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Effect of waste cooking oil biodiesel on the emissions of a diesel engine

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Abstract

This paper is focused on investigating the gaseous and particulate emissions of a 4-cylinder natural-aspirated direct-injection diesel engine fueled with different mixed concentrations of biodiesel and diesel fuel, including pure diesel fuel, B10 (diesel containing 10%vol of biodiesel), B20, B30 and pure biodiesel. Experiments were conducted with five engine loads, corresponding to brake mean effective pressures of 0.165, 0.33, 0.496, 0.661 and 0.753MPa at a constant speed of 1800rpm. The results show that biodiesel leads to reduction of HC, CO and particulate mass concentrations and number concentrations but an increase in NO_x. In addition, particulate samples were collected from the diluted exhaust and analyzed using thermogravimetric analyzer/differential scanning calorimetry (TGA/DSC). The TGA results show that with increasing biodiesel in the fuel or decreasing engine load, the volatile mass fraction of the particulate increases and the ignition temperature of the soot decreases.

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Keywords: biodiesel, diesel engine, emission, oxidation

Introduction

Increasing energy consumption and environmental deterioration drive human to finding out alternatives fuels for replacing petroleum fuels, especially for replacing diesel fuel which is widely used by commercial vehicles. Biodiesel is one of the alternative fuels for diesel engines due to its renewability, potential of reducing greenhouse gas emissions, and inhibition of PAH and soot formation [1]. Since biodiesel has many similarities to diesel fuel, it can be directly used in diesel engine without any modification. Biodiesel, consisting of alkyl monoesters of fatty acids, can be derived from vegetable oil or animal fats. There is increasing interest in applying biodiesel converted from waste cooking oil for its lower cost and added advantage of reducing waste oil disposal [2]. Significant amount of research has been carried out on the combustion and emission characteristics of diesel engines fueled with biodiesel/diesel blends [3-5]. However, very few [6-8] have been carried out on quantifying the internal nanostructure and oxidation of biodiesel soot or biodiesel/diesel blends soot, especially using waste cooking oil biodiesel.

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As a result, the aim of this investigation is to study the effect of diesel blended with different proportions of biodiesel from waste cooking oil on the emission of a diesel engine. Regulated gaseous emissions and particle size distribution and particulate mass concentration were investigated under five engine loads at a constant engine speed of 1800rpm. For further understanding to the effect of biodiesel on the soot oxidation properties, particulate samples were collected from the diluted exhaust and analyzed using thermogravimetric analyzer/differential scanning calorimetry (TGA/DSC).

Experimental approach

Experiments were carried out on a 4-cyclinder natural-aspirated direct-injection diesel engine fueled with different mixed concentrations of biodiesel and diesel fuel, including pure diesel fuel, B10 (diesel containing 10%vol of biodiesel), B20, B30 and pure biodiesel. The biodiesel used in present study was manufactured from waste cooking oil by Dynamic Progress Ltd., complying with EN14214. Table 1 gives the specifications of the engine and the main properties of pure biodiesel and diesel.

Table 1. Engine specifications and main properties of pure biodiesel and diesel fuel.

Mode	Isuzu 4HF1	Property	Biodiesel	Diesel
Type	In-line 4-cylinder	Low heating value (MJ/kg)	37.5	42.5
Maximum power	88 kW/3200 rev/min	Cetane number	51	52
Maximum touque	285 Nm/1800 rev/min	Density (kg/m^3 at 20 ^{o}C)	871	840
Bore × stroke	112 mm × 110 mm	Viscosity (mPa s at 40 ^{o}C)	4.6	2.4
Displacement	4334/cc	Carbon content (% wt)	77.1	86.6
Compression ratio	19.0:1	Oxygen content (% wt)	10.8	0
Injection pump type	Bosch in-line type	Hydrogen content (% wt)	12.1	13.4
Injection nozzle	Hole type (with 5 orifices)	Sulfur content (mg/kg)	<10	<10

The engine was operated under five engine loads, corresponding to brake mean effective pressures of 0.165, 0.33, 0.496, 0.661 and 0.753MPa at a constant speed of 1800rpm. The regulated emissions were measured using gas analyzers, which were calibrated with standard gases and zero gas before each experiment. HC was measured with heated flame ionization detector (HFID), NOx was measured with heated chemiluminicent analyzer (HCLA) and CO/CO_2 were measured with non-dispersive infra-red analyzers (NDIR). Particulate size distribution and number concentration was measured with a scanning mobility particle sizer (SMPS, TSI, Inc) and particulate mass concentration was measured with a tapered element oscillating microbalance (R&P TEOM 1105). After the exhaust gas temperature, the cooling water temperature and the lubricating oil temperature attained steady-state values, experimental data were collected. All gas concentrations and particulate mass concentration were continuously recorded for more than 5 minutes and the average results were presented in this paper. Each experiment was repeated twice and the results were found to agree with each other at 95% confidence level. Additionally, the oxidation properties was analysed with TGA/DSC following the procedures described in [9].

3. Results and discussions

3.1 gaseous emission

The regulated gaseous emissions including total hydrocarbon (THC), carbon monoxide (CO) and nitrogen oxide (NO_x) were measured and compared when the engine was fuelled with various test fuels at different engine loads. It is observed that the addition of biodiesel would lead to the decrease of THC and CO but an increase of NOx. The results are similar to those reported in the literature and hence not presented in details in this paper.

3.2 particulate mass concentration and size-number distribution

The particulate mass concentration and size-number distribution are important characteristics for particle generated from the diesel engine. Although results from TEOM or SMPS were measured with the diluted exhaust gas, the results multiplied with the corresponding dilution ratio were presented. Figure 1(a) shows the effect of biodiesel on the particulate mass concentration (PMC). Obviously, there is higher PMC at higher engine load, in which more fuel is injected into the cylinder. And the biodiesel addition can decrease the PMC because the oxygen content in biodiesel can promote the combustion, especially for the higher engine load, while biodiesel content reduces the diesel aromatics which are soot precursors.

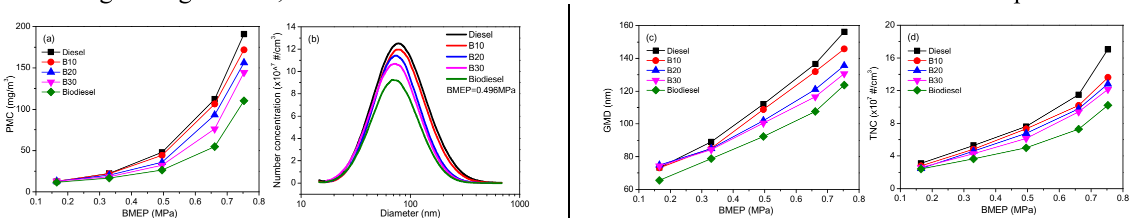

Figure 1. Effect of biodiesel on (a) PMC, (b) particulate size-number distribution, (c) GMD and (d) TNC

The SMPS was set to measure particles within the size range of 15 to 750nm. Figure 1(b) gives a typical trend of particulate size-number distribution at the BMEP of 0.496MPa. Clearly, there are fewer number of particles in all sizes when using biodiesel. Figure 1(c) and 1(d) present the geometric mean diameter (GMD) and total number concentration (TNC) for all test conditions. As expected, biodiesel addition leads to smaller GMD and decrease in TNC because of less soot nuclei formed and more complete combustion compared to diesel fuel.

3.3 Oxidation characteristics

TGA/DSC was applied to find out the volatility fraction and oxidation properties of the particles generated from the diesel engine fueled with pure diesel, B30 and pure biodiesel at the five engine loads. The typical mass loss curves and the derivative of DSC signal of the three fuels at the engine load of 0.661MPa are shown in Figure 2(a) and (b) respectively. In Fig. 2(a), two obvious decreases of each curve can be recognized: one occurs at the temperature of 200-300°C and the other one occurs at the temperature between 400 and 700°C, which respectively is mainly cause by the loss of the volatile substance and the oxidation of the non-volatile substance. The temperature-history of derivative of DSC signal shows a sudden decrease in the temperature range from 500-700°C depending on the test fuel. The temperature corresponding to the peak of this curve with the maximum rate of mass loss and heat release is defined as the ignition temperature (T_i).

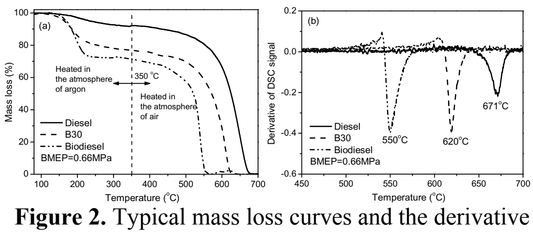

Figure 2. Typical mass loss curves and the derivative of DSC signal.

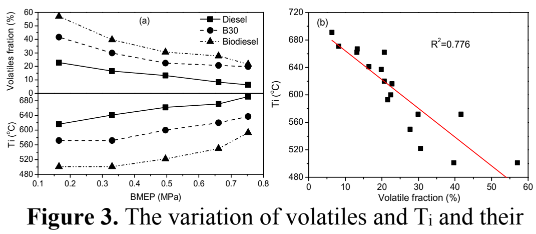

Figure 3. The variation of volatiles and T_i and their relationship.

The variation of volatiles fraction and T_i for each fuel with the engine load is shown in Figure 3(a). It can be seen that the volatile mass fraction of the particulate increases with increasing biodiesel in the fuel or decreasing engine load. It is because more organic compounds are contained in WCO biodiesel and turned into the volatile substances during the in-cylinder combustion. Moreover, the oxygen in biodiesel would lead to the generation of more oxygenated compounds, which are usually the volatiles. And the higher engine load leads to higher in-cylinder temperature, providing sufficient heat to oxidize the volatiles. It is also seen that the ignition temperature of the soot decreases with increasing biodiesel in the fuel or decreasing engine load. The ignition temperature has a strong relationship with the volatile substances because although the volatile substances are removed before the commencement of soot oxidation, it promotes the development of porosity and provides more internal surface area for oxidation. Figure 3(b) gives the relationship between the ignition temperature and volatile fraction in particulate samples and the R-square can be up to 0.776. Furthermore, the soot oxidative reactivity or ignition temperature is closely related to the nanostructure including the size, orientation and organization of the graphene layers. As pointed out by Lu et al. [9], amorphous soot particles with disordered nanostructure are easily generated at lower engine load. The more amorphous soot structure could enhance the rate of soot oxidation [10]. As a result, soot particles collected from lower engine load can be easier burn off and hence has a lower ignition temperature.

4. Conclusions

The effect of biodiesel addition on the regulated emissions, particulate number size distribution and mass concentration, as well as the particulate oxidation characteristics have been studied at five engine loads at a constant engine speed of 1800rpm. Generally, biodiesel leads to a reduction of HC, CO and particulate mass concentrations and particle number concentrations but an increase in NO_x. Moreover, particulate soot generated from biodiesel has more volatiles and is easier to be burned off than diesel soot.

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