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METHYL ESTERS OF RAPE OIL AS AN ADDITION TO DIESEL FUEL

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Summary. National Indicator Goal forces utilization of biocomponents in fuels in Poland. Minimal biofuel participation in total transportation fuel was 3,45% in 2008 and is planned to reach 4,6% of fuel energetic value in 2009. It is currently allowed to utilize diesel fuel in which volumetric participation of FAME esters do not exceed 5,0% without need to inform fuel users. Introduction of biofuel and lack of biofuel promotion causes concern of fuel users as to engines durability as well as their exploitation parameters. In this paper an analysis of 1% to 5% v/v rape oil methyl esters' (FAME) introduction into diesel fuel and its influence on diesel engine work parameters were presented. The research was conducted on a 2CA90 engine installed on a dynamometric stand.

Key words: engine fuels, diesel engine, biofuels.

INTRODUCTION

Energetic problems of the world, including ensuring proper supply of vehicle fuel, are in the group of most important determinants of future economic and social development of the world. Transport sector in the European Union utilizes 30% of total energy used. There is also a noticeable reliance on crude oil – approximately 98% of fuel is made of it. It creates problems related to energetic safety and threat for natural environment. These factors lead to a change – utilization of alternative fuels in transport stopped being a fashion and became a necessity [Bocheński Bocheńska 2008, Kupczyk 2006, Merkisz 1994].

Diesel engines are currently a dominating group of engines in land transport. They are the most efficient of all the internal combustion engines, having also great durability and reliability [Kozak, Merkisz 2007]. Traditionally, diesel fuel is used for powering them. They can also be powered with alternative biomass-derived fuels: pure plant oil or fatty acids methyl (FAME) and ethyl esters (FAEE). Currently, the most commonly used alternative fuels are fatty acids methyl esters (FAME) or mixtures of traditional diesel fuel and biocomponents. Utilization of biofuel, apart from undisputable benefits [Agarwal 2004, Baczewski, Kałdoński 2004, Uzdowski 2007, Wasilewski 2006], creates some problems among which changes in engine work parameters and necessity of new investments can be found. Moreover, limited amounts of raw material for their production might cause insufficient supply of this fuel. However, the greatest advantage of agriculture based fuels is the fact that they are environmentally friendly [Szlachta 2002, Roszkowski 2006].

National Indicator Goal forces utilization of biocomponents in fuels in Poland. Minimal biofuel participation in total transportation fuel was 3,45% in 2008 and is planned to reach 4,6% of fuel energetic value in 2009. In Poland, currently, in accordance with the Regulation of the Minister of Economy from the 19th of October 2005, regarding liquid fuels quality requirements (Dz. U. nr 216 poz. 1825) and one from the 8th of September 2006, regarding liquid biofuel quality requirements (Dz. U. nr 166 poz.1182), the following types of fuel for powering diesel engines are authorized for trade: diesel fuel which contains up to 5% of esters, fatty acids methyl esters (FAME) which are pure fuel, diesel fuel containing 20% fatty acids methyl esters. In case of pure fuel and fuel containing 20% FAME, vehicle users have got a choice, however when fuel producers add 5% of FAME into diesel fuel – there is no requirement of informing vehicle users about the presence of biocomponent. Therefore, questions concerning effects of such fuel utilization on vehicles' performance arises among vehicle users.

GOAL AND RANGE OF RESEARCH

An assessment of an influence of fuel blends, containing from 1 to 5% of rape oil methyl esters (FAME), on work parameters of an engine powered with such fuels was the goal of the presented research.

MATERIAL AND METHODS

The research was conducted on the blends of mineral diesel fuel and rape oil fatty acids methyl esters (FAME). Ethyl esters were mixed with diesel fuel, proportions were set by the volume of each, and the following blends were obtained:

B1 – 1% FAME, 99% DF blend,
B2 – 2% FAME, 98% DF blend,
B3 – 3% FAME, 97% DF blend,
B4 – 4% FAME, 96% DF blend,
B5 – 5% FAME, 95% DF blend.

The 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, which fulfils the requirements stated in PN-EN 14214 norm. Requirements and results of the diesel fuel samples' analyses are presented in Table 1.

Table 1. Properties of Ekodiesel Ultra F diesel fuel and methyl esters and their reference to PN EN 590:2006 norm [PN-EN 590:2005, Polski Koncern Naftowy 2008, Rafineria Trzebinia 2008]

Property	Unit	Requirements by norm PN-EN 590:2006	Marked value to DF	Marked value to FAME
Cetane number	–	min. 51.0	53.1	51
Cetane index	–	min. 46.0	54.0	n.d.

Density at 15ºC	$kg \cdot m^{-3}$	820-845	835	881
Viscosity at 40ºC	$mm^2 \cdot s^{-1}$	2.0-4.5	2.8	4.42
– Distillation recovered at 250 ºC – Distillation recovered at 250 ºC – 95%(V/V) recovered at	% vol. % vol. ºC	max 65 min. 85 max 360	33 95 350	n.d.
Flash point	ºC	min. 55	61	130
Sulphur content	$mg \cdot kg^{-1}$	max 350	9.6	1.9
Polycyclic aromatic hydrocarbons	% m/m	max 11	2.1	n.d.
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 ºC	µm	max 460	351	n.d
Oxidation Stability	$g \cdot m^{-3}$	max 25	6.0	n.d.
Ash content	% m/m	max 0.01	0.001	-
Copper strip corrosion (3 hours at 50ºC)	rating	No l	1	1
Carbon residue (on 10% distillaiton residue)	% m/m	max 0.30	0.01	0.04
Water content	$mg \cdot kg^{-1}$	max 200	65	148
Total contamination	$mg \cdot kg^{-1}$	max 24	11	16

Blends, after undergoing physicochemical analysis confirming conformity with PN EN 590:2006 norm, were used on dynamometric stand as fuel for 2CA90 engine in order to determine its energetic parameters.

The marking of energetic parameters was performed on the test bench of the research laboratory in the Department of Power Engineering and Vehicles of the University of Life Sciences in Lublin. The test bench included the following apparatus:

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

Fig. 1. Presents a diagram of the test bench containing the particular items of apparatus.

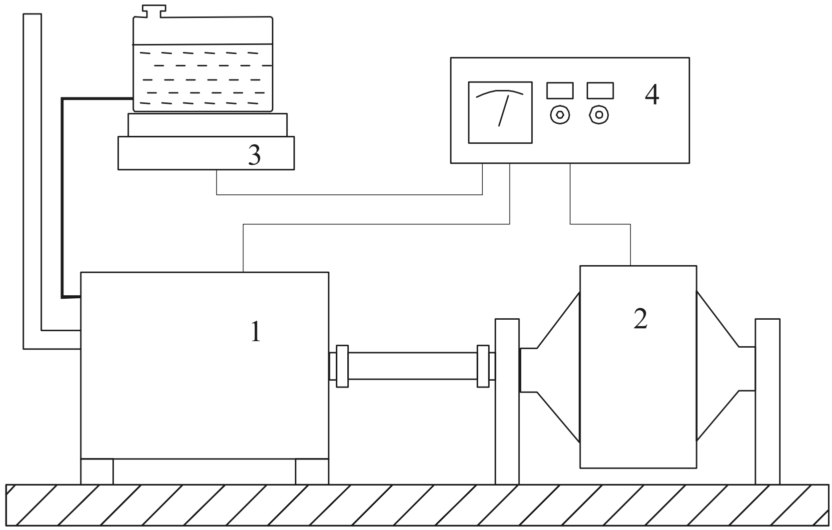

Fig. 1. Test bench diagram: 1 – 2CA90 engine, 2 – dynamometric stand, 3 – scales for measuring fuel consumption, 4– engine control and control measurement panel

Investigation of energetic parameters was based on a 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 an engine's rotation speed ranging from minimal to nominal. In this research the following kinematic and dynamic parameters of engine: torque – M_o, rotation speed –n, time in which set amount of fuel was used – τ. The amount of fuel used in the determination of this parameter was 50 g. Methodology of measurements and methods of torque and power reductions was 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 an 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. An analysis of biocomponent addition influence on energetic parameters was conducted by means of univariate variance analysis (ANOVA), and estimation of differences significance between the investigated fuels and diesel fuel by means of Tukey's least significant difference (LSD) with significance level $\alpha = 0.05$. All the statistic calculations were performed with the use of Excel and Statistica programs.

RESULTS AND THEIR ANALYSIS

Effects of methyl esters addition into diesel fuel on energetic parameters were assessed relying on external characteristics torque, power, unitary and hourly fuel consumption. Characteristics were performed for each of the fuel and the references were made to the characteristics of DF powered engine. They were referred to the characteristics elaborated during the operation of the engine powered with pure esters, however, these results were not presented in the characteristics, but used only in a relative evaluation of energetic parameters change.

An influence of ethyl esters' addition into diesel fuel on the torque, power and fuel consumption, both unitary and hourly, were presented in Figure 2a-d.

a)

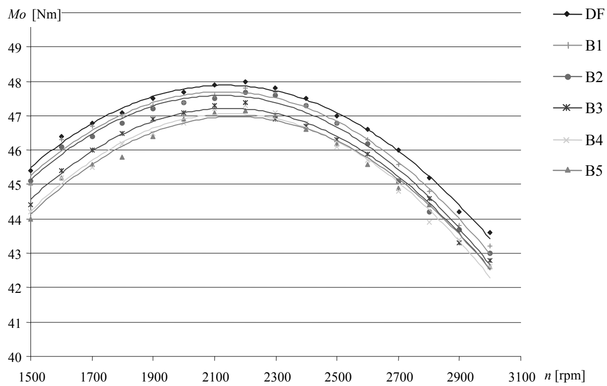

Fig. 2a. An analysis of torque curves

b)

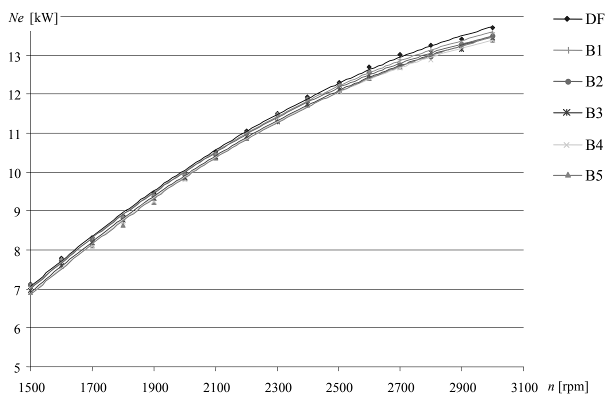

Fig. 2b. An analysis of engine power curves

c)

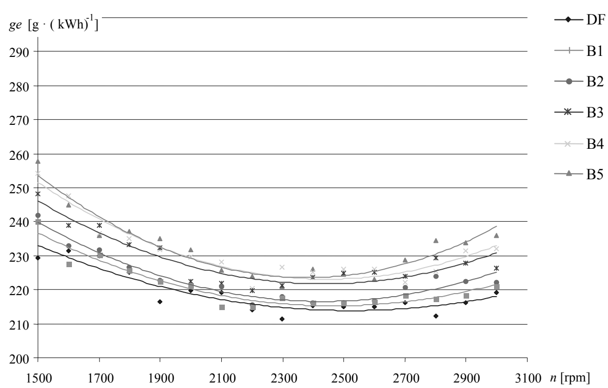

Fig. 2c. An analysis of unitary fuel consumption curves

d)

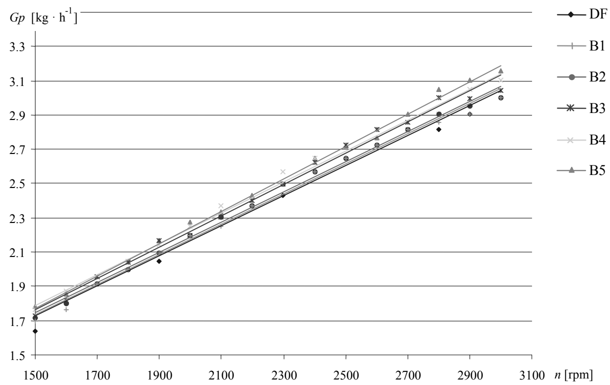

Fig. 2d. An analysis of hourly fuel consumption curves

An analysis of torque curves presented in Figure 2a shows that an addition of esters do not cause significant changes of curves course, however a decrease of torque value with an increase of biocomponent addition was noted.

For mixtures B1 and B2 and low rotational speed, to approximately 1900 rpm, the decrease of torque is small (<1%). However, differences increase with an increase of rotational speed up to approximately 1.5%. For mixtures B3, B4 and B5 the decrease of torque is noticeable in the whole range of rotational speed and reaches 1.5 and 2%, respectively.

Also the character of engine power curves for fuel mixtures do not differ from the ones recorded for DF - which was presented in Fig. 2b. An increase of ester content in a mixture causes a decrease of engine power. It must be noted that the phenomenon is most visible when rotational speeds are higher.

The curves of unitary fuel consumption presented in Fig. 2c suggest that an addition of ester into diesel fuel does not cause changes of curves' course. The presented in the picture shifts of curves towards higher values are caused by an increase of unitary fuel consumption. For mixtures B1 and B2 the increase reaches 1 and 2% and for mixtures with higher content of biocomponent, unitary fuel consumption B3 – 4%, B4 – 5%, B5 – 6%.

Curves of hourly fuel consumption for particular fuel mixtures have a similar character as those for diesel fuel. However, as presented in Fig. 2d, the curves shift towards higher values. It must be noted that changes become visible for 2% and higher addition. In case of B1 fuel, for rotational speed ranging from 1500 to 2700 rpm, curve of hourly fuel consumption corresponded with one for diesel fuel, while for higher rotational speed a difference of 3% was observed.

The statistical analysis of results of esters' addition effect on engine's torque showed that the dynamics of torque changes, when compared to DF, was characterized with variety, i.e. obtained regression curves were not parallel (utilization of proper test led to discarding hypothesis that they are parallel). It was also found, that changes of power for all the tested fuels differed from DF with significance level 0.05. Unitary and hourly fuel consumption changes were not significantly different when diesel fuel and B1 and B2 blend were taken into consideration, while in the case of B3, B4 and B5 blends differences were significant – with significance level 0.05.

Regression models for torque, power and fuel consumption, both hourly and unitary, were described with the equations presented in Table 2, in which determination coefficients R^2 were 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]	DF	$y = -0.000006 \cdot n^2 + 0.0253 \cdot n + 20.848$	0.9931
	B1	$y = -0.000006 \cdot n^2 + 0.0264 \cdot n + 19.664$	0.9866
	B2	$y = -0.000006 \cdot n^2 + 0.0270 \cdot n + 19.013$	0.9796
	B3	$y = -0.000006 \cdot n^2 + 0.0273 \cdot n + 17.938$	0.9894
	B4	$y = -0.000007 \cdot n^2 + 0.0286 \cdot n + 16.266$	0.9815
	B5	$y = -0.000006 \cdot n^2 + 0.0277 \cdot n + 16.996$	0.9845
Ne [kW]	DF	$y = 5 \cdot 10^{-10} \cdot n^3 + 2 \cdot 10^{-6} \cdot n^2 + 0.003638 \cdot n - 1.036471$	0.964398
	B1	$y = 5 \cdot 10^{-10} \cdot n^3 + 2 \cdot 10^{-6} \cdot n^2 + 0.003638 \cdot n - 1.258651$	0.966301
	B2	$y = 5 \cdot 10^{-10} \cdot n^3 + 2 \cdot 10^{-6} \cdot n^2 + 0.003638 \cdot n - 1.261531$	0.999516
	B3	$y = 5 \cdot 10^{-10} \cdot n^3 + 2 \cdot 10^{-6} \cdot n^2 + 0.003638 \cdot n - 1.214411$	0.997723
	B4	$y = 5 \cdot 10^{-10} \cdot n^3 + 2 \cdot 10^{-6} \cdot n^2 + 0.003638 \cdot n - 1.140061$	0.995931
	B5	$y = 5 \cdot 10^{-10} \cdot n^3 + 2 \cdot 10^{-6} \cdot n^2 + 0.003638 \cdot n - 1.10033$	0.990815
ge [g · kWh^{-1}]	DF	$y = 7 \cdot 10^{-9} \cdot n^3 + 8.1 \cdot 10^{-5} \cdot n^2 -0.257178 \cdot n + 465.911$	0.728238
	B1	$y = 7 \cdot 10^{-9} \cdot n^3 + 8.1 \cdot 10^{-5} \cdot n^2 -0.257178 \cdot n + 467.951$	0.826484
	B2	$y = 7 \cdot 10^{-9} \cdot n^3 + 8.1 \cdot 10^{-5} \cdot n^2 -0.257178 \cdot n + 469.928$	0.917897
	B3	$y = 7 \cdot 10^{-9} \cdot n^3 + 8.1 \cdot 10^{-5} \cdot n^2 -0.257178 \cdot n + 475.424$	0.919912
	B4	$y = 7 \cdot 10^{-9} \cdot n^3 + 8.1 \cdot 10^{-5} \cdot n^2 -0.257178 \cdot n + 477.871$	0.862449
	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
Gp [kg · h^{-1}]	DF	$y = 0.0009 \cdot n + 0.360898$	0.967544
	B1	$y = 0.0009 \cdot n + 0.368932$	0.895219
	B2	$y = 0.0009 \cdot n + 0.381609$	0.991210
	B3	$y = 0.0009 \cdot n + 0.423620$	0.966569
	B4	$y = 0.0009 \cdot n + 0.436851$	0.963562
	B5	$y = 0.0009 \cdot n + 0.453938$	0.923676

Maximal torque obtained by the engine powered with fuel mixtures was decreasing with an increase of esters' participation in them, reaching values: B1 – 47.8 Nm, B2 – 47.7 Nm, B3 – 47.4 Nm, B4 – 47.3 Nm, B5 – 47.2 Nm. The presented in Fig. 3a relative changes of torque for B1 and B2 mixtures were small and did not exceed 1%. The highest decrease of torque was noted for mixtures B5 and reached 1.77%, while for mixtures B3 and B4 it reached 1,3 and 1.5%, respectively. When the engine was powered with pure esters, the decrease reached 5%.

a)

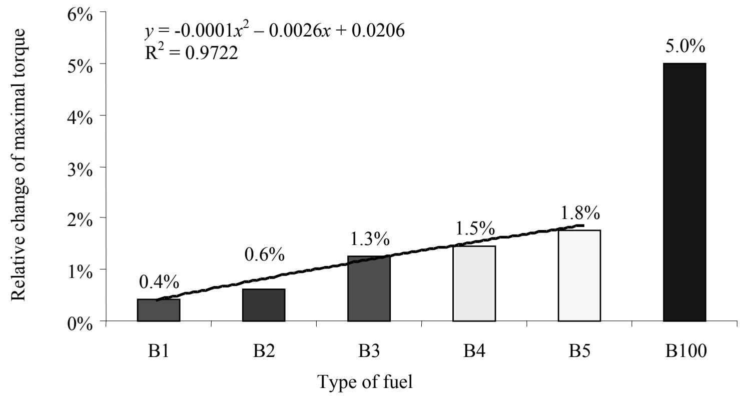

Fig. 3a. Relative changes of torque

b)

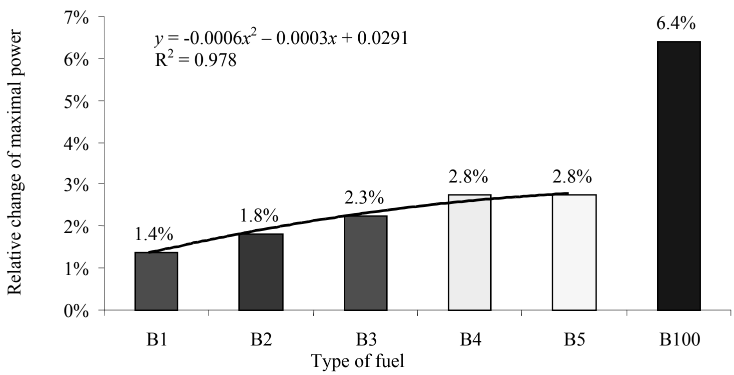

Fig. 3b. Relative changes of maximal power

c)

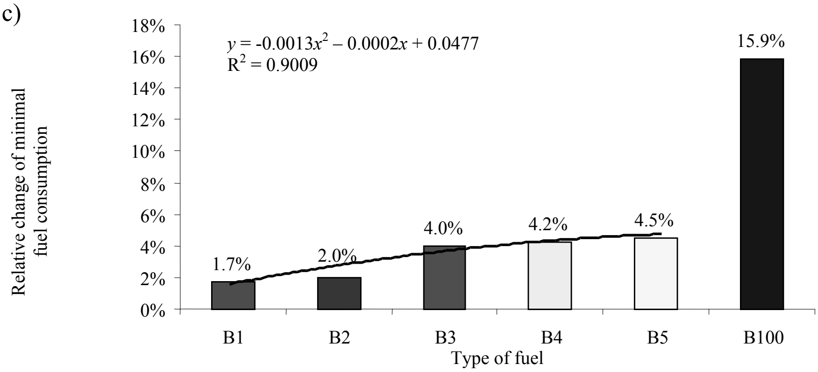

Fig. 3c. Relative changes of minimal unitary fuel consumption

d)

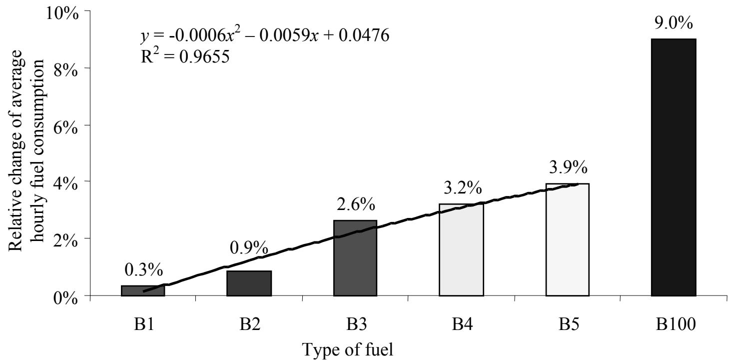

Fig. 3d. The changes of average hourly fuel consumption for mixtures compared with DF

Maximal power was decreasing with an increase of FAME volume added into the mixtures and for mixtures B1, B2, B3, B4, B5 reached 13.6 kW, 13.5 kW, 13.4 kW, 13.3 kW, 12.3 kW, respectively. Relative changes of maximal power were presented in Fig. 3b. Its analysis shows that the highest change reached 2.8% for diesel fuel containing 4 and 5% of ester. The lowest change was noted for mixtures B1 – 1,4%. When the engine was powered with pure ester the decrease of 6% was observed.

Minimal unitary fuel consumption for mixtures reached, respectively, B1 – 214.9 g · kWh^{-1}, B2 – 215.5 g · kWh^{-1}, B3 – 219.8 g · kWh^{-1}, B4 – 220.2 g · kWh^{-1}, B5 – 220.8 g · kWh^{-1}. Relative changes of minimal unitary fuel consumption were presented in Fig. 3c. The changes ranged from 1.7% for B1 mixture to 4.5% for B5, while for pure esters they reached 15.9%.

An increase of ester content in a mixture caused an increase of average hourly fuel consumption: B1 – 2.39 kg· h^{-1}, B2 – 2.41 kg· h^{-1}, B3 – 2.45 kg· h^{-1}, B4 – 2.46 kg · h^{-1}, B5 – 2.48 kg · h^{-1}. The changes of average hourly fuel consumption for mixtures compared with DF were presented in Fig. 3d. As it results from the diagram, changes for B1 and B2 mixtures are small – 0.3 and 0.9%, respectively. For fuels B3, B4 and B5 a sharp increase of 2.7, 3.2 and 4.7%, respectively, was noted. When the engine was powered with pure ester, the average hourly fuel consumption increased by 9%.

CONCLUSIONS

1. Ester fuels are characterized with other physicochemical properties than diesel fuels. It causes differences in the process of their delivering and spraying into cylinder hence in the process of combustion itself [Ambrozik *et al.* 2002]. It results in the changes of an engine's work parameters when feeded with such fuels.

2. Utilization of fuel blends containing 1-5% of rape oil fatty acids methyl esters FAME for powering diesel engine 2CA90 causes change of energetic parameters of engine work.

3. An introduction of FAME into diesel fuel significantly influenced change of effective power delivered by the engine. A decrease of maximal power for DF and FAME blends ranging from 1.4 to 2.8% was noted. Decrease of maximal Torque for DF and FAME blends ranging from 0.4 to 1.7% was noted. The torque presented a decreasing tendency with an increase of ester participation in fuel. A significant increase of hourly fuel consumption for mixtures containing 3, 4 and 5% of esters was

noted, while for mixtures containing 1 and 2% of esters no significant changes occurred. For DF and FAME mixtures average hourly fuel consumption increased from 0.7 to 3.9%. Introduction of ester caused a significant unitary fuel consumption increase. For DF and FAME mixtures a minimal unitary fuel consumption increase ranged from 1.7 to 4.5%.

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ESTRY METYLOWE OLEJU RZEPAKOWEGO JAKO BIOKOMPONENT OLEJU NAPĘDOWEGO

Streszczenie. Narodowy Cel Wskaźnikowy nakłada obowiązek stosowania biokomponentów w paliwach w Polsce. Minimalny udział biopaliw w paliwach transportowych ogółem wynosił 3,45% w 2008 na rok 2009 zakłada się 4,6% wartości energetycznej paliw. Obecnie dopuszczalne jest stosowanie oleju napędowy zawierający do

5,0% objętościowo estrów FAME bez konieczności informowania o tym użytkowników paliw. Brak szerokiej promocji biopaliw powoduje że dodawanie biopaliw wzbudza wśród użytkowników niepokój zarówno co do trwałości silników jak i parametrów eksploatacyjnych. W pracy przedstawiono analizę wpływu dodatku estru metylowego oleju rzepakowego (FAME) w ilości 1-5% v/v do oleju napędowego na parametry pracy silnika o ZS. Badania przeprowadzono na silniku typu 2CA90 zainstalowanym na stanowisku dynamometrycznym.

Słowa kluczowe: paliwa silnikowe, silnik ZS, biopaliwa.