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Study on combustion and emissions of a turbocharged compression ignition engine fueled with dimethyl ether and biodiesel blends

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ABSTRACT

In this study, combustion and emissions characteristics of a turbocharged compression ignition engine fueled with dimethyl ether (DME) and biodiesel blends are experimentally investigated. The effects of nozzle parameter on combustion and emissions are evaluated. The result shows that with the increase of DME proportion, ignition delay, the peak in-cylinder pressure, peak heat-release rate, peak in-cylinder temperature decrease, and their phases retard. Compared to the nozzle 6 × 0.40 mm, the peak cylinder pressure and peak heat-release rate are higher with nozzle 6 × 0.35 mm, and their phases are advanced. Increased DME proportion in fuel blends causes greater differences. Compared to biodiesel, NO_x emissions of blends significantly decrease; HC emissions and CO emissions increase slightly. DME–biodiesel blends can be used as an alternative in a turbocharged CI engine. To obtain low NO_x emissions and a soft engine operation, for high DME proportion blended fuels, nozzle of 6 × 0.40 mm adopted.

1. Introduction

Because of the challenge of increased vehicle population and environmental pollution, clean alternative fuels are becoming increasingly important. Both biodiesel and dimethyl ether (DME) are popular clean alternative fuels. Biodiesel is renewable, biodegradable and oxygenated. It can be used without any modification on engines, and contribute to green house gas emissions reduction, promote sustainable rural development. There are an increasing number of literatures to investigated combustion and emission characteristics of a compression ignition (CI) engine fueled with biodiesel. The results show that the use of pure biodiesel causes increased NO_x emissions when compared to conventional diesel [1–4]. The effects of biodiesel content on NO_x emissions have been studied. The results show that NO_x emissions increase with the increase in content of biodiesel [5–7]. The viscosities of biodiesel are higher than conventional diesel, which increases the tendency of the deposits formation, filters plugging, and deterioration of fuel spray atomization [8,9]. The characteristics of castor oil biodiesel are investigated, and the results show that castor oil biodiesel presents a viscosity higher than diesel, but this drawback can be corrected by means of blending with diesel [10].

DME has many advantages, such as high oxygen content, low boiling point and high cetane number. It is an excellent, efficient alternative fuel for a diesel engine. The studies show that the DME engine can achieve almost smoke-free combustion, lower combustion noise and nitrogen oxides (NO_x) emissions with a proper injection and combustion system [11–13]. The disadvantages of pure DME are low viscosity and combustion enthalpy. Its poor lubricity characteristics can cause intensified surface wear of moving parts within the fuel-injection system. The low calorific value means that a larger amount of fuel per cycle is injected to ensure the same engine power. There are many solutions to compensate for this problem, such as using larger diameter nozzle, and blending with other fuels. When biodiesel is dissolved in DME, the blended fuel has a higher energy density than the host liquid DME (the lower heating value of DME is approximate 70% of that of biodiesel in the test), and the lubricity is simultaneously improved. So the problems of DME and biodiesel to separate application can be solved by blending them.

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It is necessary to determine the solubility of DME and biodiesel blends. Used fried oil (UFO), palm methyl ester (PME) or palm oil is blended with DME, and the soluble state is examined. The blended fuel is held in room temperature, and the soluble state is examined for 12 h. The results show that DME is well soluble in UFO and PME in any blending ratio, and the soluble state can be maintained for at least 12 h. Meanwhile, palm/DME can only be used at a palm oil blend ratio of less than 25 wt% [14].

The spray characteristics of DME blended biodiesel are experimentally investigated. The results show that with the increase of DME blended ratio, the spray cone angle is enlarged. The spray area of the fuel is decreased according to the increase of the ambient pressure and DME blending ratio. The mixing ratio of DME blended biodiesel is a little influenced on the spray tip penetration compared to injection pressure [15].

The spray behaviors of biodiesel and DME are investigated using image processing and atomization performance analysis. The results show that the contour plot of the biodiesel and DME sprays show a high light intensity level in the center regions of the sprays. In addition, the atomization performance of the biodiesel spray is inferior to that of the DME spray at the same injection and ambient conditions [16].

The spray behavior and atomization characteristics of DME blended biodiesel are investigated. The results show that the blended fuel has almost the same droplet size as conventional diesel with the 50% by weight DME blending ratio. It is also shown that there exists an optimum injection pressure that has minimum droplet size when ambient pressure is constant. Droplet size becomes larger with an increase of ambient pressure [17,18].

In spite of many literatures to research the spray and atomization characteristics of biodiesel and DME [19,20], the combustion characteristics of a turbocharged CI engine fueled with DME–biodiesel blends are not available, especially the match of DME proportion with nozzle parameter. The aim of this work is to investigate the combustion and emissions characteristics of a turbocharged CI engine fueled with DME–biodiesel blends. The effects of DME proportion and nozzle parameter on combustion and emissions are evaluated.

2. Experimental apparatus

Experiments were conducted on a six-cylinder, direct injection turbocharged DME engine. The specification of turbocharged DME engine is given in Fig. 1 and Table 1, respectively. The fuel supply advance angle for the engine is 6° CA BTDC. The direct injection fuel system for DME–biodiesel consists of a fuel tank, a filter, a low-pressure supply pump, an injection pump, an injector, a pressure gauge and a relief. As DME has a high vapor pressure in the environmental situations, the low-pressure supply pump pressurizes DME or blend fuels at 1.6 MPa to prevent vapor lock in the fuel system. In-cylinder pressure is acquired with a type 6125A Kistler piezoelectric sensor and a type 5015A Kistler charge amplifier. Sampling frequency is 20 kHz. The pressure data of 50 consecutive cycles are sampled and recorded. NO_x, HC, and CO emissions are measured with an AVL CEB serials gas analyzer. The smoke opacity is measured using an AVL 439 opacimeter analyzer. The rate of heat release (ROHR) and the mean gas temperature are calculated using the first-law heat-release model. The consumption of DME is measured by an electronic scale.

The effects of DME proportion on combustion and emissions are investigated. The physic-chemical properties of DME and biodiesel (used fried oil) are shown in Table 2. The test fuel is DME100, DME70, DME50 and biodiesel, which include 100% DME, 70% DME, 50% DME and 100% biodiesel by weight respectively. The injector nozzles for DME and the blends are different from it for biodiesel due to the different physical and chemical properties. The injector nozzle 6 × 0.40 mm is adopted when the engine fueled with DME100, DME70 and DME50. The injector nozzle 6 × 0.24 mm is adopted when fueled with pure biodiesel. When the engine fueled with DME and the blends, the injector opening pressure was reduced from the recommended 24 MPa for biodiesel fueling to 19 MPa. The effects of nozzle parameter (6 × 0.40 mm and 6 × 0.35 mm) on combustion and emissions of blended fuels are also compared. In this work, the experiments are conducted at 1400 r/min, with 25%, 50%, 75% and 100% load of the maximum engine load, respectively.

3. Results and discussion

3.1. The combustion characteristics of DME–biodiesel blends

Combustion experiments of DME–biodiesel blends are carried out with in-cylinder pressure signals and emissions acquired. Fig. 2 shows the in-cylinder pressure, heat-release rate, in-cylinder temperatures and pressure rise rate at 1.52 MPa brake mean effective pressure (BMEP). With the increase of DME proportion, the peak pressure decreases and its phase retards. The in-cylinder pressure peaks are 12.5 MPa at 14.5° crank angle (CA) ATDC, 11.7 MPa at 14.5°CA ATDC, 10.9 MPa at 16°CA ATDC and 10.1 MPa at 1.5°CA BTDC. The cetane

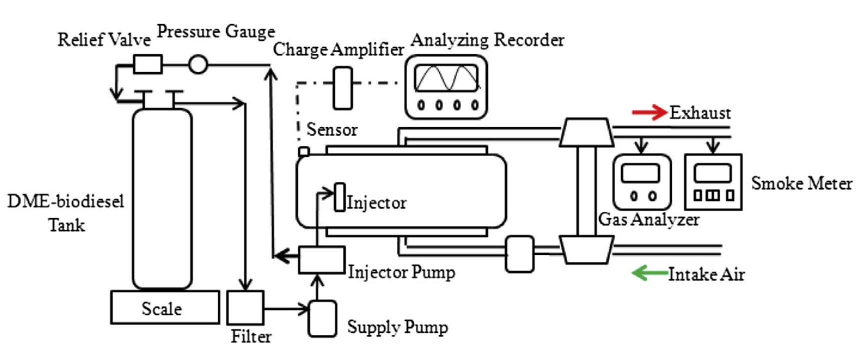

Fig. 1. Schematics of turbocharger DME engine and measurement apparatus.