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EFFICIENCY OF DIESEL ENGINE FUELLED WITH BIOFUELS OF SECOND GENERATION BIOXDIESEL

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Abstract

Paper presents schematic description of the research covering production mechanism of Fatty Acid Ethyl Esters (FAEE) from waste vegetable and animal fats, which are creating a base for multi-component fuel BIOXDIESEL as well as results of physical, chemical analysis and results of engine and vehicles tests. The characteristic of wasted material used for production of fatty acid ethyl esters is showed. Cybernetic chain of biofuel BIOXDIESEL, system analysis and structure and scheme of the chemical reaction of Ethanol esterification of fatty acids is presented. Basic properties of exemplary BIOXDIESEL and Diesel fuel were compared. Caloric values of investigated BIOXDIESELS are shown. Mixtures of the BIOXDIESEL fuels with various composition have been tested and compared with Diesel fuel during engine tests on the engine test bench, vehicle test dyno and drive tests. The diesel engines of Fiat 1.3 Multijet, Mercedes300D, Landrover and ADCR compression ignition engine were tested with biofuels. Functional schema of the measurement set up is described. Cyclodynes obtained during testing of the ADCR engine fuelled with Diesel and BIOXDIESEL fuels with their centres of gravity are presented. Obtained and described results in the form of tables and graphs can be summarized with conclusions, that the performance of engines fuelled with BIOX-DIESELS is similar to engines fuelled with Diesel fuel.

Keywords: *biofuels, Bioxdiesel, Diesel engines, engine test, drive test*

1. Introduction

Current Polish and European legal requirements allow addition to the Diesel engines fuels up to 7% of biocomponents according to calorific value. Such biocomponents form Fatty Acid Methyl Esters (FAME). It is worth to mention, that in transesterification processes methanol is used. One of the most important feature is toxicity of methanol and its vapours and it is obtained from fossil resources. Previous experience shows, that replacement of methanol by ethanol allows production of Fatty Acid Ethyl Esters (FAEE), which physical, chemical properties are beneficial from fuel application point of view. Methyl esters (RME) and Ethyl esters (REE) differ with the products of incomplete combustion in engines [1]: combustion of RME causes emission of toxic substances (e.g. formaldehyde radicals), which are not being detected during combustion of REE; exhaust gases of compression ignition engines fuelled with RME contain several times more methyl radicals in the comparison to the exhaust gases when burning REE. Application of bioethanol for production of Fatty Acid Ethyl Esters is a subject of research in many scientific groups because of its full renewability (FAME are not fully renewable).

2. Characteristics of waste materials used for production of fatty acid ethyl esters

Authors experience in the area of manufacturing of Fatty Acid Ethyl Esters clearly show, that waste animal fats (e.g. pork and poultry), waste vegetable fats (e.g. waste frying oils) and vegetable oils (e.g. rapeseed oil) are good raw materials for biofuels production. They are materials, which should be utilized, but their calorific value allows to be treated as a feedstock in biofuel production.

Unique features of animal fats, especially poultry, have been noticed also in the other research centres [2, 3]. Beef tallow is rarely used because of its structure characterized by large content of saturated fatty acids, which can cause their different physical and chemical properties. Comparison of some physical and chemical properties of waste animal fats is presented in Tab. 1.

Recently performed experiments have showed (as it was predicted) properties variation for feedstock coming even from the same supplier.

Tab. 1. Exemplary properties of fats, which can be used for biofuel production [4]

Waste material	Acid number w_{AV}	Acidity w_{FFA}	Peroxide number PV	Refractive index n_D
Beef tallow	1.07	0.54	0.00060	1.4655
Pork fat	2.86	1.44	0.00132	1.4660
Poultry fat	0.83	0.42	0.00029	1.4665
Palm oil	1.56	0.71	0.00169	1.4680
Fried palm oil	2.37	1.08	0.00045	1.4658
Rapeseed oil	1.59	0.80	0.00040	1.4723
Fried rapeseed oil	2.79	1.23	0.00067	1.4705

Cybernetic chain of biofuel BIOXDIESEL, system analysis and structure is presented on the Fig. 1. It consists of four blocks. First block shows the composition of biofuel for whose physical and chemical properties are checked and analysed. Block No. 3 presents the performances on Diesel engine fuelled with biofuel and fourth block seizes an analysis of conversion effects (efficiency, smoke, NO_x, etc.).

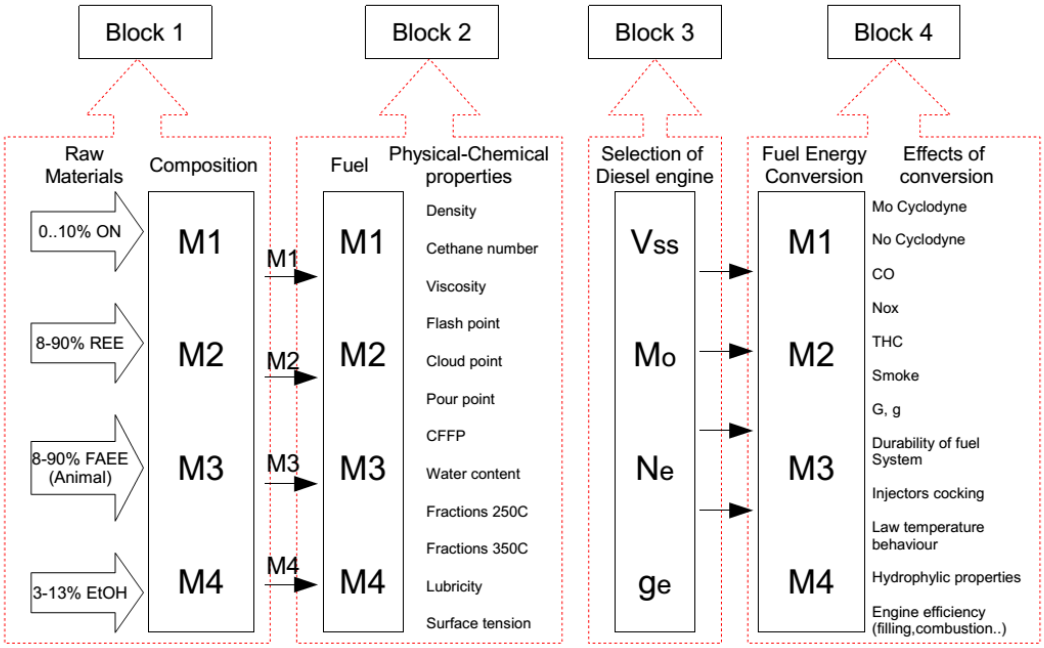

Fig. 1. Cybernetic chain of the biofuel BIOXDIESEL

The BIOXDIESEL is prepared in Wroclaw University of Technology and is the mixture of Diesel fuel and ethyl esters and additives components with different percentage quota. It is possible to fit properties of BIOXDIESEL to match requirements of particular Diesel engine application, e.g. for agriculture, municipal transportation, construction machinery, military vehicles, etc.

3. Ethanol esterification of fatty acids

One of the most frequently used methods to ‘adjust’ properties of fats to prior required properties similar Diesel fuel is transesterification. Reaction most frequently undergoes with presence of alkali catalyst. Schema of the reaction is presented in Fig. 2.

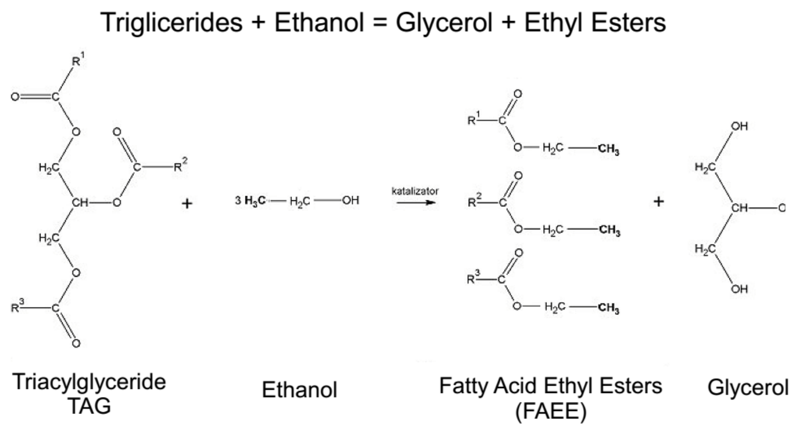

Fig. 2. Schema of transesterification reaction with application of ethanol [1]

Diversity of substrate properties causes necessity to choose an amount of catalyst for reaction, which undergoes with the excess of ethanol. It is necessary to mention, that ethanol evaporates in higher temperature range in comparison with methanol [4].

Ethyl esters as biofuels are not described in standards in Europe and in Poland. This is a reason why their physical and chemical properties are compared with the PN-EN 14214 standard. Ethyl ester constitutes a main component of the composition of BIOXDIESEL biofuel, taking into account quality and economic requirements. Such biofuel consists of a mixture of ethyl esters manufactured from waste animal and vegetable fats, rapeseed oil ethyl esters REE, Diesel fuel and ethanol. Exemplary properties of BIOXDIESEL fuel and Diesel fuel compared with PN-EN 590 standard requirements and are presented in Tab. 2.

4. Determination of Diesel engine run fuelled with chosen BIOXDIESEL mixtures

There were made tests for three mixtures of BIOXDIESEL composites named dc4.70 (caloric value 38.53 kJ/kg), B4 (caloric value 38.2 kJ/kg) and B6 (caloric value 38.8 kJ/kg) having different chemical composition which were compared to Diesel fuel. Tests were performed on three diesel engines from Fiat 1.3 Multijet, Mercedes 300D and Land Rover.

4.1. Effective work determination of Diesel engine on engine test bench

Fiat 1.3 Multijet Diesel engine has been tested on engine test bench. Fig. 3 shows the maximum engine power as a function of engine crankshaft speed when fuelling with BIOXDIESEL fuels and Diesel fuel.

Difference between maximal engine power of Fiat 1.3 Multijet Diesel engine between bioxdiesels and Diesel fuel are not significant (max. 2%). One can see that up to 4200 rpm the engine power gained from the BIOXDIESEL fuels is bigger than Diesel fuel.

Tab. 2. Comparison of basic properties of exemplary BIOXDIESEL and Diesel fuel [1]

Parameter		BIOXDIESEL	Standard Diesel fuel requirements (PN-EN 590)
Density at 15°C [kg/m^3]		0.844	0.820–0.845
Density at 20°C [kg/m^3]		0.839	–
Cetane index [–]		50	min. 46
Kinematic viscosity [mm^2/s]		2.39	2.00–4.50
Flash point [°C]		26	> 55
Cloud point [°C]		–23	–10
Pour point [°C]		–37	–24
Cold Filter Plugging Point [°C]		–33	–20
Water content [mg/kg]		97	max. 200
Fractions	up to 250°C dest. [%V/V]	42	max. 65
	up to 350°C dest. [%V/V]	98	min. 85
Sulphur content [%]		< 0.01	< 0.01
Corrosive properties		1a	1a
Lubricity HFRR [μm]		198	≤ 460

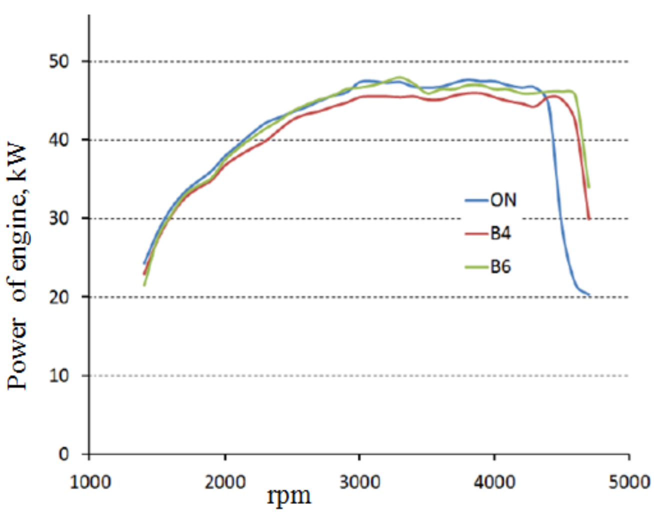

Fig. 3. Power of the Diesel engine fuelled with Diesel fuel (ON), BIOXDIESEL B4 and BIOXDIESEL B6

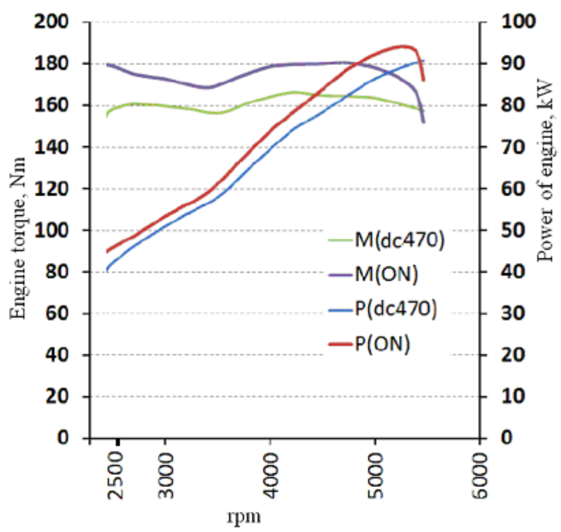

Fig. 4. Power of engine and engine torque of the diesel engine of Mercedes 300D fuelled with diesel fuel (ON) and BIOXDIESEL (dc470), P-Power of engine, M-engine torque

4.2. Effective work determination of Mercedes and Land Rover Diesel engine during the vehicle dyno test

The Mercedes 300D Diesel engine has been tested on the vehicle dyno when fuelling with BIOXDIESEL dc470 and Diesel fuel. The results of the tests are presented in Fig. 4.

Insight analysis of the results of the performance of the Mercedes 300D diesel engine shows, that diffeence between maximal engine powers fuelling with BIOXDIESEL dc 470 is insignificancy lower than fuelling with Diesel fuel and varies from 4 to 8%. One of possible explanation of the difference in the Mercedes engine performance for BIOXDIESEL and Diesel fuel is the set-up of the engine has been optimized for Diesel fuel.

Two types of BIOXDIESEL: B4 and B6 were examined on 2.0 litres BMW Diesel engine of Landrover common rail system. The results of investigations are presented in Fig. 5.

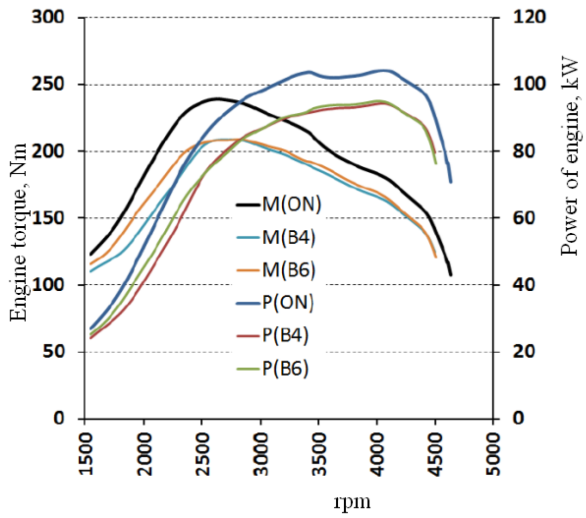

Fig. 5. External characteristics of the Diesel engine of Landrover fuelled with Diesel fuel (ON), BIOXDIESEL B4 and BIOXDIESEL B6; M-engine torque, P-Power of engine

Comparing BIOXDIESEL B4 and B6 with Diesel fuel one can see that the difference is not significant. In the range of the engine crankshaft speed, which is most frequently used in everyday exploitation of the vehicle, drop of the performance cannot be noticed by the driver.

5. Efficiency of Diesel engine fuelling with BIOXDIESEL fuel at non-stationary states

5.1. Test set up description

The subject of the testing in non-stationary conditions was ADCR compression ignition engine installed on Eddy current dyno VAL Dyno Perform 240. Test set up contained also control system and data acquisition system. Additionally it was equipped with emission recording unit.

The measurement set up has been equipped with reluctantive sensor, which has been used to measure a position of the engine crankshaft. Position of the crankshaft has been recorded with portable computer equipped with data acquisition card. Then the computer software has been used to calculate instant crankshaft speed and crankshaft instant acceleration.

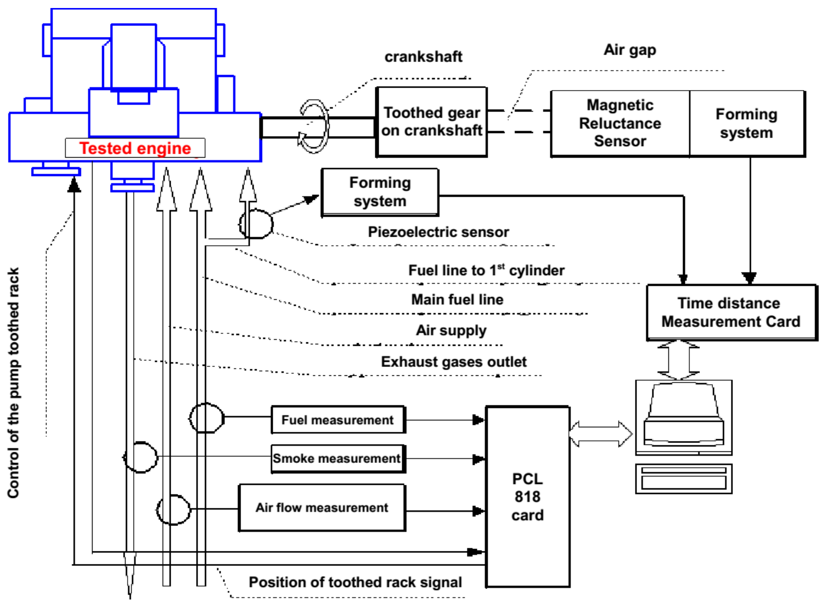

Fig. 6. Functional schema of the measurement set up [1]

5.2. Description of research procedure

Research procedure has been described in details in [1] and [5]. It contains measurement of dynamic characteristics of the engine during periodic change of engine crankshaft speed. Engine crankshaft speed varies from the idle to maximal speed, and servomechanism controls fuel system and thus eliminates 'human factor'. Engine torque is described by equation:

$$M_o = J \times \frac{d\omega}{dt} = J \cdot \varepsilon \ , \tag{1}$$

where:
J – known polar moment of inertia of the moveable engine parts,
ε – acceleration of engine crankshaft,
ω – engine crankshaft speed.

In case of the ADCR engine, which was installed on VAL dyno, the load of the engine constituted an Inertia of the engine rotation part, inertia of the dyno and the shaft connecting the engine and the dyno.

During the testing, the engine has been fuelled with Diesel fuel and BIOXDIESEL biofuels, which were manufactured on the base of FAEE esters. This paper presents comparison of the results of testing of selected biofuels, compared with the results obtained using Diesel fuel and B5.

During fuelling with each of the fuels 16 cycles of acceleration-reduction of the engine crankshaft has been performed. Instant engine crankshaft speed has been recorded. Based on the engine crankshaft speed instant value of engine crankshaft acceleration has been calculated. Then the dependence of the torque and engine crankshaft speed has been drawn.

5.3. Results of measurement

During testing, the ADCR engine in non-stationary conditions the efficiency of the engine work during fuelling with the BIOXDIESEL fuel and Diesel fuel has been compared. The shape and the surface of the cyclodynes upper part [1] obtained during fuelling with BIOXDIESEL and Diesel fuels show, that the surfaces are close to each other (Tab. 3 and Fig. 7). Even though two fuels used for testing (BIOXDIESEL and Diesel) varied in terms of the calorific values in the range
of 10%, the surface of the energy supply area, described by the surface of the cyclodyne varied only by 8%.

Tab. 3. Values of the areas and calorific values of the fuels

	Type of fuel	
	Diesel fuel	BIOXDIESEL
Surface of cyclodyne	531390.4	491636.6
Caloric value, MJ/kg	42.4	38.2

Conclusions

- Differences of power of Diesel engine and engine torque measured for BIOXDIESELS and Diesel fuel are lower than 8% in spite of the 10% differences of the calorific values between them.
- Results of the research on the engine efficiency of the ADCR engine fuelled with multi-component fuel BIOXDIESEL and Diesel fuel are similar.
- Wide range of waste animal and vegetable fats are proper raw material for production of the second-generation biofuels.

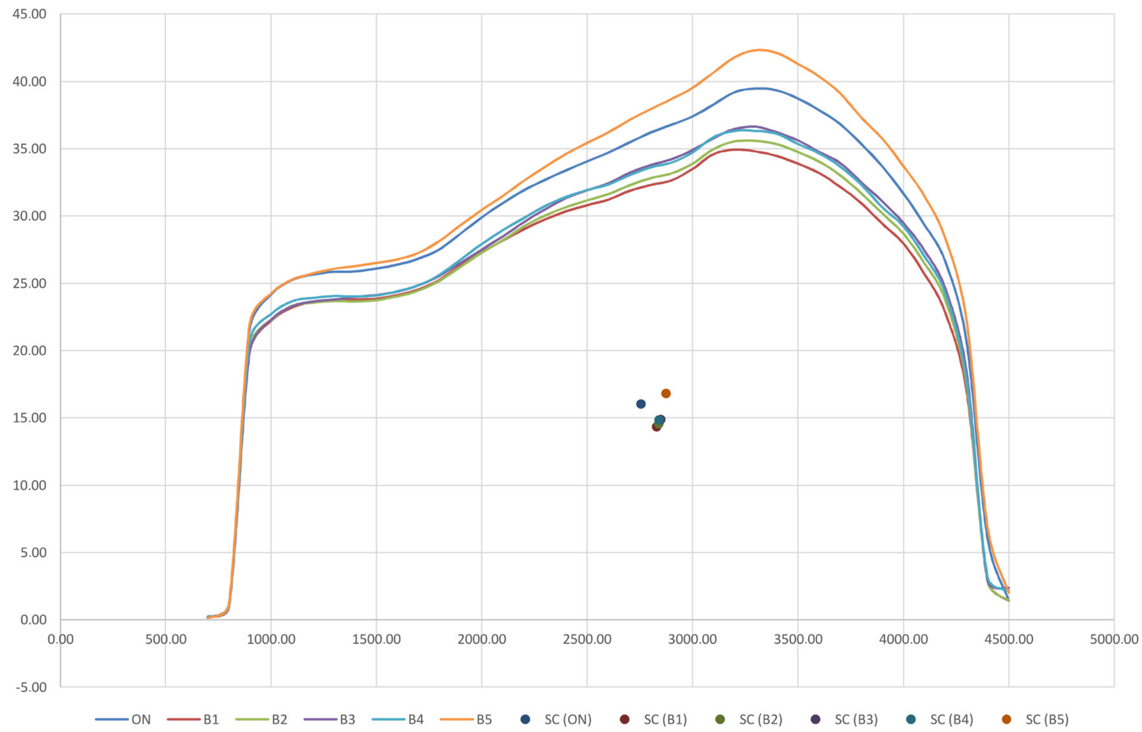

Fig. 7. Cyclodynes obtained during testing of the ADCR engine fuelled with Diesel and BIOXDIESEL fuels with their centres of gravity.

- Second generation biofuels with Fatty Acid Ethyl Esters are effective and non-toxic (environment friendly) fuels, which should be introduced to production.
- Diesel engines can be fuelled with BIOXDIESEL without noticeable drop of driving performance.
- Presented results of testing BIOXDIESEL fuels are very promising. Further development should cover fleet real-life vehicles durability testing.

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