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EMISSIONS FROM ENGINES FUELLED WITH BIOFUELS

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Abstract

In recent years, the interest in the use of renewable fuels in transport has increased. This is due to the European Union's policy to reduce greenhouse gas emissions. These fuels, in addition to the effect of reducing carbon dioxide and the other greenhouse gases, may increase the emissions of other exhaust components. The article describes the problems of pollutants emissions from the engine exhaust system, related to the use of biofuels in combustion engines or their additives in conventional fuels. The influence of the chemical composition of selected biofuels on the emissions properties of vehicles and their engines will be discussed. The tests results of engines fuelled with selected biofuels, carried out by the authors of the article, will be presented. These tests will be carried out on chassis dynamometer and engine test bench, in standard research tests used in measurements of pollutants emissions like NEDC, ESC, ETC, etc. Furthermore, selected operational parameters of vehicles and engines will be compared with biofuels and conventional fuels.

Keywords: *biofuels, emissions, road transport, combustion engines, environmental protection*

1. Introduction

Due to the need to reduce the level of emissions of pollutants and greenhouse gases to the atmosphere, the share of renewable fuels in transport has been increased in the EU Member States. This is the result of lower emissions of carbon dioxide and other greenhouse gases for individual biofuels in the WtW (Well-to-Wheel) analysis compared to conventional fuels. On the other hand, the use of biofuels may increase the emissions of other exhaust gas components.

In order to investigate the impact of the use of selected biofuels on the pollutant emissions, three types of biofuels or biocomponents used in self-ignition engines have been considered: RME, camelina oil esters and gliperol.

Esters of higher fatty acids are obtained in various ways. Most often, this is done in the transesterification process. This process involves the exchange of chemically bound glycerine in a triacylglycerol molecule (TAG) into methyl or ethyl alcohol added in the presence of a suitable catalyst. The main product of the transesterification reaction of rapeseed oil are higher fatty acids esters (methyl ones, most often), i.e. FAME. The second product of the esterification process is glycerol, which until now has been used in a relatively small amount in others industries (e.g. in the cosmetics industry), and the remaining part represents production waste [1].

Camelina is an oily plant that has been cultivated in the past throughout Europe, but has not been widely used in recent decades because of the low yields it has had. Advances in agrotechnical technology made it possible to obtain much higher yields from camelina sativa seeds. This plant is additionally characterized by low soil requirements compared to rapeseed. Methyl esters obtained from pure camelina oil cannot be marketed as an independent biofuel for self-ignition engines due to too high iodine value and cold filter block temperature; however, it is possible to use them in low-percentage blends with diesel oil [2].

Gliperol is an ester biofuel complex composed of a mixture of glycerol esters. It is a biofuel integrating glycerol, patented by Industrial Chemistry Research Institute of Warsaw (Poland). It is composed of a mixture of three molecules of FAME and a molecule of glycerol triacetate. It can be obtained after the transesterification of a mole of TG with three moles of methyl acetate using lipases of an ion-exchange acidic resin as catalyst.

The cost of producing this biofuel is 30-35% lower than the cost of producing FAME [3], and the use of glycerine as a component of biofuel reduces the ecological risk associated with its purification and processing. During the combustion of Gliperol, less greenhouse gases (CO_2) are generated in the engine, as well as less HC than in the case of petrochemical fuel combustion or classical fatty acid methyl esters (FAME).

In Tab. 1 there are presented the physicochemical properties of rapeseed oil methyl esters (RME), camelina oil esters, and conventional diesel oil (ON).

Tab. 1. Physicochemical properties of the rapeseed oil methyl esters (RME), camelina oil esters and diesel oil (ON) [4]

Parameter tested		Unit	Diesel	RME	Camelina oil esters
Density at the 15ºC		kg/m^3	817-856	886-900	880
Cold filter plug point		ºC	-34	-8	
Kinetic viscosity in 20ºC		mm^2/s	2.9-5.5	6-9	5.18
Calorific value		MJ/kg	42.7-43.5	37.02-37.20	37.0
Cetane number		-	47.1-58.6	45-59	
Clouding temperature		ºC	-33	-3	
Ignition temperature		ºC	62	166	
Elementary analysis	C	%	86-86.4	76.6-78	
	H		13.4-14	12.1	12
	O			10-11	
Stoichiometric oxygen demand		kg_{air}/kg_{fuel}	14.57	12.5	
Impurities content		mg/kg	9	14	
Fractional content	20% distilled to the temp.	ºC		334	
	40% distilled to the temp.			336	
	60% distilled to the temp.			336	
	80% distilled to the temp.			339	
	20% distilled to the temp.			343	
	End of distillation			345	
	Up to 190ºC, gets distilled:	% (v/v)	3.0		
	Up to 190ºC, gets distilled:		59.0		
	Up to 190ºC, gets distilled:		97.0		

Particular attention should be paid to the chemical composition of fuels, especially in terms of oxygen content. The share of this element in esters, both RME and oilseed oil esters amounts to approx. 10-11%, while in diesel oil it is insignificant. This means that the use of esters in the engine should promote better selfignition and more complete combustion of esters. The calorific value of RME and camelina oil ester expressed in MJ/kg is almost 14% lower than the calorific value of diesel oil. The above-mentioned differences mean that in the engine operating at load characteristics, the engine fuelled with RME and the camelina oil esters will have a greater hourly and specific fuel consumption than the diesel engine.

2. Test results

In order to determine the effect of the type of fuel on the emission of pollutants, appropriate tests were carried out on the chassis dynamometer and engine test bench. The tests on the chassis dynamometer were aimed at determining the relationship between the ambient temperature and the emissions, and the engine tests on the measurements of specific emissions.

The scope of tests included:

– pollutant emission testing as a function of ambient temperature,
– measurement of greenhouse gases (carbon dioxide and methane) emissions as a function of the ambient temperature,
– fuel consumption as a function of ambient temperature,
– power measurements on the wheels,
– measurements of the cold starting time as a function of the ambient temperature.

The tested vehicle on the chassis dynamometer was a passenger car with diesel engine with 85 kW power and swept volume of 1995 cm^3, equipped with a Common Rail system. This vehicle met the Euro 4 emissions standard.

The tested engine was a 4-cylinder CI engine, with direct fuel injection into cylinder, with swept volume of 2637 cm^3, meeting Euro III emission standards.

2.1. Tests on a chassis dynamometer

Pollution emission tests were carried out in a low temperature chamber equipped with a chassis dynamometer according to the method set out in Directive 70/220/EEC, amended by 2003/76/EC for the type VI test. In the case of hydrocarbons measurements, the method of concentration integration in the NEDC cycle was applied in accordance with the type I test for vehicles equipped with a Diesel engine. The tests were carried out in the ambient temperature range from -15ºC to 25ºC. The results are shown in Fig. 1.

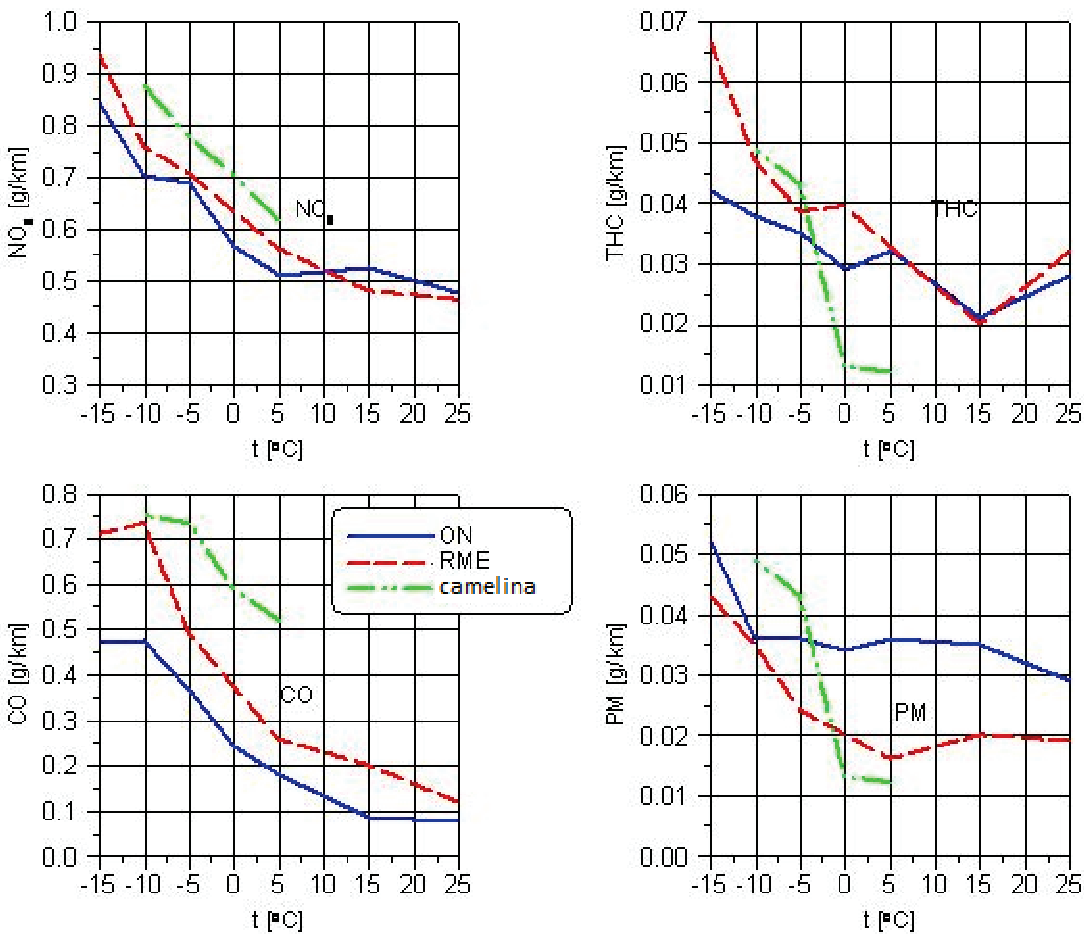

Fig. 1. Pollution emissions in the NEDC test as a function of ambient temperature

The use of RME as a fuel contributes to a significant reduction of particulate matter (PM) emissions compared to diesel oil (ON). This decrease occurs at all ambient temperatures in which tests were carried out, both in the urban and extra-urban cycle. The emission of particulate matter increases with the decrease of the ambient temperature. The average increase, however, is smaller for RME, especially at ambient temperatures from -10ºC to + 25ºC. The increase of PM emissions as the ambient temperature decreases occurs primarily in the urban cycle. The emission is approximately constant in the extra-urban cycle (Fig. 2). In the case of camelina oil esters, the emissions of particulate matters are higher at lower ambient temperatures relative to diesel oil and RME, while as the temperature rises, this emissions decrease rapidly so that at temperatures above -2ºC it is lower than in the case of diesel oil and RME.

In the case of carbon monoxide (CO), its emission when running on RME is higher than at the diesel oil, and even higher in the case of camelina esters. For this pollutant, growth occurs only in the urban cycle (Fig. 2). In the extra-urban cycle (EUDC), the emissions for running on both fuels are practically similar (close to 0). For all three tested fuels, a significant increase in CO emissions in the urban cycle was noted as the ambient temperature dropped. For example, in the case of RME, it increases from approx. 0.3 g/km at a temperature of 25ºC to approx. 2.0 g/km at -15ºC. For diesel oil, the growth is smaller. The increase in CO emission along with the temperature drop is probably caused mainly by differences in the viscosity of the tested fuels. The biofuels, characterized by higher viscosity, are worse to atomize in the process of injecting fuel into the cylinder, which makes it worse to mix with air.

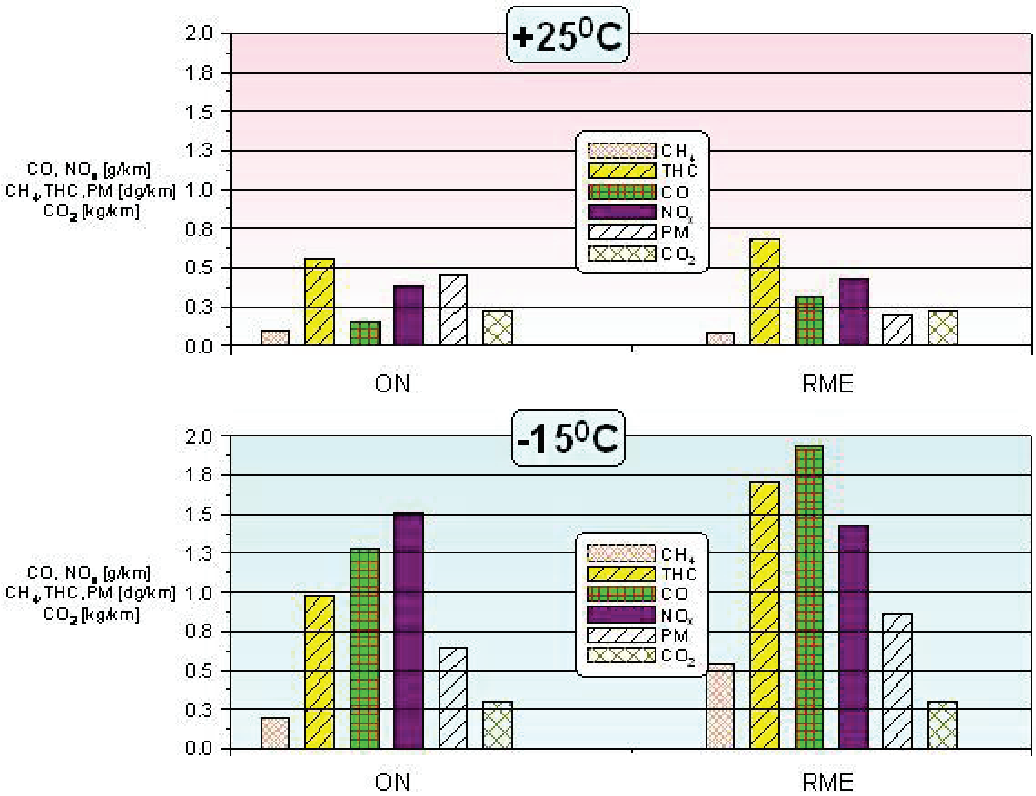

Fig. 2. Influence of ambient temperature on emission in urban test (UDC)

The emission of nitrogen oxides (NO_x) is on average higher when powered by RME. The differences are however small, generally not exceeding 15%. Under certain operating conditions, the NO_x emission, when running on the RME, was even lower than on diesel oil. In the case of camelina oil esters, the NO_x emission was higher than in the case of RME. The increase in the emission of this pollutant as the ambient temperature decreases has its source in the urban cycle, similarly as with PM and CO. For example, in the case of RME, it increases from approx. 0.4 g/km at 25ºC to approx. 1.5 g/km at -15ºC (Fig. 2). For diesel oil, the increase in NO_x emissions is similar. In the extra-urban cycle, changes in emissions as a function of temperature are much smaller.

THC emission is, on average, higher for RME, however, similarly as for NO_x, in some operating conditions its value is close to the level achieved for diesel oil. As the ambient temperature drops, the THC emission increases for all tested fuels. This increase is the smallest for diesel oil. In the case of camelina oil esters, THC emission at the lower temperatures is the highest, however, as the ambient temperature rises, this emission decreases quickly so that at a temperature of approx. -4ºC, it reaches the level lower than for other two fuels. For this pollutant, just like for CO, higher emission over the entire driving cycle for RME is mainly caused by its higher value in the urban cycle (Fig. 2). In the extra-urban cycle, the emissions for both fuels are similar.

2.2. Engine testing

In Tab. 2 there are presented the results of measurements of pollutant emissions in the selected commonly used engine emission tests. The above tests were performed for homogeneous fuels, i.e. those not being mixtures of two types of fuels (e.g. diesel oil and esters).

Tab. 2. Emission test results in the 13-phase ESC test and in the ELR test according to UN Regulation No 49, measurement with the exhaust gas recirculation switched off

Pollutant	Fuel type			
	Diesel oil	RME	Camelina	Gliperol
CO [g/kWh]	0.74	0.62	0.76	0.78
NO_x [g/kWh]	11.05	14.15	13.6	13.92
THC [g/kWh]	0.43	0.28	0.29	0.28
PM [g/kWh]	0.13	0.13	0.20	0.15
CO_2 [g/kWh]	791	754	794	745
Opacity in ELR [1/m]	0.12	0.13	–	–

In the case of RME, a decrease of CO emission compared to diesel oil was observed, as well as a significant reduction in CO_2 and THC emissions. On the other hand, in the case of NO_x, this emission increased, while the mass of PM emission remained at the same level. Camelina oil esters are characterized by lower THC emission and an increase in NO_x and PM emissions. CO and CO_2 emissions remained at a similar level. In the case of gliperol, on the other hand, it was observed that CO_2 and THC emissions were reduced, NO_x, CO and PM emissions increased, however the last two were insignificant.

The qualitative differences in the emissions of pollutants in tests on the chassis dynamometer and engine test bench should be attributed to the different engine temperature and fuel temperature during the tests. The CI engine has a tendency to increase THC and CO emissions along with a drop in temperature due to deterioration of the quality of atomisation of the injected fuel and its worse mixing with air. In engine tests, such as ESC, where an engine is warm up and the temperature of the fuel feeding the engine reaches +40ºC, the courses of fuel injection of diesel oil and biofuels are similar. Under these conditions, the decisive factor for the level of THC and CO emissions may be the presence of oxygen in biofuels, favouring better combustion of carbon and hydrogen contained in the fuel.

The fuel consumption in the NEDC test as a function of temperature was calculated on the chemical balance of the exhaust components containing carbon atoms (CO_2, CO and THC). The results are presented in Fig. 3. Analysing the course of the curves in Fig. 3, one can notice differences in the nature of the course of both curves. In the range from 0 to +25ºC, the fuel consumption for diesel oil is close to constant value, while for RME it increases systematically as the ambient temperature drops.

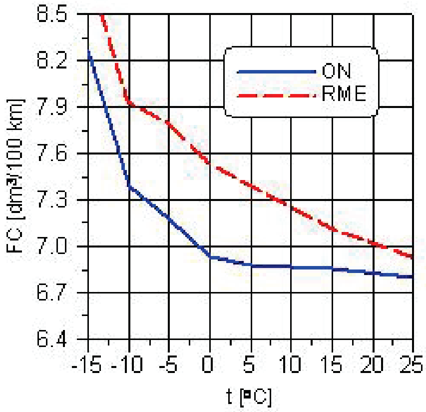

Fig. 3. Fuel consumption in NEDC as a function of ambient temperature

Figure 4 presents the loading characteristics of the tested engine fuelled with diesel oil or a blend of diesel oil with glycerine esters. The addition of glycerol esters to diesel fuel causes an increase in CO and THC concentrations in the exhaust gas with a simultaneous decrease in NO_x concentration. The use of the glycerol esters additive did not affect the CO_2 concentration. Increasing the differences in CO concentrations together with the reduction of the engine loading indicates the influence of the temperature of the charge contained in the cylinder on the quality of formation and the homogeneity of the air-fuel mixture. Deterioration of fuel atomisation affects the slowdown of heat release and, consequently, the lower NO_x emissions.

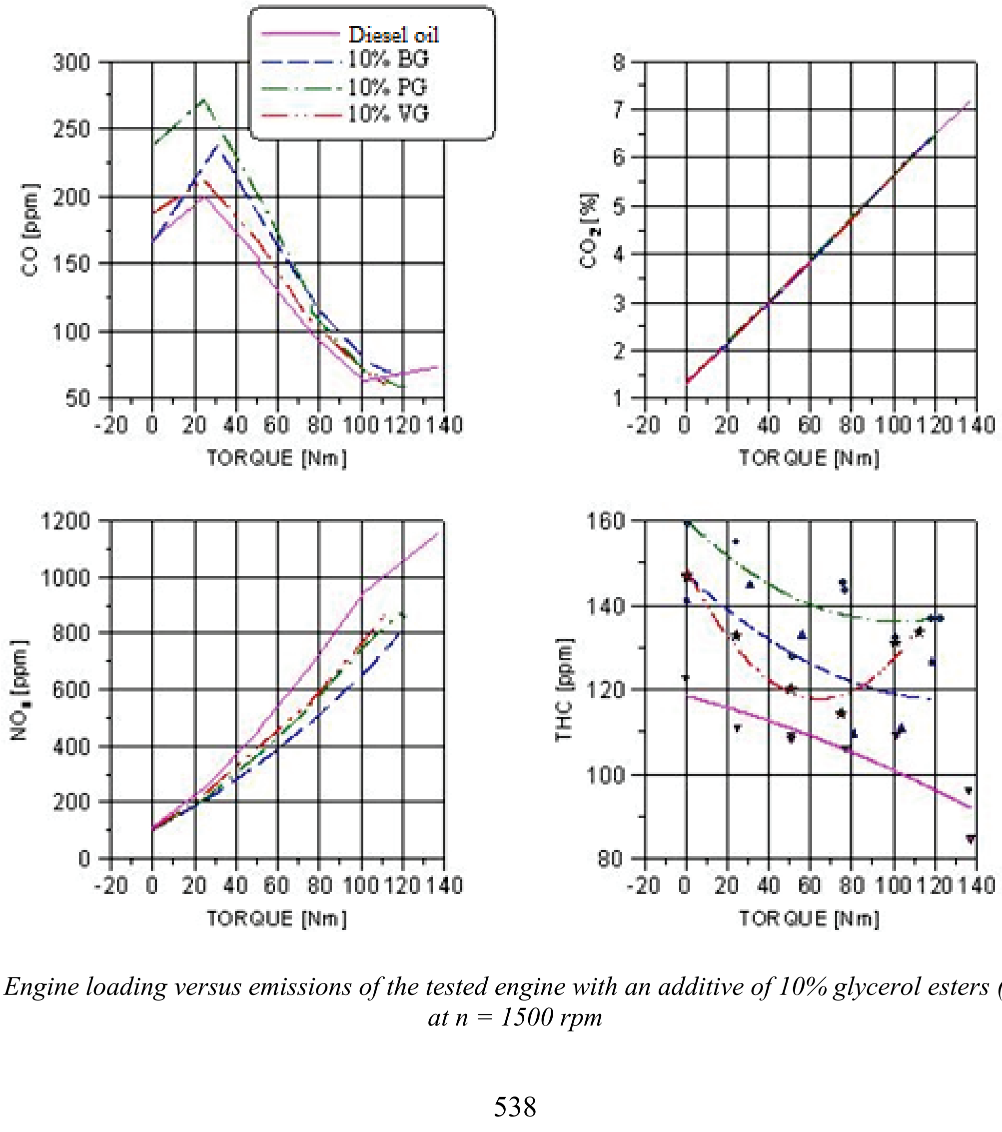

Fig. 4. Engine loading versus emissions of the tested engine with an additive of 10% glycerol esters (Gliperol) at n = 1500 rpm

3. Conclusions

1. The tests conducted have shown that the car under scrutiny running on methyl esters of rapeseed oil in comparison with Diesel fuel was characterized by higher CO, NO_x, THC, CO_2 emission and less power. At the same time, it had lower particulate matter emissions.
2. The increase in CO and THC emissions in the NEDC test together with the decrease in the ambient temperature is caused by the increased viscosity of biofuels at low temperatures, and thus by a worse atomisation of the injected fuel and its worse mixing with air.
3. Testing a warmed up engine in the ESC test showed that THC and CO emission is lower for biofuels than for diesel oil.
4. Camelina oil esters proved to be the least valuable fuel in the range of tested fuels, both in terms of pollutants emission and functional properties (poor engine start at low temperatures).

References

[1] Luque, R., Clark, J., *Handbook of biofuels production: processes and technologies*, Woodhead Publishing Limited, 2011.
[2] Orliński, P., *Ocena wpływu zmiany kąta wyprzedzenia wtrysku na proces wydzielania ciepła w silniku rolniczym zasilanym biopaliwami*, Logistyka, 3, pp. 4843-4854, 2014.
[3] *Gliperol – nowe paliwo*, Instytut Chemii Przemysłowej im. Ignacego Mościckiego: www.ichp.pl/gliperol-nowe-biopaliwo.
[4] Bocheńsk, C. I., et al., *Badania wpływu właściwości fizyko-chemicznych paliwa do silników wysokoprężnych na charakterystykę wtrysku i trwałość elementów układu paliwowego konwencjonalnego i Common Rail*, Projekt Badawczy, Nr 9TIZD00716, 2001.
[5] Żółtowski, A., Grzelak, P., *Engine testing of RME additives*, Journal of KONES, Vol. 20, No. 4, pp. 511-516, 2013.
[6] Radzimirski, S., Żółtowski, A., *Wpływ dodatku estrów metylowych oleju rzepakowego na emisję zanieczyszczeń z silnika o zapłonie samoczynnym*, Prace Instytutu Górnictwa – Naftowego i Gazownictwa, Nr 172, pp. 75-83, 2010.
[7] Gis, W., Żółtowski, A., Bocheńska, A., *Properties of the rapeseed oil methyl esters and comparing them with the diesel oil properties*, Journal of KONES, Vol. 18, No. 4, pp. 121-127, 2011.

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