Biodiesel Contamination in Engine Lube Oil

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Abstract

Recently, there have been increasing interests in using biodiesel as an alternative fuel for commercial vehicles, particularly in agriculture-based countries. Many research efforts have been focusing on proving that biodiesel is able to blend with conventional diesel and that its blend performance is similar to pure diesel. However, engine robustness has still been a concern in long-term biodiesel usage. Therefore, this research aimed to study the contamination of biodiesel in engine lube oil and its effects on the oil's properties. The selected fuels in the study consisted of biodiesel derived from palm-olein, jatropha, and used cooking oil, as well as commercial diesel as a reference. To simulate the contamination, engine oils were blended with biodiesel fuels of 5%, 10%, 15% and 20% (wt), respectively. The engine oil's properties, in terms of engine wear protection, were focused in this research, including the physical, chemical properties and selected wear protection performance. The results showed that the biodiesel contamination caused the reduction in viscosity of the engine oil, which is generally considered a serious negative effect. Nonetheless, the contamination also resulted in the increase in lubricity, which constitutes to wear protection. Moreover, different types of biodiesel showed different impacts on the engine oil's properties.

Keywords: Engine oil, Biodiesel, Density, Viscosity and Acid Value.

1. Introduction

Due to its potential as a substitute for diesel fuel, biodiesel, which is commonly produced by transesterification of vegetable oils or animal fats, has been the focus of an extensive array of research efforts. Many researchers have conducted studies on engine performance, fuel consumption, emissions, combustion characteristics and material compatibility, when using biodiesel [1]. However, there has been limited published information regarding the effects of biodiesel on crankcase oil properties.

Modern diesel engines have applied the aftertreatment system, such as diesel particulate filter (DPF), in order to achieve the tightening emission legislations. This technology requires the periodic regeneration period in which the particulate is oxidized at elevated temperature. Additional late in-cylinder injection strategy is required to rise the exhaust gas temperature. During the late injection, fuel readily passes through the crankcase and then contaminates with the engine oil due to more surface areas on the cylinder wall. After fuels dilute with the crankcase engine oil, they could vaporize and vent through the cylinder during the crankcase oil heated. However, with a higher boiling point, less biodiesel can boil out of the crankcase oil, resulting in more fuel dilution than that of diesel as reported by previous studies [2, 3].

The contamination of fuel into engine oil can cause the oil degradation resulting in the short period of oil drain interval. It effects on anti-wear additive [4], soot dispersant [5, 6] and also engine oil properties [7].

In the current study, the preliminary test of biodiesel fuel dilution in engine oil was conducted. The experiment focused the effects of biodiesel on the engine oil characteristics, in term of chemical and physical properties and wear evaluation. In addition, the effect of different biodiesel feedstock on fuel contamination was also investigated. Three biodiesel, including palm, jatropha and waste cooking oil were selected and compared with conventional diesel.

2. Experiment Setup

2.1 Fuels and Oil

Commercial SAE 15W-40 API CF 4 engine oil was used in this study. With different properties, three biodiesel, derived from palm-olein, jatropha, and waste cooking oil, were selected. The significant properties of biodiesel are shown in table 1. In addition, the commercial diesel was also included in the test for comparison.

Table. 1 Fuel Properties

Properties	Palm Oil	Jatropha Oil	Cooking Oil
Water Content, ppm	315.6	-	1485.1
Acid Value, mg KOH/g	0.17	0.525	1.15
Oxidation Stability, Hr	16.39	-	0.54
Gross Heat, MJ/kg	38.2	38.3	39.5
Density, g/cm^3	0.87	0.88	0.88
ASTM Color	0.8	0.6	-
Pour Point, ºC	12	2	7
Flash Point, ºC	162	158	-
Cloud Point, ºC	15.8	4.4	9.6
Kinematic viscosity at 40ºC, mm^2/sec	4.45	4.91	6.47

In order to simulate the portion of fuel dilution in the crankcase oil of modern diesel engine, biodiesel and diesel were blended with the lube oil at concentration 5-20 wt% with an increment of 5%. The contamination is quite high because the current study focuses on the modern diesel engine (> EURO 4) which applies the aftertreatment technology. As noted by previous studies [2, 3], aftertreatment systems have the effect in increasing engine oil dilution. In addition, a higher boiling point of biodiesel results in less fuel evaporation from the crankcase oil. These are the cause of high biodiesel contamination in the engine oil.

2.2 Test Equipment and Method

Viscosity – ASTM D445 was applied to measure kinematic viscosity at 40°C and 100°C whereas viscosity index (VI) followed ASTM D2270.

Total Acid Number (TAN) – Following ASTM D664, TAN was measured by Potentiometric 809 Titrator.

Wear Evaluation – Two lubricant bench tests, including the high frequency reciprocating rig (HFRR) and Ball-on-Flat test, were carried out to evaluate the wear performance of oil samples which diluted by certain percentage of fuels. The HFRR apparatus (PCS instrument), where the ball specimen is oscillated and rubbed against the fixed flat plate, is shown in Figure 1. Both specimens are submerged in the testing oil. The testing parameters and conditions are followed CEC-F-06-A-96 standard [8] as listed in table 2.

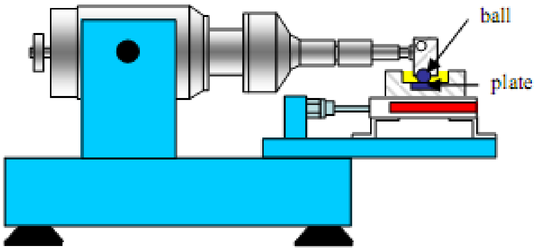

Fig. 1 HFRR Apparatus

Table. 2 HFRR Parameters and Conditions

Fluid volume (ml)	2.0±0.20
Fluid temp (°C)	60±2
Bath surface area (cm^2)	6.0±1.0
Stroke length (mm)	1.0±0.02
Frequency (Hz)	50±1
Applied load (g)	200±1
Test duration (min)	75±0.1
Specimen steel	AISI E-52100
Ball diameter (mm)	6.00
Surface finish (ball)	< 0.05 μm Ra
Hardness (ball)	58-66 Rockwell C
Surface finish (plate)	< 0.02 μm Ra
Hardness (plate)	190-210 HV 30
Ambient conditions	See Chart

After the test was completed, the wear scar on the ball was measured manually by means of an optical microscope. Then, wear scar diameter was corrected with the ambient temperature and humidity and reported as WS1.4. The details had been described in the previous study [9].

Ball-on-Flat is a method, where a ball-shaped specimen is fixed against a sliding flat specimen as a sample in the reciprocating motion. Like HFRR, both specimens are submerged in the testing oil. The UMT-2 Micro tribometer is an instrument which applied this method to measure the friction on surface and performes the simulation of wear. As shown in table 3, the test condition followed ASTM G 133-95 standard in which the lubrication oil temperature was modified to 100 °C (the operating temperature of engine oil). A cylinder liner, cut into a small piece, was selected as a sample for the study. Figure 2 presents the cut shape of the plate specimen. In the current study, wear was evaluated by the weight loss of specimen (weight $_{\text{before}}$ – weight $_{\text{after}}$).

Table. 3 Ball-on-Flat Test Conditions

Applied normal force (N)	200
Ball tip radius (mm)	6.350 (G20)
Stroke length (mm)	10
Test duration (s)	1000
Frequency (Hz)	10
Ambient relative humidity (%)	40-60
Ambient temperature (ºC)	100

Fig. 2 Cylinder Liner (Before testing : Left, After testing : Right)

3. Results and Discussion

3.1 Chemical and Physical Properties

3.1.1 Viscosity

Figure 3 shows the kinematic viscosity of sample oil at 40°C whereas Figure 4 exhibits their value at 100°C. Note that, the horizontal lines for all Figures are the results of pure engine oil, otherwise stated. As expectation, viscosity decreased with the increased concentration of fuel blended in engine oil, for both temperatures. Palm and jatropha biodiesel showed the most effect, followed by diesel while waste cooking oil presented the least impact due to its highest viscosity among others. The higher reduction of viscosity in case of palm and jatropha biodiesel could be the cause to reduce the oil drain interval when diesel is replaced with biodiesel in the engine.

Although pure palm and jatropha biodiesel have the higher viscosity than diesel fuel, their content in engine oil tended to reduce the viscosity more than diesel did. Therefore, biodiesel's properties should not be the only cause of the reduction of oil viscosity. It is possible that palm and jatropha biodiesel could react with engine oil, resulting in decreased viscosity. However, there is no direct evidence to indicate the reaction in the current study.

From kinematic viscosity at 100°C, the results show the same trend as kinematic viscosity at 40°C. In addition, the oils diluted from fuels with the concentration 10% had the viscosity lower than the standard of 15W-40 oil. Therefore, when using biodiesel in modern diesel engine with DPF system, the oil dilution should be controlled to lower than 10%.

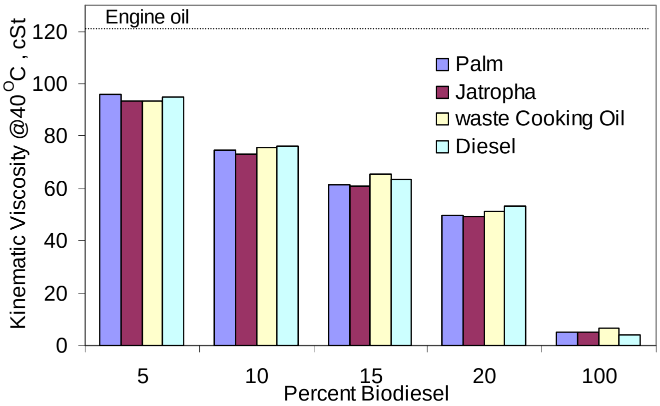

Fig. 3 Viscosity of Sample Oils @ 40°C

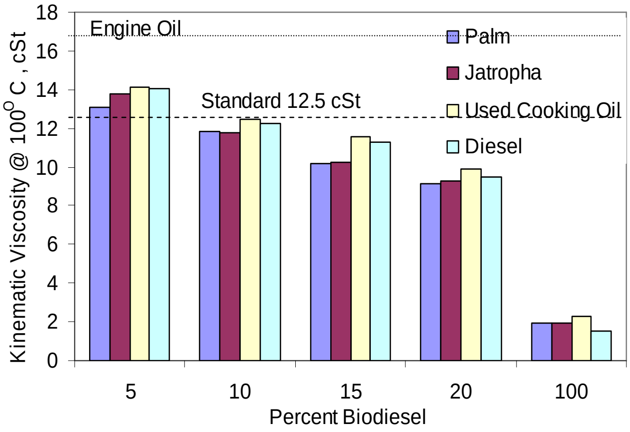

Fig. 4 Viscosity of Sample Oils @ 100°C

Excluding pure biodiesel and diesel, figure 5 presents viscosity index (VI) of engine oils at any percentage of fuel contamination. VI is used to characterize the variation in kinematic viscosity due to changes in the temperature. A higher viscosity index indicates a smaller decrease in kinematic viscosity with increasing temperature of the lubricant [10]. Except for palm biodiesel at 5 wt%, fuel contamination can improve VI of engine oil. This should increase the oil capacity to perform in a wide range of operating temperature. However, biodiesel showed the less effect than diesel. Therefore, engine oil diluted by biodiesel has the higher variation of viscosity than those of diesel dilution.

Waste cooking oil showed the most effect to improve VI when compared with Palm and Jatropha biodiesel. It is postulated that pure waste cooking oil should has the highest VI. However, in the current study, the VI of pure biodiesel could not be calculated and there is no information from the literatures. Therefore, other methods or standards to measure VI will be required to elucidate the cause.

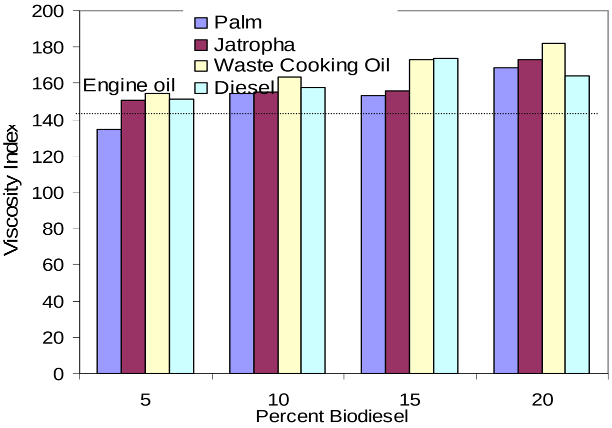

Fig. 5 Viscosity Index of Sample Oils

3.1.2 Total Acid Number

The effect of oil dilution with biodiesel on TAN is shown in figure 6. Due to lower TAN, biodiesel fuels (palm and jatropha) were the cause of decreased TAN of engine oil dilution. Waste cooking oil biodiesel showed the same effect in reducing TAN although it had the higher TAN than oil. Palm and jatropha biodiesel showed the small difference of their TAN whereas waste cooking oil had the significant reduction. Unfortunately, there is no information of diesel for comparison, due to the equipment problem. However, the previous study [11] noted that at the 5% of fuel dilution, the effect of ULSD and biodiesel on TAN showed little difference. TAN of sample oils was nearly constant when the fuels were blended at concentration 10-20%.

This corresponds well with the previous paper [2]. Hence, the percentage of biodiesel, contaminated in lubricant, had the less effect of TAN reduction. TAN can be used as one indicator to change the lubricant, if its value significant increases, although there are many factors including viscosity and Total Base Number (TBN), have to be considered.

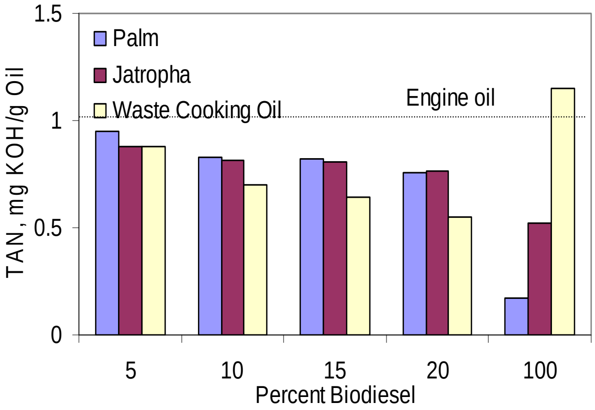

Fig. 6 TAN of Sample Oils

3.2 Wear Evaluation

3.2.1 HFRR

Figure 7 shows the image of wear scar taken from the optical microscope. Then, the wear scar was corrected to WS1.4 as shown in figure 8. The results showed that the WS 1.4 decreased when increasing the percentage of biodiesel in engine oil whereas diesel contamination resulted in the relatively constant WS1.4. Palm and waste cooking oil biodiesel showed the most effect to reduce the wear, followed by jatropha biodiesel. The WS 1.4 results seem to be contrary to the expectation that blending biodiesel should increase wear scar due to lower viscosity of biodiesel than engine oil. However, the results of the current study agree well with the previous paper [4]. They noted that fresh biodiesel might actually decrease wear while aged biodiesel causes the increased wear.

The HFRR is the method to evaluate the sample oil lubricity, associated with the boundary lubrication. This means that fresh biodiesel improves the lubricity of oil dilution, because it contains more natural molecular species with boundary lubricating properties than mineral oils [12].

In order to clarify the effect of different biodiesel feedstock on lubricity, the compositions of biodiesel are required. From the literatures [9, 13], majority composition of palm biodiesel is palmitic (C16:0) which is a saturated fatty acid whereas jatropha biodiesel composes of longer chain unsaturated oleic (C18:1) and linoleic acids (C18:2). Depended on the original sources, waste cooking oil presents the same composition as its source. Therefore, in this case for Thailand, palmitic (C16: 0) should be the majority composition.

Referring to biodiesel composition, saturated fatty acids (palmitic) of palm and waste cooking oil biodiesel seem to improve the lubricity of engine oil for the current study. However, other studies [14, 15] stated that unsaturated fatty acids and extended chain length could enhance lubrication. Hence, jatropha should increase more lubricity. This discrepancy may be caused by the impurities in biodiesel such as monoglycerid and free fatty acid, as previous studies noted [9, 16].

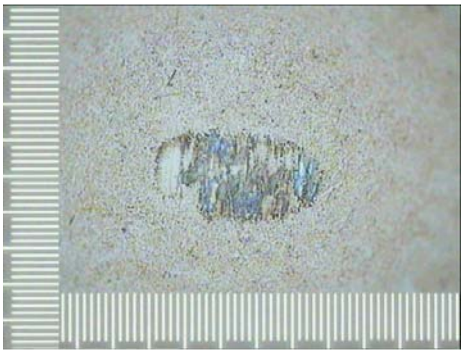

Fig. 7 Wear Scar on a Ball Surface

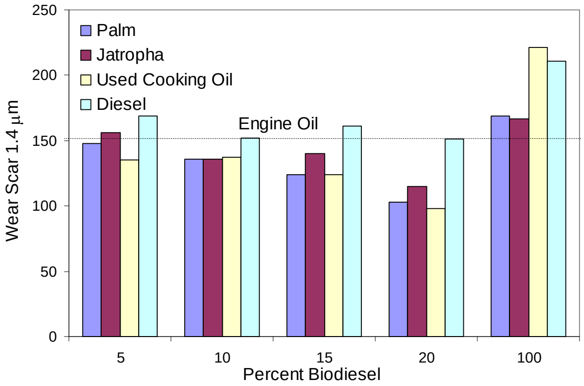

Fig. 8 WS 1.4 of Sample Oils

3.2.2 Ball-on-Flat

After simulation of wear was performed with Ball-on-Flat method, the cylinder liner was measured by weight scale. The weight losses of specimen which submerged under oil samples are shown in figure 9. Although the weight loss did not correlate with the percentage of fuels in sample oil, biodiesel tended to reduce the wear on the cylinder liner when they were blended with lubricant. The reduction of wear by adding biodiesel corresponds with the HFRR results. Palm biodiesel showed superior effect than those of jatropha and waste cooking oil while diesel dilution increased wear.

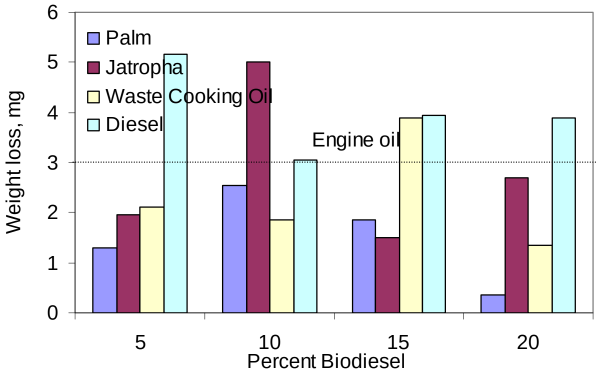

Fig. 9 Weight loss of Cylinder Liner

4. Summary

The effects of biodiesel on contaminated engine oil have been investigated in the current study. With varied concentration and type of biodiesel, sample oils were measured the chemical, physical properties and wear evaluation. The main conclusions can be summarized as follows:

- Fuel contamination shows the negative effects on engine oil in which viscosity reduces. Biodiesel shows more significant effects than diesel.
- Biodiesel contamination shows the positive effects on engine oil in which lubricity increases resulting in decreased wear.
- Diesel and biodiesel have the same effect on reducing TAN value, but the amount of fuel contamination does not correlate with the degree of reduction.

5. Acknowledgement

The authors wish to thank several sponsors helped make this work possible. This study was funded by National Metal and Materials Technology Center. The chemical and physical property tests were supported by the chemical test lab of Bioenergy laboratory.

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