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INVESTIGATION OF THE FUEL OXYGEN OF VARIOUS ORIGINS-MADE EFFECTS ON THE COMBUSTION PROCESS IN A TURBOCHARGED CRDI DIESEL ENGINE

The paper deals with the investigation of a fossil diesel and high-quality HRD (Hydrotreated Renewable Diesel) fuel blends involving Ethanol (E) or Biodiesel (B) oxygen-made effects on the combustion process in a turbocharged Common Rail Direct Injection (CRDI) diesel engine running under full (100%) loads at 1500 rpm, maximum torque speed 2000 rpm and the high speed of 2500 rpm. The study presents the experimental investigation and numerical simulation of biofuel oxygen-made effects on the combustion process in a diesel engine under brake mean effective pressures (bmep) = 1.24, 1.37 and 1.40 MPa developed for overall air-fuel ratios of λ = 1.30, 1.25 and 1.20 at the respective speeds. The fuel-oxygen mass content increased identically within the same range of 0 (E0/B0), 0.91 (E1/B1), 1.81 (E2/B2), 2.71 (E3/B3), 3.61 (E4/B4), and 4.52 wt% (E5/B5) in both fuel groups of various origins involving anhydrous (200 proof) Ethanol (E) and rapeseed Biodiesel (B). It is important to note that the cetane number possessed the same value of 55.5 for all fuel blends tested. This ensures stable auto-ignition needed to perform accurate comparison of the obtained results between the two fuel groups and extract from the study as much information as possible in the scientific research about the fuel-oxygen enrichment rate and the widely differing properties of biofuels-made effects on the combustion process. Both qualitative and quantitative analyses of the newly designed fuels-made effects on the compression ignition delay and the combustion attributes were performed comparing data between themselves in the same fuel group, between the fuel sets E and B and with the respective values measured with the reference, oxygen-free blend E0/B0 to reveal the existing developing trends. Analysis of the relative changes in compression ignition delay, specific burn angle MBF 50, maximum heat release rate and the peak in-cylinder pressure developed from combustion of oxygenated fuel blends E1-E5 and B1-B5 performed on the comparative bases with the corresponding values measured with blend E0/B0 to reveal potential developing trends in the auto-ignition delay and the combustion process.

Keywords: Diesel engine; Diesel-HRD fuel blends; Ethanol; Biodiesel; Auto-ignition; Combustion process; Maximum heat release rate; specific angle MBF 50; Maximum in-cylinder pressure.

INTRODUCTION

The increased air pollution from ground-based, trans-oceanic marine and the air traffic engines powered with a fossil origin, high-carbon fuel in a company with coal-fired power plants causes the greenhouse gas emissions leading to adverse climate changes and the tread to people’s health that is today’s the greatest long-term challenge humanity has never faced over the last century [1]. Therefore, the investigations of sustainable technologies based on environmentally friendly, sulphur-free, non-toxic, low-carbon, totally-renewable energy sources possessing high content of hydrogen biofuels have to move forward keeping up the pace to attain a newest knowledge needed to develop the production technologies of modern diesel engines for future generations [2,3]. There potentially are many alternatives to replace a fossil fuel with renewable and environmentally friendly biofuels, however still is not completely clear how much biofuel-bound oxygen of various origins could affect the auto-ignition delay period and thus the whole combustion process due to widely differing chemical and physical properties of ethanol or biodiesel added into blend. Therefore, the transfer from traditional diesel fuel type adapted over the centuries for efficient engine operation to another renewable energy sources can be a slow, costly and sometimes painful process [4].

The problem is that the widely differing chemical and physical properties of biofuels such as ethanol or biodiesel provide changes in the injection and atomisation characteristics that affects the distribution of the fuel spray patterns in the combustion chamber, their total surface area directly exposed to the hot compressed air charge, vaporisation intensity and the air-fuel mixing rate. These changes in a company with the factors the effects of which examined in the study operate simultaneously and might have strong contributing impact on the auto-ignition delay and the whole combustion process. Unfortunately, in the available literature is a lack of comprehensive studies on the changes in the fuel injection and atomisation characteristics at first [5] with the following fact-based examination of the auto-ignition delay’s behaviour, the combustion process and indicated thermal efficiency supported by the revealed numerical interrelationships between heat release characteristics and the fuel system related factors affecting them [6].

Experiments conducted by Zhang et al. [7] showed that the adding of ethanol into the kerosene promotes the spray quality and, thus, the spray cone angle increases with the increase of ethanol contend in the kerosene blend due to lower density and viscosity of fuel blends. While Tziourtzioumis and Stamatelos [8] revealed that Sauter mean diameter (SMD) of sprays is higher, coefficient of variations of Indicated Mean Effective Pressure (IMEP) increases (B20, B40), the total combustion duration (B20) and mass fraction burned for specific crank angle burn points change ambiguously and fuel burning rate decreases when running with B20 and higher biodiesel blended-fuels.

It was previously revealed [9] that both the autoignition delay and the combustion process of a naturally aspirated diesel engine strongly affects not only the blended cetane number, but also on the accompanying changes in chemical structure and fuel-oxygen mass content in ethanol-diesel-biodiesel blends. Normally ethanol or rapeseed oil methyl ester (biodiesel) is added to Hydrotreated Renewable Diesel (HRD) fuel as oxygenator source to produce environmentally friendly, triple fuel blends. Ethanol differs from most other biofuels as having the largest amount of fuel-oxygen mass content (34.78 wt%), however its using as diesel fuel supplement is limited by the widely differing chemical and physical properties, namely its extremely low cetane number. While, biodiesel as sustainable energy source is very popular in transport sector because using of neat biodiesel or at low percentage blend levels with ultra-low-sulphur diesel (ULSD) has positive impact on the environment, economic growth and the creation of new production works in rural areas.

The purpose of the experimental and numerical investigations was to define the biofuel oxygen of various origins-made effects on the combustion process in a turbocharged CRDI diesel engine operating under brake mean effective pressures (bmep) = 1.24, 1.37 and 1.40 MPa developed for overall air-fuel ratios of λ = 1.30, 1.25 and 1.20 at the respective speeds of 1500, 2000 and 2500 rpm. The numerical simulation aimed to solve some sensitive issues related to a challenging task how to separate the fuel-oxygen itself-made effects on the combustion process from additional changes caused by the combined contribution of the widely differing chemical and physical properties of anhydrous (99.9 wt%) ethanol or rapeseed oil methyl ester (biodiesel) in the experimental study.

RESEARCH METHODOLOGY, ENGINE TEST SET UP AND TEST FUELS

The fuel components used to prepare fuel blends for diesel engine tests: fossil origin diesel fuel (LST EN 590:2014+AC, Ltd. „Orlen Lietuva“); Hydrotreated Renewable Diesel (HRD) (NESTE OIL, Finland); anhydrous (200 proof, 99.9 wt%) Ethanol (LST EN 15376:2015); rapeseed oil methyl ester – Biodiesel (B) (LST EN 14214:2014, Ltd. „Rapsoila“).

The fuel-oxygen mass content has been changed from 0 to 4.5 wt % with identical increment rates for both E and B fuel groups, but these blends were purposely premixed in such proportions by mass to maintain the blending cetane number value the same of CN = 55.5 (Table 1). This precondition is important to evaluate accurately the ethanol E1-E5 or biodiesel B1-B5 oxygen-made effects on the ignition delay time, combustion history and heat release rate with the following changes in burn angle MBF 50 and the peak in-cylinder pressure. This achieved by reasonable comparison of the obtained data between themselves in the same fuel group, between differing fuel groups E and B and with the respective values measured with the reference, oxygen-free fuel blend E0/B0 to reveal the existing developing trends in the studied combustion process.

Table 1. Basic chemical and physical properties of the test fuels.

Code of fuel blends	Diesel/HRD/Ethanol	Oxygen, wt%	Carbon to hydrogen ratio	Stoichiometric air/fuel ratio, kg/kg	Net heating value, MJ/kg
E0	0,85/0,15/0	0	6,45	14,59	43,12
E1	0,804/0,196/0,974	0.9	6,33	14,48	42,74
E2	0,755/0,245/0,948	1.8	6,22	14,36	42,36
E3	0,704/0,296/0,922	2.7	6,11	14,24	41,97
E4	0,65/0,35/0,896	3.6	6,00	14,13	41,59
E5	0,592/0,408/0,87	4.5	5,89	14,01	41,21
Code of fuel blends	Diesel/HVO/Biodiesel	Oxygen, wt%	Carbon to hydrogen ratio	Stoichiometric air/fuel ratio, kg/kg	Net heating value, MJ/kg
B0	0,85/0,15/0	0	6,45	14,59	43,12
B1	0,835/0,165/0,916	0.9	6,43	14,44	42,64
B2	0,817/0,183/0,833	1.8	6,42	14,28	42,16
B3	0,795/0,205/0,75	2.7	6,41	14,13	41,68

B4	0,768/0,232/0,667	3.6	6,39	13,97	41,21
B5	0,733/0,267/0,583	4.5	6,38	13,82	40,72

Experimental engine tests performed at Power and transport machines engineering institute of Vytautas Magnus University (VDU). A turbocharged Common Rail Direct Injection (CRDI) diesel engine FIAT 192A1000 was implode for the experiments, basic design features and operational parameters of which are listed in Table 2.

Table 2. Basic design and performance parameters of the engine.

Engine type	Four-cylinder, in-line, turbocharged, JTD
Fuel injection system	Common rail, direct injection (CRDI)
Engine displacement	1910 cm^3
Bore x Stroke	82 x 90.4
Compression ratio	18.0:1
Rated power	85 kW (115 HP)
Maximal torque	255 Nm (EEC), at 2000 rpm
Maximum injection pressure	1400 bar (140±0.5 MPa)

Schematic view of the test stand, equipment, and measuring apparatus used during the experiments shows Fig. 1. The basic operational parameters determined by measuring engine torque, rotation speed of the crankshaft and turbocharger boost pressure during the experimental tests.

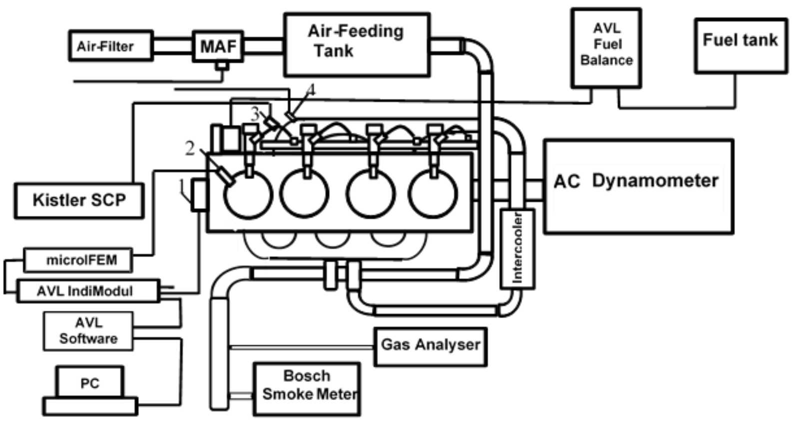

Fig. 1. Schematic arrangement of the engine test stand: (1) AVL crank-angle encoder; (2) piezoelectric in-cylinder pressure transducer; (3) fuel high-pressure line transducer at the injector; (4) air boost pressure sensor in the intake manifold.

Load characteristics with diesel-HRD fuel blends involving ethanol (E) or biodiesel (B) components achieved at the three engine speeds of 1500, 2000 and 2500 rpm with a special attention to the maximum values of loads matching the respective bmep of 1.24, 1.37 and 1.40 MPa to have a wider view for sound interpretation of the test results. Turbocharger boost pressure in the intake manifold was maintained at constant value of p_k = 1.60 bar to guarantee identical temperature of the incoming air and the combustion conditions for both E and B fuel groups at the tested engine speeds.

A high-speed multichannel indicating system, which consisted of an AVL angle encoder 365C and high-performance pressure transducer GU24D coupled to the AVL microIFEM piezoelectric amplifier and signal acquisition platform IndiModul 622, has been employed for the recording, acquisition, and processing of fast crank-angle gas pressure signals in the first cylinder. The profiles of net heat release rate in the cylinder calculated by using averaged in-cylinder pressure-data summarized over the 100 engine-cycles, instantaneous cylinder volume, and their first order derivatives with respect to crank angle. The productivity and accuracy of the measured test results increased using of the experimental data post-processing Software AVL CONCERTO™ advanced version 4.5.

The start of injection (SOI) recorded by using the Kistler piezoelectric pressure sensor ASMB 470004-1 attached with a clamp adapter on a high-pressure pipe just in front of the injector. As the start of injection was taken crank angle, at which the fuel pressure in a high-pressure pipe temporally drops down due to opening of the nozzle-needle-valve of the injector. As the start of combustion (SOC) was taken crank angle, at which the net heat release-rate crosses the zero line and changes its value from the minus side to the plus side. The auto-ignition delay determined as a period in CADs between the SOI and the SOC with an accuracy of $\pm 0.1^0$.

The AVL BOOST software programme was adapted for numerical simulation to increase the potential influence affecting variation range of fuel blends of various origins involving biofuel-oxygen mass contents increased by the same increment rates within a wide range of 0 to 4.5wt% on the main parameters of the combustion process. The experimental data collected from the university's engine testing laboratory were used in the numerical modelling. The data obtained from the experimental measurements such as the start of combustion and combustion duration were taken for the numerical modelling at first. These data further supported by the Vibe function shape parameter "m", oxygen content in the tested fuel blends, operating modes of an engine were processed by using MATLAB programme in order to reveal and describe the potential influence of the fuel-oxygen on the combustion parameters.

THE ENGINE TEST RESULTS AND ANALYSIS

The auto-ignition delay period depends on the temperature inside the cylinder, overall air-fuel ratio and the chemical structure of the fuel, if or when the blended cetane number remains of the same value. The auto-ignition delay of a pilot fuel portion for the respective more ethanol (E4) and less biodiesel (B3) oxygenated fuel blends unevenly increases to reach 10.2% and 6.8% higher levels against, 5.9^0 CADs, over which the reference blend E0/B0 catches on fire when running at the low speed of 1500 rpm (Fig. 2). The auto-ignition delay unpredictable changes with increasing fuel-oxygen enrichment rate due to greater than before temperature inside the cylinder after transition to a higher speed.

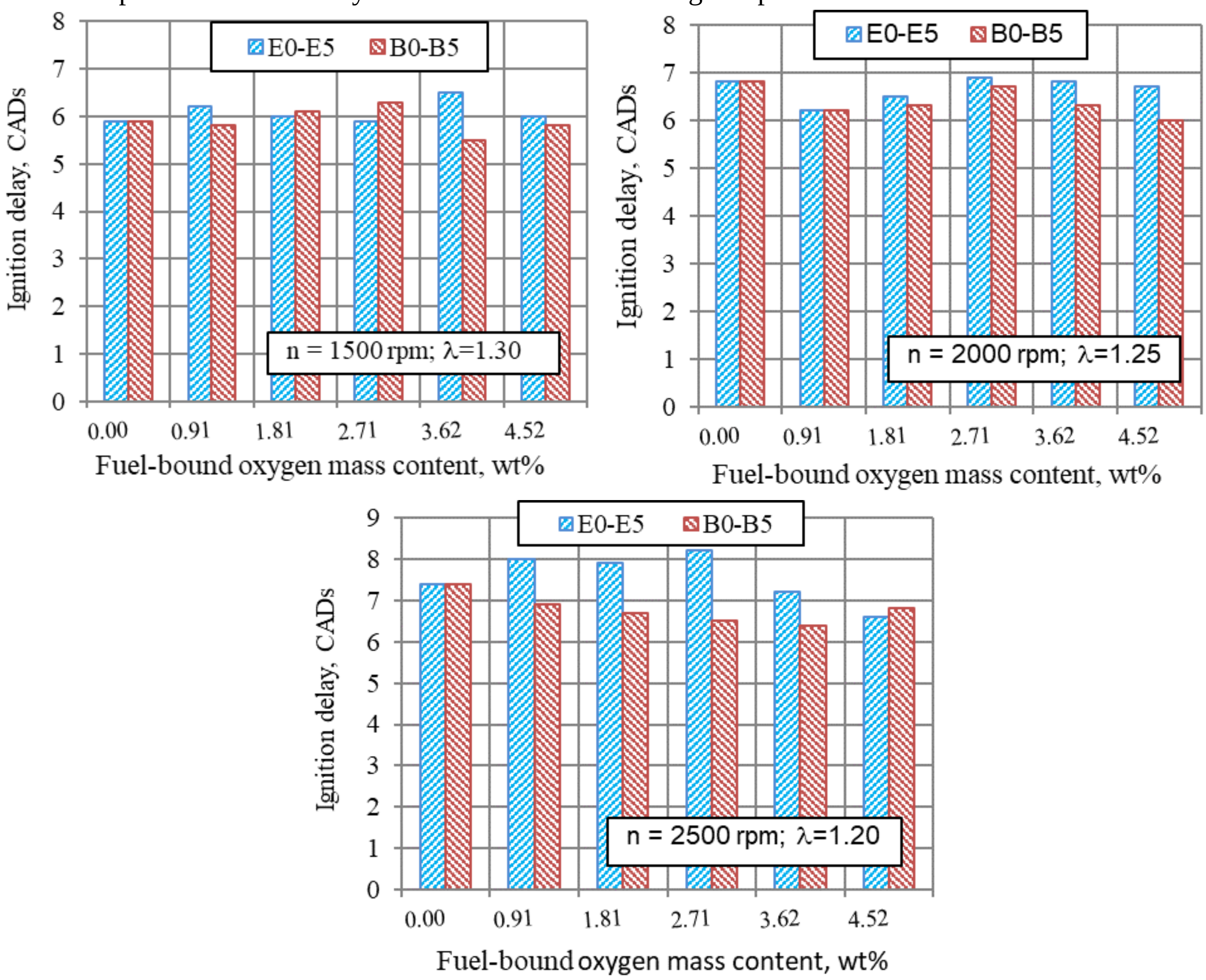

Fig. 2. The auto-ignition delay as function of ethanol-oxygen or biodiesel-oxygen mass content in fuel blends for the engine running under full (100%) loads corresponding to the respective bmep = 1.24, 1.37 and 1.40 MPa at speeds of 1500, 2000 and 2500 rpm.

Now, the auto-ignition delay period for blend's E4 case converts to be relatively 1.5% higher and, on the contrary, for biodiesel-oxygenated blend B3 it becomes relatively 1.5% lower than the reference blend

E0/B0 suggests, 6.80 CADs, for maximum torque speed of 2000 rpm. Thus, the increase in the fuel-oxygen mass content in the different ways affects the compression ignition delay at the tested speeds. Changes in the ignition delay caused not only the increase in the fuel-oxygen mass content, but also contributed both the increased with peed effect of air swirl in the combustion chamber and the widely differing physical properties of the tested fuels. However higher density, kinematic viscosity and slower evaporation of biodiesel droplets does not create significant disadvantages for the ignition process, despite the fact that 3.2 times more biodiesel was added to diesel-HRD fuel blends to maintain the same fuel-bound oxygen mass contents as those used in ethanol-oxygenated blends.

However, the biggest changes in the auto-ignition delay period occur when running with fuel blends involving biofuels of various origins at the high speed of 2500 rpm. The auto-ignition delay progressively increases reaching the highest value of 8.2^0 CADs (10.8% longer) when running with blend E3, while when using blend B4 it moves down to the lowest point of 6.4^0 CADs (13.5% shorter) than, 7.4^0 CADs, oxygen-free blend E0/B0 catches on fire under the same test conditions. Homogeneous combustible mixture with about three-fold as much higher latent heat of vaporisation and lower heating value of ethanol contributes to longer auto-ignition delay. The chemical structure of ethanol CH3CH2OH, in which the hydroxyl functional group (–OH) is attached to a carbon atom by a single, strong bound may worsen the auto-ignition process as well. While the reduction of the auto-ignition delay with fuel blend involving biodiesel B4 can be reasonably attributed to the fact that the air-fuel mixture involving biodiesel is a more heterogeneous and some part of biodiesel-oxygen is in double bounds with radicals that increases the oxidation chances. For these reasons, the fuels involving ethanol almost-always suggest the auto-ignition delay period longer than biodiesel-oxygenated blends containing the same fuel-oxygen mass content with the differences between the two fuel groups being higher the higher the speed of an engine [10]. The scientists Shropshire and Goering among the first researchers noticed this phenomenon made by the ethanol injected into the intake manifold [11].

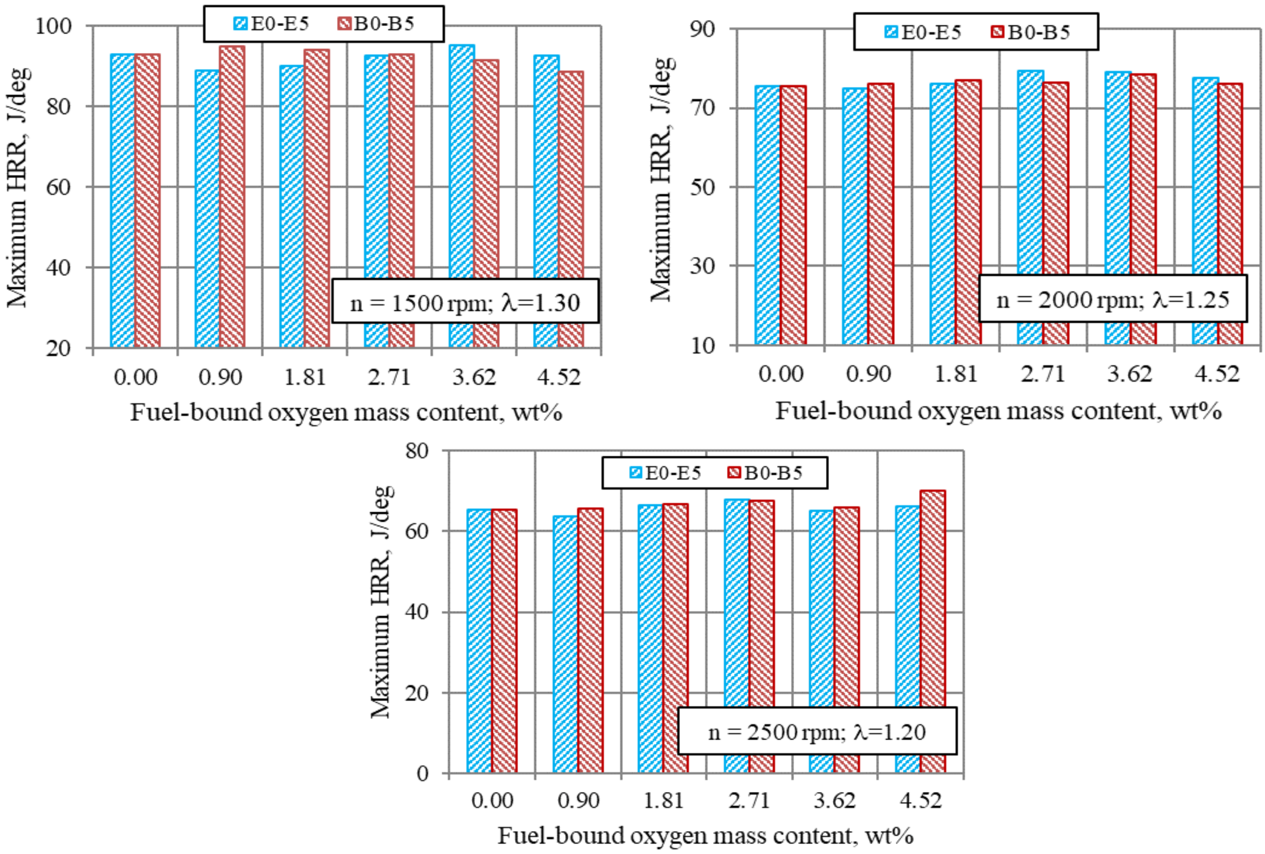

Fig. 3. Maximum heat release rate as function of ethanol-oxygen or biodiesel-oxygen mass content in fuel blends for the engine running under full (100%) loads corresponding to the respective bmep = 1.24, 1.37 and 1.40 MPa at speeds of 1500, 2000 and 2500 rpm.

As can be seen in Fig. 3, the increase up to certain degree of improvement in the fuel-oxygen enrichment rate positively affects maximum (net) heat release rate (HRR_{max}), which increases for the respective E4 and B1 blends reaching relatively 2.3% and 2.2% higher values under overall air-fuel ratio of $\lambda = 1.30$ at the low speed of 1500 rpm. The HRR_{max} monotonously increases with the increase in the fuel-oxygen mass content suggesting for the respective E3 and B4 blends relatively 5.0% and 4.0% higher values developed under overall air-fuel ratio of λ = 1.25 at maximum torque speed of 2000 rpm as well. It is worth to underline that maximum heat release rate in the kinetic combustion phase (Fig. 3) does not actually depend on the noted changes in the auto-ignition delay of a pilot fuel portion (Fig. 2). This hypothesis rests on the fact that, the HRR_{max} increases similarly for both fuel groups reaching with the respective E3 and B5 blends 3.5% and 9.9% higher values than that value of 65.5 J/deg. the combustion of the reference blend E0/B0 produces under overall air-fuel ratio of λ = 1.20 at the high speed of 2500 rpm. In general, maximum heat release rate in (J/deg.) decreases with the increase in the engine rotational speed and this decrease proceeds even faster in units of time (J/s) when running at the high speed of 2500 rpm, therefore a period of time, which is available to perform each engine cycle, becomes extremely limiting factor.

Burn angle MBF 50 represents the center of a gravity of differential heat release curve and affects fuel-energy conversion efficiency in the cylinder. The smaller the crank angle ATDC at which 50% of fuel-energy releases in the cylinder, the lower are heat losses in the expansion stroke and thus higher thermal efficiency an engine will be able to achieve. Analysis of the columns in Fig. 4 shows that a half portion specified by burn angle MBF 50 of ethanol (E4) and biodiesel (B1) oxygenated blends burns relatively by 1.9% and 0.9% sooner in an engine cycle than oxygen-free blend E0/B0 does under overall air-fuel ratio of λ = 1.30 at the low speed of 1500 rpm. The positive role of fuel-bound oxygen of both E and B origins in relocating of specific angle MBF 50 close to constant volume combustion (ATDC) and thus reducing the heat losses to the cooling system becomes even greater after transition to the higher speeds. As can be seen in columns of Fig. 4, chemical and physical properties of a lighter and volatile ethanol positively affect the combustion process and therefore specific burn angle MBF 50 almost-always is smaller when running with ethanol-oxygenated blends possessing various fuel-oxygen enrichment rates rather than with their respective biodiesel-counterparts s under identical overall air-fuel ratios and rotational speeds.

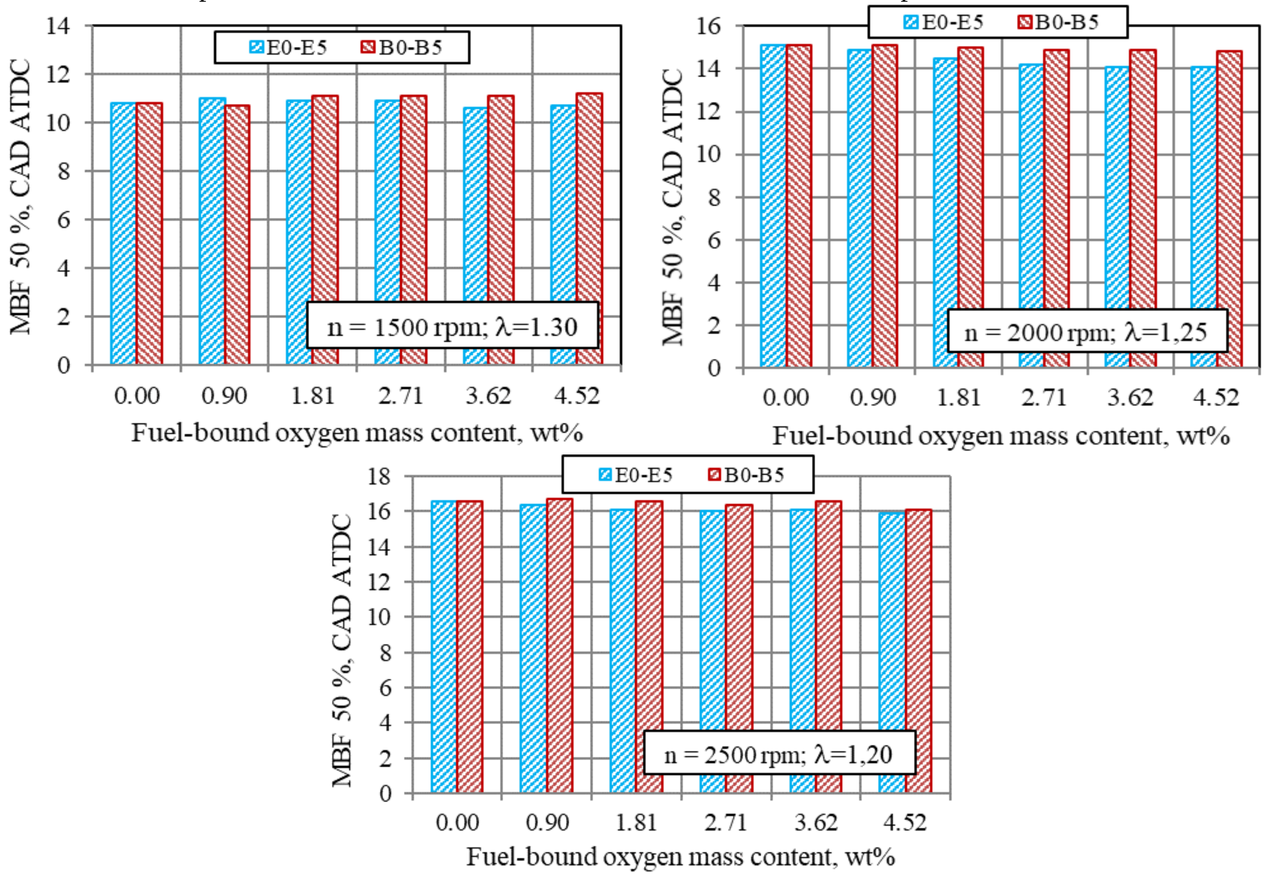

Fig. 4. Crank angle of mass burn fraction MBF 50% as function of ethanol-oxygen or biodiesel-oxygen mass content in fuel blends for a diesel engine running under full (100%) loads corresponding to the respective bmep = 1.24, 1.37 and 1.40 MPa at speeds of 1500, 2000 and 2500 rpm.

As a result, plenty oxygenated blends E4 and B5 took advantage in promoting the combustion process and thus specific burn angle MBF 50 reduces by 6.6% and 2.0% with regard to the reference value of 15.1^0 CADs ATDC that oxygen-free blend E0/B0 produces for overall air-fuel ratio of λ = 1.25 at maximum torque speed of 2000 rpm. Specific burn angle MBF 50 decreases proportionally to the increase in the fuel-oxygen mass content reaching for the most oxygenated fuel blends of both E5 and B5 origins relatively 4.2% and 3.0% lower values than that of 16.6^0 CADs ATDC the reference blend E0/B0 suggests for overall air-fuel ratio of λ = 1.20 at the high speed of 2500 rpm. Thus, the positive role of the increased biofuel oxygen mass content of both ethanol and biodiesel origins in the combustion reactions is higher, the higher the speed of an engine and thus shorter is time-span available to efficiently perform each engine cycle.

Maximum in-cylinder pressure developed by the combustion of the tested fuel blends decreases with the increase in the rotational speed mainly because the turbocharger boost pressure was maintained of the same value of p_k = 1.60 bar for all engine speeds tested (Fig. 5). It is worth to note that the in-cylinder pressure decreases with the increase in the fuel-oxygen mass contents of both E an B origins when running under overall air-fuel ratio of λ = 1.30 at the low speed of 1500 rpm. In result, the peak in-cylinder pressure developed from combustion of oxygenated blends E4 and B4 is relatively 1.5% and 2.2% lower than that of 137 bar the combustion of the reference blend E0/B0 produces under considered test conditions.

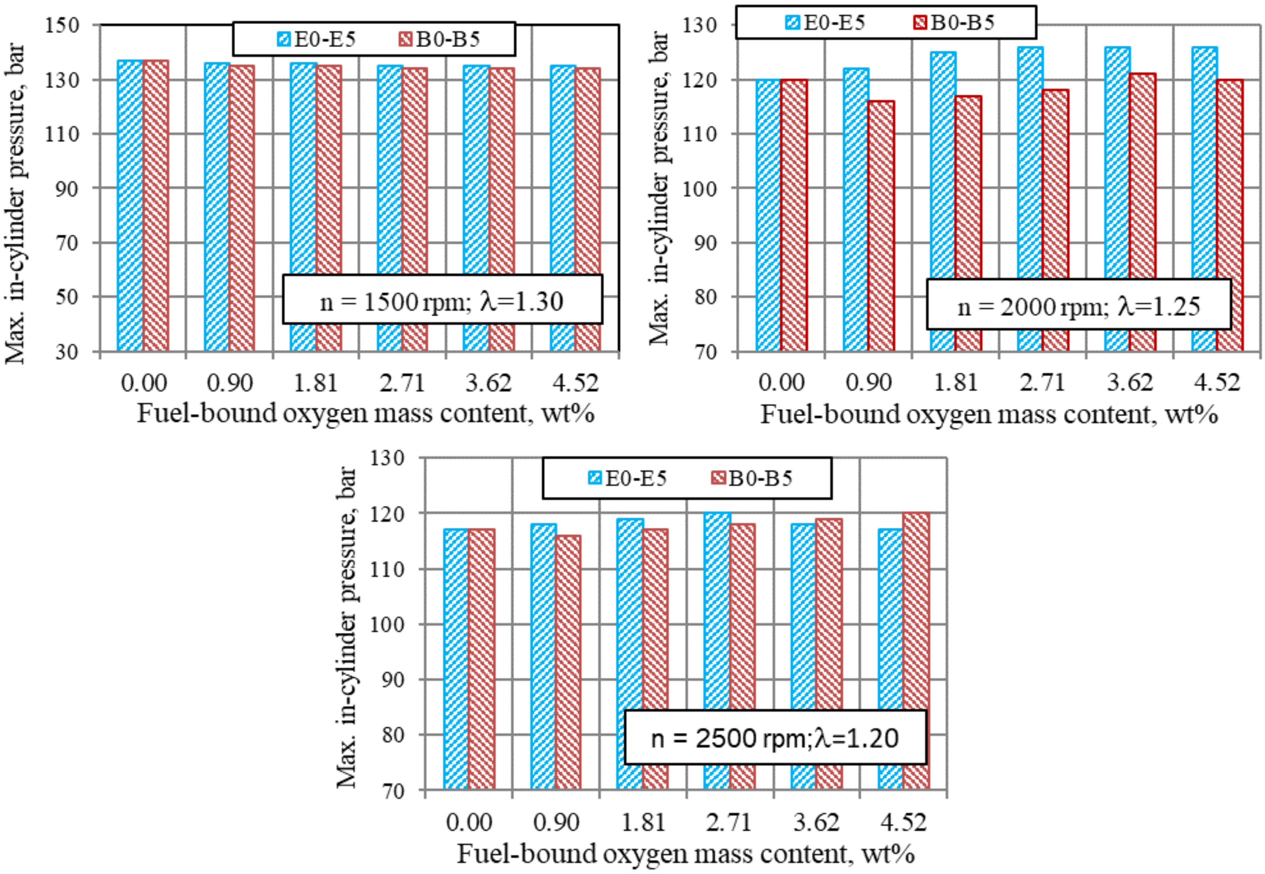

Fig. 5. Maximum in-cylinder pressure as function of ethanol-oxygen or biodiesel-oxygen mass content in fuel blends for an engine running under full (100%) loads corresponding to the respective bmep = 1.24, 1.37 and 1.40 MPa at speeds of 1500, 2000 and 2500 rpm.

The importance of fuel-bound oxygen in the combustion process increases with the increase in the engine speed and therefore in-cylinder pressure p_{max} converts to be relatively 5.0% (E4) and 0.8 (B4) higher than, 120 bar, the burned oxygen-free blend E0/B0 produces for lower overall air-fuel ratio of λ = 1.25 at maximum torque speed of 2000 rpm. The relative increase in the peak in-cylinder pressure is of the same value of 2.6% for both the combustion of less ethanol-oxygenated blend E3 and the most biodiesel-oxygenated blend B5 produce for overall air-fuel ratio of λ = 1.20 at the speed of 2500 rpm. Thus, relatively more biodiesel-oxygen needed to attain the same increase in the maximum pressure value because the low volatility of biodiesel with a bigger in diameter fuel droplets further aggravated by the highest initial/final boiling points 346/366 with extremely limited interval between them negatively affects all the vaporization intensity, the air-fuel mixing rate and thus the combustion process.

The peak in-cylinder pressure-location angle Ap_{max} from combustion of the most oxygenated fuels of both E5 and B5 origins moves by 0.6 and 0.5 CADs with regard to the reference value, 10.4 CADs ATDC, away from TDC with the increase in the fuel-oxygen mass content towards bigger cylinder volume at the low speed of 1500 rpm (Fig. 6). As a result, the noted decrease in p_{max} occurs at the low speed of 1500 rpm, and vice versa, transfer of Ap_{max} back to constant combustion volume positively affects sensitive interrelationship between both parameters promoting the development of pressure p_{max} from combustion of the fuels of both E (more) and B (less) origins at speed of 2000 rpm (Fig. 5). Thus, even negligible, relative relocation of specific angle Ap_{max} by 1.2 (E5) and 0.5 (B5) CADs towards TDC results into noticeable increase in the maximum in-cylinder pressure in this particular case. This means, the smaller the in-cylinder volume occupied by the flame is, the higher will be the peak in-cylinder pressure's sensitivity to the potential Ap_{max} changes made by the increased fuel-oxygen mass content.

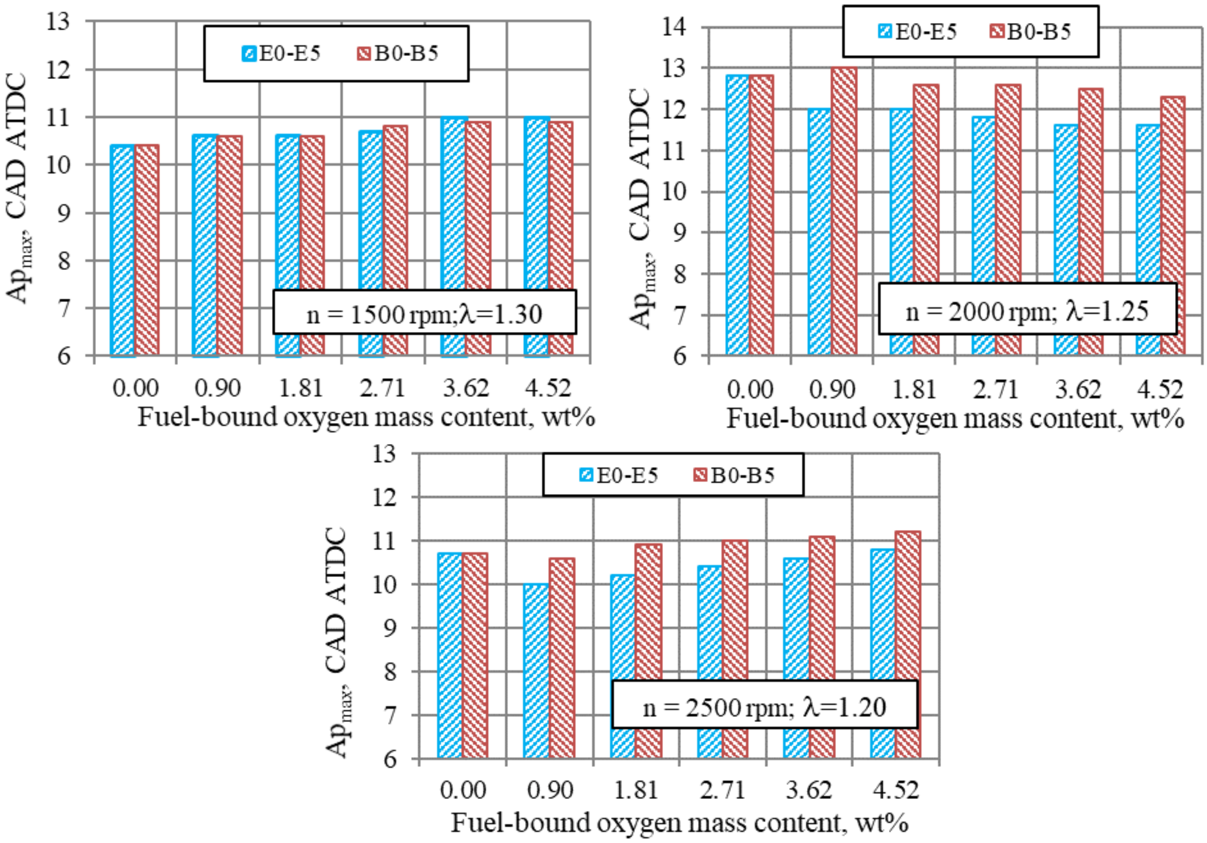

Fig. 6. Changes in the location angle Ap_{max} depending on ethanol-oxygen or biodiesel-oxygen mass content in fuel blends for an engine running under full (100%) loads corresponding to the respective bmep = 1.24, 1.37 and 1.40 MPa at speeds of 1500, 2000 and 2500 rpm.

In contrast to the widely differing p_{max} and Ap_{max} developing trends at the low speed of 1500 rpm, both the combustion history related parameters demonstrate the simultaneous increase with the increase in the fuel-oxygen mass content of both E and B origins after transition to the high speed of 2500 rpm. The relative increase in specific burn angle Ap_{max} initiated by the combustion of the most oxygenated (4.52 wt%) fuel blends E5 and B5 compiles 0.1 and 0.5 CADs only. However, even a small change of the angle Ap_{max} in a company with the improved maximum in-cylinder pressure p_{max} may contribute to faster development of engine torque and power output that improves acceleration of a turbocharged CRDI diesel engine.

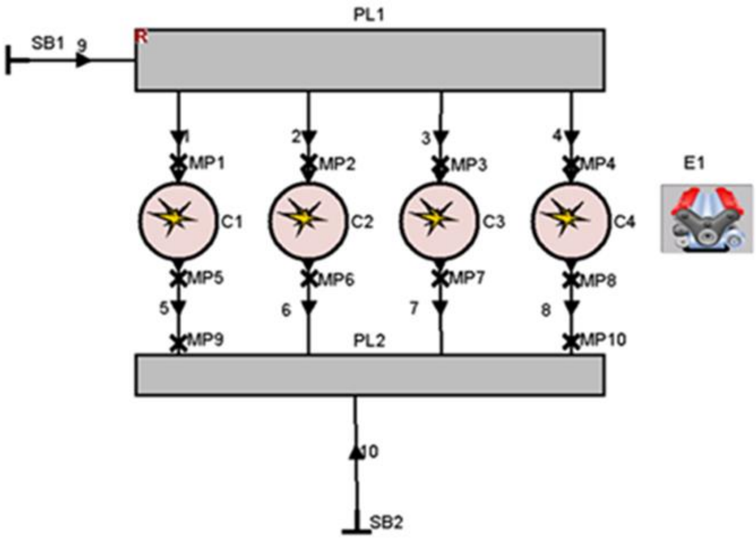

Fig. 7. Numerical modelling of the combustion process in a diesel engine (4 cylinders, 82.0x90.4) by using the AVL BOOST software programme. SB – system boundaries; PL1 – intake manifold, PL2 – exhaust manifold, MP – measurement points; C – cylinders, E1 – engine parameters.

A simplified model of the AVL programme was selected for simulation of the combustion process in a turbocharged CRDI diesel engine (Fig. 7). The needed geometrical data of specific engine elements are imported on the basis of known geometrical parameters of a diesel engine FIAT 1.9 JTD to be employed in the experimental research. The initial data required for numerical simulation: the start of combustion and duration of combustion, Vibe function shape parameter "m" of heat release characteristics in the combustion process and Vibe parameter "*a*" were generated by the MATLAB programme following the summarisation of the experimental research results and having formulated the alteration characteristics of the combustion process parameters. The developed simulation model allows quantifying and predicting of the influence of ethanol-oxygen or biodiesel-oxygen mass content (0-4.5% wt%) in the blends on the combustion parameters.

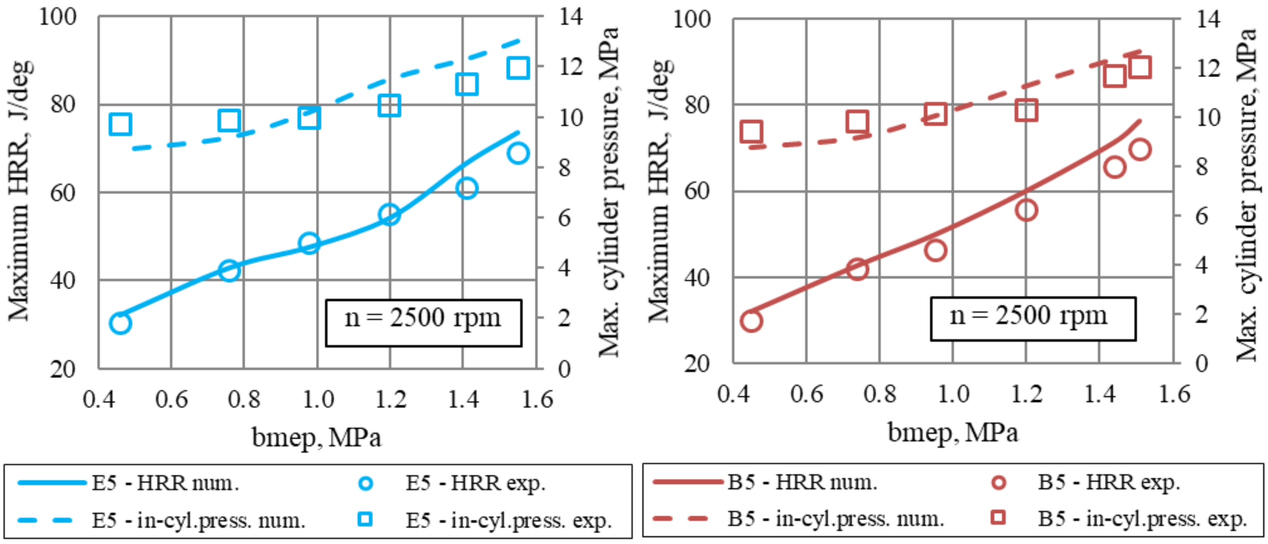

Fig. 8. Comparison between the numerical simulation and experimental data of the peak in-cylinder pressure and maximum heat release rate for diesel-HRD fuels involving ethanol-oxygen or biodiesel-oxygen

As it follows from the analysis of Fig.8, there are some discrepancies in HRR_{max} between both the numerical modelling and the experimental data. The numerically simulated maximum heat release-rate from combustion of the most ethanol-oxygenated blend E5 varies from being relatively 1.9% lower (0.98 MPa) to 9.3% higher (1.41 MPa), while the combustion of adequate percentage biodiesel-counterpart B5 produces HRR_{max} always from 2.3% (0.76 MPa) to 9.3% (1.51 MPa) higher than the respective experimental data obtained at speed of 2500 rpm. In agreement to the noted discrepancies in the HRR_{max}, the computer-generated maximum pressure p_{max} inside the cylinder also fluctuates within similar ranges of being relatively 10.4% lower at the low, 0.45 MPa, load to be 10.2% higher at medium, 1.20 MPa, load when using the most ethanol-oxygenated blend B5 under the same test conditions. While, the discrepancies in pressure p_{max} values between the computer-generated values and the experimental data vary from being 6.7% lower (0.45 MPa) to 9.7% higher (1.20 MPa) when running with the most biodiesel-oxygenated blend B5 at the high speed of 2500 rpm. Thus, the coincidence of both HRR_{max} and p_{max} values between the numerical modelling and experimental data is good enough as declared in Ref. [12], and the accuracy remains in more or less tolerable variation limits for both E and B fuel groups. This shows the potentials of AVL BOOST programme as an excellent tool for numerical simulation of the combustion processes in DI diesel engines.

CONCLUSIONS

Experimental and numerical investigation were conducted when running a turbocharged CRDI diesel engine with diesel-HRD fuel blends oxygenated in the same percentages (0-4.52 wt%) with ethanol-oxygen (E1-E5) or biodiesel-oxygen (B1-B5) under overall air-fuel ratios of λ = 1,30, 1.25 and 1.20 at the respective speeds of 1500, 2000 and 2500 rpm to reveal the fuel-oxygen-made effect on the combustion process. Comparative analysis of the test results obtained with the above mentioned fuels possessing the same blended cetane number value of CN = 55.5 revealed:

- The auto-ignition delay of a pilot fuel portion for the respective blends E4 and B3 is relatively 10.2% and 6.8% higher at the low speed of 1500 rpm. It remains relatively 1.5% higher (E4) or converts to be 1.5% lower (B3) at speed of 2000 rpm. But the biggest relative changes in the ignition delay occur at the higher speed of 2500 rpm, - it progressively increases to the highest value of 8.2^0 CADs (10.8% longer with blend E3) or moves down to the lowest point of 6.4^0 CADs (13.5% shorter with blend B4).
- Maximum heat release rate in the first combustion phase does not depend on the auto-ignition delay of a pilot fuel portion that is the fact particularly evident at the higher speed of 2500 rpm. While HRR_{max} is relatively 2.3% (E4) and 2.2% (B1) higher when running at the low speed of 1500 rpm. It predictably increases with the increase in the fuel-oxygen enrichment rate up to certain degree to be relatively 5.0% (E3) and 4.0% (B4) higher at maximum torque speed of 2000 rpm as well.
- Burn angle MBF 50 is relatively 1.9% (E4) and 0.9% (B1) smaller at the low speed of 1500 rpm. Positive role of the fuel-oxygen enrichment rate increases with the increase in engine speed and thus blends E4 and B5 took advantage in reducing burn angle MBF 50 by 6.6% and 2.0% for maximum torque speed of 2000 rpm. Specific angle MBF 50 from burning of the most oxygenated fuels E5 and B5 is relatively 4.2% and 3.0% smaller the high rotational speed of 2500 rpm as well.
- The peak pressure p_{max} developed from combustion of blends E4 and B4 is relatively 1.5% and 2.2% lower when running a fully (100%) loaded engine at the low speed of 1500 rpm. The importance of the fuel-oxygen enrichment rate increases with the increase in speed, therefore pressure p_{max} converts to be relatively 5.0% (E4) and 0.8 (B4) higher at speed of 2000 rpm. The relative increase in p_{max} is the same of 2.6% the combustion of both E3 and B5 blends produces for the high speed of 2500 rpm.
- The peak in-cylinder pressure-location angle Ap_{max} moves away from TDC towards a bigger cylinder volume by 0.6 (E5) and 0.5 (B5) CADs with the increase in fuel-oxygen mass content at the low speed of 1500 rpm. Even negligible relative relocation by 1.2 (E5) and 0.5 (B5) CADs of angle Ap_{max} towards TDC results into noticeable increase of p_{max} at speed of 2000 rpm. While the relative increase in the angle Ap_{max} compiles only 0.1 (E5) and 0.5 (B5) CADs ATDC at the high speed of 2500 rpm.

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Лабецкас Г., Славинскас С., Канапкиене И. Исследование влияние кислорода в топливе различного происхождения на процесс сгорания в дизельном двигателе CRDI с турбонаддувом.

В статье приводится анализ влияния кислорода в топливе различного происхождения на процессы самовоспламенения и сгорания в дизельном двигателе CRDI с турбонаддувом при средних эффективных давлениях 1.24, 1.37 и 1.40 МПа развиваемых при общих коэффициентах избытка воздуха λ = 1.30, 1.25 и 1.20 на соответствующих частотах вращения 1500, 2000 и 2500 мин$^{-1}$. Экспериментальные исследования и численное моделирование воздействия биотопливного кислорода на характеристики процесса сгорания выполнены при выше указанных средних эффективных давлениях и условиях работы, наиболее характерных для турбонаддувного дизеля. Оценка качественных и количественных изменений в характеристиках процесса сгорания выполнена с учетом химических и физических свойств смесей дизельного топлива и гидрированное возобновляемого дизельного топлива (HRD), обогащенных в одинаковых процентах по массе 0 (E0/B0), 0.91 (E1/B1), 1.81 (E2/B2), 2.71 (E3/B3), 3.61 (E4/B4) и 4.52 wt% (E5/B5) кислородом различного происхождения, - безводным (200 proof) этанолом (E) или метиловым эфиром рапсового масла (B) при достаточно высоком в обеих топливных группах цетановом числе 55,5. Сравнительный анализ в количественных изменениях периода задержки самовоспламенения предварительной порций топлива, специфического угла сгорания MBF 50, максимальной скорости тепловыделения (HRRmax) и максимального давления в цилиндре (pmax) в итоге применения кислородом обогащенных топливных смесей E1-E5 или B1-B5 выполнен с учетом соответствующих значений параметров замеренных при работе двигателя на нормальной смеси (ноль кислорода) E0/B0 с целью выявить потенциальные тенденции развития процесса сгорания.

Ключевые слова: Дизельный двигатель; экологически чистое топливо HRD; топливные смеси, обогащенные этанолом и биодизелем; самовоспламенение; процесс сгорания; тепловыделение; максимальное давление в цилиндре.

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