ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1137354

THE INFLUENCE OF CAMELINA OIL ESTER ADDITIVE TO DIESEL FUEL ON SELF-IGNITION ANGLE IN AGRICULTURAL ENGINE

Piotr Orliński

Warsaw University of Technology
Institute of Vehicles
Narbutta Street 84, 02-524 Warsaw, Poland
tel.: +48 22 2348566
e-mail: p.orlinski@simr.pw.edu.pl

Abstract

The article presents the results of investigations referring to self-ignition delay angle determined experimentally and through simulations. It was done using charged agricultural Perkins 1104C-E44T engine powered by pure diesel fuel (ON) and fuel mixtures, such as: diesel fuel with 10% camelina oil ester additive (L10) and diesel fuel with 15% camelina oil ester additive (L15). Camelina oil ester was used to show that it can also be used as an additive plant to diesel fuel (according to the plans of the European Union). Similarly to on a large scale used ester of rapeseed oil. The main aim of the above mentioned research was to show the influence of the fuels on the change of self-ignition delay angle for different rotational velocity conditions of the engine and for maximum volumetric dose of ignited fuel. The research was performed using a dynamometer test stand equipped with measurement system of fast-changeable needle lift of injector and the pressures of working substance. Before starting the investigations, selected physicochemical properties of researched fuels were determined that significantly influence that parameter of the combustion process. At the end of the article the conclusion of experiments and simulations results referring to self-ignition delay angle are analysed.

Keywords: *Camelina oil ester, self-ignition delay angle, diesel engine*

1. Introduction

The self-ignition delay period is calculated from the instant fuel is injected into the combustion chamber until the moment of the chain-thermal explosion of pre-flame reactions recorded in an indicator diagram as the beginning of the rapid rise in the pressure and temperature of the operating medium caused by fuel combustion. The length of this period affects the course of the initial combustion phase, i.e. combustion speed, pressure and temperature growth, engine performance properties, noise and others [2, 3, 5]. In literature it is most often presented as the crankshaft rotation angle during which the self-ignition of the fuel-air mixture is delayed.

The moment at which the injector needle starts to lift is regarded as the beginning of the injection which starts the self-ignition delay period. A thorough examination of multi-hole injectors which was conducted at the AVL Institute in Graz showed that at the very first moment of the injector needle lift to the value of $h = 0.04$ mm there is no flow but only elastic strain of the injector nozzle occurs. Considering high flow resistance at very small injector nozzle's hole openings we can assume that the dynamic start of the injection corresponds to the injector needle lift equal to 0.04 mm [8].

The point at which the combustion process starts is defined as the intersection point of the $T(\alpha)$ or $p(\alpha)$ characteristic determined for the compression process (in newer engines – for decompression) and the combustion process (self-ignition point, rapid pressure and temperature increase).

The self-ignition delay angle depends, among others, on the following factors [3, 7, 9]:

– physicochemical properties of fuel (chemical composition, viscosity, density, cetane number),

– engine design features (combustion chamber type, cylinder diameter, compression degree,, mean effective pressure, injection advance angle, injector type and injection characteristics),
– operating conditions (engine rotational speed, liquid coolant temperature, engine load, injection advance angle, combustion chamber tightness, excess air coefficient, exhaust gas residue).

The magnitude of the self-ignition delay angle determined on the basis of the indicator diagram can show the direction of the adjustment changes in the angle of the dynamic start of fuel pumping depending on the type and fractional composition of fuel.

2. The aim of the research

The aim of the research was to assess the effect of mixtures of diesel fuel and camelina oil ester on the self-ignition delay angle in the self-ignition Perkins engine, Model 1104C–E44T. During experimental tests the engine worked in the same velocity conditions. Investigations were carried out over the entire range of the engine's crankshaft rotational speed and at maximum volumetric fuel charge. At the end of the paper the self-ignition delay angles determined experimentally and through simulations are compared.

3. Test stand and physicochemical properties of examined fuels

The test stand was based on a four-cylinder self-ignition Perkins engine, model 1104C-E44T (Euro Stage II) manufactured in 2010. This model was equipped with a turbo-compressor unit and rarely encountered system of two controllers. One was responsible for the motor operation supervision, whereas the other one was located on a radial piston distributor injection pump Bosch VP-30. The stand was also equipped with a measuring system enabling determination of the engine's operating parameters and fast-changing pressures of the operating medium. The compression degree in the engine was 18.2, and the static angle of injection advance – 10 CA deg. before TDC.

The fuels tested were selected in view of their availability on the market and non-uniform physicochemical properties which usually exert a significant effect on the course of the combustion process [4, 6, 8, 9].

The L10 and L15 mixtures used in the tests were volumetric mixtures consisting of 10% or 15% of camelina ester, respectively, and low-sulphur diesel fuel (ON). The block diagram of the test stand is depicted in Fig. 1. Tab. 1 compares selected (main) physicochemical properties of the fuels used in our research (which are also referred to the EN 590 standard for diesel fuel).

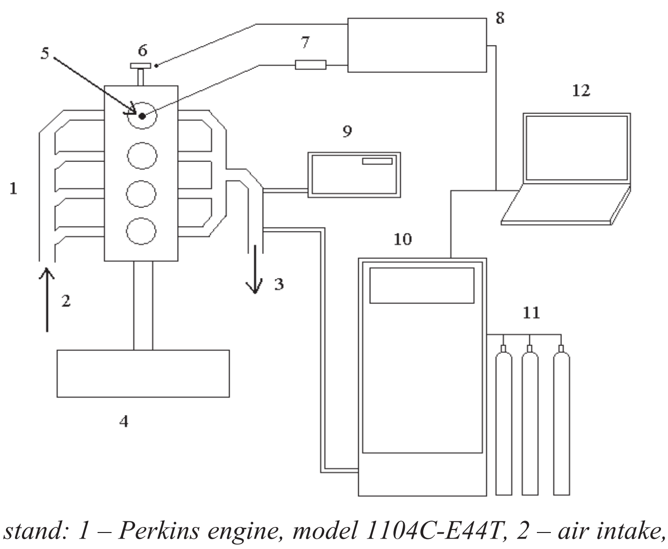

Fig. 1. Block diagram of test stand: 1 – Perkins engine, model 1104C-E44T, 2 – air intake, 3 – air outlet, 4 – Schenck eddy current brake, 5 – piezoelectric pressure sensor, 6 – crankshaft rotation angle recorder, 7 – signal amplifier, 8 – AVL IndiSmart indicating system, 9 – AVL 415 solid particle emission analyser, 10 – AVL CEB II exhaust gas analyser, 11 – set of reference gases, 12 – measuring computer

Tab. 1. Selected physicochemical research results for mixtures of camelina oil ester and diesel fuel

Parameter	Diesel fuel – ON (in parantheses – values according to EN 590 standard)	L10	L15
Cetane number	52.4 (min. 51)	51.6	51.4
N.c.v. [MJ/kg]	43.2	42.5	42.2
Density at 15°C [kg/m^3],	835.4 (820–845)	846	848
Kinematic viscosity (~40°C) [mm^2/s]	2.64 (2.00–4.50)	3.26	3.40
Ignition temperature [°C]	63 (min. 55)	75	80
Cold filter plugging point (CFPP) [°C]	–15 (max. 0)	–12	–11
Sulphur content *S* [mg/kg]	9 (max. 10)	8.9	8.9
Water content [mg/kg]	43.8 (max. 200)	58	63

4. Determination of self-ignition delay

On the basis of experimental data (the start of fuel injection and the start of the operating medium combustion) we can calculate the self-ignition delay angle or period from the relationships [1, 8, 11]:

$$\alpha_{os} = \alpha_{ps} - \alpha_{pw}, \; [°\text{CA}], \tag{1}$$

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

Figure 2 depicts the methodology of determining this quantity on the basis of temperature determined thanks to experimentally measured pressure of the operating medium.

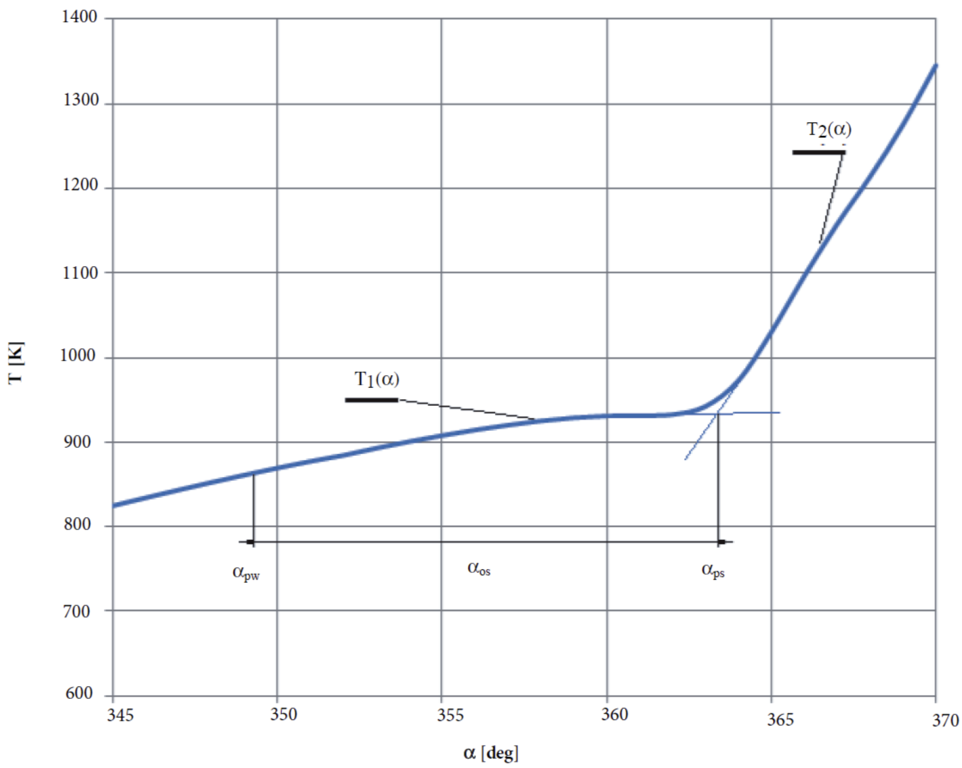

Fig. 2. Graphic presentation of the method for determination of self-ignition delay angle employing the real course of the operating medium temperature in the combustion chamber where: α_{pw} – angle corresponding to the start of fuel injection, α_{ps} – angle corresponding to the start of the combustion process, $T_1(\alpha)$ – temperature for the operating medium being air, $T_2(\alpha)$ – temperature for the products of total and complete combustion

The self-ignition delay angle for a self-ignition engine with fuel directly injected to the combustion chamber can be determined through simulations using to this purpose an equation proposed by Sitkei [10]:

$$\alpha_{os} = 6 \cdot n \cdot 10^{-3} \left[a_{os} + b_{os} \cdot \mathrm{e}^{\left(\frac{7.8}{6.9167 \cdot \overline{R} \cdot T}\right)} (1.0197 \cdot p^{-0.7}) \right] + c_{os} \cdot \mathrm{e}^{\left(\frac{7.8}{6.9167 \cdot \overline{R} \cdot T}\right)} (1.0197 \cdot p^{-1.8}), \quad (3)$$

where:

$a_{os} = 0.5$, $b_{os} = 0.135$, $c_{os} = 4.8$ – constant quantities depending on the engine type (their standard values),

p – mean pressure (determined from the start of injection till the start of combustion),

T – mean temperature (determined from the start of injection till the start of combustion),

$\overline{R}$ – universal gas constant,

n – engine's crankshaft rotational speed.

In reality the values of coefficients a_{os}, b_{os}, c_{os} depend on the engine size or, in other words, on engine cubic capacity. For the most accurate determination of the self-ignition delay angle through simulations these values must be selected individually. On the basis of literature analysis [10] we suggest that these values should be in the ranges: $a_{os} = 0.1–1.0$, $b_{os} = 0.105–0.135$, $c_{os} = 3.12–4.80$. Within the given ranges the values of coefficients b_{os}, c_{os} should decrease as the examined engine cubic capacities increase. The situation is opposite in the case of coefficient a_{os}, the value of which can even equal 1 when it comes to determination of the self-ignition delay angle in large self-ignition engines.

Another way of determining the self-ignition delay angle is possible when we know the value of activation energy. A. I. Tolstov puts forward the following formula to calculate the self-ignition delay angle in self-ignition engines [1, 8]:

$$\tau_{os} = 10^{-2} B \sqrt{\frac{T_{pw}}{p_{pw}}} \, \mathrm{e}^{\left(\frac{Ea}{\overline{R}T}\right)}, \quad (4)$$

where: $B = B_o\,(1 - K{\cdot}n)$, $B_o \approx 3.8 \cdot 10^{-4}$, and $K = 1.6 \cdot 10^{-4}$ is a coefficient taking into account the impact of the operating medium movement intensity in the cylinder (proportional to rotational speed n) on the processes of heat and mass transfer in the self-ignition centre and other operating medium parameters at the beginning of the fuel injection process which depend on n, p_{pw}, T_{pw}, E_a. For this reason the term E_a should be understood as conventional activation energy of the pre-flame reactions.

Tolstov's formula is widely used for the combustion process calculations for self-ignition engines. To enhance credibility and accuracy of the obtained research results, quantities B_o and E_a determined according to the experimental data for a given engine must be specified [1].

5. Research results

Below you will find research results concerning the determined self-ignition delay angle. In the first phase of research this quantity was determined experimentally on the basis of momentary magnitudes of the injection advance angle and the angle corresponding to the start of the operating medium combustion in the Perkins engine, model 1104C–E44T. To supply the engine during the research tests we used diesel fuel and its mixtures with the camelina oil ester. The research was conducted for the whole range of the crankshaft rotational speeds at the maximum volumetric fuel charge. At the subsequent stage the self-ignition delay angle was determined from Sitkei's equation as the most appropriate one for this engine type. Fig. 3 depicts a compilation of research results for this parameter determined both experimentally and through simulations. The magnitude of the self-ignition delay angle determined through simulations was denoted by adding the "s" letter to the name of fuel; additionally the character of changes in this parameter is shown by a broken line.

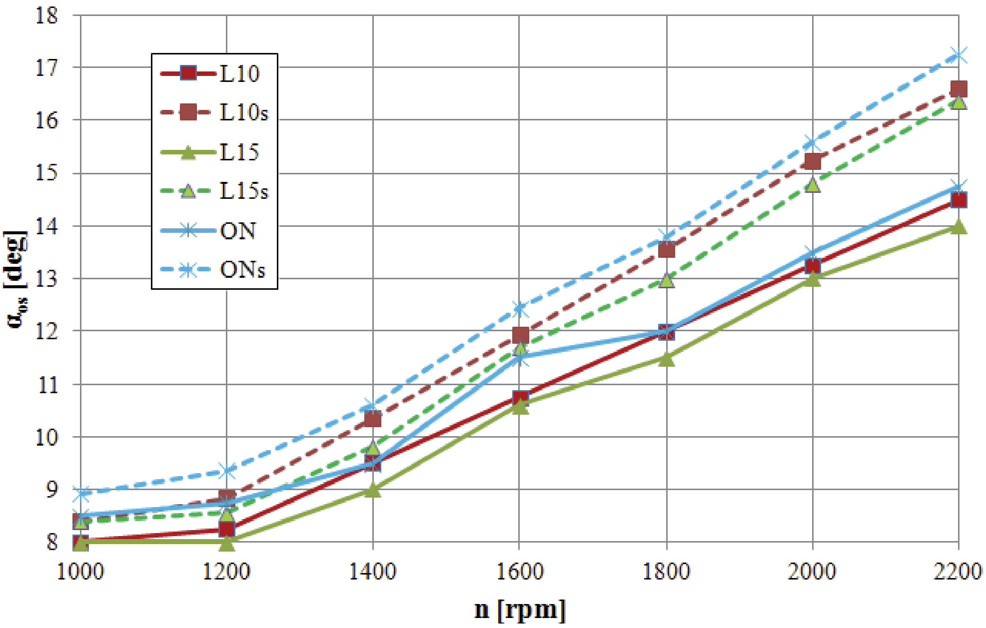

Fig. 3. Comparison of the value of the self-ignition delay angle for fuels: diesel fuel (ON), the mixture of diesel fuel and 10% of camelina oil ester (10L), the mixture of diesel fuel and 15% of camelina oil ester (15L) over the whole range of crankshaft rotational speeds of the Perkins engine, model 1104C-E44T and at the maximum volumetric fuel charge (continuous line – experimental test results, broken line – simulation test results)

6. Summary and conclusions

Analysing correlations describing the self-ignition delay angle one can state that it is determined by such factors as: the pressure and temperature in the combustion chamber, the crankshaft rotational speed and kinematics of the crankshaft-piston system, and the magnitude of activation energy (particularly important when the self-ignition delay angle is determined through simulations).

On the basis of a comparison of experimental research results for three fuels, i.e. diesel fuel (without any rapeseed ester additives in its composition – as in the case of commercial diesel fuels) and its two mixtures with methyl ester of camelina oil (volumetric contents of 10% and 15%), the following conclusions can be formulated:

– supplying the engine with a mixture of diesel fuel and camelina oil ester causes a shorter self-ignition delay angle (max. by 8%) which results mainly from the differences in the physico-chemical properties of the said fuels,
– an increase in the engine's crankshaft rotational speed is accompanied by an increase in the self-ignition delay angle for all examined fuels.

The self-ignition delay angles determined through simulations were always larger (max. by 17%) than those determined experimentally. It was noticed that together with an increase in the engine's crankshaft rotational speed the difference between the values of this parameter determined experimentally and through simulations is increasingly bigger.

During the simulation tests aiming at determining the self-ignition delay angle the standard values of coefficients in Sitkei's formula, such as a_{os}, b_{os}, c_{os} were used. In the future, in order to improve the convergence between experimental and simulation results for the self-ignition delay angle, the values of these coefficients should be selected individually depending on the examined engine type.

Acknowledgements

This paper was developed on the basis of the research results obtained within the author's own research project No. N N504 701340.

References

[1] Ambrozik, A., *Analiza cykli pracy czterosuwowych silników spalinowych*, Monografie, Studia, Rozprawy M-16, Wyd. Politechniki Świętokrzyskiej, s. 252, Kielce 2010.

[2] Ambrozik, A., Kruczyński, P., Orliński, P., *Wpływ zasilania silnika o ZS paliwami alternatywnymi na wybrane parametry procesu spalania oraz emisję składników toksycznych spalin*, Zeszyty Naukowe Instytutu Pojazdów 2(78)/2010, s. 157-163, Warszawa 2010.

[3] Ambrozik, A., Kruczyński, S. W., Orliński S., *Wpływ właściwości paliw naturalnych i roślinnych na opóźnienia samozapłonu w silniku AD3.152*, Autobusy: Technika, Eksploatacja, Systemy Transportowe, 7(6)/2006, s. 25-27, 2010.

[4] Ambrozik, T., Łagowski, P., *Wielkości i parametry diagnostyczne procesu spalania w silniku o zapłonie samoczynnym*, Zeszyty Naukowe Instytutu Pojazdów 1(73)/2009, s. 5-15, Warszawa 2009.

[5] Assanis, D. N., Filipi, Z. S., Fiveland, S. B., Syrimis, M. A., *Predictive Ignition Delay Correlation Under Steady-State and Transient Operation of a Direct Injection Diesel Engine,* Journal of Engineering for Gas Turbines and Power, Vol. 125, No. 2, pp. 450-457, 2003.

[6] Demirbas, A., *Biofuels Sources, Biofuel Policy, Biofuel Economy and Global Biofuel Projections*, Energy Conversion and Management, Vol. 49, No. 8, pp. 2106-2116, 2008.

[7] Lotko, W., *Ocena opóźnienia samozapłonu silnika wysokoprężnego z wtryskiem bezpośrednim zasilanego mieszaninami oleju napędowego z estrami metylowymi oleju rzepakowego,* Archiwum Motoryzacji 4/2005, s. 321-337, 2005.

[8] Orliński, P., *Wybrane zagadnienia procesu spalania paliw pochodzenia roślinnego w silnikach o zapłonie samoczynnym,* Instytut Naukowo Wydawniczy SPATIUM, s. 137, Radom 2013.

[9] Ozsezen, A. N., Canakci, M., *Determination of Performance and Combustion Characteristics of a Diesel Engine Fueled with Canola and Waste Palm Oil Methyl Esters*, Energy Conversion Manage, Vol. 52, No. 1, pp. 108-116, 2011.

[10] Schwarz, C., Stiesch, G., Otto, F., Merker, G. P., *Simulating Combustion: Simulation of Combustion and Pollutant Formation for Engine-Development,* Springer-Verlag, pp. 426, Berlin Heidelberg 2006.

[11] Shahabuddin, M., Liaquat, A. M., Masjuki, H. H., Kalam, M. A., Mofijur, M., *Ignition Delay, Combustion and Emission Characteristics of Diesel Engine Fueled with Biodiesel*, Renewable and Sustainable Energy Reviews, Vol. 21, pp. 623-632, 2013.