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EMISSION OF TOXIC EXHAUST COMPONENTS OF THE ENGINE A8C22 WORKING IN THE LOCOMOTIVE SM-42 AND SUPPLIED BY THE MIXTURE RME WITH DIESEL FUEL IN THE TEST F OF THE 2004/26/WE DIRECTIVE

EMISJA TOKSYCZNYCH SKŁADNIKÓW SPALIN SILNIKA A8C22 LOKOMOTYWY SM-42 ZASILANEGO MIESZANINĄ RME Z OLEJEM NAPĘDOWYM NA EMISJĘ W TEŚCIE F DYREKTYWY 2004/26/WE

A b s t r a c t

The paper presents the analysis of results of the investigation on exhaust gas toxicity for 4 fuels supplying the engine a8C22 of the diesel locomotive SM42-2331: diesel fuel – ON, 40, 50 and 50% (with a pack of special additives) rape oil methyl esters, in "F" test according to the 2004/26/WE Directive and UIC 624 Charter. The values of unitary emission of carbon monoxide, non-burned hydrocarbons, nitric oxides and particulate matters, were analysed by a 3-points test "F". The investigation showed that the tested engine does not meet legal regulations even in the case of using diesel fuel. The addition to the conventional fuel of rape oil methyl esters causes a constant small rise of the NOx unitary emission. However, the emission of the compounds of imperfect and incomplete combustion grows rapidly only at 50% contents of RME in diesel fuel. Even though the additive to the fuel B50+ reduces NOx emission, but then, the emission of carbon monoxide and particulate matters increases.

Keywords: biofuels, RME, FAME, diesel engine, exhaust gases emission, ecology

S t r e s z c z e n i e

W artykule przedstawiono analizę wyników badań toksyczności spalin 4 paliw zasilających silnik a8C22 lokomotywy spalinowej SM42-2331: olej napędowy – ON, 40, 50 i 50% (z pakietem specjalnych dodatków) estrów metylowych oleju rzepakowego w teście „F" zgodnym z Dyrektywą 2004/26/WE oraz kartą UIC 624. Analizie poddano wartości emisji jednostkowej tlenku węgla, niespalonych węglowodorów, tlenków azotu oraz cząstek stałych w 3-puktowym teście „F". W wyniku badań okazało się, że stosowany silnik nie spełnia obowiązujących norm nawet na oleju napędowym. Dodawanie do konwencjonalnego paliwa estrów metylowych oleju rzepakowego powoduje ciągły, niewielki wzrost emisji jednostkowej NOx. Natomiast emisja związków niezupełnego i niecałkowitego spalania gwałtownie wzrasta dopiero przy 50% RME w oleju napędowym. Dodatek do paliwa B50+ zmniejsza wprawdzie emisję NOx, ale jednocześnie wzrasta wówczas emisja tlenku węgla i cząstek stałych.

Słowa kluczowe: biopaliwa, RME, FAME, silnik z zapłonem samoczynnym, toksyczność spalin, ekologia

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1. Introduction

The study on applying bio fuels in diesel engines follows the EU regulations, which require introducing them as an additive to the petroleum fuels. In 2012, this additive should be 12 %, and the target amount until 2020 should be 20%.

In Central and North Europe, the most popular oil vegetable is the rape. Therefore, the investigation focussed on the rape oil bio fuels. Using rape oil in its natural form as a fuel for diesel engines involves solving many technical problems resulting from the different physical and chemical properties as compared with diesel fuel. One of the methods to solve this problem is a transesterification of rape oil by alcoholysis with methanol or ethanol. As result of this process, we get methyl or ethyl esters of the rape oil fatty acids with smaller particulates and properties close to the diesel fuel.

Application of the fuels alternative to diesel fuel, including bio fuels, is interesting mainly for the users of big engines, consuming great amounts of fuels and having large fleets of cars. This paper presents the results of the research on applying mixtures of diesel fuel with rape oil methyl esters to supply a diesel engine type a8C22 of the locomotive SM42.

The engine a8C22, even though its design is old, is still in common use in the shunting locomotives SM42 because of its high durability. The technical condition of the tested engine was average, the locomotive was allowed to work.

2. Purpose and scope of the investigation

The purpose of the investigation, which results are presented in the paper, was to determine the influence of tested bio fuels (methyl esters components of rape oil and their mixtures with diesel fuel), as compared with a standard diesel fuel, on unitary emissions of the exhaust gas toxic components and the exhaust gas smokiness of the engine a8C22 of the diesel locomotive SM42-2331, in accordance with 2004/26/WE Directive and UIC 624 Charter.

Four fuels were used to supply the engine a8C22: standard diesel fuel ON and this fuel with addition of 40 and 50% of the fuel B100 (rape oil methyl esters). Moreover, the fuel B50+ was used with a pack of special additives. The fuels B70 and B100 were disqualified as result of determining the smokiness level in the nozzles [6].

The analysis of the exhaust gas toxicity for the fuels supplying the engine a8C22 has been carried out in the firm NEWAG in Nowy Sącz. All necessary measurement systems were connected to the engine a8C22 in the diesel locomotive SM42-2331, working in locomotive test bed – electric resistor, providing the realisation of the required points of the engine operation.

The combustion engine type a8C22 is a diesel, four-stroke engine with direct fuel injection, V-type with the angle of flare 50°, without crosshead, non-reversible, supercharged with a turbo compressor, without air-cooling behind the turbo compressor. Basic technical data of the applied engine are presented below:

- power rating 588 kW,
- nominal rotational speed 1000 rpm,
- engine capacity 82,1 dm^3,
- piston diameter 220 mm,
- piston stroke 270 mm,

- number and system of cylinders 8/V (50°),
- ignition type self-ignition,
- compression ratio 13,5,
- maximum firing pressure 10 Mpa,
- mean effective pressure 0,88 Mpa,
- mean piston speed 9,0 m/s,
- minimum specific fuel consumption 224 g/kWh,
- mean consumption of lubricating oil 4,8 g/kWh.

The scheme of the test bed for the engine a8C22 of the diesel locomotive SM42-2331 with measurement equipment is presented in Fig. 1. Essential elements of the test bed used in the study are:

1 – tested locomotive,
2 – fuel consumption meter AVL,
3 – sampling of exhaust gas for the analysis,
4 – smoke meter AVL,
5 – system for analysing exhaust gaseous components AVL CEBII,
6 – set of calibrating and working gases,
7 – compressor for CEB II system,
8 – measuring system with diluting tunnel for measuring PM,
9 – micro-scales for measuring PM mass,
10 – measurement system for determining the temperatures in the slotted line.

For measuring the exhaust gaseous components (CO, HC, NO_x), limited by the standards mentioned above, the apparatus type CEB II of the firm AVL was used. It contained among the others:

- analyser of infrared adsorption NDIR, for measuring the concentration of the carbon monoxide CO,
- heated chemiluminescence analyser CLD, for measuring the concentration of the nitric oxides NOx,
- heated flame ionisation detector FID, for measuring the amount of non-burned hydrocarbons HC,
- magnetooptic analyser PMD, for measuring the concentration of the oxygen O_2,
- analyser of infrared adsorption NDIR, for measuring the concentration of the carbon dioxide CO_2,
- heated way for sampling the exhaust with heated preliminary filter,
- module determining the efficiency of the No_2/NO conversion,
- divisor of the calibrating gases concentration to determine the linearization function for the used analysers (16 linearization gases were used, with the concentrations from 0 to maximum, i.e. the calibrating gas concentration).

The base for calibrating analysers applied for the investigation, declared in our procedure, were reference gases of the degree of purity and the accuracy of concentration required by ECE standards.

The measuring stand, designed in this way, allowed carrying out the investigation determining the influence of tested bio fuels on energy parameters and exhaust toxicity of the applied engine.

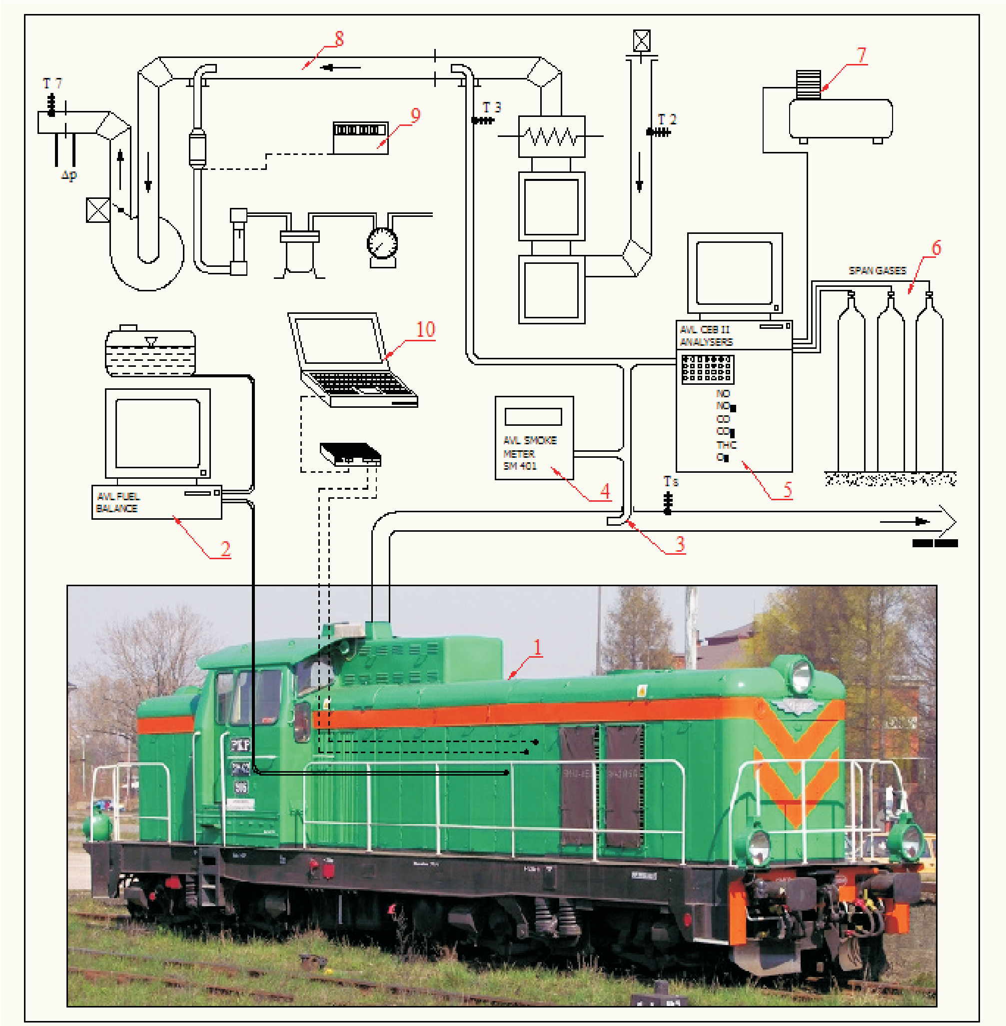

Fig. 1. Scheme of the test bend (description in the text)

Rys. 1. Schemat stanowiska pomiarowego (opis w tekście)

Photo 1. View of the desk controlling rotational speed and loading of the engine in the locomotive test bed

Fot. 1. Widok stanowiska kontroli prędkości obrotowej i obciążenia silnika lokomotywy

Photo 2. Test stand for determining the emission of exhaust components – type CEB II of the firm AVL, used in the investigation: 1 – Set of analysers CEB II of AVL (Austria), 2 – Heated line for exhaust sampling, 3 – Set of 8 cylinders with calibrating and working gases, 4 – Stand controlling the settings of the tunnel diluting exhaust gases (measurement of particulate matters)

Fot. 2. Stanowisko pomiarowe do określania emisji składników spalin – typ AVL CEB II, stosowany w czasie badań

Photo 3. General view of the measurement stand for determining the emission of particulate matters with a tunnel diluting the exhaust gases

Fot. 3. Widok stanowiska pomiarowego do określania emisji cząstek stałych z tunelem rożcieńczającym spaliny

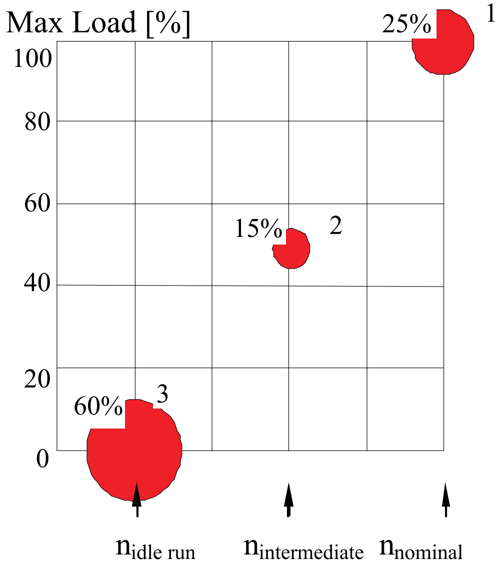

Fig. 2. Course of the investigation test type "F" in accordance with the directive 2004/26/WE with marked values of the coefficient of mass fraction [2]

Rys. 2. Przebieg testu „F" zgodnie z dyrektywą 2004/26/WE z zaznaczonymi współczynnikami udziału wagi

Tabela 1

Limits of emissions of exhaust toxic components according to UIC 624 [2]

<table>
<tr><td>Exhaust toxic components</td><td colspan="2">Boundary admissible values from 01.01.2003 [g/kWh] UIC II</td><td>Boundary admissible values from 01.01.2006 [g/kWh] UIC III A</td><td>Boundary admissible values from 01.01.2007 [g/kWh] UIC III A</td><td>Boundary admissible values from 01.01.2009 [g/kWh] UIC III A</td><td>Boundary admissible values from 01.01.2009 [g/kWh] UIC III A</td></tr>
<tr><td></td><td>P ≤ 560 kW</td><td>P > 560 kW</td><td>P > 130 kW</td><td>P > 130 kW
P ≤ 560 kW</td><td>P ≤ 560 kW</td><td>P > 2000 kW i</td></tr>
<tr><td>CO</td><td>2,5</td><td>3</td><td>3,5</td><td>3,5</td><td>3,5</td><td>3,5</td></tr>
<tr><td rowspan="2">NO_x</td><td rowspan="2">6</td><td>n > 1000 obr/min
9,5</td><td rowspan="3">NO_x + HC
4,0</td><td rowspan="3">NO_x + HC
4,0</td><td rowspan="2">6,0</td><td rowspan="2">7,4</td></tr>
<tr><td>n ≤ 1000 [obr/min]
9,9</td></tr>
<tr><td>HC</td><td>0,6</td><td>0,8</td><td>0,5</td><td>0,4</td></tr>
<tr><td>PM</td><td>0,25</td><td>0,25</td><td>0,2</td><td>0,2</td><td>0,2</td><td>0,2</td></tr>
<tr><td>Test cycle</td><td>F</td><td>F</td><td>C.1</td><td>F</td><td>F</td><td>F</td></tr>
</table>

Tabela 2

Course of the investigation test type „F“ for the engine a8C22 of diesel locomotive SM42 in accordance with the directive 2004/26/WE [1]

Test points	*n* [rpm]	*Ne* [kW]	U_i [%]
1. $n_{idle\ run}$	500	0	60
2. $n_{intermediate}$	712	303	15
3. $n_{nominal}$	1000	530	25

3. Analysis of test results

The investigation of the engine a8C22 was carried out in accordance with the test “F” of the international charter UIC 624 and the directive 2004/26/WE. The results of the tests are presented graphically in diagrams on Figures 1–5.

The analysis of the obtained results permits to state that the unitary emission of the carbon monoxide ECO (Fig. 1) significantly exceeds limit values determined by UIC 624 standards (Tab. 1). It concerns both the diesel fuel and all tested bio fuels. Limit value of the ECO emission, determined by 2004/26/WE Directive and by UIC 624 Charter, comes to 3.5 g/kWh. For diesel fuel, the determined ECO emission was 5.97 g/kWh. The increase of the amount of RME in the mixture with diesel fuel caused increasing CO emission in exhaust gas. For the fuel B50 (50% RME in ON) the emission of ECO was 6.18 g/kWh, while for 50% rape oil methyl esters in diesel fuel, with a pack of additives, the emission of ECO increased to the value 7.06 g/kWh. Although the applied set of additives to the B50 fuel caused an increase of the incomplete combustion compounds CO) of about 18% as compared with the diesel fuel and an increase of the carbon monoxide emission of about 14% in the case of B50 fuel, it contributed however to reduce the amount of the nitric oxides NO_x.

The data presented on diagrams in Fig. 3 indicate that the additive to the fuel B50+, by decreasing the self-ignition delay τs and, in consequence, reducing the combustion temperature, caused a reduction of the unitary emission of the nitric oxides ENO_x as compared with the fuel B50. It is important, because, as it is well known, the emission of nitric oxides ENO_x is the most harmful (among the exhaust gaseous components) for living organisms.

A similar influence of the bio fuels contents, as on the nitric oxides emission, was observed for the unitary emission of non-burned hydrocarbons EHC, which can be seen on the diagram in Fig. 2. It results from these data that the increase of the RME amount to the content of 50% in diesel fuel causes the growth of the non-burned hydrocarbons amount. The pack added to the B50 fuel (B50+) caused the reduction of EHC unitary emission after the test “F” of about 34%.

The values of the unitary emission of particulate matters EPM, presented on the diagram in Fig. 4, show that the fuel B40 has the EPM values similar to these of the diesel fuel. Further increase of the RME amount in ON leads to a rapid growth of particulate matters EPM emission in tested engine a8C22 in the locomotive SM42-2331. It is very important as the particulate matters, apart from nitric oxides NO_x, are the most cancer causing and mutagenic from among all toxic components of the diesel engine exhaust gases.

The first stage of the investigation, which determined the influence of tested fuels from B0 to B100, eliminated the fuels B70-B100 because of the degree of coking in fuel nozzles. In the second stage of the investigation, regarding unitary emission of particulate matters EPM, it is proposed to use the components of rape oil methyl esters with diesel fuel up to mass concentration non-exceeding 40%.

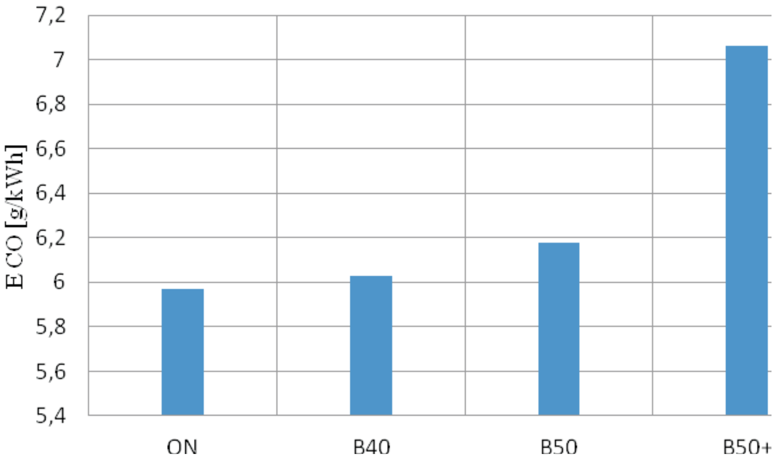

Fig. 3. Unitary emission of carbon monoxide CO in the test “F” according to the Directive 2004/26/WE for tested fuels

Rys. 3. Emisja jednostkowa tlenku węgla CO w teście „F” zgodnym z Dyrektywą 2004/26/WE dla testowanych paliw

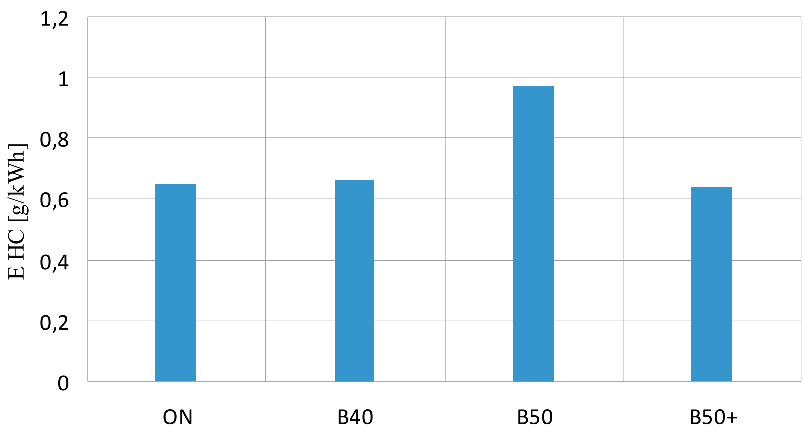

Fig. 4. Unitary emission of non-burned hydrocarbons HC in the test “F” according to the Directive 2004/26/WE for tested fuels

Rys. 4. Emisja jednostkowa niespalonych węglowodorów HC w teście „F” zgodnym z Dyrektywą 2004/26/WE dla testowanych paliw

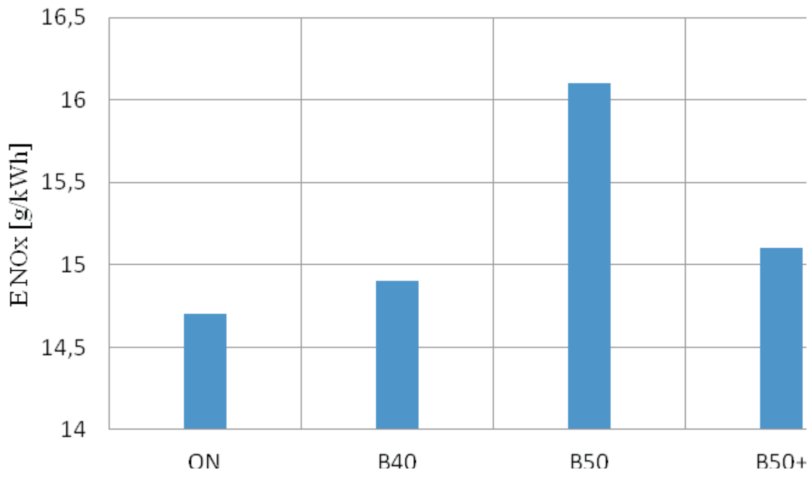

Fig. 5. Unitary emission of nitric oxides NO_x in the test "F" according to the Directive 2004/26/WE for tested fuels

Rys. 5. Emisja jednostkowa tlenków azotu NOx w teście „F" zgodnym z Dyrektywą 2004/26/WE dla testowanych paliw

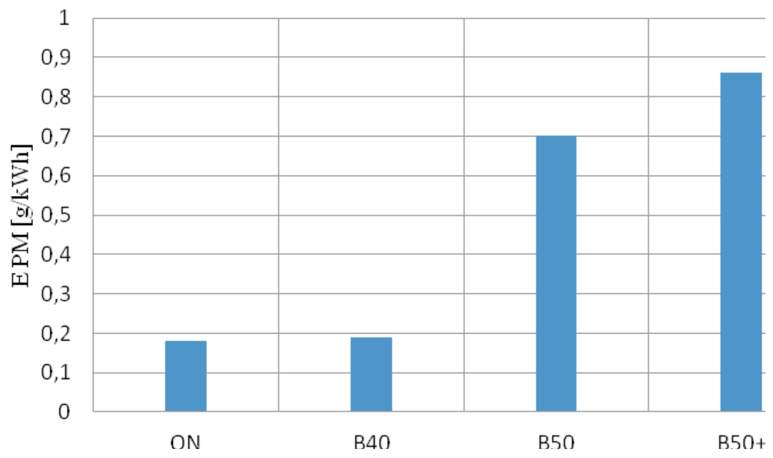

Fig. 6. Unitary emission of particulate matters PM in the test "F" according to the Directive 2004/26/WE for tested fuels

Rys. 6. Emisja jednostkowa cząstek stałych PM w teście „F" zgodnym z Dyrektywą 2004/26/WE dla testowanych paliw

4. Conclusions

Performed investigation permits formulating essential conclusions:

1. Hourly emission of nitric oxides E_{NOx} decreases along with the amount of the bio fuel in the mixture with ON at the idle engine run. It is important, because diesel engines in the locomotive of this type usually work long time without loading, which is expressed by the highest value of the coefficient of mass fraction in the test "F" for this point of the engine operation.
2. For the fuel B40, the emission of particulate matters E_{PM} does not differ significantly from the emission of the diesel fuel. However, further increase of the RME fraction in the mixture with ON causes a rapid increase of E_{PM} for the tested engine a8C22.
3. Unitary emission of carbon monoxide E_{CO} after the test "F" significantly exceeds limit values determined by UIC 624 standards. It concerns the diesel fuel as well as all examined bio fuels. The increase of the RME amount in the mixture with ON caused an increase of E_{CO} in exhaust gas.
4. The pack of additives to the fuel B50 (fuel B50+) caused a reduction of unitary emission of nitric oxides E_{NOx},
5. A similar influence of the bio fuels contents, as on the nitric oxides emission, was observed for the unitary emission of non-burned hydrocarbons E_{HC}. The increase of the RME fraction to the contents of 50% in ON causes the rise of non-burned hydrocarbons amount. The pack added to the fuel B50 (B50+) produced a reduction of the unitary emission E_{HC} after the test "F" of about 34%.

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