



Full Length Article

Experimental study on combustion and emissions of n-butanol/biodiesel under both blended fuel mode and dual fuel RCCI mode

Zunqing Zheng, Mingtao Xia, Haifeng Liu*, Ran Shang, Guixiang Ma, Mingfa Yao

State Key Laboratory of Engines, Tianjin University, Tianjin 300072, PR China

ARTICLE INFO

Keywords:

n-Butanol/biodiesel
Blended fuel
RCCI
Combustion
Emissions

ABSTRACT

Oxygenated biofuels have become one of the research focuses of engines due to their renewability and improvement in combustion. There has been some studies concentrating on the dual fuel RCCI mode or blended combustion mode using biofuels in engines and valuable progress has been obtained. However, the comparison between biofuel RCCI and blended combustion modes has been rarely reported. Therefore, in current work, experimental study was conducted on a single-cylinder engine to investigate the differences between the two combustion modes fueled with biodiesel/n-butanol at different EGR rates (0%, 30%, 50%), n-butanol ratios (20%, 50%, 80%), injection timings and engine loads (low, medium, high). Results show that the ignition delay of blended mode is longer than that of RCCI mode, and more sensitive to n-butanol ratio and EGR rate. The optimum EGR rate is 30% considering efficiency and emissions for both combustion modes. Blended fuel mode can maintain high efficiency at all test loads and n-butanol ratios, the maximum indicated thermal efficiency (ITE) is up to 47.5%, while RCCI only shows comparable efficiency at high load. The problem of high maximum pressure rise rate (MPRR) that blended fuel mode faces can be addressed by retarded combustion phasing. Under current research conditions, blended fuel mode usually presents lower soot, HC, CO emissions and slight higher NO_x compared with RCCI mode. Generally, blended mode has better performance when MPRR problem is addressed while RCCI mode shows the potential in load extension due to the low MPRR and flexible split ratio and injection timing.

1. Introduction

Internal combustion engine has been dominant in power device application due to the high power output, efficiency and reliability. However, problems of energy shortage and environmental pollution are attracting attentions all over the world and promoting the progress in combustion technology. New combustion modes represented by homogeneous charge compression ignition (HCCI) [1,2], low temperature combustion (LTC) [3–5], partially premixed combustion (PPC) [6–8] and reactivity controlled compression ignition (RCCI) [9–12], etc., which can be generally called low temperature combustion, have shown great potential to achieve clean and efficient combustion. Many studies have focused on the advanced engine technologies or/and control strategies to improve combustion process and performance of new combustion modes, e.g. intake boosting [13,14], variable valve actuation (VVA) [15,16] and multiple injection strategy [17,18]. Optimizing fuel property is another important method that has been widely acknowledged to improve the combustion performance of internal combustion engine. Oxygenated biofuels have become one of the

research focus due to the superiority on reducing soot emissions under high EGR rate and their renewability which can reduce the consumption of conventional fossil fuel and alleviate energy crisis as well [19–21].

Oxygenated biofuels can be classified into two categories, one is called the first generation biofuels represented by biodiesel [22–24] and bioethanol [25–27] which are made from food raw materials such as sugar and starches by fermentation, and their application in engines has been widely researched. Ethanol is considered to be an ideal alternative fuel for gasoline engine and also shows advantages in high load extension for PPC combustion because of the high octane number and good volatility [17,28]. Studies show that ethanol has very finite miscibility in diesel fuel [29–31] and ethanol/diesel mixtures always present phase separation, while it can be dissolved in biodiesel at any proportion [32]. Another kind of biofuels which is called the second generation biofuel, is made from non-food raw materials with widely available resources in nature such as woody stem, agricultural residues, corn and straw fiber, have entered into people's horizon and become research focus as engine fuel. N-butanol is typical representatives of the

* Corresponding author.

E-mail address: haifengliu@tju.edu.cn (H. Liu).

second generation biofuels [33–35]. Besides the properties of high octane number, n-butanol shows some advantages over ethanol, such as higher energy density, lower volatility and hydrophilicity, which means it is less corrosive to fuel system and is more suitable for transportation and storage [36]. For traditional diesel engine, it is widely acknowledged that the trade-off relation between soot and NO_x emissions makes it difficult to reduce them simultaneously. A large number of researches [37–40] show that applying exhaust gas recirculation (EGR) to realize LTC is an effective way to reduce NO_x emissions. However, the increase in EGR rate is limited by soot emissions due to the soot bump which appears in high EGR rate region. Although the trade-off relation can be improved under appropriate EGR rate, the decreased combustion temperature caused by EGR reduces combustion efficiency to some extent and results in quite high HC and CO emissions [41,42]. Researches show that the problems of LTC can be addressed by adding oxygenated biofuels into diesel, especially for soot emissions at heavy EGR rate, mainly due to the high octane number [43,44] and oxygen containing [45,46] of biofuels. The high octane number property of fuel can prolong the ignition delay, which promotes fuel/air mixing progress. Meanwhile the oxygen content in fuel can restrain the generation of smoke precursors mainly by alleviating the situation of high local equivalence ratio during combustion process. Other physical properties such as viscosity [47], boiling point [48] and dilution (less aromatic hydrocarbon) [49] also have different impacts on combustion. Though high blending ratio of oxygenated biofuel can improve the emissions greatly, excessive pressure rise rate at high load [19,50] is a substantial restriction which limits the maximum blending ratio of biofuels.

Fuel blends that contain oxygenated biofuels have been widely researched all over the world. Huang et al. [51] conducted experimental researches of n-butanol and diesel blend on a compression ignition engine under various EGR rates. The results show that the introduction of n-butanol prolongs the ignition delay, decreases the combustion temperature and cylinder pressure compared to neat diesel. N-butanol shows great potential in reducing soot emissions and particle diameter, however, it increases particle number. Rakopoulos et al. [52] conducted an experimental investigation on a four-stroke, high-speed direct injection Ricardo/Cussons diesel engine to evaluate the effects of using n-butanol/diesel blends. N-butanol/diesel fuel blends with 8%, 16% and 24% n-butanol (in volume) or neat diesel fuel were selected as test fuels, with the engine working at the speed of 2000 rpm and three different loads. The results show that the smoke and CO emissions of n-butanol/diesel blends are significantly lower than that of neat diesel fuel, and higher blending ratio leads to a further decrease. NO_x emissions can be reduced slightly by n-butanol addition, while HC emissions increase with the use of n-butanol. Other researches [53] indicate that blending n-butanol with diesel or biodiesel prolongs the ignition delay and improves the trade-off relation between NO_x and soot emissions, but brings the problem of high pressure rise rate and coefficient of variation. While Huang [54] found that the pressure rise rate of compression ignition engine fueled with n-butanol/diesel blend can be significantly reduced by optimized pilot injection, THC and CO emissions are also cut off greatly. Dogan [55] performed a research on a small diesel engine fueled with B5 (contains 5% n-butanol and 95% diesel fuel in volume), B10, B15, B20 and neat diesel fuel to evaluate the performance and exhaust emissions. Results show that n-butanol can be blended with diesel without phase separation and brake thermal efficiency is increased a little with increasing n-butanol content. N-butanol/diesel blend produces less soot, NO_x and CO emissions while more HC emission than neat diesel. The exhaust gas temperature is reduced with increasing n-butanol content in fuel blends with respect to those of neat diesel. Other researches [56,57] demonstrate that latent heat of vaporization, oxygen content and cetane number also play important roles in blended combustion mode.

On the other hand, oxygenated biofuels can be introduced into the cylinder not only by blending, but also by using dual fuel RCCI combustion. Dual fuel RCCI combustion is a concept which is developed on

the basis of premixed combustion by professor Reitz [11], and has become research focus recently. In RCCI combustion mode, generally the high reactivity fuel is supplied by direct injection (DI) while the low reactivity fuel is supplied by port fuel injection (PFI) separately, which enables a flexible operation over a wide range of engine speed and load by modifying the ratio of DI/PFI fuels and DI timing [58]. One advantage of RCCI combustion mode is that it is beneficial for premixed mixture formation and can solve the miscibility problems for some fuels at blended fuel mode. Benejas [59,60] optimized RCCI combustion strategy to realize smooth operation over the whole engine map. The results show that the strategy should change as the engine load increases, starting from a fully premixed combustion at low load, then switch to a highly premixed combustion at mid-high load, then reach a mainly diffusive combustion at full load. And EURO VI emission standard can be satisfied over the whole engine map with a maximum gross thermal efficiency of 48.2% at lower compression ratio (11).

Tong et al. [61] performed an RCCI research on a single cylinder diesel engine, polyoxymethylene dimethyl ethers (PODE) was selected as the direct injection high reactivity fuel, and gasoline was selected as the port injection low reactivity fuel in dual-fuel RCCI operation. The results show that stable and controllable RCCI operation is obtainable by applying gasoline/PODE fuel strategy. Improved indicated thermal efficiency (ITE) and ultra-low smoke can be achieved with a slight penalty but still comparable NO_x emission. The maximum load of gasoline/PODE RCCI operation can be extended to 1.76 MPa indicated mean effective pressure (IMEP) with single injection strategy, which is significantly higher than that of gasoline/diesel RCCI operation with optimized double-injection strategy (1.39 MPa IMEP), while still maintains ultra-low smoke and comparable ITE and acceptable maximum pressure rise rate (MPRR). It is worth noting that stoichiometric and clean gasoline/PODE dual-fuel RCCI operation is achievable at high load, which enables the possibility to apply a low-cost three-way catalyst to further reduce the NO_x, HC and CO emissions, and offers a very competitive pathway to achieve clean and highly efficient diesel combustion. While it is widely recognized that high HC emission is a common problem of RCCI, many researches [62,63] were carried out to address this problem, and results show that CO and HC emissions can be reduced via optimizing the spray angle, start of injection (SOI), pre-mixed ratio and low reactive fuel stratification.

As mentioned above, there has been a lot of studies concentrating on the dual fuel RCCI mode or blended combustion mode with biofuels and valuable progress has been obtained. However, the comparison between dual-fuel RCCI and blended fuel combustion modes has been rarely reported as using biofuels. Actually, it is important to make clear what kind of combustion mode is more suitable at different operating conditions and boundary conditions. Therefore, in this paper, comparisons between n-butanol/biodiesel dual fuel RCCI (biodiesel as DI and n-butanol as PFI) and n-butanol/biodiesel blended fuel combustion mode (biodiesel/n-butanol blends) are investigated to reveal the characteristics of each combustion mode at different loads, EGR rates and combustion phasing.

2. Experimental setup and methods

2.1. Experimental setup

The single cylinder, 4-stroke, 4-valve diesel engine used in this experiment was modified from a six-cylinder heavy-duty diesel engine produced by Guangxi Yuchai Co., Ltd. The test single cylinder was separated from the other five cylinders for test purposes and equipped with independent port injection and in-cylinder direct injection fuel systems, intake temperature and pressure regulating systems, an EGR system, and other relevant systems or instruments. An external air compressor was used for intake boosting, while an intake heater combined with an intercooler was employed to control the intake temperature. A cooled EGR system was employed and the EGR rate could

Download English Version:

<https://daneshyari.com/en/article/6630892>

Download Persian Version:

<https://daneshyari.com/article/6630892>

[Daneshyari.com](https://daneshyari.com)