Fuel 103 (2013) 730–735

Contents lists available at SciVerse ScienceDirect

Fuel

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

Combustion and emissions of 2,5-dimethylfuran addition on a diesel engine with low temperature combustion

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HIGHLIGHTS

- ▶ Differences of combustion and emissions for D40 and G40 are great for CI engine.
- ▶ When DMF fraction is up to 40%, the trade-off between NO_x and soot is solved.
- ▶ DMF or gasoline addition has little effects on CO and THC emissions.
- ▶ NO_x emissions increase for DMF-diesel blend.
- ▶ D40 may be a better fuel to meet future emissions regulations with medium EGR.

ARTICLE INFO

Article history:
Received 16 April 2012
Received in revised form 20 April 2012
Accepted 28 August 2012
Available online 27 September 2012

Keywords:
DMF
Low temperature combustion
Fuel property
Gasoline
Emissions

ABSTRACT

Biomass is the largest and most important renewable energy option at present. Because of similar physicochemical properties to gasoline and improved production methods, 2,5-dimethylfuran (DMF) has drawn extensive attention of global researchers. But currently, little investigations have been carried out on DMF as the engine fuel, especially on CI engines. In this paper, effects of DMF addition on combustion and emissions were investigated on a modified single cylinder heavy-duty diesel engine with low temperature combustion, and the characteristics of DMF and gasoline were compared specially. The results show that when DMF fraction is up to 40%, the trade-off relationship between NO_x and soot disappears and soot emissions are close to zero. DMF addition has little effects on CO and THC emissions. Although the physicochemical properties of DMF and gasoline are similar, due to the difference of ignition delay and DMF is oxygenated, it makes a great difference in combustion and emission characteristics.

1. Introduction

Due to high combustion efficiency, reliability, adaptability and cost-effectiveness, diesel engines are widely used in agriculture, transportation and industry, which contribute to today's major concerns of energy shortage and environmental pollutions. Advanced combustion techniques and the use of renewable fuels are promising ways to fulfill these challenges. Of renewable fuels for diesel, bio-fuels are important parts. Among the various kinds of bio-fuels, ethanol [1,2], methanol [3,4], biodiesel [5,6] and *n*-butanol [7,8] are the main representatives that are widely studied at the present. With deep research, more bio-fuels suitable for diesel are found, such as 2,5-dimethylfuran. Ethanol has long been considered as the gasoline alternative. But it is known that ethanol has some significant drawbacks in terms of combustion and emission performances, such as lower energy density, unstable storage. Compared to ethanol, DMF's physicochemical properties are more competitive. In the past, DMF did not draw extensive attention of researchers because of difficulty in preparation. Recently, significant breakthroughs have been made in production methods of DMF [9–11], which makes it possible to be widely applied as a main automotive fuel.

Before new production methods of DMF aforementioned, the study on DMF is mainly concentrated in pyrolysis [12,13] and low-pressure premixed laminar [14,15]. The world's first investigation on the use of DMF as a biofuel in the engine was carried out by Xu et al. [16,17]. Xu et al. compared the performance and emissions of DMF with commercial gasoline and bioethanol in a single-cylinder, spark-ignition (SI), GDI (gasoline direct-injection) engine at various engine loads. Results showed that because of similar physicochemical properties of DMF and gasoline, DMF exhibited very similar combustion and emissions characteristics to gasoline. Meanwhile, the experiments highlighted the competition DMF created with ethanol in replacing gasoline as a SI fuel. However, no publications can be found as diesel fuel with DMF.

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0016-2361/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2012.08.045

In recent years, low temperature combustion (LTC) has gained tremendous attention due to its benefits of low nitrogen oxides (NO_x) and particulate matter (PM) emissions [18–21]. Compared to traditional diesel combustion, LTC achieves simultaneous reduction of NO_x and PM emissions by suppressing combustion temperature and premixing fuel with the cylinder charge prior to ignition. For traditional diesel combustion, it is generally considered that increasing fuel cetane number is an effective way to decrease NO_x emissions and peak cylinder pressure. But for LTC with a large amount of exhaust gas recirculation (EGR), previous research [22–24] results showed that employing lower cetane number fuels could decrease PM and NO_x emissions and improve thermal efficiency. But researches are mainly with gasoline-diesel blends. Because of lower cetane number of DMF, diesel-DMF blended fuel is more suitable for LTC.

Currently, few researches are carried out with bio-fuels and no research with DMF-diesel blends about LTC. For CI engines, it is difficult to ignite using pure DMF or gasoline because of their higher octane number. Thus, Different volume fractions of DMF were blended into diesel fuel. In this paper, the study is focus on the effects of fuel properties and EGR on performance and emissions under both conventional and low temperature combustion mode with diesel, diesel-DMF blends and diesel–gasoline blends, as well as the comparison of combustion and emissions difference using DMF or gasoline on a CI engine. In the following sections, a brief description of the experimental setup and procedure is given in Section 2 and then the results of various text runs are presented in Section 3. Finally, major conclusions from this work are outlined in Section 4.

2. Experimental setup and methods

2.1. Engine and instrumentation

The experiments were performed on a modified single-cylinder, 4-valve, four-stroke, water-cooled, diesel engine equipped with a common rail fuel injection system, as shown in Fig. 1. Key specifications of the engine are summarized in Table 1.

The engine was coupled to a DC dynamometer to maintain a constant speed of 1400 rpm (±2 rpm) regardless of the engine torque output. The cylinder pressure was measured using a pressure sensor (Kistler 6125A) with corresponding charge amplifier and data acquisition system. The pressure data were taken every 0.2 crank angle degree and the reported data were the ensemble average of 100 consecutive engine cycles. To ensure the repeatability and comparability of the measurements, the cooling water temperature was automatically controlled by a temperature controller to 85 °C, and held with ±1 °C, while the lubricating oil temperature varied from 95 to 100 °C, depending on the engine load.

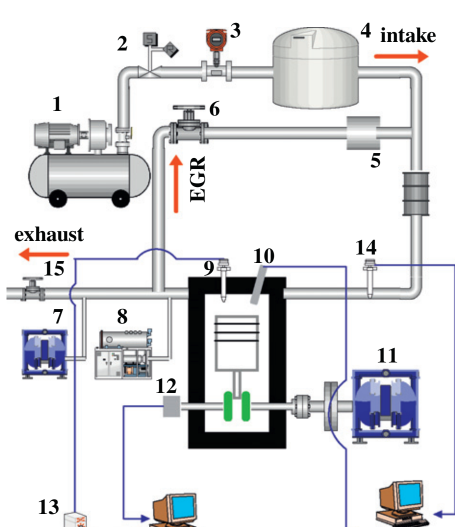

Fig. 1. Schematic of experimental setup. 1: Air compressor. 2: Three-way valve. 3: Flow meter. 4: air pressure stabilizer. 5: EGR cooler. 6: EGR valve. 7: Smoke meter. 8: Exhaust gas analyzer. 9: In-cylinder pressure transducer. 10: Injector. 11: Dynamometer. 12: Angle encoder. 13: Charge amplifier. 14: Oxygen concentration sensor. 15: Back pressure valve.

Table 1
Engine specifications.

Bore	105 mm
Stroke	125 mm
Connecting rode length	210 mm
Compression ratio	16.0:1
Displacement	1.081 L
Intake valve closure timing	−137 °CA ATDC
Number of nozzle holes	8
Included spray angle	155 °
Fuel injection system	Common rail
Injection pressure	1600 bar
Combustion chamber	Bowl in piston

Gaseous emissions were measured by a gas analyzer (HORIBA MEXA 7100DEGR), which measures THC by a method of hydrogen flame ionization (FID), CO and CO_2 by non-dispersive infra-red (NDIR) and NO_x using a chemiluminescent analyzer (CLA). Smoke was measured by an AVL 415S filter paper smoke meter. Then specific dry soot emission (g/kW h) can be calculated from filter smoke number (FSN) through the following formula [25]:

$$\text{Soot} = \frac{1}{0.405} * 5.32 * \text{FSN} * \exp^{0.3062 * \text{FSN}} * 0.001 * \frac{m_{\text{air}} + m_{\text{fuel}}}{1.2929} \quad (1)$$

The intake air to the engine was supplied using an external compressor and air conditioning system that made it possible to control the intake pressure and temperature. The intake temperature was kept 25 °C and intake pressure was kept 0.18 MPa. EGR rate was calculated by the concentration of carbon dioxide (CO_2) in intake and exhaust gas through the following formula:

$$\text{EGR}\% = \frac{(CO_2\%)_{\text{intake}}}{(CO_2\%)_{\text{exhaust}}} \times 100\% \quad (2)$$

2.2. Test fuels and experimental procedure

The test fuels used in this paper were diesel, DMF and gasoline. Table 2 shows the properties of the three fuels used in the study. Conventional diesel fuel was used as the base fuel. Mixtures of 20% and 40% by volume fraction of DMF with the base diesel fuel were tested in the research, referred to as D20 and D40, and 40% by volume fraction of gasoline as G40.The tested diesel and gasoline fuels are provided by China Petroleum and Chemical Cor-

Table 2
Properties of diesel, gasoline and DMF.

	Diesel	Gasoline	DMF
Molecular formula	C_{12}–C_{25}	C_2–C_{14}	C_6H_8O
Cetane number	52.1	13–17	–
H/C ratio	1.92	1.865	1.33
O/C ratio	–	35.1	0.17
Oxygen content (%)	–	117.7	16.67
Stoichiometric air/fuel ratio	14.3	14.56	10.72
Density at 20 °C (g/cm^3)	0.826	0.745	0.89
Lower heating value (MJ/kg)	42.5	43.5	33.7
Auto-ignition temperature (°C)	180–220	310	333
Latent heating (kJ/kg)	270–301	40–200	92–94