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Experimental investigation on the macroscopic and microscopic spray characteristics of dieseline fuel

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ABSTRACT

The application of dieseline fuel (blends of diesel and gasoline) into compression ignition engines has been intensively investigated in recent years due to its good combustion performance and low smoke emissions. In this study, the main objective was to investigate the spray characteristics of dieseline fuel. Macroscopic spray characteristics in terms of spray morphology and penetration were investigated in a constant volume vessel under elevated ambient pressures using high-speed imaging system, while the microscopic spray characteristics including droplet size and velocity distribution were measured at atmospheric condition using Phase Doppler Particle Analyzer (PDPA) system. The results have shown that the gasoline/diesel blending ratio played an important role in affecting the spray atomization process. With the increase of the gasoline/diesel blending ratio, spray penetration length, droplet mean velocity, and droplet Sauter Mean Diameter (SMD) decreased gradually, especially at low injection pressure and low ambient pressure conditions. Both the results of macroscopic and microscopic studies indicate a better atomization quality can be achieved by increasing the proportion of gasoline in the dieseline.

1. Introduction

In recent decades, there is an increasing concern regarding the environmental impact of emissions from internal combustion engines. Furthermore, the emission standard is becoming increasingly stringent in recent years. Compression Ignition (CI) diesel engines have high thermal efficiency but produce a lot of nitrogen oxides (NOx) and soot emissions. To meet the emission legislation, diesel engines have to be equipped with a high pressure common rail injection system and costly after treatment equipment. On the other hand, although the harmful exhaust emissions from Spark-ignition (SI) gasoline engines can be reduced by the implementation of a costly effective three-way catalyst, however, the thermal efficiency of gasoline engines is lower than diesel engines.

Much research has shown that the smoke emissions of diesel engines can be significantly reduced by fuelling the engines with gasoline or gasoline/diesel blends; while the reduction of NO_x can also be facilitated by increasing the exhaust gas recirculation ratio [1–6]. Kalghatgi et al. [1] successfully tested a gasoline fuelled partially premixed compression ignition (PPCI) engine and showed that even at the high load of 15.95 bar indicated mean effective pressure (IMEP), almost zero smoke emissions and a low indicated specific fuel consumption (ISFC) of 179 g/kW h were obtained. Similar findings were also demonstrated by Ciatti et al. [2] and Manente et al. [3]. At the University of Birmingham, researchers investigated the idea of altering fuel characteristics through blending gasoline with diesel and the resulting fuel was named '*Dieseline*' [4–7]. According to the experimental results, dieseline has great advantages over diesel for smoke reduction when being used in both PPCI and conventional diesel engines. Weall and Collings [8] found that the PPCI operating range can be extended by using the dieseline fuel. Yu et al. [9] investigated homogeneous charge induced ignition (HCII) mode by using gasoline–diesel blends and found that soot emission can be significantly reduced by increasing the proportion of gasoline fuel. Similarly, Liu et al. [10] showed that using diesel/gasoline blends can significantly reduce soot emissions at both medium load and high load in low-temperature combustion (LTC) mode.

Both the chemical and physical properties of fuel can affect the combustion performance and emissions of diesel engines. Compared to pure diesel, the lower cetane number of gasoline and dieseline, which increases the ignition delay and mixing time, has definitely contributed to their low smoke emissions [11]. It was demonstrated by Han et al. [12] that the usage of dieseline fuel reduced the dependence of smoke reduction on high injection

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pressure. Zheng et al. [13] conducted an optical study on the combustion process of gasoline–diesel blends in a constant volume vessel and showed that the flame lift-off length increases non-linearly and the soot concentration decreases significantly with the increase of gasoline proportion. Wu et al. [14,15] experimentally studied the combustion characteristics of diesel–gasoline blend fuel in a controllable active thermo-atmosphere and found that the ignition delay decreases as the diesel increases under low temperature. Wu et al. [16] experimentally compared the narrow-band emissions of dieseline and diesel spray combustion in a constant volume combustion chamber and reported that dieseline has a weaker average flame emission intensity than diesel for the 430 nm and 470 nm band with 800 K and 1200 K ambient temperatures. Jeon et al. [17] found that longer ignition delay, shorter combustion duration and significant soot reduction can be achieved in an optical CI engine by using diesel/gasoline blends. The investigations of diesel-like fuels show that the spray characteristics also play an important role in the emission formations of diesel engines [18–20]. For example, over-penetration can cause piston bowl/cylinder wall wetting and thus increase particle, UHC and CO emissions; particle emissions can be effectively reduced with better spray atomization. Payri et al. [21] reported that there was little difference between diesel and gasoline in terms of momentum flux and penetration length (steady region) in a high pressure common rail injection system, independently of the nozzle diameter. Han et al. [22] showed that slightly shorter penetration length and larger spray cone angle for diesel/gasoline blends can be observed at atmospheric pressure and temperature. Similar findings were also reported by Ma et al. [23] and Javier Lopez et al. [24]. Recently, Feng et al. [25] investigated spray and atomization characteristics of diesel/gasoline/ethanol blends in high pressure common rail injection system by using particle/droplet image analysis (PDIA) technique. Their results showed that the increased gasoline fraction in diesel/gasoline blends leads to decreased spray tip penetration and significant smaller average droplet size. Similar results were also found by Park et al. [26].

It can be seen that a series of studies on dieseline fuels have been carried out in terms of their spray and combustion processes. However, most of the spray studies have focused on the macroscopic characteristics, while the study on microscopic characteristics are still comparatively rare. This study compared the macroscopic and microscopic spray characteristics of different dieseline blends. The objective is to further understand the behaviour of the spray and atomization processes of dieseline fuel.

2. Experimental methods

The experimental setup includes fuel injection system, pressure vessels, image acquisition system, Phase Doppler Particle Analyser (PDPA) system and the ventilation system. The schematic of the experimental setup is shown in Fig. 1.

2.1. Fuel injection system

The fuel injection system was pressured by a fuel pump and controlled by electrical pulses, which were generated from the injection trigger unit and amplified by a driver. The 7-hole diesel injector with a nozzle diameter of 0.15 mm was fueled with various dieseline fuels. The fuel pump can provide a high rail pressure up to 1500 bar, however, with the increased ratio of gasoline in dieseline, the injection system cannot achieve its maximum injection pressure since the pump was designed for diesel and it had a lower performance for gasoline. So the maximum injection pressure for G100 was 1000 bar. The rail pressure and the ambient conditions are listed in Table 1.

Five fuels including pure diesel (G0), 20% (G20), 50% (G50), 70% (G70) gasoline blended dieseline and pure gasoline (G100) were tested in this study. The pure diesel and pure gasoline used in the test were the European standard diesel (EN590) and 95 octane gasoline (ULG95). The physical properties of all the five fuels are shown in Table 2.

2.2. Pressure vessels

The spray experiments were carried out in two test rigs, separately. One is the high pressure constant volume vessel (CVV) for macroscopic characteristics studies under elevated ambient pressures, and the other is the low pressure vessel for microscopic characteristics studies. The spray photography tests were carried out in the high pressure CVV which is pressurized by compressed nitrogen gas. Fig. 2 shows a schematic of the design of the high pressure CVV. Four windows were designed for this vessel, three small windows were located on the side and one big window is at the bottom. The size of the visible glass on the small side windows is 40 mm in diameter and the bottom glass is 68 mm in diameter. The optical glass was fixed on the window holders and sealed by heat resistant silicone. This vessel has an 86 mm × 100 mm cylindrical chamber, which aims to simulate the real cylinder of the diesel engine. The left image in Fig. 2 shows

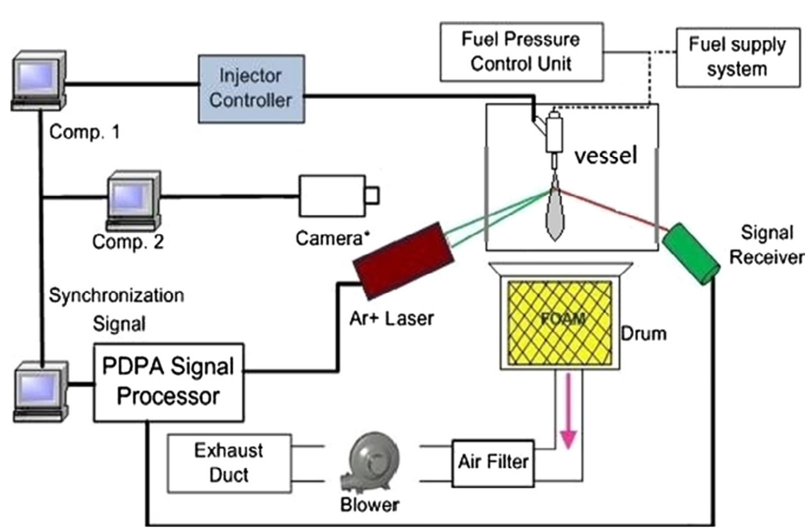

Fig. 1. Schematic of the experimental setup.