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EVALUATION OF EMISSION LEVEL OF BIOFUELS FROM WASTE-FREE PRODUCTION IN COMPRESSION-IGNITION ENGINES

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Abstract

This article presents the impact of biofuel for compression-ignition engines, produced with the use of innovative production technology, on the emission of toxic substances.

The innovative production technology of biodiesel does not generate by-products, eliminating the need for development glycerol fraction and toxic methanol, substances inconvenient for environment. This technology is not currently well known and not used on an industrial scale. The essence of this technology is to carry out the transesterification of triglycerides and methyl acetate in special conditions and with using an alkaline catalyst. The only product of this technology is a mixture of fatty acid methyl esters and glycerol triacetate (no by-products). In the first part of the article, selected physical and chemical properties of such biofuel in comparison to the limits specified in the standard quality requirements for this type of products (EN 14214) were discussed.

In the next part, the results of empirical studies were evaluated, showing the influence of speed and load conditions in test engine Perkins 1104C-E44TA on concentrations of harmful components in the exhaust gases such as carbon monoxide, nitrogen oxides, hydrocarbons, particulates. Engine tests were performed with using biofuels selected by the authors. The measurement system, consisted of an AVL CEB II gas analyser and MEXA-1230PM device for measure of particulate matter in real time, to measure the concentrations of toxic exhaust components was used. Based on the concentration of toxic components of exhaust gases according to Test C1 according to ISO 8178, the emission of the above-mentioned normalized toxic components of exhaust gases was determined. In the final part of the article, the results of empirical studies on the concentrations of toxic exhaust gases in the linear-point diagrams, and emission in the bar chart diagrams were presented.

Keywords: *biodiesel, waste-free production technology, exhaust emission*

Introduction

This article presents the assessment of the influence of biofuels supplying the compression ignition (CI) engine, manufactured using an innovative production technology, on the emission of exhaust toxic components. The developed innovative technology for the production of biofuel for CI engines does not generate by-products, which eliminates the necessity to dispose of arduous for environment glycerol fraction and toxic methanol. At present, this technology is not known and not applied at industrial scale. The essence of this technology is conducting the transesterification of triglycerides and methyl acetate in special conditions and using an alkaline catalyst. The only product obtained from this technology is the mixture of fatty acid methyl esters and glycerol triacetate (there are no by-products). The article describes selected physicochemical properties of

such type of biofuel in comparison to the limits determined in standardized quality requirements for this type of products (EN 14214).

The next part of the article assesses the results of empirical tests which show the influence of speed and load conditions of the operation of Perkins 1104C-E44T test motor on the concentrations of harmful components (such as: carbon monoxide, nitric oxides, hydrocarbons, particulate matter) in exhaust gas. The tests were conducted in case when the engine is supplied with selected biofuels from waste-free production. The unitary emissions of above-mentioned standardized toxic components of exhaust gas were determined on the basis of the concentrations of toxic exhaust components, in accordance with C1 test as per ISO 8178.

1. Biodiesel production technology

For many years, the vegetable oils are a significant raw material for the production of higher fatty acid methyl esters. Biofuel of this type is successfully applied for driving the vehicles equipped with compression ignition engines. Oils and fats can be transformed into biofuels using various methods [3].

The most known method of biofuels production is the transesterification of triglycerides with methanol (methanolysis). This technology has been known and applied at industrial scale for almost 20 years. The fat raw material is subjected to reaction at the temperature of 20-70°C, using basic catalysts, such as sodium and potassium hydroxides or their methoxides. Acidic catalysts can also be used, but in this case, the lower reaction rates are obtained. The fatty acid methyl esters (applied as biodiesel) and the glycerol fraction, which is a production waste arduous for environment, are obtained as the result of the transesterification process [11]. The main problem in the production of biodiesel by the transesterification reaction is the low productivity. This situation results from a low selling price of biodiesel, which is similar to the price of crude vegetable oil. Moreover, glycerol obtained as a by-product is difficult to sell due to the market saturation [12].

A completely new approach to the processing of vegetable oils for biofuels is the technology developed within the framework of the project titled: “Research on waste-free biofuels production technology”, contract no.: POIG.01.04.00-08-147/12, i.e. the transesterification of triglycerides with the participation of methyl acetate instead of methanol. At present, this technology is not known and not applied at industrial scale. The essence of this technology is conducting the transesterification of triglycerides and methyl acetate in special conditions and using the alkaline catalysts (25% solution of potassium methoxide in methanol). In order to increase the production efficiency, the mixing in reactor is aided by ultrasounds [4, 10].

The final product is the mixture of rape oil methyl esters and glycerol triacetate. The developed technology eliminates then the necessity to dispose of environment arduous glycerol fraction. As it was shown by analytical tests presented below, such mixture can be applied as the fuel supplying the CI engines.

The entire production process consists of the following stages:

- de-acidification of vegetable oil (method of initial esterification),
- filtering 1 (separation of soaps),
- transesterification (mixing aided by ultrasounds),
- filtering 2,
- distilling off the excess methyl acetate (re-using in the process),
- distillation under reduced pressure (only if the product does not meet the standard after the transesterification).

The main elements of the installation are:

- de-acidification reactor,
- filter for soaps separation,
- transesterification reactor,

– stripper columns (first stripper distils off methyl acetate and methanol, the second column distils off glycerol triacetate, and the third column distils, if necessary, the whole biodiesel).

2. Test biofuels – properties

As a result of conducting all the stages of biofuel production process, two biofuels, differing slightly by the contents of methyl acetate in FAME, were selected for engine tests.

a) test biofuel – P1

Composition of P1 biofuel:

– 94% fatty acid methyl esters,
– 6% glycerol triacetate;

b) test biofuel − P2

Composition of P2 biofuel:

– 96% fatty acid methyl esters,
– 4% glycerol triacetate.

The B100 commercial biofuel (consistent with PN-EN 14214) was used for comparative tests.

The quality of obtained biofuels was compared to the requirements of PN-EN 14214 [8] standard. P1 and P2 biofuels meet all the quality requirements, besides the oxidation stability. However, this parameter can be improved by the application of anti-oxidizing additives in case when produced biofuel is applied as not a component but as a 100% fuel.

3. Examination of concentrations and emission of toxic exhaust components

In order to determine the toxic exhaust components it was necessary to use a braking station, allowing conducting the tests of CI engine, supplied with various kinds of liquid fuels, with the possibility to measure the concentrations of toxic exhaust components. The test station was adapted to supplying the CI engine with liquid fuels of various physicochemical properties [1, 2, 5]. It resulted with different course of the combustion process, which has the most significant influence on the emission of toxic exhaust components [6, 9]. The braking station, built on the basis of the Perkins 1104C-44T CI engine, was used for that purpose. During the tests, the engine was loaded by means of the Schenck WM 400 eddy current brake. The scheme of this station is presented in Fig. 1 [7].

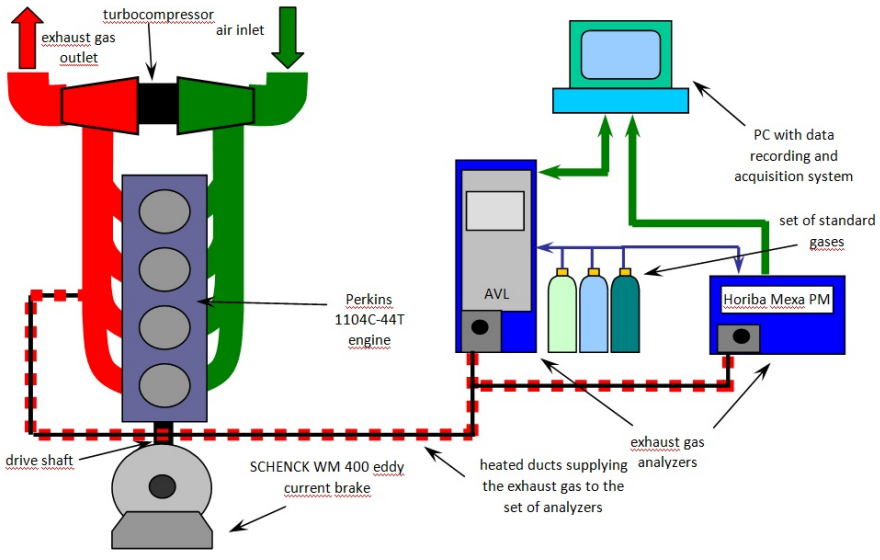

Fig. 1. Block diagram of test station

The operating parameters of the (combustion engine and brake) were regulated and controlled by means of the electronic control module Schenck X-ACT. The measurement of CO, THC, NO_X concentrations in engine exhaust gas was conducted by means of exhaust gas analyser CEB II of AVL Company. The Horiba Mexa 1230 PM device was used for the measurement of particulate matter emission. During the measurements, the measured values of concentrations of harmful compounds in exhaust gas were recorded on PC integrated with the test station.

During the station tests, the consumption of liquid fuels was measured with the volumetric meter, which was an integral part of the braking station.

4. Description of engine research tests

The concentrations of toxic exhaust components were measured at appropriate points of engine operation, in accordance with ISO 8187 standard. Unitary emissions of toxic exhaust components for all examined fuels were obtained on the basis of these concentrations. The engine, on which the tests were conducted, was manufactured after the year 2004 and was qualified to C1 category as per ISO 8178 standard and it was subjected to examination consistent with 11-phase test. The 11-phase test was conducted on the engine braking station and was the basis to determine the average emission of individual toxic components of exhaust gas. The factors of participation in the i^{th} phase, u_i (factor of given phase importance) are variable and selected depending on engine application [7].

Tab. 1. Factors of participation in the i^{th} phase for the C1 test (importance factor of given phase for individual tests)

Phase Test	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
C1	0.15	0.15	0.15	0	0.10	0.10	0.10	0.10	0	0	0.15

Figure 2 presents the weighting factors depending on the rotational speed and load in the above-mentioned test.

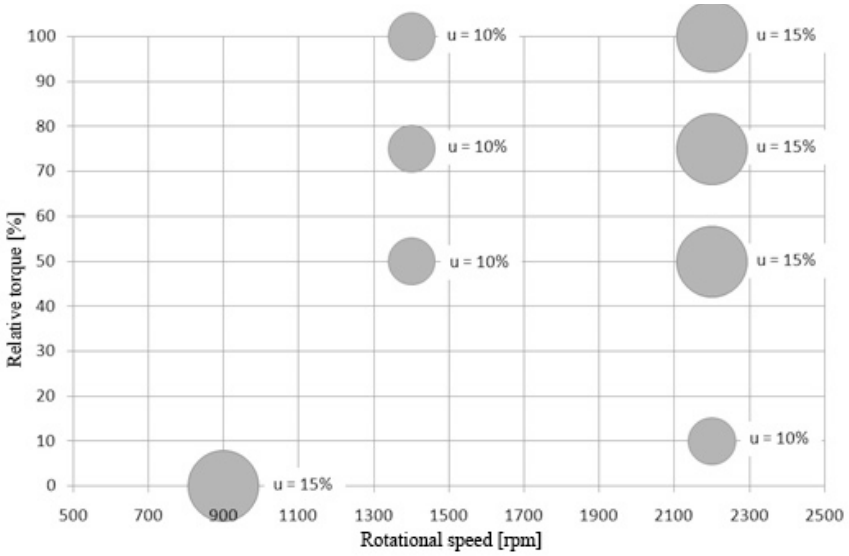

Fig. 2. Weighting factors depending on the rotational speed and load in the C1 test acc. to ISO 8178 standard

5. Results concerning the concentrations of toxic exhaust components

During the experimental investigation the test engine was supplied with various fuels and was working in various speed and load conditions, in which the measurements of concentrations of basic exhaust components, i.e.: nitric oxides – NO_X, hydrocarbons – THC, carbon monoxide – CO

and the measurements of particulate matter (PM) concentration, were conducted. Such methodology of empirical investigation is commonly used for determining the toxic components of exhaust gas when the engine is supplied with liquid alternative fuels [5].

The results of concentration measurements for listed toxic components of exhaust gas from the Perkins 1104C-E44T engine, working according to the load characteristics for the rotational speeds of 1,400 rpm and 2,200 rpm and supplied with tested P1 and P2 biofuels, and additionally with B100 (as a reference fuel), are presented in Fig. 3 to 10.

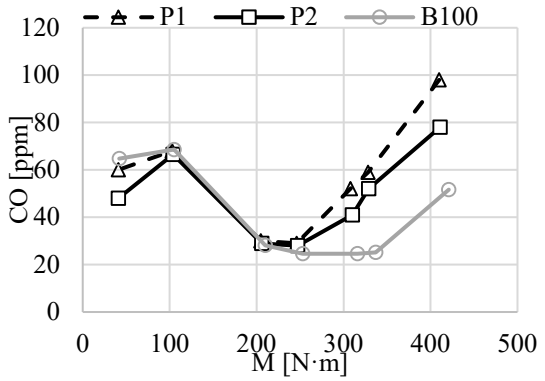

Fig. 3. Dependence of carbon monoxide concentration on torque change for P1, P2 test fuels and B100 fuel, rotational speed 1,400 rpm

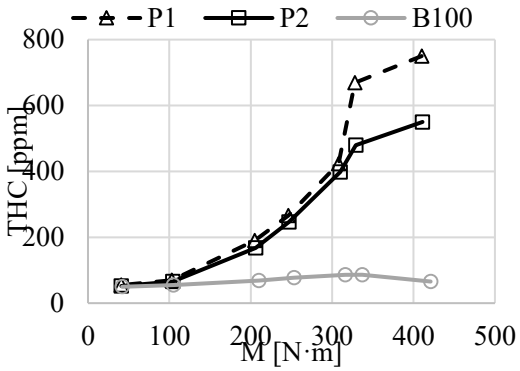

Fig. 4. Dependence of hydrocarbons concentration on torque change for P1, P2 test fuels and B100 fuel, rotational speed 1,400 rpm

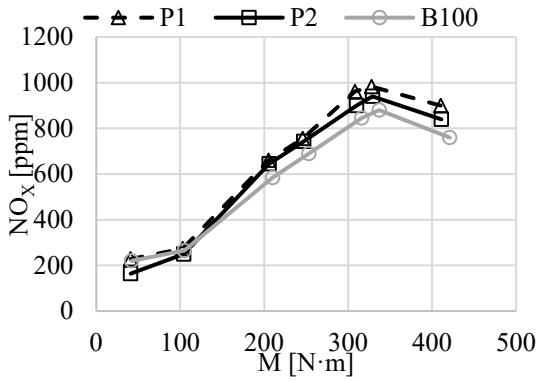

Fig. 5. Dependence of nitric oxides concentration on torque change for P1, P2 test fuels and B100 fuel, rotational speed 1,400 rpm

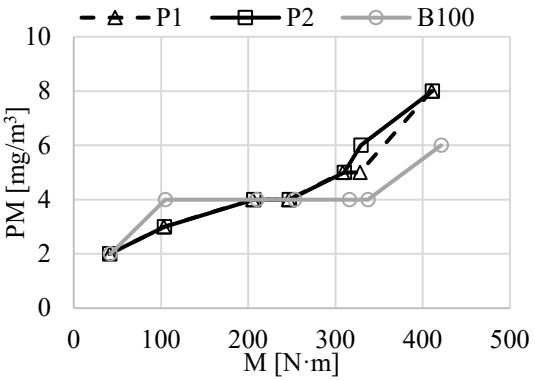

Fig. 6. Dependence of particulate matter concentration on torque change for P1, P2 test fuels and B100 fuel, rotational speed 1,400 rpm

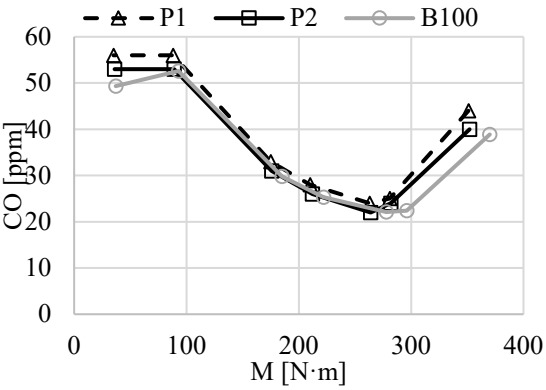

Fig. 7. Dependence of carbon monoxide concentration on torque change for P1, P2 test fuels and B100 fuel, rotational speed 2,200 rpm

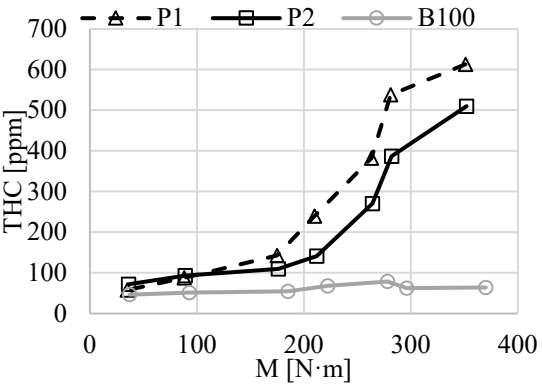

Fig. 8. Dependence of hydrocarbons concentration on torque change for P1, P2 test fuels and B100 fuel, rotational speed 2,200 rpm

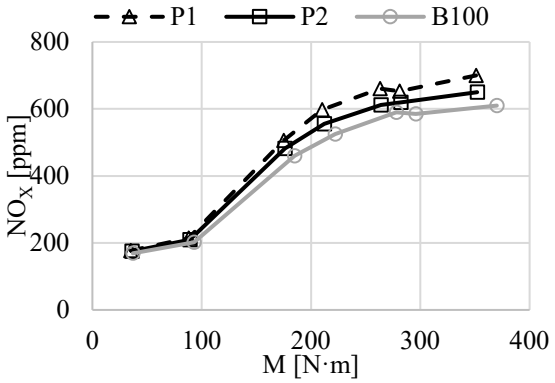

Fig. 9. Dependence of nitric oxides concentration on torque change for P1, P2 test fuels and B100 fuel, rotational speed 2,200 rpm

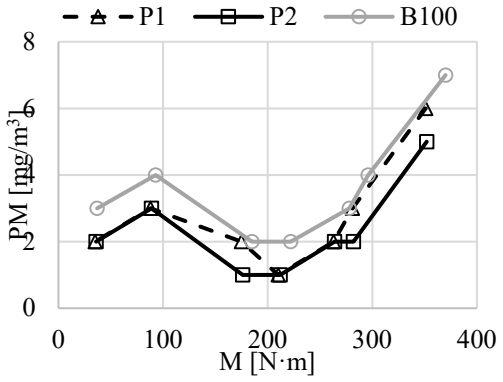

Fig. 10. Dependence of particulate matter concentration on torque change for P1, P2 test fuels and B100 fuel, rotational speed 2,200 rpm

6. Results concerning the unitary exhaust emission in C1 test as per ISO 8178 standard

The unitary emission was calculated for an off-road engine belonging to the category F, 75 ≤ P < 130 kW (85 kW). Fig. 11 presents the results for unitary emission determined for 3 fuels: P1, P2 and B100 in C1 test.

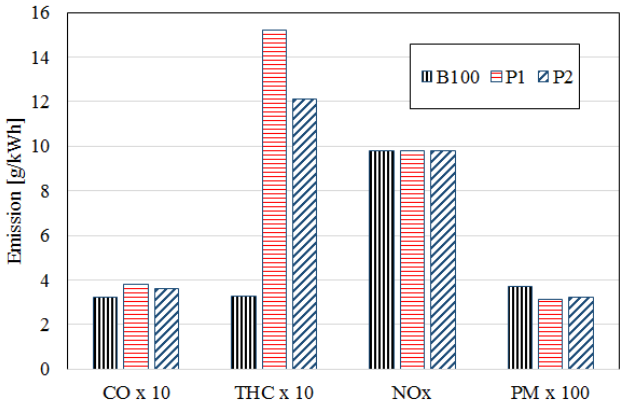

Fig. 11. Examination of toxic substances emission in C1 test as per ISO 8178

7. Conclusions

This article presents general information regarding an innovative waste-free technology for the production of biofuel for the supply of CI engines, using methyl acetate. Due to the application of innovative solutions, this technology is characterized of high productivity, and it does not generate by-products. The only product is the mixture of fatty acid methyl esters and glycerol triacetate.

This product meets the quality requirements stipulated in the Regulation of the Minister of Economy of 22 January 2009 on the quality requirements for liquid biofuels. According to the new requirements of PN-EN 14214 standard, the limit for the oxidation stability parameter is 8.0 h, so the produced biofuels are not within the required limit. However, this parameter can be easily improved by the application of anti-oxidizing additive.

The results of empirical tests regarding the toxic exhaust components indicate that both test fuels, i.e. P1 and P2, achieve the values of nitric oxides concentrations higher maximally by about 12% and the values of hydrocarbons concentrations higher maximally ten times in comparison to B100 fuel, at both rotational speeds of the engine crankshaft. At high engine loads the concentrations of carbon monoxide are higher by about 50% for P1 fuel and by 25% for P2 fuel at

the crankshaft rotational speed of 1,400 rpm and for the rotational speed of 2,200 rpm these values are similar and the difference is about 5% maximally. The value of particulate matter concentration is lower for both test fuels in comparison to B100 reference fuel and it amounts to maximally 25% for both characteristic rotational speeds.

In C1 test, the unitary emissions of CO and NOx are on similar level. The unitary emission of PM is slightly lower comparing to B100 fuel. The worst results in comparison to B100 fuel were obtained for the unitary emission of THC. It is over four times higher in case of P1 fuel and over three times higher in case of P2 fuel.

The determined concentrations and calculated emissions of toxic exhaust components are affected mainly by physicochemical properties of examined biofuels, presented in Tab. 1. Moreover, the tested biofuels coming from waste-free production contain glycerol triacetate, which contributes significantly to the increase of THC unitary emission.

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