



Investigation of Effects of Ignition Improver on Ignition Delay Time of Ethanol Combustion with Rapid Compression-Expansion Machine

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Abstract

This work presents the effect of ignition improvers, i.e. 5% glycerol ethoxylate and additive ED95, on the hydrous ethanol 95% (Eh95) under simulated diesel engine conditions using the rapid compression-expansion machine (RCEM). The results show that Eh95 without ignition improver shows longest ignition delay and highest the peak rate-of-pressure-rise, while 5% glycerol ethoxylate and additive ED95 as ignition improvers have similar peaks rate-of-pressure-rise, but 5% glycerol ethoxylate shows slightly shorter ignition delay. The highest NO_x and lowest soot occurred in case of 5% glycerol ethoxylate related to the shortest ignition. In addition, the flame of Eh95 with 5% glycerol ethoxylate also shows the brightest apparent flame. The flame of Eh95 without ignition improver is brighter than that of ED95.

Keywords: Ethanol, Ignition improver, Rapid compression-expansion machine and Compression ignition engine.

1. Introduction

Ethanol is considered as an alternative fuel for diesel engine. It can reduce not only the use of petroleum diesel but also the emission from combustion especially particulate matter [1-3] NO_x [2-4] and CO [4].

During years 2006 to 2009, the BioEthanol for Sustainable Transport (BEST) project had performed in several European countries. The purpose was to create the right market conditions through the public and private



sector together for change from fossil to ethanol fuelled vehicles [5].

However, the direct use of ethanol in diesel engine tolerates from poor ignition quality due to ethanol is difficult to achieve simultaneously suitable concentration and temperature for self-ignition in a spray mixture formation [6]. The main reasons of poor ignition quality are its properties. In comparison with conventional diesel fuels, ethanol has smaller stoichiometric air/fuel ratio and larger latent heat for evaporation, which require higher energy to evaporate [7]. With poor quality of ignition, ethanol has longer ignition delay than that of diesel fuel. For a long ignition delay, most of fuel is injected before ignition start. It provides a large mixing between fuel and air which yields a rapid pressure rise when combustion occurs with high peak pressure. This produces audible knocking sound referred to diesel knock. As ignition start too late in expansion stroke, incomplete combustion, reduced power output and poor fuel conversion efficiency are occur [8]. Nevertheless, ethanol and hydrous ethanol with water content 10 %v are auto-ignited approximately 950 K, but a temperature of 1,100 K is required to generate sufficiently short ignition delay which produce suitable rate of pressure rise for diesel engine [8]. However, the typical engine is difficult to get this condition. Therefore, auto-ignition of ethanol for diesel engine can be achieved by the improvement of engine and fuel. Engine modifications can improve the ignition of ethanol, for example, dual fuel injection [2], EGR [4] and spark assistant [10]. On the other hand, these methods would be rather complicated. While fuel improvement is required some engine

modifications, for instance, fuel system replacement, higher compression ratio, adjusting the fuel injection to provide the same heat release as diesel. It seems to be practical application for modified diesel engine with fuel improvement. However, Hardenberg and Schaefer [3] recommended that the cost of ethanol with ignition improver should not exceed those of pure ethanol by more than 25%, because fuel consumption of an ethanol-fuelled SI engine is normally at least 25% higher than that of a DI diesel engine which uses ethanol or diesel fuel under practical conditions. As the cost of blend between ethanol and ignition improver is less than 25%, the use of ethanol with ignition improver represents an economical alternative to the use of pure ethanol in SI engine.

Many ignition improvers were tested in unmodified diesel engine of compression ratio 17:1. The results were concluded that nitrate-based improvers seem to have a strong effect on ignition improving in alcohol [3, 11]. Simonsen and Chomiak [12] also concluded that nitrate ester as ignition improver with the trade name AVOCET is most efficiency improver. However, they may increase corrosion, often explosion, toxicity, insufficient lubrication and NO_x emission. Furthermore, the production is presently stopped. For this reason, polyethylene glycol in the trade name BERAID is used to replace nitrate-base improver with various contents. The efficiency of polyethylene glycol improvers increase with increasing of the molar mass, i.e. shorter ignition delay, because the increasing of the molecular chain length with increasing of molar mass provides more site of attack for creation of radical. However, its solubility is a problem when the

ambient temperature is approximate 0 °C. In 1995, the Swedish ethanol buses switched from 2% AVOCET to 7% BERAID, which yields the same ignition delay with no difference at the price.

Recently, ED95, i.e. 95% hydrous ethanol and 5% additives in which developed by Swedish ethanol producer (SEKAB), was used as a fuel for buses and heavy diesel vehicles in several European countries and Brazil. In addition, the demonstration project that use ED95 in a diesel bus for public transportation is performing in Thailand. The use of ED95 seems to be a promisingly practical application for diesel engine.

However, a few works have been done about mechanisms of ignition improver (ED95) in combustion processes. Therefore, this work presents the ignition and combustion characteristics of ED95 under simulated diesel engine conditions. Hydrous ethanol 95% (Eh95) without ignition improvers and hydrous ethanol 95% (Eh95) with glycerol ethoxylate, which has high molecular weight, are also investigated. The ignition delay, heat release rate, combustion efficiency are analyzed by in-cylinder pressure data and high speed direct photograph of flame during combustion. In addition, NO_x and soot are also measured.

2. Description of the experiment

2.1 Apparatus

To simulate a single diesel cycle, the experiments were carried out on a rapid compression-expansion machine (RCEM) that more details are shown in [13]. The compression ratio of RCEM is 8.5. Bore and stroke of RCEM cylinder are 100 mm and 150 mm, respectively. Initial gas temperature can vary between 25-180

°C. Common rail system can provide injection pressures can be varied from 30-130 MPa. Spray flame combustion is recorded by high speed camera at 10,000 fps. Mixing tank prepares homogeneous mixture gas of 80% Argon and 20% Oxygen. The schematic diagram of the experiment shows in Fig. 1.

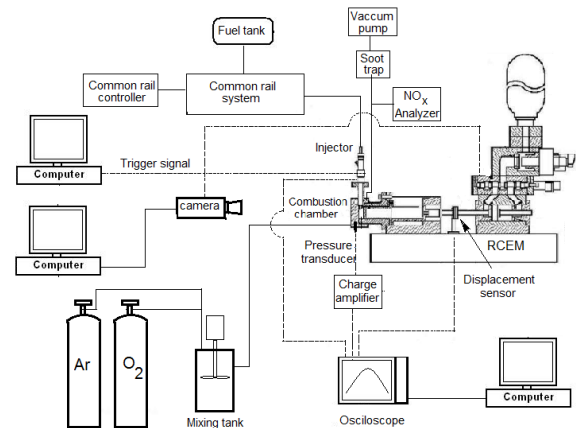


Fig. 1 schematic diagram of the experiment

2.2. Experimental conditions

For all experiments in-cylinder mixture gas is 20% oxygen and 80% argon, which instead of nitrogen because it has higher specific heat ratio than nitrogen, to get higher temperature. The mixture gas is compressed within 30 ms in compression stroke. At TDC, mixture gas density, pressure and temperature are then 21 kg/m³, 4 MPa and 900 K, respectively. These experimental conditions represent isentropic compression of air from ambient conditions at compression ratio as high as 22 and engine speed 1000 rpm. Fuels for experiment are shown in

Table. 1.

Lauric acid 1%wt is added to Eh95 for lubricity in case of Eh95 without improver and with glycerol ethoxylate.



Table. 1 Testing fuels

Fuels	Compositions
Eh95	Ethanol:water = 95:5%wt
ED95	Eh95:ED95 master batch = 88.8:11.2%wt (90:10%v)
Eh95 with glycerol ethoxylate	Eh95:glycerol ethoxylate = 95:5%wt

Fuel injection pressure is kept constant at 90 MPa. The calorific value of each fuel is also kept constant. The experimental conditions show in Table. 2

Table. 2 Experimental conditions

Surrounding conditions	
Temperature : T_g	900 K
Pressure : P_g	4 MPa
Density : ρ_g	21 kg/m ³
Injection conditions	
Nozzle diameter	0.24 mm x 1
Injection pressure	90 MPa
Injection duration	Eh95 = 3.05 ms ED95 = 3.09 ms Eh95 with glycerol ethoxylate = 3.3 ms
Injection amount	Eh95 w/o imp. = 36.68 mg ED95 = 36.77 mg Eh95 with glycerol ethoxylate = 36.99 mg

3. Results and discussion

The average ignition delay, combustion efficiency, NO_x and soot with error bars indicating 95% confidence interval for Eh95 without ignition improver, ED95 and 95% Eh95 with 5% Glycerol ethoxylate are showed in Fig 2.

In Fig 2 (a), the results showed that commercial ignition improver and glycerol ethoxylate can improve the ignition of ethanol. The ignition delay in case of Eh95 with glycerol ethoxylate is shortest. The ignition delays for Eh95 with glycerol ethoxylate, ED95 and Eh95 without ignition improver are 0.79, 0.91 and 1.33 ms, respectively. It can be explained the number of attack sites on the molecule for creation radicals increase with increasing of molecular weight (higher carbon number) which yield a shorter ignition delay [8, 12].

Apparent combustion efficiencies, which are the ratio of calorific value from combustion that included heat loss to calorific value of fuel, for all fuels are similar as shown in Fig 2 (b). The combustion efficiency was calculated by the apparent heat release which was obtained by an analysis of measured cylinder pressure. Therefore, this includes the heat loss during combustion. The average combustion efficiency in case of Eh95 with glycerol ethoxylate shows slightly higher than that of ED95 and Eh95 without ignition improver.

The rate-of-pressure-rise, heat release rate and heat release for ED95 are nearly same as those for Eh95 with glycerol ethoxylate, while Eh95 without improver is clearly different as shown in Fig. 3 (a) – (c).

In Fig. 3 (a) shows in-cylinder pressure, Eh95 without ignition improver has the largest rate-of-pressure-rise that is 1.04 MPa/ms, while the rate-of-pressure-rise for ED95 and Eh95 with glycerol ethoxylate is 0.59 MPa/ms and 0.58 MPa/ms, respectively. The rate-of-pressure-rise depends on ignition delay. As the long ignition

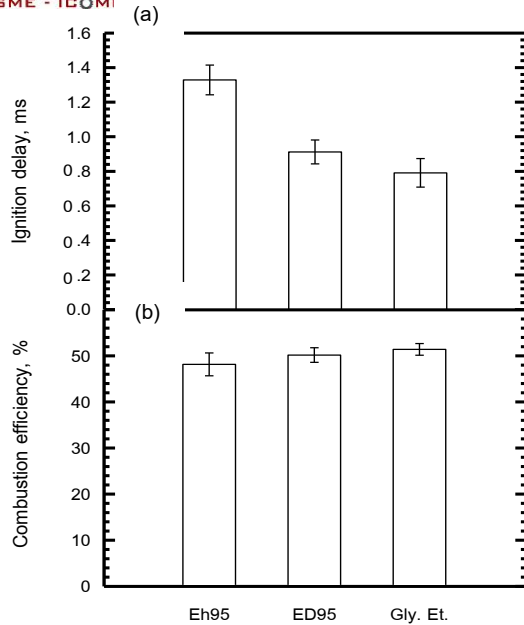


Fig. 2 Ignition delay and combustion efficiency for Eh95 w/o ignition improver, ED95 and Eh95 with glycerol ethoxylate

delay, the fuel and air can be mixed before start of combustion in a large amount. The high mixing between air and fuel leads to a rapid pressure rise and high heat release rate in premixed combustion phase.

Therefore, Eh95 without improver shows a rapid pressure rise as shown in Fig. 3 (a). The rapid pressure rise can increase engine wear and combustion noise that refer to the diesel knock [8, 12]. Heat release in premixed combustion phase accounts 57.2% of total heat release for Eh95 without ignition improver, 25.9% for ED95, and 25.5% for Eh95 with glycerol ethoxylate as shown in Fig. 3 (b) and (c).

In Fig. 4, NO_x in case of Eh95 without ignition improver, ED95 and Eh95 with glycerol ethoxylate are 103, 116.5 and 123.4 ppm, respectively. The highest NO_x in case of Eh95 with glycerol ethoxylate may be due to the higher flame temperature which will be observed in high

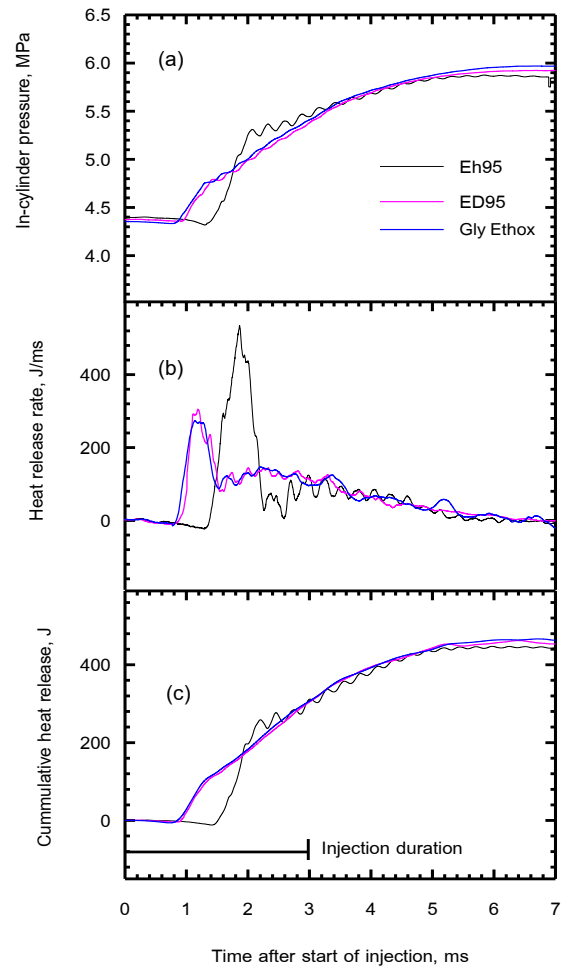


Fig. 3 In-cylinder pressure, heat release rate and cumulative heat release for Eh95 w/o ignition improver, ED95 and Eh95 with glycerol ethoxylate

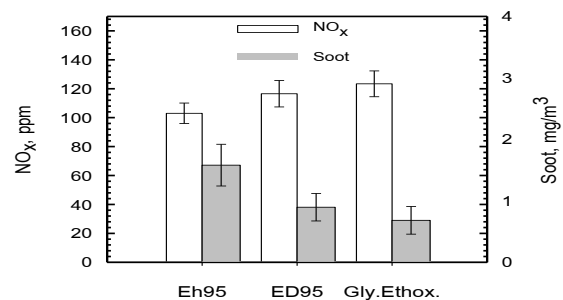


Fig. 4 NO_x and soot for Eh95 w/o ignition improver, ED95 and Eh95 with glycerol ethoxylate speed photographs of flame as the brightest luminosity in the followings. The highest flame temperature enhances NO_x formation and reduction of soot, as shown in Fig. 4.

Soot for Eh95 with glycerol ethoxylate is 0.68 mg/m³, which lower than that of Eh95



without ignition improver and ED95 (1.59 and 0.9 mg/m³, respectively).

From experimental results under diesel engine condition, the ignition delay has effect on rate-of-pressure-rise and emissions, i.e. NO_x and soot. As ignition delay increases, rate-of-pressure-rise and soot are increased, while NO_x are decreased.

The direct high speed photographs for single spray apparent flame for Eh95 without ignition improver, ED95 and Eh95 with glycerol ethoxylate are showed in Fig. 5 (a) – (c).

Fig. 5 (a) shows a sequence of photographs of Eh95 without ignition improver. Ignition occurs at 1.8 ms after injection at the spray tip, while ignitions of ED95 and Eh95 with glycerol ethoxylate occur at the times of 1.4 and 1.5 ms, respectively, as shown in Fig. 5 (b) and (c).

The flame colors of three fuels when ignition start are orange that means luminous from carbon (soot) burnup at low temperature [8]. The flames then spread rapidly along the direction of spray. As flames are developing, the dark-brown region can be observed in the center of flame. This is soot clouds which are cooled in the near field of quartz window. When the flame impinges instantly the wall, it is expected that the large entrained air is rapidly mixed and burned the soot in this process. The luminous flames around center of spray flame become yellow-white. It is expected that NO_x is formed rapidly in this process. After flame impinging, the flame at the surface of cylinder wall is brown due to heat is transferred to cylinder wall and the air-fuel mixing rate is lower.

From direct high speed photograph, the flame of Eh95 with glycerol ethoxylate seems to be brightest flame. This presumes that highest flame temperature, while the flame of Eh95 without ignition improver shows brighter than that of ED95. Therefore, flame temperature measurement is required to reveal the flame temperature of ethanol.

4. Conclusions

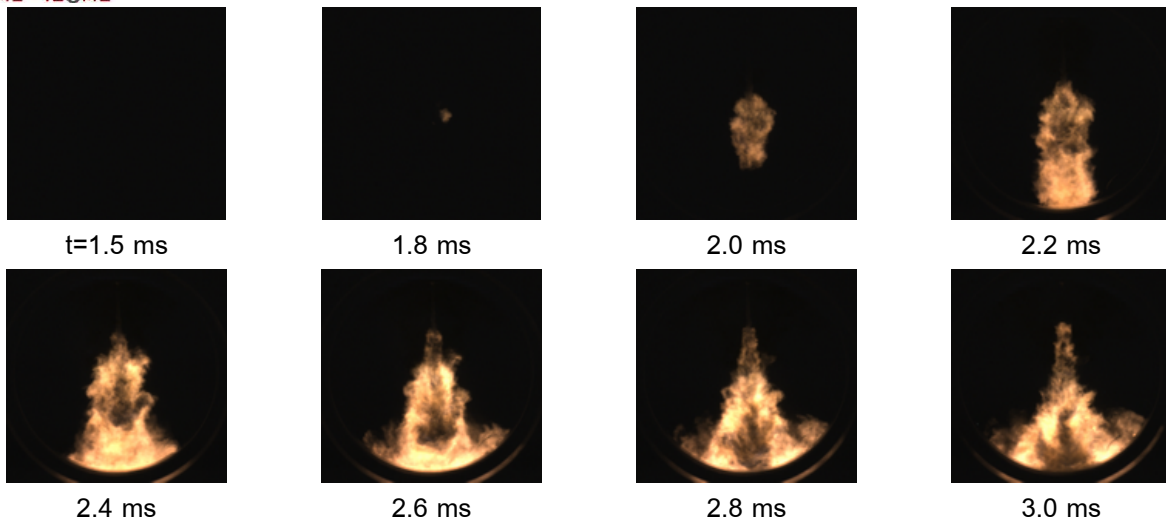
This study represents ignition and combustion characteristics of Eh95 without ignition improver, ED95 and Eh95 with glycerol ethoxylate under diesel engine condition.

Ignition delay has effect on rate-of-pressure-rise and emissions. Eh95 without ignition improver shows longer ignition delay and higher the peak rate-of-pressure-rise that is not proper for diesel engine operating, while glycerol ethoxylate improver and ED95 show the similar the peak rate-of-pressure-rise. But glycerol ethoxylate improver shows slightly shorter ignition delay.

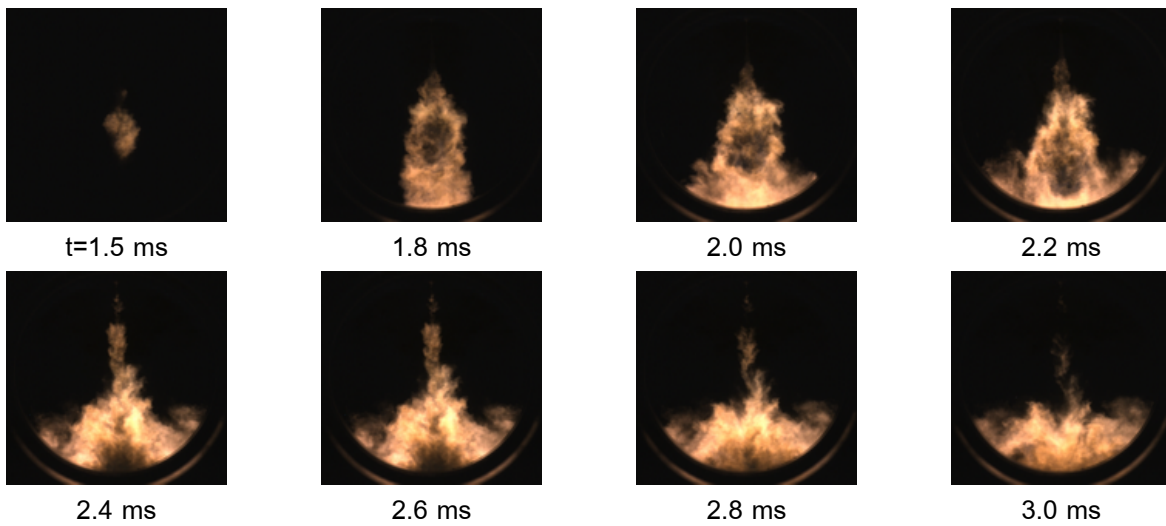
NO_x and soot formations depend on combustion characteristics in combustion process. Highest NO_x and lowest soot occurred in case of the use of glycerol ethoxylate improver which shows lowest ignition delay. The combustion efficiency is not affected significantly by cetane improver in this study.

The flame of Eh95 with glycerol ethoxylate is also brightest, i.e. highest flame temperature, and the flame of Eh95 without ignition improver is brighter than that of ED95.

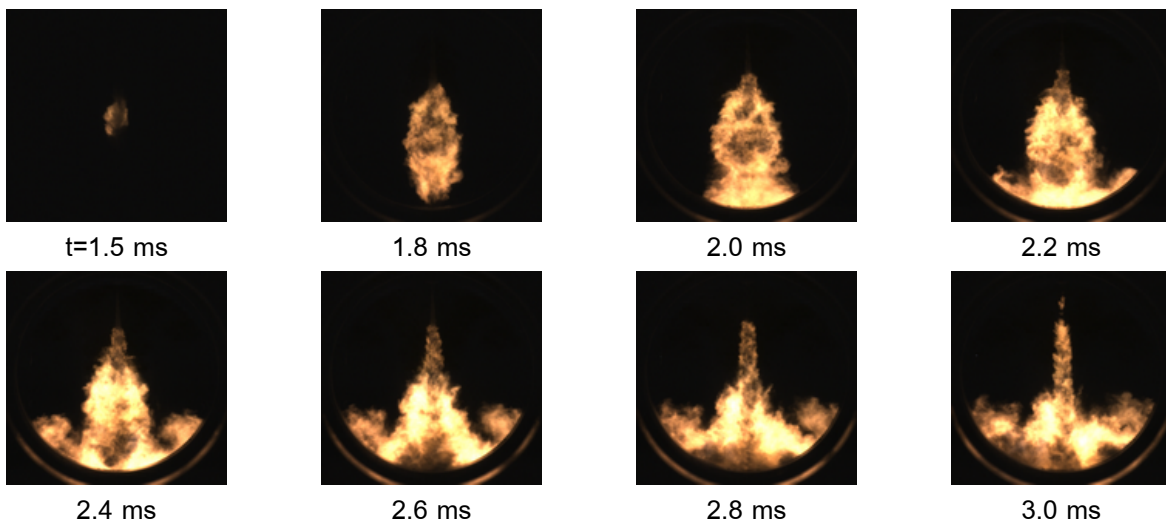
From the experiments, glycerol ethoxylate and ED95 shows the satisfied results. Glycerol ethoxylate can be used as an ignition improver



(a) Eh95 without ignition improver



(b) ED95



(c) Eh95 with glycerol ethoxylate

Fig. 5 Example of photographs for flame of (a) Eh95, (b) ED95 and (c) Eh95 with glycerol ethoxylate using high speed video camera at 10000 fps



Eh95. However, the production costs of glycerol ethoxylate still remain relatively high in comparison to that of ethanol, the smaller mixture of glycerol ethoxylate should be investigated

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