IMPACT OF THE APPLICATION OF BIOESTERS' ADDITION TO DIESEL OIL ON THE COURSE OF TURNING MOMENT AND POWER WITHIN THE SCOPE OF LOW ROTATIONAL SPEED AT VARIABLE SETTINGS OF FUEL INJECTION

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Abstract
Combustion engines with self-ignition, are the basic source of drive in vehicles and machines. The fuel used by them is the diesel oil.
At present, the basic fuel for powering engines with self-ignition is the diesel oil of fossil origin. The increase in the use of bioesters obtained from products of organic origin, creates problems as far as correct operation of the above mentioned engines are concerned. The features of diesel oil of connate origin and of biocomponent as similar, however there occur many adverse effects. In the study there are presented the studies on the drive unit powered with the mixtures of diesel oil and fatty acid methyl esters. There was studied the course of changes of power and the turning moment within the scope of the rotational speed up to 2250 rev./min at variable injection parameters' settings. It has been established, that the addition of bioesters has an impact on lowering of power and the turning moment. Obtaining of satisfactory results is possible following adjustment of the fuel's dose and the supercharging pressure. It has been found, that the addition of bioester results in lowering of power and the turning moment, however increase of the fuel's dose and supercharging allows to obtain a similar or even a higher power and of the turning moment.

Key words: *biofuels; environment protection; turning moment; power of a diesel engine; means of transport; working machines.*

INTRODUCTION

Exhausting resources of fossil fuels and striving after limitation of CO_2 emission, result in an increasing interest in fuels of renewable origin. For diesel engines with self-ignition, the use of bioesters as a fuel, is conductive for limiting emission of CO_2 and NOx *(Hosain S. et al. 2008)*. Bioesters may be obtained from the fat of plant or animal origin, and even from fat obtained from wastes. However, production of fuels should not be a competition for food production that is why sources of bioesters from other raw materials, for ex. from algae are sought *(Lin L. 2011)*. Bioesters obtained from products of renewable origin, may have very differentiated properties. They depend on both the raw material, as well as on the technology of their processing. On the performance parameters of fuel there have the impact the following features: temperature of ignition, temperature of filter's blocking, cetane index, heat of combustion *(Hoekman K. et al. 2011)*. Moreover, the conducted studies point at lower emission of particulate solids at the time of fuel's combustion with bioesters' additive. However, a drop in power has been noticed together with the content of biocomponent (lower fuel's calorific value). It has been found in the studies, that the change of the fuel injection's beginning may be a way to maintain the power *(Monyem A. & Van Gerpen J. 2001)*. There are also analysed other manners of powering engines with self-ignition just as the use of the additive of alcohol or water emulsion to diesel oil *(Kowalski M. & Jankowski A. 2018)*. Most often, the drop of power caused by the use of the additive of bioesters to diesel oil, is proportionate or higher than the one resulting from the drop of the fuel's calorific value *(Lapuerta M. et al. 2008)*.

More and more restrictive requirements demanded from combustion engines, aim at lowering of the global emission of greenhouse gases. However, it is encountered by resistance on the side of both the producers as well as users. The willingness to maintain good performance parameters as well as high reliability result in the increase of the costs of production and servicing of combustion engines.

The rape-seed oil following treatment is one of the most popular raw material used for production of biofuels *(Uzdowski M., 2006; Uzdowski M., 2008)*.
Maintaining of a constant, high quality of fuels of renewable origin is very important, as it is one of the main factors influencing the parameters of machines and vehicles' operation *(Markiewicz-Patalon M., Muślewski M., Kaszkowiak K., 2018; Markiewicz-Patalon M., et al.,2018)*.
Low contents of bioesters in fuel do not result in occurring of bigger differences in properties of fuels as well as the effects of their use. Noticeable changes, both in physio-chemical as well as in performance properties, occur most often only with the content above 25-30% *(Markiewicz-Patalon M., Kaszkowiak K., 2017; Markiewicz-Patalon M., et al., 2017)*. For the vehicles in which engines with self-ignition are used, particularly important for the correct usage are both the maximum values as well as the course of the value of power and of turning moment, especially within the range of low and medium turning values. They influence both the fuel consumption as well as the comfort of the vehicle's handling. The purpose of the study was to determine whether it is possible to achieve satisfactory engine operation parameters in the range of low rotational speeds fed with a blend of diesel and bioester when changing the settings of the fuel injection controller.

MATERIALS AND METHODS

The tests were conducted on the chassis dynamometer type DynoTech – weight bearing, with Eddy current brake consisting of a frame, rollers with housing, measuring controller and with software. The vehicle was powered with an engine with self-ignition, supercharged, with the ignition system Common Rail. The operating parameters (maximum power and maximum moment) measured for standard settings, for an engine powered with standard fuel, differed from the ones declared by the producer. Precise, real data of the engine are presented in the table 1. That unit is commonly used both in delivery trucks as well as in passenger vehicles. Design of the engine, its fittings and the type of fuel's injection, are typical for the solutions applied at present also in units of higher power that is why it will be possible to make an attempt of the obtained results' transposition. The results obtained for the analysis purposes, consider the losses in the vehicle's mechanical elements (an engine, power transmission system).

Tab. 1 Real technical data of a power unit

swept capacity [cm^3]	1560
engine power [KM]/[kW]	102/78
maximum turning moment [Nm]	238
number of cylinders	4
diameter of a cylinder [mm]	73
piston stroke [mm]	88.3
number of valves	16
type of injection	direct, Common Rail
Supercharging	turbocompressor
filter of particulate solids	does not have

The tested engine was broken-in and fully technically efficient, air filter was replaced into a new one prior to the cycle of tests' commencement. Prior to commencement of the measurements, the engine was heated up to the temperature corresponding to average usage conditions (temperature of liquid in cooling system 85-90^{0}C). The power transmission system was efficient, had no clearances and other defects. The exhaust system was not equipped with particulate solids' filter. View of the power unit is presented in drawing 1. The power unit cooperates with the dual-mass flywheel and a turbocompressor of variable geometry, what has an impact of the engine's performance increase.

During the studies, the engine was powered with a mixture of a diesel oil (of mineral origin) and the additive of fatty acid methyl esters. The tests were conducted for pure diesel oil (fuel I) and mixture of diesel oil and the content of bioester 50% (by weight) (fuel II). The results obtained for powering engine with fuel without the additive of bioesters at factory's setting, have been assumed as the reference level.

Fuels used for powering the engine during the tests, have been assessed as far as parameters are concerned. The selected real properties of the fuels used for tests, are presented in table 2.

Tab. 2 Properties of fuel used in the studies (average values)

Feature	Diesel oil 100% (Fuel I)	50% of diesel oil and 50% of bioester (Fuel II)
Viscosity [mPa • s]	6.46	8.56
Mass density [$kg \bullet dm^{-3}$]	0.83	0,86
Cetane number	53.3	58.4
Heat of combustion [J/g]	44277	41770
Calorific value [J/g]	43097	40590

The tests were conducted in turn for pure diesel oil (fuel I) ND for fuel comprising 50% of diesel oil and 50% of bioesters (fuel II), changing in the software of the computer controlling the injection parameters (dope of fuel and supercharging). Each time, for the change of the injection's parameters settings, the disassembly of the computer was performed, and modified software was installed. There were tested the maximum values and the course of the power and the turning moment one by one for: standard settings, dose of fuel increased by 2%, dose of fuel increased by 4%, does of fuel increased by 6%. Moreover, for the dose of fuel increased by 6%, the measurement was conducted at the supercharging increased from 50 to 150 hPa. The studies were conducted one by one for fuels of the content of bioesters: 0% and 50%. Each test was repeated 10 times.
An exemplary injection map for a 2% increased fuel dose is shown in Figure 1.

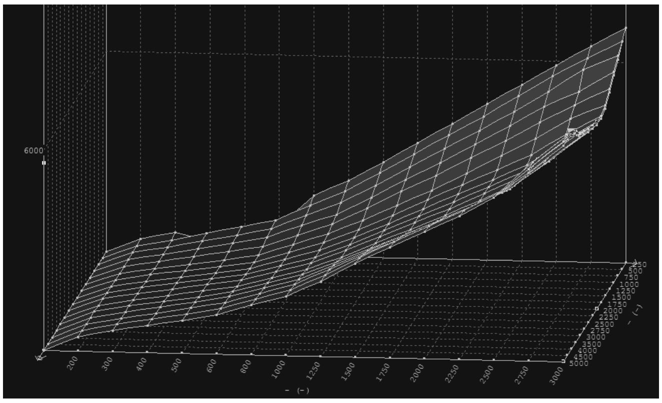

Fig. 1 Injection map for the fuel dose increased by 2%.

The view of the stand for introducing changes in the unit controlling the engine is presented in drawing 2.
The following results have been used for further analysis: powering of the engine with fuel I and at standard settings (A), for fuel II at standard settings (B), dose of fuel increased by 2%(C), dose of fuel increased by 6%(D) and supercharging increased by 50 hPa, and the dose of fuel increased by 6% and supercharging up to 150 hPa(E). The obtained results were exposed to the statistical analysis with the use of the STATISTICA programme.

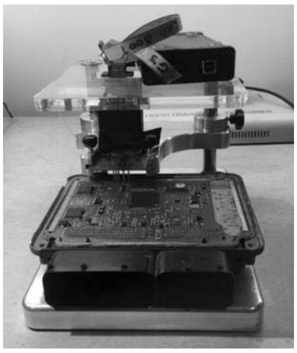

Fig. 2 The stand for the engine controller's software modification

RESULTS AND DISCUSSION

Based on the conducted tests it has been found, that in case of powering with fuel with 50% of bioesters' additive for standard settings (B), the drop of power and turning moment was observed almost within the whole scope of turning speeds with reference to the engine powered with diesel oil of mineral origin (A). The differences were statistically important and changed within the range from 0 to 18 kW. The biggest differences occurred within the scope of low revolutions (up to 1350 rev/min). Within the range of low rotating speeds 0– 2250 rev/min, the differences occurred within the whole range. Within the range from 1250 rev/min up to 2150, the differences were statistically essential (p=0,05). Similar results were observed by many researchers, including *Orliński (2013) and Kurczyński et al. (2012)*. However, no test results were found on the modification of the injection controller settings. A slight decrease in power and torque was observed by *Xue et al. (2011)*, however, their research was conducted at a lower bioester content in the fuel.

Increasing of the fuel's dose by 2% (with the use of fuel II) (C) made it possible to obtain the power not differing statistically from the power reached by the engine for the fuel I, at standard settings. Increasing of the fuel's dose by 6% and supercharging increased by 50 hPa resulted in subsequent increase of power as compared to the values obtained for fuel I and II at manufactory's settings and for the fuel II at the dose increased by 2%. The obtained mean values are presented in Fig 3. Within the analysed range it has been found, that the most favourable as far as the reached power for fuel II is concerned, is application of the increased dose of fuel and increase of supercharging by 50 hPa. It makes it possible to reach the values higher than for the remaining variants.

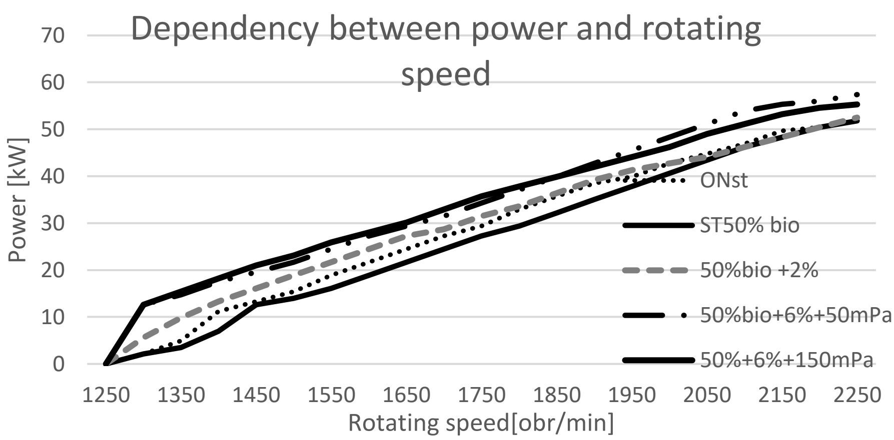

Fig. 3 Dependency of power and rotating speed for the tested types of fuels and settings of the engine work's controller.

The course of power's increase for the engine powered with fuel II at the dope of fuel increased by 6% and supercharging in turn with 50 hPa and 150 hPa, had the highest value within the range up to 2250 rev/min. Similar results were obtained by *Buyukkaya (2010)*, where the maintenance of high torque and

power required an increase in the amount of fuel supplied by about 8-9%, however in relation to the maximum values.
For these two conditions, within the range of the rotating speed up to 1850 rev/min, the power values did not differ statistically significantly between themselves. At the speed above 1800 rev/min, higher power was reached by the engine at supercharging increased by 50 hPa. The differences were statistically significant.
The engine's turning moment for the tested types of fuels and settings, had the course of a character close to the course of the power changes. The course of the changes of the turning moment is presented in fig. 4. The lowest values of the moment within the whole tested range, has been established for the fuel II at standard settings. For the scope 1350 rev/min-2250 rev/min, the difference between the value of the turning moment for an engine powered by fuel I and II at standard settings, substantially differed statistically and oscillated within the limits 10 – 66 Nm.

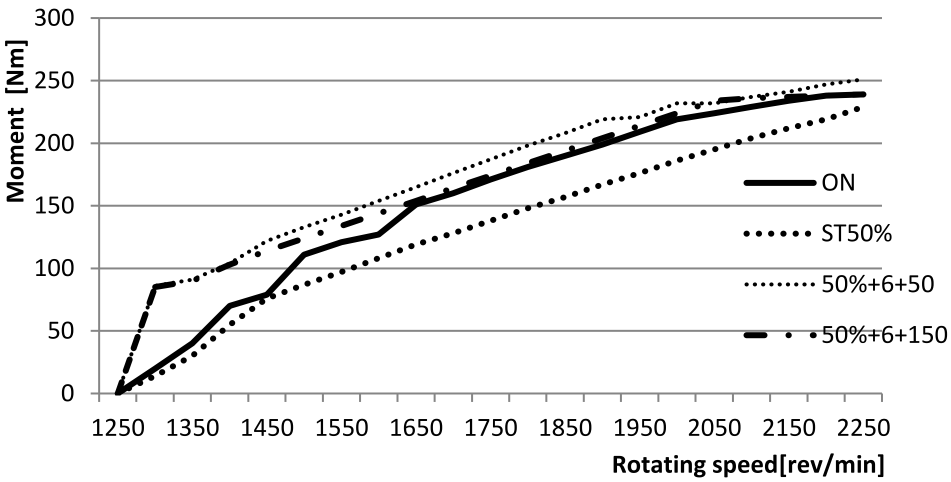

Fig. 4 Course of the turning moment's changes depending on the rotating speed for the tested types of fuel and settings of the engine's controller

A smaller power drop for the 1200-2600 rev / min rotating speed when using the addition of bioesters was observed by Adaileh and AlQdah (2012). However, the bioesters used by them in the studies were preoxidated, which increased their energy value.

CONCLUSIONS

Usage of the addition of biofuel results in reduction of power and of the turning moment. It has been established in many tests conducted in different centers. As a result of the conducted tests it has been found, that powering of the engine with fuel II (50% of bioester) caused the drop in power within the tested range of rotating speeds even by 18 kW. The decrease of power was observed within the whole tested range.
A similar drop was observed for the course of turning moment. The biggest drop in the turning moment amounted to 33 Nm. Such a big drop in power and moment, in particular within the range of lower and medium rotating speeds, shall result in worsening of the traction vehicles' properties, the engines of which are powered with such fuels.
As a result of the conducted experiment covering changes of the engine's operating parameters it has been pointed out, that it is possible to reach the engine's performance parameters not worse than while powering with fuel of connate origin. However, making changes in the manufactory's settings of the engine's operation shall be necessary. Increase of the fuel's dose by 2% as compared to the manufactory's settings (provided for fuel comprising 10% of bioester), has resulted in reaching of engine's performance not differing from the results obtained for I at manufactory's settings.
Further adjustment of the settings of the unit controlling the engine's operation has showed, that it is possible to reach values of power and turning moment higher than for standard settings in case of powering with fuel I (diesel oil of connate origin). The increase of the fuel's dose by 6% and supercharging by 50 hPa, has resulted in the increase of turning moment and power. The difference of the turning

moment for the engine powered with fuel with addition of 50% of biocomponent at standard settings (B) and the setting in which the dope has been increased by 6% and supercharging by 50 hPa (D), amounted maximally to 72 Nm (at 1300 rev/min). A similar increase was observed for the course of power. Increase of power within the range of low rotating speeds amounted from 5- 12 kW. Further increase of supercharging resulted in lowering of power and moment.

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