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Impact of Biodiesel Contamination on Engine Wear using Four-ball Wear Tester and Laser Particle Size Analyzer

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Abstract

The diesel engine is a compression ignition engine which converts chemical energy into mechanical energy. The energy forces the piston to perform up and down movement. The sliding movement of the components surfaces produces friction and wear. The lubricant protects an engine by producing the oil film to minimize the contacting surfaces. An incomplete combustion leads to fuel contamination, the contamination effect to oil degradation and lubrication breakdown. This research is aimed to investigate the effects of biodiesel contamination on the engine oil properties and wear characteristics. The used SAE0W30 engine oils were collected from diesel engine vehicles (B5-7). The amount of fuel contamination and particle size were measured by FT-IR and laser particle size analyzer, respectively. The results showed that the average amount of fuel contamination in used oils from the diesel engine vehicles was about 2% by weight. In addition, the new SAE0W30 engine oils were blended with biodiesel fuel to simulate fuel contamination. Friction torque and wear characteristics were evaluated by Four-ball wear tester and the worn surfaces of the balls were examined by scanning electron microscope (SEM) and 3D optical microscope. The particles in the Four-ball tested oil were also measured. The biodiesel contamination shows the negative effect on lubricating oil such as wear scar diameter and friction torque increase. On the other hand, it shows the positive effect to reduce surface roughness.

***Keywords**:* Lubricant, Friction and Wear, Engine, Biodiesel, Four-Ball wear tester

1. Introduction

Recently, diesel engine is widely used as the powertrain in many fields. The advantage of the diesel engine is high efficiency due to high compression ratio. The engine converts chemical energy into mechanical energy. The contacting of metal to metal surfaces inside the engine generate heat and friction that can resulted in increases wear. Lubricant has an advantage in reducing friction prevent wear and removing frictional heat. It has an ability to minimize metal to metal contact by generating a lubricating film between the surfaces. The lubrication regimes can be divided into a boundary lubrication, mixed film lubrication, and full film lubrication [1, 2].

Biodiesel is an alternative fuel which is produced from vegetable oil or animal fat which plays an important role in petroleum diesel replacement. Biodiesel is an oxygenated fuel that makes more completely combustion process which resulted in lower carbon monoxide and unburned hydrocarbon. Khongdet [3] investigated performance and wear of the diesel engine which used diesel, biodiesel blends as a fuel. The results showed that the engine power and torque were similar to diesel engine. However, the amount of wear from biodiesel engine was higher than the diesel engine. Fazal et al. and Haseeb et al. [4, 5] studied the tribological properties of the palm biodiesel blends by using Four-ball wear tester. The tests were tested at different rotating speeds and temperatures. The results showed that wear scar diameter (WSD) and friction torque were increased proportionally to rotational speeds and temperature. Fuel film thickness was reduce, when the heat and rotational speeds increase, resulting in larger WSD. On the other hand, the WSD was decreased when biodiesel blends was increased, because of higher viscosity.

Jame et al. [6] reviewed the types of diesel engine lubricant contaminations. The fuel contamination are driven into the crank case engine oil by the high pressure during the combustion process. The solid particle which is larger than lubricant film thickness can lead to abrasive and fatigue wear. Water and fuel contamination can corrosive the component surface and makes lubricant breakdown. Kiatkong et al. [7] investigated the effect of fuel contamination on engine oil properties by using high frequency reciprocating rig. The results showed that the increasing of fuel contamination decreases oil viscosity. However, the contamination of biodiesel fuel resulted in increased lubricity, which resulted in decreases wear.

This research is aimed to investigate the effects of biodiesel contamination on the engine oil properties and wear characteristics.

2. Experiment Setup

2.1 Physical and Chemical Properties of Used Oil

The main purpose of this part was to measure the amount of fuel contamination in used engine oils from the real situations. The oils were collected from diesel engine vehicles. The engine displacement volume and the rate output were 1,500 cc and 105 HP, respectively. It was four cylinder, four strokes, used commercial diesel (B5-7) as a fuel. The engines were used SAE0W30 as an engine oil. The technical properties of the oil are shown in Table 1. The used engine oils were kept from the real diesel engine vehicles. The oils had the mileage and oil aged in a range of 3,000-20,000 and 0-10,000 km, respectively.

The amount of fuel contamination was measured by Fourier Transform Infrared (FT-IR) Spectrometry followed ASTM E-2412. The amount of total wear metal was measured by rotating disc electrode atomic emission spectroscopy (RDE-AES) followed ASTM D-6595. The morphology of wear particle was investigated by ferrogram and fitragram analysis. The particle sizes in the used oils were measured by laser particle size analyzer.

Table. 1 Properties of SAE0W30 engine oil

Properties	Specification
Viscosity @ 40 °C, (cSt)	44.5
Viscosity @ 100 °C, (cSt)	9.6
Viscosity Index	207
Oxidation, (Abs)	18.1
TBN, (mg KOH/g)	5.6

2.2 Effect of Fuel Contamination on Metal Wear

The main purpose of this test was to investigate the effect of fuel contamination on engine wear by using Four-ball wear tester and laser particle size analyzer. The commercial diesel (B5-7) and palm biodiesel blends (B20, B50 and B100) were blended with the new SAE0W30 engine oil at concentration of 2% by weight. The fuel properties and the list of different biodiesel blends mixed with new engine oil are shown in Table. 2 and Table. 3, respectively.

The Four-ball wear tester is used to determine wear preventive properties of lubricant in sliding contact. This machine consists of four 12.7 mm diameter steels ball which covered with lubricating oil, the three lower balls are held in a steel cup with fixed position and the fourth ball is rotating ball that held in the upper chunk. The test methods and conditions are followed standard test ASTM D4172 [8]. The fourth ball is pressed with a force of 392 N and it is rotated at 1,200 rpm. The temperature of lubricant and the operating time are 75 °C and 60 min. During the test, the friction torque is recorded by load cell sensor. After the test, the Four-ball tested oils were measured particle size by using laser particle size analyzer. The wear scar diameter and the surface roughness of the balls were measured by using scanning electron microscope and 3D optical microscope.

Laser particle size analyzer is used to determine the size distribution of the particles. It was measured by Malvern Mastersizer 2000 particle size analyzer. The machine is capable for measuring particles between 0.01 and 20000 μm.

Table. 2 Fuel Properties

Fuel properties	Biodiesel	Diesel
Cetane Number	70	55
Heating Value, (kJ/kg)	39,550	46,800
Density, (kg/m3)	847.73	844.78
Viscosity @ 40 °C, (cSt)	4.5	3.0
Flashpoint, (°C)	70	64

Table. 3 Fuels mixed with the engine oils

Samples	% SAE0W30	Fuel Type	% Fuel
NE	100 %	-	-
EB7	98 %	Commercial diesel (B7)	2 %
EB20	98 %	B20	2 %
EB50	98 %	B50	2 %
EB100	98 %	B100	2 %

Table. 4 Mileage and Oil aged of the used engine oils

Samples	Mileage (Km)	Oil age (Km)
1	19,046	9,362
2	19,500	9,800
3	19,779	9,811

3. Result and Discussion

3.1 Fuel contamination

Figure 1 shows the amount of (a) total wear metal and (b) fuel contamination by using oil analysis methods in the condition of 2,000 – 20,000 km of mileage and 2,000 - 10,000 km of oil aged. Total wear metal and fuel contamination were measured by using FT-IR and RDE-AES, respectively. The result showed that the total wear metal and fuel contamination increased with the increasing in mileage and oil aged. The average amount of fuel contamination was about 2% by weight.

Figure 2 shows the image of ferrogram and filtergram analysis. They are used to analysis the wear particles inside the used oil. A used oil from real diesel engine vehicle which had the oil aged around 9,800 km was chosen for ferrographic analysis. The results showed that the wear particles were 50% normal rubbing wear, 30% fatigue bearing wear, 10% black and red oxides, 5% white metal and 5% dirt and dust.

The three used engine oils from real diesel engine vehicles, which has similar mileage and oil aged as shown in Table. 4. It were collected and measured the particle size distribution by using the laser particle size analyzer. Fig. 3 shows particle size distribution of used oil. It occurs as a bimodal distribution. The particle sizes were in the range of 0.1 – 23 μm. The first and the second fraction were in the range of 0-1.4 μm and 1.4 – 23 μm, respectively. It might be expected that the particle sizes in this range were not trapped by the oil filter. The small and large particle might be soot and metal wear debris, respectively.

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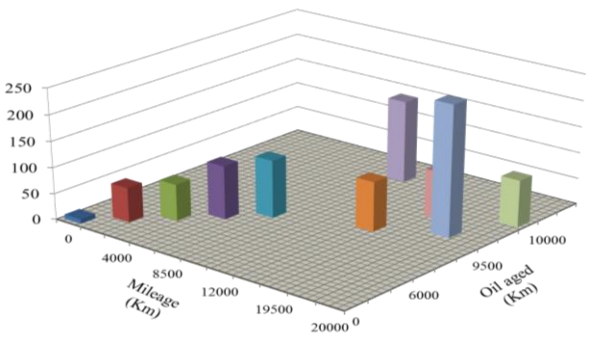
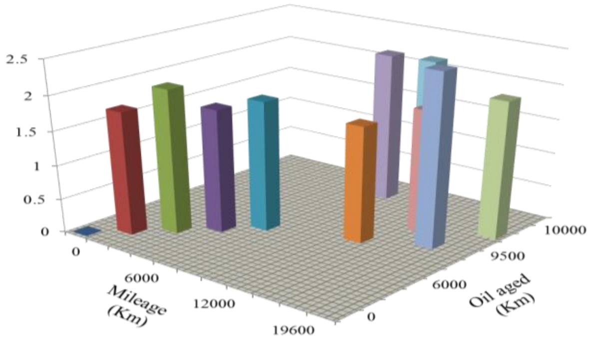
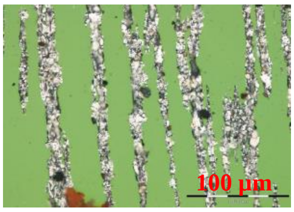


(a) Total wear metal (ppm)

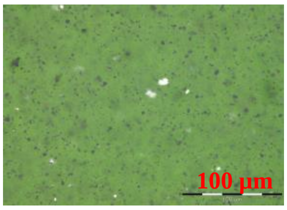


(b) Fuel contamination (%wt)

Fig. 1 (a) total wear metal and (b) fuel contamination on mileage and oil age from real diesel engine vehicles



(a) Ferrogram image



(b) Filtergram image

Fig.2 Image of (a) ferrogram and (b) filtergram analysis from real diesel engine vehicles

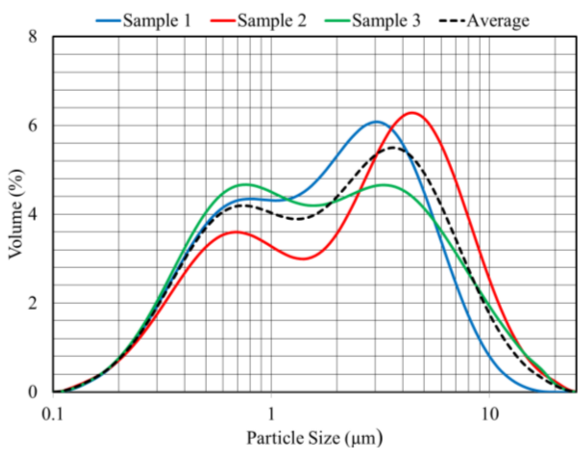


Fig. 3 Particle Size Distribution of used oil from real diesel engine vehicles by using laser particle size analyzer

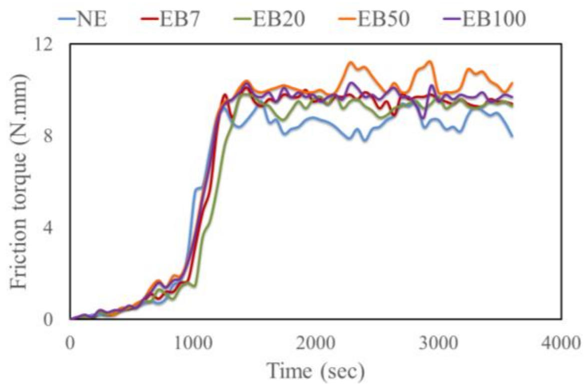


Fig. 4 Behavior of friction torque respect to times during using Four-ball wear tester

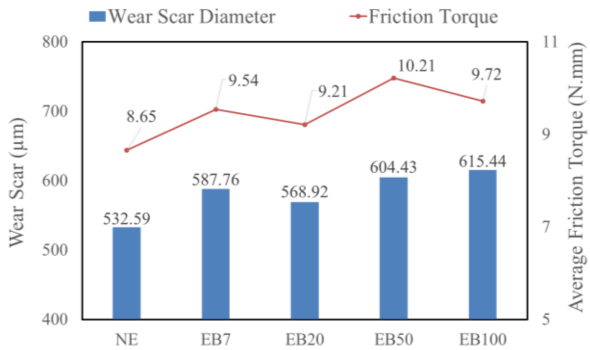


Fig. 6 Average Friction Torque and Average Wear Scar Diameter of each sample

3.2. Friction and wear properties

Figure 4 shows the behavior of friction torque respect to times of each sample, which recorded during using Four-ball wear tester. At the beginning of each test, the friction torque was increased with time. And a few minute later, the friction torque was almost stable. It might be expected that the removing of peak asperities makes the surfaces become smoother and increased the friction torque to the steady state condition.

Figure 6 shows the average friction torque from the steady state condition. The steady state condition was in the range of 1,200 - 3,600 second. The results showed that the average friction torque increased with the increasing in the percentage of biodiesel blends. However, EB20 gives the average lowest amount of friction torque as compared to other biodiesel blends contamination. The average wear scar diameters of each sample are shown in Fig. 5. The results showed that the average WSD increased with the increasing in the percentage of biodiesel blends. This trend was also similar to the friction torque.

After the Four-ball tests, the lower ball of each sample was collected for measure the surface roughness. The surface roughness were measured three places along the surface of the ball, as shown in Fig.5. Fig. 7 (a) shows the surface profiles of the tested balls, and (b) the average surface roughness of Four-ball tested balls.

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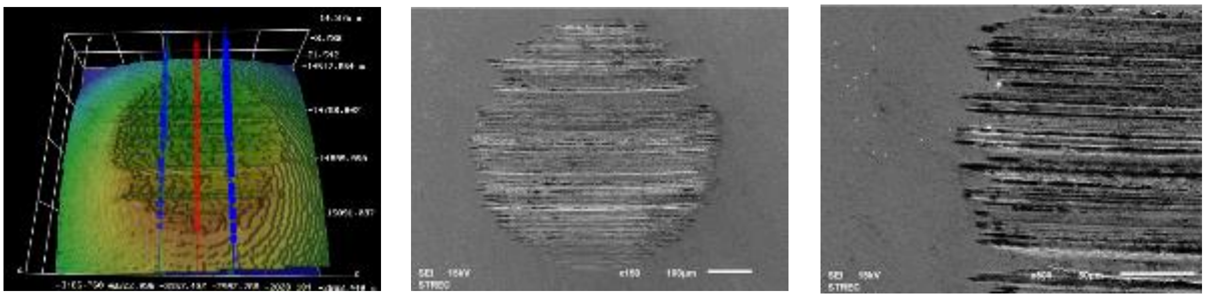
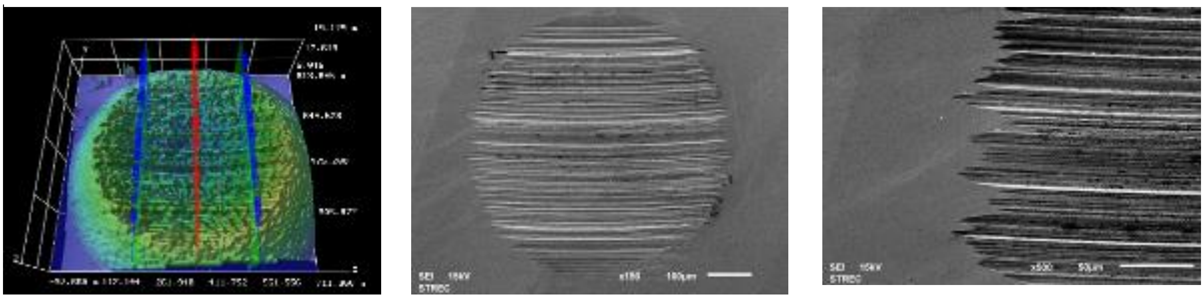
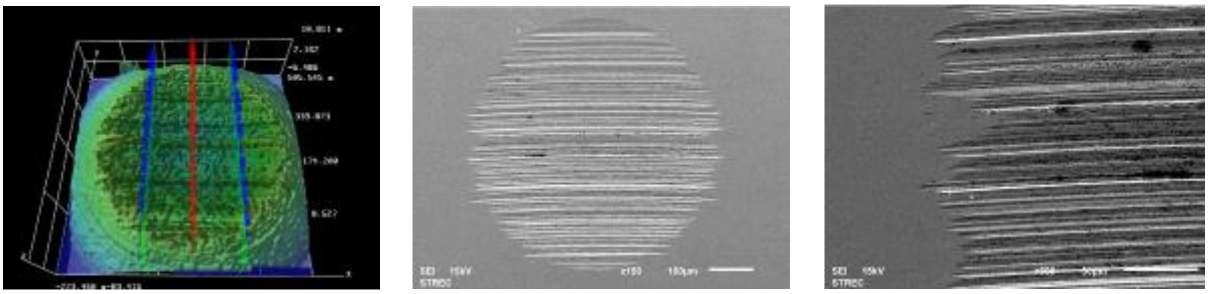


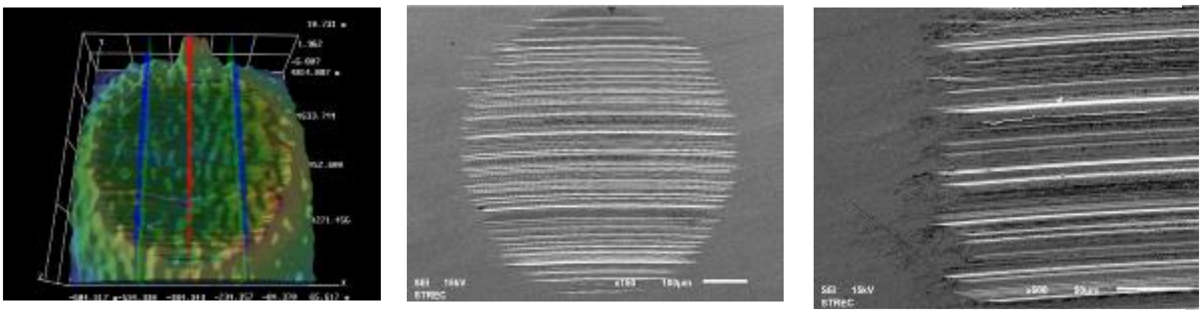
(a) NE



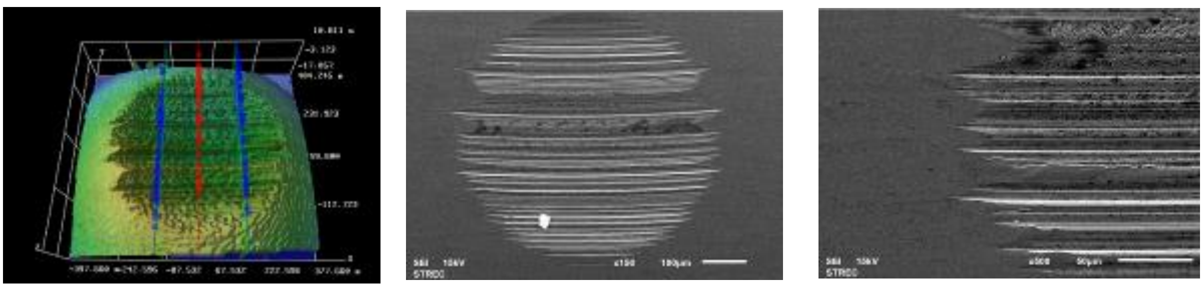
(b) EB7



(c) EB20

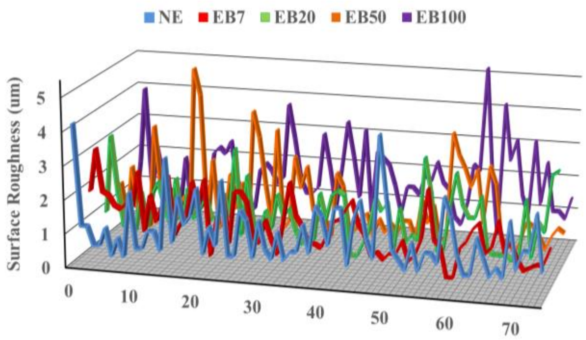


(d) EB50

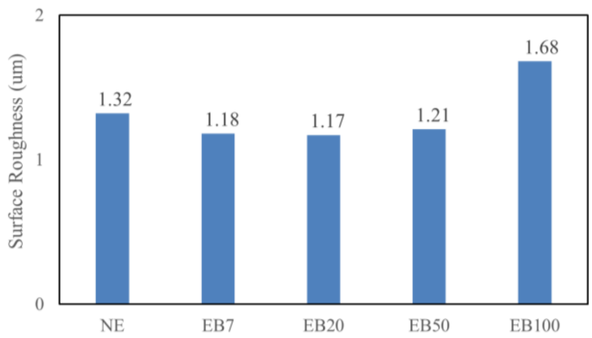


(e) EB100

Fig. 5 The wear surfaces under 3D optical microscope and scanning electron microscope of (a) New SAE 0w30 engine oil (b) Commercial diesel (B7)-2% (c) B20-2% (d) B50-2% (e) B100-2%

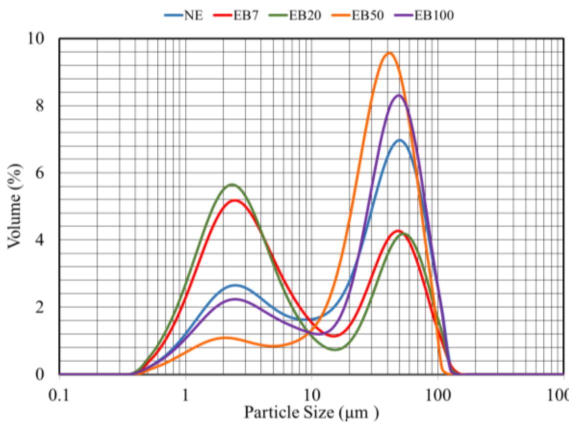


(a) Surface Profile

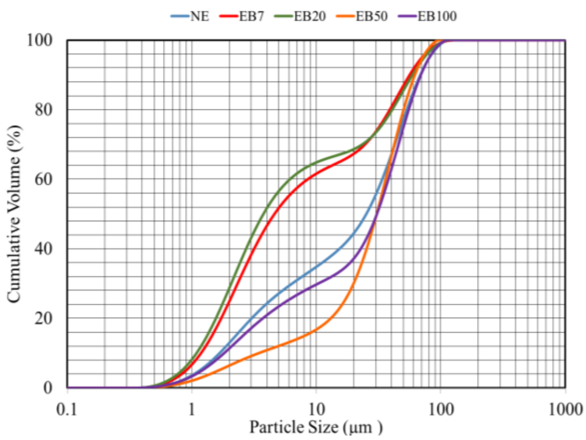


(b) Average surface roughness

Fig. 7 (a) Surface Profiles and (b) Average surface roughness of Four-ball tested balls



(a) Wear particle size distribution



(b) Cumulative Volume

Fig. 8 (a) Wear particle size and (b) Cumulative particles volume of Four-ball tested oils

The results showed that the average surfaces roughness of the biodiesel blends contamination (EB7, EB20 and EB50) were lower than the pure engine oil (NE). However, the surface roughness of EB100 was higher than NE.

3.3. Laser particle size analyzer

After Four-ball tests, the Four-ball tested oils were measured the particle size distribution by using laser particle size analyzer. Fig. 8 shows (a) Particle size distribution and (b) Cumulative Volume of Four-ball tested oils. The particles sizes were in the range of 0-125 µm. The size distributions occur as bimodal distribution. The first and the second fraction were in the range of 0-15 µm and 15-125 µm, respectively.

The results showed that the EB7 and EB20 consist mostly of the small particles. However, the NE, EB7 and EB100 consist mostly of the large particles. At 20 % cumulative volume of NE, EB7, EB20, EB50 and EB100, the particle sizes were in the range of 0-3.2, 0-1.9, 0-1.6, 0-13.7 and 0-4.0 µm, respectively. At 40% cumulative volume, the particle sizes of each sample were in the range of 0-15.9, 0-3.2, 0-2.7, 0-25.3 and 0-23.3 µm, respectively. At 80% cumulative volume, the particle sizes of each sample were in the range of 0-54.4, 0-39, 0-40.7, 0-50.2 and 0-54.4 µm, respectively.

4. Conclusions

This study has been investigated the effect of fuel contamination on lubricating oil properties and wear characteristics.

The fuel contamination in used engine oils of diesel engine vehicles was about 2% by weight. The particles size in the oil pan of the engine were in the range of 0.1 – 23.3 µm. The soot and metal wear particle sizes might be in the range of 0 - 1 µm and 1-23.3 µm, respectively.

The effect of biodiesel contamination were increasing in wear scar diameter and friction torque. However, the surface roughness was decrease. It might be expected that hetero atom of bio-oxygenate fuel promote more heterogeneous oil film.

Wear particle size distribution in the Four-ball tested oils occurred as a bimodal distribution. Moreover, the low biodiesel-blended fraction (B7 and B20) produce more amount of smaller size of metal wear particles.

5. Acknowledgement

The authors would like to acknowledge Energy Policy & Planning Office (EPPO), Thailand Research Fund (TRF) and FOCUSLAB Ltd. for providing facility and research funding.

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