

Effects of Hydrotreated Vegetable Oil (HVO) as Renewable Diesel Fuel on Combustion and Exhaust Emissions in Diesel Engine

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ABSTRACT

The effects of Hydrotreated vegetable oil (HVO) on combustion and emission characteristics in a diesel engine were investigated by using spray analyzer, engine dynamometer and vehicle tests. Spray analysis showed that spray characteristics was virtually the same for HVO and diesel. From the results of the engine dynamometer and the vehicle tests, it was found that the high cetane number and the zero aromatics of HVO could reduce in HC and PM emissions. Moreover, as a result of optimized engine calcification, HVO is capable of improving partial fuel consumption and full-load torque. These results indicate that HVO has beneficial fuel characteristics for diesel engine.

INTRODUCTION

From the viewpoint of curbing global warming, it is essential to introduce and expanded the use of powertrains that emit low green house gas emission. Diesel engines have been expected to be a promising candidate because of higher thermal efficiency over gasoline engines. However, the emission reductions from diesel engines remain an issue to be solved. In recent years, biofuels have attracted attention because of their potential to decrease criteria air pollutants from diesel vehicles, lower carbon dioxide (CO₂) emissions, and improve energy security.

Fatty acid methyl ester (FAME) is made by a transesterification process that converts vegetable oils such as rapeseed oil into ester type biodiesel fuel. Recently, in many countries, diesel fuel is being mixed with FAME. However unsaturated FAMEs such as rapeseed methyl ester (RME) or soy methyl ester (SME) adversely affect oxidation stability [1]. A high concentration of FAME in diesel fuel might cause problems in vehicle fuel systems if fuel quality cannot be secured. Therefore, it is generally recommended

that only low-concentration (B5-B7) FAME blends should be used as automotive fuels.

Hydrotreated vegetable oil (HVO) is made by a refinery-based process that converts vegetable oils and animal fat into paraffinic hydrocarbons. HVO do not contain unsaturated compounds because it basically a mixture of normal- and iso-paraffins. Consequently, the oxidation stability of HVO is better than that of FAME [2]. Additionally, HVO is considered as a possible alternative to diesel fuel because it contains no sulfur or aromatics and it has a high cetane number.

Currently, the use of FAME and HVO has been criticized because these fuels can be produced also from feedstock suitable for human consumption. However, next-generation biofuels can be produced from agricultural and forestry residues, as well as from algae and microbial oil. These alternative feedstocks are being researched and are not yet available in commercial quantities.

In contrast, HVO supplies are projected increase around the world in the future. For example, Neste oil announced they will supply 198,000 tons per year by 2011. Therefore, it is essential that to evaluate the effects of the properties of HVO on combustion and exhaust emissions in a diesel engine.

Although there are reports of HVO improving combustion and emissions properties in engines and vehicles [3-9], the effects of its particular fuel properties on combustion and emissions are not fully clear. Therefore, in order to clarify the influence of each fuel characteristic on combustion and exhaust emissions, testing in this study was conducted using spray analyzer, engine dynamometer and vehicle tests.

TEST FUEL PROPERTIES

Table 1 shows the properties of the HVO test fuel and the reference diesel fuel. All investigations in this paper were conducted with NExBTL, which is a hydrotreated vegetable oil made by Neste Oil. NExBTL is being used in a number of actual vehicle field trials in Europe and is also being commercialized in Finland in blends with conventional diesel. The main differences between HVO and diesel fuel are described below.

Table 1 Test Fuel Properties

	Unit	HVO (NExBTL)	Diesel fuel
Viscosity (40°C)	mm ² /s	2.99	2.68
Density (15°C)	kg/m ³	779.9	835.7
Heating value	MJ/kg	43.7	42.9
Cetane number	-	88.2*	53
Aromatics	vol%	0	19.7
Paraffin	vol%	100	-
Sulfur	ppm	3	6
H/C ratio	-	2.14	1.88
Cloud point	°C	-12	-14

* As obtained by ignition quality tester

Viscosity and Density

The higher viscosity and lower density of HVO can adverse effect on fuel spray by worsening atomization and causing an insufficient fuel quantity. Although one report has described the spray characteristics of HVO [5], these results used a simulated comparison based on calculations. It will be necessary to examine the actual effect of HVO on injection spray.

In addition, the heating value of HVO is 5% lower per volume than diesel under normal temperatures and pressures. Consequently, HVO fuel injected at full load has a lower heating value than diesel, which might cause a decrease in torque.

Cetane Number

According to results obtained by an ignition quality tester, the cetane number of HVO is 88. Its high ignition quality has the potential of decreasing unburned hydrocarbons (HC) and partly burned carbon monoxide (CO). Since the cetane number of HVO is higher than that of GTL, HC and CO emission of HVO may be less than that of GTL.

Aromatics

The content of aromatic compounds is an essential parameter for diesel combustion. As aromatics play important role in the soot formation. While conventional diesel fuel has an aromatic content of 19.7%, HVO has zero aromatics. This means that HVO have the potential to lower smoke and PM.

Distillation Characteristics

Since the cloud point of HVO is the same as diesel, its cold flow properties are not a concern. However, it was found that HVO has fewer low-boiling components since it contains more substances that distillate between approximately 260 and 300°C (Fig. 1). This means that HVO can mainly be obtained by hydrotreating vegetable oils. Since HVO consists of n- and iso-paraffin, its components are more unequally distributed than diesel (Fig. 2). Fewer low-boiling components can worsen fuel spray and evaporation characteristics when the engine is started in low temperatures, which could have an adverse effect on vehicle startability.

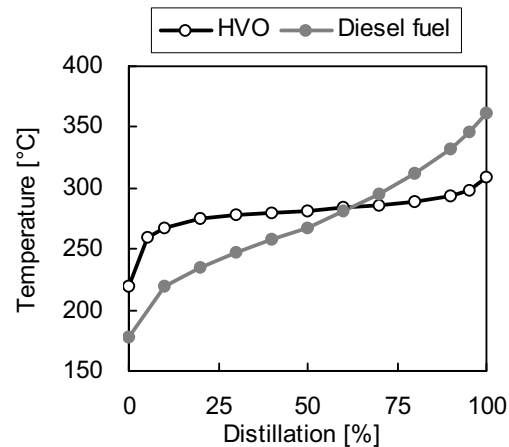


Figure 1 Distillation Curves of Test Fuels

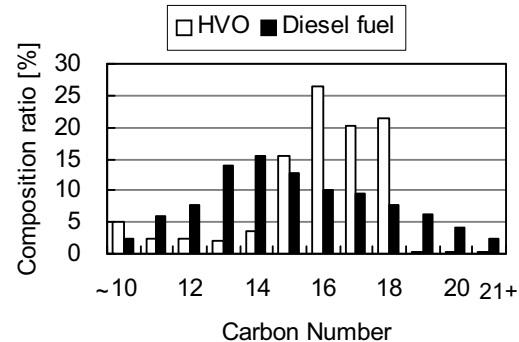


Figure 2 Comparison of Number Distribution in Fuel

TEST ENGINE AND VEHICLE SPECIFICATIONS

TEST ENGINE

Figure 3 shows the engine system used in the engine dynamometer tests, and Table 2 lists the engine specifications. The base engine used in the research was an inline 4-cylinder direct injection turbocharged diesel engine with a common rail fuel injection system.

VEHICLE

To investigate the effects of the HVO fuel, vehicle emissions tests were conducted on a chassis dynamometer. Table 3 shows the specifications of the vehicle.

the vehicle used in the test. The test vehicle was a production model passenger car with a six-speed manual transmission and the inertial weight of 1590 kg. The engine had the same specifications as those used for the engine dynamometer tests. The vehicle was not equipped any aftertreatment system. The emissions of the test vehicle were measured under the New European Driving Cycle (NEDC) (Fig. 4).

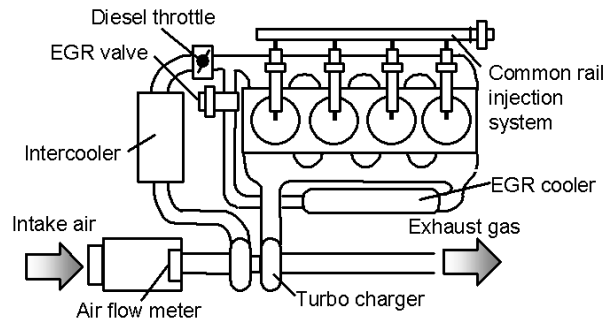


Figure 3 Test Engine System

Table 2 Test Engine Specifications

Engine type	Inline 4-cylinder
Displacement	2231 cm ³
Bore × stroke	86.0 × 96.0 mm
Compression ratio	15.8:1
Fuel injection system	Common rail
Aspiration	Turbocharged intercooled

Table 3 Test Vehicle Specifications

Vehicle type	Passenger car
Transmission	6-speed manual
Inertial weight	1,590 kg
Aftertreatment	None

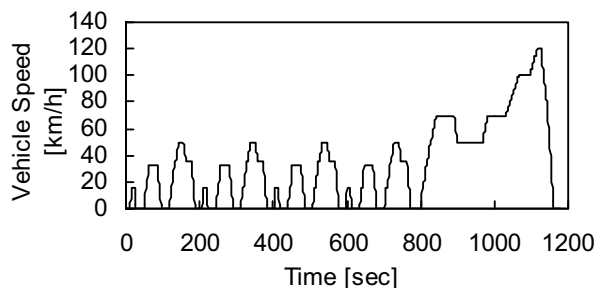


Figure 4 New European Driving Cycle

COMPARISON OF HVO AND DIESEL FUEL CHARACTERISTICS IN CONVENTIONAL DIESEL ENGINE

EFFECT OF VISCOSITY AND DENSITY ON FUEL SPRAY

Fuel Spray Characteristics using Spray Analyzer

The apparatus shown in Fig. 5 was used to study the effects of the properties of HVO on the fuel spray. Experimental conditions are shown in table 4. The injection quantity was set to be corresponding to the main fuel injection under combustion and emission tests. Ambient gas pressure was set to engine internal gas density when fuel injection starts. Table 5 shows the specifications of the injector used to study the spray. The same injector specifications as the test engine were adopted and the fuel was injected through a single nozzle hole when the droplet size distribution was evaluated.

As a result, it was found that the penetration, droplet size (Sauter mean diameter), and spray angle were virtually the same for the HVO and diesel fuel sprays (Fig. 6). In addition, as shown by the images in Fig. 7, no major differences were found between the sprays in terms of diffusion.

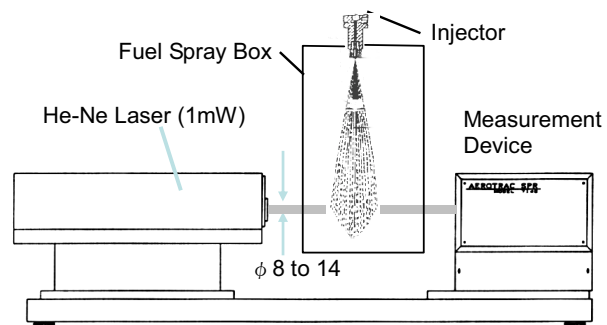


Figure 5 Laser Diffraction Spray Analyzer

Table 4 Experimental Conditions

Injection quantity	15 mm ³ /st
Displacement injection pressure	50 MPa
Fuel temperature	40 °C
Ambient pressure for spray imaging	0.85 MPa (CO ₂)
Ambient gas temperature for spray imaging	300 K (room temperature)

Table 5 Specifications of Injector for Studying Fuel Spray

Nozzle hole diameter	0.12 mm
Number of nozzle holes	10
Nozzle length	0.8 mm
Oil flow	895 cm ³ /min
Cone angle	154.5 deg.

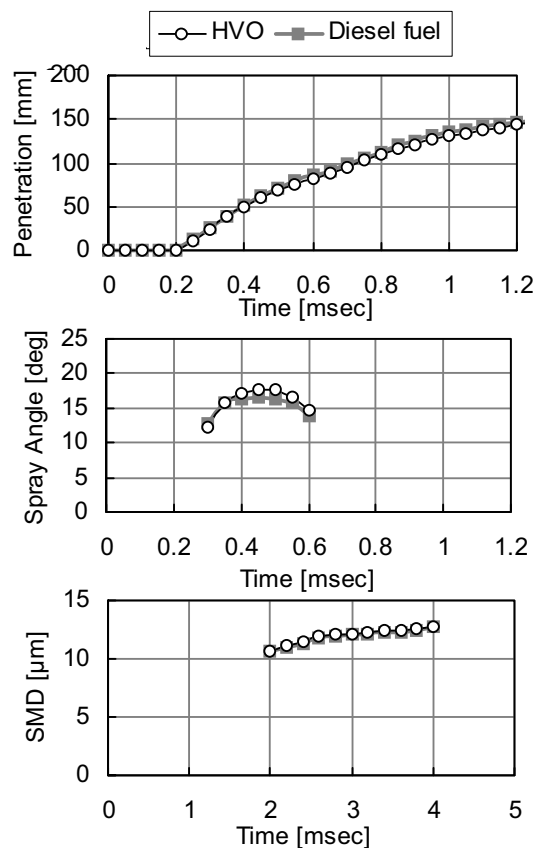


Figure 6 Comparison of Fuel Spray Performance

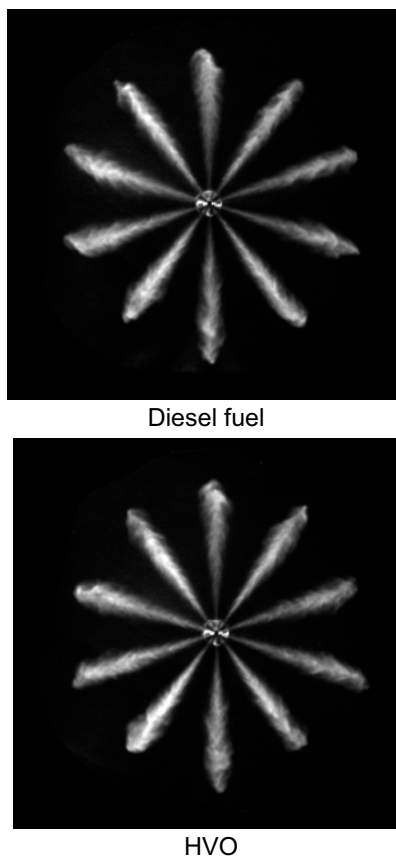


Figure 7 Comparison of Fuel Spray (1 ms after Spray Start)

Full Load Performance in Engine Dynamometer Tests

The volumetric heating value of HVO is 5% lower than diesel, creating a concern that torque might decrease at full load. Consequently, the test engine described in Fig. 3 and Table 2 was used to compare full load performance with HVO and diesel injection set to the same indicated value.

It was found that the same torque and the same brake specific energy consumption (BSEC) could be obtained with HVO even at the same indicated value of injection duration as diesel fuel (Fig. 8). As described below, this is because, the injection quantity of HVO increases and the same heating value is obtained. These results show that, despite its lower volumetric heating value, HVO does not result in lower torque in full load operation.

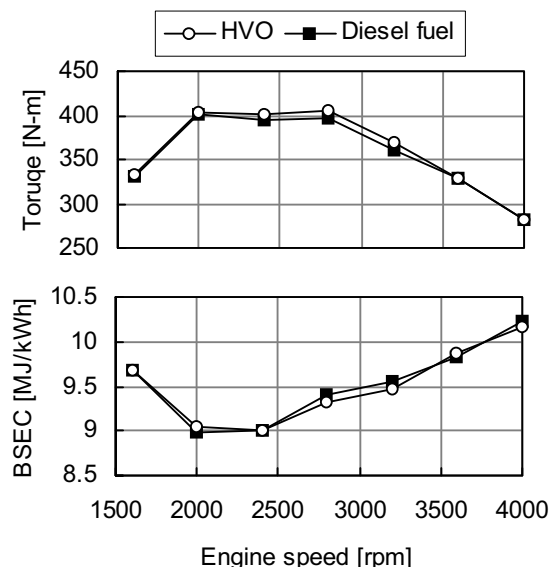


Figure 8 Comparison of Full Load Performance

Injection Quantity in Engine Dynamometer Tests

The relationship between the indicated and actual injection quantities was compared for HVO and diesel fuel using the test engine described in Fig. 3 and Table 2. A constant engine speed of 2000 rpm was used in the test, with single fuel injection and an injection pressure of 120 MPa. Actual injection quantity was measured by fuel consumption meter.

When the injection quantity was varied under these conditions, the injection amount of HVO was approximately 5% higher than diesel even when the indicated injection quantity was the same as with diesel fuel (Fig. 9). Figure 10 shows energy consumption (= fuel consumption x heating value). It was found that HVO and diesel had roughly the same energy consumption. The same trend was found when small quantities were injected to simulate pilot injection.