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A COMPARISON OF SELECTED OPERATING PARAMETERS OF THE DIESEL ENGINE FUELLED WITH MIXTURES OF DIESEL OIL OR LIQUID BIO-FUEL AND NATURAL GAS FOR LOW-POWER GENERATORS

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Abstract

Following the modern fuel market, one can notice that prices of liquid petroleum derivatives – petrol and diesel oil – which most often fuel piston internal combustion engines are increasingly higher. Similarly, the price of petroleum-derivative gas (LPG – the liquefied petroleum gas – simply speaking, a mixture of propane and butane) is also growing. Many academic and industrial institutions of science conduct research to determine whether it is possible to replace liquid petroleum-derivative fuels with some other potentially cheaper ones. It would also be beneficial if these new fuels were more "ecological" – so that their combustion products would not be harmful for the environment and if they were produced with the use of plants. Fuel stations commonly offer a fuel for diesel engines which is a mixture of fatty acids methyl esters (FAMEs) from vegetable oils, in Poland for instance from rape seeds. The paper presents a comparison of selected operating parameters of the Hatz 1B40 engine fuelled with mixtures of diesel oil or liquid bio-fuel and natural gas. Indicator diagrams, exhaust gases composition and vibration signals recorded on the engine body were analyzed. The study was conducted on the Hatz 1B40 diesel engine which is used among others in FOGO power generator sets, after replacing the original feeding system by common rail system for liquid fuels and after adding natural gas feeding system.

Keywords: *diesel engine, dual fuel engine, bio-fuels, alternative fuels*

1. Introduction

Following the modern fuel market, one can notice that prices of liquid petroleum derivatives – petrol and diesel oil – which most often fuel piston internal combustion engines are increasingly higher. Similarly, the price of petroleum-derivative gas (LPG – the liquefied petroleum gas – simply speaking, a mixture of propane and butane) is also growing. Many academic and industrial institutions of science conduct research to determine whether it is possible to replace liquid petroleum-derivative fuels with some other potentially cheaper ones. It would also be beneficial if these new fuels were more "ecological" – so that their combustion products would not be harmful for the environment and if they were produced with the use of plants. Fuel stations commonly offer a fuel for diesel engines which is a mixture of fatty acids methyl esters (FAMEs) from vegetable oils, in Poland for instance from rape seeds. There also appear first stations offering compressed methane (CNG – compressed natural gas; basically, in Poland there is no demand for LNG – liquefied natural gas), which comes not only from natural gas deposits but also from biogas-works. In Poland, the latter source of methane seems to be very promising (due to the fact that the country's economy is still based on agriculture, biomass is commonly available), even more promising than the opportunity to retrieve gas from gas slates (since the politicians are increasingly careful about their limitless exploitation).

Utilizing methane (natural gas) in diesel engines initially relied on replacing part of the diesel oil dose with methane. Yet, recently, more and more often it is claimed that only the dose igniting the mixture of air and natural gas should be diesel oil, while the mixture composition should ensure combustibility, as well as the required power and torque. This article presents results of research in the first case when gas replaces only part of liquid fuel in the context of possible differences in the engine performance when either petroleum-derivative diesel oil or pure fuel FAMEs from vegetable oils are the liquid fuel.

2. The test bed and the course of the experiment

The study concerned a single-piston four-stroke spontaneous combustion naturally aspirated engine – HATZ 1B40. This engine is used for instance as a source of power for generators in low-power FOGO aggregate units. Originally, the engine is fed with diesel oil by a plunger fuel injection pump system and an injector opening at a certain pressure. For the sake of the experiment, this system was replaced with an accumulator injection system with an electromagnetic injector, which enabled controlling the injection period of the liquid fuel, thus also controlling its dose. In order to feed the engine with natural gas the outlet of gas installation was connected to the inlet manifold, and the quantity of compressed gas was regulated by the degree at which an appropriate valve was opened. Similarly to the original version, the engine worked with a set (3000 rpm) rotational speed of the crankshaft, powering the electricity generator, which worked at 50% of its maximum power. A detailed description of the natural gas and liquid fuel feed system used in the analysed engine as well as its power take-off can be found in [1].

The following values were registered in the research:

- indicator diagrams, by means of the engine indicating system AVL Indimodul 621,
- exhaust gases composition, by means of a movable emissions analyzer BACHARACH ECA 450,
- vibration signals on the engine body, by means of a vibration sensor (SIEMENS 5WK96063 knock sensor) and a digital oscilloscope Agilent Technologies DSO7034A.

A thorough description of registering the indicator diagrams can be found in [1], the emissions analyzer system – in [2] and [3], while the vibration signal – in [4].

During the study, the engine was fed with natural gas available at fuel stations: CNG with 98.195%mol of methane acc. to PN-C-04752:2011 "*Natural Gas. Quality Of The Gas Transmitted Through A Pipeline Grid*", *Regulation of the Minister of Economy of 28 December 2006 on quality requirements for compressed natural gas (CNG),* and *Regulation of Minister of Economy of 2 July 2010 on the detailed conditions relating to the functioning of the gas system*. Liquid fuels comprise:

- EKODIESEL ULTRA D 6.8 oil acc. to PN-EN 590+A1:2011 "*Automotive fuels. Diesel oils. Requirements and test methods*" and *Regulation of Minister of Economy of 8 December 2008 on quality requirements for liquid fuels*,
- pure fuel BIO100 esters – pure fuel fatty acids methyl esters from vegetable oils acc. to PN-EN 14214+A1:2011 "*Automotive fuels. Fatty acid methyl esters (FAME) for diesel engines. Requirements and test methods*" and *Regulation of Minister of Economy of 22 January 2009 on quality requirements for liquid biofuels*,

which are commonly available at fuel stations. The comparison of chosen parameters of both applied liquid fuels is presented in Tab. 1.

As it has already been mentioned, when the study was undertaken, the engine's crankshaft worked with a set rotational speed generating a set power. The study was performed for three different combinations of liquid fuel and natural gas quantities delivered to the engine in such a way that it could work steadily. The liquid fuel was delivered from the fuel feed chamber, where it was compressed to the constant pressure of 25 MPa, through an electromagnetic injector opening when the injection advance angle equalled 24°. The period of the injector opening T_{injLF} (thus also the dose of liquid fuel injected under constant pressure) varied – from maximum when the engine was fed only with liquid fuel, to values respectively lower by app. 20% and 50%, with the gas dose increasing. The dose of natural gas was altered by changing the volumetric flow rate

Vt_{CH_4} with a regulation valve, expressed in litres/min. The gas was delivered to the inlet manifold under the constant pressure of 0.22 MPa, which was set by the pressure reducer on a CNG bottle. The volumetric flow rate values for natural gas Vt_{CH_4}, for different liquid fuel injection periods T_{injLF}, necessary for the engine to work smoothly are presented in Fig. 1. As it can be seen, replacing EKODIESEL oil with BIO100 esters led to an increase in natural gas consumption, which did not exceed 3.2%.

Tab. 1. Comparison of chosen parameters of the applied liquid fuels [5]

Parameter	EKODIESEL ULTRA D 6.8	BIO100
Fatty acids methyl ester content	6.8 %(V/V)	97.4 %(m/m)
Density at 15°C [kg/m^3]	836	882
Kinematic viscosity at 40°C [mm^2/s]	2.88	4.53
Cetane number	51.0	51.9
Flash point [°C]	67	111
Cloud point [°C]	-4	-6
Cold filter plugging point [°C]	-18	-23
Carbon residue on 10% distillation residue [%(m/m)]	0.04	0.19
Sulphur content [mg/kg]	7.8	5.5
Water content [mg/kg]	111	154
Solid pollutants [mg/kg]	7.3	17
Copper corrosion test for 3h at 50°C [class]	1	1

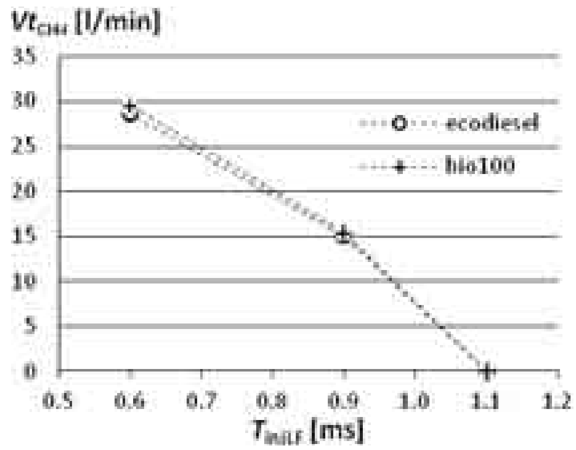

Fig. 1. Natural gas volumetric flow rate Vt_{CH4} which ensures steady engine performance at various doses (injection periods T_{injLF}) of liquid fuels

3. Results

Figure 2 presents fragments of sample indicator diagrams for the applied combinations of liquid fuels and natural gas. These fragments include compression (from –180° to 0° crankshaft angle) and expansion (from 0° to 180° crankshaft angle) strokes for 20 subsequent cycles of the engine's performance (0° crankshaft angle was assumed for the crankshaft position reflecting the top dead centre between compression and expansion strokes). First of all, the results are highly repeatable – for the assumed scale of figures all presented diagrams have similar courses and practically everywhere constitute a black line of the same thickness. Secondly, gradually replacing liquid fuels with growing methane doses generates increasingly smaller and postponed pressure maximums inside the cylinder, which occur due to the air-fuel mixture combustion (which is seen as 'softer' performance of the engine). Thirdly and finally, replacing petroleum-derivative EKODIESEL with vegetable esters BIO100 slightly (by a few percent) lowers maximum pressures inside the cylinder, which are related to the air-fuel mixture combustion. These differences increase as the dose of methane in the air-fuel mixture grows, not exceeding 10% in the conducted experiment. Thus it was found that feeding the engine with FAMEs from vegetable oils as pure fuel instead of petroleum-derivative diesel oil – maintaining the generated power and independently of the natural gas content in the air-fuel mixture – additionally 'softens' performance of the engine.

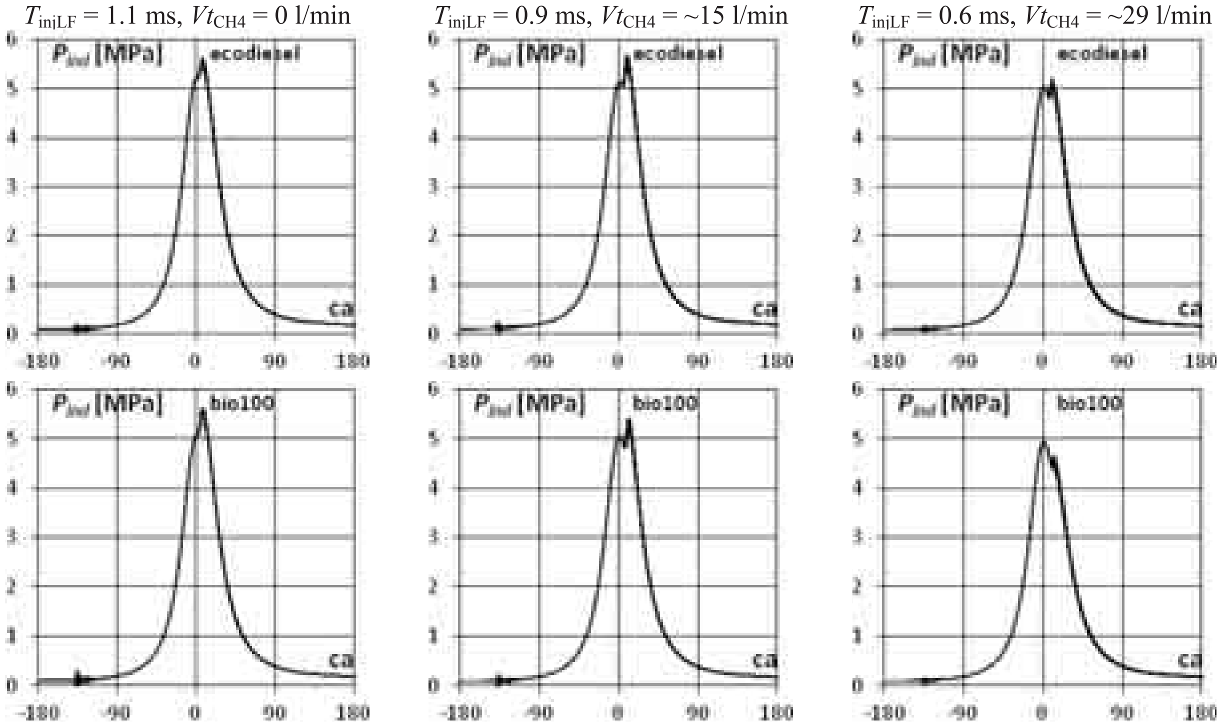

Fig. 2. Changes of pressure P_{ind} in the cylinder of the analysed engine fed with various air-fuel mixtures (20 fragments of engine performance cycles lining up)

Figure 3 presents diagrams of changes in contents of chosen substances in exhaust gases (respectively: carbon oxide, carbon dioxide, sulphur dioxide, nitrogen oxide, nitrogen dioxide, nitrogen oxides together, hydrocarbons and oxygen), and calculated on the basis of some of them the value of the air-fuel ratio (λ) for the applied combinations of natural gas and liquid fuels. The observed differences result primarily from dissimilar structures of petroleum-derivative diesel oil molecules (mainly paraffin hydrocarbons [aliphatic alkanes with open straight and branched chains] and naphthenic hydrocarbons [alicyclic aliphatic alkanes] with 8 to 21 atoms of carbon) and FAMEs from vegetable oils (mainly with $COOCH_3$ group attached to alkyl groups [open non-branched aliphatic chains] with 6 to 18 atoms of carbon), which consequently means that the course of pyrolisis and the course of combustion of air-fuel mixture are slightly different for the molecules of these fuels. The results show that replacing EKODIESEL oil with BIO100 esters when natural gas is not applied results in lower carbon oxides emissions (due to lower carbon content in the fuel), lower sulphur emissions (due to lower sulphur content in the fuel), higher nitrogen oxides emissions (as a result of a higher combustion temperature), while the final oxygen residue in the exhaust gases (and the calculated air-fuel ratio) is higher (due to oxygen content in the fuel molecules), while hydrocarbons content in the exhaust is basically the same. Replacing liquid fuels with natural gas reverses these correlations – when the liquid fuel doses are lowered by half and methane doses are appropriately increased, all registered correlations reversed (apart from sulphur oxides emissions, since there is simply considerably lower content of sulphur in esters than in diesel oil) – more oxygen is used and combustion temperatures are lowered. Yet, generally speaking, there are no significant differences in the changes in the observed emissions, while contents of methane in air-fuel mixtures are growing at the expense of EKODIESEL oil or BIO100 esters.

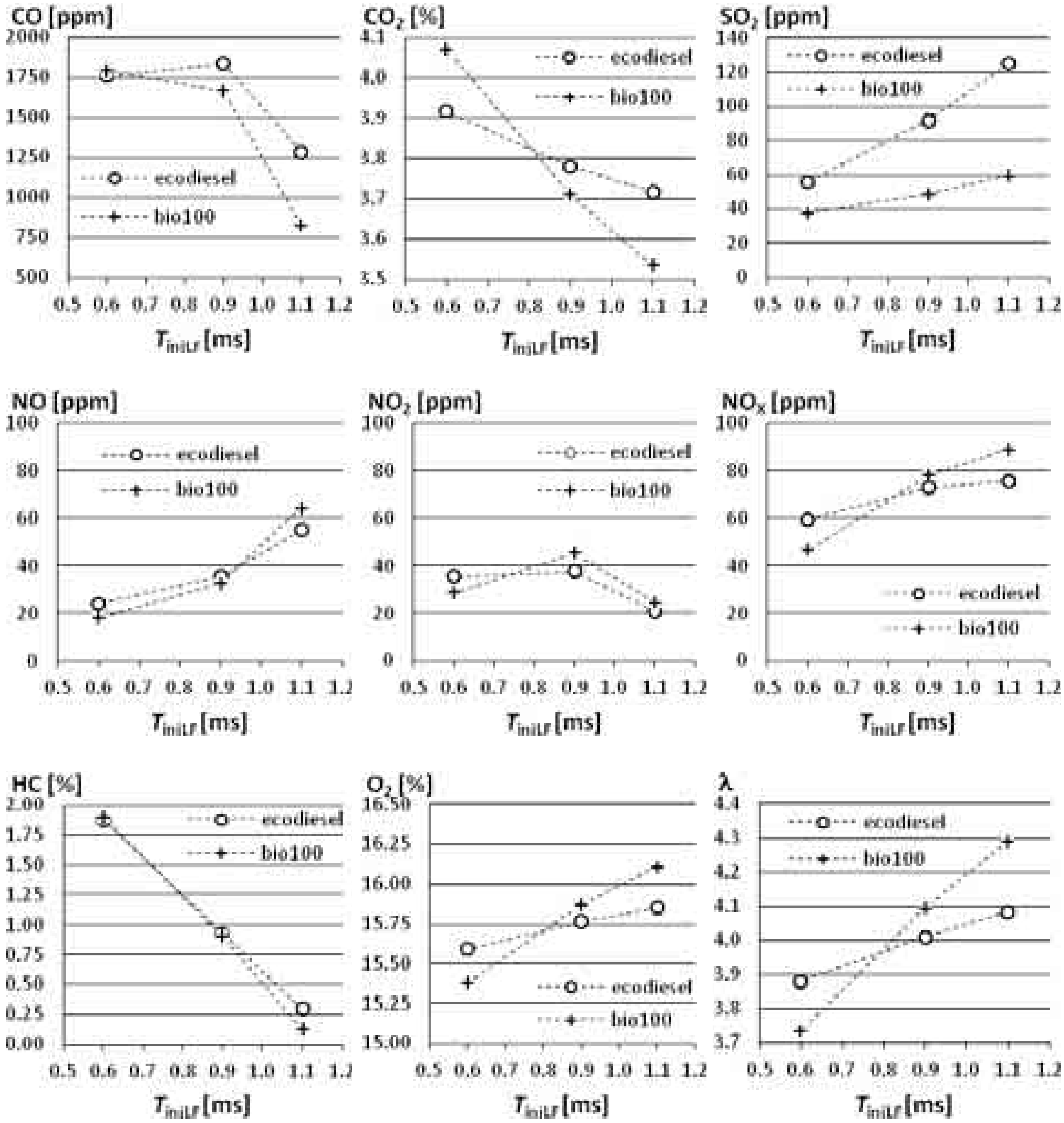

Fig. 3. Content of chosen substances in the exhaust gases of the analysed engine fed with various air-fuel mixtures (liquid fuel injection period T_{injLF} on the axes, volumetric flow rate of natural gas Vt_{CH4} acc. to Fig. 1)

Figure 4 presents examples of fragments of timing diagrams for vibration signals registered on the engine body for the applied combinations of liquid fuels and natural gas. These fragments include three cycles of engine performance (6 turns of the crankshaft), i.e. they are 120 ms long for the crankshaft rotational speed of 3000 rpm and were chosen in such a way that they start and finish in the top dead centre between exhaust and intake strokes. The range of signal values is presented in Fig. 4 and it amounts to 10 V. A detailed analysis of the components of vibration signals from the engine is presented in [4]. On the basis of this analysis, oval shapes mark the fragments which reflect the injection of liquid fuel, its self-combustion and the air-fuel mixture combustion. Comparing the marked fragments for the applied mixtures of air and fuel, it cannot be unambiguously stated on the basis of the registered vibration signals which liquid fuel was used.

4. Conclusion

There are small differences among the engine performance parameters analyzed in the experiment for various combinations of different quantities and kinds of liquid fuels and natural gas delivered to the engine. Thus it seems that replacing petroleum-derivative EKODIESEL oil with FAMEs from vegetable oils used as pure BIO100 fuel in a dual-fuel feed system (delivering one of these liquid fuels and natural gas) does not significantly affect the changes of the analyzed engine performance parameters.

It seems recommendable to conduct further studies into the subject of engine performance parameters for various liquid fuels limited only to doses igniting air-natural gas mixtures.

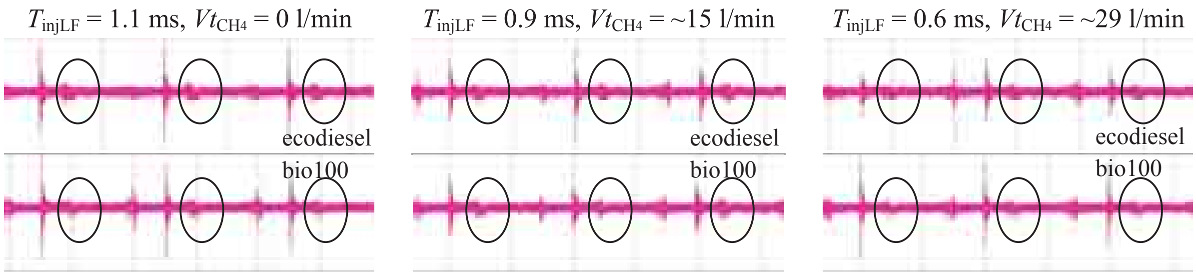

Fig. 4. Fragments of timing diagrams for vibration signals registered on the body of HATZ 1B40 engine for a set rotational speed of the crankshaft of 3000 rpm when the engine is fed with various air-fuel mixtures; marked oval fragments reflect the liquid fuel injection, its self-combustion and the onset of air-fuel mixture combustion

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Research Task No. 4

DEVELOPMENT OF INTEGRATED TECHNOLOGY OF FUELS AND ENERGY FROM BIOMASS, AGRICULTURAL WASTE AND OTHER