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Effects of injection pressure on ignition and combustion characteristics of diesel in a premixed methanol/air mixture atmosphere in a constant volume combustion chamber

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HIGHLIGHTS

- The combustion characteristics of diesel in MAA at different injection pressures were investigated.
- The inhibitory effect of methanol on diesel ignition was enhanced at high injection pressure.
- Due to the addition of methanol, the peak values of AHRR were higher and the combustion durations became shorter.
- The differences of FLoL between in AA and MAA became smaller with the combustion continuing.
- The values of SINL and TINL were both lower in MAA than those in AA.

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ABSTRACT

The experiments on the ignition and combustion characteristics of diesel in air atmosphere (AA) and premixed methanol/air mixture atmosphere (MAA) were conducted in a constant volume combustion chamber (CVCC) equipped with a high pressure common-rail injection system. The ignition and combustion processes were recorded by a high-speed camera and a combustion pressure acquisition system. Results show that with the increase of injection pressure from 40 to 160 MPa, the flame lift-off length (FLoL) becomes longer; and the ignition delay is shortened from 2.80 ms to 2.03 ms (AA) and 2.90 ms to 2.27 ms (MAA) respectively; and correspondingly the combustion duration is shortened from 5.17 ms to 2.47 ms (AA) and 4.83 ms to 2.13 ms (MAA). Compared those in AA, the ignition delay is prolonged by 0.14 ms on average, while the combustion duration is shortened by 0.27 ms in MAA. At high injection pressure, the moments that the maximum combustion pressure occurs and the apparent heat release rates (AHRR) starts to rise are advanced; while in MAA both of them are delayed; and the peak value of AHRR increases. With the increase of injection pressure, both spatially integrated natural luminosity (SINL) and time integrated natural luminosity (TINL) reduce significantly, but the reduction trends of TINL weaken. Due to the addition of methanol, the FLoL of diesel becomes longer, and the SINL and TINL in MAA are both lower than those in AA.

1. Introduction

As the problems of environmental pollution and energy shortage have become prominent increasingly, advanced high efficiency and clean combustion technology and complex after-treatment system are adopted in the practical application of internal combustion engines to meet more and more stringent fuel consumption regulations and emission regulations. Due to their good fuel efficiency and durability, diesel engines are used in the worldwide, but their NOx and soot emissions are high, so the demands of

Abbreviations: AA, air atmosphere; MAA, methanol/air mixture atmosphere; CVCC, constant volume combustion chamber; FLoL, flame lift-off length; SINL, spatially integrated natural luminosity; TINL, time integrated natural luminosity; SMD, Sauter Mean Diameter; PM, particulate matter; CNG, compressed natural gas; DME, dimethyl ether; DMDF, diesel/methanol dual fuel; PN, particulate number; DAQ, data acquisition; SOC, start of combustion; AHRR, apparent heat release rate.

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efficient combustion and low emission are more urgent for diesel engines. Because high injection pressure can promote the atomization and evaporation of diesel fuel and accelerate the mixing of fuel and air, optimizing injection pressure is one of the main in-cylinder purification technologies [1–3]. Experimental results of previous visualization studies indicated that the Sauter Mean Diameter (SMD) of diesel fuel reduced and velocity of oil-beam increased at high injection pressure [4–6]. And experiments on diesel engine test bench showed that both soot and particulate matter (PM) emissions reduced with the increase of injection pressure [7–9].

In addition, alternative diesel fuels attract more and more attention, including compressed natural gas (CNG), alcohols (methanol, ethanol, butanol et al.), dimethyl ether (DME) and so on. It is because the promotion and application of alternative fuels are beneficial for decreasing the dependence on petroleum and reducing the exhaust emissions. Among the alternative fuels mentioned above, methanol is one of the most promising ones in China. Because the main raw material of methanol production is coal, which is abundant in China. Furthermore, methanol also has the advantages of low cost and easy storage. And as a kind of alternative fuel, methanol has great potential to reduce soot and NOx emissions simultaneously owing to its high latent heat of evaporation and oxygen content. However, the miscibility of diesel and methanol is not high without additives. Besides, the auto-ignition temperature of methanol is higher than that of diesel. So the best way for the application of methanol in diesel engine is methanol fumigation method, in which methanol is injected to the intake port to form homogenous mixture with air, and then the mixture is ignited by the direct-injected diesel fuel. Yao et al. [10,11] proposed a diesel/methanol dual fuel (DMDF) combustion mode, which also adopted the method mentioned above. A series of researches have indicated that both thermal efficiency and exhaust emissions of the engine improved significantly in DMDF mode. Geng et al. [12] and Dou et al. [13] found that in a DMDF engine, both particulate matter (PM) and particulate number (PN) reduced with the increase of methanol ratio at part loads. Wei et al. [14] and Wang et al. [15] observed that the trade-off relationship between soot and NOx emissions was broken at high methanol substitute percent. Wei et al. [16] showed that unregulated and regulated gaseous emissions in DMDF mode increased, but pilot injection strategy could reduce most of gaseous emissions. Masimalai [17] and Pan et al. [18] investigated that the thermal efficiency of diesel engine improved in DMDF mode; and Han et al. [19] revealed that the reduction in cooling loss in DMDF mode was the dominant factor for the higher thermal efficiency. From the previous researches, DMDF mode has the advantage for improving engine performance. The emission regulations for China National V legislation (CHN V, which is similar to Euro V) have been implemented since January 1, 2017; and DMDF combustion mode will have a broader application prospect. The emission limits of CHN V for compression ignition engines of vehicles are shown in Table 1.

To clarify the interaction of dual fuel combustion, apart from experiments from the engine test bench, Yin et al. [20] researched the effect of temperature on diesel combustion in a premixed methanol/air mixture atmosphere in a constant volume chamber; results showed that methanol could inhibit the ignition of diesel, but the inhibitory effect disappeared when ambient temperature was higher than 960 K. The conclusions were almost in accord with the simulation researches, which were performed based on a skeletal kinetic model of methanol/n-heptane blends created by Xu et al. [21]. Dai et al. [22] studied the ignition characteristics of diesel in an ethanol-air mixed atmosphere; results showed that both the ignition delay and flame lift-off lengths (FLoL) of the diesel fuel were prolonged by ethanol. However, injection pressure becomes higher and higher in the practical application of diesel engines, there are few researches about the effects of injection pressure on the combustion characteristics of diesel in a premixed methanol/air mixture atmosphere so far. And it is not clear for the interaction between the two fuels at high injection pressure. In this study, to clarify the interaction between diesel and methanol at different injection pressures, the experiments were conducted in an optical constant volume combustion chamber (CVCC) equipped with a high-speed camera and a combustion pressure acquisition system. The ignition and combustion processes of diesel in a premixed methanol/air mixture atmosphere were recorded. The natural luminosities of each flame image and FLoL were acquired. The effects of injection pressure and the interaction between the two fuels on the ignition and combustion characteristics of diesel were investigated; and the interaction between the physical factor (i.e. injection pressure) and chemical factor (i.e. the interaction between the two fuels) were illuminated.

2. Experimental setup and procedures

The experiments were conducted in a CVCC. The schematic diagram of the experimental setup is depicted in Fig. 1. It mainly consists of a CVCC system, a fuel injection system, and a high-speed camera system.

2.1. Constant volume combustion chamber (CVCC) system

The CVCC has a cylindrical bore of 80 mm in diameter and 268 mm in depth. The chamber can simulate the high ambient temperature and pressure in the cylinder of a diesel engine. There is a ceramic furnace in the metal chamber. And 5 kW resistance wires are installed in the furnace. The compressed air of 14.8 kg/m^3 in the chamber can be heated from room temperature to 1000 K in 10 min by the resistance wire. The temperature control unit controls the entire heating process. To prevent heat loss, there is thermal insulation material between the chamber wall and the ceramic furnace. Two pieces of fused silica windows are mounted at both ends of cylindrical bore as necessary optical windows, which have dimensions of 80 mm in diameter and 40 mm in thickness. The optical windows can bear a maximum operating pressure of 10 MPa. A single-hole, high-pressure common-rail injector is located at the top of the chamber such that the diesel spray is injected into the center of the cylinder bore directly. A thermocouple mounted on the top of the chamber is used to measure the temperature in the cylinder bore. The in-chamber pressure is recorded by a quartz pressure transducer (Kistler 6125C)

Table 1
The emissions limits of CHN V for compress ignition engines of vehicles.

European Steady-state Cycle (ESC)	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	PM (g/kWh)
	1.5	0.46	2.0	0.02
European Transient Cycle (ETC)	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	PM (g/kWh)
	4.0	0.55	2.0	0.02
European Load Response test (ELR)	Soot (m^{-1})			
	0.5			