Fuel 208 (2017) 168–173

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Particulate matter and unregulated emissions of diesel engine fueled with 2-methylfuran diesel blends

Helin Xiao, Ru Wang, Pengfei Zeng, Ao Jiang, Beibei Hou, Shengbing Yang *

Hubei Key Laboratory of Advanced Technology for Automotive Component, Wuhan University of Technology, 122 Luoshi Road, Wuhan 430070, China
Hubei Collaborative Innovation Center for Automotive Components Technology, Wuhan University of Technology, Wuhan 430070, China

A R T I C L E I N F O

Article history:
Received 2 March 2017
Received in revised form 29 April 2017
Accepted 27 June 2017
Available online 12 July 2017

Keywords:
2-Methylfuran
DICI engine
Unregulated emissions
Particulate matter

A B S T R A C T

2-Methylfuran (MF), an environmental-friendly biofuel, has drawn extensive attention from fuel researchers. In this study, the particulate matter (PM) and unregulated emissions of diesel engine were investigated. All experiments were performed in a direct injection compression ignition (DICI) engine fueled with diesel–MF blends (10%, 20% and 30% mass fractions of MF were blended with diesel). The test conditions were a constant speed of 1800 rpm and load from 0.13 to 1.13 MPa brake mean effective pressure (BMEP). Among the tested fuels, the emissions of 1,3-butadiene, benzene and acetaldehyde are all decreased with the increase of engine load except benzene of M30 at 1.13 load. In addition, the diesel–MF blends promote acetaldehyde emissions, but reduce benzene and 1,3-butadiene emissions. At the engine load of 0.38 MPa BMEP, with the increase of MF fraction in blends, more particle numbers for both nucleation mode and accumulation mode are yielded than pure diesel. At 0.88 and 1.13 MPa BMEP, with the increment of MF ratio in blend fuels, the particle numbers rise at small diameter of particle (Dp) (5–10 nm) compared to pure diesel, but decline at large diameter of particle (Dp) (10–250 nm). The increment of MF blending ratio increases the particulate number concentration. Moreover, with the rise of MF mass fraction in the mixtures, the particulate mass concentration decreases gradually at above 0.63 MPa BMEP. However, particulate mass concentration of M30 is the highest at lower loads.

1. Introduction

Diesel engine is extensively used in transportation and power generation sectors due to the excellence in combustion efficiency, reliability, adaptability and cost-effectiveness, however, there are also major concerns such as energy shortage, greenhouse gas and environmental pollutions [1–3]. In order to reduce the dependence on fossil fuels and to restrict PM emissions, biofuel has been explored in some recent studies [4–7]. In Europe, the promotion of biofuel has led to legislation [8] and it is generally accepted that there is a good prospect for the blending of biofuels and fossil fuels in the fuel market.

2-Methylfuran (MF) as an environmental-friendly biofuel has made breakthrough in its mass-production methods [9–12]. Compared with bioethanol (Table 1), the most widely-used biofuel in internal combustion engines, MF has some significant advantages, such as higher energy density, stable storage, and lower energy consumption in production. MF also has ideal physicochemical properties, some are shown in Table 1. Recently, there are several studies about the combustion and emission characteristics of MF in internal combustion engines. Wei et al. [13] probed into the burning and emission performances of MF gasoline mixtures in a spark-ignition engine and found low MF-gasoline blends with shorter combustion duration and higher brake torque were competitive to ethanol gasoline blends. However, the diesel-MF blends emit more NOx emission, which is mainly attributed to the high oxygen content from MF [14]. Thewes et al. [15] first experimentally studied the spray formation and evaporation as well as combustion performance of MF and found MF was a prominent biofuel alternative with short combustion duration and high combustion stability in combustion, especially under cold conditions. More recently, we studied the combustion and regulated emission of MF-diesel blends in a direct injection compression ignition (DICI) engine and found the soot emissions from diesel-MF blend are significantly reduced compared to pure diesel [12]. All the studies indicate that MF is well compatible with the existing combustion systems and is a promising alternative biofuel.

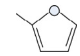
One major drawback of diesel engine is the heavy PM emissions, which are related to environment and health problems, the PM emissions are likely formed during the rich diffusion-controlled

* Corresponding author at: Wuhan University of Technology, 122 Luoshi Road, Wuhan, Hubei 430070, China.

E-mail address: hlxiao_qcxy@whut.edu.cn (S. Yang).

http://dx.doi.org/10.1016/j.fuel.2017.06.118
0016-2361/

Table 1
Properties of diesel, bioethanol, MF and gasoline.

Parameters	Diesel	Bioethanol	MF	Gasoline
Chemical formula	C_{12}-C_{25}	C_2H_6O		C_4-C_{12}
Research Octane number	20–30	109	103	96.8
Motor Octane number	–	90	86	85.7
Octane number	–	108	–	90–99
Cetane number	52.1	8	–	10–15
Oxygen content (%)	0	34.78	19.51	0
Stoichiometric air/fuel ratio	14.3	8.95	10.05	14.7
Density at 20 °C (kg/cm^3)	826	790.9	913.2	744.6
Water solubility (wt%,20 °C)	N	Miscible	N	N
Latent heating (kJ/kg) at 25 °C	270–301	919.6	358	373
Lower heating value (MJ/kg)	42.5	26.9	31.2	42.9
Initial boiling point (°C)	180–370	78.4	64.7	32.8
Auto-ignition temperature (°C)	180–220	434	–	420

Note: N – Negligible.

combustion, due to under-mixing, poor spray evaporation and wall wetting [16,17]. The existing research on engine PM emissions is focused on particle numbers and size distributions [18–21]. The diesel particles, which are mainly at the scale of submicron in size [22,23], spread rapidly in the air and could be breathed by humans [24,25]. Daniel et al. [26] compared the combustion and emissions among MF, 2,5-dimethyfuran, gasoline and ethanol in a DISI engine and found lower PM number and smaller mean diameter in nucleation mode of MF than gasoline. According to the authors' previous study, it revealed that MF was a promising alternative fuel to diesel engine in reducing soot emissions.

Meanwhile, unregulated engine emissions from diesel engine would lead to severe health effects on humans, such as cough, dizziness, irregular heartbeat, drowsiness, headache, sore throat, and breath shortage [27]. In addition, PM also causes damage to respiratory organs [28]. To our knowledge, there is rare comprehensive characterization of unregulated emissions from MF-diesel fuels.

The high octane number of pure MF largely restricts its compressed ignition in a DICI engine. Thus, we blended diesel with different mass fractions of MF and investigated the unregulated emissions and PM emissions. We expected to uncover how MF blending and engine loading affected particulate emissions and unregulated emissions.

2. Experimental setup and procedure

2.1. Engine and instrumentation

The four-cylinder and four-stroke, water-cooled, DICI engine equipped with a common rail fuel injection system used here is illustrated in Fig. 1. An eddy current (EC) dynamometer was added to adjust the speed and torque output of the engine. An electrical control unit (ECU) controlling the engine working parameters was coordinated on manager software. The specification of the engine is showed in Table 2. The pressure and temperature (20 ± 0.5 °C) of the intake air were controlled by a supernumerary compressor and an air conditioning system, respectively. We first warmed the engine up to a steady condition, ensuring the reliability and reproducibility of all test data, and then used a temperature controller to maintain the lubricating oil and coolant at 85 ± 1 °C.

The concentrations of unregulated emissions of 1,3-butadiene, acetaldehyde and benzene were measured by gas chromatograph (GC) with accuracy of 0.1 ppm. The particle size distribution function (PSDF) and particle number concentration were detected by a DMS500 differential mobility spectrometer. The combustion differential mobility spectrometer has 5% uncertainty in particle size measurement for particles smaller than 300 nm and 10% uncertainty for larger particles. Exhausts were transferred from the exhaust port along a long tube to sample bags for off-line measurement. The oil - water separator was used to dry the exhausts. In order to prevent the condensation of the exhausts on the interior wall of the sample bags, the measurement was carried out immediately after sampling.

2.2. Test fuels and experimental procedures

Conventional diesel (basic fuel) and MF (TZHL Biological Technology Co. Ltd, 99% purity) were used in this study. The basic fuel was blended with 10%, 20%, and 30% of MF (mass fraction), marked as M10, M20, and M30, respectively, and compared with pure diesel (M0).

The experimental conditions were: engine speed at 1800 rpm; load sweep increment at 20% and from 10% to 90%, forming the brake mean effective pressure (BMEP) of 0.13, 0.38, 0.63, 0.88 and 1.13 MPa. The injection timing was fixed at 7.5 crank angle (CA) before top dead center (BTDC) on the manager software ECU.

3. Results and discussion

3.1. Unregulated emissions

The unregulated emissions from the tested fuels were compared at varying loads and 1,3-butadiene, acetaldehyde and benzene were analyzed respectively in this study.

Fig. 2 presents the effect of MF addition on 1,3-butadiene emissions which can cause acute and chronic symptoms. It is obvious that the 1,3-butadiene emissions decline with the rise of engine load, which is similar to Takada et al. [29]. It is mainly attributed to the high combustion temperature of high engine load that improved the 1,3-butadiene oxidation, which helped to reduce 1,3-butadiene emission. Meanwhile, the 1,3-butadiene emissions from the test fuels decrease with the rise of MF mass fraction. High-oxygen MF was favorable for the improvement of combustion degree and further promoted the oxidation of 1,3- butadiene. In addition, the fraction of olefins has a great influence on the emission of 1, 3- butadiene [27]. Unlike diesel, MF has no hydrocarbon species with large fraction of olefin, which reduces the 1,3-butadiene emissions at the source for MF-diesel blends.

Fig. 3 compares acetaldehyde emissions which are carbonyl compounds commonly emitted from diesel engine. At 0.13-1.13 MPa BMEP, the acetaldehyde emissions of tested fuels are