IMPACT OF ETHER/ETHANOL AND BIODIESEL BLENDS ON COMBUSTION PROCESS OF COMPRESSION IGNITION ENGINE

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Abstract. Ethanol is very attractive alternative fuel, which is successfully used for some time in different blends with gasoline in spark ignition engines. As it is oxygenated fuel, it could have also a great potential for compression ignition engines, especially in particulate emission reduction. Therefore, research in the combustion process of ethanol or ether based fuel mixtures with biodiesel is very important. The paper presents the preliminary research results (mean indicated pressure, ignition delay angle, angle of fuel injection, etc.) of an investigation carried out by the authors on the potentiality of different biofuel blends as an alternative fuel for compression ignition engines. In that case AD3.152 type engine was bench tested in the laboratory of the Vehicle Technical Exploitation Department at the Technical University of Radom (Poland).

Keywords: ethanol, biofuels, oxygenated fuels, diesel engine, engine testing.

Introduction

The rising oil prices, ecology aspects, the desire to increase energy self-sufficiency and create employment are motivating the countries around the world in support of biofuels research and production. Since the global energy crisis in the 1970s, more extensive attention has been focussed on two main renewable fuels: biodiesel and ethanol. As both of these fuels can be made from all kinds of raw materials, they are the most widely studied renewable motor fuels for compression ignition engines in the recent years.

Biodiesel is an alkyl ester of fatty acids and can be made from different oils via transesterification process. At first biodiesel was known in 1853 – many years before the first diesel engine became accessible to society – and from 1990s it is produced industrially in many countries. It is a good choice fuel, because it can be blended in any proportion with fossil diesel to create a blend, which can be used in any compression ignition engine without modifications.

Ethanol also is produced from organic feedstock, but it is used mainly as a fuel for spark ignition engines due to certain advantages. During the last years different solutions have been developed to make the diesel engine technology compatible with the properties of ethanol fuel. Investigations of the use of ethanol in diesel engines have been performed in Germany and the United States since 1980s [1; 2] with the aim to reduce smoke and particle emissions in the exhaust gases of the engine. Although there were different solutions about ethanol use in diesel engines, extensive application was found at one of them - preparing blends of diesel-ethanol fuel that requires no modifications to the engine. The use of ethanol-diesel or ethanol-biodiesel fuel blends left a positive impact on the engine power and exhaust emissions, but it can be accompanied also with adverse effects concerning the engine performance due to lower viscosity and lubricity, reduced ignability and cetane number, higher volatility and lower miscibility [3]. For example, lower volumetric heat content can contribute to power loss [4], lower cetane number – can contribute to engine efficiency loss [5]. Facing all these disadvantages, researchers are looking for different fuel compositions to use potential of all these fuels in compression ignition engines. As direct blending of ethanol or ethyl tert-butyl ether (ETBE) provides higher oxygen concentration in blends than biodiesel, than it could be a more effective particulate emission reduction tool for the same volume of blended fuels.

The objective of this study is to investigate the effects of ETBE and ethanol addition to biodiesel fuel on the selected parameters of the combustion process.

Materials and methods

The research was carried out on an AD3.152 type engine installed in the laboratory of the Vehicle Technical Exploitation Department at the Technical University of Radom. It was a three-cylinder, four stroke, water cooled, 16.5:1 compression ratio engine with industrial application. The maximum torque was 160 Nm at 1200 rpm, and the maximum engine power was 31 kW at 2000 rpm.

The engine was coupled to a brake and equipped with the instrumentation to its control and for the measurement of the main parameters (pressure in combustion chamber, fuel injector needle lift, pressure in fuel delivery pipe) necessary for this research. In-cylinder pressure variations were recorded with use of an AVL QC34D pressure sensor connected to a signal amplifier and Keithely KPCI-3110 data acquisition board inserted in PCI slot of PC work station. A high pressure, miniaturized quartz transducer AVL QC34D is mounted directly at the combustion chamber, thus providing measurements unaffected by oscillations and damping effects that are usual when a connecting pipe is used. The schematic of the experimental setup is shown in Fig. 1.

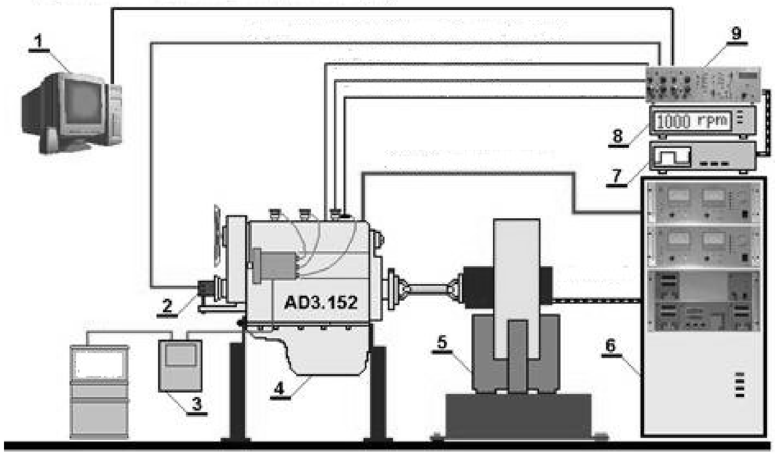

Fig. 1. **Diagram of test stand:** 1 – computer with measurement card; 2 – encoder of crankshaft angle; 3 – fuel flow meter; 4 – tested engine; 5 – engine brake; 6 – steering module of engine brake; 7 – time base generator; 8 – control module of engine crankshaft speed; 9 – signal amplifier

The injection timing was set at 17 ° before TDC for all tested fuels. The research was carried out in steady state conditions of engine work for its two different loads (100 and 140 Nm) and crankshaft speeds: 1200 and 1600 rpm.

Tested fuel properties

In this study three kinds of fuels were used: diesel fuel (DF) as the baseline fuel, 30 % ethanol blending with 70 % biodiesel (denoted as Eth30B) and 30 % ETBE blending with 70 % biodiesel (denoted as ETB30B).

Ethanol molecules contain polarized OH- group and for this reason their miscibility with also polarized water molecules is perfect, but significantly limited with diesel fuel. It is known, that miscibility of ethanol with diesel fuel depends on temperature variations and presence of water in the mixture. In low temperature phase separation of ethanol/diesel fuel blends can be observed (Fig. 2).

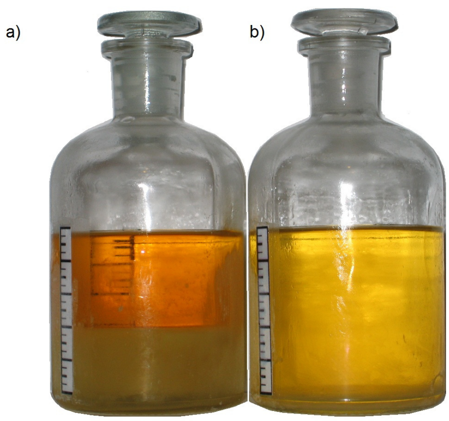

Fig. 2. **Samples of fuel blends:** a – pure ethanol/diesel fuel; b – ETBE/diesel fuel stored in -10 ºC (in both cases volumetric proportion of base fuels in mixture equals: 50-50 %)

99.5 % pure ethanol may be blended in any proportions with biodiesel, but such mixtures are stable in higher temperatures only (above 10 ºC). It should be noted that water, which may be present in fuel, promotes ethanol/biodiesel fuel phase separation.

Most of ethers are significantly less polar than alcohols. For this reason ETBE miscibility with water is strongly limited, but excellent with petroleum based diesel fuel or biodiesel.

In preliminary research blends of ether or ethanol with biodiesel were chosen. In both cases volumetric addition of oxygenated fuel in biodiesel was the same and equal 30 %. Higher content of ethanol or ETBE in biodiesel can promote a possibility of misfire – ignition delay is prolonged due to a low cetane number of the tested oxygenated fuels.

Table 1 lists the selected physicochemical properties of the tested base fuels: diesel fuel, ethanol, ETBE and biodiesel (FAME – fatty acid methyl ester).

Table 1

Physicochemical properties of diesel, ethanol, ETBE and biodiesel

Property	**DF**	**Ethanol** [6; 10; 11]	**ETBE** [7; 10; 11]	**FAME** [10; 11]
Molecular weight ($kg \cdot kmol^{-1}$)	-	46	102	-
Boiling temperature (ºC)	-	78.1	72	-
Density ($g \cdot cm^{-3}$, at 20 ºC)	0.85	0.78	0.74	0.88
Viscosity at 40ºC, ($mm^2 \cdot s^{-1}$)	2.5	<1	<1	4.95
Lower heating value ($MJ \cdot kg^{-1}$)	42.74	28.40	36.2	36.8
Cetane number	52.7	6	8	37.6-49
Surface tension, ($mN \cdot m^{-1}$)	25.9	22.3	20.6	-
Carbon content (wt. %)	86	52.2	70.53	77.5
Hydrogen content (wt. %)	14	13.1	13.81	12.1
Oxygen content (wt. %)	0	34.8	15.66	10.4

Results and discussion

Figure 3 shows the effect of the tested fuels on variations of the angle of injection start – α_{inj}, for the selected crankshaft rotational speeds and engine loads. Injection of ethanol based fuels starts slightly earlier compared to fossil diesel. As ethanol has lower density, viscosity and surface tension than biodiesel, the use of ethanol-biodiesel fuel blends can promote earlier fuel injection and improve the spray characteristics.

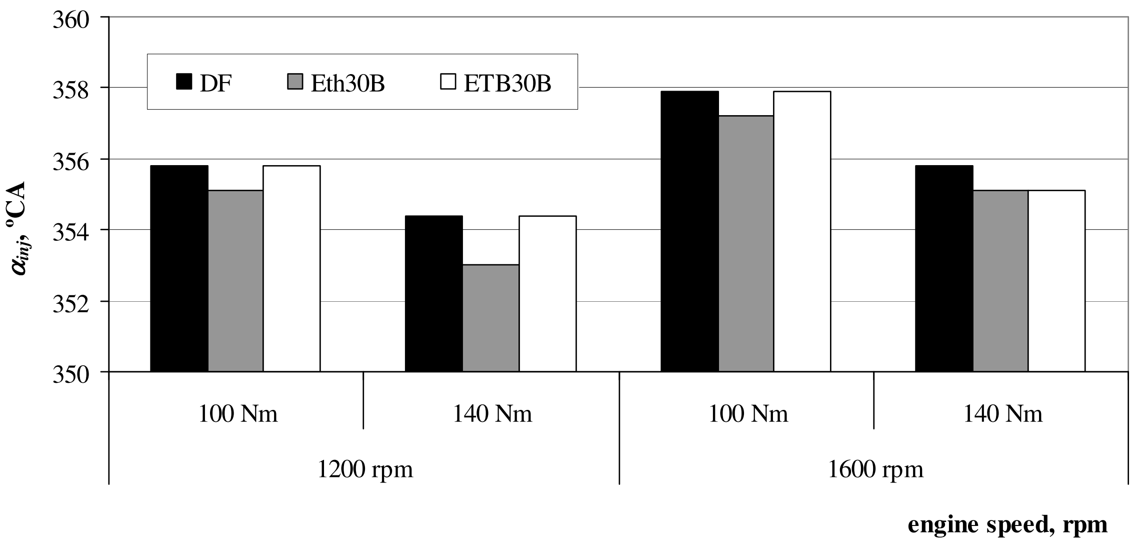

Fig. 3. **Effect of different fuels on variations of angle of injection start for selected rotational speeds of the engine crankshaft**

The research shows that the presence of ethanol in fuel blend Eth30B promotes slightly longer self-ignition delay, but the presence of ETBE – promotes shorter self-ignition delay compared to fossil diesel (Fig. 4). Increase of the ignition delay can be connected with a very low cetane number of ethanol, which reduces the level of cetane number also for biodiesel-ethanol blends.

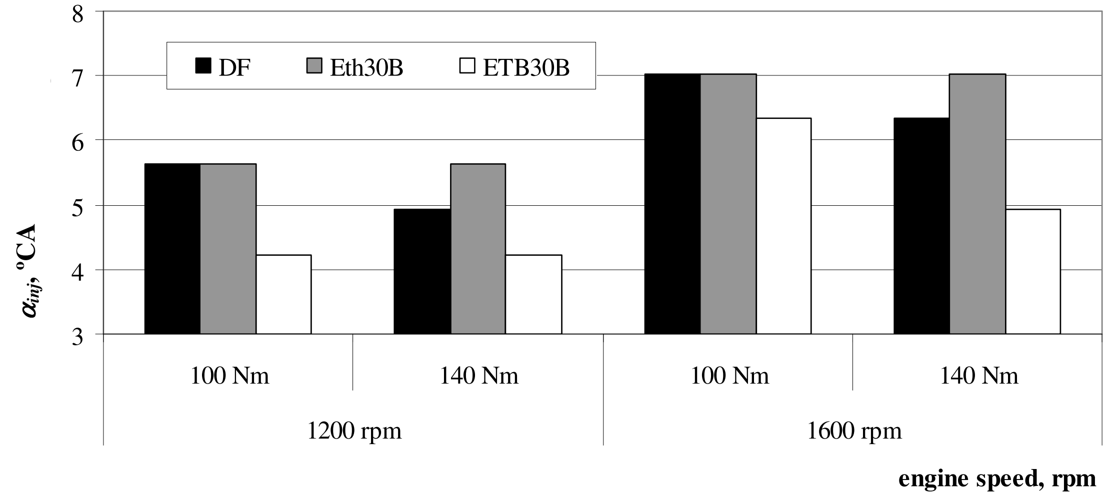

Fig. 4. **Effect of different fuels on variations of self-ignition delay angle for selected rotational speeds of engine crankshaft**

Figure 5 shows the changes of the peak pressure in the combustion chamber for all fuels in the same testing conditions. The figure shows that the maximum pressure with diesel fuel is being reached on 1200 rpm at 140 Nm – 6.31 MPa, but the minimal value on 1600 rpm at 100 Nm – 5.35 MPa. Ethanol fuel blend reached the maximal value on 1200 rpm at 140 Nm and showed the largest value of peak pressure at most testing conditions. The change in pressure for ETBE fuel blend is similar to diesel. The increase of the maximum combustion pressure could be explained with better mixing of fuel and air, which can promote better combustion and higher combustion pressure [8].

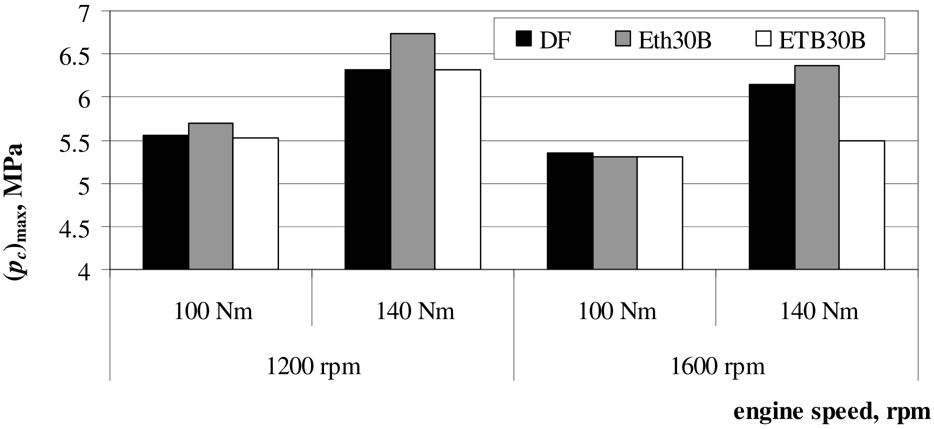

Fig. 5. **Effect of different fuels on cylinder maximum pressure variations for selected rotational speeds of engine crankshaft**

As it is seen from Fig. 6, the results of the indicative pressure are higher for fossil diesel at all testing conditions. The value of the mean indicated pressure depends on the engine mechanical efficiency. Viscosity of fossil diesel (Tab. 1) is significantly higher in comparison to neat ethanol or ETBE. The engine mechanical efficiency grows up, when fuel with lower viscosity is mixed with fossil fuel. It seems that the flow resistance of ethanol or ETBE blends with diesel fuel is lower. In this case the value of the mean indicated pressure is lower, too.

As it was expected, the results confirm that the presence of 30 % by volume of ethanol or ETBE increased the specific fuel consumption (Fig. 7) compared to fossil diesel due to loss of the heat content. The maximal values were reached in work with ethanol fuel blend in all testing conditions with average increase 19 % on 1200 rpm and 14 % on 1600 rpm. Not so large increase in the specific fuel consumption was determined in work with ETB30B and reached 6 % on average compared to fossil diesel.

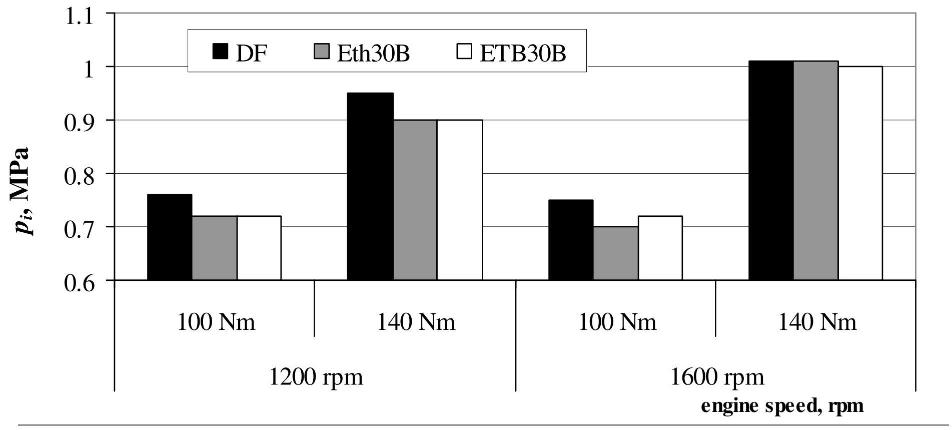

Fig. 6. **Effect of different fuels on mean indicative pressure variations for selected rotational speeds of engine crankshaft**

Such increase in fuel consumption is directly connected with a lower oxygenated fuel heating value. As all of the fuels have a lower heating value compared to fossil diesel then, to get the same power output from the engine, it is necessity to consume more fuel.

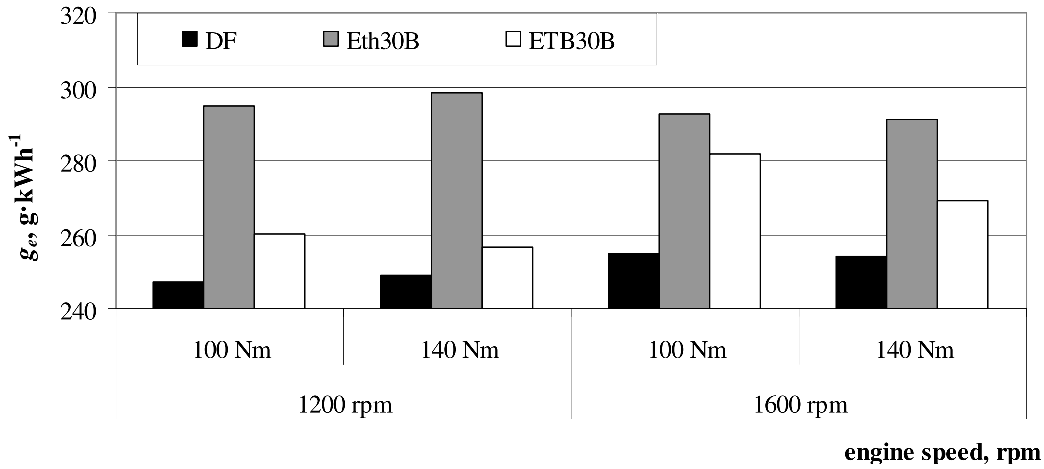

Fig. 7. **Effect of different fuels on specific fuel consumption variations for selected rotational speeds of engine crankshaft**

Conclusions

The main aim of the paper was to describe the first experiences in range of the use ethanol or ETBE added into biodiesel on the selected parameters of the combustion process. The evaluation was carried out using an AD3.152 direct-injection diesel engine installed in the laboratory of the Vehicle Technical Exploitation Department at the Technical University of Radom.

Diesel engine combustion characteristics are strongly affected by physicochemical properties of the fuels. The heating value is one of the most important properties for oxygenated fuels. There are also other properties (cetane number, viscosity), which ally in affecting of the engine performance and fuel consumption increase. Lower cetane number may increase the ignition delay and retard start of combustion. On the other hand, lower surface tension and viscosity of the tested oxygenated fuels affect better fuel atomization and vaporization. It may reduce the value of fuel ignition delay, which was confirmed by the research results with ETB30B. Lower viscosity leads to greater leakage from the fuel pump and the injector, and therefore reduces the amount of the delivered fuel, but it promotes earlier fuel injection.

Ethanol fuel blends promote also higher combustion pressure and therefore better combustion and lower amount of exhaust components [9]. The research in these fuels will be continued with attention to exhaust gases.

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