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SOME PROPERTIES OF THE DI DIESEL FUELLED WITH THE FUEL FROM PLASTIC WASTE

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Summary. The researches concerning the use of fuel obtained from plastic wastes have been presented in the paper. Polyolefin's catalytic cracking have been used as the source of the fuel. Physical properties of the analysed fuel have been determined. Operational parameters of DI diesel fuelled with the tested fuel mixtures have been determined as well. Typical test equipment and brakeless test set-up with special data acquisition system was used for the tests. Speed dynamic characteristics and exhaust gas emission and smokiness for the tested fuel has been presented. The test results have been compared to the standard diesel fuel.

Key words: diesel engine, recycling, alternative fuel, dynamic test, engine characteristics

INTRODUCTION

The search for new alternative fuels, along with the necessity of searching new technology to reduce the negative environment impacts of plastic wastes, have led to the idea of studying the effect of the fuel derived from plastic wastes on combustion engine operation.

An emerging alternative for the treatment of plastic wastes is feedstock recycling, which allows the plastic residues to be transformed into chemicals and fuels. In this way, thermal and catalytic degradations have been used to convert different polyolefins into hydrocarbon mixtures. Thermal and catalytic processes of waste polymers are economically and environmentally accepted methods of their recycling [Walendziewski, 2002].

Catalytic degradation of plastic waste offers considerable advantages as compared to pure thermal degradation, as the latter demands relatively high temperatures and its products require further processing for their quality to be upgraded. Catalytic degradation occurs at considerably lower temperatures and forms hydrocarbons in the range of motor engine fuel [Masuda et al., 1999; Angyal et al., 2007], eliminating the necessity of further processing. In such a recycling process, the most valuable product is obviously liquid fuel. Although gaseous products are also useful, as their burning can contribute to the energy demand of an endothermic polymer cracking process, excess gas production is not desirable.

The presented research involved engine tests under transient conditions, which could result in the wider use of alternative fuels [Mysłowski and Mysłowski, 2006; Lotko, 2001].

TEST FUELS

The test material was PolyOlefin Catalytic Cracking fuel (POCC) and its mixtures with standard diesel fuel [Baczewski and Kałdoński, 2004] taken from public gas station (Orlen distributor net). The properties of POCC fuel and diesel fuel are presented in Table 1.

Table 1. Specification of the fuels used in the tests according to the PN EN-590 and ZN/ITN-ORLEN/NF-229/2004 standards

No	Performance characteristics	Measured value POCC	Measured value DF Verva	Requirements PN EN-590
1.	Density at temp. 15°C [kg/m3]	780	837	820÷845
2.	Physical distillation [% V]: up to 100°C distillates up to 150°C distillates up to 250°C distillates up to 350°C distillates 95% distillates up to temperature [°C]	 13.4 30.7 360	 33 96.5 344.4	 min. 65 max. 85 max. 360
3.	Cetane Index		58.1	min. 46
4.	Kinematical viscosity [mm2/s] at 40°C	1.701 (at 20°C)	3.001	2÷4.5
5.	Sulphur content [% m/m]	0.0125	0.0085	0.01
6.	Flash Point [°C]	0	75	min. 56
7.	Copper strip corrosion (3h, 50°C)	1	1	No. 1
8.	Oxidation stability [g/m3]		8	10
9.	Ash content [% m]		0.001	max. 0.01
10.	Carbon residue [% m]		0.01	max. 0.03
11.	Cloud point [°C]		-13	-
12.	Cold filter block temperature [°C]		-14	max. -20
13.	Water content [mg/kg]		70	max. 200
14.	Aromatic hydrocarbon content [% m]		1.80	max. 7
15.	Lower heating value MJ/kg	42		

The waste polymers were fed to a melter, then the preheated polymer was put into the reactor. Inside the reactor the polymers were warmed and their carbon chain cracked into shorter molecular fragments. POCC fuel was taken as product of C5 ÷ C25 hydrocarbons. The use of catalysts in the reactor decreased the temperature required for polyolefins pyrolysis and modified the product distribution. Moreover, it improved the yield of volatile products and provided selectivity in the product distribution, especially for obtaining products of great commercial interest (gasoline and monomers) [Walendziewski and Steininger, 2001; Horvat and Flora, 1999]. The catalysts activated the well-known carbocationic mechanisms for cracking the primary product molecules and the subsequent reactions of isomerization, oligomerization-cracking and hydrogen transfer [Masuda et al., 1999]. During the researches catalyst of Si/Al_2O_3 was used [Kiernicki et al., 2009].

Measurement results obtained for POCC fuel were compared to the ones for actual diesel fuel [Podniało, 2002] (in this case - "Verva" from Orlen distributor net).

TESTING METHODS

Dynamic speed characteristics of the engine [Piętak, 1990] are obtained by inertial method [Bernhardt et al., 1988]. This method is based on the measurements of engine crankshaft speed and crankshaft angular acceleration working out. When mass moment of engine inertia and crankshaft angular acceleration is known it is possible to calculate the engine torque T_e but angular acceleration is also serviceable for the purpose of comparison researches.

Functional dependencies among engine parameters in transient conditions [Kiernicki, 2004] are shown in the formula:

$$T_e = f(\omega, p_e, \alpha, \ldots, t), \tag{1}$$

where: T_e, p_e - torque and mean effective pressure of the engine, α - injection pump control element position, ω - crankshaft angular velocity, t - time.

The components of the formula have instantaneous running values dependent on time t. Torque balance under transient conditions can be noted as:

$$J_z \cdot \frac{d\omega}{dt} = T_e - T_{op}, \qquad \frac{d\omega}{dt} \neq 0, \tag{2}$$

where: T_e - running output torque, T_{op} - running torque of receiver, including resistance connected to receiver inertia, J_z - equivalent mass inertial torque of mobile engine elements in relation to crankshaft axis.

If the energy receiver is detached ($T_{op}=0$), the equation (2) will present the engine torque change caused for example by the quick increase of the fuel dose supplying the cylinders:

$$T_e = J_z \cdot \frac{d\omega}{dt} = J_z \cdot \varepsilon . \tag{3}$$

But in case of engine supply switched off ($T_e=0$), the equation (2) will present the internal resistance change during engine retardation started at high initial rotational speed:

$$T_{op} = -J_z \cdot \frac{d\omega}{dt} = J_z \cdot (-\varepsilon). \tag{4}$$

The research process was the following: for every tested fuel and engine the measurement cycle was executed. Measurement cycle included the following steps:

– engine operation at idling,
– quick increasing of engine speed (acceleration),
– engine operation at maximum speed,
– return to idling (retardation after the dosing is switched out).

Sample courses of engine free acceleration and retardation are presented in Figure 1. Rotational speed changes n=f(t) during measurement cycle are presented in Figure 1a, and crankshaft angular acceleration changes ε=f(n) during measurement cycle are presented in figure 1b. The recorded process was about 10 seconds long.

The testing of fuel properties comprised 20 measurement cycles when the engine operated without any external load. First the utmost courses were rejected and next mean value and intervals were worked out from the rest 10 (or 5) courses. The mean parameter value was calculated as:

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i . \tag{5}$$

These values were taken as representative values of the analyzed fuel mixture and used for the comparison goal.

TEST SET-UP

Motor tests consisted of the determination of engine speed operational characteristics and smokiness and composition of exhaust gases as well. Engine transient characteristics have been used there and were performed on the brakeless set-up with the digital data acquisition system [Kiernicki, 2001]. The block diagram of the test main measurement channel of set-up is shown in Figure 1.

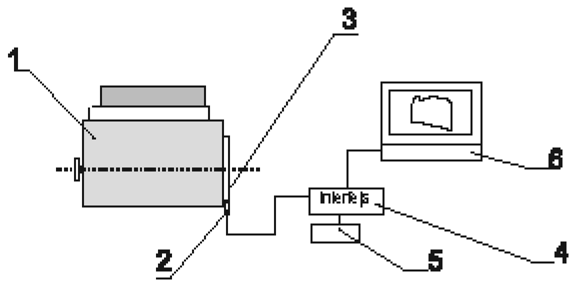

Fig. 1. Block diagram of the test stand data acquisition system: 1 – tested engine, 2 – angular velocity sensor, 3 – crankshaft angle position marker, 4 – measurement interface, 5 – interface power pack, 6 - notebook 486/33 MHz

The main component of the test set-up is the angular acceleration measurement system [Kiernicki, 2001], made at the Automotive Vehicle Department of the Lublin University of Technology. The measurement system controlled by the laptop 486/33MHz enables measuring and recording instantaneous rotational speed and determining instantaneous angular acceleration of the engine crankshaft. The signal is taken directly from the engine crankshaft. This system is used for the measuring of engine operation parameters and also for the controlling of engine running-up process.

The test bench was prepared on the basis of Ursus C-360 farm tractor which is equipped with four cylinder direct injection diesel, of S-4003 type. The clutch was disconnected so the engine worked without external load. The modified supply control system enabled a quick change of injection pump lever position. Elastic tractor wheels avoided all problems connected with engine suspension and vibrations. Environmental conditions and engine temperature were checked by the typical equipment of test house.

Exhaust gas composition was measured with Technotest meter that enables CO, CO2, HC and NOx measurements. Optical flow meter Olivier was used for smokiness measurements.

Speed dynamic characteristics were based upon unloaded engine response for step function of fuel dosage. Engine was forced to accelerate by the step change of fuel dose up to maximum value. The quick switching off the dosage caused the engine's slowing down. Thus, transient conditions of engine work adequate to engine operational characteristics were achieved [Bernhardt et al., 1988; Plint and Martyr, 1999].

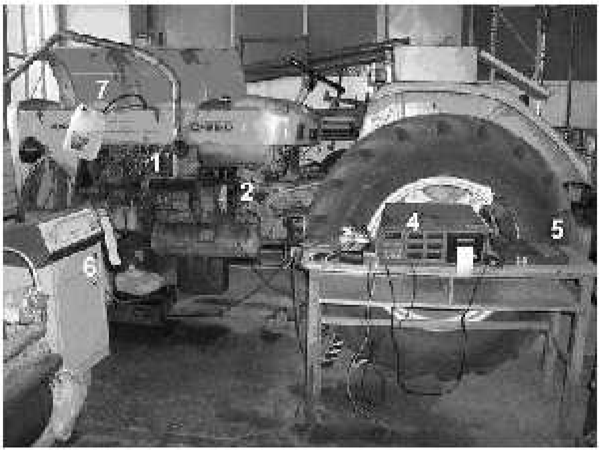

Fig. 2. The view of the test set-up: 1 – tested engine, 2 – angular velocity sensor, 3 – measurement interface, 4 – Technotest gas meter, 5 – control unit (notebook 486/33 MHz), 6 – Olivier smoke meter, 7 – changeable fuel tank

EXPERIMENTS AND TEST RESULTS

The measurements were performed in series, for each fuel successively. Each series comprised 20 acceleration-retardation cycles, executed in the same test start conditions: rotational speed (close to idle speed) and constant temperature of the motor oil and the coolant (according to the manufacturer's specifications). Engine speed and angular acceleration were automatically recorded by he measurement system. The test results were obtained as the courses of angular acceleration versus engine speed. The registered courses during engine free acceleration are shown in Figure 3.

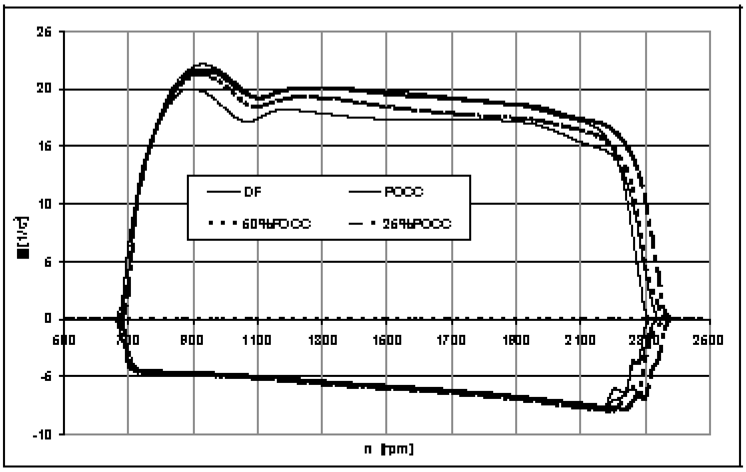

Fig. 3. Registered courses of crankshaft angular acceleration during free acceleration of S-4003 DI diesel for the tested fuels

The engine was operated without any external load during the tests. The supply system was flushed and the fuel filter was changed together with the exchange of the tested fuel. An average course obtained from the 10 closest tests was recognized as the representative one for the tested fuel.

The comparison of engine transient operation parameters enables the assessment of the effect of different fuels on engine operation. Relative values referred to the ones obtained for pure diesel fuel have been specified in order to analyze the obtained results. The changeability of angular acceleration together with fuel composition change, both for POCC fuel and diesel fuel, was determined according to the formula:

$$\Delta \varepsilon_i = \frac{\varepsilon_{iDF} - \varepsilon_{ix}}{\varepsilon_{iDF}} \cdot 100\%, \qquad (6)$$

where: ε_{ix} – angular acceleration for the analysed fuel mixture, $1/s^2$,

ε_{iDF} – angular acceleration for diesel fuel (Verva), $1/s^2$.

The results are presented in Figure 4.

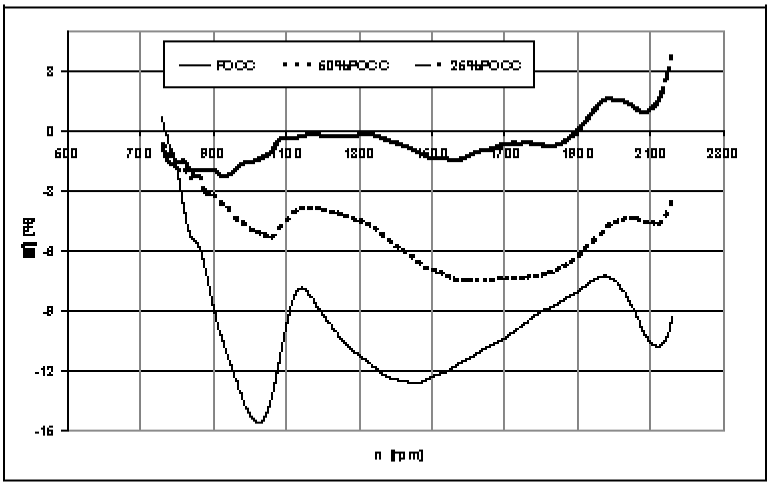

Fig. 4. Percentage differences between crankshaft angular acceleration when POCC fuel mixtures are used in the reference to standard diesel fuel (Verva)

Operational parameters (crankshaft angular acceleration) values during engine speeding up are generally lower for POCC fuel mixtures. It is caused by lower viscosity of POCC fuel in comparison to diesel fuel and worse sealing of injection pump elements. This results in smaller fuel dose. The other reason of parameter worsening was lower cetane number caused by 30% admission of light hydrocarbons. But, on the other hand, light hydrocarbons admission could improve fuel burning when the 25% POCC fuel mixture is used.

Smokiness measurements are presented in Figure 6. Absolute smoke values and smoke factor K were measured. Percentage changes of both the types of results are similar. The smokiness for POCC fuel was much lower than for the diesel fuel. The smokiness of fuel mixtures decreases with an increase of POCC fuel content.

The percentage changes of smokiness together with fuel composition change, both for POCC fuel and diesel fuel, were determined according to the formula:

$$\Delta N_i = \frac{N_{i,DF} - N_{i,x}}{N_{i,DF}} \cdot 100\%, \qquad (7)$$

where: $N_{i,x}$ – smokiness (or K factor) for the analysed fuel mixture, %,
$N_{i,DF}$ – smokiness (or K factor) for diesel fuel (Verva), %.

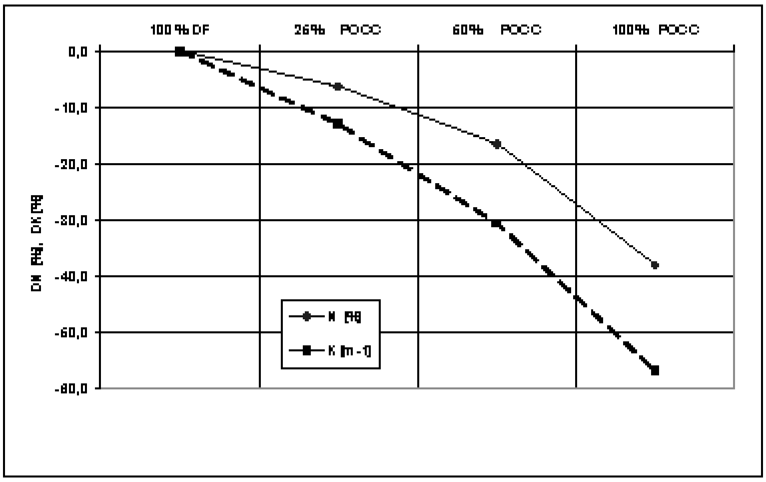

Fig. 5. Percentage changes of smoke and smoke factor K for mixtures POCC fuel and Diesel fuel during free acceleration test, measured with Olivier meter

In Figures 6-9 the changes of exhaust gas elements quantity versus PolyOlefin Catalytic Cracking fuel content in the fuel mixture with Diesel fuel are presented.

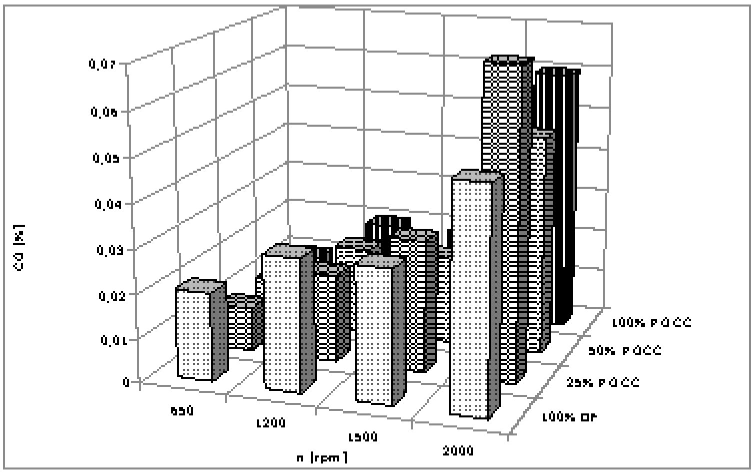

Fig. 6. Changes of CO content for mixtures POCC fuel and Diesel fuel

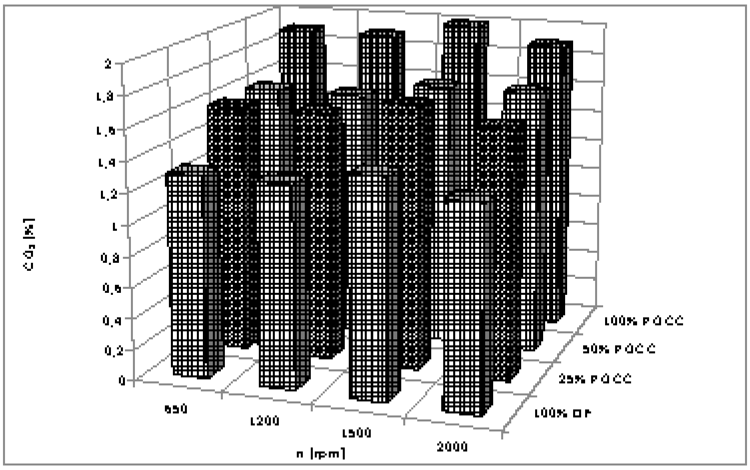

Fig. 7. Changes of CO_2 content for mixtures POCC fuel and Diesel fuel

There is a tendency towards the increase of CO_2 content in exhaust gas with the increase of POCC fuel content in mixtures POCC fuel and Diesel fuel. The level of exhaust gas elements was mostly similar to the one of diesel fuel. The abnormal or significant changes of CO, CO_2, HC and NO_x content in exhaust gas were not observed.

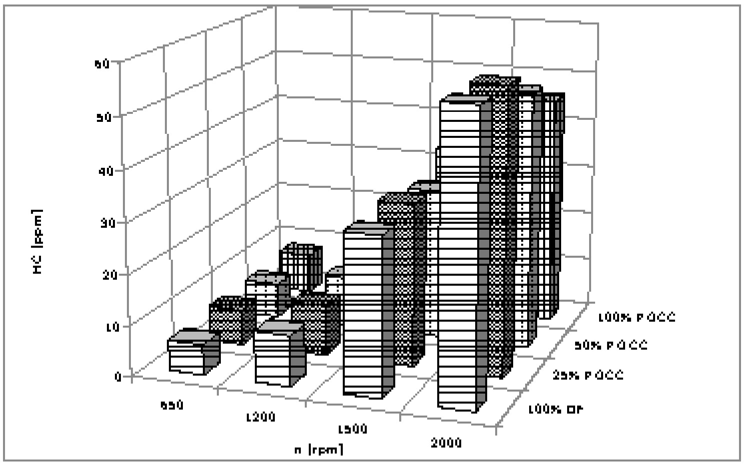

Fig. 8. Changes of HC content for mixtures of POCC fuel and Diesel fuel

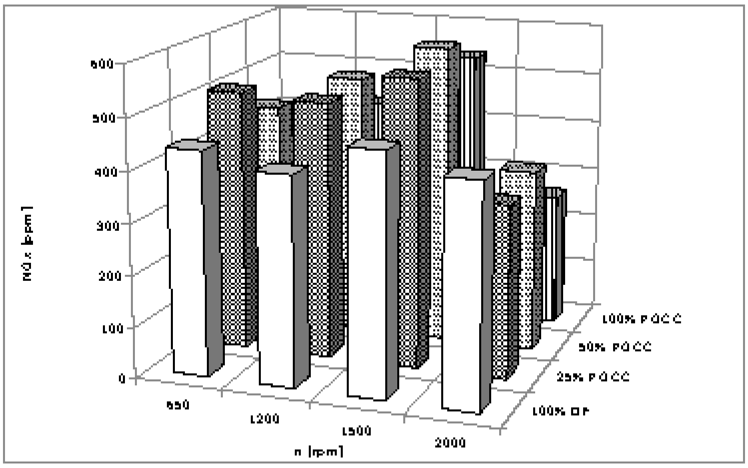

Fig. 9. Changes of NO_x content for mixtures of POCC fuel and Diesel fuel

CONCLUSIONS

On the basis of the obtained test results it may be stated that:

1. The content of POCC fuel up to 25% in the mixture with DF does not cause any significant decrease of DI engine operational parameters (torque, crankshaft angular acceleration).
2. The analysis of percentage changes of crankshaft angular acceleration show that parameter values worsens monotonically within the whole speed range with POCC fuel content growth in fuel mixture.
3. The lower level of exhaust gases smokiness for the tested POCC fuel mixtures in comparison to the diesel fuel was observed. For POC fuel the smoke level was 38% lower than for Diesel fuel.
4. The level and its changes of exhaust gas elements were similar to the ones of diesel fuel. The significant changes of CO, CO2, HC and NOx content in exhaust gas were not observed for the analyzed mixtures.
5. In the next research stage POCC fuel after separation of light hydrocarbons should be tested. This will make it possible to compare fuels that are closer with their physical-chemical properties.

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NIEKTÓRE WŁAŚCIWOŚCI SILNIKA WYSOKOPRĘŻNEGO ZASILANEGO PALIWEM Z ODPADÓW PLASTIKOWYCH

Streszczenie. W referacie przedstawiono badania dotyczące zastosowania paliwa uzyskanego z odpadów plastikowych. Źródłem paliwa był katalityczny kraking poliolefin. Określono właściwości fizyczne analizowanego paliwa. Określono także właściwości robocze silnika wysokoprężnego z wtryskiem bezpośrednim zasilanego badanymi mieszaninami paliwa. W badaniach wykorzystano bezhamulcowe stanowisko badawcze ze specjalnym systemem rejestracji danych oraz typowe wyposażenie hamowni. Przedstawiono prędkościowe charakterystyki dynamiczne silnika oraz emisję gazów wydechowych i zadymienie spalin dla badanych paliw. Wyniki pomiarów porównano z wynikami uzyskanymi dla standardowego oleju napędowego.

Słowa kluczowe: silnik wysokoprężny, recykling, paliwo alternatywne, pomiary dynamiczne, charakterystyka silnika