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Research Article

Injection Characteristics of Gasohol using a Common Rail Injection System

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Abstract: The worldwide emission regulations for compression ignition (CI) engines have become more stringent driven by global warming issues and public health concerns. A promising solution to decrease greenhouse gas and emissions from CI engines is gasohol considered as a fuel-replacing diesel. The objective of this study is to study effect of gasohol on fuel injection characteristics of a common rail injection system used in CI engines. Gasohol E85, containing 85% ethanol and 15% gasoline, is tested and conventional diesel is a reference fuel. An injection measurement device based on Zeuch method was used for investigating the injection characteristics including injected amount and discharge coefficient. Gasohol were injected with both single and double injection strategies at a constant injection pressure of 450 bar into a back-pressure of 40 bar. The findings of this study clearly show that injection characteristics of gasohol were significantly differed from those of diesel, due to physical properties changed. At the same injection conditions, injected fuel rate are different.

Keywords: Gasohol; Fuel Injection Characteristics and Common Rail Injection System.

1. Introduction

Nowadays, the stringent emission regulations drive the development in internal combustion engines. For the diesel engines, it is difficult to meet the stringent regulations, because of the simultaneous reduction of soot and oxide of nitrogen. With this issue, the homogeneous charge compression ignition (HCCI) was proposed to operate with a fully premixed and lean charge resulting ultralow soot and NO_x (Thring, 1989). Though HCCI has potential to control the emissions, the efficiency at high load suffered from combustion controllability and excessive rate of heat release (Hasegawa and Yanagihara, 2003 ; Sjöberg and Dec, 2006 ; Yao et al, 2009) . To eliminate the limitation at high load of HCCI, the partially premixed combustion (PPC) was introduced. PPC allows partially premixed air-fuel charge. The advantages are a better fuel-air mixing compared to diesel engines, and a better combustion controllability at extended load compared to diesel engines, resulting in high efficiency and low emissions. Recent works showed that PPC could be operated efficiently in a wide range of engine load with the high octane number petroleum based fuels (Johansson, 2015 ; Noehre et al, 2015 ; Hanson et al, 2009 ; Kalghatgi et al, 2006 ; Kalghatgi et al, 2007 ; Hildingsson et al, 2010 ; Manente et al, 2011). The fuel for PPC is a gasoline with octane number in the range of 70 [11]. Ethanol-gasoline blended fuel, known as gasohol, is considered as a more sustainable and friendly-environmental energy compared to the conventional gasoline. Gasohol can reduce consumption of petroleum-based fuel and greenhouse gas emissions. For PPC, gasohol showed the promising and positive results at high and half load (Manente et al, 2009a ; Manente et al, 2009b ; Manente et al, 2010; Dec et al, 2015). Nevertheless, PPC at low load meets late combustion phasing, high hydrocarbon emissions and high cycle-to-cycle variation (Manente et al, 2011). To overcome the principal difficulties on PPC at low loads, the fuel injection strategy (Kaiadi et al, 2013; Rousselle et al, 2013; Labreche et al, 2009; Munsin et al,

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2017) is one of solution by changing local temperature and equivalence ratio in the combustion chamber. Some works (Kaiadi et al, 2013; Rousselle et al, 2013; Labreche et al, 2009) showed that double injection strategy should be favored for PPC at low loads. It showed good controllability, high efficiency, low emissions and low level of combustion noise.

PPC is intensively studied using the common rail injection system that is only possible to perform the multiple fuel injection schemes. In this combustion regime, fuel is early injected during the compression stroke to form a partially premixed air-fuel charge. With early injection, high injection pressure is not necessary for PPC, because it has enough time for mixing. In addition, high injection pressure enhances impinging on the walls caused high HC. To operate PPC with alternative fuels replacing conventional petroleum-based fuels, the measurements of injection characteristics, i.e. injection delay, injection rate and discharge coefficient, are required. Change of fuel properties results the different fuel injection characteristics in the common rail injection system. Fuel injection characteristics can be obtained by using Zeuch method, which injects fuel into a constant volume chamber filled with the same fuel at a certain pressure, and fuel pressure trace is used to calculate the rate of injected fuel. Zeuch method showed the precise and acceptable results (Bower and Foster, 1991). From previous studies, most of them focused on the injection measurement of diesel (Ikeda et al, 2001; Benajes et al, 2005; Marcic, 2006) biodiesel (Srichai et al, 2018) and some on high octane number fuels, e.g. gasoline (Payri et al, 2012) and ethanol (Munsin, 2015). However, there is no work, which investigate the injection characteristics of gasohol using the common rail injection system, especially at the low injection pressure. A knowledge gap exists in this area. Therefore, the objective of this work is to investigate injection characteristics of gasohol using the common rail injection system. The results are expected to be relevant to PPC operation and provide extended data in the area of analysis on the injection characteristics of gasohol.

2. Methodology

Injection characteristics including injection rate, injection delay and discharge coefficient are studied. Injection rate measurements are performed by Zeuch's measuring method (Bower and Foster, 1991; Marcic, 2006). With this method, the test fuel is injected into a constant volume chamber filled with test fuel at a certain pressure. The chamber pressure is increased in proportion to the injected fuel. Using bulk modulus of elasticity of the fuel and the conservation of mass, injection rate can be estimated by Eq. (1).

$$dm/dt = \rho_f (V/K)(dP/dt) \qquad (1)$$

where

ρ_f Fuel density (kg/m^3)

V Chamber volume (m^3)

K Modulus of compressibility (Pa)

dP/dt Rate of pressure changed (Pa)

A typical fuel injection rate profile can be divided into four stages, i.e. injection delay, needle opening (transitional zone), stabilized zone and needle closing (transitional zone). The injection delay is the period between start of energizing (SOE), i.e. supplying voltage for injector, and start of injection (SOI) where injection rate recover from the negative value. More details of injection rate are explained in (Munsin et al, 2015).

2.1 Experimental Setup

A system using Zeuch method for fuel injection rate is shown in Fig. 1. It consists of common rail injection system, hand pump, constant volume chamber and data acquisition. For common rail injection system, pump is driven by a motor to generate high pressure and deliver fuel to the common rail and injector. Then the injector is energized by a controller with the setting conditions, e.g. injection pressure, energizing time and dwell time.

Before the experiments using test fuels, the modulus of compressibility was calibrated with a pneumatic driven plunger (Munsin, 2015). To find injection rate, test fuel is filled into the constant volume chamber by hand pump until reach the desired pressure measured by a static pressure transducer. Then test fuel is injected by an injector, resulting in a steep pressure rise measured by a dynamic pressure transducer. The injection rate (dm/dt) can be calculated by replacing the measured dynamic pressure trace in Eq. (1).

2.2. Experimental condition

Table 1 shows the experimental conditions. To focus on the effect of fuel on injection characteristics under partially premixed combustion condition with low injection pressure, back-pressure (pressure in the chamber) and fuel injection pressure were kept constant at 4 MPa and 45 MPa, respectively, and were used consistently for all experiments. Test fuels are diesel and gasohol E85, which is a blended fuel between 85% ethanol and 15% gasoline. Properties of test fuels are shown in Table 2. Test fuels are injected via a six hole nozzle with diameter of 0.14 mm. The single and double injection strategies are used. The injection signal for both strategy is shown in Fig. 2. For double injection strategy, the first injection and dwell time are varied. The results of fuel injection were averaged from 10 tests to analyze uncertainty and repeatability.

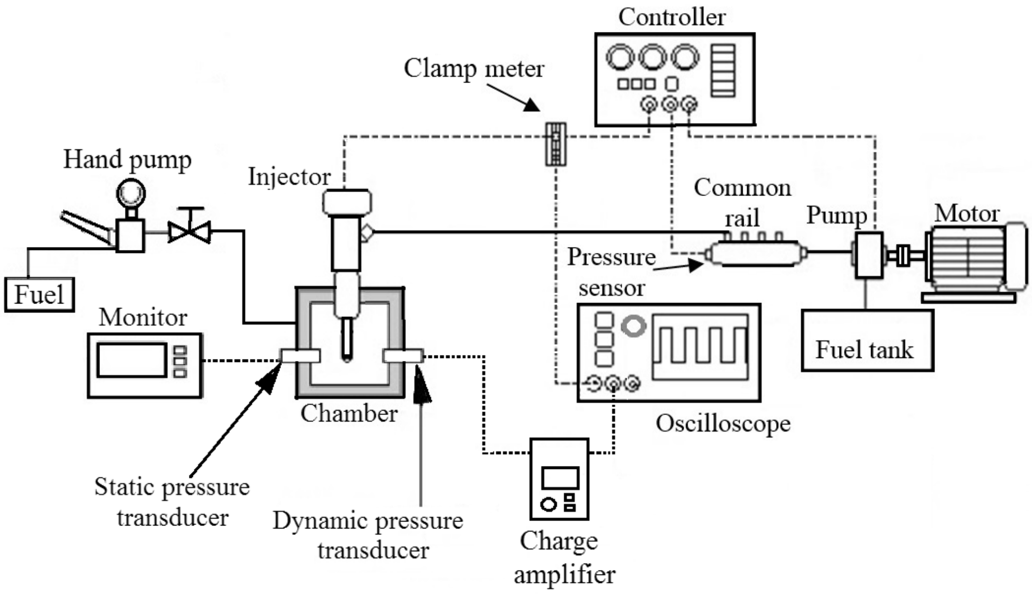

Fig. 1 Fuel injection meter using Zeuch method.

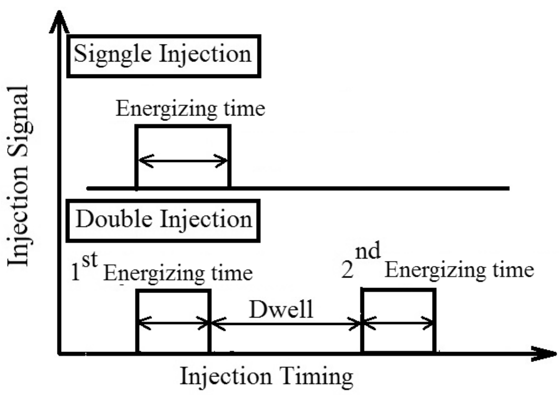

Fig. 2 Injection signal for different injection strategy.

Table. 1 Experimental conditions

Surrounding condition	Value	Unit
Back-pressure: P_b	4	MPa
Injection conditions		
Nozzle hole no.	6	holes
Hole diameter: ϕ	0.14	mm
Injection pressure: P_{inj}	45	MPa
Test fuels	Diesel/E85	-
Injection strategy		
Single injection		
- Energizing time	1, 2	ms
Double injection		
- 1st Energizing time	1, 1.5	ms
- Dwell time	1, 2	ms
- 2nd Energizing time	1	ms

Table 2. Properties of test fuels

Test Fuels	Density @40°C (kg/m^3)	Viscosity @40°C (cSt)	Modulus of compressibility at 4 MPa (GPa)
Diesel	820	2.38	1.27
E85	767	1.09	1.09

3. Results and Discussions

In this section, the results concerning the experimental setup mentioned above are presented. Test parameters in Table 1, i.e. test fuels and injection strategy, for all tests have been carried out. For single injection, energizing time is varied, while double injection varied 1st energizing time and dwell time.

3.1 Single Injection

Injection rates of test fuels using single injection with the different energizing times of 1 and 2 ms at a constant injection pressure of 45 MPa and a constant back-pressure of 4 MPa are shown in Fig. 3 (a) and (b), respectively. The time after start of energizing is used as the time scale because it is convenient to measure the injection delay (hydraulic delay) of each fluid. With energizing time of 1 and 2 ms, diesel and E85 have the different injection delays caused by differing modulus of compressibility as shown in Table 2. E85 needs more time to raise the injector needle due to the higher compressibility of E85, resulting in the longer injection delay and shorter injection duration.

In comparison at the end of the injection rates, the closing of injection is faster in case of E85. This can be explained by the value of viscosity. With lower viscosity of E85, when the needle goes down to the initial position after finishing the energizing process, less viscous forces against the closing of the injector compared to diesel. In case of diesel, longer time is required to stop the injection, because higher viscous forces of diesel slows down the needle movement. This work shows the similar results to previous work (Payri et al, 2012) that investigate the effect of gasoline on injection characteristics using common rail injection system with high injection pressures.

3.2 Double Injection

Injection rates of test fuels using double injection with the different 1st energizing times and dwell time were tested at a constant injection pressure of 45 MPa and a constant back-pressure of 4 MPa.

Fig. 4 shows the injection rate of diesel and E85 using double injection strategy with 1st energizing time of 1 ms, dwell time of 1 ms and 2nd energizing time of 1 ms. The similar results to single injection are observed for both fuels. E85 has longer injection delay and faster needle closing for 1st injection. However, at 2nd injection, there are no longer different for both fuels at needle closing, but E85 injection rate rises faster than that of diesel.

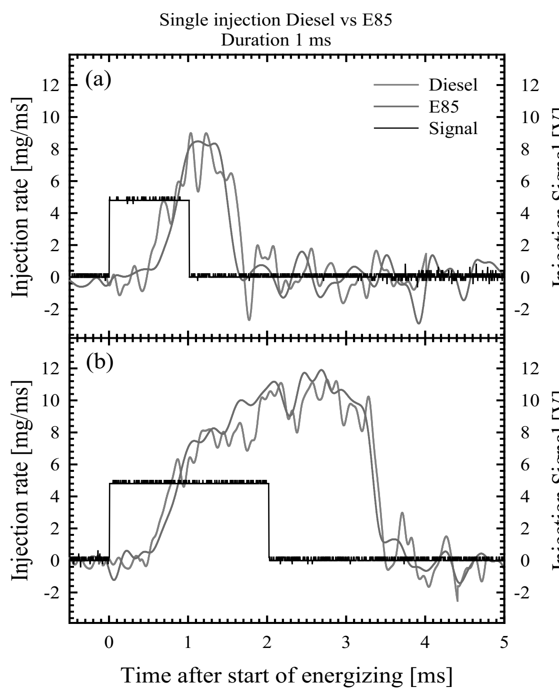

Fig. 3 Injection rate of diesel and E85 with (a) energizing time of 1 ms and (b) energizing time of 2 ms

In Fig. 5, increase of 1st energizing time to 1.5 ms increases the 1st injection duration as expected, while dwell time and 2nd emerging time are kept constant, but the duration of stop of injection is shorten. It could be explained that the needle is fully opened by the 1st energizing time of 1.5 ms, and dwell time of 1 ms is too short for complete closing of needle before another injection started. It seems to be plenty to shorten the duration of stop of injection and increase the 2nd injection duration for both fuels. It clearly observed that the needle opening and closing is significantly faster in the case of E85.

Fig. 6 shows effect of dwell time. When dwell time is prolonged, the 2nd injection durations and injection rates of test fuels are smaller. It is not clear why smaller injection duration and rate occurred. It may be postulated that with long dwell time, complete closing of needle is occurred, and it cause large fluctuation on fuel pressure in pipe, resulting to rate and duration of 2nd injection.

Effect of fuels for double injection strategy can be summarized that E85 has

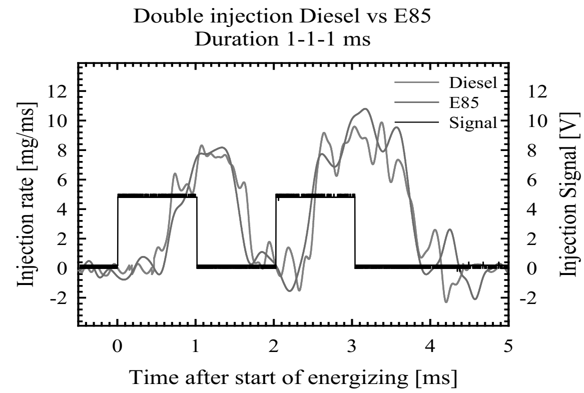

Fig. 4 Injection rate of diesel and E85 using double injection with 1st energizing time of 1 ms, dwell time of 1 ms and 2nd energizing time of 1 ms.

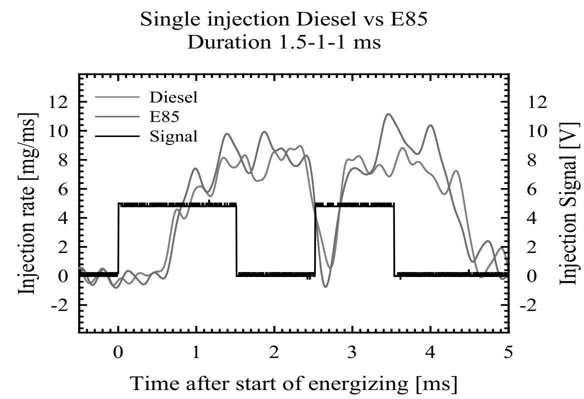

Fig. 5 Injection rate of diesel and E85 using double injection with 1st energizing time of 1.5 ms, dwell time of 1 ms and 2nd energizing time of 1 ms.

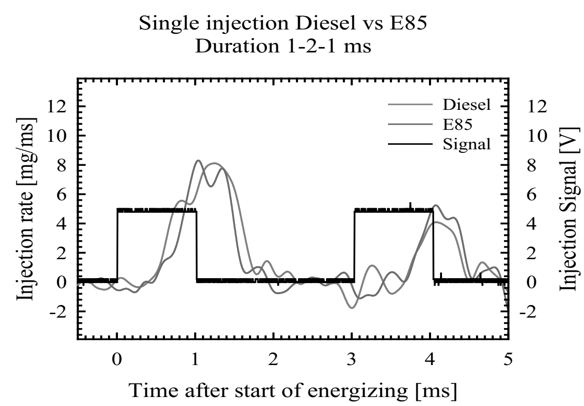

Fig. 6 Injection rate of diesel and E85 using double injection with 1st energizing time of 1 ms, dwell time of 2 ms and 2nd energizing time of 1 ms.

longer injection delay in the 1st injection for all test compared to diesel, while there is no different for injection delay of both fuels in the 2nd injection. Comparing to diesel, E85 insignificantly changed both 1st and 2nd injection duration, but has slightly higher injection rate.

4. Conclusion

This study presents a comparison between diesel and gasohol E85 on the injection behavior using Zeuch method. The major findings are the different injection rates. For single injection, E85 changes not only hydraulic delay but also injection duration and closing period. Longer hydraulic delay and shorter injection duration compared to diesel are caused by lower modulus of compressibility of E85.

For double injection with variation of 1st energizing time and dwell time, the injection characteristics of E85 and diesel showed the similar results to single injection. Increase of 1st energizing time decreases needle closing time. The needle opening and closing for both injection are significantly faster in the case of E85. Longer dwell time is insignificant effect on 2nd injection rate.

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