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FEEDING THE ENGINES OF FLEET VEHICLES WITH BIOXDIESEL FUEL AND HEAVY ALCOHOLS

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Abstract

This paper presents results of the research on the efficiency of the Diesel engines of the fleet vehicles fed with the new type of second-generation biofuel BIOXDIESEL at non-stationary and stationary conditions and natural operation on roads. The BIOXDIESEL fuel used for the laboratory testing of physical and chemical properties, engine tests and natural road operation, which is a blend of fatty acid ethyl esters (FAEE) obtained from the waste vegetable and animal fats, bioethanol and Diesel fuel. For the testing, several different types of vehicles have been used: passenger vehicles, small parcel delivery vans, agriculture machines and heavy trucks used for long distance international transport. The results of the vehicles engines testing in non-stationary conditions, results of measurement engines performance on vehicle test bed and results of natural road operation on roads of the vehicles used for testing indicate quasi-identical efficiency of the engines, which were fueled with BIOXDIESEL fuel and standard Diesel. The paper also presents results of initial research, which indicates the direction of future research, which is related to increase the calorific value of the biofuels, which may be obtained by replacement of used bioethanol with the heavier alcohols of renewable resources. Physical and chemical properties of the heavier alcohols indicate the possibility to use them as an additive to the biofuels. The paper presents also results of initial engine tests with a blend of the fuel with different heavier alcohols.

Keywords: *engines, cyclodyne, BIOXDIESEL, fatty acid ethyl ester, ethanol, heavy alcohol, exhaust emission*

1. Introduction

Engine manufacturers use many ways to reduce the impact of the exhaust gases on the environment, starting from catalytic converters, very accurate fuel injection systems, and engine supercharging, to selective catalytic reduction systems and specially designed fuel-feeding system to use biofuels.

One of possible way to reduce negative impact of combustion engines on environment is using of biofuels, where are made with waste animal and vegetable resources.

Current Polish and European law allow addition of up to 7% of biocomponents coming from Fatty Acid Methyl Esters to the fuel used in Diesel engines.

One of the big advantage of the ethyl esters over the methyl esters is their full renewability methanol has fossil origins, while ethanol can be fully renewable.

According to the actually law in Poland, the selected fleet of vehicles is defined as a group of at least 10 vehicles, agriculture tractors or off-highway machines or group of locomotives or ships, equipped with the engines which can be fuelled with liquid biofuel, which are used by the same user. Such selected fleet can be fuelled with the fuel, which meets different requirements than stated by the standards or other legal requirements.

2. Description of fuel used for testing

For testing of the engines of the fleet vehicles experimental fuel BIOXDIESEL has been used. This new experimental fuel is a three-component mixture of Fatty Acid Ethyl Esters (FAEE), bioethanol with addition of standard Diesel fuel. The properties of the BIOXDIESEL fuel are meeting the requirements stated in the PN-EN 590:2013, which describes Diesel fuel characteristic parameters. Currently there are no legal or standard requirements of FAEE, this is why in the paper properties of ethyl esters are compared with the PN-EN 14214 standard.

Tab. 1. Selected properties of BIOXDIESEL requirements of the PN-EN 590:2013 and PN-EN 14214+A1 standard

Parameter	Units	Properties of BIOXDIESEL fuel	PN-EN 590:2013 requirement		PN-EN 14214+A1 requirement	
			min	max	min	max
Cold Filter Plugging Point	[°C]	–17	From April 16 to September 30: 0°C From March 1 to April 15 and October 1 November 15: –10°C From November 16 to end of February: –20°C		From April 16 to September 30: 0°C From March 1 to April 15 and October 1 November 15: –10°C From November 16 to end of February: –20°C	
Cetane number		51.9	51		51	
Density at 15°C	[kg/m^3]	868	820	845	860	900
Flash point	[°C]	24	55		101	
Viscocity at 40°C		2.33	2	4.5	3.5	5
Calorific value	[MJ/kg]	38.5	42.8		38	

The Fatty Acid Ethyl Esters (FAEE) was obtained in the transesterification process with bioethanol in presence of alkali catalyst. The feedstock selection for the process is described in details in [3]. It is worth to mention, that vast part of the BIOXDIESEL fuel components is obtained from waste animal and vegetable fats. Such wastes are converted in trans-esterification process into a main biocomponent of BIOXDIESEL fuel, which main properties are not different to standard Diesel fuel [3, 4].

The BIOXDIESEL used for feeding the engines of the fleet vehicles used for the testing were mixed with 70% of biocomponents (FAEE and bioethanol) and 30% of Diesel fuel with additives.

3. Description of engines used for testing

During the testing the wide spectrum of the vehicles were used: agriculture machines (tractor), small commercial vehicles (parcel delivery services), passenger vehicles and heavy trucks.

The biggest group of vehicles used in the test were the parcel delivery vans, together 15 pieces. The vehicles have been used on different duty cycles: 5 vehicles were operated in the cities, 5 in long distances and 5 vehicles in the mixed duty cycles. The other passenger vehicles were used in mixed duty cycles. The trucks were used for long distance international transport.

Tab. 2. Short description of the fleet vehicles and their engines

	Type of the vehicle	Make, model	Year of build	Engine displacement [ccm]	Fuel injection system, supercharging	Max engine power [BHP]	Max torque engine [Nm]
1	Truck	Scania R440	2013	12700, 6 cyl.	HPI, turbocharger	440	2300
2	Truck	Scania R420	2008	11700, 6 cyl.	PDE, turbocharger	420	2100
3	Parcel delivery van	Citroen Jumper	2011	2200, 4 cyl	Common rail, turbocharger	100	250
4	Parcel delivery van	Citroen Berlingo	2011	1560, 4 cyl	Common rail, turbocharger	75	185
5	Passenger vehicle	Mazda 6	2005	1998, 4 cyl.	Common rail, turbocharger	136	310
6	Passenger vehicle	Mercedes W211	2003	2148, 4 cyl	Common rail, turbocharger	150	340
7	Passenger vehicle SUV	Land Rover Freelander	2005	1950, 4 cyl.	Common rail, turbocharger	112	260

4. Testing procedures of the engines of fleet vehicles fed with BIOXDIESEL fuel

On the day of the replacement of the fuel into BIOXDIESEL, the parcel delivery vans have been tested on the vehicle test bed, where the performance of the engine has been measured. The motors have also been tested in non-stationary conditions. Cyclodynes have been measured according to the procedure described in [4], including calculation of following indicative parameters, such as area of the cyclodyne, location of centre of gravity of cyclodyne.

4.1. Vehicle test bed testing procedure

The testing of the vehicle has been performed in co-operation with the ECU-PROJECT company, on the 4WD test bed manufactured by Dynoproject. The bed is able to test the vehicles with maximum power of 1000 BHP and maximum torque 1000 Nm and results obtained by from the test bed are corrected according to DIN70020.

In the first stage of the test, the engine torque and power have been measured when supplying with Diesel fuel. After replacement of the fuel into BIOXDIESEL, the measurement of torque and power were repeated.

4.2. Vehicle engine test in non-stationary state

The engine is alternatively rapidly accelerated from idling to maximal revolution, and then decelerated from maximal crankshaft back to idling. The values of torque are calculated according to:

$$M = I\varepsilon\,, \tag{1}$$

where:
I – moment of inertia,
ε – angular acceleration.

The cyclodynes are the curves drawn on the engine torque – engine revolution plane. In case, when the polar moment of inertia of the engine is not exactly specified, it is possible to draw cyclodynes in the angular acceleration – engine crankshaft rotational velocity.

The cyclodynes remain loops, which positive part is drawn when accelerating and negative part during deceleration. The area of the positive part of cyclodynes is related to the energy generated by the engine during acceleration (depend calorific value of the fuel and efficiency of burning of the fuel), while negative part of the cyclodyne depends on overall condition engine and quality of lubrication oil in the engine.

5. Result of the testing of the engines with BIOXDIESEL

5.1 Results of testing the fleet vehicles' engines on the vehicle test bed

On the same day, when the fuel was replaced to BIOXDIESEL, the parcel delivery vehicles had undergone testing on the vehicle test bed.

Figures 1 and 2 present results of the vehicle test bed results for parcel delivery vans Citroen Berlingo and Citroen Jumper. One can notice that the maximal power and torque engines are slightly lower for engines feeding BIOXDIESEL. However, research shows traction, that values of maximal torque and power are not influencing performance of the vehicle at natural everyday operation.

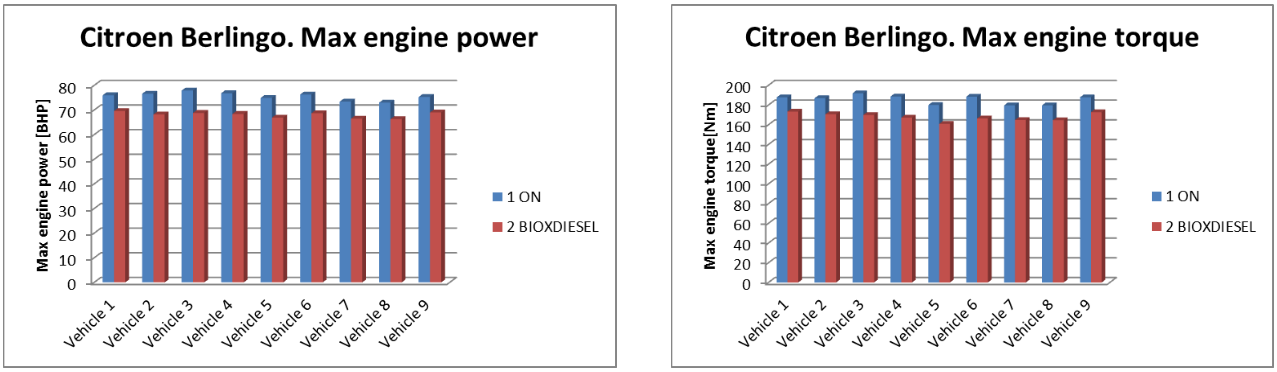

Fig. 1. Comparison of measured power and torque generated by the engine for two different fuels Citroen Berlingo parcel delivery vans. Measurement taken on the first day of testing

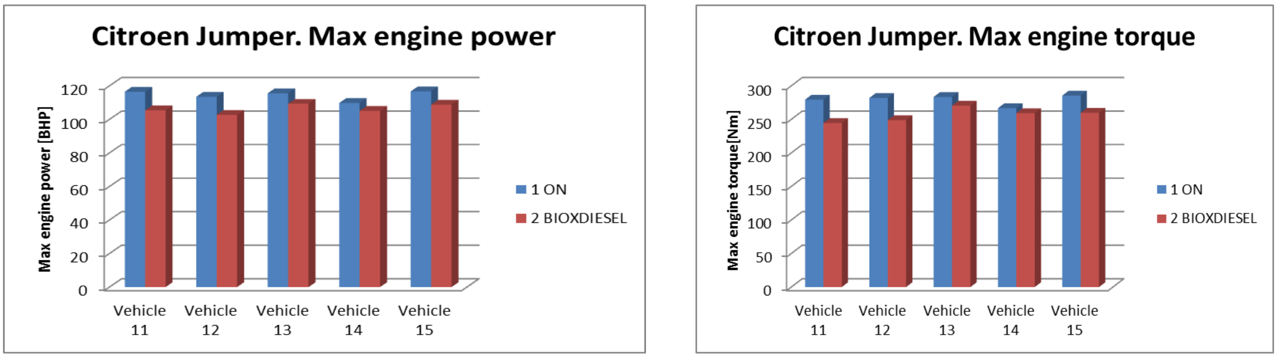

Fig. 2. Comparison of measured power and torque generated by the engine for two different fuels Citroen Jumper parcel delivery vans. Measurement taken on the first day of testing on the vehicle test bed

5.2. Results of vehicles' tests in non-stationary states

The fleet vehicles have been tested at non-stationary states several times during the course of the BIOXDIESEL road testing. The vehicles returned to the workshop for testing. Fig. 3 and 4 present examples of cyclodynes drawn for Scania R420 and one of the Citroen Berlingo vehicles used for testing. The shapes and areas of cyclodynes measured for all vehicles feeding with standard Diesel fuel and BIOXDIESEL are very similar to each other. Points A presented on the graphs below are the centres of gravity of cyclodynes, A1 centre of positive part of cyclodynes and A2 centres of negative part of them.

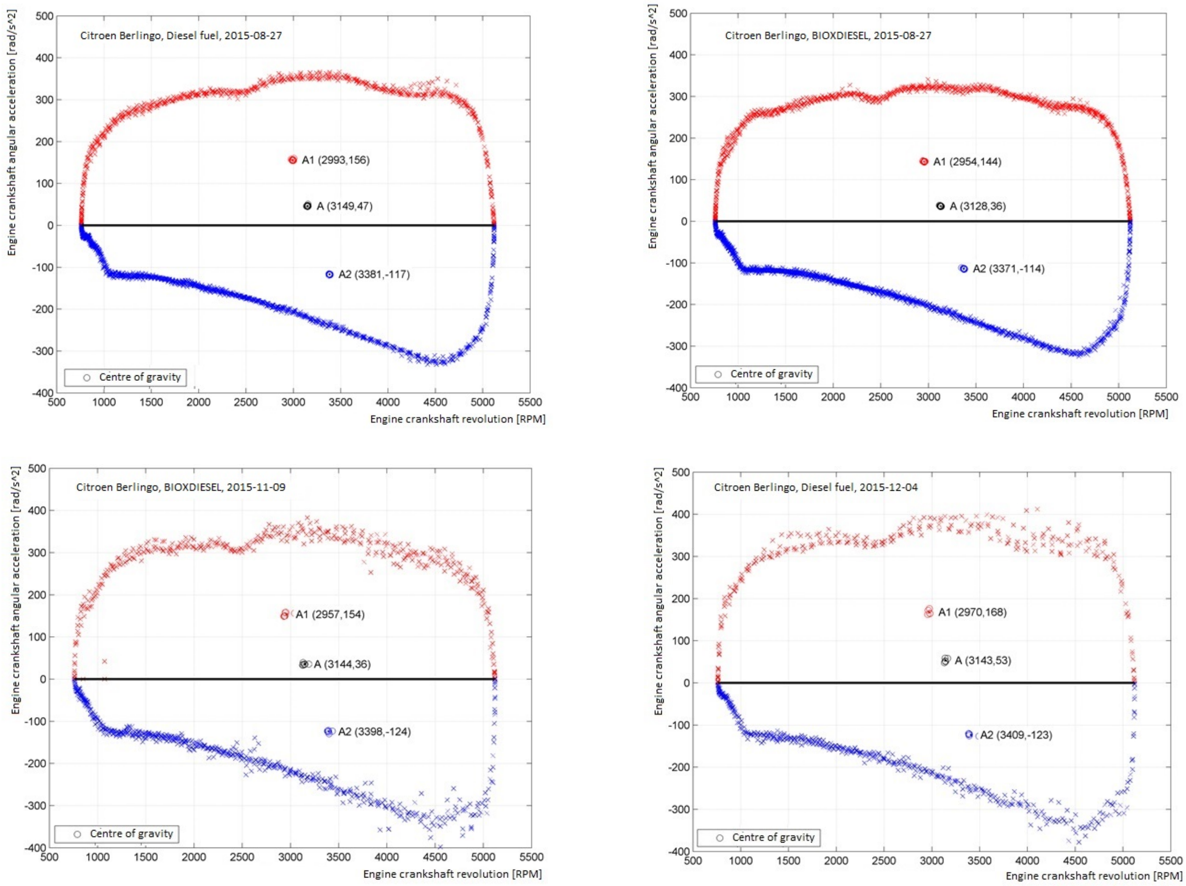

Fig. 3. Examples of cyclodynes at periods of test one of Citroen Berlingo (Diesel and BIOXDIESEL)

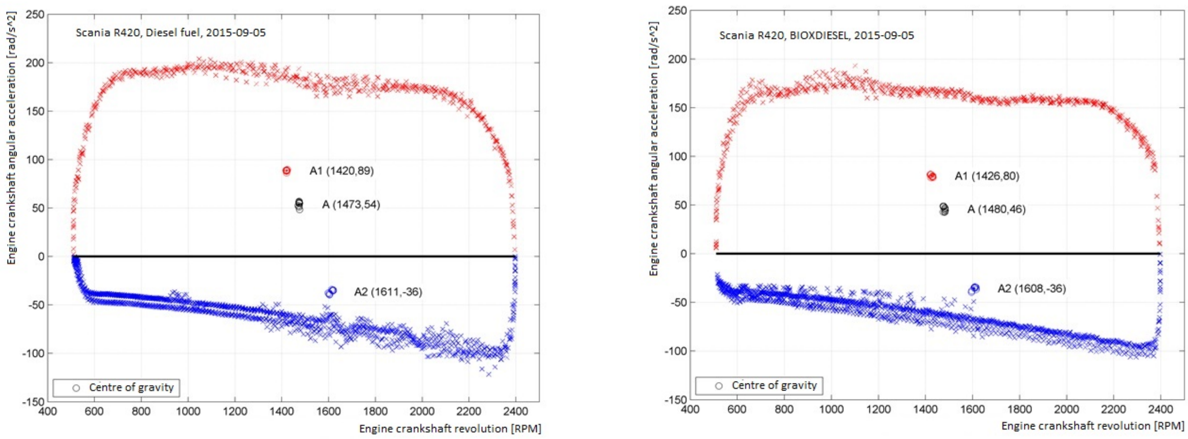

Fig. 4. Examples of cyclodynes at periods of test one of SCANIA R420 (Diesel and BIOXDIESEL)

5.3. Results of road testing of fleet vehicles

The parcel delivery vans were the biggest group of the vehicles used for the test. The exploitation of them is strictly supervised.

Table 3 presents comparison of fuel consumption during the test with the BIOXDIESEL fuel as well as the similar data for corresponding periods of time one year before start of the test. One can notice that the fuel consumption of the BIOXDIESEL fuel is fairly the same as standard Diesel fuel in the corresponding periods. Small differences may be caused by different duty cycles of the vehicles, different loads during the testing, different drivers operating the vehicles and many other reasons.

Tab. 3. Comparison before and during 2 stages of BIOXDIESEL tests (Selected vehicles)

vehicles registration number	vehicle make	Diesel fuel August - December 2014			Diesel fuel February - July 2015			BIOXDIESEL August - December 2015			BIOXDIESEL February - April 2016		
		amout of fuel [litres]	Covered distance [km]	Fuel consumption [litres/100km]	amout of fuel [litres]	Covered distance [km]	Fuel consumption [litres/100km]	amout of fuel [litres]	Covered distance [km]	Fuel consumption [litres/100km]	amout of fuel [litres]	Covered distance [km]	Fuel consumption [litres/100km]
DW381YG	Citroen Berlingo	271	2824	9.6	124	1073	11.6	173	1460	11.9	175	1738	10.1
DW922YK	Citroen Berlingo	312	3531	8.8	-	-	-	312	3503	8.9	276	2812	9.8
DW009YW	Citroen Jumper	1901	18795	10.1	546	4235	12.9	-	-	-	389	3152	12.3
DW008YW	Citroen Jumper	1037	10611	9.8	1129	12505	9.0	-	-	-	538	4598	11.7

5.4. Results of engine performance and emission tests

This paper presents also results of emission tests, performed according to the EUDC procedure using 1.3 SDE turbocharged Diesel engine, equipped with Common Rail system. Maximal torque generated of the engine is 180 Nm at 1750 RPM and maximal power generated by the engine is 70BHP at 4000 RPM. Below, in Tab. 4, the measurement points of the test cycle are presented.

Tab. 4. List of measurement points according to EUDC testing procedure

Measurement point	Engine revolution [RPM]	Engine torque [Nm]	Corresponding vehicle speed/gear [kmph/gear]
1	820	45	
2	850	20	
3	1050	15	
4	1250	20	
5	1400	40	
6	1550	4	35/III
7	1590	10	50/IV
8	1650	37	
9	1730	11	70/V
10	1740	26	
11	1800	38	
12	1920	3	15/I
13	2050	26	
14	2200	4	50/III
15	2260	4	32/II
16	2400	55	
17	2500	34	100/V
18	2700	73	
19	2930	80	
20	3020	55	120/V

On the Fig. 5 and 6 results of the engine performance and emission measurements are presented: engine efficiency, fuel consumption and also results of emission tests: like concentration of carbon oxide, hydrocarbons, nitrogen oxides, smoke, sooth and lambda coefficient.

Results of testing the engine prove, that the performance of the engine fed with BIOXDIESEL fuel are very similar, and in many cases better in comparison to feeding with Diesel fuel (Fig. 5a presents results of the engine efficiency measurement at different points of EUDC cycle).

Results of emission of carbon oxide and hydrocarbons are very distinctive: BIOXDIESEL fuel causes much lower emission in comparison with standard diesel. Emission of nitrogen oxides, sooth and smoke is very similar for both fuels (Fig. 6 and 7).

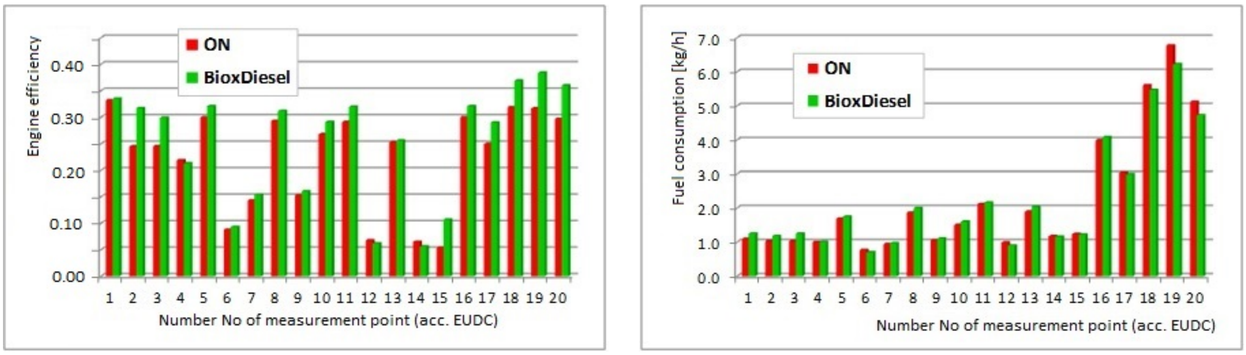

Fig. 5. Results of the performance testing of the 1.3 SDE Diesel engine: engine efficiency, fuel consumption

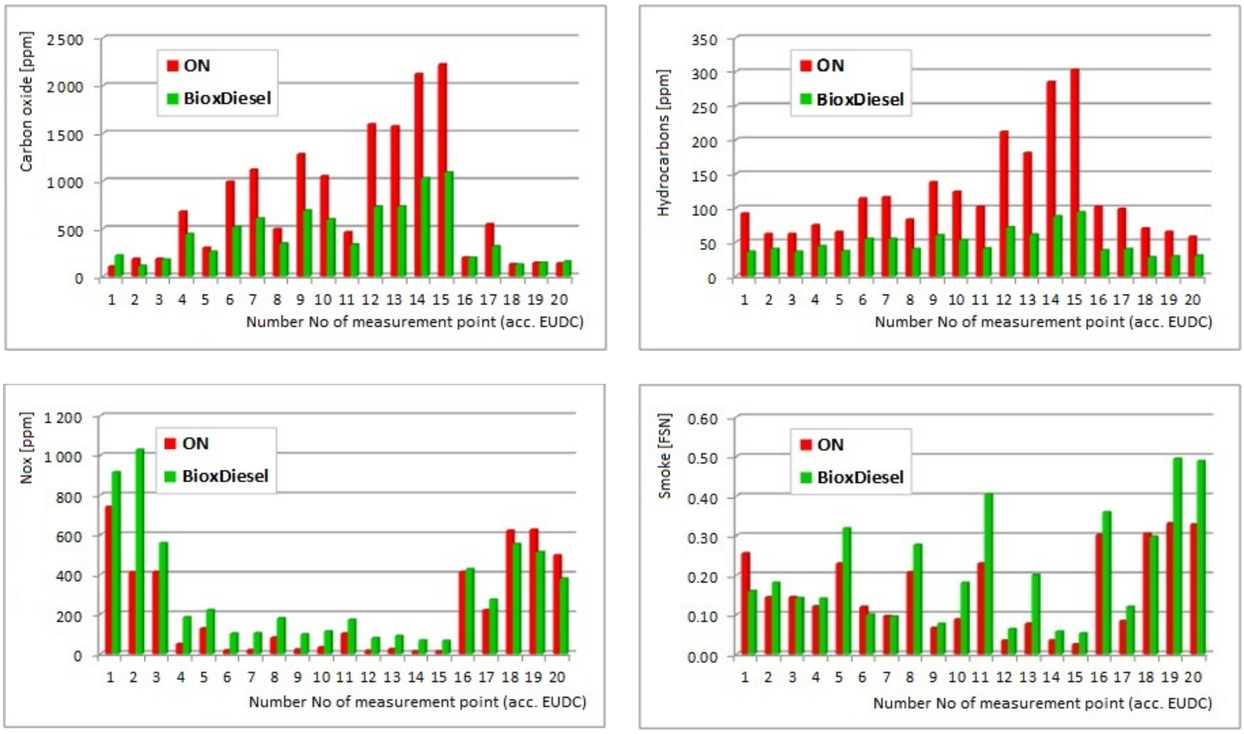

Fig. 6. Results of emission testing of 1.3 SDE engine: carbon oxide, hydrocarbons, nitrogen oxides and smoke

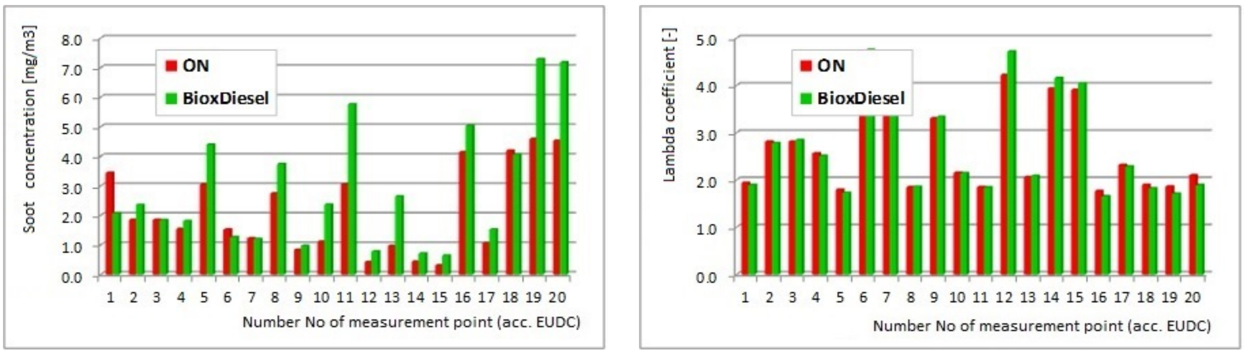

Fig. 7. Results of emission testing of 1.3 SDE engine: soot and lambda coefficient

Hitherto presented research show, that BIOXDIESEL fuel is very advanced fuel, which application for vehicles does not require any additional changes in the engine design or any changes in engine fuel system and engine control unit (ECU). The performance of testing vehicles over the course of the test showed no major problem with engines of the test BIOXDIESEL or additional engine related devices.

6. Testing of the engines fed with mixtures of Diesel fuel with heavier alcohols

It is presumed, that one of the methods higher calorific values of the BIOXDIESEL fuel is to replace the bioethanol and use heavier alcohols coming from biomass processing due to the higher calorific values of heavier alcohols [1, 2]. The initial tests of that possibility were performed.

The various heavier alcohols were blended in the ratio 9:1 with Diesel fuel [2]. In the Tab. 5 shows a comparison of physical and chemical properties of selected heavier alcohols.

Tab. 5. Physical and chemical properties of alcohols of temp 20°C

Lp.	Alcohols	Boiling point [°C]	Ignition temperature [°C]	Autoignition temperature [°C]	Molar mass [g/mol]	Density [kg/dm^3]	Calorific value [MJ/kg]
1	Metanol	64.6	11	455	16	0.791	22.614
2	Etanol	78.0	12	365	46	0.789	27.502
3	Propan-1-ol	97.2	22	370	60	0.800	32.593
4	Propan-2-ol	82.5	12	399	60	0.790	33.049
5	Butan-1-ol	116.0	35	342	74	0.810	36.310
6	Butan-2-ol	99.0	22	406	74	0.808	35.669
7	Pentan-1-ol	138.0	33	343	88	0.814	37.049

Preliminary tests were carried out on the engine of portable power generator VIRGO 6.6 kW with direct injection. Specific fuel consumption for the tested engine is 424 g/kWh. The Figs. 8-10 presents results of testing the engine the mixtures of Diesel fuel with different alcohols in the 9:1 (v/v) ration. All results were presented relation to the base fuel (Diesel).

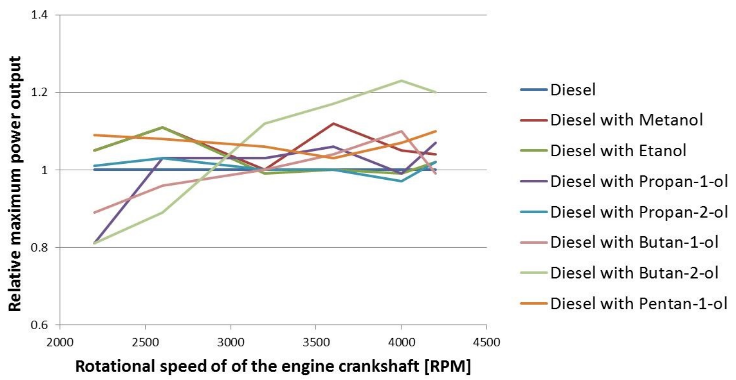

Fig. 8. Power generated by the engine fed with mixtures of Diesel and heavier alcohol

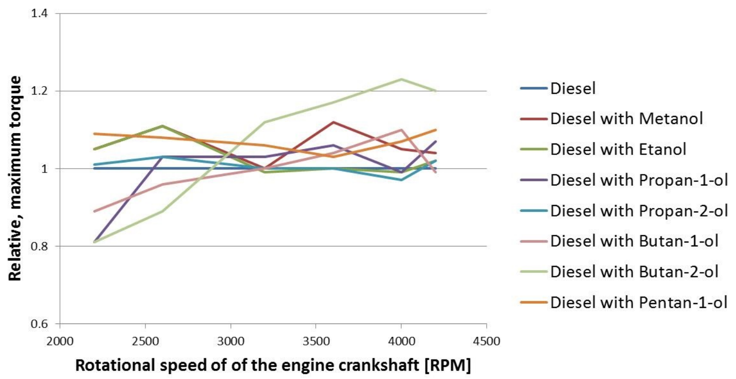

Fig. 9. Torque generated by the engine fed with mixtures of Diesel and heavier alcohol

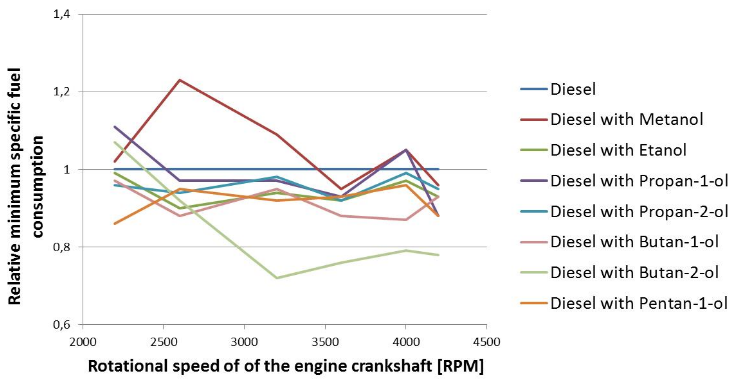

Fig. 10. Relative specific fuel consumption generated by the engine fed with mixtures of Diesel and heavier alcohol

Above presented results of initial testing allow concluding, that the effectives of the engine is higher when supplying the engine with the mixture of Diesel fuel with pentan-1-ol. At the rotational speed above 2900 rev/min is doing noticeably better when applying a mixture of Diesel with butan-2-ol up to 25%. Similar properties can be observed in terms of torque. Also specific fuel consumption is lower when supplying the engine with Diesel with butan-2-ol.

7. Conclusions

Presented results of testing the engines fuelled with the BIOXDIESEL and Diesel show:

– similar efficiency engine feeding BIOXDIESEL and Diesel,
– lower emission of toxic content of exhaust gases for BIOXDIESEL, the most significant impact is clearly seen on the emission of carbon oxide and hydrocarbons, smoke and sooth emission is very similar for both fuels, during the observation of the vehicles in everyday operation as well as during vehicle test bed measurement smoke emission was much smaller for BIOXDIESEL emission,
– fuel consumption, vehicles behaviour in everyday natural operation remained the same for standard Diesel and BIOXDIESEL;

Obtained results of research entitle to state, that the BIOXDIESEL fuel is very advanced and can be used as an alternative fuel for all Diesel engines. Previous results of research use of heavier alcohols with may be obtains for structural modification of the BIOXDIESEL fuel in order to improve calorific value of this fuel, however research in this should be continued.

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