

A Comparison of Performance and Emissions of an Engine Fuelled with Diesel and Biodiesel

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ABSTRACT

The paper presents a comparative analysis of the operational parameters, smoke emission and the content of toxic components in exhaust gases of a compression ignition engine fuelled with fossil diesel, commercially available biodiesel (fatty acid methyl ester) and their 50%/50% blend. The study was carried out using a diesel engine equipped with an in-line injection pump used in delivery vans. An indirect injection, considerably worn engine was chosen because such engines are very often fuelled with the less expensive biodiesel. Measurements were made on an engine operated at different rotational speeds under full load as well as using the European Stationary Cycle (ESC) test. Emissions of regulated and non-regulated compounds were measured with the use of the Fourier-Transform Infrared (FTIR) analytical system, which provided concentrations of 23 exhaust gas components. The results showed that the use of commercially available biodiesel instead of diesel fuel did not considerably reduce engine performance. However, increased fuel consumption was noted. The biggest differences between the fuels were observed in the case of smoke and CO emissions, which were substantially lower for the engine fuelled with biodiesel. The study indicated that the environmental effect of the fuel used was not only different for various toxic components but also depended on engine operating conditions.

INTRODUCTION

In a large measure, research on biocomponent-based alternative fuels for compression ignition engines is oriented towards the assessment of their environmental impact [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17]. Researchers also pay much attention to engine performance and economic aspects of biofuel use as well as to the evaluation of long-term behavior and wear of engines [4,12,13]. A general

conclusion drawn from the literature is that the use of biodiesel decreases engine performance, but, on the good side, it reduces all regulated toxic exhaust gas components, excluding nitrogen oxides [3,4,5,6,7,12,13,14,16,17]. Nevertheless, it should be mentioned that in many cases authors report contrasting results [2,10,15]. Among unregulated compounds of exhaust gas, polyaromatic hydrocarbons (PAH), aldehydes and aromatic hydrocarbons (AHC) are the most often discussed in the literature [3,4,6,7,13]. A majority of researchers have observed some decrease in PAH and AHC emissions and an increase in aldehydes emissions when using biodiesel. However, many of them acknowledged that the results were not sufficiently clear and depended on fuel, engine and test conditions or found that the differences were insignificant [4,6,7,13].

In Poland, similar to other European countries, biodiesel is available at petrol stations. This fuel is manufactured mainly from rapeseed methyl ester (RME). Its marketability due to lower prices in comparison to fossil diesel is quite high, and large numbers of customers, mainly those driving older vehicles, use this fuel. Owners of new and modern engines use biodiesel much less often because they are afraid of its long-term effects on their engines and problems with warranty - connected with some resistance from car manufacturers.

In this paper, operational and emissions parameters of an engine fuelled with fossil diesel, commercial biodiesel and their blend were compared.

EXPERIMENTAL SET-UP AND TESTING PROCEDURE

The tests were conducted on a 4-cylinder, naturally aspirated diesel engine with displacement of 2.4 dm³ and power of 51.5 kW delivered at 4200 rpm. The engine had a combustion

chamber with a pre-chamber and in-line injection pump. The injection pump settings were constant for all tests, i.e. it was not adjusted according to different physical properties of investigated fuels. The engine was considerably worn and was not equipped with an exhaust aftertreatment system. The reason for choosing an older-design, worn engine for the experiments was the fact that such engines are the most often fuelled with less expensive biodiesel.

Tests were run in scope of performance, fuel consumption, smoke emission and emission of toxic components of exhaust gases on an engine fuelled with fossil diesel (D 100%), biodiesel (B 100%) and their blend with 50% mass fractions of the two components. Both fuels were commercially available and were supplied by one oil company. The used diesel fuel was ultra low sulphur diesel sold under the trade name of Ekodiesel Ultra F4.8 and used biodiesel was sold under the trade name of Bioester B 100 (F). [Table 1](#) shows selected parameters of the investigated fuels.

(See [Table 1](#) after last section of paper)

The engine was operated at full load (fuel dose set to maximum) and several rotational speeds and under an ESC steady-state test cycle [18]. The experiments were conducted on an engine test bench equipped with an eddy-current dynamometer. Fuel consumption was measured with AVL Dynamic Fuel Balance. Smoke emission was measured with the AVL opacimeter type Smoke Meter 437. The composition of exhaust gases was determined with the use of the AVL SESAM FTIR (Fourier Transform Infrared) multi-component gas analytical system. The device used a scanning Michelson interferometer. Spectra of infrared light absorbed by a gas sample were recorded in a wavelength range of 700 to 4000 cm^{-1} with an optical resolution of 0.5 cm^{-1} . The concentrations of 23 different exhaust gas components could be measured simultaneously. In the range of unburned hydrocarbons and nitrogen oxides, the contents of individual chemical compounds were analyzed.

Exhaust gas was delivered to the measurement chamber of the interferometer with the use of a heated lines system and a 4-way heated sample selection unit with a ceramic heated filtering element. The heated gas sampling system worked at a constant temperature of 185°C. The recorded spectra were compared with spectra obtained from ambient air, dried and filtered from carbon dioxide, flowing through the filter and the sampling lines. This excluded the influence of deposits in the filter and the sampling lines. The sampling rate of the gas analytical system was below 1 second. An average of the results recorded during 30 seconds was adopted as a result of a single measurement.

[Table 2](#) shows a list of compounds the molar fractions of which were determined in the experiments. The molar

fraction of total hydrocarbons (expressed as the number of carbon atoms) was calculated as a weighted sum of all the measured hydrocarbons from the following equation:

$$x_{\text{HC}} = x_{\text{CH}_4} + 2x_{\text{C}_2\text{H}_2} + 2x_{\text{C}_2\text{H}_4} + 10x_{\text{C}_8\text{H}_{18}} + 7.5x_{\text{C}_7\text{H}_8} + 3x_{\text{C}_3\text{H}_8} + 2x_{\text{C}_2\text{H}_6} + 3x_{\text{C}_3\text{H}_6} + 4x_{\text{C}_4\text{H}_6} \quad (1)$$

whereas the molar fraction of nitrogen oxides was calculated from equation:

$$x_{\text{NOx}} = x_{\text{NO}} + x_{\text{NO}_2} + 2x_{\text{N}_2\text{O}} \quad (2)$$

where x_i were molar fractions of the individual exhaust compounds.

(See [Table 2](#) after last section of paper)

The analyzer provided the concentrations of the individual components in the exhaust gas in ppms. Molar masses of the components necessary for recalculating the molar fractions (ppm) to specific emissions (g/kWh) are given in [Table 2](#). In the case of smoke emission, which was recorded in 1/m, the results of measurements were divided by brake power.

RESULTS

ENGINE PERFORMANCE

[Figure 1](#) presents engine performance and fuel consumption versus rotational speed at the maximum position of the injection pump lever. Fuel consumption (mass flow rate) of biodiesel was 6% higher than the consumption of fossil diesel. This was mainly a result of the 5% higher density of biodiesel. The differences in fuel consumption increased with rotational speed (from 3% at low speed to 9% at the highest rotational speed), which could be ascribed to the injection pump characteristic and higher viscosity of biodiesel.

Engine torque and power were about 3% lower for biodiesel, despite a higher mass of the injected fuel. As a result, brake specific fuel consumption of the engine fuelled with biodiesel was, on average, 9% higher. Such results are consequences of, on average, 10% lower heating value of biodiesel in comparison to diesel. Calculated overall efficiencies of the engine were practically the same for all tested fuels. The exception were efficiencies on biodiesel at low rotational speeds, which were of several percent higher than on the other two fuels. The following calorific values were assumed for this calculations: 42.7 MJ/kg for diesel, 37.6 MJ/kg for biodiesel and the mean of these two values for the blend.

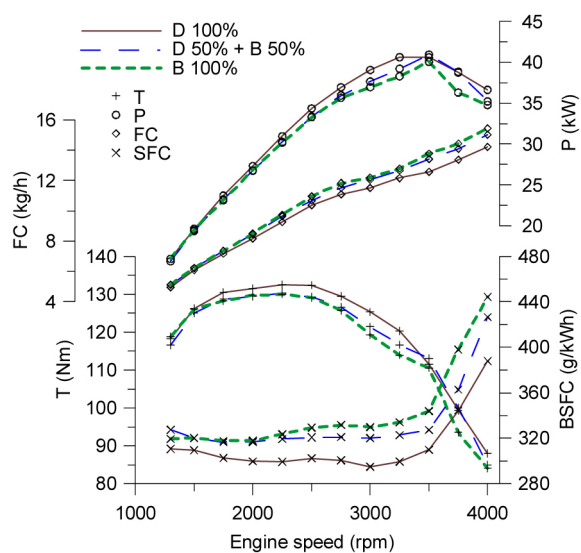


Fig. 1. Torque (T), power (P), fuel consumption (FC) and brake specific fuel consumption ($BSFC$) vs. rotational speed

EMISSION AT ENGINE FULL LOAD

Fuelling of the engine with pure biodiesel (B 100) reduced smoke emission, which in the range of low rotational speeds was, on average, three times smaller and at higher speeds several percent smaller than for fossil diesel fuel (Fig. 2). Considering the substantial difference in exhaust opacity, it can be assumed that, at the same torque - achieved by increased mass of biodiesel injected, smoke emission would be lower for biodiesel than for fossil diesel. Smoke emission of the engine fuelled with a blend of diesel and biodiesel was also much lower than one obtained with the use of neat fossil diesel.

Reduced smoke emission at low and medium speeds can be an effect of oxygen content in biodiesel fuel. It resulted in increase of oxygen excess in air-fuel mixture. It should be noticed that this benefit was observed for both biodiesel and its blend with fossil fuel. Considering that factory settings of the injection pump provided relatively high mass of fuel injected, even small addition of oxygen in the blend of fuels resulted in substantial reduction of exhaust opacity. However, due to injection pump delivery rate characteristic, at higher rotational speeds mass of fuel injected was reduced, thus higher oxygen excess for all fuels appeared. Emission of CO and its relation to rotational speed (Fig. 2) was similar to smoke emission. It proves hypothesis that the emissions benefits at low and medium speeds are most likely to be oxygen excess dependent.

Emissions of nitrogen oxides were, on average, 17% higher for the engine fuelled with biodiesel than for the one fuelled with diesel within the entire range of engine speeds. NO_x

emissions for the blend were in-between those for neat diesel and biodiesel (Fig. 2).

In the case of unburned hydrocarbon emissions, the results were not clear. In the range of small rotational speeds, HC emissions seemed not to be fuel-related. However, in the range of high speeds, HC emissions from the engine fuelled with biodiesel were considerably higher in comparison to those from the engine fuelled with diesel fuel and the blend. In the range of medium speeds, the lowest HC emissions were obtained when the engine was fuelled with the blend of diesel and biodiesel (Fig. 2).

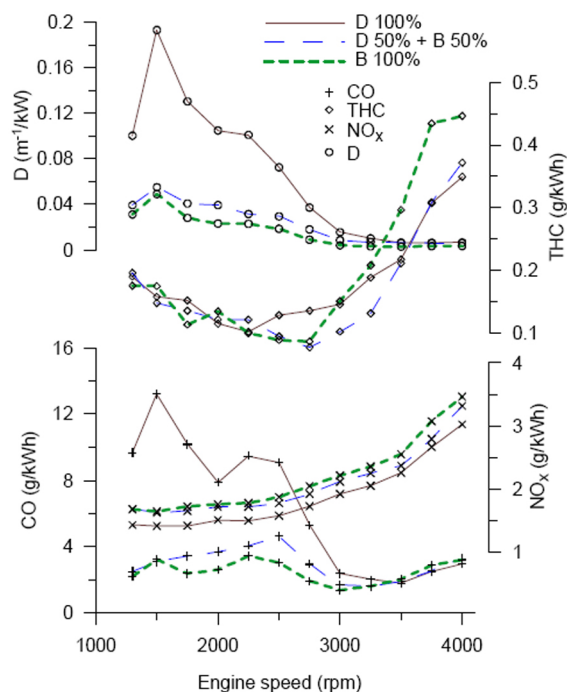


Fig. 2. Emissions of smoke (D), carbon monoxide (CO), unburned hydrocarbons (THC) and nitrogen oxides (NO_x) for fuels tested at full load

An analysis of the effect of the fuel used on emissions of particular hydrocarbons (Figs. 3 and 4) showed that ethylene (C_2H_4) and n-octane (C_8H_{18}) had the largest contribution to THC, and emissions of both were higher on biodiesel. Lower emissions with biodiesel were observed only for 1,3-butadiene (C_4H_6) and slightly lower, but only in the range of low and medium speeds, for propylene (C_3H_6). In the case of the other determined hydrocarbons, including AHC represented by toluene, no distinction could be made between the fuels. Emission of ethane was extremely low and was not presented in the figures.