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THE INFLUENCE OF HYDROCARBON FUELS AND BIOFUELS ON SELF-IGNITION DELAY PERIOD

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Summary. The paper discusses an influence of hydrocarbon fuels and biofuels properties on self-ignition delay period in AD3.152 UR engine. The period significantly affects the combustion speed, the rate of pressure and temperature increase, easy engine starting and other engine performance characteristics. It also influences the emission values of basic toxic components such as CO, HC, NOx, PM in exhaust gases. The values of self-ignition delay period were determined when the engine was fuelled by EKODIESEL PLUS 50 hydrocarbon fuel (environmentally friendly winter diesel oil) and FAME (Fatty Acid Methyl Esters) plant fuel, made of plant or animal oils fatty acids methyl esters. Investigations into the engine were conducted in an engine test house equipped with a system for measuring pressures and other fast changing values. In investigations the engine was operated under load conditions at the maximum torque speed n = 1400 rpm and rated power speed n = 2000 rpm. The analysis of results was made on the basis of averaged pressures in indicator diagrams taken on 100 engine work cycles.

Key words: combustion engines, indicator diagram, self-ignition delay period, engine fuels

INTRODUCTION

The self-ignition delay period is an angle between the injection beginning (the start of the injector needle lift) and the instant of combustion onset, which is equivalent to the beginning of quick increase in pressure and temperature of the working medium in the cylinder [Ambrozik 2001]. The angle affects the combustion speed and the rate of pressure and temperature increase, easy engine starting and other engine performance characteristics.

The value of injection and self-ignition delay angle depends [Ambrozik 2004] on: physical and chemical properties of the fuel, the engine design features, the kind of injection apparatus and the engine service conditions.

While using fuels of different physical/chemical properties to fuel self-ignition engines it is necessary to take high accuracy measurements of pressure and other quantities that change in injection and combustion processes [Ambrozik and Kurczyński 2006].

The fuel fraction composition and cetane number, mutually connected to a great extent, are among the primary factors that affect self-ignition delay period and combustion character. Higher cetane number fuels show shorter self-ignition delay period.

The shortening of self-ignition delay period with an increase in cetane number (CN) is quite considerable, thus when high CN fuels are used, the engine operation becomes softer. Average values of pressure increase rate are relatively low then.

Apart from cetane number, self-ignition temperature also affects the duration time of the self-ignition delay period. In order to produce ignition, the fuel with low self-ignition temperature needs shorter time to appropriately heat the fuel and overheat vapours, which leads to the reduction in ignition delay period.

Paraffin hydrocarbons with long straight saturated chains have the best self-ignition properties. The disadvantage associated with paraffin hydrocarbons is their high solidification temperature and paraffin crystallisation on cooling. That results in blocking the fuel flow and the engine stoppage. In order to lower the diesel oil solidification temperature depressant additives are used. They are surface active substances which delay the formation of spatial skeleton of solidified paraffins. Naphthenes have a greater, and aromatic hydrocarbons the greatest self-ignition delay. Aromatic hydrocarbons considerably lengthen the fuel self-ignition. They cause carbon deposit formation in the combustion chamber and an increase in particulate matter emission.

AIM OF INVESTIGATIONS

The aim of investigations was to compare values of self-ignition delay angle when AD3.152 UR engine was fuelled by „Ekodiesel Ultra D" hydrocarbon fuel and FAME plant fuel, i.e. methyl ester of fatty acids of rapeseed oil.

The value of self-ignition delay angle was determined using measurements of the injector needle lift and also the experimentally taken indicator diagram. These quantities values are helpful to estimate and define regulatory changes in the angle of the dynamic start of fuel, pumping depending on the fuel type and its fraction composition. Self-ignition delay angle is an important diagnostic parameter of the engine because its value decides, to a great extent, on the engine noise level and toxic component emission in exhaust gases.

CHARACTERISTICS OF THE EXAMINED FUELS

The paper analyses self-ignition delay period in AD3.152 UR engine fuelled by two different fuel kinds: „Ekodiesel Ultra D" mineral fuel and FAME plant fuel, i.e. methyl ester of fatty acids of rapeseed oil.

Diesel oils are known to be commonly used to fuel spontaneous ignition combustion engines. Stricter standards that result from heightened environmental awareness and gradual depletion of crude oil resources both contribute to increased importance placed on alternative fuels, and consequently, reduce the amount of hydrocarbon fuel used. With respect to self-ignition engines, plant fuels either alone or in blends with diesel oil become a possible solution. FAME, i.e. methyl esters of fatty acids of rapeseed oil, is an example of such fuel types. They show a clear advantage over diesel oils as they produce far less adverse effects on the environment.

The cetane number of the plant fuel used in the investigations is close to that of „Ekodiesel Ultra D” oil, but the biofuel is characterised by higher density, lower calorific value, higher turbidity and cold filter blocking temperature. The use of the biofuel under winter conditions is possible only with appropriate additives. FAME fuel contains much more oxygen when compared to diesel oil, moreover, it has good lubricating properties which are advantageous for the operation and service life of the engine fuel feeding system. FAME does not contain volatile compounds, which results in the low pressure of its saturated vapours and high ignition temperature. Much higher ignition temperature of esters prevents the explosion of vapours, thus improving the safety of engine fuelling [Ambrozik and Kurczyński 2006]. Basic physical and chemical properties of engine fuels used in investigations are shown in Table 1.

Table. 1. Basic physical and chemical properties of engine fuels used in investigations [Ambrozik and Kurczyński 2006]

Parameter	Ekodiesel Ultra D diesel oil	FAME plant fuel
Cetane number	51.4	51
Calorific value, MJ/kg	43.2	36.7
Density at 15°,C g/cm^3,	0.8354	0.883
Kinematic viscosity, mm^2/s (~40°C)	2.64	4.47
Surface tension, N/m (20°C)	$3.64 \cdot 10^{-2}$	$3.58 \cdot 10^{-2}$
Ignition temperature, °C	63	above 130
Turbidity point, °C	-17	-2
Cold filter blocking temperature, °C	-23	-14
Average element composition, %		
– C	87.2	76.8
– H	12.7	12.1
– O	0	11
Sulphur content S, mg/kg	9	8.1
Water content, mg/kg	43.8	113
Particulate matter content, mg/kg	5	18
Coke-cake remainder in 10% distillation residue, % (m/m)	0.01	0.28
Examination of corrosive action on copper plates, class	1	1

RESEARCH STAND DESCRIPTION – THE ENGINE DATA

The object under investigation was spontaneous ignition Perkins AD3.152UR engine with fuel directly injected into the combustion chamber. The engine was operated at the test stand equipped with a system for measuring pressures and other fast changing values.

The basic technical data of AD3.152 UR engine are presented in Table 2. The diagram of the research stand is shown in Fig. 1

Table. 2. Basic technical data of the engine [Ambrozik and Kurczyński 2006]

Spontaneous ignition AD3.152 UR engine		
Parameter	Unit	Value
Cylinder arrangement	-	row
Number of cylinders	-	3
Type of injection	-	direct
Sequence of cylinder operation	-	1 – 2 – 3
Compression ratio	-	16.5
Cylinder diameter	mm	91.44
Piston stroke	mm	127
Engine cubic capacity	dm^3	2.502
Connecting rod length	mm	223.80÷223.85
Maximum engine power	kW	34.6
Maximum power rotational speed	rpm	2250
Maximum torque	Nm	168.7
Maximum torque rotational speed	rpm	1350
Static angle of injection advance	CA deg	17
Angle of inlet valve opening	CA deg	13
Angle of inlet valve closing	CA deg	43
Angle of outlet valve opening	CA deg	46
Angle of outlet valve closing	CA deg	10
Idle run rotational speed	rpm	750±50

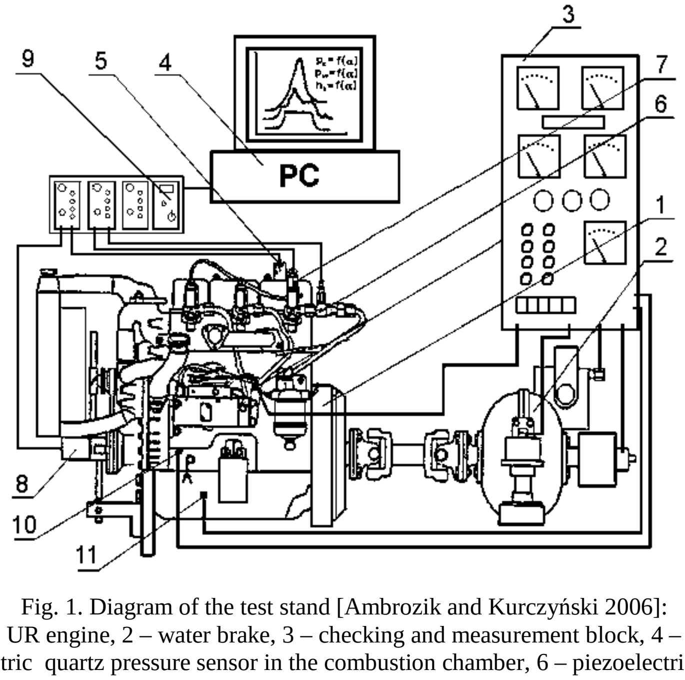


Fig. 1. Diagram of the test stand [Ambrozik and Kurczyński 2006]:
1 – AD3.152 UR engine, 2 – water brake, 3 – checking and measurement block, 4 – PC computer, 5 – piezoelectric quartz pressure sensor in the combustion chamber, 6 – piezoelectric quartz pressure sensor in the injection pipe, 7 – transformer displacement sensor, 8 – crankshaft rotation angle transmitter, 9 – set of sensor signal amplifiers, 10 – engine coolant temperature sensor, 11 – engine oil temperature sensor

DESCRIPTION OF INVESTIGATIONS METHODOLOGY

Prior to taking measurements, the engine was brought to the state of thermal equilibrium, which was followed by checking the performance of all control and measurement devices at the research stand.

Investigations were conducted when the engine was operated under load characteristics, i.e. at the rotational speed corresponding to the maximum torque n = 1400 rpm and the loads expressed in power units: N_e = 4, 8, 12, 16, 20 kW and at rated power speed n = 2000 rpm and powers: N_e = 8, 12, 16, 20, 24, 28 kW. Measurements were taken when the angle of the dynamic start of the fuel pumping was set constant at α_{dpt}=17.5 CA deg. The analysis of the results was made on the basis of averaged values of quantities measured at 100 engine work cycles.

Figure 2 shows the curve of the injector needle lift and developed indicator diagram, in which injection advance angle and self-ignition delay angle are marked.

The graphs of fuel pressure in the injection pipe and combustion pressure in the engine cylinder were plotted by means of piezoelectric quartz sensors which underwent static and dynamic calibration under close-to-real conditions. The injector needle lift was recorded with a displacement sensor.

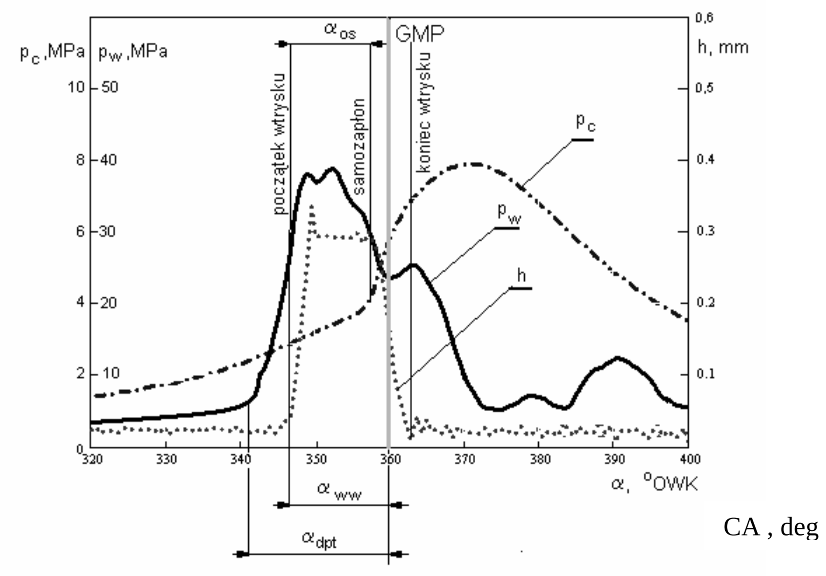


Fig. 2. Lift of injector needle (h), fuel pressure in injection pipe (p_w) and open indicator diagram (p_c) with marked angles [Ambrozik 2001]: α_{os} – self-ignition delay angle, α_{ww} – injection advance angle, α_{dpt} – dynamic pumping beginning angle

The graphic presentation of the method for the determination of the instant of self-ignition occurrence is shown in Fig. 3. The intersection of $T(\alpha)$ characteristics for compression determined with the assumption that air is the working medium, and $T(\alpha)$ curve determined for $\alpha \leq \alpha_{GMP}$ with the assumption that products of total and complete combustion are the working medium. *T(α)* curve for compression process was plotted for $\alpha \geq \alpha_{pw}$, whereas T(α) curve for combustion process was plotted for $\alpha \leq \alpha_{GMP}$.

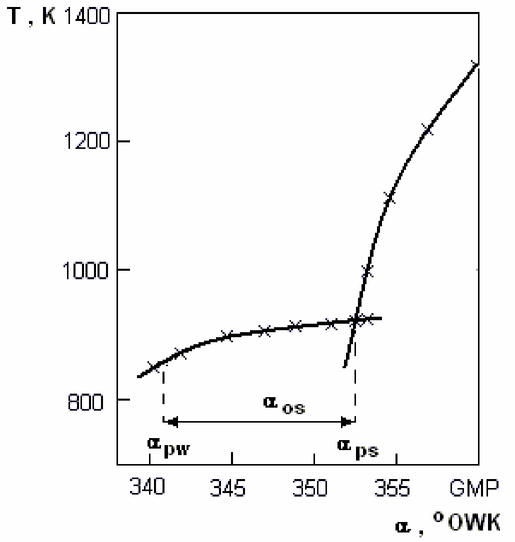
The self-ignition delay period is [Ambrozik 2004]:

$$\alpha_{os} = \alpha_{ps} - \alpha_{pw} \text{ , CA deg} \tag{1}$$

$$\tau_{os} = \frac{\alpha_{os}}{6n} \text{, s} \tag{2}$$

where:

α_{os} – self-ignition delay angle,
α_{ps} – combustion onset angle,
α_{pw} – injection beginning angle.



CA , deg

Fig. 3. Illustration of self-ignition delay period determination method [Ambrozik 2001]: α_{pw} – beginning of fuel injection, α_{ps} – beginning of combustion process

ANALYSIS OF EXPERIMENTAL RESULTS

Values of self-ignition delay period determined in the investigations and their presentation in a graphic form are shown in Table 3 and Figs 4 and 5, respectively.

In Figure 4, self-ignition delay angles are compared for the examined fuels, under different loads at the rotational speed 1400 and 2000 rpm.

Table. 3. Values of self-ignition delay period determined for the examined fuels in experimental investigations

N_e, kW	Self-ignition delay angle Θ_{os} , CAdeg at n = 1400 rpm,	
	Ekodiesel Ultra D	FAME plant fuel
4	20.1	17.5
8	16.8	15.4
12	15.1	14
16	13.9	13.1
20	13	11
N_e, kW	Self-ignition delay angle Θ_{os} ,CAdeg at n=2000rpm,	
	Ekodiesel Ultra D	FAME plant fuel
8	23	21.5
12	21.5	20.5
16	19	18
20	18.2	16.5
24	17.3	15.5
28	15	13

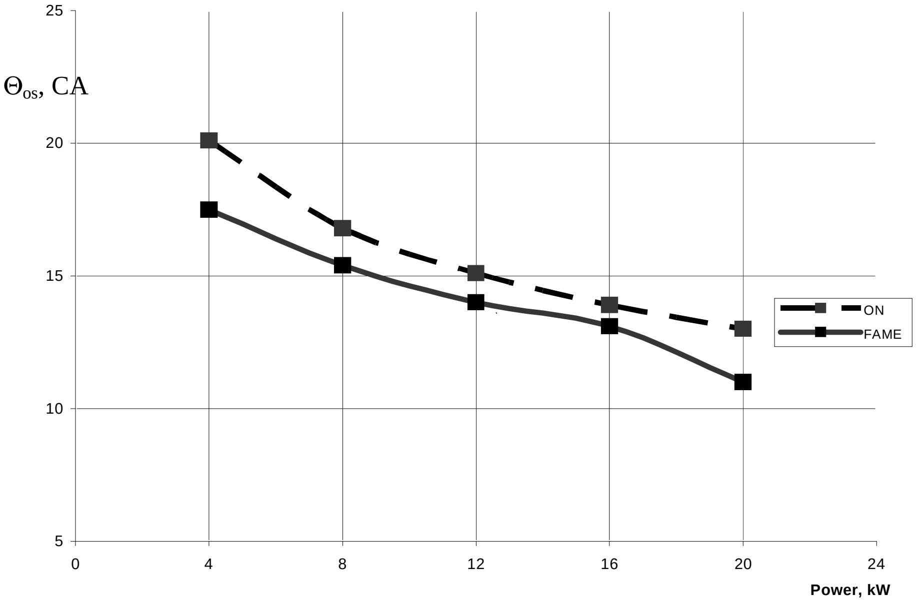


Fig. 4. Comparison of self-ignition delay angle values for Ekodiesel Ultra D and FAME fuels when an engine is operated at the rotational speed n = 1400 rpm.

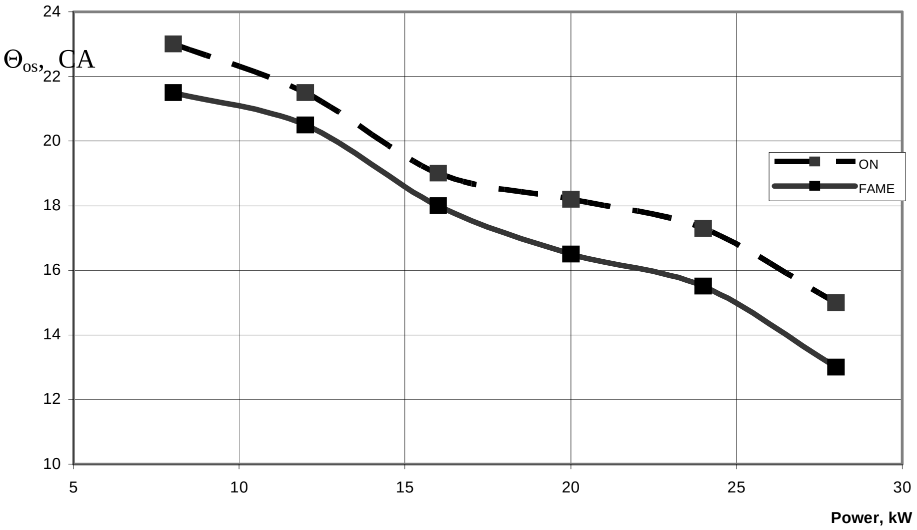


Fig. 5. Comparison of self-ignition delay angle values for Ekodiesel Ultra D and FAME fuels when an engine is operated at the rotational speed *n* = 2000 rpm

CONCLUSIONS

The following conclusions can be drawn on the basis of the results of experimental investigation into self-ignition delay period in AD3.152 engine fuelled by „Ekodiesel Ultra D" diesel oil and FAME, methyl esters of fatty acids of rapeseed oil:

1. Fuelling the engine by FAME methyl esters of fatty acids of rapeseed oil, which have approx. 10% more oxygen than hydrocarbon fuels, accelerates the combustion process, which reduces values of self-ignition delay angles by approx. 0.8÷2 CA deg in the whole range of the examined loads, both for the rotational speed of rated power *n* = 1400 rpm and the maximum torque speed *n* = 2000 rpm.
2. Further research into combustion processes when engine is fuelled by both mineral and plant fuels is fully justifiable. The aspects of natural environment protection (decrease in the toxic exhaust gases emissions and engine produced noise) and the use of alternative fuels of new generation enforced by fossil fuels resources depletion and price increase should also be taken into account.

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