COMPERATIVE ANALYSIS OF EMISION FROM ENGINE FUELLED WITH DIESEL AND BIO-DIESEL

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Abstract

The paper presents comparative analysis of operational parameters, smoke emission and toxic components contents in exhaust gases of a compression ignition engine fuelled with fossil diesel, commercial bio-diesel (fatty acid methyl ester) and their blend. Measurements were conducted on an older generation diesel engine equipped with in-line injection pump. Engine was operated in conditions of full load rotational speed characteristic and also ESC steady-state test cycle. Fourier Transform Infrared (FTIR) analytical system provided contents of 23 exhaust gas components.

In particular chosen parameters of investigated fuels (on the base of quality reports), performance and fuel consumption characteristic versus rotational speed, smoke emission (D) and content of carbon monoxide (CO), unburned hydrocarbons (THC) and nitrogen oxides (NO_x), sulphur dioxide (SO_2) and carbon dioxide (CO_2) in exhaust gas of the engine fuelled with investigated fuels, emission of specific hydrocarbons of the engine fuelled with investigated fuels, of non-regulated compounds measured during the research, molar mass of analyzed exhaust compounds are presented in the paper.

Keywords: *diesel engine, alternative fuel, bio-diesel, exhaust emissions*

1. Introduction

In large measure research of the alternative fuels for compression ignition engines based on bio-components are oriented towards assessment of their environmental impact. Researchers put a lot of effort into economic aspects of bio-fuels application as well as evaluation of performance and durability of the engines [1, 2, 8-10]. On the base of the literature studies one general conclusion can be drawn that use of bio-diesel decreases engines performance, however enabling to reduce all toxic exhaust gas components, excluding nitrogen oxides [3-5, 7]. Nevertheless, it should be mentioned that numerous quantitative results presented in the literature not only differ but also they are often in contradiction.

In Poland, similarly to other European countries, since some years ago bio-diesel fuel is available in petrol stations. Bio-diesel is manufactured mainly on the base of RME (Rapeseed methyl ester). Its marketability due to lower prices in comparison to fossil diesel causes that large number of customers, mainly those driving older vehicles are using this fuel.

In this paper operational and ecological parameters of the engine fuelled with fossil diesel, commercial bio-diesel and their blend were compared. As an object of the research older design of the engine from domestic manufacturer was chosen.

2. Method of research

The research was conducted on 4-cylinder, naturally aspirated diesel engine with displacement of 2.4 dm^3 and power of 51.5 kW delivered at 4200 rev/min. The engine had combustion chamber with pre-chamber and in-line injection pump. The engine was considerably worn. Before the experiments injection pump was not regulated. The purpose of choice of this object of the research (older design, worn engine) was the fact that such engines are the most often fuelled with less expensive bio-diesel.

The research were conducted in scope of performance, fuel consumption, smoke emission and exhaust toxic components emission of the engine fuelled with fossil diesel (ON 100%), bio-disel (B 100%) and their blend with mass fractions of the two components 50%. Both fuels were commercially available and were supplied by one oil company. Tab. 1 presents chosen parameters of investigated fuels.

Tab. 1. Chosen parameters of investigated fuels (on the base of quality reports)

Lp.	Parameter	Unit	Fuel	
			ON Ekodiesel Ultra F4.8	Bioester B 100 (F)
1	Density at 15°C	kg/m^3	838.8	883
2	Kinematic viscosity at 40°C	mm^2/s	2.736	4.47
3	Cethane number	–	51.6	51
4	Flash-point	°C	65	130
5	Carbon residue from 10% of distillation residue	%	0.013	0.13
6	Sulphur content	mg/kg	6.32	4.7
7	Water content	mg/kg	75.8	117
8	Total impurities	mg/kg	11.1	17
9	Corrosive effect on Cu plates (3h at temp. 50 °C)	–	class 1	Class 1
10	Temperature of cold fuel filter blockage	°C	-32	-23
11	Content of fatty acid methyl esters (FAME)	% (m/m)		97.3

The engine was operated in conditions of full load rotational speed characteristic (fuel dose set to maximum) and ESC steady-state test cycle [11].

The research was conducted on an engine test bench equipped with eddy-current dynamometer Zollner type Alpha 240. Fuel consumption was measured with AVL Dynamic Fuel Balance. Smoke emission was measured with AVL opacimeter type Smoke Meter 437.

Determination of exhaust gas composition was done with the use of AVL SESAM FTIR (Fourier Transform Infrared) multi-component gas analytical system. The device used scanning Michelson interferometer. Spectra of infrared light absorbed by gas sample were recorded in range of wave number from 700 to 4000 cm^{-1} with optical resolution of 0.5 cm^{-1}. Contents of 25 different exhaust gas components could be measured simultaneously. In the range of unburned hydrocarbons and nitrogen oxides contents of separate chemical compounds were analyzed.

Exhaust gas was delivered to the measurement chamber of the interferometer with the use of heated lines system and 4-way heated sample selection unit with ceramic heated filtering element. The heated gas sampling system was working in constant temperature of 185 °C. Recorded spectra were compared with spectra obtained from ambient air dried and filtered from carbon dioxide flowing through the filter and the sampling lines. It allowed excluding influence of deposits in the filter and the sampling lines. Sampling rate of the gas analytical system was below 1 second, however considering sample delivery time, response time was about 3 seconds.

Table 2 presents list of compounds which molar fractions were indicated during the research. Molar fraction of total hydrocarbons (as number of carbon atoms) was calculated as weighted sum of all measured hydrocarbons from following equation:

$$\tilde{x}_{HC} = \tilde{x}_{CH_4} + 2\tilde{x}_{C_2H_2} + 2\tilde{x}_{C_2H_4} + 10\tilde{x}_{C_8H_{18}} + 7.5\tilde{x}_{C_7H_8} + 3\tilde{x}_{C_3H_8} + 2\tilde{x}_{C_2H_6} + 3\tilde{x}_{C_3H_6} + 4\tilde{x}_{C_4H_6}, \quad (1)$$

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

$$\tilde{x}_{NO_x} = \tilde{x}_{NO} + \tilde{x}_{NO_2} + 2\tilde{x}_{N_2O}, \quad (2)$$

where $\tilde{x}_i$ are molar fractions of specified exhaust compounds.

Tab. 2. Names, chemical symbols and molar mass of analyzed exhaust compounds

No.	Name of compound	Chemical symbol	Molar mass $\left[\frac{g}{mol}\right]$
1	Nitrogen monoxide	NO	30.1
2	Nitrogen dioxide	NO_2	46.01
3	Nitrous oxide	N_2O	44.01
4	Carbon monoxide	CO	28.01
5	Carbon dioxide	CO_2	44.01
6	Methane	CH_4	16.04
7	Acethylene	C_2H_2	26.04
8	Ethylene	C_2H_4	28.04
9	Ethan	C_2H_6	30.04
10	Prophylene	C_3H_6	42.08
11	Propane	C_3H_8	44.1
12	1.3 butadiene	C_4H_6	54.09
13	N-octane	C_8H_{18}	114.23
14	Aromatic hydrocarbons (tuluol)	C_7H_8	92.2
15	Formaldehyde	$HCHO$	30.03
16	Acetaldehyde	CH_3CHO	44.05
17	Formic acid	$HCOOH$	46.03
18	Isocyanic acid	$HNCO$	43.03
19	Water	H_2O	18.01
20	Ammonia	NH_3	17.03
21	Hydrogen cyanide	HCN	27.03
22	Sulphur dioxide	SO_2	64.05
23	Carbonyl sulfide	COS	60.08

3. Results

Figure 1 presents engine performance and fuel consumption versus rotational speed at maximum position of injection pump lever. Fuel consumption of bio-diesel was 6% higher than consumption of fossil diesel. It was mainly the result of 5% higher density of bio-diesel. The differences of fuel consumption rose with rotational speed (from 3% to 9% at the highest rotational speed), what could be ascribed to injection pump characteristic and higher viscosity of bio-diesel.

Engine torque and power were lower about 3% for bio-diesel despite higher mass of injected fuel. As a result, brake specific fuel consumption of the engine fuelled with bio-diesel was, on average, 9% higher.

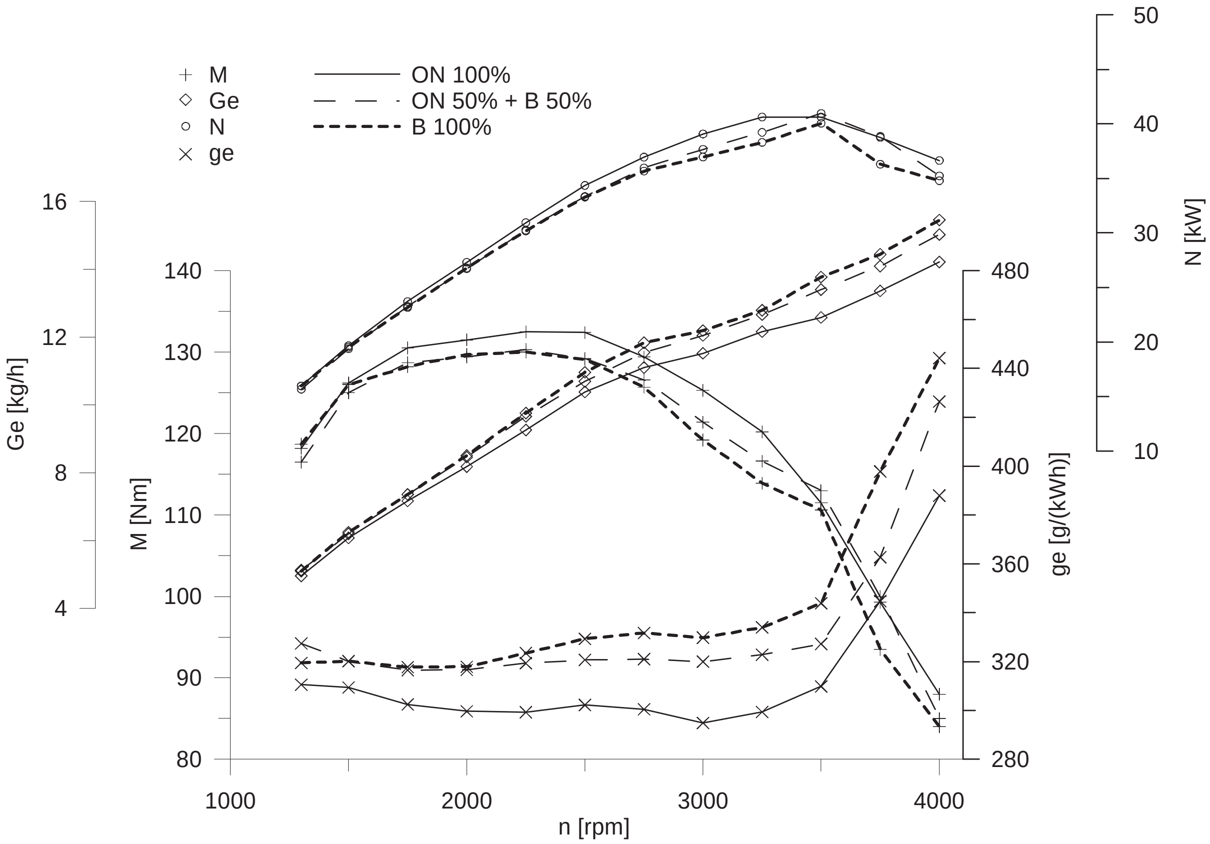

Fig. 1. Performance and fuel consumption characteristic versus rotational speed

Fuelling of the engine with pure bio-diesel (B 100) was in favour of smoke emission, which in the range of small and medium rotational speeds was, in average, three times smaller and at higher speeds was decreased by a few tens percent in comparison to fossil diesel fuel (Fig. 2). Considering substantial difference of exhaust opacity, it can be assumed that smoke emission would be lower for bio-diesel even for enlarged fuel dose, providing the same torque as fossil diesel. The research would be more objective if smoke emission was compared at the same torque. Smoke emission of the engine fuelled with blend of ON and B 100 fuels also was much lower than one obtained with the use of pure fossil diesel.

Analysis of exhaust toxic components in conditions of rotational speed engine characteristic showed that use of bio-diesel had highly advantageous effect on carbon monoxide emission in the range of low and mean rotational speeds. CO emission in this speed range was three times lower for bio-diesel than for fossil diesel. At higher speeds CO emission was comparable for all three investigated fuels (Fig. 2).

Similar dependence was observed in case of unburned hydrocarbons. In the range of small and medium rotational speeds HC emission from bio-diesel was considerably smaller, while at higher speeds it was few percent higher than one for fossil diesel. The lowest HC emission was obtained when engine was fuelled with blend of both fuels (Fig. 2).

In case of nitrogen oxides emission results were not clear. Content of nitrogen oxides was 7% higher at low rotational speed and about 3% higher at medium speed for engine fuelled with bio-diesel. However, at high speeds emission was 5% lower for bio-diesel (Fig. 2).

Conducted research indicated that relative emission of different toxic components measured in conditions of full load speed characteristic of the engine is highly variable. Moreover, those dependences were not varied in a monotonous way (e.g. HC emission). Such characteristics of the exhaust composition could provide some complication of data interpretation.

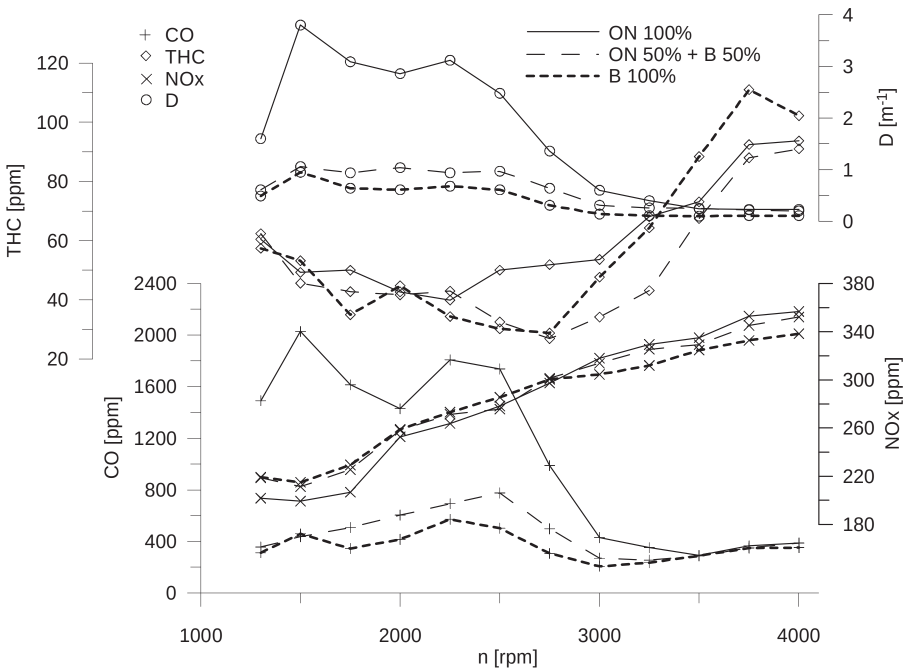

Fig. 2. Smoke emission (D) and content of carbon monoxide (CO), unburned hydrocarbons (THC) and nitrogen oxides (NO_x) in exhaust gas of the engine fuelled with investigated fuels

Figures 3-5 presents results obtained in the ESC test. In case of non regulated chemical compounds their emission was calculated in the same way as for regulated compounds (CO, THC and NO_x), i.e. as weighted mean values of results obtained in individual 13 phases of the test [11].

In case of all regulated exhaust gas components emission in ESC test of the engine fuelled with bio-diesel was lower in comparison to fossil diesel. Emission of CO was decreased by 20%, THC – 11% and NO_x – 1.5%. Emission of SO_2 was significantly reduced by 40%, while emission of CO_2 rose about 5%. However, the lowest emission of all mentioned above components, was achieved for engine fuelled with blend of fossil diesel and bio-diesel (Fig. 3). For blended fuel following reductions compared to fossil diesel were obtained: CO – 21%, THC – 33%, NO_x – 5%, SO_2 – 40%, CO_2 – 0.5%.

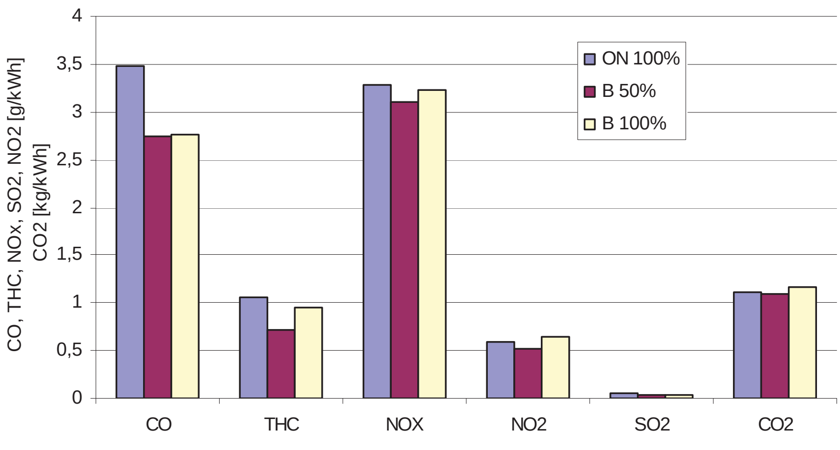

Fig. 3. Emission of carbon monoxide (CO), unburned hydrocarbons (THC), nitrogen oxides (NO_x), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and carbon dioxide (CO_2) of the engine fuelled with investigated fuels

Figure 4 presents emission obtained in ESC test for specific hydrocarbons which are the constituents of THC. For engine fuelled with pure bio-diesel emission of n-octane (C_8H_{18}), propane (C_3H_8), aromatic hydrocarbons (AHC), 1.3-butadiene (C_4H_6) end ethane (C_2H_6) was reduced in comparison to fossil diesel, while emission of ethylene (C_2H_4), prophylene (C_3H_6) and methane (CH_4) was higher. Emission of acethylene (C_2H_2) was very small and independent of used fuel. It should be noticed that for all investigated fuels more than a half of THC was constituted by n-octane. Considering this, content of this component determined THC emission in a large extent.

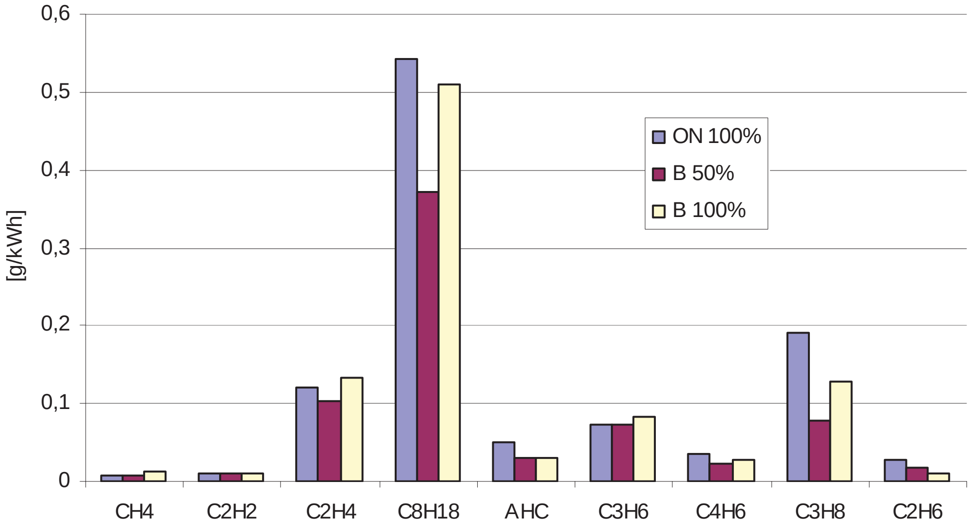

Fig. 4. Emission of specific hydrocarbons of the engine fuelled with investigated fuels

Emission of isocyanic acid (HNCO), acetaldehyde (CH_3CHO) and formaldehyde (HCHO) in exhaust gases of the engine fuelled with bio-diesel were slightly higher than for fossil diesel fuel. In case of those components, definitely lower emission was observed for engine fuelled with blend of fossil diesel and bio-diesel. Emission of formic acid and ammonia was significantly (about 60%) reduced for bio-diesel fuel, however, in general emission of ammonia was very small for all investigated fuels. Emission of strongly toxic hydrogen cyanide, in practice, was at the same level and independent of fuel used (Fig. 5).

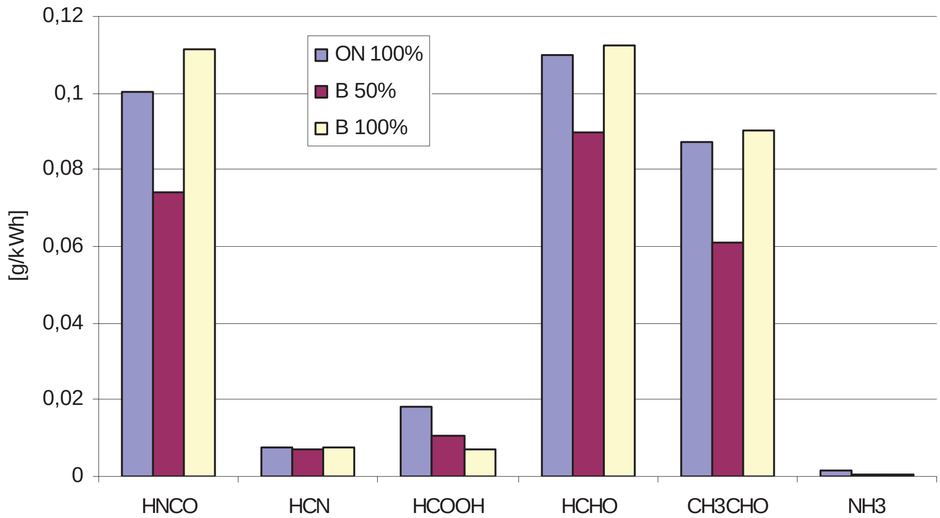

Fig. 5. Emissions of non-regulated compounds measured during the research

4. Conclusions

In this work main performance and ecological parameters of the compression ignition engine fuelled with fossil diesel, bio-diesel and their blend were determined. Moreover, emission of regulated and non-regulated chemical compounds was indicated. Measurements were done on engine operated in conditions of rotational speed characteristic and ESC stationary test. Realized tests and their results allowed authors to draw the following conclusions:

1. Performance of the engine fuelled with bio-diesel was insignificantly lower (decrease of power by 3%) then one obtained for fossil diesel as fuel. This change in engine performance would not be noticeable for a driver. However, some increase of fuel consumption could be noticed.
2. Fuelling of the engine with bio-diesel provided substantial decrease of smoke emission in comparison to fossil diesel.
3. The use of bio-diesel was beneficial to reduction of carbon monoxide emission in ESC test and also at low and medium rotational speeds at full load operation.
4. Similarly, fuelling of the engine with bio-diesel allowed to reduce emission of unburned hydrocarbons in ESC test. Considering the fact that engines the most often are operated at low and medium rotational speeds [6], also results obtained at full load should be treated as in favour of bio-diesel.
5. Measurements done with the use of investigated fuels could not provide clear results concerning emission of nitrogen oxides. Emission of nitrogen oxides in ESC test was insignificantly lower for bio-diesel, while at full load operation this fuel caused rise of emission in comparison to fossil diesel.
6. In general, the lowest emission level was obtained for blend of fossil diesel and bio-diesel.

Summarizing, it can be found that use of commercially available bio-ester B 100 for fuelling of the older generation diesel engine with in-line injection pump did not considerably influence engine performance, however was beneficial to reduction of exhaust emission.

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