Energy 95 (2016) 223–232

Contents lists available at ScienceDirect

Energy

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

Effects of methanol to diesel ratio and diesel injection timing on combustion, performance and emissions of a methanol port premixed diesel engine

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ARTICLE INFO

Article history:
Received 9 August 2015
Received in revised form
10 November 2015
Accepted 6 December 2015
Available online 30 December 2015

Keywords:
Combustion
Emission
Methanol
Injection timing
Diesel engine

ABSTRACT

In this study, port premixed methanol compression ignition combustion was performed on a heavy-duty diesel engine. The effects of methanol to diesel ratio (R_{MD}) and DIT (diesel injection timing) on combustion, performance and emissions were comprehensively investigated. The experimental results demonstrated that R_{MD} and DIT played important roles in combustion and emission control. With the increasing R_{MD}, the ignition delay was prolonged and the combustion duration was shortened. And as DIT retarded, the ignition delay was also prolonged and the combustion duration basically remained unchanged at the beginning, and then followed by a slight decrease. The maximum in-cylinder mean temperature decreased with the retarding DIT and it was largely affected by the combine of R_{MD} and DIT. The brake thermal efficiency remained stable at low R_{MD}, but showed a slight decrease at high $R_{MD.}$ NO_X and soot emissions and the RI (ringing intensity) were all decreased as RMD increase, while HC and CO emissions increased significantly. With the retarding DIT, HC emission firstly increased and then decreased, while CO emission always increased. It was more important that the trade-off relationship between NO_X and soot was significantly improved with the increasing R_{MD} and almost disappeared at R_{MD} 1.54.

1. Introduction

Diesel engines are widely utilized due to their high thermal efficiency, reliability and good power and fuel economy performance. Especially for today's society commercial transportation and urban public transport, heavy-duty diesel engines have become popular power unit. However, as a result of the diesel properties of high viscosity, low volatility and easy ignitability, it is difficult to prepare homogeneously premixed diesel/air mixture before ignition. Therefore, conventional diesel combustion process is mixing controlled diffusion combustion, and the presences of locally rich as well as high temperature regions produce relatively high NO_X and PM (particulate matter) emissions [1]. To accomplish the reduction of NO_X and soot emissions, forming a fairly homogeneous charge prior to ignition is very important. Based on this, port premixed charge compression ignition combustion in which the quasi-homogeneous charge is fed into combustion chamber before compression ignition was utilized by many researchers [2,3].

Yu et al. [4] and Yang et al. [5] used gasoline as the port injection fuel and achieved extremely low NO_X and soot emissions with the introduction of EGR (exhaust gas recirculation). Papagiannakis et al. [6,7] used natural gas and Barik et al. [8] used biogas as the port premixed fuel and they found dual fuel combustion was a promising technique for controlling both nitrogen monoxide and soot emissions. Song et al. [9] used methanol as the port injection fuel and observed a significant reduction in smoke emission and a modest reduction in NO_X emission. Zhang et al. [10] used methanol and Yao et al. [11] used ethanol as the port injection fuel respectively, and the results showed NO_X and particulate mass and number concentrations were effectively reduced. Ethanol was also used by Lu et al. [12], the experimental result showed that NO_X and smoke emissions simultaneously decreased by 35–85%. In addition, Wang et al. [13] and Zhao et al. [14] used dimethyl ether as the port injection fuel and also observed lower NO_X and smoke emissions. In summary, many fuels can be used as the port injection fuel and all the above studies have proved that port premixed charge compression ignition combustion technology is one of the effective means for simultaneous reduction of NO_X and smoke emissions.

On the other hand, the world petroleum resources are reducing and they are non-renewable. Therefore, it is necessary to find

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http://dx.doi.org/10.1016/j.energy.2015.12.020
0360-5442/

suitable alternative fuels. Among the above fuels, methanol is promising on account of its abundant production resources and low cost in China. Methanol can be produced by a variety of materials such as coal, natural gas and lots of renewable biomass [15,16]. In fact, methanol can be made from any material that can be decomposed into hydrogen and carbon monoxide (CO) or carbon dioxide (CO_2) [16].

Methanol is a low-reactivity fuel due to its low cetane number. Using port injected methanol combining with direct injected diesel, the combustion phase can be flexibly controlled due to the different reactivity gradient of the fuels. Li et al. [17,18] realized methanol/diesel RCCI (reactivity controlled compression ignition) by using the low-reactivity of methanol. The effect of several parameters, including mass fraction of premixed methanol, start of diesel injection, initial in-cylinder temperature and so on were investigated. The results showed the RCCI combustion with high methanol fraction and advanced start of injection exhibited higher fuel efficiency and lower emissions. Moreover, methanol is also beneficial for reducing both NO_X and smoke emissions, because it contains 50% of oxygen content and its latent heat of vaporization is about 3.5 times higher than that of diesel. Yao et al. [19,20] investigated the effect of port premixed methanol on the emission characteristics of a naturally aspirated diesel engine and a turbocharged diesel engine respectively. The experiment results showed that port premixed methanol was able to simultaneously reduce the brake specific equivalent fuel consumption, NO_X and soot emissions. Cheung et al. [21] also reported that there was a reduction in both NO_X and PM emissions with port-injected methanol. Zhang et al. [22] studied the particulate emissions of a methanol fumigated diesel engine and found that with increasing fumigation methanol the particulate mass and number concentrations both decreased.

Most previous studies on port premixed methanol were focused on the impact of premixed methanol on the engine performance and emission characteristics. But as for the effect of diesel injection strategy on the details of combustion process, it was less concerned. Usually, diesel fuel was injected into the combustion chamber at specific injection timing pre-determined based on diesel operation recommendation and unchanged throughout the tests [23,24]. For a diesel engine, fuel injection timing is one of the most important parameters for optimizing engine efficiency and emission controlling. The effects of fuel delivery advance angle on the combustion and emission characteristics have been extensively investigated on the engines fueled with diesel methanol blends [25–27]. However, it is not well known how DIT (diesel injection timing) affects the performances of the methanol port premixed diesel engine, especially the detailed combustion process. On the other hand, methanol and diesel are two fuels with different reactivity, and there is interaction between the two fuels especially under low temperature oxidation [28]. So the ratio between methanol and diesel might have a huge impact on the ignition and combustion process. Zhang et al. [24] investigated the influence of fumigation methanol on the combustion of a diesel engine based on different ratios of fumigation methanol and the ratio of fumigation methanol was defined as the ratio of engine load took up by methanol in the experiment. So the effects of ratios between methanol and diesel on combustion characteristic were not exactly known. Liu et al. [29] analyzed the effects of injection timing on performance and emissions of a diesel/methanol compound combustion engine based on methanol substitution ratios. As for the ratio between methanol and diesel, it changed with the changing of injection timing even under the same methanol substitution ratio. Therefore, the effects of ratios between methanol and diesel were also not clear. In fact, most of previous literature about port premixed methanol diesel dual fuel combustion were based on energy contribution ratio of methanol [29], engine load took up by methanol [24,30] or percentage reduction of diesel fuel due to the addition of methanol [31]. The influence of ratio between methanol and diesel on engine combustion and emission performances was rarely studied experimentally, so how is the effect going on needs to reveal. The objective of this study is to discuss the coupling effects of methanol to diesel ratio and DIT on the engine combustion, performance and emission characteristics. Moreover, how to optimize the NO_X and soot emissions by adjusting the two parameters was also discussed in this study.

2. Experimental apparatus and method

2.1. Test engine

The baseline engine used was a 6-cylinder, direct injection, turbocharged with common rail system diesel engine manufactured by WEICHAI POWER Co., Ltd. (WEICHAI) in China. This type of engine is commonly used on the heavy-duty truck and coach in China. The summary specifications of the engine are listed in Table 1.

2.2. Fuel and the supply system

In this study, the diesel fuel used contained less than 50 ppm by weight of sulfur and the methanol was industrial grade obtained from the local distribution network in Weifang, China. The detailed properties of the two fuels are listed in Table 2.

In order to implement port premixed methanol compression ignition combustion, a methanol injection system was installed on the engine. The methanol fueling system consisted of methanol tank, pump, filter, pressure regulator, common rail and methanol injectors. After regulator, the pressure of methanol was kept at 0.4 MPa. Methanol injectors have 4 holes and were mounted at the middle of each intake manifold, 45 mm away from the outlet to ensure methanol uniformity, as shown in Fig. 1. The included spray angle, steady flow rate and injection pressure of the methanol injectors are 15°, 532 ml/min and 0.4 MPa, respectively. A methanol ECU (electronic control unit) was used to control the amount of methanol by changing the methanol injection duration. The diesel injection and control system was manufactured by BOSCH Co., Ltd. (BOSCH) and remained unchanged in this study. The number of holes, included spray angle and the maximum injection pressure of the diesel injectors are 7, 153° and 160 MPa, respectively. The schematic diagram of engine setup is shown in Fig. 1.

Table 1
Summary specifications of the engine.

Description	Specification
Engine type	6-cylinder DI engine
Bore × stroke (mm)	126 × 130
Connecting rod length (mm)	219
Crank radius (mm)	65
Displacement (L)	9.726
Compression ratio	17
Max. torque/speed (N m/rpm)	1500/1200–1500
Rated power/speed (kW/rpm)	247/1900
Fuel injection system	Common rail
Combustion chamber	ω bowl in piston
Intake valve open	−36 °CA ATDC
Intake valve close	246 °CA ATDC
Exhaust valve open	−258 °CA ATDC
Exhaust valve close	30 °CA ATDC