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Biodiesel Usage in a Common Rail Vehicle – Performance and Emission Characteristics after 60,000km

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Abstract

The effects of biodiesel on on-road fuel use experience have been investigated in this study. With a common rail fuel injection system, an unmodified van TOYOTA HIACE 2,494 CC engine was selected to run as a modern diesel engine. The vehicle fueled with neat palm biodiesel operated continuously on regular on-road conditions and accumulated mileages to achieve 60,000 kilometers. The engine performance, fuel consumption and exhaust gas emissions were measured periodically on a chassis dynamometer and compared with the reference value recorded at the start of biodiesel usage. In addition, commercial diesel fuels were fueled for comparison during the dynamometer test.

Although biodiesel exhibited lower power and higher fuel consumption than those of diesel, their use could lead to substantially lower particulate matter. For a long term test result, the vehicle has been successful to complete the test with no problems of any consequence. Engine performance and fuel consumption has not been influenced by engine deterioration when using biodiesel. However, there are some effects on exhaust emissions at 60,000-km.

Key words: Biodiesel, common rail, engine performance, emissions

1. Introduction

There has been increasing interest in using alternative fuels to substitute petroleum-derived fuels. Biodiesel, derived from transesterification of vegetable oils or animal fats, is a promising fuel for compression-ignition (CI) engines, due to the similarity between its properties and those of diesel. In particular, biodiesel has a high cetane number that is comparable to diesel's, making it possible to self-ignite in a diesel engine. Moreover, biodiesel has superior characteristics than diesel in terms of higher lubricity [1], very low sulfur and aromatic-hydrocarbon content, and substantial reduction in net CO_2 emissions. However, biodiesel also has major drawbacks, such as higher viscosity and poorer oxidation stability, which may result in problems in the fuel injection system or corrosion. Since there are a vast variety of production techniques and feedstock, such as soybean, waste cooking oil, rapeseed and palm oil [2], the chemical and physical properties of biodiesel can vary and have different impacts on an engine and its emissions [3]. For instant, palm biodiesel yields a high cetane number but causes cold filter plugging, because of its saturated fatty acids [4].

Many researchers have conducted studies on the use of both pure biodiesel and biodiesel blends in CI engines [5]. The studies included engine performance, fuel consumption, emissions, combustion characteristics and material compatibility, compared to results from using regular diesel fuel [6]. A short-term test demonstrated the use of biodiesel in a diesel engine without a substantial reduction in engine performance or requiring engine modification [7]. Cycle-to-cycle variability with biodiesel was shown to be on the same order as that of petroleum diesel fuel [8]. Biodiesel resulted in a longer ignition delay period but faster combustion, while diesel yielded a higher peak of combustion pressure [9]. Higher specific fuel consumption of biodiesel was necessitated, due to its lower heating value, but lower exhaust emissions, such as CO and HC, were emitted [10]. Moreover, particulate matter was significantly reduced [11, 12]. However, increased NO_X emission was measured [10].

The effects of biodiesel on engine durability over a long-term period have also been studied. Nevertheless, most of the work focused only on the reduction of engine performance, emissions, and wear. In one example, after an engine was run continuously for a long period with biodiesel B20 (20% biodiesel blended with 80% diesel), exhaust emissions were found to be higher than that of pure diesel [13]. Another study showed that the engine oil's viscosity reduced to below a standard minimum value, after a short period of using soybean biodiesel [14]. This indicated that biodiesel passed through the crankcase and diluted the oil. However, low concentrations of all elements were found, indicating that the engine wear was normal. The common problems observed during the use of biodiesel in long-term durability tests were failure of fuel pumps, filter plugging, and injector cocking [15].

In the current study, the effects of biodiesel on on-road fuel use experience have been investigated. After the vehicle fueled with biodiesel had run to accumulate mileages, chassis dynamometer tests were conducted to measure vehicle's performance, fuel consumption and exhaust emissions. Then, the results were compared with the initial condition. Of significant note, the effects of biodiesel usage over the long-term period did not compared with those of diesel usage in the current study. However, the comparison was performed during the chassis dynamometer test.

2. Materials and methods

2.1 Test Vehicle

A commercial Toyota Hiace van was used in the experiment, as shown in Figure 1. The engine in the van is a four cylinder direct injection diesel engine which applies a common rail fuel system. Detailed specifications of the engine are listed in Table 1. This dedicated diesel engine was employed throughout the study without any modifications.

Table 1 Engine specifications

Engine model	2KD-FTV
Number of cylinder	4
Cylinder displacement	2,494 cc
Cylinder width and bore stroke	92 x 93.8 mm^2
Compression ratio	18.5 : 1
Fuel injection system	Commonrail direct injection
Turbo charger	Yes
Overhead camshaft	Double overhead camshaft
Max. power	75 kW at 3,600 rpm
Max. torque	260 Nm for 1,600-2,400 rpm

To ensure the engine condition, the vehicle was operated with diesel during the first 10,000 kilometers which recommend by the OEM for run-in distance. The engine was run normally without any problems in this period. Therefore, the biodiesel usage test was started at 10,000 km of mileage accumulation as referred to the initial condition.

Fig. 1 Toyota Hiace van

Table 2 Fuel Properties

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.OxidationStability	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

Pure palm-olein biodiesel, purchased from Pathum Vegetable Oil Co., Ltd., was used throughout the experiment. The significant properties of fuel, which comply with Thailand's commercial biodiesel standard, are shown in Table 2.

2.3 Test Procedure

Before the fuel was changed from diesel to neat palm biodiesel at initial condition, the engine performance and tail-pipe exhaust emissions were measured. The experiment was conducted with diesel and biodiesel as a fuel. The results were used to be the baseline reference.

The vehicle fueled with neat palm biodiesel operated continuously on regular traffic conditions and accumulated mileages to achieve 60,000 kilometers. Most of travel route is located in Bangkok area but not limited the location or traffic conditions. The regular service and maintenance, including engine oil and filter replacement, were performed as the vehicle used diesel. Engine performance and exhaust emission experiment was conducted again after the vehicle operated through 20,000 km and completed the test at 60,000 km.

All performance and emission tests were carried out at Pollution Control Department. The vehicle operated on chassis dynamometer as shown in Figure 2. Exhaust emissions were measured according to Thailand emission standard test, TIS 2160-2003 which is equivalent to EURO 3 legislation (Directive 1999/102/EC). The driving cycles used during this study was Bangkok Driving Cycle. The test cycle consisted of warm-up, urban and sub-urban driving sequence. The total duration of the cycle is 1,961 minutes which cover 24.9 km. The maximum and average speed is 120 and 53.53 km/hr, respectively. Figure 3 shows the detailed driving cycle.

The exhaust emissions were diluted by using a constant volume sampling (CVS) system. A flame ionization detector (FID) analyser was used to measure exhaust UHC emissions. Chemiluminescent analyser was used to measure the oxides of nitrogen in the exhaust gas. CO and CO_2 concentration was measured by the non-dispersive infrared (NDIR) technology. Fuel consumption was calculated by means of Carbon Balance method.

The engine performance was measured in term of power at full load when vehicle was driven at 3rd gear. The roller of the chassis dynamometer was controlled at the constant speed ranging from 40-80 km/hr with an increment of 5 km/hr while driver accelerated the engine to wide open throttle. The power used to break the vehicle was recorded.

Fig.2 Performance and Emission Test Setup

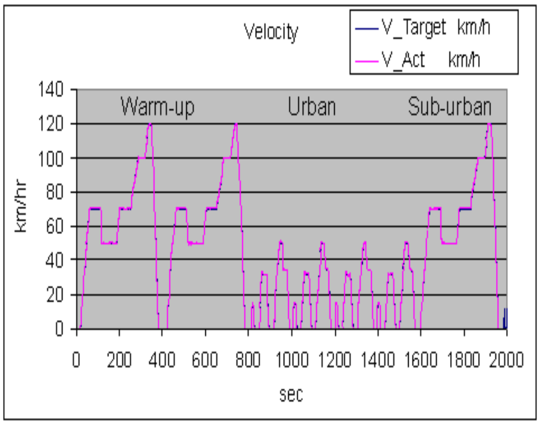

Fig.3 Bangkok Driving Cycle

3. Results and discussions

With the regular service and maintenance, the vehicle has been successful to complete the test with no problems of any consequence. After the test (@10,000 km) was begun in February 2007 the measurement on the chassis dynamometer after 20,000 km was conducted in November 2008. Subsequently, the final test was performed in September 2010 after 60,000 km.

3.1 Performance and Fuel Consumption

Figure 4 presents the full load power test results at any speed when vehicle used diesel and biodiesel as fuel. The results show that at all speeds and accumulated distance, the full load powers of biodiesel are lower than those of diesel approximately 10 %. This is due to the lower heating value of biodiesel as discussed in many previous papers.

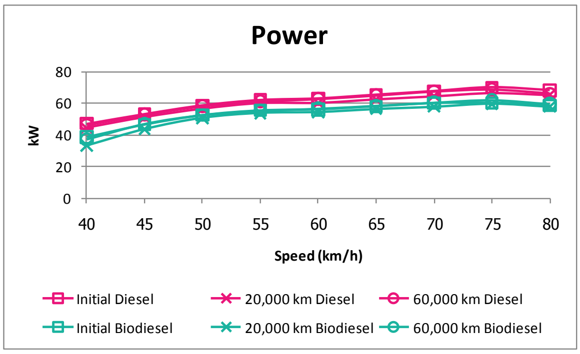

Fig.4 The Full Load Power at any Speeds

When compared with the initial condition, biodiesel had the similar full load power after the vehicle was operated to 20,000 and 60,000 km. This corresponded well with the result of diesel. Hence, biodiesel usage had no effects on the vehicle power.

Fuel consumption, separated as individual and total mode of driving cycle is exhibited in Figure 5. Due to its lower heating value, biodiesel was consumed more amount than diesel for the same distance. The results agree well with other authors [5, 7, 10]. After 20,000 km of mileage accumulation, an unexpected result, in which fuel consumption significant reduced from the initial condition, was found when vehicle used diesel as the test fuel. However, fuel consumption had nearly the same value as the initial condition after vehicle was operated to 60,000 km. Diesel fuel had been purchased from the retail station. Therefore, it is not possible to control the quality of diesel. Unfortunately, diesel blended with biodiesel 2% (B2) and 3% (B3) was regulated in Thailand market during the test period. Consequently, the quality of diesel could affect this result.

When using biodiesel as the test fuel, fuel consumption slightly reduced after the mileage accumulation increased. It seems to be contrary to the expectation that engine deterioration from long-term usage should affect fuel consumption. However, this can conclude that biodiesel usage in the vehicle did not show the significant effect on engine deterioration.

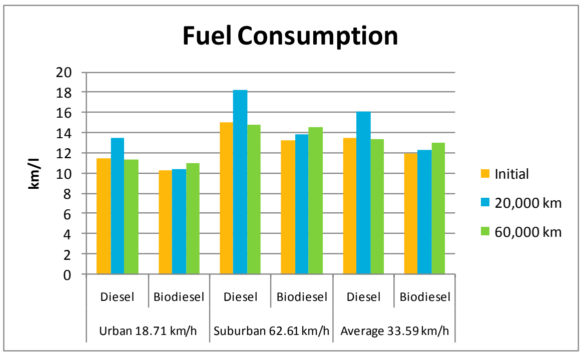

Fig. 5 Fuel Consumption

3.2 Exhaust emissions

The tail-pipe exhaust emissions at the initial condition during urban and sub-urban mode were shown in Figure 6 and 7, respectively. Due to constant speed, the vehicle emitted lower exhaust gas emission when operated at sub-urban mode. For both driving conditions, CO_2 were nearly the same for biodiesel and diesel. Biodiesel obviously reduced particulate matter but significantly increased CO emission. During urban mode, lower NO_X emission was emitted from biodiesel combustion while it increased at the sub-urban condition.

The effect of biodiesel to reduce particulate matter corresponds well with the previous studies [11, 12] due to the presence of oxygen molecule. However, contrary to other authors [5, 10] but similar to the study of Laforgia and Ardito [7], increased CO emission is resulted from using neat palm biodiesel in this study. The different of the feedstock of biodiesel as well as the test condition are the key factors [13].

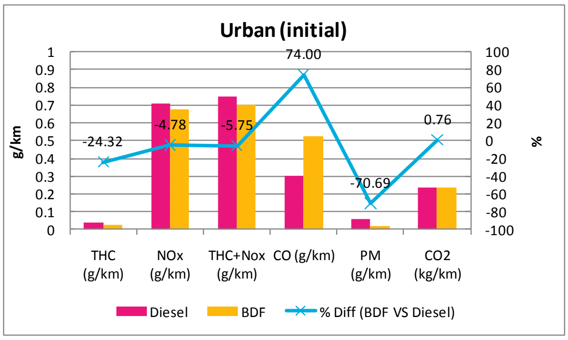

Fig.6 Tail-Pipe Exhaust Emissions during Urban Mode at Initial Condition

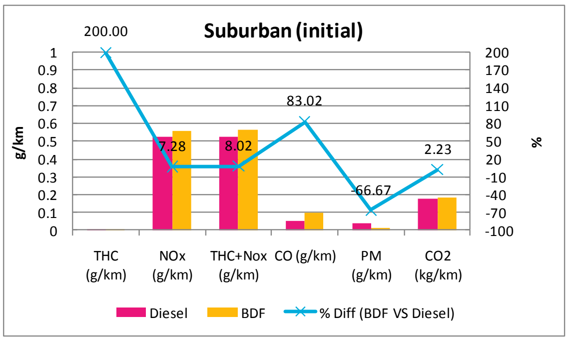

Fig. 7 Tail-Pipe Exhaust Emissions during Sub-Urban Mode at Initial Condition

Figure 8 shows the results of tail-pipe exhaust emissions after 20,000 and 60,000 km of using biodiesel with urban driving condition, whereas Figure 9 presents the results of sub-urban mode. The exhaust emission is quite sensitive to the fuel properties. Therefore, there is no correlation of exhaust emission with the accumulated distance when experiment was conducted by diesel. As discussed above, conventional diesel was used to test during the initial condition followed by B2 at 20,000 km and B3 after 60,000 km.

By using biodiesel as the test fuel, the results were the same for both urban and sub-urban mode. Except for PM value which increased when accumulated distance increased, emissions such as NO_X, CO and

THC, decreased with the long-term 20,000 km test and then increased with 60,000 km distance while a comparable amount of CO_2 emission was emitted for all conditions. Although the exhaust emission did not correlate with the accumulated distance, the noticeable increased amount of emissions such as CO, THC, NO_X and PM at 60,000 km could be caused by the engine deterioration after the long-tem usage. Unfortunately, there is no direct evidence to indicate the effect of biodiesel usage on these increased emissions, due to lacking of data of diesel usage in parallel. It is worth to note that exhaust emission was measured from tail-pipe. Hence, exhaust gases increased probably due to deterioration of an exhaust after treatment system.

The increased exhaust emissions due to the long-term usage in the current study seem to be contrary with the result of Yang et al [13] in which B20 was used in the experiment. They claimed that the regulated pollutant do not increase significantly after 80,000 km driving in which the engine run on the dynamometer. The small amount of biodiesel may have the less effect than neat biodiesel in the current study.

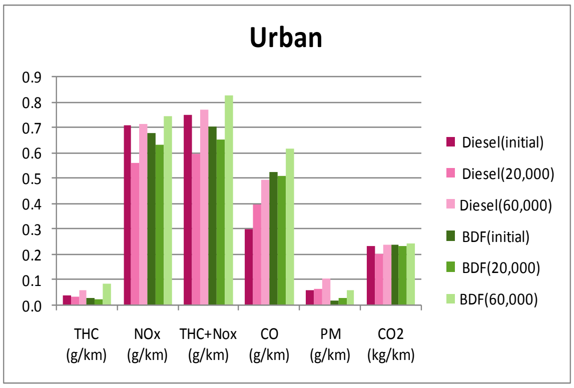

Fig.8 Tail-Pipe Exhaust Emissions during Urban Mode after 20,000 and 60,000 km.

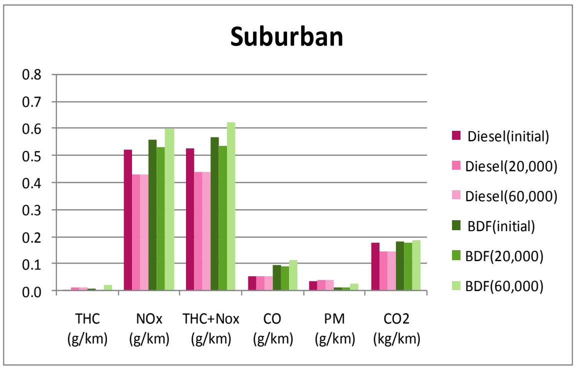

Fig.9 Tail-Pipe Exhaust Emissions during Sub-Urban Mode after 20,000 and 60,000 km.

4. Conclusions

In the current study, the effects of biodiesel usage in a common rail vehicle on engine performance and exhaust emissions have been investigated. The main conclusions can be summarized as follows:

- Without any engine modification, the test van was successfully operated as far as 60,000-kilometer of running distance.
- The vehicle power and fuel consumption has not been influenced by engine deterioration when using biodiesel.

- Running vehicle in the long-term period caused the increased exhaust emissions. However, it is difficult to indicate that this is due to biodiesel usage or nature of the engine.

5. Acknowledgements

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