Fuel 166 (2016) 42–50

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Ion current signal and characteristics of ethanol/gasoline dual fuel HCCI combustion

Yintong Liu, Liguang Li *, Junyu Ye, Jun Deng, Zhijun Wu

School of Automotive Studies, Tongji University, 4800 Cao'an Road, 201804 Shanghai, China

HIGHLIGHTS

- Ethanol/gasoline dual fuel HCCI combustion is achieved by PFI and GDI.
- The enhancement effects of GSOI on combustion and IC signal are studied.
- Adjusting GSOI and X_{EtOH} can advance IC signal detection timing effectively.

ARTICLE INFO

Article history:
Received 9 February 2015
Received in revised form 18 August 2015
Accepted 20 October 2015
Available online 2 November 2015

Keywords:
HCCI
Ethanol
Dual fuel
Ion current

ABSTRACT

Ion current (IC) is a novel and feasible method for the diagnosis of in-cylinder combustion. The improvement of IC signal quality and reliability is always a challenge before it is applied as a sensor of engine combustion. In this paper, the characteristics of homogeneous charge compression ignition (HCCI) and IC signal with ethanol/gasoline dual fuel have been presented. The results show that increased ethanol mass fraction X_{EtOH} retards and weakens both combustion and IC signal, with extending the phase difference ($\Delta\theta_{IC}$) between start of ion current (SOIC) and CA_{50} (crank angle of 50% heat release). The delayed start of gasoline injection (GSOI) enhances combustion and IC signal, but the effect is declined when X_{EtOH} increases. This result provides a balance achieving both better quality and wider misfiring diagnosis window of IC signal. The CFD simulation results present the differences between in-cylinder local and global ion concentration with different X_{EtOH} and GSOIs. According to the spatial distribution of electrons during the combustion, delayed GSOI causes more concentrated ionization and smaller difference between local and global start of electron appearance (SOEA).

1. Introduction

Homogeneous Charge Compression Ignition (HCCI) is considered as a feasible combustion mode achieving the requirements of the extremely stringent emissions regulations. Because the lean premixed air–fuel mixture causes low combustion temperature, HCCI combustion mode has extremely low NO_X and PM emissions [1–3]. However, as HCCI is directly caused by the fuel auto-ignition, the combustion process of HCCI is fast and unpredictable. Auto-ignition is mainly influenced by chemical kinetics and leads to challenges in the combustion control [4,5]. Although many technologies, such as intake air heating system, exhaust gas recirculation (EGR), intake/exhaust boost, and spark assistance, are utilized achieving reliable HCCI combustion [6–8], the reference signal of control in these technologies is still mainly based on cylinder pressure signal which is expensive.

Ion Current (IC) is closely related to combustion and reflects the real-time combustion state inside cylinder with much lower costs than cylinder pressure [9]. The studies show that the ionization process in the flame is based on chemical mechanism, and demonstrate the correlations among the parameters of combustion and IC signals [10–12]. In this case, IC signal has been used as a feasible feedback signal for closed-loop combustion control. However, the IC sensor detects a local concentration of ion production instead of global concentration, which is different from pressure sensor. Therefore, IC still has difficulties in utilization for most of HCCI working conditions due to the lean combustion that makes the IC signal weak [13].

Besides the difficult combustion timing control, HCCI application is also limited by the narrow speed and load range [14]. The

Abbreviations: ATDC, after top dead center; DI, direct injection; GSOI, start of gasoline injection; HCCI, homogeneous charge compression ignition; IC, ion current; PFI, port fuel injection; SOEA, start of electron appearance; SOIC, start of ion current.

* Corresponding author.
E-mail address: liguang@tongji.edu.cn (L. Li).

http://dx.doi.org/10.1016/j.fuel.2015.10.082
0016-2361/

Nomenclature

CA_{10}	crank angle of 10% heat release	X_{EtOH}	mass fraction of ethanol-in-gasoline
CA_{50}	crank angle of 50% heat release	$dI/d\theta$	differential of ion current signal
I_{Vmax}	peak of ion current signal voltage	θ_{dI}	crank angle of $dI/d\theta$ peak
P_{max}	peak of combustion pressure	$\Delta\theta_{IC}$	phase difference between SOIC and CA_{50}
Q_t	total energy of fuel per cycle	λ	excess air index

technologies such as intake boost, EGR, and alternative fuel have been employed extending HCCI operation range [15]. As ethanol is one of the main alternative fuels with higher octane number and thus better anti-knock performance, ethanol has also been investigated for HCCI combustion [16,17]. In spite of delayed auto ignition, ethanol is still not the perfect fuel for HCCI as it requires higher temperature for reliable auto-ignition. Therefore, ethanol has been mixed with diesel or gasoline for HCCI achieving repeatable auto-ignition [18].

In this paper, the HCCI combustion characteristics with ethanol/gasoline dual fuel are investigated in a modified HCCI test engine. Ethanol is port fuel injected (PFI) and gasoline is directly injected (DI) into cylinder. In this case, both the combustion states and the ion current signals are studied with different amounts of ethanol and gasoline. CFD simulations analyze the spatial and temporal distribution of electrons.

2. Engine test bench

The test engine is based on a 2-cylinder diesel engine. The compression ratio is reduced from 17 to 11.5. The schematic diagram of the test bench is shown in Fig. 1. The specifications of the engine are shown in Table 1. Ensuring the fuel–air mixture ignited reliably, an intake air heater is installed in front of the throttle body, which can warm up the air to a maximum temperature of 300 °C. Freescale MC9S12X series chip is employed as control unit core. Achieving faster response of DI injector, the drive voltage is set as 60 V. As two different fuels are injected in this experiment, two separate fuel supply systems are established. The PFI pressure of ethanol is set as 0.3 MPa and the DI pressure of gasoline is set as 8 MPa. The cylinder pressure is measured by a Kistler 6125B piezoelectric pressure sensor, with a Kistler 5007 charge amplifier. HC and NO_X emissions are measured by the fast response emissions analyzers: HFR500 for HC and CLD500 for NO_X, both from Cambustion LLC. The IC signal is measured by self-built IC detection system. All the signals are sampled with NI PCI-6250 high-speed data acquisition.

3. Ion Current (IC) sensing principle

During combustion, ionization reactions occur in the flame. The major reactions which are believed responsible for the production of electron and H_3O^+ from hydrocarbon fuel are shown as following [19],

$$CH + O \rightarrow CHO^+ + e^- \tag{1}$$

$$CHO^+ + H_2O \rightarrow H_3O^+ + CO \tag{2}$$

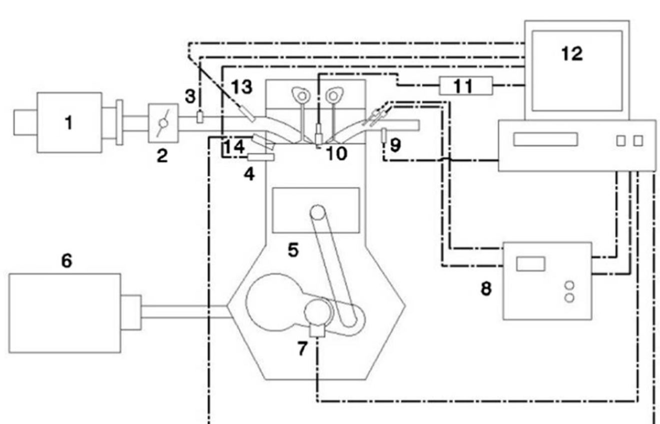
$$H_3O^+ + e^- \rightarrow H_2O + H \tag{3}$$

$$H_3O^+ + e^- \rightarrow OH + H + H \tag{4}$$

$$CHO^+ + e^- \rightarrow CO + H \tag{5}$$

Table 1
Test engine specifications.

Item	Value
Displacement (cc)	808
Bore (mm)	95
Stroke (mm)	114
Compression ratio	11.5
IVO (°CA BTDC)	17
IVC (°CA ABDC)	43
EVO (°CA BBDC)	47
EVC (°CA ATDC)	17
Injection type/fuel	Port fuel injection/99.5% ethanol Direct injection/RON #93 gasoline



1 – Intake Heater; 2 – Throttle; 3 – Air Temperature Sensor; 4 – Cylinder Pressure Sensor
5 – Test Engine; 6 – Dynamometer; 7 – Crank Position Sensor; 8 – HC & NOx Analyzer
9 – Oxygen Sensor; 10 – Spark Plug; 11 – IC Sensing System; 12 - Computer
13 – PFI Injector; 14 – GDI Injector

Fig. 1. Schematic diagram of HCCI test bench.