



Full Length Article

Experimental study on combustion and emission characteristics of iso-butanol/diesel and gasoline/diesel RCCI in a heavy-duty engine under low loads



Suozhu Pan^{a,b,c}, Xingwen Liu^{b,c}, Kai Cai^{b,c}, Xin Li^{b,c}, Weiqiang Han^{a,b,c,*}, Bolun Li^{b,c}

^a Key Laboratory of Fluid and Power Machinery, Ministry of Education, Xihua University, Chengdu 610039, China

^b Vehicle Measurement, Control and Safety Key Laboratory of Sichuan Province, Xihua University, Chengdu 610039, China

^c School of Automotive and Transportation, Xihua University, Chengdu 610039, China

ARTICLE INFO

Keywords:

Iso-butanol

Gasoline

RCCI

Combustion

Exhaust emissions

Low loads

ABSTRACT

This work experimentally studies the combustion and emission of iso-butanol/diesel RCCI (Reactivity Controlled Compression Ignition) under low loads and compares its results with gasoline/diesel RCCI. The results show that iso-butanol/diesel RCCI has better power recovery ability than gasoline/diesel RCCI. When R_p (Premixed Ratio) is 50% and 60%, IMEP (Indicated Mean Effective Pressure) of iso-butanol/diesel RCCI is 1.4% and 3.9% higher than maximum IMEP of CCM (Conventional Combustion Mode) respectively. Both iso-butanol/diesel and gasoline/diesel RCCI contain LTHR (Low Temperature Heat Release) and HTHR (High Temperature Heat Release). With increase of R_p in both RCCI combustion modes, combustion phase retard, peak value of heat release and maximum PRR (Pressure Rising Rate) decrease, ID (ignition delay), CD (combustion duration), CA50-CA10, maximum mean in-cylinder temperature and ITE (Indicated Thermal Efficiency) increase. Compared with the gasoline/diesel RCCI, iso-butanol/diesel RCCI has later combustion phase, longer ID, CD and CA50-CA10, higher maximum mean in-cylinder temperature and ITE, as well as lower maximum PRR. Furthermore, with increase of R_p , CO (Carbon Monoxide), NO_x (Nitrogen Oxides) and PM (Particulate Matter) emissions decrease, HC (Hydrocarbon) increases for both gasoline/diesel and iso-butanol/diesel RCCI. Compared with the gasoline/diesel RCCI, iso-butanol/diesel RCCI achieves lower CO, HC, NO_x and PM emissions.

1. Introduction

With the increasingly severe international energy situation and stricter emission regulations, scholars successively have put forward multiple advanced combustion technologies to achieve the high-efficiency and clean combustion of the internal combustion engine [1,2], such as HCCI (Homogeneous Charge Compression Ignition), PCCI (Premixed Charge Compression Ignition) and SCCI (Stratified Charge Compression Ignition). These combustion technologies can achieve relatively high thermal efficiency and reduce NO_x and soot emissions simultaneously. However, they still have some drawbacks to be solved, such as narrow operation condition range and difficult control of ignition time and combustion rate [3,4]. To overcome the shortcomings of these combustion technologies, a more advanced RCCI combustion mode is proposed, in which port injection of low reactivity fuel (gasoline-like fuel) combined with in-cylinder direct injection of high reactivity fuel (diesel-like fuel) [5].

The RCCI combustion mode is able to effectively control the combustion phase, HRR (Heat Release Rate) and PRR through adjusting the reactivity stratification and concentration distribution of in-cylinder mixtures to achieve the purpose of optimizing the combustion process, lifting the thermal efficiency and reducing emissions [6]. Li et al. [7] demonstrated that RCCI combustion mode could decrease the combustion rate and maximum in-cylinder pressure by adjusting the reactivity stratification. In addition, low NO_x and soot emissions could be achieved. Wang et al. [8] carried out a comparative study on the performance of RCCI and HCCI combustion mode through numerical simulation and experiment. Both combustion modes showed very similar combustion performance under low and medium load conditions. However, RCCI combustion mode would stably operate under high load condition and maintained relatively low NO_x and soot emissions. Splitter et al. [9] pointed out that the ITE of RCCI combustion mode could achieve up to 60% under the optimal combustion management strategy and thermodynamic condition. Curran et al. [10] also found

* Corresponding author at: Key Laboratory of Fluid and Power Machinery, Ministry of Education, Xihua University, Chengdu 610039, China.

E-mail address: zyzdlg@163.com (W. Han).

<https://doi.org/10.1016/j.fuel.2019.116434>

Received 8 August 2019; Received in revised form 12 October 2019; Accepted 15 October 2019

0016-2361/ © 2019 Elsevier Ltd. All rights reserved.

that RCCI combustion mode fueled with gasoline/diesel could reduce over 90% of NO_x and PM emissions compared with the conventional diesel combustion mode.

Low reactivity fuel is one of the key factors that influence the combustion process and performance of RCCI engine [11]. It affects not only the fuel-air mixing in cylinder, but also the heat release process and heat transfer [12]. In early stage of RCCI combustion study, gasoline was usually used as low reactivity fuel, which could achieve low NO_x and soot emissions and relatively high IMEP [13]. In recent years, alcohol fuels as the low reactivity fuel of RCCI engine have gained wide attention due to its excellent physical and chemical properties [14–16]. Several researches showed that alcohols applied in RCCI engine not only can increase the thermal efficiency, but also can decrease harmful exhaust pollutants [17–19]. Among various kinds of alcohols, it is worth noting that butanol has been considered as more potential low reactivity fuel in RCCI combustion mode because of its excellent properties, such as high calorific value, high energy density, low hydrophilicity and non-corrosion to existing fuel pipelines [20,21].

There are four isomers of butanol, namely n-butanol, 2-butanol, iso-butanol and tert-butanol. Among four isomers of butanol, n-butanol as the alternate fuel has been applied in numerous engine studies and gained more attention around the world [20,22]. Relevant results exhibited that n-butanol used in RCCI engine not only can increase the BTE (Brake Thermal Efficiency), but also can decrease the exhaust emissions [20]. However, compared with n-butanol, iso-butanol has higher octane value, lower boiling point and LFL (Lower Flammable Limit). These outstanding properties can improve the fuel-air mixing in cylinder and combustion process of RCCI engine, which may further promote the increase of thermal efficiency and the reduction of exhaust emissions [23]. A high octane value not only can increase the ignition delay to promote the fuel-air mixing in cylinder, but also can create larger activity gradients in cylinder to broaden the operation condition range in RCCI combustion mode [7,16]. A low boiling point is advantageous to the evaporation and atomization of the fuel to enhance the mixing quality of fuel and air in cylinder, which can further promote the optimization control of combustion phase [24]. A low LFL is conducive to the occurrence of combustion reaction at small equivalent ratio conditions to improve the combustion quality [25]. In addition, iso-butanol can be produced by several biological methods such as the organic matter fermentation method [26], the valine biosynthesis pathway and so forth [27,28]. Gevo and DuPont Company have paid more attention to the production of iso-butanol and have actively participated in its promotion and application in internal combustion engine [29,30].

At present, the engine studies of iso-butanol mainly involve the CI (Compression Ignition) engine fueled with blends of iso-butanol with diesel fuel and the RCCI combustion mode fueled with iso-butanol (as low reactivity fuel). The previous engine studies pointed out that CI engine fueled with blends of iso-butanol with diesel fuel not only can increase the thermal efficiency, but also decrease the NO_x and soot emissions. Kumar et al. [31] compared the influence of iso-butanol/diesel blends and n-pentanol/diesel blends on the combustion and emission characteristics in a single cylinder CI engine. They found that CI engine fueled with iso-butanol/diesel blends had higher BTE and lower NO_x and soot emissions compared with n-pentanol/diesel blends. This result mainly caused by the better evaporation and atomization of iso-butanol due to its lower viscosity, which led to better combustion process. The experimental study performed by Murat et al. [32] in a single cylinder engine showed that blends of iso-butanol with diesel (10% iso-butanol by volume) could decrease the NO_x emission and increase the BTE and power within the speed range of 2400 to 2800 r/min compared with the conventional pure diesel combustion mode. Wei et al. [33] experimentally studied the influence of blended fuels, including diesel (D100), 70% diesel/30% gasoline (D70G30, by mass), 70% diesel/30% iso-butanol (D70B30) and 70% diesel/15% gasoline/15% iso-butanol (D70G15B15), on the performance and emissions of a

4-cylinder CI engine. Their results indicated that the addition of iso-butanol into diesel not only can increase the BTE (the ascending order of BTE: D100 < D70G30 < D70G15B15 < 70B30), but also can decrease the mass and number of PM (the descending order of mass and number of PM: D70B30 < D70G15B15 < D70G30 < D100). Ozsezen et al. [34] studied the influence of iso-butanol/diesel blends on the emission characteristics in a 6-cylinder heavy-duty CI engine. They found that iso-butanol/diesel blends can significantly decrease the NO_x, CO and soot emissions of the tested engine compared with conventional pure diesel combustion mode. In addition, with the increase of iso-butanol content in blended fuel, these exhaust emissions decreased gradually.

Although iso-butanol as the low reactivity fuel of RCCI combustion mode has gained more attention by scholars, but related studies are rarely reported. DelVescovo et al. [35] studied the effect of iso-butanol as low-activity fuel on the combustion process of RCCI combustion mode under 0.6 MPa IMEP condition in a single cylinder engine. They pointed out that compared with the gasoline/diesel RCCI combustion mode, the iso-butanol/diesel RCCI combustion mode not only can postpone and suppress the LTHR, but also can increase the combustion duration owing to forming great reactivity gradient of mixtures in cylinder. Additionally, owing to high octane number of iso-butanol, a great amount of high reactivity fuel was provided (i.e. decreasing the R_p of iso-butanol) to match the reasonable combustion phase. Based on the numerical simulation study, Wang et al. [8] found that the steady RCCI combustion can be achieved under wide operation condition range by port-injected iso-butanol and direct-injected diesel or mixtures of iso-butanol and DTBP (di-tert-butyl peroxide). Furthermore, compared with iso-butanol/iso-butanol + DTBP RCCI combustion mode, iso-butanol/diesel RCCI combustion mode had better combustion and emission characteristics under medium and high load conditions.

In summary, as the alternative fuel of internal combustion engine, iso-butanol has attracted extensive attentions. Its production methods and commercial developments have been put forward by several companies. Besides, the unique physicochemical properties and molecular structure of iso-butanol inevitably influence the ignition characteristics, intermediates, oxidation processes of the in-cylinder charge in the combustion process, and cause unique combustion and emission behaviors of the internal combustion engine. Nevertheless, the previous engine studies mainly focused on the application of blends of iso-butanol with fossil fuel in conventional diesel engine. The studies of iso-butanol as low reactivity fuel in RCCI combustion mode were still rarely reported. Therefore, it has important theory significance to clarify the effects of iso-butanol on the combustion and emission behaviors of RCCI combustion mode. This will provide the theoretical supports and references for the application of iso-butanol and combustion process control in RCCI engine.

The purpose of current work is to shed light on the effect of iso-butanol (as low reactivity fuel) on the combustion and emission of RCCI combustion mode. Particularly, the effect of iso-butanol on the power performance, fuel economy and exhaust emission characteristics of RCCI engine is studied at very early direct injection timing condition (−35°CA ATDC (After Top Dead Center)) in detail. In this paper, the fuel supply system of a 6-cylinder heavy-duty turbo-charged diesel engine was modified to achieve the RCCI operating mode. The combustion parameters (in-cylinder pressure, HRR (heat release rate), ID, CD, etc.) and exhaust emissions (CO, HC, NO_x, PM) of iso-butanol/diesel RCCI combustion mode were measured and analyzed under various operation conditions. Additionally, its results were also compared with gasoline/diesel RCCI combustion mode.

2. Experimental setup and method

2.1. Experimental setup

Fig. 1 shows the experimental setup. An inline 6-cylinder heavy-

Download English Version:

<https://daneshyari.com/en/article/13415897>

Download Persian Version:

<https://daneshyari.com/article/13415897>

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