

SOME PROBLEMS USING OF VEGETABLE FUELS IN DIESEL ENGINES

Andrzej Ambrozik¹, Antoni Jankowski², Marcin Slezak³

¹Kielce University of Technology

Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland
tel.: +48 41 3424344, fax: +48 41 3424340, e-mail: silspal@tu.kielce.p

²Institute of Aeronautics

Al. Krakowska 110/114, 02-256 Warsaw, Poland
tel.: +48 22 846011, fax: + 48 22 8464432, e-mail: ajank@ilot.edu.pl

⁴Motor Transport Institute

Jagiellonska 80, 03-301 Warsaw, Poland
tel.: +48 22 6753058, fax: +48 22 8110906, e-mail: marcin.slezak@its.waw.pl

Abstract

Experimental results of the four-stroke CI direct injection engine fed with vegetable fuel - methyl esters of the rapeseed oil in aspect pressure course and heat release are presented in the paper. Aim realized researches was estimation of the influence feed of the CI engine a vegetable fuel on performance of the CI engine mainly in an aspect of the heat release. This influence estimated on the basis of engine research on dynamometer test bench with additional high-frequency measurement of the pressure in the combustion chamber and the feed system and lift of nozzle needle. In estimation works there were performed: the analysis change route of increasing of the pressure in the injection pipeline of the engine feed system and as result of appointment of relative characteristics of the heat release quantity during combustion process. This analysis realized basing on average values of 100 engine work cycles received from experimental measurement on engine dynamometer test bench.

Characteristics of the relative heat release quantity during combustion process were appointed basing on the analysis of 100 engine work cycles received from experimental indicator diagrams. Indicator diagrams were obtained at work of the engine according to the external speed engine characteristics. The analysis of indicator diagrams of the engine oriented on to calculating characteristics of the heat release was realized at the regard of the change composition and the working charge quantity of kilo mole during combustion process and at neglect of losses of heat caused with the dissociation combustion products. The quantity heat exchanged between the working charge and walls combustion chamber was appointed basing on the empirical dependence for coefficient proposed by Woschni.

Test results indicate the two-phase- course of combustion process. The speed of the heat release concerning combustion of vegetable fuel is greater comparatively for this speed concerning the diesel oil. Initial values of speed jet of injected fuel, the drop break-up terms and the spray ranges were comparable for both fuels. These proprieties have an essential influence on performances of the engine.

Keywords: powertrain technology, alternative fuel engines, rapeseed oil methyl esters, fuel injection, heat release

1. Introduction

The aim of investigations was to experimentally determine the character of changes in fuel pressure, averaged over 100 cycles, in the injection duct and the working medium pressure in the engine cylinder and also the nozzle needle lift. Values of the above-mentioned parameters made it possible to determine the rate of the fuel flow out of the nozzle, the mean diameter of sprayed fuel droplets, the spreading angle of the injected fuel jet and its penetration. Those provided means to plot the diagrams of the relative amount of heat released during combustion. The measurements of

the above-mentioned values were taken for the engine operating in accordance with external speed performance. The engine was fuelled by EKODIESEL PLUS 50B and BIODIESEL D-FAME, the basic physical and chemical properties of which are given in Table 2. The engine basic technical data is presented in Table 1.

Table 1. Basic technical data of the AD3.152UR test engine

Parameter	Unit	Value
Cylinder system	-	row
Number of cylinders	-	3
Kind of injection	-	direct
Sequence of cylinder operation	-	1 – 2 – 3
Compression ratio, ϵ	-	16.5
Cylinder diameter, γ	mm	91.44
Piston stroke, S	mm	127
Engine cubic capacity, V_{SS}	dm ³	2.502
Connecting rod length, l_K	mm	223.80÷223.85
Maximum engine power, N_e	kW	34.6
Maximum power speed of rotation, n_{max}	rpm	2250
Maximum torque, M_{emax}	Nm	168.7
Maximum torque speed of rotation, n_M	rpm	1350
Fuel injection advance angle, α_{WW}	°CA	17
Idle run speed of rotation, n_I	rpm	750±50
Nozzle orifice diameter, d_r	mm	0.28
Nozzle channel length, l_r	mm	4

Table 2. Basic physical and chemical properties of fuels used in the investigations

PARAMETER	EKODIESEL PLUS 50 B	BIODIESEL D-FAME
Cetane Number, CN	51.5	51.3
Density at 20°C (10^{-3} kg/m ³)	0.836	0.882
Kinematical Viscosity at 40°C (10^{-6} m ² /s)	2.75	4.52
Calorific Value, MJ/kg	43.4	38.9
Surface Tension σ , 10^{-2} , N/m	3.47	3.55
Physical/ chemical properties for the diesel oil were given in accordance with the Polish and European standard PN-EN 590, for the FAME biofuel_ - PN-EN 590:2005		

The investigations covered the measurements of pressures in the cylinder and the injection duct and also the injector needle lift as the function of the rotation angle of the engine crankshaft in the thermal steady state and operating under the conditions corresponding to the rated power and the maximum torque.

2. Test Stand

The diagram of the research stand equipped with control and measurement devices to take measurements of fast-changing quantities is shown in Fig. 1. The block diagram of the system for the measurements of quantities subject to rapid change is shown in Fig. 2.

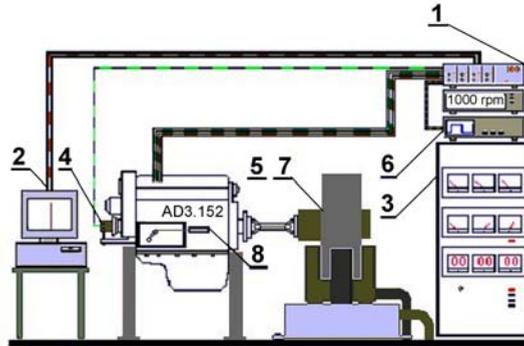


Fig.1. Research stand diagram 1 - block of amplifiers of signals from piezoelectric sensors, 2 - PC with a measurement card, 3 - control and check module, 4 - transmitter of the crankshaft rotation angle, 5 - AD3.152 UR engine, 6 - time base generator, 7 - water brake, 8 - injection pump control slat

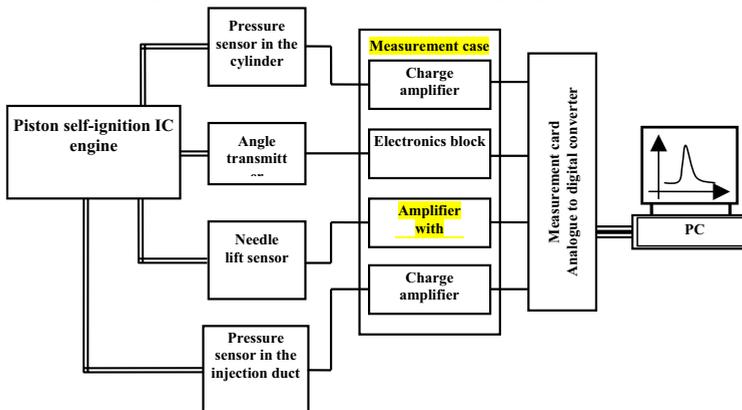


Fig. 2. Block diagram of the measurement system for fast changing quantities in piston compression ignition engine

The engine under investigation was mounted at the engine test stand equipped with water brake and control / measurement devices. They made it possible to control the engine and brake operation and also, to read and control the quantities measured. Amplifiers in the measurement paths enhanced signals generated by sensors. They were converted to voltage signals and then transferred to analogue-to-digital converter and recorded in the digital form.

3. Test results

Exemplary graphs of pressure changes in the cylinder and the injection duct and also the injector needle lift changes are shown in Fig. 3.

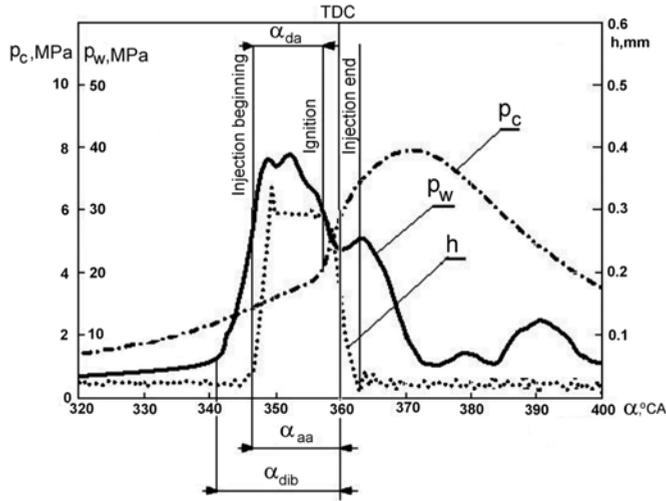


Fig.3. Changes in the injector needle lift (h), fuel pressure in the injection duct (p_w) and open indicator diagram (p_c) with marked angles: α_{dib} - angle of dynamic injection beginning, α_{aa} - injection advance angle, α_{da} - ignition delay angle

The way the volatile mixture is produced inside the engine significantly affects the combustion process and heat release in the cylinder. The character and parameters of fuel injection depend on the injection system type and its design parameters, the amount and quality of the injected fuel, the process phases and duration and also the parameters of the fuel jet sprayed in the cylinder.

Investigations were carried out at the engine test stand. They concerned the AD3.152 UR engine, operating under the conditions of rated power and the maximum torque. The engine was fuelled by two kinds of environmentally friendly fuels, i.e. low sulphur diesel oil EKODIESEL PLUS 50B and Fatty Acid Methyl Esters of Rapeseed Oil BIODIESEL D-FAME. The investigations were intended to determine changes, averaged over 100 cycles, in the pressure values in the cylinder, the injection duct and also the nozzle needle lift changes. Exemplary graphs of averaged fuel pressure values in the injection duct are presented in Fig. 4.

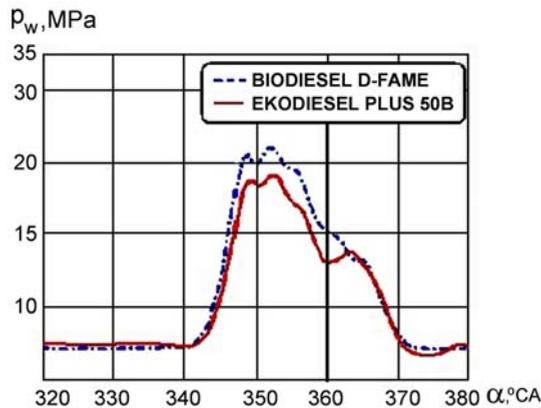


Fig. 4. Exemplary averaged changes in the fuel pressure values in the injection duct as the function of crankshaft rotation angle of AD3.152 UR engine operating at $n = 1400$ rpm and $M_e = 165$ Nm

The following were computed on the basis of measurements results: the rate of fuel flow out of the nozzle, its critical value, at which droplet disintegration starts, the critical diameter value of the droplets formed at their secondary disintegration, the spread angle of the fuel jet cone, droplet Sauter mean diameter d_{32} and the jet range for $t \leq t_{\text{break-up}}$ and $t > t_{\text{break-up}}$. The calculation results (1, 4) are shown in Table 3, 4, 5, and 6.

Table 3. Values of the maximum pressure differences in the nozzle and the engine cylinder Δp and the speed initial w_p and critical w_e values of fuel droplets

Fuel	Pressure difference in the nozzle and the cylinder		The stream initial speed	Droplet critical speed
	ΔP	Pa	w_p , m/s	w_e , m/s
EKODIESEL PLUS 50-B Diesel Oil				
EKODIESEL PLUS 50-B	19	400	136.92	158.84
BIODIESEL D-FAME Biofuel				
BIODIESEL D-FAME	23	600	149.80	164.18

Table 4. Droplet Sauter Mean Diameter

Parameter	Diesel Oil	Biofuel
	EKODIESEL PLUS 50-B	BIODIESEL D-FAME
Fuel charge, mm^3/cycle	54	50
Droplet Sauter Mean diameter d_{32} μm	40.2	38.85

Table 5. Spread angles of spray fuel jet cone

Spray angles	Diesel Oil	Biofuel
	EKODIESEL PLUS 50-B	BIODIESEL D-FAME
$\arctg\Theta/2$	0.1384	0.1366
$\text{tg } \Theta/2$	7.50°	7.40°

Table 6. Values of spray fuel jet penetration

Parameter	Diesel Oil	Biofuel
	EKODIESEL PLUS 50-B	BIODIESEL D-FAME
Disintegration time, ms	0.535	0.512
Jet penetration, mm for $t \leq t_{\text{break-up}}$	129	137
Jet penetration, mm for $t > t_{\text{break-up}}$	124	154

The experiments were carried out at special test stand, which enabled realization of single injection (also multiphase) at variable pressures using the visualization of the process. The properties of two different fuels, which were used in the experiment, are shown in Fig. 5

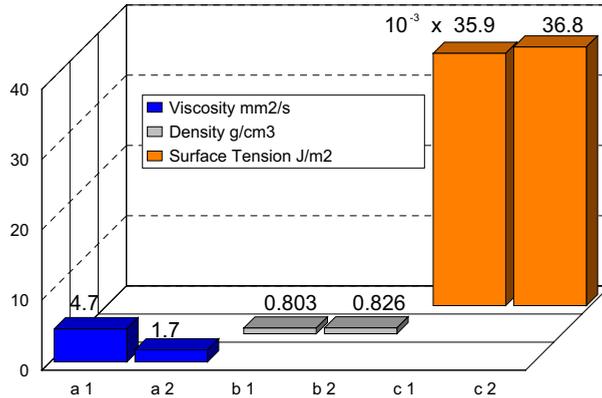


Fig. 5. Characteristics of tested fuels: 1 and 2
a - viscosity
b - density
c - surface tension

4. Heat release analyses

Owing to experimentally taken indicator diagrams of the working medium in the engine cylinder, it is possible to determine the self-ignition delay time and make analyses of heat release in the combustion process. The paper presents heat release analyses for AD3.152 UR engine operating under the conditions of rated power and the maximum torque, at the injection advance angle $\alpha_{aa} = 17^\circ \text{CA}$, fuelled by the above-mentioned environmentally friendly fuels.

The self-ignition delay time was determined as the difference between the angular displacement of the crankshaft corresponding to the beginning of the combustion α_{ps} and the angle corresponding to the fuel injection beginning α_{ib} i.e. $\alpha_{da} = \alpha_{cb} - \alpha_{ib}$. The combustion beginning was stated as the intersection point of the curve representing change in temperature $T_p(\alpha)$, determined for the compression process, at the assumption that air is the working medium, with the curve $T_s(\alpha)$ also determined for pressure values for $\alpha \in \langle \alpha_{ib}, \alpha_{TDC} \rangle$, yet at the assumption that in the cylinder there are the products of the total and complete combustion. In the experiments conducted by the authors so far, the methodology has proved very convenient and accurate enough. The method graphic representation is shown in Fig. 5. The results obtained for the tested engine are presented in Fig. 6.

Relative amount of heat released during the combustion process as well as the heat release rate were analysed on the basis of an equation for the first law of thermodynamics and the state equation. Changes in the working medium composition and amount in the course of the combustion process and also heat transfer to the walls enclosing the combustion space were taken into account. Heat losses due to dissociation were disregarded (2). The graphs showing the analyses of heat release during combustion in AD3.152 UR engine are presented in Fig. 7 and 8.

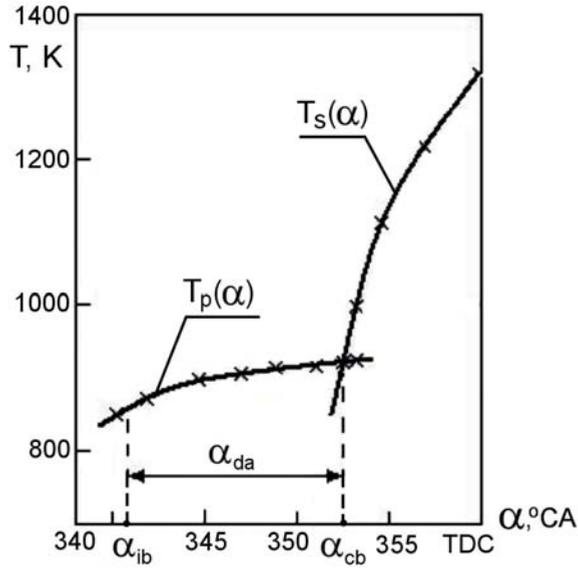


Fig.5. Graphic presentation of the method for the determination of ignition delay angle (2): α_{ib} – fuel injection beginning, α_{cb} – combustion beginning, α_{da} – injection delay angle

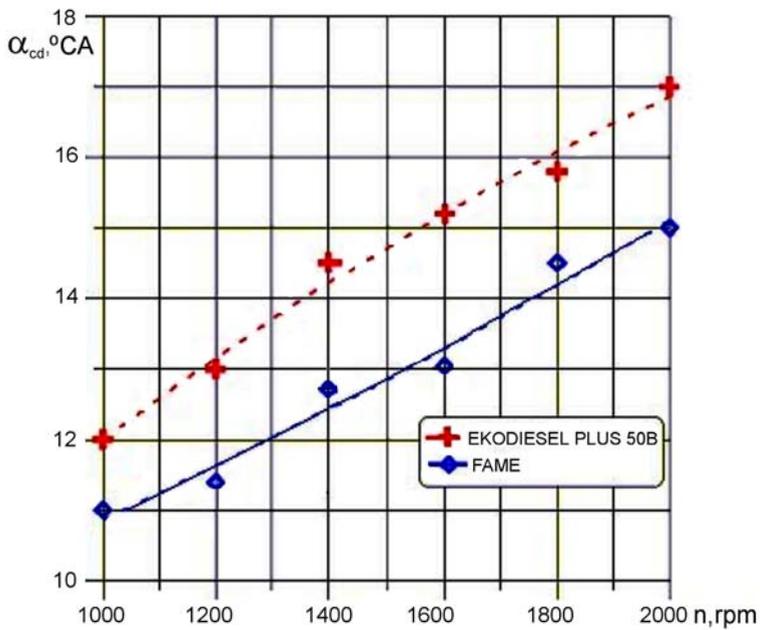


Fig. 6. Values of self-ignition delay angle in AD3.152 UR engine operating in accordance with the external speed performances, fuelled with two different fuels for the injection advance angle $\alpha_{aa} = 17$ °CA

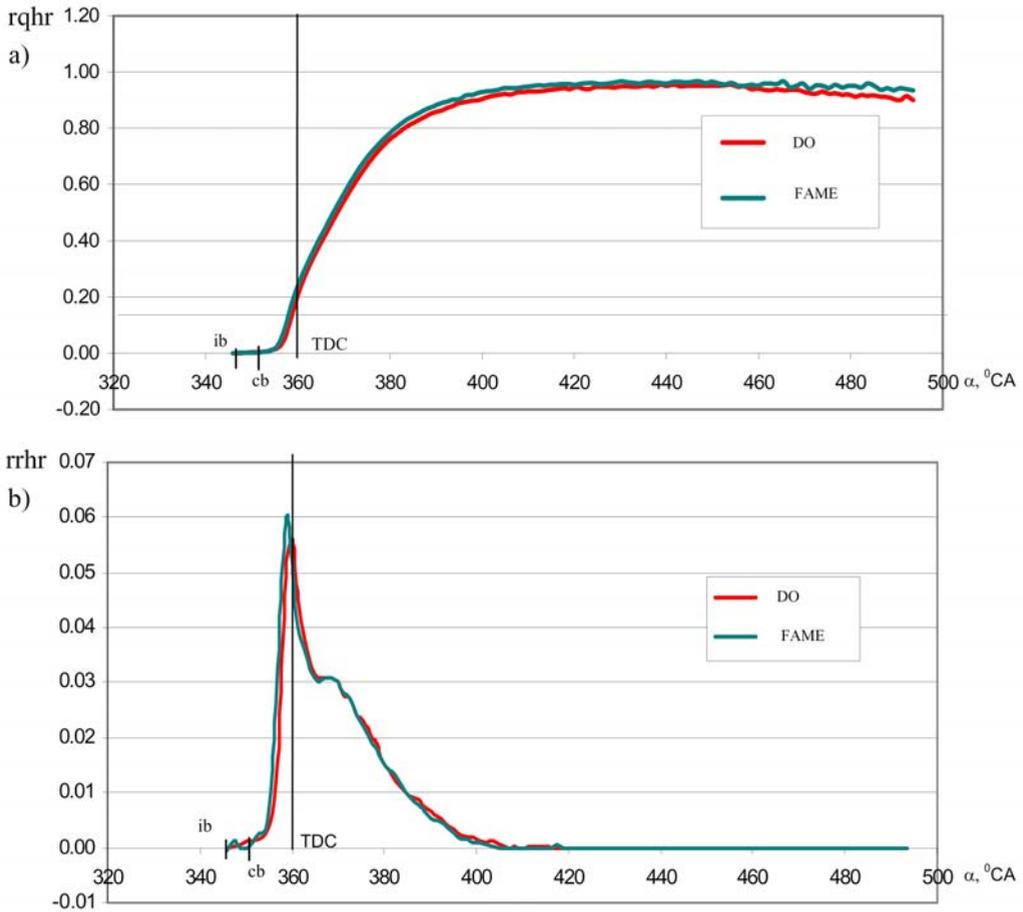


Fig. 7. Analyses of the relative quantity ($rqhr$) and rate ($rrhr$) of the heat release during combustion in AD3.152 UR engine operating at $n = 2000$ rpm and $N_e = 32$ kW, $\alpha_{aa} = 17$ °CA

The values of self-ignition delay angle were higher for the engine fuelled by diesel oil than biofuel. Computed droplet Sauter Mean Diameters d_{32} and critical droplet diameters d_{cr} of biofuels were smaller than those of droplets formed by diesel oils. Greater droplet critical diameters in diesel oil result probably from a little lower value of their surface tension. The determined initial values of velocities of the injected fuel jet, droplets disintegration time and fuel jet penetrations were comparable for both fuel types.

5. Conclusions

Although only a few issues that concern the fuelling of piston internal combustion engines by diesel oils and biofuels were presented, moreover, in a rather selective manner, they show the necessity of conducting further research. Thorough investigations should focus on complex physical and chemical processes of volatile mixture formation and combustion in CI engines.

Experimental results and their analysis made so far indicate two-phase character of the combustion process. It is characterised by the occurrence of the two maximum heat release rates. The first one is found in the kinetic phase of the combustion of the mixture produced from a part

of the fuel fed during self-ignition delay. The other maximum rate occurs when the combustion intensity is conditioned by the intensity of fuel vapours and oxidant mutual dissociation. The rate of heat release during biofuel combustion reached higher values when compared with diesel oil combustion.

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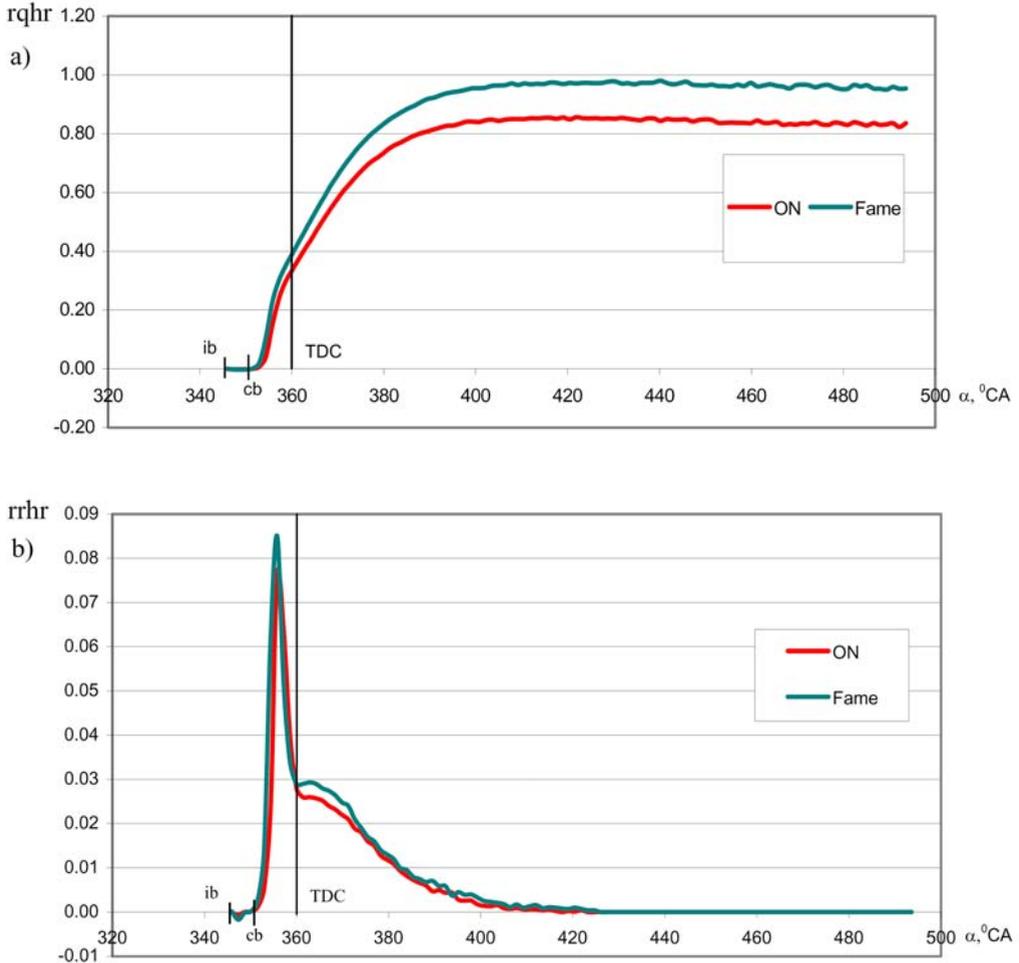


Fig. 8. Analyses of the relative quantity ($rqhr$) and rate ($rrhr$) of the heat release during combustion in AD3.152 UR engine operating at $n = 1400$ rpm and $N_e = 23$ kW, $\alpha_{aa} = 17$ °CA

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References

- [1] Ambrozik, A., Selected Issues of Heat Processes in Piston IC Engines (in Polish). Kielce University of Technology Publishing House, Kielce 2003.
- [2] Badania wpływu właściwości fizykochemicznych paliwa do silników wysokoprężnych na charakterystykę wtrysku i trwałości elementów układu paliwowego konwencjonalnego i Common - Rail. – Projekt badawczy finansowany przez KBN. Warszawa 2001. Kierownik projektu C. I. Bocheński.
- [3] Falkowski, H., Injection Systems in Diesel Engines (in Polish). WKL, Warsaw 1989.
- [4] Orzechowski, Z., Prywer, J., Liquid Spraying (in Polish). WNT, Warsaw 1991.
- [5] PKN ORLEN S.A, Trzebinia Refinery, Fuel Quality Certificates (in Polish), 2006.
- [6] Technical documentation of the measurement stand for fast changing parameters (in Polish), IEPiM, Radom 2001.
- [7] Jankowski, A., et al Exhaust Emission Reduction Problems of Internal Combustion Engines Fuelled with Biofuels, p. 93-108, Journal of KONES. Internal Combustion Engines. Vol. 10, No 3-4, Warsaw 2003.
- [8] Jankowski, A., et al, Measurement of Drop Size Distribution in Fuel Sprays by Laser Methods, p. 334-345, Journal of KONES. Internal Combustion Engines. Vol. 8, No 3-4, 2001, Wyd. Permanent Committee of KONES, Warsaw 2001.
- [9] Jankowski, A., et al, Rape Seed Oil Methyl Ester Fuel as Alternative Diesel Fuel for High Speed Diesel Engines for Urban Buses, s. 105-109, ICE - Vol. 24, Wyd. ASME, New York 1995.