



Full Length Article

Combustion and emission characteristics of diesel engine fueled with 2,5-dimethylfuran and diesel blends



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HIGHLIGHTS

- Unregulated emissions and Particle size distribution were studied.
- At higher load, the PNC of diesel-DMF blends is higher than that of diesel.
- The blending with DMF increases the acetaldehyde emissions, but reduces the benzene and 1,3-butadiene emissions.
- At low loads, the combustions of D30 are unstable.

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ABSTRACT

Currently, worldwide interest has been triggered in the potential of 2,5-dimethylfuran (DMF) due to the discovery of improved production methods. However, the combustion and emission properties of DMF have been rarely characterized. Here we studied how the fuel properties and loads affected the combustion and emission of diesel-DMF blends or pure diesel in a four-cylinder direct-injection compression-ignition (DICI) engine. The experimental conditions were load from 0.13 to 1.13 MPa brake mean effective pressure (BMEP) and constant speed at 1800 rpm. We find at 0.38 MPa BMEP, the maximum heat release rate (HRR) rises and the peak cylinder pressure decreases both significantly with the increase of DMF mass fraction in the blends. However, at 0.63 MPa BMEP, the peak cylinder pressure and HRR both increased with the rise of DMF mass fraction. For each tested fuel, the emissions of 1,3-butadiene, benzene and acetaldehyde all declined with the increment of load. In addition, the DMF and diesel blending increased the acetaldehyde emission and reduced the benzene and 1,3-butadiene emissions. The nucleation mode greatly dominated the particle size distribution within the entire load range. The DMF and diesel blending tended to reduce particulate mass concentration and number concentration under most operating conditions. At 1.13 MPa BMEP, however, the DMF and diesel blending tended to increase particulate number concentration.

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1. Introduction

The oil shortage and global warming have made it urgent to revolutionize the energy supply networks, particularly in the transport field. Growing attention has been paid to the generation of fuels from renewable feedstock in the past ten years [1–4]. Among all well-studied biofuels, the most common fuel in SI engine is bioethanol due to its large octane number [5–8]. It is also used in diesel engines. In China, however, large-scale

popularization of the bioethanol is impossible due to the limitation of cultivated land areas and the huge population.

The development of fuel production technology has led to the discovery of numerous alternatives for diesel, such as 2,5-dimethylfuran (DMF). Recently, DMF production techniques have been significantly improved [9–11], which promotes it to widely replace diesel in compression ignition engines. For instance, the efficiency and yield in the fructose-to-DMF or biomass-to-liquid conversion were largely improved [12,13]. This concept was further developed and supported by the high-yield production of 5-hydroxymethylfurfural (HMF, an intermediate of DMF) independent on acid catalysts [10]. This method largely saves costs and uses glucose as a feedstock for HMF. Moreover, cellulose can be

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converted to furanic products [14]. All of these methods have promoted the application of DMF.

DMF has similar physiochemical properties as gasoline (Table 1) and some of the properties are more potential as an engine fuel. Firstly, the energy density of DMF is 40% higher than ethanol, which is approximately that of gasoline (within 8%) [15]. Secondly, the higher boiling point than ethanol reduces the volatility of DMF during transport [16]. Finally, due to the indissolubility in water, DMF does not absorb water from the air like ethanol, so it can be stably stored without causing contamination or being polluted by water in underground transport pipelines [17]. These properties render DMF a very promising alternative to gasoline.

The combustion and emission of DMF have been widely characterized [18–22]. Daniel et al. [23] examined the effects of spark timing and load on a DMF-fueled direct-injection spark-ignition (DISI) engine and found DMF had similar combustion and emission characteristics as gasoline. Daniel et al. [22] also examined the combustion performance of DMF blends in an SI engine and found DMF was very promising for the dual-injection system. However, the burning and emission of DMF in diesel engines have been rarely characterized. Zhang et al. [24,26] and Chen et al. [25] found DMF addition could effectively reduce soot emissions on the diesel engine.

Unregulated emissions would severely harm the health of humans and other living beings. Some of the unregulated emissions, even in minor quantities into the air, can induce major health problems in large sections of the affected population. There is much research on the regulated emissions of DMF, but rarely on the unregulated emissions of formaldehyde, acetaldehyde or benzene. Airborne particulate matter (PM) is also associated with several severe health hazards. Thus, we studied the combustion and unregulated emission characteristics as well as PM emission from diesel engine on different DMF and diesel blends compared with baseline diesel. The experimental conditions were constant engine speed of 1800 rpm and loads from 10% to 90% at an interval of 20%, corresponding to 0.13, 0.38, 0.63, 0.88 and 1.13 MPa BMEP, respectively.

2. Experimental systems and methods

2.1. Engine and instrumentation

A modified water-cooled four-cylinder and 4-stroke direct-injection compression-ignition (DIC) engine installed with a conventional rail fuel injection system (Fig. 1) was used here with

the specifications shown in Table 2. The engine was connected to an eddy current dynamometer, which kept the engine speed constant at 1800 ± 5 rpm and adjusted the torque output. To determine and monitor the desired engine parameters, the engine was modified with an Electrical Control Module (ECU) (provided by Cheng Du ELECK Company, China). The timing and mass of fuel injection were precisely regulated by an electrical control module (ECU). The injection timing was maintained constant at 7.5 crank angle (CA) before top dead center (BTDC) on the ECU manager.

A Kistler 6025C pressure transducer installed to the cylinder head wall detected the in-cylinder pressure. The signals were transferred first to a charge amplifier and then to a CB-466 combustion analyzer. A hundred consecutive cycles of samples were collected at an interval of 0.25 CAD so as the average the measurements. The temperature (25 ± 1 °C) and pressure of the intake air were controlled by an air conditioning system and an additional compressor, respectively. Coolant and oil were maintained by temperature controllers at 85 ± 1 °C, while the lubricating oil was stabilized at 87 ± 2 °C along with the loading. Temperatures were measured by K-type thermocouples.

Particle size distribution and particle number concentration (PNC) were measured by a DMS500 Combustion differential mobility spectrometer, which offered a number/size spectrum for the 4.87–1000 nm particle size. Various unregulated emission species were measured using a gas chromatograph (GC).


2.2. Test fuels

Diesel (the base fuel, China Petroleum & Chemical Corp.) and DMF (TZHL Biological Technology Co. Ltd., 99% purity) were used here. The blends of 0, 10% and 30% DMF with diesel (mass fraction) were referred to as D0, D10 and D30, respectively.

2.3. Experimental procedure

The engine was regarded as warm when the lubricating oil and coolant were kept at 87 and 85 °C, respectively. Other test conditions were speed at 1800 rpm, injection timing at 7.5° CA BTDC, and ambient air intake (25 ± 1 °C). Engine load was varied at a 20% interval from 10% to 90%, corresponding to 0.13, 0.38, 0.63, 0.88 and 1.13 MPa BMEP, respectively. After change to a new fuel, the engine was allowed to operate for 15 min prior to data collection, which purged the fuel supply system and ensured no residue

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

Parameters	Diesel	Bioethanol	DMF	Gasoline
Chemical formula	C ₁₂ –C ₂₅	C ₂ H ₆ O		C ₄ –C ₁₂
Research Octane number	20–30	109	101	96.8
Motor Octane number	–	90	88	85.7
Octane number	–	108	119	90–99
Cetane number	52.1	8	9	10–15
Oxygen content (%)	0	34.78	16.67	0
Stoichiometric air/fuel ratio	14.3	8.95	10.79	14.7
Density at 20 °C (kg/cm ³)	826	790.9	889.7	744.6
Water solubility (wt%, 20 °C)	N	Miscible	N	N
Energy density (MJ/L)	34.92	23	31.5	35
Latent heating (kJ/kg) at 25 °C	270–301	919.6	332	373
Lower heating value (MJ/kg)	42.5	26.9	33.7	42.9
Initial boiling point (°C)	180–370	78.4	92	32.8
Auto-ignition temperature (°C)	180–220	434	286	420

Note: N – Negligible.

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