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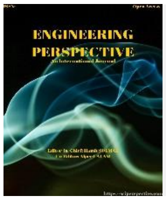

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Research Paper

Combustion, Performance and Emissions of Ethanol/n-Heptane Blends in HCCI Engine

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Abstract

The aim of this study was to investigate the effects of the ethanol on combustion, performance and emission characteristics of a single cylinder, port fuel injection HCCI engine was investigated. 15% ethanol and 85% n-heptane were blended. N-heptane was used as reference fuel. The experiments were performed at 1200 rpm and fix inlet air temperature of 60 °C. The parameters such as in-cylinder pressure, heat release rate, CA50, CA10, ringing intensity, indicated thermal efficiency were detected. Beside this, the emissions of CO and HC were also given in the study. The experimental results showed that E15 didn't significantly effect in-cylinder pressure and heat release rate and there have been slight increase compared to n-heptane. CA50 was retarded about 1.5 °CA and indicated thermal efficiency increased about 3% with E15 at λ=2.5. Ringing intensity increased about 30% and HC emission decreased with the addition of 15% ethanol and 85% n-heptane fuel

Keywords: Ethanol, combustion, HCCI, performance

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1. Introduction

In recent years, the energy need in the world has been increasing due to the developing industrialization [1,3]. Similarly, the use of fossil fuels, which meet most of the energy needs, is increasing day by day, but the resources of these fuels are extremely limited. The environmental pollution due to the use of fossil fuels is also a research topic that has been dealing by many researchers. Homogeneous charge compression ignition (HCCI) combustion technology which has high efficiency and very low NO_x and soot formation is one of the alternative combustion concepts [4-10]. Ignition starts spontaneously in the combustion chamber and homogeneous charge burns in HCCI engine. Thereby, the disadvantages of spark ignition engines or diesel engines like flame propagation which affects the autoignition or heterogenitiy can be eliminated by HCCI engines. Besides this, start of combustion can not be directly controlled by any mechanism in HCCI engines [11-17]. So, the problems like misfiring at low loads and knocking at high loads occurs in HCCI combustion [18-21]. There are several methods to solve these problems such as using alternative fuels which has low or high reactivity.

Many researchers have carried out a number of studies which invastigates the effects of alcohols on HCCI combustion. The alcohols like ethanol and methanol are easily accessible, inexpensive and produced from natural sources. Polat [21] performed his experiments at low compression ratio and examined the effects of ethanol in HCCI engine. Ethanol was added into the n-heptane as the ratios of 10, 15 and 20%. The results showed that maximum in-cylinder pressure and heat release rate decreased with increasing the ethanol amount in the mixture. Gawale and Srinivasulu [22] investigated the effects of different mass flow rates of ethanol in HCCI engine at different engine loads. They reported that ignition delay increased with the increase of mass flow rate, however, in-cylinder temperature and pressure reduced. Beside this, NOx and smoke opacity was also reduced owing to low in-cylinder temperature. Taghavifar et al [23] investigated the effects of diesel-DME-methanol blends on combustion in HCCI engine. The experimental results showed that the addition of 20% DME and 30% methanol showed higher pressure and accumulated heat at 1400 rpm. Ghareghani [24] used three fuels, natural gas, ethanol and methanol, in his study and investigated the load limits of HCCI engine. He reported that natural gas is better choice for higher intake temperatured and rich mixtures while ethanol and methanol are good for low intake temperature and lean mixtures. Bendu and Sivalingam [25] invetigated the effects of charge temperature on ethanol fuelled HCCI engine. It was reported that intake air temperature significantly effects the in-cylinder pressure, combustion and thermal efficiency and ringing intensity.

The current study examined, the effects of 15% ethanol (E15) and 85% n-heptane fuel on combustion, performance and emissions in a single cylinder, port fuel injection HCCI engine and compared to n-heptane (H100) reference fuel. For this purpose, in-cylinder pressure, heat release rate, CA10, CA50, indicated thermal efficiency (ITE), ringing intensity (RI), and CO and HC emissions were presented in this paper.

2. Experimental methodology

A single cylinder, port fuel injection HCCI engine which was converted from single cylinder SI engine was used in the experiments. The schematic view of the engine setup and the specifications of the engine were given at Figure 1 and Table 1, respectively.

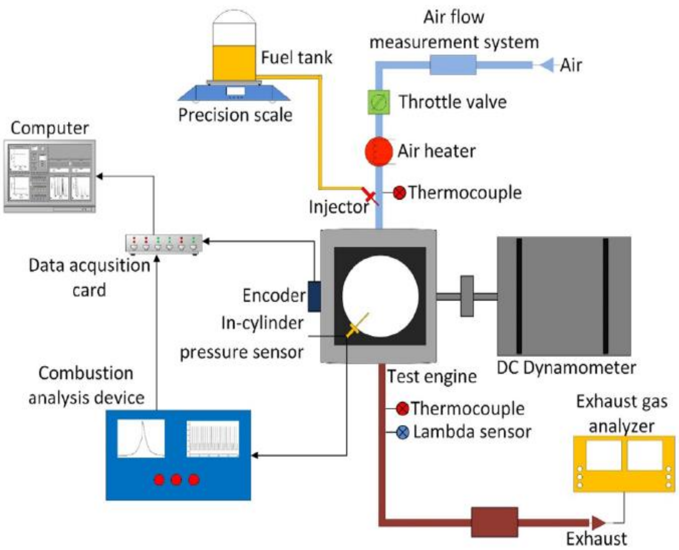

Figure 1. Schematic view of the engine setup

Table 1. The specifications of the engine

Engine model	Ricardo Hydra
Cylinder number	1
Fuel injection system	Port
Bore (mm) x Stroke (mm)	80.26 x 88.90
Compression ratio	13:1
Maximum power outpu (kW)	15

The experiments were performed at 1200 rpm engine speed, 60 ºC and various lambda values (λ=1.7-3.0). DC dynamometer was conducted to the engine and temperatures were measured with K-type thermometer. In-cylinder pressure was quantified with Kristler model 6121 piezoelectric pressure transducer and scaled up by Cussons P4110 analysis device. National Instruments USB 6259 data acquisition card converted the data to digital signals and recorded via the computer. NO, CO emissions and lambda were measured with exhaust gaz analyzer device. Table 2 and 3 shows the technical properties of exhaust gas analyzer and cylinder pressure transducer, respectively. Two fuels were used in the experiments, the first one is as reference fuel n-heptane (H100) and the second one is 15% ethanol added feul (E15). The fuel properties were given at Table 4.

Table 2. The properties of the exhaust gas analyzer

Exhaust gas analyzer	Operating range	Accuracy
CO (%)	0-15	0.001
NO (ppm)	0-9999	1 ppm
HC (ppm)	0-5000	1 ppm
O_2 (%)	0-20	0.01
CO_2 (5)	0-25	0.1
Lambda	0.6-4	0.001

Table 3. Technical properties of the cylinder pressure transducer

Model	Kistler 6121 piezo electric
Operating range (bar)	0-250
Measurement precision (pC/bar)	14.7
Operating temperature (ºC)	-50-350
Accuracy (±%)	0.5

Table 4. Fuel Properties

	Ethanol	n-Heptane
Chemical Formula	C2H6O	C7H16
Density (kg/m^3)	789	679.5
Octane number	110	0
Lower heating value (MJ/kg)	26.95	44.56
Boiling point (ºC)	78.37	98

Heat release rate was calculated by Equation 1. Thermal efficiency was defined by the ratio between the net work and released energy from fuel (Eq. 2) and the net work was calculated by Equation 3.

$$\frac{dQ}{d\theta} = \frac{k}{k-1} P \frac{dV}{d\theta} + \frac{k}{k-1} V \frac{dP}{d\theta} + \frac{dQ_{heat}}{d\theta} \tag{1}$$

$$\eta_T = \frac{W_{net}}{m_{fuel1} \times Q_{LHV1} + m_{fuel2} \times Q_{LHV2}} \tag{2}$$

$$W_{net} = \int PdV \tag{3}$$

3. Results and Discussion

Figure 2 shows the variation of in-cylinder pressure and heat release rate versus crank angle at 1200 rpm and 60 ºC inlet air temperature. It can be seen that knocking tendency appeared for both fuels at low lambda values. But it was found that ethanol addition had positive effect on knocking owing to its higher octane number when lambda value increased. It can be said that more stable combustion achieved with ethanol addition. What can be clearly seen in Table 4 is ethanol has lower LHV than n-heptane. Lower LHV resulted in a slight increase in HRR. Combustion phasing was retarded and combustion was achieved after top dead center for E15 at almost all lambda values. But lower boiling point of ethanol advance the auto-ignition reactions and decrease the temperature at the end of the compression stroke. However, ethanol has much higher octane number than n-heptane and this provides higher auto-ignition temperatures which led to observe lean mixture zones. This phenomenon can be explained with the higher octane number of ethanol which means higher resistance to auto ignition. Both in-cylinder pressure and heat release rate increased for low lambda values. When the mixture gets richer, charge concentration increases which results in higher reaction rate and accelerated heat release progress that increase maximum pressure.

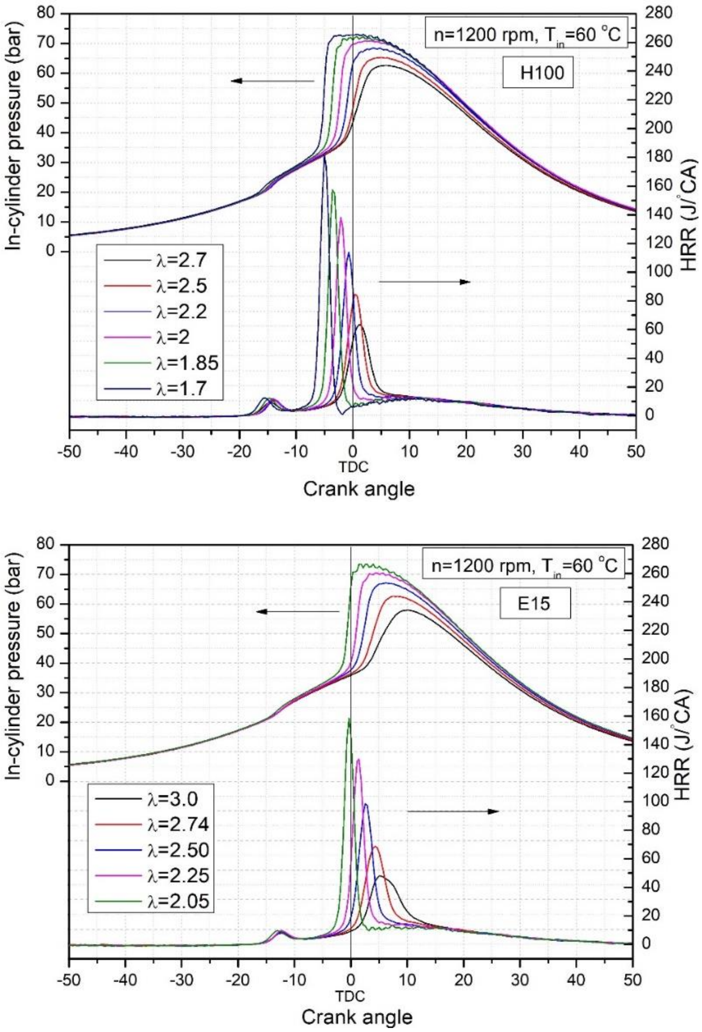

Figure 2. In-cylinder pressure and HRR

The chemical kinetics and pressure-temperature history in the combustion chamber are the main parameters effect the start of combustion in HCCI combustion. Figure 3 shows the variation of CA10 versus lambda. CA10 can be defined as the start of combustion or the crank angle where the 10% mass fraction of the fuel burned. Figure 3 reveals that combustion phasing was retarded with the increase of lambda value. The mixture gets leaner with the increase of lambda value and this means that less fuel molecules contact with oxygen

molecules and combustion starts at later crank angles. Auto ignition was retarted at leaner mixture conditions due to the lower fraction of the fuel. The CA10 values of H100 and E15 were 2.16 (BTDC) and 0.96 (BTDC), respectively, at λ=2.5.

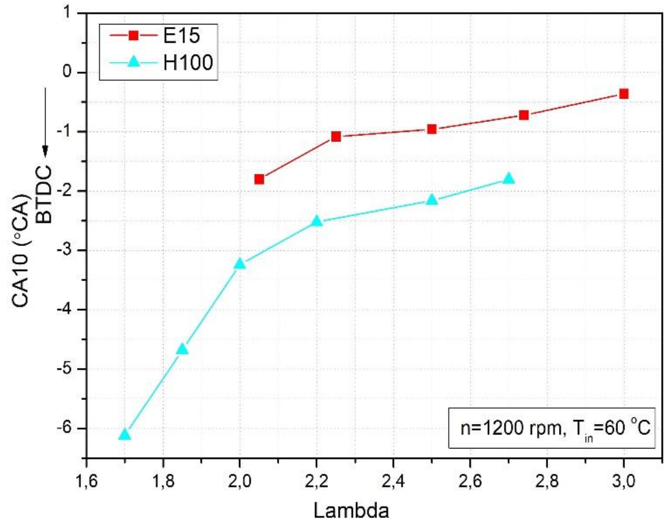

Figure 3. The variation of CA10

Figure 4 represents CA50 and indicated thermal efficiency versus lambda at 1200 rpm and 60 ^{o}C inlet air temperature. Octane number increases with the ethanol addition into the mixture and fuel evaporates more difficulty. For this reason, the burning is prolonged and the start of ignition is delayed. The high reactivity of n-heptane fuel causes HCCI combustion start at earlier cranck angles. Accordingly, the combustion process is developing rapidly and CA50 is advanced. CA50 occurs before the TDC especially in the rich mixture regions due to the high reaction speed in the cylinder and the usage of high reactivity fuel. This causes an increase in the negative work applied on the piston and consequently a low thermal efficiency. As the mixture becomes poor, the reaction rate decreases and the combustion slows down. Accordingly, the CA50 is delayed. The occurrence of CA50 just after the TDC ensures the highest thermal efficiency. The CA50 values of E15 and H100 are 4.32 ^{o}CA (ATDC) and 2.88 ^{o}CA (ATDC) at λ=2.5. The highest efficiencies were obtained at λ=2.5 for E15 and H100 as 48.5% and 47%, respectively.

The variation of ringing intensity was given in Figure 5. Ringing intensity is mostly affected by in-cylinder pressure, pressure rise rate and engine speed. When the Figure 6 was examined that ringing intensity decreases when the lambda increased. The charge mixture gets richer when the lambda decreased and this means the amount of reacting fuel molecules increase which results in higher pressures. The higher density and the oxygen molecule content of ethanol enhance the oxidation reactions and the end of combustion pressure increases rapidly. So, ringing intensity increases. The ringing intensity of E15 and H100 are 8.71 MW/m^2 and 6.09 MW/m^2, respectively, at λ=2.5.

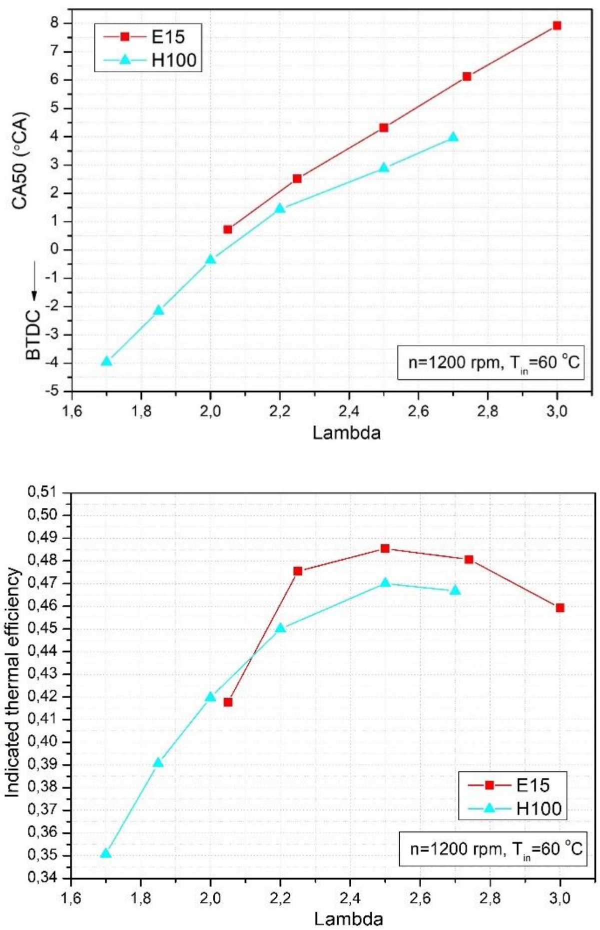

Figure 4. CA50 and indicated thermal efficiency

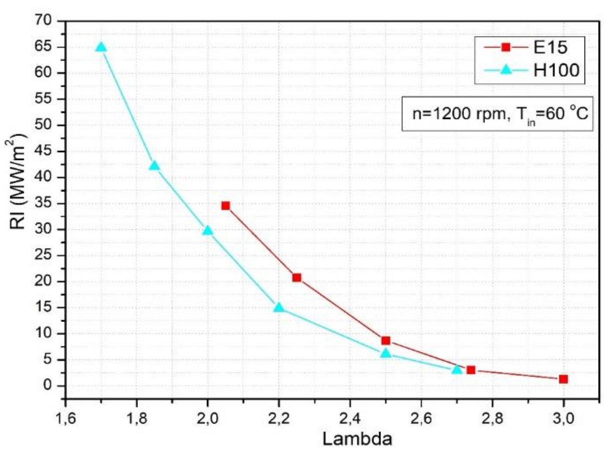

Figure 5. The variation of ringing intensity

Figure 6 shows the variation of HC and CO emissions of the test fuels. Since HCCI combustion occurs at low temperatures, the temperature required for the oxidation of the whole fuel molecules may be insufficient. At the same time, the formation of CO, the incomplete combustion product, is accelerating. When the Figure 6 was mentioned it can be seen that HC emissions decrease with the decrease of lambda. It is because that the excess air increases, sufficient oxygen concentration can be provided for the oxidation of the fuel in the combustion chamber, and so HC decreases. Flame can be extinguished as a result of the inability to ignite the fuel towards rich mixtures, especially in the regions close to the cold cylinder walls. The HC emissions of E15 and H100 were 275 ppm and 348 ppm, respectively, at λ=2.5. The formation of CO increased with the increase of lambda value. As the excess air increases, the gas temperature after combustion decreases and oxidation reactions slow down. This causes to incomplete combustion. The CO emissions of E15 and H100 were 0.1% and 0.08%, respectively, at λ=2.5.

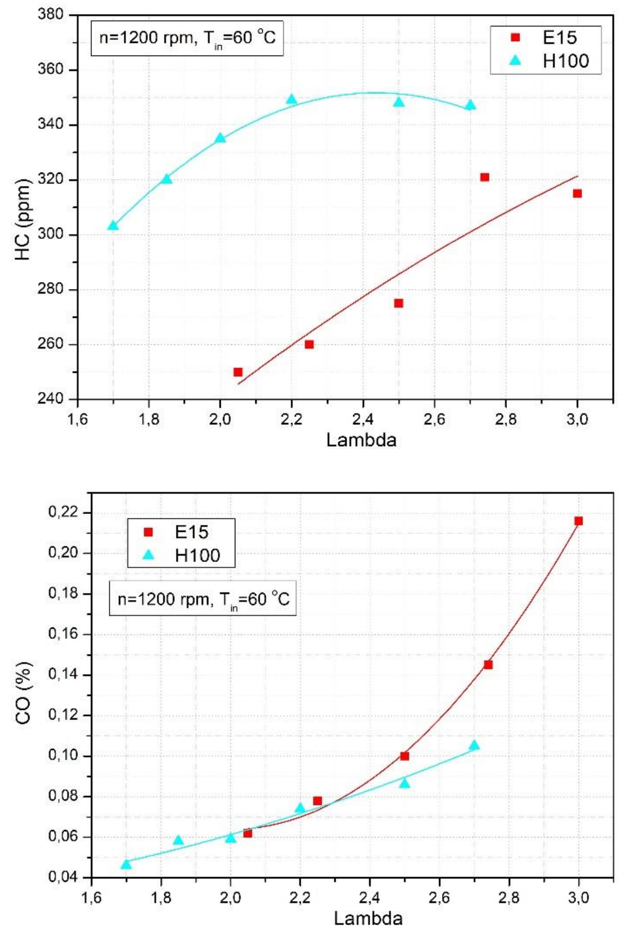

Figure 6. The variation of HC and CO emissions

4. Conclusions

In the current study, the effects of ethanol/n-heptane feul blends in a HCCI engine on the combustion, performance, and exhaust emission characteristics were examined. The experiments were carried out at a constant inlet air temperature of 60 ºC, compression ratio 13 and various lambda values. In-cylinder pressure, heat release rate, CA10, CA50, indicated thermal efficiency, ringing intensity and HC and CO emissions were presented according to the experimental findings. Start of combustion and combustion phase retarded with ethanol addition. CA10 was retarded about 3.12 ºCA at λ=2.5 compared to neat n-heptane. The increasing of lambda value also retarded CA10. CA50 was retarded about 1.5 ºCA with E15 at λ=2.5. Indicated thermal efficiency increased about 3% with ethanol addition at λ=2.5. It is possible to say that ethanol provided more stable combustion in HCCI engine.

Nomenclature

dQ	heat release
dQ_{heat}	heat transferred to cylinder walls
dθ	crank angle
k	ratio of specific heat
P	cylinder pressure (bar)
dV	variation of cylinder volume
W_{net}	net work (joule)
m_{fuel}	consumed fuel per sycle (kg)
Q_{LVH}	lower heating value (kcal)

Conflict of Interest Statement

The author declares that there is no conflict of interest

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