjusting the camshaft profile angle. The engine was loaded at 50%, 75% and 100% of full load with constant engine speeds of 3,600 rpm. The experimental results showed that retarding the fuel injection led to the improvement of brake specific fuel consumption and NOx emissions when the engine was operated with waste plastic oil at all engine operating loads tested. The slightly reduction in the maximum brake power was obtained by the use of waste plastic oil with respect to diesel fuel. To meet benefits of using waste plastic oil as a feasible alternative for next generation fuels in compression ignition engines, the retard of fuel injection was recommended to adjust the injection timing of the engine operated with waste plastic oil.

1. Introduction

Waste plastic can be considered as a very serious environment issues because of their disposal problems all over the world. According to the Ministry of Natural Resources and Environment’s record, Thailand plastic waste of 2.7 million tons was generated in 2015 (approximately 7,000 tons per day) and only 30% of them was recycled, while the rest of them was dumped and burned. Nowadays, by utilizing pyrolysis techniques, waste plastics can be successfully converted into fuel oil as an alternative energy source for internal combustion engine. Most of research works have been done to investigate the performance, emission and combustion characteristics of the engine operated with waste plastic oil [1, 2]. Almost all the literature it was reported that the crude waste plastic pyrolysis oil can be used directly in the engine without any engine modification [3, 4]. However, the main pollutant emissions especially NOx are higher compared to diesel fuel due to their properties and combustion characteristics.

In order to control NOx, the fuel injection timing was retarded from the original injection timing. Many researches of injection timing effects on emission characteristics have been studied with diesel fuels [5-7]. However only few publications have been found for the waste plastic oil. Consequently, the effect of injection timing on the engine performance and emission characteristics of a single cylinder diesel engine fuelled with waste plastic oil are investigated in this study.
2. Methodology

Waste plastic oil produced from pyrolysis process was carried out in this experiment. Table 1 shows the basic physical and chemical properties of waste plastic oil and bio diesel compared to commercial diesel fuel. Waste plastic oil possesses slightly lower calorific value while its cetane index and flash point are higher with respect to those of diesel fuel.

| Properties                 | Waste Plastic Oil (WPO) | Bio Diesel B40 | Diesel       |
|----------------------------|-------------------------|----------------|--------------|
| Color                      | Black                   | Clear Orange  | Yellow       |
| Specific gravity at 15.6 °C | 0.800                   | 0.859         | 0.828        |
| Gross calorific value [MJ/kg] | 44.98                  | 40.1          | 45.39        |
| Kinematic viscosity [cSt] at 40 °C | 3.065                  | 3.85          | 3.439        |
| Cetane index               | 68.98                   | -             | 60.18        |
| Flash point [°C]           | 36                      | 120           | 78           |

Figure 1 below shows the schematic diagram of the experimental setup. A 15-hp eddy current dynamometer was coupled to the engine to simulate the operating load. The research engine is a four stroke single cylinder air-cooled diesel engine and the specifications are given in table 2. The fuel flow rate was measured on mass basis using an electronic weighing scale and a stopwatch. Thermocouples were used to measure the exhaust gas temperature and oil temperature. A TDC encoder was used to detect the engine crank angle.

Figure 1. A schematic diagram of the experimental setup.
1: Dynamometer 2: Tested Engine 3: Weighing Scale 4: Encoder Wheel 5: Load cell 6: Control Unit

An exhaust gas analyser was used to measure NOx emissions in the exhaust. The engine was loaded at 50 %, 75 % and 100 % of full load with constant engine speeds of 3,600 rpm. All the tests were conducted by starting the engine with diesel fuel and then switched over to run with waste plastic oil. At the end of the test, the engine was run for some time with diesel to flush out the waste plastic oil from the fuel line and the injection system.
Table 2. Detailed specifications of the tested engine.

| Engine Model       | Kawama 500D                        |
|--------------------|-----------------------------------|
| Type               | four stroke single cylinder air-cooled diesel engine |
| Bore x Stroke [mm] | 68 x 54                            |
| Displacement [cc]  | 196                                |
| Compression ratio  | 22 : 1                             |
| Rated output power [kW]@3400 rpm | 2.42                               |
| Torque [N.m]@3400 rpm | 6.48                           |
| Lubrication oil    | 10W30                              |

The camshaft profile of fuel injection pump was modified to obtain the early fuel injection of 25° CA bTDC and the late fuel injection of 15° CA bTDC compared to the standard injection timing of the engine (20° CA bTDC) so that the influence of injection timing on engine performance and emissions was studied. Figure 2 shows the detail of the modified camshaft. The camshaft profile can be switched between +/- 10 degree from the normal position and then the injection timing can be adjusted for advanced or retarded injection timing from the default factory position.

![Injection Pump Cam Shaft](Image)

Figure 2. Modification of fuel injection pump camshaft.

3. Results
A series of performance and emission tests were carried out on the research engine using diesel fuel and waste plastic oil at different engine operating conditions and the results are presented.

3.1. Engine performance
Figure 3 below shows the variation of torque and brake power. It can be observed that the maximum brake power is 2.5 kW at rated speed for diesel fuel which was exceeded the rated engine power claimed by the manufacturer. This may be due to the variation of diesel fuel properties and testing environment conditions. The reduction in the brake power was obtained by the use of waste plastic oil. The engine operated with waste plastic oil decreases the maximum brake power about 8% with respect to that of diesel fuel. It is clear that the brake power of the waste plastic oil is closer to diesel up to
75% of rated power, beyond which it starts decreasing. At higher load, more fuel was injected to combustion chamber to produce the power needed so the difference in calorific value can play more important role to generate different brake powers when diesel fuel and waste plastic oil were used to operate the engine. As a consequence of lower calorific value than diesel fuel, the engine fuelled with waste plastic oil showed the lower maximum brake power. This may be due to the fact that at full load, the exhaust gas temperature and the heat release rate are marginally higher for waste plastic oil compared to diesel. This may result in higher heat losses and lower brake power in the case of waste plastic oil [8].

Figure 3. Performance curve of tested engine with (a) diesel and (b) waste plastic oil.

3.2. Brakes
The brake specific fuel consumption (BSFC) at different injection timings tested with waste plastic oil is shown in figure 4. It is clearly seen that BSFC increased by 3.11% on advancing the injection timing to 25°CA bTDC while reduced by 5% on retarding to 15°CA bTDC from the original injection timing of 20° CA bTDC. Because of advancing the injection timing of fuel to 25°CA bTDC, more complete combustion would have been taken place that results in higher BSFC. While retarding the injection to
15°C A bTDC, the less time for combustion process can result in more incomplete combustion leading to the lower BSFC. The improvement of BSFC was obtained as the engine operating loads was increased. The higher fuel conversion efficiency can be used to justify such reduction in BSFC, when the engine was operated at higher engine loads.

Figure 4. Variation of brake specific fuel consumption at different injection timings and engine loads for waste plastic oil.

Figure 5. Variation of NOx emissions at different injection timings and engine loads for waste plastic oil.

3.3. NOx emissions

Figure 5 shows NOx emissions from the combustion of waste plastic oil at different injection timings and engine loads. The results showed that the advanced injection timing tended to increase NOx emissions for all engine operating loads tested. This can be attributed to more available time for the combustion process with advanced injection timing where mostly all the injected fuel can be burnt near TDC to produce more complete combustion, resulting in higher combustion temperature which favours NOx formation [3, 9]. When the injection timing was retarded, less fuel was burnt before TDC while the remaining fuel was burnt in early expansion stroke resulting in less combustion temperature related to the reduction in NOx emissions [6, 7]. With the same injection timing, the reduction in NOx emissions was found as the engine loads increased. The higher amount of fuel injected to the
combustion chamber may participate in the reduction in combustion temperature, as a consequence of higher heat needed to vaporize more fuel molecules during the mixing process with the air leading to lower combustion temperature and lower NOx emissions.

4. Conclusions
The effects of injection timing on the engine performance and NOx emissions by the use of waste plastic oil as an alternative fuel for a compression ignition engine without any other engine modifications was investigated in the study. The penalty of NOx emissions from the combustion of waste plastic oil seems to be controlled by the fuel injection timing. To reduce NOx emission, the retard of fuel injection may be needed to delay the start of combustion obtained by waste plastic oil. The experimental results on engine test showed that the reduction in NOx emissions was found with the retarded injection timing at all engine operating loads tested. In addition, the retarded injection timing with the use of waste plastic oil can improve the brake specific fuel consumption. As the benefits mentioned, the retard of fuel injection can be considered for the engine operated with waste plastic oil.

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