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Effects of gasoline research octane number on premixed low-temperature combustion of wide distillation fuel by gasoline/diesel blend

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HIGHLIGHTS

- WDFs by blending diesel and gasoline with various RONs were tested in CI engine.
- At medium load, WDF containing gasoline with lower RON has lower fuel consumption.
- At high load, no significant differences in emissions and fuel economy were observed.
- WDFs have much lower soot emissions at medium and high loads compared with diesel.
- WDFs show lower fuel consumption and lower pressure rise rate compared with diesel.

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ABSTRACT

Wide Distillation Fuel (WDF) refers to the fuels with a distillation range from initial boiling point (IBP) of gasoline to final boiling point (FBP) of diesel. In this paper, the WDF was prepared by blending diesel fuel and different gasoline fuels with various RONs (90#, 97# and 100#). Experiments were conducted on a direct injection diesel engine with these fuels to investigate the sensitivity of gasoline RON on combustion and emission characteristics in premixed LTC mode from medium load (6 bar IMEP) to high load (10 bar IMEP). The results indicate that WDF90 has slightly higher combustion efficiency at medium load with a slight increase in NOx emissions. At high load, no significant difference in combustion and emission characteristics was observed WDFs with different RONs from 90# to 100#. All of the three WDFs can significantly reduce soot emissions at both medium load and high load in LTC combustion compared with diesel fuel. Premixed low-temperature combustion of WDF is a promising approach to increase gasoline thermal efficiency compared to SI mode, whereas thermal efficiency is insensitive to gasoline RONs.

1. Introduction

Energy saving and CO_2 reduction are the major research objectives for the next generation internal combustion engines. Compared to Spark Ignition (SI) engines, Compression Ignition (CI) engines have much higher thermal efficiency which is favorable for energy saving and CO_2 reduction. But for conventional CI engines, combustion occurs right after the start of fuel injection, and there is no enough time for fuel–air mixing, which leads to soot formation in fuel rich region and NOx formation in local high temperature region. Homogeneous Charge Compression Ignition (HCCI) was regarded as an ideal combustion mode due to its high efficiency, low NOx and soot emissions. However, its combustion process was mostly controlled by chemical kinetics which can hardly be applied to high load due to the rapid heat release of simultaneous auto-ignition. As a promising combustion mode, Low Temperature Combustion (LTC) can improve the trade-off of NOx and soot in conventional diesel engine in a wide operating

Abbreviations: SI, spark ignition; CI, compression ignition; HCCI, homogeneous charge compression ignition; LTC, low temperature combustion; EGR, exhaust gas recirculation; WDF, wide distillation fuel; IBP, initial boiling point; FBP, final boiling point; MPRR, maximum pressure rise rate; HC, hydrocarbon; HCII, gasoline homogeneous charge induced ignition by diesel; PCCI, premixed charge compression ignition; GDBF, gasoline/diesel blend fuel; PPCI, partially-premixed compression ignition; RON, research octane number; SOI, start of injection; COV, coefficient of variation; EOI, end of injection; IMEP, indicated mean effective pressure; CA BTDC, crank angle before top dead center.

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range. The main feature of LTC combustion mode is to promote air–fuel mixing before compression ignition. In diesel LTC combustion, high Exhaust Gas Recirculation (EGR) and injection pressure are usually used to prolong ignition delay and improve mixing respectively. Even though, LTC operating range was still limited from low to medium load because of short ignition delay and low volatility of diesel fuel.

In order to overcome the drawback of using diesel in LTC and improve gasoline efficiency, a fuel concept called Wide Distillation Fuel (WDF) was proposed in recent years. WDF refers to fuels with a wide distillation range from initial boiling point (IBP) of gasoline to final boiling point (FBP) of diesel. WDF contains high volatile components which are beneficial for atomization and evaporation. WDF ignition delay is longer than commercial diesel fuel. Direct blending of commercial gasoline and diesel is the most convenient method to produce WDF. Some studies have been carried out using commercial gasoline and diesel blends on some novel combustion modes such as LTC, and Premixed Charge Compression Ignition (PCCI) [1–10]. Xu et al. [1–3] named gasoline–diesel blend fuel as "dieseline" and studied premixed charge ignition combustion fueled with dieseline. The dieseline was prepared by blending standard diesel and 95 octane gasoline ULG95. The results showed that dieseline can greatly reduce the total concentration and mean diameter of particulate matter without penalty of fuel consumption. Yu et al. [4] made a comparative study on two approaches: Gasoline Homogeneous Charge Induced Ignition by Diesel (HCII) and gasoline/diesel blend fuel (GDBF). The gasoline Research Octane Number (RON) in the research was 93. The results showed that both approaches had an obviously higher thermal efficiency than gasoline engines, and reached or even surpassed the thermal efficiency of diesel engines. As the proportion of gasoline increases, soot emission is significantly reduced due to the increase in the proportion of premixed combustion. The hydrocarbon (HC) emissions in GDBF mode remained almost unchanged, while the HC emissions in HCII mode increased dramatically. Weall and Collings [5] investigated Partially-Premixed Compression Ignition (PPCI) mode by using gasoline–diesel blends and found larger low emission operating range compared to diesel. They also used 95 octane gasoline for blending. Han et al. [6–8] studied the premixed LTC fueled with gasoline–diesel blends and extended load range by using intake boost and EGR. The commercial gasoline used for preparing blends had an octane number, (MON + RON)/2, of 93. Valentino et al. [9,10] investigated premixed LTC with optically accessible engines. Commercial EURO IV 98 octane gasoline was chosen. After these work, more studies have been carried out using gasoline–diesel blends by Hyun et al. [11], Yang et al. [12], Park et al. [13], Benajes et al. [14]. WDF of different gasoline proportions were investigated such as 20–40% [6–8], 50% [2–5] and 70–90% [11,12]. But there were still some limitations in using WDF. Many results have proved that high gasoline ratio have more advantage in reducing soot emissions in rich operating condition because it helps to form a uniform mixture before combustion. Han et al. investigated three gasoline ratio, 0%, 20% and 40% and found that soot emissions became insensitive to changes in intake oxygen concentration and remain at a low level when 40% gasoline was blended [6]. Yu et al. proved that again by using the similar gasoline ratio of 60% [4]. And 0.06 g/kW h NOx, 0.008 FSN smoke were achieved under the equivalence ratio of 0.91 by G50 [3]. Moreover engine idle operation was possible using a 50% gasoline proportion test fuel, although the emissions of CO and THC are high [5]. Lower ratio of less than 40% was not enough to attain soot-free combustion. High gasoline addition of more than 80% limited the usage of EGR because of the combustion stability and NOx emissions became issues [12]. And it may also further deteriorate combustion at engine idle operation, misfire cannot be avoid. So the gasoline ratio of 50% is a compromise choice to achieve low soot emissions and maintain combustion stability both at low load and high EGR conditions for WDF LTC combustion.

Although different proportions of gasoline/diesel have been studied, effects of gasoline properties such as RON on LTC of WDF have not been investigated yet. Since RON is the most important chemical properties of gasoline in SI combustion mode, the effect of gasoline RON on low-temperature combustion of WDF was studied in this paper. WDFs were prepared by blending diesel fuel and different gasoline fuels with various RONs (90#, 97# and 100#) which covers the range of commercial gasoline. And the gasoline ratio in this experiment is 50% by volume. The major objective of this paper was to investigate the combustion and emission characteristics of WDFs with various gasoline RONs in premixed LTC mode and to propose solutions to minimize the side effects in WDF combustion.

2. Experimental setup

2.1. Engine and test system

The experiments were performed using a single-cylinder research engine retrofitted from a four-cylinder common-rail compression ignition engine. The engine specifications are listed in Table 1. This engine was equipped with a Delphi six-hole injector with cone angle of 156°. Turbocharger was removed from the engine and an external air compressor was used to supply intake air.

Fig. 1 illustrates the schematic of the engine testing system. In-cylinder pressure was measured with a pressure transducer (AVL GH14P) and combustion pressure data were recorded with the resolution of 0.5 °CA. Combustion analysis data was calculated based on the average cylinder pressure of 250 consecutive cycles. CA10, CA50, and CA90 were defined as the crank angle at which 10%, 50%, and 90% fuel mass fraction was consumed, respectively. Ignition delay was the crank angle interval between Start of Injection (SOI) and CA10. Combustion duration was defined as the crank angle interval between CA90 and CA10.

Gaseous emissions were measured by AVL CEBII pollutants analyzer, while soot emissions were measured by AVL 439 Opacimeter.

2.2. Test fuels

Four fuels were tested in this work, commercial diesel fuel, WDF90, WDF 97, and WDF100. Here, WDF90 and WDF 97 represent the blending fuels of diesel with commercial gasoline with RON of 90 and 97, respectively. WDF 100 is a blending fuel of diesel with isooctane. The blending ratio was 50:50 by volume. The detailed properties of each gasoline and diesel can be found in Table 2. 97# gasoline contents 1.63% oxygen due to the oxygenated octane enhancing additive.

2.3. Operating conditions

All four fuels were tested at the same operating conditions. The operating speed was kept at 1600 rpm and both medium load (0.6 MPa) and high load (1.0 MPa) Indicated Mean Effective

Table 1
Engine specifications.

Compression ratio	16.7
Displacement	0.5 L
Bore	83.1 mm
Stroke	92 mm
Connecting rod length	145.8 mm
Swirl ratio	1.7
Injection pressure	40–180 MPa