

The Impact Upon Durability of Heavy-Duty Diesel Engine Using 5 Percentage Biodiesel

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ABSTRACT

Due to the increasing price of crude oil, biofuel as an alternative of fossil fuels is sought to be a global wide solution to reduce the emission of green house gas. In order to compare the influence on engine which meet euro IV emission standard by using pure fossil diesel, 2% and 5% biodiesel. A long-term operation with blended 2% and 5% biodiesel by standard engine test had been evaluated in this study. The results could be referred to the consideration of marketing promotion strategy as well as government policy in Taiwan. Both B2 B5 diesel fuel (2 and 5 vol% biodiesel) and diesel fuel were employed to the same engines for testing purpose to compare the influence. The engines were equipped with an electronically controlled common-rail fuel injection system. After 500 hours full load durability operation, the key components of the engines were analyzed and characterized by a series of inspections to identify the degree of decay and wear behavior. In addition, the engine performance which by the test procedure for SAE J1995 and emission measured which by the test procedure for FTP transient cycle were also determined at each maintenance stage. In this study, oil characteristics after durability test had also been evaluated. The results indicated that the engine components including piston rings, cylinder liners and needle valves of injector were less difference in dimensions comparison before and after durability tests. The fuel supply system of the diesel engine consists of a fuel tank, fuel pipes, fuel filters, and a low pressure pump had also been evaluated. According to microscopic characterization and engine oil analyses, the wear loss of the key components was insignificant and tribological performance of the B5 biodiesel was slightly better than that of diesel fuel. It was found that the performance and emissions were varied under $\pm 3\%$ when diesel engine was fueled with B5 biodiesel.

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INTRODUCTION

The biofuel used in diesel engines is mostly produced from animal fats or vegetable oils via transesterification process. The last decade has seen growing importance placed on research in application of biodiesel field. The advantages of biodiesel have been widely discussed, compared with fossil diesel, biodiesel produces lower engine emissions of carbon monoxide (CO), hydrocarbons (HC), particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), and carbon dioxide (CO₂), which significantly reduce the impact of greenhouse effect on the earth [1,2,3]. Biodiesel is composed of methyl esters and has higher oxygen content, about 11% of total composition, lower emission of the particles and CO during the burning process. Besides, pure biodiesel contains almost no sulfur and it is renewable energy to be one of solutions in oil market and reducing impact on economy [4].

Most researches found that the fretting wear performance of biodiesel was better than that of diesel fuel. The engine oil,

used in a compression ignition engine fueled with linseed oil methyl ester (LOME) for durability test, has been analyzed by atomic absorption spectroscopy (AAS). The results showed that the wear debris of metal in the engine oils was significant decreased than that with the traditional diesel fuel. Moreover, according to the dimensions difference of the engine component before and after durability test, the difference in dimensions of engine component test with biodiesel is smaller than that with traditional diesel. These results imply that biodiesel can reduce the wear of engine components [5,6,7]. However, some researches indicated that biodiesel could cause more wear on some engine components and affect engine operation. S. Kaul et al. presented the study of using nonedible oils for corrosion tests. It soaked the diesel engine components in four kinds of oils chronically. Only salvadora oil caused dramatically corrosion on engine components. It is attributed to the high content of sulfur while the others had the same results as that of petro-diesel [8].

Japanese Automobile Manufacturers Association (JAMA) also pointed out that using biodiesel over a long period of time possibly caused negative influence on vehicles. For instance, the components of common-rail system may tend to wear, which caused poor atomizing during injection period and unexpectedly engine burning. Biodiesel may also corrode fuel tank and pipes for long-term operation [9].

In June 2007, Taiwan government has legislated CNS 15072 as national biodiesel standard and CNS 1471 which allowed blends up to 5% of fatty acid methyl ester (FAME) in diesel fuel. B1 biodiesel has been widely used in Taiwan from July 2008. Furthermore, the biodiesel percentage has been increased to B2 in market from 2010 to achieve the goal of at least one hundred million liters of biodiesel used for each year. In Taiwan, the next step of biodiesel policy will upgrade to B5 in 2016. In order to confirm the influence of nationally-made biodiesel on vehicle, the effects on engine components, including cylinders, piston rings, needle valves, pistons and fuel injection nozzles had been examined in this paper to explore the differences of wear with microscopic analysis. The compositions of carbon deposits in engines had been observed and the exhaust emissions, performance and fuel consumption of test engines had also been evaluated during durability tests.

EXPERIMENTAL METHODS

Three new diesel engines of the same type were used for durability tests. The engine equipped with common rail fuel injection system was a 2977 c.c. MITSUBISHI 4M42-4AT2 diesel engine which widely used as a commercial truck engine, complied with the environmental protection regulations in Taiwan. The basic specifications of the test engine are shown in Table 1. The test fuels complied with CNS 1471 (Chinese National Standards, CNS) were 100% diesel (D100), B2 biodiesel which was blended with 2 vol% biodiesel and 98 vol% diesel and B5 biodiesel which was blend with 5 vol% biodiesel and 95 vol% diesel. The biodiesel (B100) was made from waste cooking oils by local manufacturers in Taiwan and complied with the biodiesel standard CNS 15072 which worked out based on EN 14214.

Table 1. Test engine specifications

Item	Specification
Engine Type	MITSUBISHI 4M42-4AT2
Displacement	2977 c.c.
Rated Power	92.0 kW/3200rpm
Rated Torque	294 Nm/1700rpm
Cylinders	In-line 4 Cylinder/4 Stroke
Compression Ratio	17 : 1
Fuel System	Common Rail (Direct Injection)
Injection Pressure	1600 bar max.
Nozzle	Hole
Air Intake System	Turbocharged with intercooler
Emission Control System	DOC, PCV, EGR

The properties of biodiesel are different from fossil diesel fuel, such as cetane index and viscosity are higher, lower content of sulfur so it would not increase the sulfur content after blending, as well as aromatic hydrocarbon. The lubricity of engine can be improved with adequate amount of biodiesel. Table 2 shows the properties of the test fuels and it indicated that except the lubricity, the difference between B5, B2 and D100 can be neglected.

Table 2. Fuel properties

Test item	Engine 1-D100	Engine 2-B2	Engine 3-B5	Unit	Test method	CNS 1471
Cetane index	52	52	55	—	CNS 12761	48 min.
Density, 15°C	0.8455	0.8461	0.8441	g/mL	CNS 14474	report
Copper strip corrosion (3hr at 50 °C)	1a	1a	1a	rating	CNS 1219	No.1
Flash point	76.0	75.0	75.5	°C	CNS 3574	52 min.
Kinematic viscosity, 40°C	3.522	3.512	3.504	cSt	CNS 3390	2.0-4.5
Carbon residue (on 10% distillation residue)	<0.1	<0.1	<0.1	% (m/m)	CNS 14477	0.3 max.
Distillation, IBP	203.0	201.7	207.7	°C	CNS 1218	
Distillation, T95	349.6	348.2	354.4	°C	CNS 1218	360°C max.
Distillation, FBP	354.4	352.3	356.8	°C	CNS 1218	
Ash	<0.001	0.001	0.001	% (m/m)	CNS 3576	0.01 max.
Sulfur content	23	23	24	ppm	CNS 14505	50 max.
Polyaromatics content	3.72	4.52	5.89	% (m/m)	CNS 15079	11 max.
Lubricity, corrected wear scar diameter (1.4 wsd, 60°C)	509	228	307	μm	CNS 15074	460 max.
Fatty acid methyl ester content	-	2.03	5.0	% (v/v)	CNS 15057	5 max.
Water and sediment	0	-	0	% (v/v)	CNS 14766	0.05 max.
Water content	135	162	95	ppm	CNS 4446	200 max.
Total contaminant	0.3	0.5	1.19	ppm	CNS 15055	24 max.
Pour point*	-6	-6	-6	°C	CNS 14667	-3 max.
Cold filtration plug point (CFPP)*	-3	-2	-1	°C	CNS 15061	-3 max.
Oxidation stability, 110°C	0.3714	0.4714	1.32	g/m3	CNS 15078	25 max.
Heating value	10975	10963	10948	kcal/kg	ASTM D240	—

* Diesel fuel blended with fatty acid methyl ester must conform to at least one of the above requirements.

The equipment of engine exhaust emission laboratory and the sampling system of engine exhaust of this study is shown in Figure 1, including AC Motor Engine Dynamometer, Exhaust Analysis, Full Flow Dilution Sampling System.

Direct Sampling System, Particle Matter Sampling System, etc, to conduct the durability tests and the examination of the amount of exhaust emission. The examination equipment and sampling systems of engine exhaust are described as the followings.

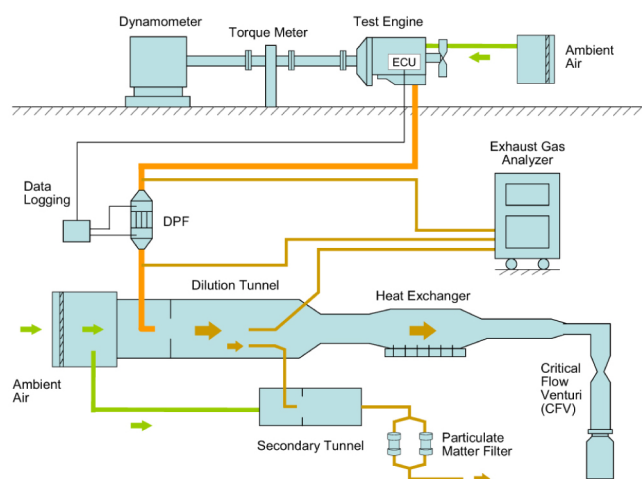


Figure 1. Schematic of Equipments of Engine Test Lab.

This experiment used the SCHENCK MP-DYNAS 335 AC motor engine dynamometer and specifications are 800N.m maximum within 8000rpm. The engine dynamometer reaction rate of positive torque and negative torque is less than one second; it can effectively conduct EU ETC and EU ESC test cycle.

The durability test with full-load operation was performed in the present of study. At each maintenance stage (125hr or 250hr), the engine performance was determined using SAE J1995 test method and the measurement of emission was conducted by engine dynamometer under US FTP transient cycle. Table 3 shows the test methods in this study. Figure 2 is the running mode of full-load operation for durability test, where each cycle takes 2 hours and is repeated for 500 hours [10].

HORIBA CVS 9400T was the sampling equipment and HORIBA MEXA 7500D was exhaust emission analysis instrument has been used in this study.

As for the wear of engine components in detailed inspection, the 3D coordinate measuring machine (CMM), profile meter and other measuring rigs were used to measure the dimension of specific parts and calculate the dimension variation for each component before and after durability tests. After the tests, the engine components were cut into appropriate dimensions and characterized by Field-Emission Scanning Electron Microscope (FESEM) to identify the wear characteristics of each part of the components. In addition, the test methods of CNS standard were also employed to probe into the change of the composition in the engine oils and fuel hoses to interpret the difference on the wear of components.

Table 3. Test methods of engine operation and components

Item	Engine1-D100	Engine2-B2	Engine3-B5
Durability operation	Full loading 500hour		
Emission test cycle	FTP Transient Cycle		
Engine performance	SAE J1995		
Wear of Engine Components	Dimension, microscopic observation (Cylinder liner, piston ring, needle valve)		
Carbon Deposits	Weight, composition, microscopic observation(Piston, nozzle)		
Engine Oils	Replaced oil during maintenance period (CNS test method)		
Fuel Supply System	Fuel tank, fuel pipe, filter, rubber hose (CNS test method)		

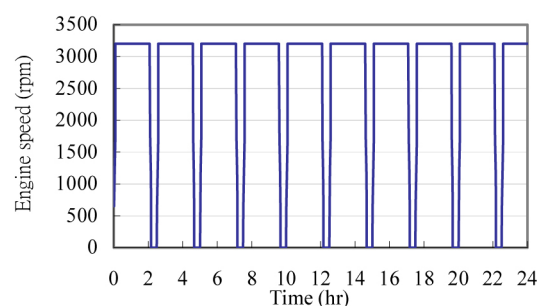


Figure 2. Full-load operating procedure for engine durability test

RESULTS AND DISCUSSION

Wear on Engine Components

The wear analysis of the diesel engine components, including cylinders, piston rings, and needle valves were accomplished as shown in following sections. The dimension variation for the specific positions and detailed cut view on worn components were examined.

Cylinder

For engine operation, the friction mainly loss was between the piston ring and cylinder. The cylinders are made of cast iron with acceptable damping ability which is one of the best materials used to make cylinder walls. Table 4 is the change of average measurement values for the diameter (Dy) in the impinging direction, side diameter (Dx), and overall change of average diameter (D0) of the cylinder in all test conditions. In general, after the engines run for a long-term operation, the surface of the cylinder will be worn and the material will be lost. However, the durability test results (see Table 4) depicted a significant reduction in Dy of the engine due to burning substances and reactants in the oil adhered to the impact surface or the contrast surface. Meanwhile, the