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Experimental study on spray combustion characteristics of gasoline–diesel blended fuel in a controllable active thermo-atmosphere

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HIGHLIGHTS

- We study the combustion characteristics of diesel–gasoline blend fuel.
- It shows two different characteristics under different temperature.
- Under high temperature the ignition delay increases as the diesel increases.
- Under low temperature the ignition delay decreases as the diesel increases.
- A two-state mechanism for blend fuel auto-ignition is proposed.

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ABSTRACT

The lift-off flame of gasoline/diesel blend fuel spray in controllable active thermo-atmosphere (CATA) was captured by a high speed camera to investigate the auto-ignition characteristics of blend fuel, meanwhile a database for further simulation work was provided. The experimental results showed that the influence of co-flow temperature on spray lift-off flame has two opposite trends: Under higher co-flow temperature, the flame lift-off height increases with the increase of blended ratio of diesel, and the ignition delay gets longer; when the co-flow temperature is lower, the increment of diesel ratio in blend fuel leads to decrement in lift-off height, and the auto-ignition delay becomes shorter. According to the results, the equilibrium temperature "Te" was defined to represent the co-flow temperature, where diesel and gasoline ignited spontaneously, and under the test conditions of this paper, it is around 1117 K. The exact value of equilibrium temperature of diesel and gasoline fuel under the conditions of an internal combustion engine (ICE) still needs to be verified by further experimental studies, but the change rules and trend of the equilibrium temperature that proposed in this paper should be applicable to real engines.

1. Introduction

In recent years, with advances in diesel engine technology, the performance of diesel engine has been greatly improved in terms of power, economy, vibration, noise and emissions. On the other hand, the NO_x and soot (PM) emission of diesel engine is much higher than that of gasoline engine, and the NO_x–PM trade-off in a conventional diesel engine is hard to dispose. Scholars from all over the world have put forth lots of new combustion concepts to resolve this dilemma; one of them is the low-temperature combustion (LTC) concept, which can sufficiently solve this trade-off problem.

There are two types of LTC. For the first type, the ignition timing has nothing to do with the injection time but is totally decided by the chemical reaction kinetics; and for the second type, the combustion phase control is coupled with the injection timing [1]. In the combustion system of the first kind, fuel and air are fully premixed before ignited, the fuel/air mixture can be regarded as homogenous with an equivalence ratio less than one. One typical example for this type is the homogeneous charging compression ignition [2,3] (HCCI). For the second combustion system, the time interval between the injection and ignition is too short to form a homogeneous mixture. So the equivalence ratio of many local

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Nomenclature

Upper case letters
Te equilibrium temperature (K)
T local temperature (K)

Greek lower case letters
φ equivalence ratio

areas is still more than one. That is to say, the air and the fuel are still undergoing a mixing process during the combustion, and the highest flame temperature can be close to the adiabatic flame temperature at the stoichiometric ratio condition. In this case, strategies like smaller compression ratio, larger exhaust gas recirculation (EGR) ratio and retarded injection timing are used to suppress the rise of flame temperature.

The processes of HCCI combustion are controlled mainly by the chemical kinetics. Almost all known ICE fuels, including gasoline and diesel, such as methanol, dimethylether [4], ethanol [5], natural gas [6], hydrogen [7] and the blend fuels of them [8,9] are applicable on the ICE to achieve HCCI mode. However, some inherent drawbacks of HCCI combustion mode have hindered its wider application in ICE. For example, there will be a higher HC and CO emission during low load for HCCI. And in order to prevent the knock tendency in high load, the operating range of engine is usually limited in mid-low load. Thus, more researches should be conducted on the issue of homogenous gas formation and HCCI control strategies.

Aiming at overcoming the drawbacks of current HCCI mode, researchers all around the world are taking efforts at improving the system's practicality while maintaining its advantages. Among the various HCCI technology substitutes, LTC mode has been a hot research area due to its adaptability to current engine configuration and compatibility with the existing and future emission regulations.

Unlike the HCCI mode, in the premixed LTC mode, fuel is injected directly into the combustion chamber at sometime during compression stroke, a quasi-homogenous mixture is formed within a relative longer time. So compared with HCCI mode, the combustion timing of premixed LTC is not solely dependent on the chemical kinetics but also closely related to the injection timing. According to the different fuel injection strategy, LTC can be classified as early-injection LTC and late-injection LTC.

The main idea of LTC is to reduce combustion temperature and equivalent ratio to avoid the main production region of soot and NO_x. All the elements that affect combustion temperature and equivalent ratio should be taken into consideration. For this sake, EGR ratio [10], compression ratio [11], swirl rate [12,13], air boost [11] and physiochemical property [14] all will exert an influence on the LTC mode.

Among various elements that listed above, physiochemical property of fuel has a larger influence on LTC combustion characteristic. And also, adjusting the physiochemical property is the easiest and the least cost-demanding controlling strategy. As two most common fuels of ICE, gasoline and diesel are complementary because of their huge difference in their physiochemical properties. So, researchers have shown great enthusiasm for LTC mode characteristic with gasoline and diesel blend fuel.

Zhong et al. [15] named the blend fuel of gasoline/diesel as 'dieseline' and conducted research on its combustion characteristics. The result shows that compared with pure diesel, dieseline has a longer ignition delay and a larger evaporation rate which is more suitable for a partially premixed compression ignition (PPCI) mode. Research made by Weall [16] on dieseline PPCI combustion shows that dieseline has a longer ignition delay and a higher volatility which contribute to a more uniform mixture. Han et al. [17,18] conducted a systematic research on self-ignition characteristics and LTC characteristics of gasoline/diesel blend fuel, the results show that when gasoline was added to the diesel, the viscosity and surface tension changed. The Sauter Mean Diameter (SMD) of spray decreased when there's more gasoline in the mixture. There were more small droplets in the spray which makes the fuel/air mixture more even. A longer ignition delay and higher volatility can decrease soot and NO_x emissions which enables low temperature combustion under low EGR rate. Zhang [19] made a research on combustion and emission characteristics of diesel engine LTC. The result shows that gasoline/diesel blend fuel can significantly reduce emission and improve engine performance. Reitz et al. [20] came up with a reduced chemical reaction mechanism for gasoline/diesel blend fuel that can be used for coupled with CFD calculation.

Recent researches on gasoline/diesel blend fuel mainly have a fixed mixture ratio, the effect of variation of gasoline/diesel ratio on the combustion characteristics is lacking. Still, because most experiments were conducted on real engines, it is hard to measure the in-cylinder combustion process, especially to collect multiple data simultaneously. Besides, the complex geometry of combustion chamber and boundary conditions not conducive to the numerical simulation of the combustion. So it is hard to investigate the combustion mechanism in this way. Meanwhile, low temperature oxidation reaction process of blend fuel must be investigated in a steady state first. The CATA combustor [21] is essential to provide a stable temperature field for this situation. Various results show that this combustor is suitable for the research of stable self-ignition of gas and liquid fuel.

Using CATC, this paper investigates the auto-ignition characteristic of gasoline/diesel blend fuel spray in thermo-atmosphere, the flame lift-off height, auto-ignition delay and flame development law was studied. The combustion characteristics for gasoline–diesel blended fuel is explored which provides a theoretical guidance for blend fuel LTC in real engines.

2. Test fuels and devices

2.1. Test fuels

Test fuels employed in this paper were neat diesel (D100) and its blends with gasoline (D0), meeting the Chinese national

Table 1
Specification of diesel and gasoline.

Fuel type	Diesel (0#)	Gasoline (93#)
Chemical formula	$C_{16–23}$	$C_{4–12}$
Sulfur content (mg/kg)	$\leqslant$50	$\leqslant$50
Flash point (°C)	55	−50
Boiling point (°C)	180–330	40–200
Lower heating value (MJ/kg)	42.6	43.9
Latent heat (kJ/kg)	270	310
Octane number	–	$\geqslant$93
Cetane number	$\geqslant$49	–