Impacts of Biodiesel on the Durability of an Advanced After-Treatment Diesel Engine

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ABSTRACT

Due to the rising price of crude oil, biofuel is being considered as a global alternative for fossil fuels to reduce the emission of greenhouse gases. Diesel blended with biofuel is currently being widely adopted in many countries. The Taiwanese government has been enforcing the adoption of B2 since 2010. However, there have remained consistent concerns about engine durability related to the use of biofuel, especially regarding after-treatment systems. A selective catalytic reduction system (SCR) has been utilized recently to reduce NO\textsubscript{X} emission in order to meet the Euro IV and V emission standards. To evaluate the impact of biodiesel on the durability of engines equipped with the SCR system, a long-term testing program was organized for the purposes of this study. The results can be used as a reference for the development of marketing promotion strategies as well as government policies in Taiwan. B8 diesel fuel (8 vol% biodiesel) was employed in a commercial heavy duty common-rail fuel injection engine for testing purposes to determine its influence on the durability of engine components and the SCR system. After a 1000-hour full load test operation, the key components of the engines, including the injector, piston ring, and catalyst were analyzed and characterized through a series of inspections to identify the degree of decay and wear behavior. In addition, the engine performance was evaluated with the SAE J1995 test procedure, and the emissions were measured using the ETC test procedure at each maintenance stage and after the durability test to determine any variations in performance and emissions. Furthermore, non-regulatory emissions, such as PM\textsubscript{2.5}, PM diameter distributions, and particle numbers, which have been proved to be critically important in terms of causing cancer from diesel engine emissions, were also evaluated in this study. It was found that the standard deviation of performance and emissions varied less than 3% when the diesel engine was fueled with B8 biodiesel. The results also indicated that the SCR system still maintained conversion efficiency at 70–95% after the 1000hr durability tests.


INTRODUCTION

Biodiesel is being utilized widely all over the world to reduce dependency on fossil fuel and to slow down climate change. The advantages of biodiesel have been extensively discussed and compared with those associated with fossil diesel [1–5]. Biodiesel may reduce toxic engine emissions, including carbon monoxide (CO), hydrocarbons (HC), particulate matter (PM), and polycyclic aromatic hydrocarbons (PAHs), which are closely related to human health, and it also may abate the net production of carbon dioxide (CO\textsubscript{2}), which may significantly reduce the impact of the greenhouse effect on the earth [6–8]. However, NO\textsubscript{X} emissions have increased with the adoption of biodiesel fuels. Kooter et al. [9] revealed that NO\textsubscript{X} increased as higher percentages of biodiesel were used when they compared the emission of B0, B5, B10, B20, B100, PPO (pure plant oil) and B0+DPF. However, the PM showed an opposite trend. The research of Charles J. Mueller et al. [10] showed that increases in NO\textsubscript{X} were not influenced only by a single fuel characteristic, but were also influenced by interaction factors such as injection timing, combustion phasing, radiative heat transfer, adiabatic flame temperature, etc. Furthermore, Wayne A. Eckerle et al. and Janet Yanowitz et al. [11–12] showed that when using B20, which has a lower heating value than fossil fuel, in different engine calibration situations, NO\textsubscript{X} increased under an FTP testing procedure. Somnuek Jaroonjitsathian et al. [13] indicated that the utilization of B20 would decrease torque by approximately 3%, but there was no obvious influence on performance and emissions when an engine was fueled with B5 and B10 after 400hr of durability testing. Jose et al. [14] conducted a study using fossil diesel, B20 and pure biodiesel to compare the emissions by using EGR/DPF and SCR systems, and the results showed that the EGR/DPF system reduced...
the CO and PM emissions more than the SCR system. In contrast to the EGR/DPF system, the SCR system reduced the NO\textsubscript{X} and CO\textsubscript{2} emissions more than the EGR/DPF system. The impact on engine emissions equipped with a SCR system was investigated by Lyn McWilliam et al. [15]. They utilized a CAT6.6 engine fueled with B0, B20 and B100 under a NRTC (Non-Road Transient Cycles) testing pattern. Their results showed that NO\textsubscript{X} emissions increased only 1% at the exhaust valve outlet, but increased 12.5% at the SCR downstream, and the concentration of NO\textsubscript{X} increased 3 ppm when using B20. The trend was similar to that found when using B100; NO\textsubscript{X} increased 4.8% at the exhaust valve outlet and increased 105.7% at the SCR downstream, and the concentration increased by 25 ppm. The conversion efficiency of SCR decreased by 1% and 6% when using B20 and B100, respectively. Aaron Williams et al. [16] investigated the impact of B20 on the performance of a selective catalytic reduction (SCR) system. The results showed no change in the NO\textsubscript{X} conversion in the SCR system using B20, but the NO\textsubscript{X} emission levels were slightly higher for B20 than for ultra-low sulfur diesel. In addition, Aaron Williams et al. [17] developed an accelerated durability test method to determine the potential impact of specific biodiesel impurities. Their study showed that ash, alkali metals, and sodium and potassium can adversely impact the performance of DOC, DPF and SCR systems after long term operation with B20. Jürgen Krahl et al. [18] conducted a 1000hr durability test using different concentrations of phosphorus (9,14.7mg/kg) blended in biodiesel. The results indicated that NO\textsubscript{X} emissions exceeded the emission standard after a 1000hr durability test even when using an engine equipped with an SCR system. Therefore, they suggested that the phosphorus content should not exceed 10 mg/kg when using biodiesel.

In Taiwan, the use of biodiesel has been ongoing since 1992. In 2008, the Taiwanese government mandated a 1% biodiesel policy and increased the percentage to 2% in 2010. A new policy to increase the percentage up to 5% in the forthcoming year has been announced, and in the meantime, an even higher percentage biodiesel such as 8% will be promoted to fleets. However, fleet owners are concerned about the durability issue when the use of high percentage biodiesel is enforced. There are not much local data to persuade vehicle users. Therefore, the purpose of this study is to evaluate the performance of and emission variations in engines equipped with SCR systems after a durability test when fueled with 8% biodiesel.

**EXPERIMENTAL METHODS**

Figure 1 illustrates the engine laboratory equipment and the exhaust sampling system used in this study. The SCHENCK MP-DYNAS 335 AC motor engine dynamometer was used for engine test. Its maximum capacity is 800N-m, and its maximum speed is 8000rpm. The reaction rate from positive torque to negative torque is less than one second. It can effectively conduct EU ETC as well as EU ESC test cycles. Exhaust analysis was carried out with the HORIBA CVS 9400T sampling system and the HORIBA MEXA 9200D analyzer. In addition, the HORIBA MEXA 7500D direct sampling system was used for evaluation of SCR catalyst performance.

A diesel engine equipped with an SCR system was used for the durability tests in this study. It was a 4462 c.c. Cummins diesel engine equipped with a common rail fuel injection system. This engine is widely used as a commercial truck engine and complies with the regulations issued by the Taiwan EPA in 2012, which are equivalent to those of the Euro IV standard. The basic specifications of the test engine are shown in Table 1.

A Sequential Mobility Particle Sizer (SMPS+C) was connected to another sampling tube downstream of the dilution tunnel, as shown in Figure 1. This system is used to measure the number concentration and diameter distribution of particulates. The SMPS+C system is composed of two parts: a Differential Mobility Analyzer (DMA), which is used to set the measurement range, which is from 0.005 to 1 \( \mu \) m in this study, and a Condensation Particle Counter (CPC), which is used to count the number of particles, with a limitation of measurement of 10\(^7\) #/cm\(^3\). An electric heating element is required to keep the sampling system at 300 °C to avoid vapor condensation and to remove volatile content such that only the non-volatile and solid particle matters can be collected.

Figure 2 shows the engine/SCR system experimental device layout used in this study. The engine is controlled with a standard ECU. The exhaust gas after-treatment system is a Cummins SCR-kit device, consisting of a 300mm (diameter)*1000mm (L) catalyst, a urea dosing unit, a nozzle, a urea tank, an NO\textsubscript{X} sensor, a catalyst inlet and...
an outlet temperature sensor and pipes. The air-assisted urea dosing pump is driven by a 2-phase stepping motor. A CAN bus (SAE J1939) signal controller is implemented via the engine ECU (CM2150E type) environment.

Table 1. Test Engine Specifications

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>4462 c.c.</td>
</tr>
<tr>
<td>Rated Power</td>
<td>112.3 kW/2500rpm</td>
</tr>
<tr>
<td>Rated Torque</td>
<td>588 N.m/1100rpm</td>
</tr>
<tr>
<td>Cylinders</td>
<td>In-line 4 Cylinder/4 Stroke</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>17.3:1</td>
</tr>
<tr>
<td>Fuel System</td>
<td>Common Rail (Direct Injection)</td>
</tr>
<tr>
<td>Injection Pressure</td>
<td>1800 bar max.</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Hole</td>
</tr>
<tr>
<td>Air Intake System</td>
<td>Turbocharged with intercooler</td>
</tr>
<tr>
<td>Emission Control System</td>
<td>SCR, OBD</td>
</tr>
</tbody>
</table>

Table 2. Fuel Properties of Blend with 8% Biodiesel

<table>
<thead>
<tr>
<th>Test item</th>
<th>D100(B0)</th>
<th>B100</th>
<th>B8</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cetane index</td>
<td>52</td>
<td>61</td>
<td>54</td>
<td>—</td>
</tr>
<tr>
<td>Density, 15°C</td>
<td>0.834</td>
<td>0.881</td>
<td>0.840</td>
<td>g/mL</td>
</tr>
<tr>
<td>Copper strip corrosion (1hr at 50°C)</td>
<td>1a</td>
<td>1a</td>
<td>1a</td>
<td>rating</td>
</tr>
<tr>
<td>Flash point</td>
<td>76.0</td>
<td>174.0</td>
<td>76.5</td>
<td>°C</td>
</tr>
<tr>
<td>Kinematic viscosity, 40°C</td>
<td>3.125</td>
<td>4.286</td>
<td>3.287</td>
<td>cSt</td>
</tr>
<tr>
<td>Carbon residue (on 10% distillation residue)</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>% (m/m)</td>
</tr>
<tr>
<td>Distillation, 195</td>
<td>349.6</td>
<td>348.0</td>
<td>353.1</td>
<td>°C</td>
</tr>
<tr>
<td>Ash</td>
<td>&lt;0.001</td>
<td>0.004</td>
<td>&lt;0.001</td>
<td>% (m/m)</td>
</tr>
<tr>
<td>Sulfur content</td>
<td>8.5</td>
<td>3.1</td>
<td>7.0</td>
<td>ppm</td>
</tr>
<tr>
<td>Polyaromatics content</td>
<td>5.00</td>
<td>----</td>
<td>5.58</td>
<td>% (m/m)</td>
</tr>
<tr>
<td>Lubricity, corrected wear scar diameter (1.4 wsd, 60°C)</td>
<td>425</td>
<td>----</td>
<td>225</td>
<td>μm</td>
</tr>
<tr>
<td>Water and sediment</td>
<td>0.00</td>
<td>----</td>
<td>0.01</td>
<td>% (v/v)</td>
</tr>
<tr>
<td>Water content</td>
<td>135</td>
<td>354</td>
<td>183</td>
<td>ppm</td>
</tr>
<tr>
<td>Total contaminant</td>
<td>0.3</td>
<td>6.3</td>
<td>6.2</td>
<td>ppm</td>
</tr>
<tr>
<td>Pour point</td>
<td>-6</td>
<td>----</td>
<td>-5</td>
<td>°C</td>
</tr>
<tr>
<td>Cold filtration plug point (CFPP)</td>
<td>-3</td>
<td>-1</td>
<td>-3</td>
<td>°C</td>
</tr>
<tr>
<td>Group I metals (Na + K)</td>
<td>----</td>
<td>0.27</td>
<td>----</td>
<td>ppm</td>
</tr>
<tr>
<td>Group II metals (Ca + Mg)</td>
<td>----</td>
<td>0.13</td>
<td>----</td>
<td>ppm</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>----</td>
<td>0.30</td>
<td>----</td>
<td>ppm</td>
</tr>
</tbody>
</table>

A full-load operation was performed for the durability test in this study. The whole process was 1000 hours, representing 160,000 km of operation in the real world. Every 125 hours, the operation was stopped temporarily for engine maintenance and examination. Every 250 hours, engine performance, regulatory and non-regulatory emissions were measured. The engine performance was determined using the SAE J1995 test method. The emission measurements were conducted according to the EU ETC cycle. As for the conversion efficiency of the SCR system, the ESC cycle was adopted.

To conduct a detailed inspection of the wear of engine components, the 3D Coordinate Measuring Machine (CMM), profile meter and other measurement rigs were used to measure the size of specific parts and calculate the size variations in each component before and after the durability tests. After the tests, the engine components were cut into appropriate sizes and examined with a Field-Emission Scanning Electron Microscope (FESEM) to identify the wear characteristics of each part of the components.
RESULTS AND DISCUSSION

Engine Performance and Fuel Consumption

The engine performance was evaluated using the SAE J1995 test procedure. Figure 3 shows the engine torque variations that occurred during the durability test. The engine torque was measured from 900rpm to 2700rpm at an interval of 200rpm, and the maximum torque at 1600rpm was also included. The test results showed the engine performance to be very stable. This engine exhibited stable torque output in a wide range of speed. The engine torque varied from 563.4 to 572.5 N-m in a speed range of 1100rpm to 1900rpm. The torque curve remained almost the same before and after the durability test. Standard deviations of torque at all speeds were under 2.5%, as shown in Figure 3. This indicated that the utilization of B8 biodiesel had little influence on engine torque and durability performance.

Figure 4 shows the variations in fuel consumption during the durability test. The same conclusions as those for the engine performance test were drawn. Fuel consumptions varied very little for all the speeds both before and after durability test. Standard deviations in fuel consumption were under 2.5%.

In summary, no deterioration was observed for B8 biodiesel after 1000 hours of durability testing. Both engine performance and fuel consumption remained the same before and after the durability test. The deviations were under 3% for all the tests conducted in this study.

Regulatory Emissions

The regulated pollutants emitted by diesel vehicles include carbon monoxide (CO), total unburned hydrocarbons (THC), nitrogen oxides (NOx) and particulate matter (PM). The diesel emissions measured during the durability test are shown in Figure 5. The emissions were measured under the ETC testing procedure. The measured values of CO and THC are fairly low: CO is 7%, and THC was 1% of the current Taiwan emission standard set by the Taiwan EPA in 2007, which is equivalent to Euro IV. However, NOX was 71%, and PM was 47% of the emission standard. No obvious trends in variations for all regulated emissions could be observed from the test results. It seems that use of B8 biodiesel does not deteriorate engine emissions after 1000 hours of durability testing. The engine emissions meet the Euro IV emission standard for all the tests conducted in this study.

Linear least square fitting was used to calculate the deterioration factor (DF) of the emissions. If the calculated value of the DF is under 1, this means that the emission of the pollutant does not deteriorate at all, and the DF is set as 1.0. The DFs of the regulated emissions are shown in Table 3. It can be seen that the emission of CO exhibits a negative slope after the durability test. Its DF was set as 1.00. The DFs are near 1 for both NOX and PM, which means that the engine and the SCR system worked normally and did not deteriorate. Only the emission of THC exhibits a mild positive slope. However, the THC emission factor for this engine is only 1% of the emission standard. Even with a 33% increase in THC after 1000 hours of durability testing, its value was still much lower than the standard.
Non-Regulatory Emissions

Fine particulate matter (PM$_{2.5}$) is not regulated in the current emission standard. However, PM$_{2.5}$ is an important issue that has gained more and more public concern due to the adverse health effects associated with it, especially lung cancer. The emission factor of PM$_{2.5}$ was also evaluated in this paper. Moreover, particulate number (PN) is also not one of the regulated emissions for diesel engines. It is only regulated for cylinder direct injection gasoline vehicles at the present time. However, since fine particles will be the focus of emission regulation in the future, and particulate number is more closely related to fine particles than particulate weight, the characteristics of particulate number for biodiesel are also investigated in this study.

No standard procedure for PM$_{2.5}$ measurement for diesel engine is available at the present time. The PM$_{2.5}$ was therefore measured using the system shown in Figure 1.

The PM$_{2.5}$ emission factors are shown in Table 4. The table indicates that the PM$_{2.5}$ emission increases gradually in the first 500 hours, and a jump can be observed in the last 500 hours during the durability test, just like PM. However, the PM$_{2.5}$/PM ratio does not remain constant, showing that the deterioration of PM$_{2.5}$ is not the same as that of PM. However, no solid conclusion can be drawn at the present time because very few data are available. Further investigation on the deterioration of fine particulates in diesel engines is needed in the future.

<table>
<thead>
<tr>
<th>Stage</th>
<th>PM2.5 Emission Factor (g/kW-h)</th>
<th>PM2.5/PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 hr</td>
<td>0.0125</td>
<td>89.9</td>
</tr>
<tr>
<td>500 hr</td>
<td>0.0127</td>
<td>89.4</td>
</tr>
<tr>
<td>750 hr</td>
<td>0.0150</td>
<td>99.3</td>
</tr>
<tr>
<td>1000 hr</td>
<td>0.0144</td>
<td>98.6</td>
</tr>
</tbody>
</table>

It has been reported that the amount of particulates in diesel engines will increase when a high percentage of bio diesel fuel is used. This is because the heating value of bio fuel is lower than that of fossil fuel. More fuel must be injected to maintain the same engine output, which will result in more particles in the engine exhaust [14]. In addition, Di et al. also found that the particle size will decrease as more bio diesel fuel is blended with traditional diesel [15].

Table 5 presents the variations in the PN measurements that occurred during the durability test. We can see that the PN emission increases steadily during the durability test, unlike the results shown in Figure 6, where the variations in the increase rate of PM and PM$_{2.5}$ differs in the first 500 hours and the last 500 hours. The deterioration factor of PN is much higher than that of PM and PM$_{2.5}$, indicating that the mechanism to generate fine particles may have changed after the durability test because PN is more closely related to very fine particles. Since PN is not regulated for diesel engines, very little data are available for comparison to validate the trend found in this paper. Further investigation is thus needed.

Engine Components Wear Analysis

It has been reported that biodiesel contains some trace elements that will result in deposition on the nozzles of injectors [16–19]. For example, Kaneko found that if biodiesel contains 1 ppm zinc, the amount of fuel injection will be reduced by 10% after 108 hours of running due to deposition on the nozzle tip [20]. In addition, the moisture content of biodiesel will cause corrosion of metal parts inside the engine cylinder. In this paper, the needle tip of injector and the nozzle orifice were examined to locate any corrosion problems after the durability test.

It also has been reported that the atomization of biodiesel fuel after injection is impaired because of its higher viscosity [21–23]. The fuel droplets impinged on the cylinder wall will be scraped out by the piston ring and diluted lubrication oil, which will result in scratches on the piston rings and liner. For example, a study conducted by Thornton et al. revealed that lubricating oil was diluted 5–10% for B20 fuel equipped with a NAC system after running for 50–150 hours. As a result, the piston ring was also examined in this paper to check the durability performance of biodiesel fuel [24].

There are three rings in the piston of a diesel engine, two compression rings and one oil ring, to prevent air leakage from the clearance between the piston and the cylinder wall. To conduct a detailed inspection of the wear on the piston rings, the piston rings were cut into appropriate sizes and examined using a Field-Emission Scanning Electron Microscope (FESEM) after the durability tests to identify the wear characteristics. Figure 7 shows the FESEM pictures for the piston ring on the surface that had direct contact with the cylinder liner. The pictures are magnified 500 times. There is wear on the first ring that was due to abrasive wear and surface fatigue. On the second ring, there is carbon deposition on the contact surface that was caused by the partial oxidation of the fuel. However, the contact
surface of the third piston ring is very smooth, and there is no obvious wear trace on the surface, indicating that the surfaces were protected well by the oil film between the surfaces of the piston ring and the liner. It can therefore be concluded that the wear loss after 1000 hours of testing was not serious on the surface.

![Figure 7. Piston Ring Wear](image)

The appearance of the nozzle tip observed using SEM is shown in Figure 8. A total of eight holes are located around the tip, and three of them can be observed clearly in the figure. Each hole is surrounded by carbon deposits that were the result of incomplete combustion. A more clear view of the hole can be observed in Figure 8(b). The unburned carbon deposits were located around the hole, but the hole was not blocked at all. Its shape remained very sharp after 1000 hours of durability testing. This indicated that the carbon blockage in the nozzle after 1000 hours of testing was not serious for B8 biodiesel.

![Figure 8. Microscopic Analysis of Injection Nozzle after Durability Testing](image)

**SCR Catalyst Analysis**

Since the emission standards for diesel vehicles are becoming more and more stringent, especially in the case of NOX, the Urea-Selective Catalytic Reduction (SCR) system has become standard equipment for modern diesel vehicles to reduce NOX emissions. The principle of SCR is a chemical reaction that converts NH3 and NOX into N2 and H2O. However, NH3 is toxic and difficult to transport or store, so more stable and harmless urea has been utilized to replace NH3 in vehicle applications for many years. In this study, the performance of the SCR system was checked every 250 hours during the 1000 hours of durability testing to determine the deterioration of the system. The test was conducted using the ESC procedure. The NOX emissions were measured before and after the use of the catalyst with the Horiba MEXA 7500 direct emission analyzer. The NOX emissions before and after the introduction of the catalyst were used to determine the conversion efficiency of SCR, and the variations in the conversion efficiency during the durability test were used to evaluate the deterioration of the catalyst equipped on the testing engine fueled with B8 biodiesel. The exhaust temperature variations under the ESC testing procedure are given in Figure 10. Since NOX conversion efficiency is closely related to exhaust temperature, it was expected that conversion efficiency would be different at different testing points.
Figure 11 shows the results for the catalyst conversion efficiency at different operating points. Measurements were carried out for every 250 hours of testing. The overall conversion efficiency varied in the range 65~95% except in mode 1, in which the exhaust temperature was lower than 180 °C. Mode 11 exhibited relatively low conversion efficiency because its temperature was the lowest if mode 1 was not included. An examination of the relationship between conversion efficiency and exhaust temperature revealed 200°C as the minimum requirement for the SCR system to work efficiently.

There was no consistent trend for the variations in the conversion efficiency at each mode during the 1000 hour durability test. For example, the conversion efficiency was increasing at mode 11. However, it was decreasing in mode 3. The average conversion efficiency was obtained by multiplying the conversion efficiency at each mode with a weighting factor that was defined by the ESC procedure. Figure 12 shows variations in the average conversion efficiency of about 80% during the durability test. It can be seen that no obvious deterioration of the SCR catalyst occurred during the 1000 hours of durability testing.

Figure 10. Emission Conversion Efficiency of SCR Catalyst Related to Exhaust Temperature

In this experiment, biodiesel containing excess phosphorus (9.14,7mg/kg) was used in the diesel engine equipped with a SCR system, which met the EURO IV emission standard. The influence of NOX and PM was evaluated after 1000 hours of durability testing. The results showed that biodiesel containing phosphorus has an obvious influence from NOX. Phosphorus caused the active decrease of the catalyst. [25]

In order to determine the decay velocity of catalyst activation fueled with B8 biodiesel, an analysis of the SCR catalyst using EDS was conducted. Energy-dispersive X-ray spectroscopy (EDS, EDX, or XEDS) is an analytical technique used for the elemental analysis or chemical characterization of a sample. In this study, a small piece of catalyst was detached after the durability test. This piece was analyzed with EDS to find any impurities in the biodiesel. The EDS showed the fuel products with B8 biodiesel on the catalyst, and it indicated whether they had caused deposits or contaminated it. Carbon deposits will cause choking, and magnesium will form a sulfate, which decreases the adsorption capability of a catalyst. Figure 13 shows the spectrum of the catalyst from the EDS analysis, and Table 6 shows the catalyst elements that indicate that the carbon and magnesium increased slightly and that no phosphorus was detected. Titanium Dioxide(TiO2) to be the carrying layer of carrier of cordierite and Vanadium pentoxide(V2O5). Silicon and Tungsten (W) are the additives of the Vanadium catalyst used to enhance the reaction temperature range of the catalyst. The EDS result shows that the differences in values should be due to the sample point detection instead of the influence of biodiesel.

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Table 6. Composition of Particle Ratio after Durability Test

<table>
<thead>
<tr>
<th>Element (%)</th>
<th>C</th>
<th>O</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>Ti</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Durability</td>
<td>3.0</td>
<td>55.9</td>
<td>--</td>
<td>Micro scale</td>
<td>5.1</td>
<td>30.3</td>
<td>5.4</td>
</tr>
<tr>
<td>After Durability</td>
<td>5.8</td>
<td>65.6</td>
<td>5.4</td>
<td>9.3</td>
<td>12.2</td>
<td>1.7</td>
<td>--</td>
</tr>
</tbody>
</table>
The conclusions obtained in this work indicate the influence of B8 biodiesel. The conclusions are detailed as follows:

With respect to the engine emission and performance, B8 biodiesel, which was blended with 92% fossil diesel and 8% biodiesel complied with CNS 15072, had slight effects on the exhaust emission under the durability test. The changes in engine performance and fuel consumption were less than 3%.

After the durability test, the DFs were near 1 for NOX and PM, which means that the engine and the SCR system worked normally and did not deteriorate. The PM emissions indicated the deterioration factor of PN to be much higher than that of PM and PM2.5, indicating that the mechanism to generate fine particles may have changed after the durability test.

After the durability test, for the full-load operation, B8 biodiesel did not have any obvious influence on the sizes of the engine components. From the microscopic observation, the wear behavior of the piston ring as well as the needle valve of the engine using B8 biodiesel also exhibited no obvious difference.

No heavy metal deposits or contaminated catalyst were found, and NOX averaged a conversion efficiency of about 80% at each 250 hour check, which indicated there was no deterioration of the SCR catalyst after the durability test using B8 biodiesel.

REFERENCES


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**DEFINITIONS/ABBREVIATIONS**

CMM - Coordinate Measuring Machine
CNS - Chinese National Standard
ESC - European Stationary Cycle
ETC - European Transient Cycle
NAC - NOx Absorber catalysts
NRTC - Non-Road Transient Cycles
PPO - Pure Plant Oil
SCR - Selective Catalytic Reduction
SD - Standard Deviation
SMPS - Sequential Mobility Particle Sizer
EDS - Energy-dispersive X-ray spectroscopy

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