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COMPARISON OF AN EFFECT OF FAME AND FAEE ADDITION TO DIESEL FUEL ON ENERGETIC PARAMETERS OF AN ENGINE

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Summary. An analysis and comparison of an influence of fuel blends containing rape oil ethyl esters (FAEE) and methyl esters (FAME) on diesel engine work parameters were presented in this paper. Research was conducted on engine type 2CA90 installed on dynamometric stand. Relying on undertaken research it was noted that utilization of fuel blends containing 5% of fatty acids ethyl esters and 5 % of fatty acids methyl esters causes changes of energetic work parameters of a diesel engine. Research has not shown a determining effect of type of ester used in fuel mixture on energetic parameters of the engine.

Key words: engine fuels, diesel engine, biofuel.

INTRODUCTION

Prospect of forthcoming exhaustion of crude oil resources, used as main source of energy, especially in transportation, as well as threat to natural environment, forces search of alternative energy sources. It requires intensification of works leading to an improvement of engine and its systems aimed at improving their energetic, economical and ecological parameters. Therefore, currently the main factor stimulating development of internal combustion engines and determining their success is low adverse affect on natural environment – possibly lowest emission of toxic compounds of exhaust gases and low fuel consumption [Merkisz 2000, Mekisz *et al.* 2005, Zabłocki 2004]. One of the most important research areas, aimed at a fulfillment of requirements set for engines, is utilization of alternative plant-derived fuels, including fuels based on oily plants oil utilized as fuel for diesel engines (DE) [Szlachta 2003, Baczewski Kałdoński 2005].

Use of alternative fuel produced from oily plants' seeds, at least as good as diesel fuel but cheaper and safer for the environment, is one of the most efficient method of powering diesel engines [Williamson , Badr 1998].

It is a common practice that esters of higher fatty acids of plant oils, obtained from rape, soy or palm oil in the process of transestrification, are used as biofuel powering diesel engines. Transestrification is a process of exchanging the glycerine group by alcohol group. Alcohols which can be used in this process are: methanol, ethanol, prophanol, buthanol and amyl alcohol [Ma, Hanna 1999, Srivastava, Prasad 2000].

Currently, in industrial transestrification, methanol is used leading to formation of rape oil fatty acid methyl esters (FAME). In order to standardize quality of this source of energy European norm EN 14214:2004 was elaborated [Górski 2002].

Fatty acid ethyl esters (FAEE), during the production of which methanol is substituted by ethanol, can be considered an alternative for FAME. The reason for methanol utilization in process of estrification is low cost of its production. Methanol produced in industrial quantities is a by-product of organic-synthesis industry. However, ethanol, as a raw material used in esters production, can by obtained from renewable sources, hence it is a more environment-friendly product. Yet, its utilization is limited by its price as well as necessity, required during transesterification, of its deep dehydration (≤ 0,2% H_2O) [Graboski, McCormick 1998].

Properties of FAME and FAEE are similar and predispose both of them towards utilization as diesel engines fuel. They can be utilized as separate type of fuel along with diesel fuel or as mixture of esters and mineral diesel fuel with set amount of esters in it [Merkisz, Kozak 2003; Zając, Węgrzyn 2008]. Using mixture of esters and DF seems to be a compromise reconciling opposite expectations of producers of oily plants and fuel, car or food industry. Bearing in mind the above-mentioned aspects, it was decided that an attempt of explaining effects of rape oil fatty acid ethyl esters introduction into DF must be undertaken.

GOAL AND RANGE OF RESEARCH

The goal of this paper is determination of effect caused by type of fuel used in 2CA90 diesel engine on its work parameters. Conventional Ecodiesel Ultra F diesel fuel and its mixtures containing (by volume) 95% DF and 5% of FAME or 5% of FAEE were used in this research. Mixtures containing 5% addition of biocomponent were chosen relying on diesel fuel standards which allow 5% participation of esters in DF. Complying with these norms enables distribution of such mixtures as diesel fuel.

MATERIAL AND METHODS

The research was conducted on blends of mineral diesel fuel and rape oil fatty acids ethyl esters (FAEE) as well as methyl esters (FAME). Blends were prepared on the basis of, available in trade, diesel fuel Ekodiesel Ultra F and rape oil fatty acids methyl esters (FAME) obtained from industrial installation as well as rape oil fatty acids ethyl esters (FAEE) obtained from experimental installation. Ethyl esters were mixed with diesel fuel, proportions were set by the volume of each, and the following blends were obtained: B5 – 5% FAME, 95% ON; D5 – 5% FAEE, 95% ON.

The requirements and results of diesel fuel samples analyses are presented in Table 1. The marking of energetic parameters was performed on the test bench of the research laboratory in the Department of Power Engineering and Vehicles of University of Life Sciences in Lublin. The test bench included the following apparatuses:

- diesel engine 2CA90;
- electro whirl brake AMX 210;
- control and measurement system AMX 201, AMX 211;
- fuel consumption measurement system;
- engine's measurement system: fume's temperature t_{sp}, oil's temperature and oil's pressure p_{ol}.
- surroundings measurement system: surroundings temperature t_{ot}, atmospheric pressure and air humidity φ.

Table 1. Properties of Ekodiesel Ultra F diesel fuel, methyl and ethyl esters and their reference to PN EN 590:2006 norm [PN-EN 590:2005, Polski Koncern Naftowy 2005, Rafineria Trzebinia 2005]

Property	Unit	Requirements by norm PN-EN 590:2006	Marked value to DF	Marked value to FAME	Marked value to FAEE
Cetane number	–	min. 51,0	53,1	51	-
Cetane index	–	min. 46,0	54,0	n.d.	n.d.
Density at 15°C	$kg \cdot m^{-3}$	820-845	835	881	873
Viscosity at 40 °C	$mm^2 \cdot s^{-1}$	2,0-4,5	2,8	4,42	4,16
Distillation recovered at 250 °C, Distillation recovered at 350 °C 95%(V/V) recovered at	% (V/V) % (V/V) °C	max 65 min. 85 max 360	33 95 350	n.d.	n.d.
Flash point	°C	min. 55	61	130	60
Sulphur content	$mg \cdot kg^{-1}$	max 350	9,6	1,9	n.d.
Polycyclic aromatic hydrocarbons	% m/m	max 11	2,1	n.d.	n.d.
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C	µm	max 460	351	n.d	n.d.
Oxidation Stability	$g \cdot m^{-3}$	max 25	6,0	n.d.	n.d.
Ash content	% m/m	max 0,01	0,001	-	-
Copper strip corrosion (3 hours at 50°C)	rating	Class 1	1	1	-
Carbon residue (on 10% distillaiton residue)	% m/m	max 0,30	0,01	0,04	n.d.
Water content	$mg \cdot kg^{-1}$	max 200	65	148	80
Total contamination	$mg \cdot kg^{-1}$	max 24	11	16	8

Fig. 1 presents a diagram of the test bench containing the particular apparatuses.

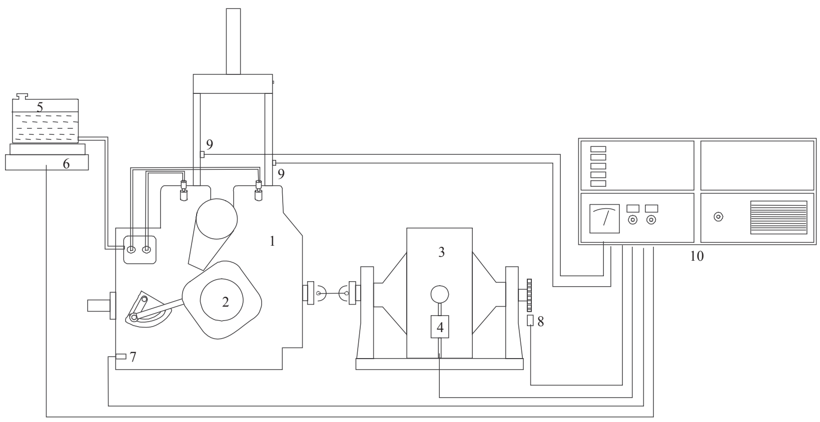

Fig. 1. Test bench diagram: 1 – 2CA90 engine, 2 – engine control, 3 – AMX 210 electro whirl brake, 4 – tensometer, 5 – fuel tank, 6 – scales for measuring fuel consumption, 7 – oil temperature sensor, 8 – engine speed sensor, 9 – exhaust emission temperature sensor, 10 – control measurement panel

Investigation of energetic parameters was based on set of measurements conducted for each of the investigated fuels with regard to PN norm, which enabled elaboration of data essential for determining external characteristics with engine's rotation speed ranging from minimal to nominal. In this research the following kinematic and dynamic parameters of engine were considered: torque – M_o, rotation speed –n, time in which set amount of fuel was used – τ. Amount of fuel used for determination of this parameter was 50 g. Methodology of measurements and methods of torque and power reductions were conformed to the following norms: PN-78/S-02005, PN-88/S-02005, BN-79/1374-03 and BN-74/1340-12.

Statistical analysis of research results embraced assessment of variation of energetic parameters, significance analysis of differences between value of these parameters and determination, based on curvilinear regression method, of function dependencies. Analysis of biocomponent addition influence on energetic parameters was conducted by means of univariate variance analysis (ANOVA), and estimation of differences significance between investigated fuels and diesel fuel by means of Tukey's least significant difference (LSD) with significance level $\alpha = 0.05$.

RESULTS AND THEIR ANALYSIS

An effect of biocomponent addition on energetic parameters was determined relying on the obtained external characteristics of the engine powered with DF and ester mixtures. Changes were than referred to characteristics prepared for engine running on DF. Results of research on FAME and FAEE addition influence on engine energetic parameters were presented in Fig. 2 a-d.

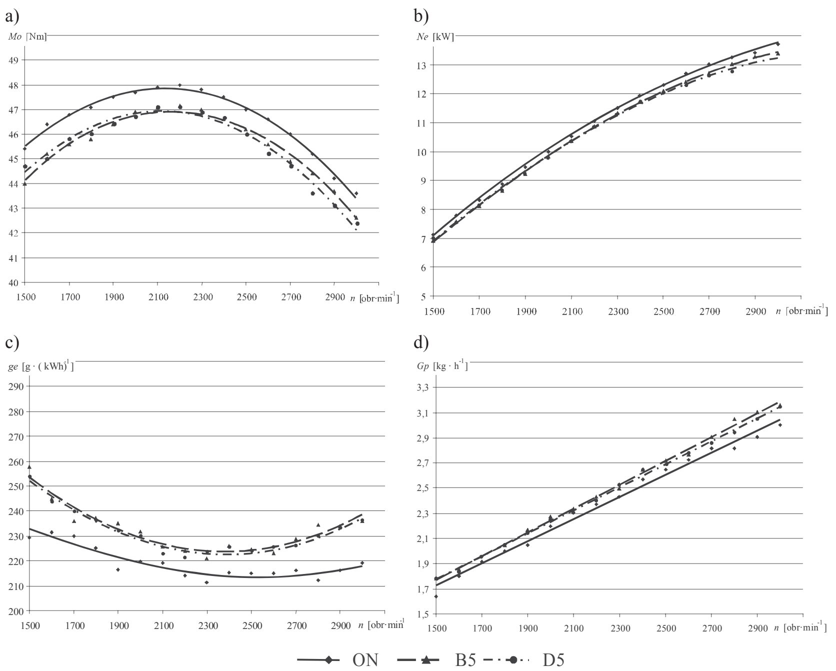

Fig. 2. External characteristics of 2CA90 engine powered with diesel fuel and blends of ethyl ester and diesel fuel: a) torque, b) power, c) unitary fuel consumption, d) hourly fuel consumption

An analysis of torque curves presented in Fig. 2a indicates that utilization of esters as an addition to diesel fuel does not cause significant changes of curves course characteristics, while torque decrease of about 2% is visible throughout the whole range of rotation speeds.

Also character of power curves course for fuel mixtures is not different from the ones obtained for DF (Fig. 2b). Using fuels enriched by biocomponent addition causes decrease of engine power, however, it is most noticeable for higher rotation speeds.

As it can be seen, in presenting changes of unitary fuel consumption, Fig. 2c, biocomponent addition into DF does not cause changes of curves course character. The shifts of curves visible in this figure result from unitary fuel consumption increase.

Curves of hourly fuel consumption for particular fuel mixtures have similar character as for diesel fuel, the only noticeable difference is their shift towards higher values, which is presented in Fig. 2d.

Statistical analysis of results of esters addition on engine torque showed that changes of torque, when compared to DF, has different dynamics. Obtained regression curves were not parallel (utilization of proper test allowed rejection of hypothesis that they are parallel) both for methyl and ethyl esters. Power, unitary and hourly fuel consumption for fuels containing esters were significantly different from ones for DF (significance level 0,05).

Regression models for torque, power, unitary and hourly fuel consumption for particular fuels were described by equations presented in Table 2, in which determination coefficient R^2 was also included.

Table 2. Regression equations for variables calculated relying on research results

Dependent variable *y*	Fuel	Regression equations	Coefficient of determination R^2
Mo [Nm]	ON	$y = -0{,}000006 \cdot n^2 + 0{,}0253 \cdot n + 20{,}848$	0,9931
	B5	$y = -0{,}000006 \cdot n^2 + 0{,}0277 \cdot n + 16{,}996$	0,9845
	D5	$y = -0{,}000006 \cdot n^2 + 0{,}0267 \cdot n + 18{,}594$	0,9754
Ne [kW]	ON	$y = 5 \cdot 10^{-10} \cdot n^3 + 2 \cdot 10^{-6} \cdot n^2 + 0{,}003638 \cdot n - 1{,}036471$	0,964398
	B5	$y = 5 \cdot 10^{-10} \cdot n^3 + 2 \cdot 10^{-6} \cdot n^2 + 0{,}003638 \cdot n - 1{,}10033$	0,990815
	D5	$y = 5 \cdot 10^{-10} \cdot n^3 + 2 \cdot 10^{-6} \cdot n^2 + 0{,}003638 \cdot n - 1{,}124681$	0,998014
ge [g · kWh^{-1}]	ON	$y = 7 \cdot 10^{-9} \cdot n^3 + 8{,}1 \cdot 10^{-5} \cdot n^2 - 0{,}257178 \cdot n + 465{,}911$	0,728238
	B5	$y = 7 \cdot 10^{-9} \cdot n^3 + 8{,}1 \cdot 10^{-5} \cdot n^2 -0{,}257178 \cdot n + 479{,}255$	0,644621
	D5	$y = 7 \cdot 10^{-9} \cdot n^3 + 8{,}1 \cdot 10^{-5} \cdot n^2 - 0{,}257178 \cdot n + 478{,}273$	0,644621
Gp [kg · h^{-1}]	ON	$y = 0{,}0009 \cdot n + 0{,}360898$	0,967544
	B5	$y = 0{,}0009 \cdot n + 0{,}453938$	0,923676
	D5	$y = 0{,}0009 \cdot n + 0{,}435303$	0,953390

As presented above, both ethyl and methyl esters cause deterioration of energetic parameters. Analysis of diagrams presented in Fig. 3a suggests that type of ester introduced into a fuel mixture does not have a significant effect on the obtained engine energetic parameters. Maximum torque obtained for FAME mixture was only 0,1 Nm higher.

Type of ester used in mixture does not have a significant effect on the obtained maximum power, which is presented in Fig. 3b. Higher values of power were observed for mixture based on FAME, and the highest observed difference reached 0,06 kW.

However, it was noted that in case of methyl esters, when hourly fuel consumption was taken into consideration, more fuel mixture was used. Yet, the observed differences were small and reached maximally 0,03 kg · h^{-1} (Fig. 3c).

When unitary fuel consumption was investigated it was noted that in case of the mixture based on ethyl ester higher values were recorded, and the highest difference reached 1,2 g · (kWh)$^{-1}$ (Fig. 3d).

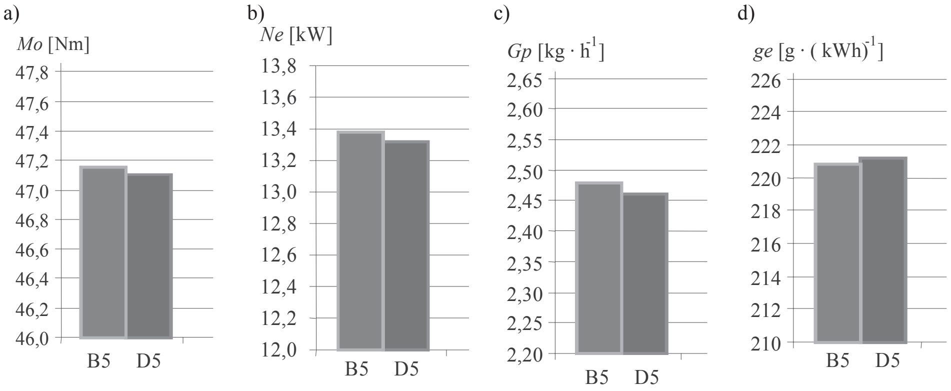

Fig. 3. Comparative analysis of FAME and FAEE addition influence on: a) maximum torque, b) maximum power, c) mean hourly fuel consumption, d) minimal unitary fuel consumption for 2CA90 engine

CONCLUSIONS

1. Utilization of fuel mixtures, containing 5% of fatty acids methyl and ethyl esters, for powering diesel engine causes change of engine energetic parameters. An analysis of results of measurements conducted on 2CA90 engine has shown that:

a) Introduction of FAME and FAEE into DF significantly affected engine effective power. Decrease of maximum power, when compared to DF, observed for FAME and DF, and FAEE and DF mixtures reached 2,8% and 3,2%, respectively.

b) Change of maximum torque for mixtures of DF and FAME, and DF and FAEE reached 1,7% and 1,9%, respectively.

c) Addition of biocomponent caused significant increase of unitary fuel consumption, which for mixtures of DF and FAME, and DF and FAEE reached 4,5% and 4,7%, respectively.

2. Research has not shown determining effect of type of ester used in fuel mixture on energetic parameters of the engine.

3. Ester fuels are characterized with other physicochemical properties than mineral fuels. It causes differences in the process of their delivery and spraying into cylinder, hence in the combustion process itself [Ambrozik *et al.* 2002]. Therefore, a wide use of esters in powering modern engines requires further engine and exploitation research concerning changes of engine work parameters, wear off of its elements, durability and reliability, determination of engine optimal settings etc.

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PORÓWNANIE WPŁYWU DODATKU FAME I FAEE DO OLEJU NAPĘDOWEGO NA PARAMETRY ENERGETYCZNE SILNIKA

Streszczenie. W pracy przedstawiono analizę wpływu mieszanin paliwowych zawierających estry etylowe (FAEE) i metylowe(FAME) oleju rzepakowego na parametry pracy silnika o ZS. Badania przeprowadzono na silniku typu 2CA90 zainstalowanym na stanowisku dynamometrycznym. Na podstawie przeprowadzonych badań stwierdzono, że zastosowanie do zasilania mieszanek paliwowych zawierających 5% estrów etylowych i 5% estrów metylowych powoduje zmianę parametrów energetycznych pracy silnika wysokoprężnego. Badania nie wykazały determinującego wpływu rodzaju estru w mieszaninie na parametry energetyczne silnika.

Słowa kluczowe: paliwa silnikowe, silnik wysokoprężny, biopaliwa.