

Spray and Combustion Characteristics of Ethanol Blended Gasoline in a Spray Guided DISI Engine under Lean Stratified Operation

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ABSTRACT

An experimental study was performed to evaluate the effects of ethanol blending on to gasoline spray and combustion characteristics in a spray-guided direct-injection spark-ignition engine under lean stratified operation. The spray characteristics, including local homogeneity and phase distribution, were investigated by the planar laser-induced fluorescence and the planar Mie scattering method in a constant volume chamber. Therefore, the single cylinder engine was operated with pure gasoline, 85 %vol, 50 %vol and 25vol % ethanol blended with gasoline (E85, E50, E25) to investigate the combustion and exhaust emission characteristics.

Ethanol was identified to have the potential of generating a more appropriate spray for internal combustion due to a higher vapor pressure at high temperature conditions. The planar laser-induced fluorescence image demonstrated that ethanol spray has a faster diffusion velocity and an enhanced local homogeneity. In comparison to the iso-octane spray from the planar Mie scattering images, ethanol spray was verified to have a smaller liquid phase area in the spark plug position. This is an indication for ethanol spray to feature a faster vaporization and this to be more suitable for stable ignition.

With gasoline, the retardation of the injection timing was limited to 24 crank angle degree (CAD) before top dead center (TDC) because a locally rich mixture at high ambient pressure. With ethanol blending, the injection timing could be retarded closer to the TDC as the ethanol content increased. These results can be explained by the faster vaporization and

enhanced local homogeneity of ethanol. As a result, a higher IMEP was achieved by retarding the combustion phase near to the TDC. The NO_x emissions were decreased with ethanol blending due to the lower peak of in-cylinder temperature by the combustion retardation. Ethanol-blended gasoline also showed less smoke emission due to the reduced local enrichment region and the kinetic characteristics of ethanol as an oxygenated fuel.

INTRODUCTION

In order to reduce hazardous emissions and to increase fuel economy, the automobile industry has focused on direct-injection spark-ignition (DISI) engines. In the early and mid 2000's, a wall-guided DISI engine, using the internal flow driven by the piston bowl and the spray for the stratified mixture preparation, was researched actively [1]. However, the stratified combustion of the wall-guided DISI engine showed unstable combustion characteristics at different engine operation conditions because the internal flow sensitively varies with the operating conditions of the engine [2]. In addition, fuel collision with the piston resulted in hydrocarbon (HC) and smoke emissions. For this reason, many of the recent studies on the DISI engine are mainly focused on the spray-guided DISI engine, which uses the spray momentum to prepare the stratified premixed mixture [3].

On the other hand, ethanol is widely used as an alternative fuel or an effective additive of gasoline due to the advantage of its high octane number and its 'self sustaining' concept, which can be supplied regardless of the fossil fuel [4]. Thus, many studies on the DISI engine were conducted with

ethanol as an alternative or additive fuel to the gasoline focused mostly on the stoichiometric operation condition [5, 6]. Recently feasibility research of ethanol blended gasoline for spray-guided DISI engine under stratified operation focused on combustion [7] and spray characteristics [8] were reported. However, the characteristics of the lean stratified combustion of the DISI engine using ethanol are not completely investigated. In this study, the spray and combustion characteristics of ethanol-blended gasoline under the lean stratified operation in a spray-guided DISI engine were discussed.

EXPERIMENTAL APPARATUS

SPRAY VISUALIZATION

A schematic diagram of the optical diagnostic system for spray visualization is shown in Fig. 1. The spray images were taken by planar laser-induced fluorescence (PLIF) and planar Mie-scattering. Optical access to the pressure chamber was available through three window glass. The chamber was pressurized with nitrogen at room temperature. The incident light laser beam was provided by Nd-Yag laser (Spectra Physics), operating at 10 Hz repetitions in the external trigger mode. The laser beam was formed into a collimated laser sheet with a cylindrical lens. The 4th harmonic wavelength (266 nm) was used for the fluorescence and Mie scattered light source. An ICCD (Princeton Instruments) camera captured the fluorescence and the Mie scattered light with a 512×512 pixels spatial resolution and 10 μ s of exposure time through the perpendicular window of the chamber.

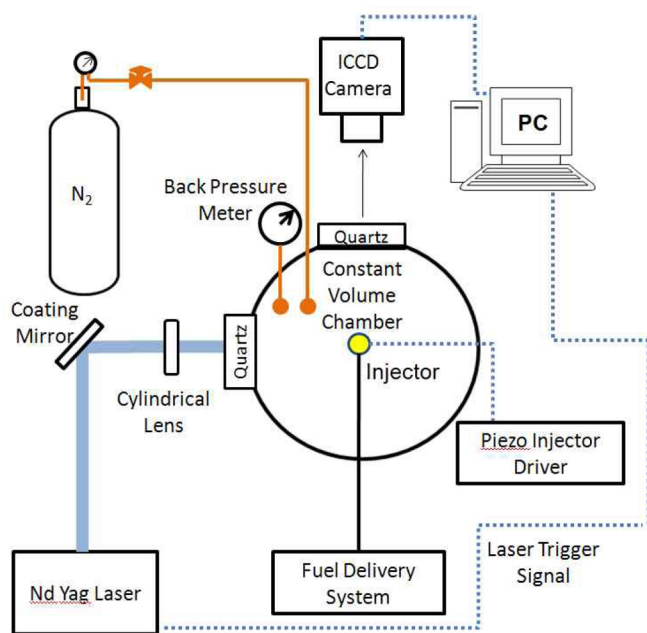


Figure 1. Schematic diagram of experimental set up for PLIF and planar Mie scattering imaging

For PLIF and Mie scattering visualization, a single-component base fuel-tracer mixture was used to simulate the gasoline and ethanol spray behavior. Isooctane was selected as a surrogate fuel of gasoline. 20%vol of 3-pentanone was mixed in the isooctane to produce a fluorescence signal, as suggested in earlier studies [9, 10]. In the same way, 20%vol of acetone was used as a co-evaporating fuel tracer for the ethanol spray visualization as suggested in a previous study [11]. Feasibility of these fuels was discussed in early studies [11, 12]. These tracers and their concentration were suggested as the optimal solution for tracking the fuel distribution correctly, showing almost non-varying fluorescence during the evaporation process as well as substantial similarity to physical properties of real fuels. The physical properties of each fuel and tracer are summarized in Table 1. The PLIF image of each fuel should be corrected because of the fuel tracer fluorescence intensity differences. The correction was executed with the assumption that the integrated signal of the image taken after the end of injection (EOI) is proportional to the injection quantity of each fuel. Eq. (1) adjusts the contrast of the ethanol PLIF image.

$$IMG_{ethanol} = IMG_{raw, ethanol} \times \frac{\sum_{i,j} I_{ethanol,EOI}(i,j)}{\sum_{i,j} I_{isooctane,EOI}(i,j)} \times \frac{\dot{m}_{ethanol}}{\dot{m}_{isooctane}} \quad (1)$$

Table 1. Properties of fuels and tracers for PLIF and planar Mie scattering

Isooctane fuel (representing gasoline)		
properties	fuel	tracer
Chemical Species	iso-octane	3-pentanone
Chemical formula	C ₈ H ₁₈	C ₅ H ₁₀ O
Molecular weight [kg/kmol]	114.23	86.13
Boiling point @ 1atm [°C]	99.25	102
Density (Kg/m3)	0.688	0.814
Ethanol fuel		
properties	fuel	tracer
Chemical Species	ethanol	acetone
Chemical formula	C ₂ H ₅ OH	OC(CH ₃) ₂
Molecular weight [kg/kmol]	46.07	58.08
Boiling point @ 1atm [°C]	78	56.53
Density (Kg/m3)	0.692	0.79

$IMG_{ethanol}$ represents the corrected ethanol PLIF image, $IMG_{raw,ethanol}$ is the raw image of ethanol PLIF, $\dot{m}_{ethanol}$ and $\dot{m}_{isooc \tan e}$ are the injection quantities of each fuel [mg/stroke], $I_{ethanol,EOI}(i,j)$ and $I_{Isooc \tan e,EOI}(i,j)$ are the intensities at pixel i,j of images taken after EOI.

RESEARCH ENGINE

A single-cylinder spray-guided DISI engine with a piezo actuated outward opening injector (Continental) was used to test the combustion and emission characteristics. Gasoline, E25 (25%vol of ethanol blended in gasoline), E50, and E85 were tested. The engine specifications are listed in [Table 2](#). The schematic diagram of the experimental setup is shown in [Fig. 2](#).

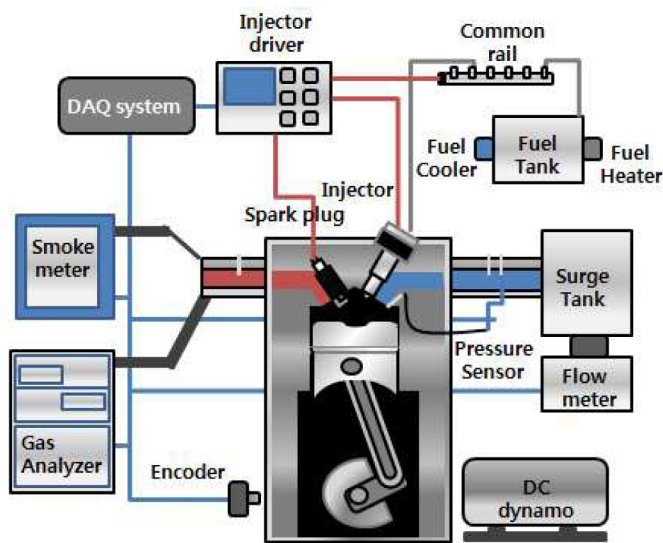


Figure 2. Schematic diagram of engine experimental set up

Table 2. Engine specification

Bore×stroke [mm]	85×88
Compression ratio	12:1
Engine type	Spray guided DI, DOHC
Intake valve timing	ATDC11~ ABDC 22
Exhaust valve timing	34 BBDC ~ 10 ATDC
Injector type	piezo outward opening
Injector mount	Central

Table 3. Fuel property of gasoline and ethanol

Property	gasoline	ethanol
Viscosity @ 203 K [cp]	2.92	1.20
Density @ 15 °C [g/cm3]	0.737	0.797
RVP @37.8°C [kPa]	61	15.5
Boiling point [°C]	-	77.6
Latent heat vaporization [KJ/Kg]	422	846
Stoichiometric AF ratio	14.7	9.0
RON	96.4	111
Oxygen content [%]	0	0.49
Lower Heating value [MJ/Kg]	43.05	26.90
Aromatics vol [%]	27.6	0
Flammable limit [%vol]	1.4-7.7	3.3-19.0

The engine speed was controlled constantly by a DC dynamometer. A programmable injector driver controlled the fuel injection parameters, including injection pressure, quantity, and timing for the common-rail system (Zenobalti Co., IDU 5000B). A rotary encoder (Autonics, 3600 pulses/revolution) mounted on the crankshaft, was used to control the fuel injection timing. The in-cylinder pressure was recorded with a piezoelectric pressure transducer (KISTLER, 6043Asp). Recording was done with a step size of 0.1 crank angle degree (CAD). After measurement of 100 engine cycles, the average was used to calculate the heat release rate and indicated mean effected pressure (IMEP).

EXHAUST GAS MEASUREMENT

The gaseous emissions were analyzed with an exhaust gas analyzer (HORIBA MEXA 1500D) that contains a nondispersive infrared absorption (NDIR) analyzer to measure carbon monoxide (CO) and carbon dioxide (CO₂), a chemiluminescence detector (CLD) to measure nitrogen oxides (NO_x), and a flame ionization detector (FID) to measure HC. A smoke meter (AVL, 415S) was used to measure smoke emission in filtered smoke number (FSN). Part of the exhaust gas flow is sampled by means of a probe in the exhaust line and drawn through a filter paper. The resultant blackening of the filter paper is measured by a reflectometer and represents a measure of smoke content in the exhaust gas. FSN of 1 corresponds to a concentration of 17.84 mg/m³ at the sampling point. The resolution of this device is 0.001 FSN and 0.01 mg/m³.