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SOOT AND IGNITION INVESTIGATION ON GASOLINE–BIODIESEL BLENDED FUEL IN A CONSTANT-VOLUME CHAMBER

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ABSTRACT

Compression ignition (CI) engines have evolved into one of the world's most capable and reliable forms of motive power for transportation due to high fuel efficiency and high-power output. However, to cope with stringent emission standards, improving the combustion processes, make use of cleaner combustion and implement exhaust gas cleaning systems is necessary. The gasoline biodiesel fuel (GB) blends have the potential to reduce soot formation during the combustion process and will be deeply investigated in this paper. Experiments were performed using 10%, 20%, and 40% blend ratios by volume where both the fuels possess distinct fuel properties to investigate the ignition and soot formation for gasoline biodiesel fuel (GB) blends using an optically accessible constant volume combustion chamber (CVCC). The fuel blends were injected into the CVCC to combust under elevated high pressure-temperature conditions using a single-hole research grade injector. Broadband chemiluminescence technique is utilized to determine ignition characteristics. Natural soot luminous images from the combustible flame were captured by a CMOS camera to determine soot particles during combustion. A wide range of experimental conditions from 800 K to 1200 K and the oxygen concentration 21% was investigated. The experimental observations showed that a higher gasoline content produced a significantly longer ignition delay, thus improving and extending the evaporation process. The combustion properties of gasoline-biodiesel blends are significantly improved with the decrease in gasoline content, and this has the great potential for power generation in the GDI engine. The tests also showed a significant decrease in soot formation for the higher gasoline content.

Keywords: ignition delay, lift-off length, injection pressure, injection duration, oxygen concentration, ambient gas density

1. INTRODUCTION

Over their hundred-year development, compression ignition (CI) engines have evolved into one of the world's most capable and reliable forms of motive power for transportation due to high fuel efficiency and high-power output [1]. To meet stringent emission standards and satisfy the demand of decreasing fuel consumption, engine researchers must continually find new solutions to make engine emissions cleaner. Emissions of nitrogen oxides (NOx), total hydrocarbons (THC), non-methane hydrocarbons (NMHC), and carbon monoxide (CO), particulate matter (PM), and greenhouse gases have been a severe problem that needs to be solved for CI engines [2]. Hence, near-term solutions, including diesel oxidation catalysts, diesel particulate filters, selective catalytic reduction, and lean NOx trap regeneration, have been used to remove the emissions [3]. High costs are an economic barrier against post-treatment techniques, which are applied commonly in IC engines. Additionally, the search for new combustion concepts and diversifying combustion strategies are long-term solutions to reduce pollutant emissions.

Dual-fuel combustion is a potential technology to significantly reduce NOx and soot emissions while maintaining high engine efficiency [4, 5]. The results show that fuel consumption was simultaneously improved; in particular, NOx and soot emissions experienced over 90% reduction by using gasoline-diesel dual-fuel combustion.Adams et al. [6] used GB blends at 5% and 10% biodiesel content with the partially premixed, split-injection combustion strategy to improve the engine operating range, obtain stable combustion, and reduce the intake temperature requirement. Yanu et al. [7] used GB blends at 5%, 10%, 15%, and 20% biodiesel in combination with a change in the injection strategy, EGR, and boosting pressure to investigate an optimal area of the GB blends. The authors found some good results, i.e., as combustion efficiency increased up to 98%, THC and CO emissions were reduced 50% in comparison with diesel fuel.

However, there are not enough detailed results on the spray combustion of GB blends. In this work, the effects of a wide range of experimental conditions on the ignition characteristics and soot formationof the gasoline-biodiesel blend under diesel-like engine conditions were investigated using the CVCC. The ambient temperature varied in the range of 800 K to 1200 K to represent real engine operating conditions and 21% oxygen. The other parameters were kept constant. By using the broadband chemiluminescence technique and direct imaging, the ignition behavior and soot formation were methodically analyzed for gasoline-biodiesel blends. This experimental study expands the understanding of spray combustion of gasoline-biodiesel blends and provides detailed experimental data to promote the application of the gasoline-biodiesel blends in diesel engines.

2. EXPERIMENTAL SETUP AND MATERIAL

2.1 Constant-volume combustion chamber

The scheme of the CVCC apparatus implemented in the experiments is illustrated in Fig. 1. A self-written LabVIEW-program was used to control the filling procedure via the PID method as a filling program. A pressure transducer (4045A50) is used to measure the in-chamber pressure as feedback to the filling program during the filling process. A high-frequency pressure transducer (Kistler, 6056A) coupled with a charge amplifier (5010B) is installed to measure the in-chamber pressure. The chamber wall is preheated up to 343 K to ensure complete combustion of the premixed charge gases. Eight heater elements are installed longitudinally with a PID temperature controller to maintain the wall temperature.

The fuel system is a common-rail direct fuel injection system that features a peak and holds injector driver (ZB-5100), a common-rail injection pressure controller (ZB-1100), pressure control valve, rail pressure sensor, high-pressure pump, low-pressure pump, and a single-hole with a nozzle tip of 0.2 mm. The pressure controller is used to manage the fuel pressure through the pressure control valve up to 1800 bar. Additionally, a LabVIEW program installed on the NI computer is used to control the injection timing and injection duration by using feedback from the pressure sensor installed in the chamber.

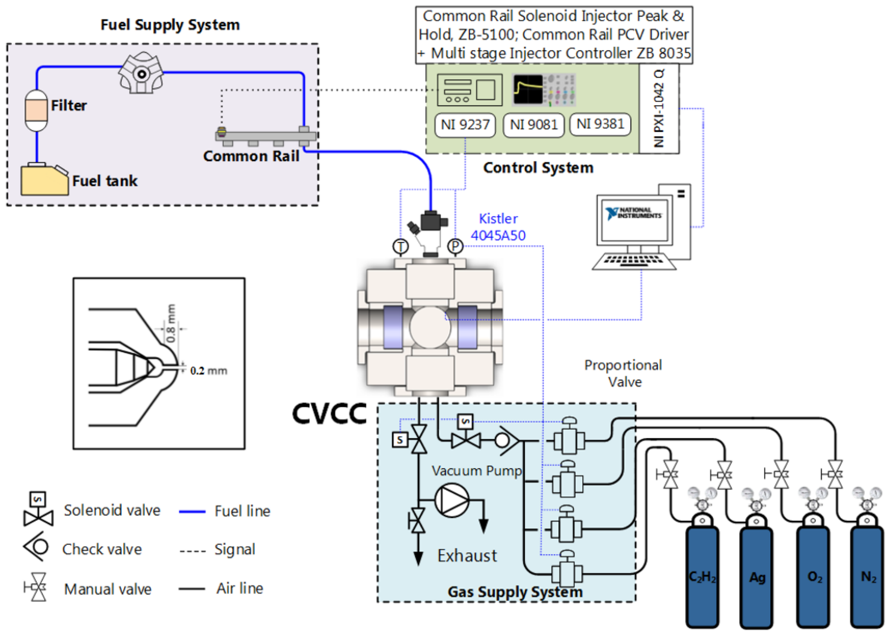

Fig 1 Schematic of the CVCC apparatus implemented in the experiments

2.2 Fuel and test matrix

Table 1: Physical properties of gasoline, biodiesel, GB10, GB20, and GB40.

Property	Unit	Test method	GB00	GB10	GB20	GB40	B100
Density at 15 °C	kg/m^3	KS M ISO 12185:2003	712.7	732.2	757.1	789.3	882.3
Lubricity	µm	KS R ISO 12156-1:2012	548	282	236	212	189
Cloud point at 15 °C	15 °C	KS M ISO 3015:2008	−57	−32	−16	−8	3
Pour point	°C	ASTM D6749:2002	< −57	< −57	< −57	< −57	< 1
Kinematic viscosity at 40 °C	mm^2/s	KS M ISO 3104:2008	0.735 [26]	1.0844 [27]	1.4338 [27]	2.1326 [27]	4.229
Heating value	MJ/kg	ASTM D240:2009	45.86	44.92	43.6	43.6	39.79
Surface tension at 20 °C	mN/m	ASTM D971:2009	21.56 [28]	20.26 [29]	21.53 [29]	24.07 [29]	31.7 [30]
Stoichiometric air-fuel ratio	–		14.7	14.488	14.276	13.852	12.58
Blend ratio	–		1.0	0.90	0.80	0.60	–

In this study, the fuel examples are GB10, GB20, and GB40, which is a mixture of conventional unleaded gasoline and biodiesel at 10%, 20% and 40% percent biodiesel by volume. The gasoline is produced by a network of S-oil in South Korea. Biodiesel refers to an alternative fuel which synthesized from soybeans in this study. The physical properties of pure gasoline and pure biodiesel, which are used as a base for the GB10, GB20, and GB40 blend, were measured via K-Petro in South Korea, as provided in Table 1.

2.3 Ignition delay

The ignition delay is determined as the time interval between the fuel injection and the fuel ignition. The method is based on a bright spot appearing on the combustion image. The bright spot, which is considered

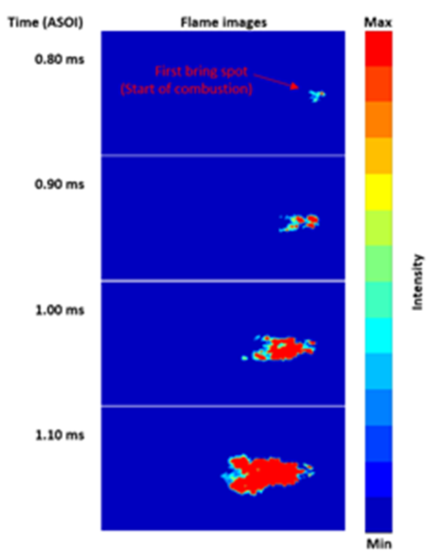

Fig2 Images of the spray combustion evolution sequence

as the start of combustion, is where the flame kernel actually develops. This definition of luminous ignition delay is illustrated in Fig 2.

2.4 Combustion Intensity

Figure 3 demonstrates the picture average intensity history during a fuel combustion spray. For all pictures during the combustion sequence, the averaged intensity value was calculated and plotted over the time scale. This diagram gives information about the qualitative soot formation during combustion.

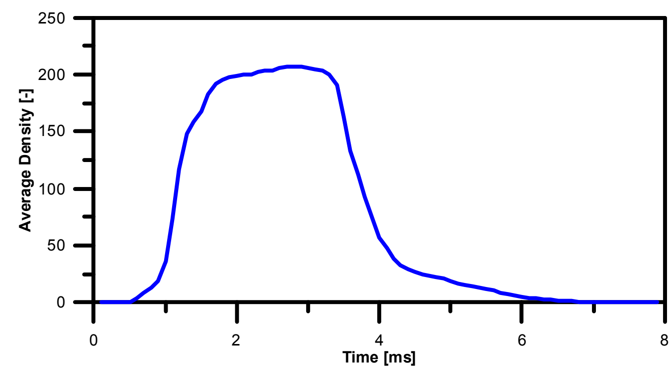

Fig 3Averaged picture intensity history for GB10 at 1200K

3. RESULTS AND DISCUSSION

Combustion Intensity

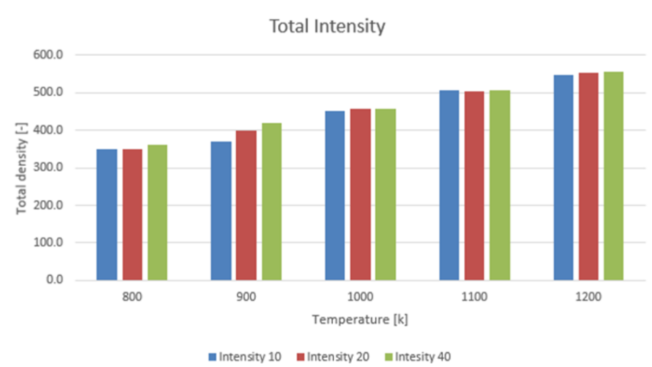

Fig 4Total intensity history for GB10, GB20, and GB40 blends

In Fig 4 the total intensity for 800 bar, 15 kg/m^3 of density, and a wide temperature range from 800K to 1200K presented a compare to each fuel example. All fuel examples following the same trend of increasing of the soot radiation intensity with the increase ofambient temperature. However, the GB10 had the lowesttotal intensity due to longer Ignition delay, thus improving the mixing process.

Ignition characteristic

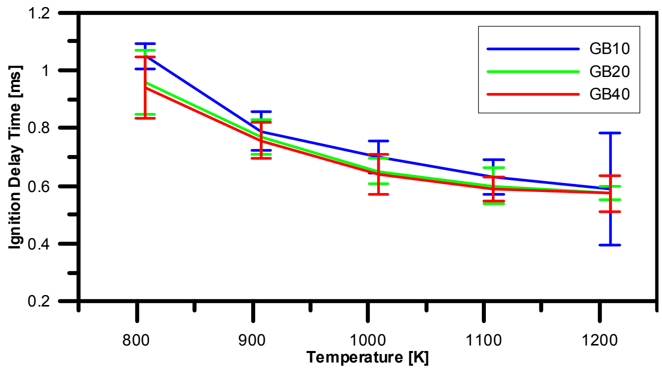

Fig 5Ignition delay time for GB10, GB20 and GB40 blends at various ambient temperatures

Fig5presentsGB10 has longer ignition delays than the other blends under all ambient temperature due to its higherRON and MON. The ignition delay of GB10 is significantly longer than GB20 and GB40. It is the reason why the GB10 had lower luminosity during combustion process than others.

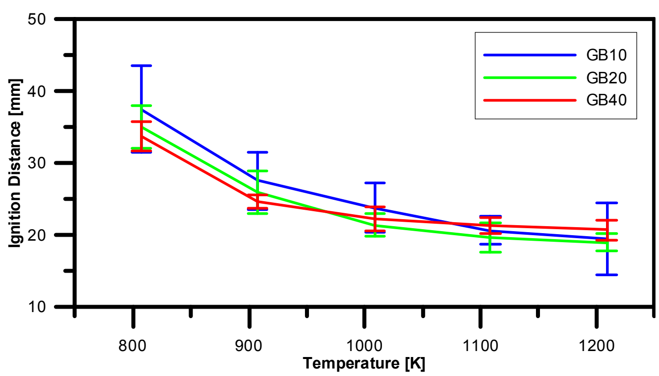

Fig 6Ignition distance for GB10, GB20 and GB40 blends at various ambient temperatures.

The ignition distance for all fuel blend at various ambient temperatures is shown as Fig. 6. Generally, the addition of biodiesel would significantly decrease the ignition distance under all test conditions due to the decrease of ignition delay. However, for GB40 ignition distance is father than GB10 and GB20. A plausible explanation for this increase is the size of fuel droplets and the mixing process of fuel and air in the combustion chamber. The increase in low-volatility and high-viscosity biodiesel produced bigger fuel droplets and hindered the mixing which leads to higher momentum in the fuel spray; the combustion region therefore moves further downstream and the ignition distance increases.

4. CONCLUSIONS

A series of experiments was performed to measure and analyze three different blended fuels. Following observations, the main conclusions can be obtained as follows:

- The ignition delay of GB10 is significantly longer than GB20 and GB40. Therefore, it presented the lower luminosity during the combustion process.

- The increase biodiesel leads to higher soot information due to shortening ignition delay, thuspoorer mixing process. Therefore, a small biodiesel addition is required to improve the auto-ignition delay of the blends while maintaining enough longer ignition delay to obtain good air-fuel mixing process which reduces soot emission.

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