Comparison of energy performance and toxicity of diesel engine fuelled with diesel oil, rapeseed oil and oil mixture

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Abstract. The paper presents results of testing a diesel engine fuelled by diesel oil, rapeseed oil and the mixture of the above mentioned oils at the ratio of 50:50. The study was performed in steady state conditions of engine work for the selected crankshaft speed (1600 rpm) and constant engine load (60 Nm). To develop an ecological analysis of the diesel engine test results were presented of the emission of toxic exhaust gas components (THC, CO, NOₓ), gases considered to be greenhouse gases (CO₂), and a comparison was carried out of values of unit energy consumption. The obtained results indicate that an engine fuelled exclusively by rapeseed oil is characterised by high emissions of THC, CO, CO₂ and NOₓ, nevertheless emission decreases may be observed, which result from varying compression levels.

1. Introduction

In the past thirty years the European Union, and consequently each of its Member States, tends to pay increasing attention to usage of energy from renewable sources and to improvement of air quality. Over the years several legal acts have been adopted related to changes in this respect [1,2]. Pollution, primarily on urbanised areas, originate inter alia from transport, which to a great extent depends on crude oil. Already since the 1990s [3-5] studies have been executed on the usage of diverse unconventional fuels for diesel engines to achieve better ecological properties of selected transport means. A considerable share is constituted by studies on the usage of vegetable fuels in diesel engines [6,7]. Nevertheless results of many of them indicate that due to certain physical and chemical properties the use of pure rapeseed oil (PVO) considerably hinders the feasibility of its use as fuel in diesel engines [8]. For this reason a technology has been developed for the production of methyl esters of higher fatty acids with properties similar to standard diesel oil[9-14]. Furthermore, as has already been indicated, the usage of crude rapeseed oil as fuel entails the risk of damage to the engine [15-17].

The objective of this study was to determine the impact of rapeseed oil and mixture of rapeseed oil and diesel oil (at the ratio of 50%-50%) on energy parameters, toxicity and exhaust gas opacity as well as parameters of indicator graphs on the operation of a diesel engine as compared to diesel oil.

The studies pertained to assessing the impact of fuelling of a SB3.1 diesel engine with direct fuel injection operating at constant engine rotational speed n=1600 rpm and constant load of M₀=60 Nm. The engine was fuelled by diesel oil (ON), rapeseed oil (OR) and their mixture 50%ON+50%OR. For each of the studied fuels a change was made to the regulation parameter, and namely the commencement of fuel pumping by an injection pump (αₚ=-30,-20,-10° OWK in relation to TDC) and the structural parameter of the engine – compression level Eₚₛ = 14 and 16.
2. Methodology of analysis execution

The studies were performed on a breaking test stand with the use of a generator test bench and a single cylinder research high-speed, naturally aspirated diesel engine. The technical characteristics of the engine were presented in table 1. Measurements of toxic components of exhaust gases were conducted using measuring appliances consistent with standards ISO/CD 8178-1 and ECE-R49/2. Measurements of exhaust gas components (CO, CO2, HC, NOx), limited by the specified standards, were carried out with the use of AVL type CEB II measurement appliances.

The usage of SB3.1 engine is perfectly suited to conduct research on the combustion process and selection of fuels (including biofuels), because this system can work under varying conditions (e.g. crankshaft speed, engine load). In paper authors focused on the concentration of compounds in case of changes of commencement of fuel pumping and compression level.

The application of modern electronic power supply apparatus with a lot of adaptation and improvements, (to which authors did not have access), can give new opportunities to examine the specific fuel consumption and emissions, which depend directly from the latter. The results of article justify the need for research of reduction of the opacity of exhaust emissions and toxic ingredients.

Table 1. Technical characteristics of engine SB3.1.

| Engine type | SB3.1. |
|-------------|-------|
| Combustion system | Direct fuel injection to open combustion chamber in piston |
| Cylinder diameter | 127 mm |
| Piston stroke | 146 mm |
| Cylinder capacity | 1.85 dm³ |
| Compression degree | 15.75 |
| Rated power (for fuelling by diesel oil) | 23 kW |
| Rated rotational speed | 2200 rpm |
| Rotating direction of crankshaft | Left |
| Greasing | Closed circuit pressurised type |
| Cooling | Forced water cooling |
| Geometric fuel pumping commencement (for ON) | 27° OWK before TDC |
| Static opening pressure of injector (for ON) | 17 MPa |
| Injection pump | Pump piston, type P56-01A |
| Regulator | Type R 14V-20-110/12M |
| Injector | Type W1B-01 |
| Spray (4-opening, d=0.35 mm) | Type D1 LMK 14/2 |

3. Results

The conducted tests have shown that in all the analysed cases the smallest hourly fuel consumption was recorded for the combustion of diesel oil (ON), and the highest one – rapeseed oil (OR), while an intermediate one for the mixture of both fuels (figure 1).
Figure 1. Hourly fuel consumption of test fuels (diesel oil ON, mix 50% ON+50%OR, rapeseed oil OR), for 3 times of start pumping fuel $\alpha_p = \{-30, -20, -10\}^{\circ}$ OWK by TDC and 2 values of the compression engine $E_{ps} = 16$ and $E_{ps} = 14$.

In the studied scope of changes, the increase of the compression level (from $E_{ps} = 14$ to $E_{ps} = 16$) causes a lowering of the hourly fuel consumption. Attention is drawn here to two facts: (1) the analysed fuels have different calorific values, and for this reason the graphs do not present the general engine performance, (2) rotational speed and engine load are identical in all cases, and so the unit fuel consumption is subject to the same dependencies. In this case the increase in fuel consumption is caused by delay in fuel pumping commencement, and consequently also its injection. From the viewpoint of fuel consumption the most advantageous for the engine used in testing beginning of fuel injection for diesel oil amounts to $-27^{\circ}$ crankshaft rotations (OWK) in relation to the upper deadpoint area (TDC). The increase of engine compression level affects fuel consumption for diesel oil and rapeseed oil in a non-uniform way. In the event of early commencement of fuel pumping, assuming an increase in the compression grade from 14 to 16, the fall in fuel consumption for ON amounts to ca. 8%, and for OR –2%. In the same conditions, if fuel is pumped in later on, reduction of hourly consumption of fuel for
ON is omissible, while for rapeseed oil it amounts to ca. 5%. This means that the increase in the compression level, for later commencement times of fuel injection, is a process that is more advantageous for an engine fuelled with rapeseed oil.

![Graph showing concentration of carbon dioxide in flue gas for test fuels](image)

**Figure 2.** Concentration of carbon dioxide in flue gas for the test fuels (diesel oil ON, mix 50% ON+50%OR, rapeseed oil OR), for 3 times of start pumping fuel $\alpha_p = -30$, -20, -10° OWK by TDC and 2 values of engine compression $E_p = 16$ and $E_p = 14$.

The concentration of carbon dioxide in the exhaust gas is a parameter that has to be limited according to legal regulations adopted by the EU and in Poland. The conducted studies (figure 2) indicate that the addition of rapeseed oil to diesel oil leads to an increase in the amount of carbon dioxide emitted with the exhaust gas regardless of the time when pumping is commenced and the value of engine compression degree. This result may be due to the fact of bigger fuel consumption by the engine.

Concentration of carbon monoxide CO for diesel oil ON, rapeseed oil OR and mixture 50%ON + 50%OR and the adopted values for fuel pumping start and changes of the compression degree have been presented in a graphical way on figure 3.
Figure 3. Concentration of carbon monoxide in flue gas for test fuels (diesel oil ON, mix 50% ON + 50% OR, rapeseed oil OR), for 3 times of start pumping fuel $\alpha_p t = -30$, -20, -10° OWK by TDC and 2 values of the compression engine $E_{ps} = 16$ and $E_{ps} = 14$.

It may be seen that bigger amounts of rapeseed oil in a mixture with diesel oil are accompanied by an increase in carbon monoxide concentration. For higher degrees of engine compression and earlier beginning of fuel injection, the concentration of CO in exhaust gas is lower. It should be borne in mind that in the event of higher compression degrees the differences in CO concentration for diesel oil and rapeseed oil are much smaller than for lower values of the compression degree. As an example:
- for the compression stage of $E_{ps} = 14$ and the beginning of fuel pumping for $\alpha_p t = -10°$ OWK in relation to TDC the differences in values of CO concentration amount to as much as 123%,
- for the compression stage of $E_{ps} = 16$ and the beginning of fuel pumping for $\alpha_p t = -10°$ OWK in relation to TDC the differences in values of CO concentration amount to only ca. 40%.

It should also be borne in mind that from the viewpoint of CO emission, the delay in commencement of pumping and the start of fuel injection for rapeseed oil – in relation to engine fuelling by diesel oil –
is not advantageous, because it additionally increases disproportions between the concentration of this toxic component for diesel oil and rapeseed oil.

As a rule changes in concentration of incomplete combustion compounds are similar as changes of compounds of incomplete combustion for the use of diverse fuels in diesel engines. This provides proof for the impact of tested fuels on the concentration of non-combusted hydrocarbons – figure 4. The addition of rapeseed oil to conventional fuel – diesel oil increases the concentration of THC in exhaust gases. However in this case the delay in commencement of fuel pumping leads to reducing the emission of non-combusted hydrocarbons, contrary than for the concentration of CO. The increase in the value of compression degree affects positively the reduction of THC concentration, and – what is of particular importance – decreases differences between the concentration of unburnt hydrocarbons for diesel oil and rapeseed oil.

**Figure 4.** Concentration of THC in flue gas for test fuels (diesel oil ON, mix 50% ON+50%OR, rapeseed oil OR), for 3 times of start pumping fuel $\alpha_p=-30$, -20, -10° OWK by TDC and 2 values of the compression engine $E_{ps}=16$ and $E_{ps}=14$. 
An analysis of concentrations of nitrogen oxides in exhaust gases is of particular importance, especially for a study of diesel engines. They are one of the most toxic gaseous components of exhaust gases. For the studied conditions: diesel oil ON, rapeseed oil OR and the mixture 50%ON+50%OR and applied values of the fuel pumping start and changes in the compression degree, the NO\textsubscript{x} concentrations have been presented in a graphical way on figure 5. Naturally the growth in compression degree and hastening the start of pumping of each of the tested fuels leads to an increase in concentration of nitrogen oxides. Nevertheless it may be presumed that in the case of early start of fuel pumping $\alpha_{pt} = -30^\circ$OWK in relation to TDC the differences in NO\textsubscript{x} concentration for diesel oil and rapeseed oil are advantageously bigger than for the higher compression degree ($E_{ps} = 16$), i.e. in those circumstances a considerable reduction may be observed of NO\textsubscript{x} concentration (by ca. 20%) as compared to a 9% reduction of NO\textsubscript{x} for the compression degree of $E_{ps} = 14$.

Figure 5. Concentration of nitric oxides in the flue gas for the test fuels (diesel oil ON, mix 50% ON+ 50%OR, rapeseed oil OR), for 3 times of start pumping fuel $\alpha_{pt} = -30, -20, -10^\circ$ OWK by TDC and 2 values of the compression engine $E_{ps} = 16$ and $E_{ps} = 14$. 

![Figure 5](image-url)
4. Conclusions
Based on the executed analysis it is possible to draw the following conclusions: (1) particularly disadvantageous in a comparison of fuels (for diesel oil and rapeseed oil) is the contents of carbon monoxide and unburnt hydrocarbons in exhaust gases, (2) authors observed an advantageous impact on the value of compression degree on reducing adverse differences between the tested fuels while using rapeseed oil as an engine fuel, (3) to disadvantageous phenomena can be an increase in the contents of nitrogen oxides connected with the increase of compression degree and hastening the start of fuel injection (figure 6).

![Figure 6. Summary of study results.](image.png)

In an assessment of results of the performed analysis it may be presumed that the mixture of oils (50%ON + 50%OR) may only be used as alternative fuel for a diesel engine [16, 4, 19-21].

Furthermore it should be borne in mind that currently the Member States have undertaken preparations for the development of advanced biofuels. The European Union adopted Directive 2015/1513 [18], and one of its main assumptions pertains to limiting the share of energy generated from biofuels produced from cereal plants, other high-starch plants, sugar beets and oilseeds and plants cultivated for energy purposes on farmed areas as main cultivations, up to 7% of final energy use in the transport sector until 2020. This means a decline in the importance of first generation fuels and a reduction in their share in transport [22].

Nomenclature list
- THC – total unburned hydrocarbons
- CO – carbon monoxide
- CO₂ - carbon dioxide
NOx - nitrogen oxides
Ep - compression level
rpm - rotational speed (as revolutions per minute)
Nm - newton metre

\[ 1 \text{ N} \cdot \text{m} = 1 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} \]

TDC – top dead centre (of the piston)
°OWK - degree of crankshaft rotation angle (crank angle)
ON - diesel oil
OR - rapeseed oil

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