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Experimental investigation on regulated and unregulated emissions of a diesel engine fueled with ultra-low sulfur diesel fuel blended with biodiesel from waste cooking oil

Yage Di[a,b], *C.S. Cheung*[b,*], *Zuohua Huang*[a]

[a]*State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiao tong University, Xi'an 710049, PR China*
[b]*Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, PR China*

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ABSTRACT

Experiments were conducted on a 4-cylinder direct-injection diesel engine using ultra-low sulfur diesel, bi oesel and their blends, to investigate the regulated and unregulated emissions of the engine under five engine loads at an engine speed of 1800 rev/min. Blended fuels containing 19.6%, 39.4%, 59.4% and 79.6% by volume of biodiesel, corresponding to 2%, 4%, 6% and 8% by mass of oxygen in the blended fuel, were used. Biodiesel used in this study was converted from waste cooking oil.

The following results are obtained with an increase of biodiesel in the fuel. The brake specific fuel consumption and the brake thermal efficiency increase. The HC and CO emissions decrease while NO_x and NO_2 emissions increase. The smoke opacity and particulate mass concentrations reduce significantly at high engine load. In addition, for submicron particles, the geometry mean diameter of the particles becomes smaller while the total number concentration increases. For the unregulated gaseous emissions, generally, the emissions of formaldehyde, 1,3-butadiene, toluene, xylene decrease, however, acetaldehyde and benzene emissions increase.

The results indicate that the combination of ultra-low sulfur diesel and biodiesel from waste cooking oil gives similar results to those in the literature using higher sulfur diesel fuels and biodiesel from other sources.

1. Introduction

Biofuels such as alcohols and biodiesel have been proposed as alternatives for diesel engines (Agarwal, 2007; Demirbas, 2007; Ribeiro et al., 2007). In particular, biodiesel has received wide attention as a replacement for diesel fuel because it is biodegradable, nontoxic and can significantly reduce toxic emissions and overall life cycle emission of CO_2 from the engine when burned as a fuel (Cvengroš and Považanec, 1996; USEPA, 2002). Moreover, it can be used as a blended fuel in diesel engines without modification to the engines. Biodiesel is made by the transesterification of their feedstock (Ma and Hanna, 1999) or transesterification of waste cooking oil (Kulkarni and Dalai, 2006). There are increasing interest in applying biodiesel converted from waste cooking oil for its lower cost and added advantage of reducing waste oil disposal (Wang et al., 2007; Canakci, 2007). This is particularly important currently when the diesel fuel price is rising and becoming even more expensive than biodiesel.

Significant amount of research has been carried out on the combustion and emission characteristics of diesel engines fueled with diesel–biodiesel blends. Choi et al. (1997) reported

* *Corresponding author*. Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hong Kong. Tel.: +852 2766 7819; fax: +852 2365 4703.
E-mail address: mmcsc@polyu.edu.hk (C.S. Cheung).

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that the biodiesel has an advance of injection timing due to its lower compressibility, which may lead to the higher cylinder pressure and temperature (Leung et al., 2006). The variation of the physico-chemical properties of diesel–biodiesel fuel blends has been discussed in Ribeiro et al. (2007). Lapuerta et al. (2008b) conducted an extensive review on the effect of biodiesel fuels on diesel engine emissions. They found that in most of the investigations, HC, CO, smoke and particulate emissions are reduced. However, there is a slight increase in NO_x emission. The emission of aromatic and polyaromatic compounds as well as their toxic and mutagenic effect has been generally considered to be reduced with biodiesel. However, there is no conclusive trend in the emissions of oxygenated compounds such as aldehydes and ketones.

Biodiesel from waste cooking oil is a more economical source of the fuel. Kulkarni and Dalai (2006) concluded that the engine performance of biodiesel obtained from waste cooking oil is better than that of diesel fuel while the emissions produced by the use of biodiesel are less than those using diesel fuels except that there is an increase in NO_x. Lapuerta et al. (2008c) tested two different biodiesel fuels obtained from waste cooking oils with different previous uses on diesel particulate emissions. They found no important differences in emissions between the two tested biodiesel fuels.

Prior emissions studies were focused mainly on regulated pollutant emissions while a limited number have included unregulated emissions, such as formaldehyde, acetaldehyde, 1,3-butadiene, benzene, toluene and xylene (BTX). There are even less literatures available on the characteristics of regulated and unregulated emissions of a diesel engine fueled with biodiesel blended with ultra-low sulfur diesel (ULSD). In some previous work, the fuel sulfur content was not specified (Pang et al., 2006; Correa and Arbilla, 2008) while in other cases, the sulfur content was much higher (Turrio-Baldassarri et al., 2004; Lapuerta et al. 2008c). ULSD fuel is becoming more and more popular in application to diesel vehicles, thus further work on regulated and unregulated emissions using ULSD blended with biodiesel is required. Furthermore in view of the lack of energy resources, further research on the use of biodiesel from waste cooking oil will promote its application to in-use diesel engines. The aim of this investigation is therefore to study the regulated and unregulated emissions of a diesel engine fueled with ULSD blended with different proportions of biodiesel from waste cooking oil. The engine performance, regulated and unregulated gaseous emissions, particle size distribution and particulate mass concentration were investigated under five engine loads at an engine speed of 1800 rev/min.

2. Test engine and fuel properties

Experiments were carried out on a naturally-aspirated, water-cooled, 4-cylinder direct-injection diesel engine. Specifications of the engine are shown in Table 1. The engine was coupled with an eddy-current dynamometer. A control system is available for adjusting the engine speed and torque.

The fuels used in this study include ULSD and biodiesel. The major properties of ULSD, biodiesel and their blends are shown in Table 2. Biodiesel used in the present study was manufactured from waste cooking oil, with methanol, by Dunwell Petro-Chemical Ltd. The four blended fuels were designed to have oxygen concentrations of 2%, 4%, 6% and 8%. The volumetric concentration of each blended fuel was determined for the desired oxygen concentration. The lower heating value of each blended fuel was calculated based on the mass fraction of each chemical in the blended fuel.

Table 1 – Engine specifications

Model	Isuzu 4HF1
Type	In-line 4-cylinder
Maximum power	88 kW/3200 rev/min
Maximum torque	285 Nm/1800 rev/min
Bore × stroke	112 mm × 110 mm
Displacement	4334/cc
Compression ratio	19.0:1
Fuel injection timing (BTDC)	8°
Injection pump type	Bosch in-line type
Injection nozzle	Hole type (with 5 orifices)

3. Experimental setup, equipments and procedure

Fig. 1 shows the schematic of the experimental system. T_1 and T_2 are thermocouples which measure the inlet air temperature and the exhaust gas temperature. The measuring instruments used in this study are given in Table 3. The gaseous species in the engine exhaust were measured on a continuous basis. The gas analyzers for measuring regulated gases were calibrated with standard gases and zero gas before each experiment. Unregulated gases including benzene, toluene, xylene, formaldehyde, acetaldehyde and 1,3-butadene were measured with the Airsense multi-component gas analyzer. The analyzer is an Ion Molecule Reaction (IMR) mass spectrometer, which allows dynamic studies of gaseous emission in low concentration. The detection principle of the instrument is based on the analysis of the molecular weight of the gas species. The instrument uses electron ionization to create a primary ion beam of mercury, xenon or krypton. Sample gas is introduced to a high vacuum chamber and transformed by the primary ion beam into ions that are subsequently mass selected by electromagnetic fields and counted in a particle counter. Further information about the instrument and the calibration can be found in Villinger et al. (1993), Villinger et al. (1996) and Dearth (1999). The gas sample was taken directly from the engine exhaust and maintained at 190 °C to the multi-component gas analyzer. In this study, benzene, toluene, formaldehyde were calibrated directly using their respective standard gases, while the other unregulated gases were calibrated through an indirect way based on information provided by the equipment supplier. Particulates in the engine exhaust were measured with a scanning mobility particle sizer (SMPS) for size distribution and number concentration and a tapered element oscillating microbalance (TEOM) for particulate mass concentration. The exhaust gas from the engine was diluted with a Dekati mini-diluter before passing through the SMPS and the TEOM. For each test, the volumetric flow rate of fuel was measured and then converted into the mass consumption rate based on the density of the fuel.