ANALYSIS OF TOXIC COMBUSTION COMPONENTS OF THE DIESEL ENGINE POWERED WITH A BLEND OF DIESEL FUEL AND BIODIESEL

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Abstract
One of the most important problems for road transport is environmental protection. A way to reduce the emission of toxic components of exhaust gases emitted by engines and to reduce the consumption of fossil energy sources is to use fuel from renewable sources. The most popular alternative fuel are fatty acid methyl esters, which are used as an additive to diesel fuel. The paper presents a study of toxic products of fuel combustion in diesel engines fuelled with a blend of 70% diesel fuel and 30% fatty acid methyl esters. The conducted tests allowed to determine the quantitative content of toxic products of combustion of the tested blend in comparison to diesel fuel.

Keywords: *transport; environmental protection; diesel engine; compression-ignition engine; biofuels; means of transport; toxic components of exhaust gases.*

INTRODUCTION

The use of alternative fuels to supply internal combustion piston engines is associated with high demand and dwindling natural resources. The first compression-ignition engine developed by Rudolf Diesel was fuelled with peanut oil. Only after the development of oil refining technology did it become clear that diesel is a much more versatile fuel for diesel engines. The advantages of diesel fuel are its good lubricating properties, its viscosity of 2.0-4.5 mm^2*s-1 and its high cetane number, which testifies to the engine's ability to self-ignite *(Zając P., 2009)*. Despite the superiority of petroleum fuels over vegetable fuels, the concept of supplying combustion engines with alternative fuels was reinstated for environmental reasons. The fuel with intermediate parameters between vegetable oil and diesel fuel turned out to be methyl esters of fatty acids *(Piętak A., Radkowski S., 2006)*. FAME (pure fatty acid methyl esters), commonly referred to as biodiesels or biocomponents, are the most popular alternative fuel used to fuel diesel engines. They are most often used as an additive to diesel fuel.

Since 2003, in accordance with the decision of the European Union, biodiesels have been used as a mandatory additive to marketed diesel fuel. The basic legal act which determined the development of the biofuel market was Directive 2003/30/EC (Official Journal of the European Union L 123), which obliged, out of concern for environmental protection, EU member states to participate in the share of fatty acid methyl esters in transport fuels in the minimum amount of 5.75%. In 2009, the regulations were amended by introducing by the European Parliament the Directive 2009/28/EC, which imposes an obligation to share 10% of biofuels in the transport sector by the end of 2020 (Official Journal of the European Union L 140). The Directive also sets out sustainability criteria for the classification of biofuels as renewable energy sources. In the record of development in the liquid biofuels market, the criterion concerning the reduction of greenhouse gas emission in relation to conventional fuels is also taken into account. The level of 35% was expected to be reached by the end of 2017 and then gradually increase to 50%. The transposition of the Directive on the promotion of renewable energy sources in the Member States of the European Union was to take place on 5 December 2010 and ensure an increase in the share of renewable energy sources.

Fuel properties have a major impact on the combustion process and reliability of the facility in operation *(Markiewicz-Patalon M., et al., 2018; Markiewicz-Patalon M., et al., 2018)*. The addition of biodiesel to the diesel fuel improves lubricating properties, extends engine life and emits negligible amounts of sulfur. There are also complications associated with the use of the biofuels, such as obtaining a high cetane number, the solubility of plastics, changes in physical properties and viscosity due to temperature increase *(Dzieniszewski G., 2015)*. The blend of diesel fuel with 10% biodiesel has physical and chemical properties similar to diesel fuel *(Markiewicz-Patalon M., et al., 2017; Markiewicz-Patalon M., et al., 2017)*. The basic properties of both fuel blends are presented in Table 1.

Tab. 1 Properties of diesel fuel and biodiesel blend

Characteristics of blends	BIODIESEL BLEND	DIESEL FUEL
Viscosity [mm² • s^{-1}]	3.5-5.0	2.0-4.5
Sulfur content [mg • kg^{-1}]	≤ 10	≤ 350
Density [$g \bullet cm^{-3}$]	0.86-0.90	0.82-0.845
Cetane number	≥ 47	≥ 51
Particulate content [$mg \bullet kg^{-1}$]	≤ 24	≤ 24
Water content [$mg \bullet kg^{-1}$]	≤ 500	≤ 200
Carbon residue [%]	≤ 0.3	≤ 0.3
Ignition point [°C]	≥ 101	≥ 55

Additional supply of combustion engines with biodiesel blends reduces the emission of toxic components of exhaust gases such as carbon oxides, hydrocarbons and particulate matter *(Agarwal A. K., et al., 2013; Arapaki N., et al., 2007; Armas O., et al., 2010; Bala B.K., 2005; Choi S., Oh Y., 2006; Dzieniszewski G., 2009; Fontaras G., et al., 2009; Knothe G., et al., 2006; Lapuerta M., et al., 2008; Leung D., et al., 2006)*. The exception is nitrogen oxides, which show an increase of several percents in relation to pure diesel fuel *(Merkisz J., Kozak M., 2003)*.
The aim of the study was to determine the toxic components contained in the splanons of the propulsion unit of the transport vehicle powered by blends of diesel oil and fatty acid methyl esters.

MATERIALS AND METHODS

The material used in the tests was a blend of 70% of diesel fuel and 30% of fatty acid methyl esters (Blend I) and diesel fuel without biodiesel (Blend II) presented in Figures 1 and 2.

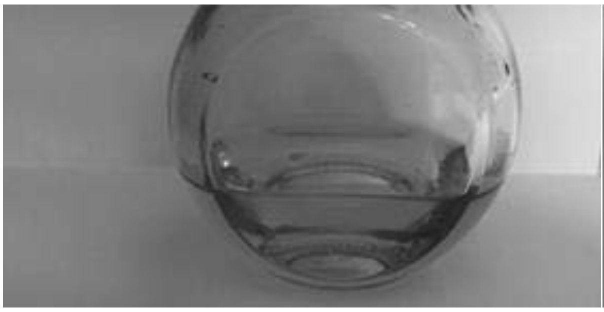

Fig. 1 Blend I

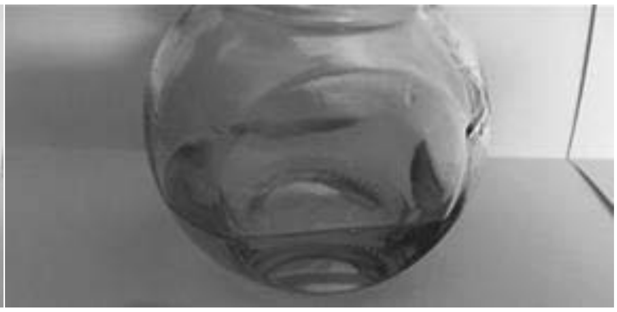

Fig. 2 Blend II

The conducted tests covered the measurement of performance parameters of the engine fuelled with these blends. The measurement included the composition of exhaust gases and the content of particulate matter in exhaust gases. The measurement of the toxicity of exhaust gases included such compounds as oxygen (O2), carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and nitrogen oxide (NO2).
The tests were conducted on an 81 kW diesel engine with Common Rail direct fuel injection and electromagnetic injectors, which is shown in Figure 3. The engine used in the tests was not equipped with a diesel particulate filter.

Fig. 3 The engine used in the tests

In order to efficiently replace the fuel supplying the engine, modifications to the fuel supply system have been made. The adaptation of the engine fuel supply system has not introduced any changes to the design of the engine, but only covered its accessories. The modifications included the installation of an external fuel tank and disconnecting the fuel supply from the factory tank installed in the vehicle. No additional fuel filters or fuel pump were installed in the engine. The fuel supply system was connected directly to the external tank and the engine. During the study, standard filters for the engine model were used. Excess fuel from the engine supply system returned to the external tank by means of a return line. After changing the fuel from diesel fuel to a blend of 70% diesel fuel and 30% fatty acid methyl esters, the engine ran for about 10 minutes at idle to remove the residues of the previous fuel from the fuel filter and fuel supply system.
The experiment was conducted to determine the engine performance parameters for two tested blends. The tests of these parameters were performed in the laboratory environment with the use of a chassis dynamometer simulating road conditions. The preparation of the object for the experiment was in accordance with the recommendations of the dynamometer manufacturer. In addition, only probes to measure the components of exhaust gases and particulates have been installed. Prior to each measurement, the engine was warmed up to 85 °C of coolant.
The measurement of the concentration of toxic components in exhaust gases was performed with the use of a diagnostic method, which made it possible to determine the quantitative content of components emitted into the environment in the form of exhaust gases. The measurement with the MGT-5 exhaust gas analyzer included the quantitative determination of the volumetric compositions of particular components in the exhaust gas. The view of the toxic exhaust gas analyzer is shown in Figure 4. The exhaust gas analyzer used for the tests met the requirements of the European Parliament and Council Directive 22/2004/EC. During the test, the analyzer was controlled from a PC. The measurement of carbon dioxide, carbon monoxide and hydrocarbons contained in exhaust gases are performed in the form of infrared radiation of exhaust gases, while the measurement of oxygen is performed by electrochemical method.

Fig. 4 MGT-5 exhaust gas analyzer

Particulate emissions were measured using the optical method with the MPM-4 analyzer, shown in Figure 5. The measurement method consisted in measuring the intensity of the light beam passing through the exhaust gas stream *(Pelkmans L., Debal P., 2006)*. The particulate matter produced during fuel combustion in diesel engines is carbon particles and smaller particles absorbed by carbon, i.e. soot *(Peterson C., et al., 2000)*. The analyzer took a sample of the exhaust gas through a measuring probe, which was exposed to a laser. Then, using the scattered light detector, the size and concentration of particulate matter were measured.

Fig. 5 MPM-4 particulate matter analyzer

Each measurement of the performance parameters of the tested engine was carried out 30 times under maximum load.

RESULTS AND DISCUSSION

On the basis of the literature analysis, evaluation criteria for a diesel engine fuelled with a blend of diesel fuel and fatty acid methyl esters have been established. In this study, performance parameters important for environment protection were featured. The following parameters were analyzed: carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), hydrocarbons (HC), nitrogen oxide (NO_2) and particulate matter (PM). The analysis included 30 measurements of selected values of performance parameters of a diesel engine for diesel fuel (Blend I) and blend of 70% diesel fuel and 30% fatty acid methyl esters (Blend II). The main statistical values of the analyzed performance parameters of the diesel engine fuelled with diesel fuel are presented in Table 2.

Tab. 2 Mean values of test results for blend I

Material	CO [% vol.]	CO_2 [% vol.]	O_2 [% vol.]	HC [ppm]	NO_2 [ppm]	PM [ppm]
Mean value	0.13	11.96	17.29	51.46	227.23	95.93
Median	0.11	12.0	17.09	43.5	227.5	96.0
Standard deviation	0.071	0.384	0.694	19.937	12.983	2.249
Coefficient of variation	0.546	0.032	0.04	0.387	0.057	0.023
Minimum	0.04	11.2	16.21	30.0	196	92.0
Maximum	0.43	12.9	18.47	88.0	251.0	99.0

Table 3 presents a statistical analysis of performance parameters of a diesel engine fuelled with a blend of 70% diesel fuel and 30% fatty acid methyl esters.

Tab. 3 Mean values of test results for blend II

Material	CO [% vol.]	CO_2 [% vol.]	O_2 [% vol.]	HC [ppm]	NO_2 [ppm]	PM [ppm]
Mean value	0.068	11.88	10.24	9.033	237.76	75.03
Median	0.04	9.0	9.98	9.0	236.5	75.5
Standard deviation	0.065	0.325	2.069	0.546	16.132	4.468
Coefficient of variation	0.957	0.027	0.202	0.061	0.068	0.06
Minimum	0.04	11.3	6.96	8.0	207.0	68.0
Maximum	0.28	12.7	18.98	10.0	283.0	85.0

The measurement of exhaust gases and particulate matter was performed in order to determine the quantitative content of toxic components for a diesel engine fuelled with a biodiesel blend. Data from the table (mean and median values) are presented graphically in Figures 6-7.

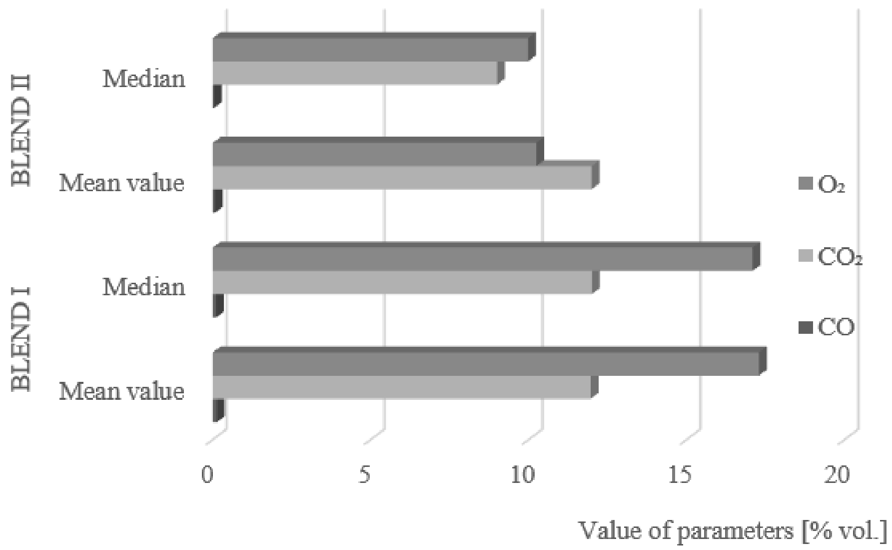

Fig. 6 Performance parameter values for engine

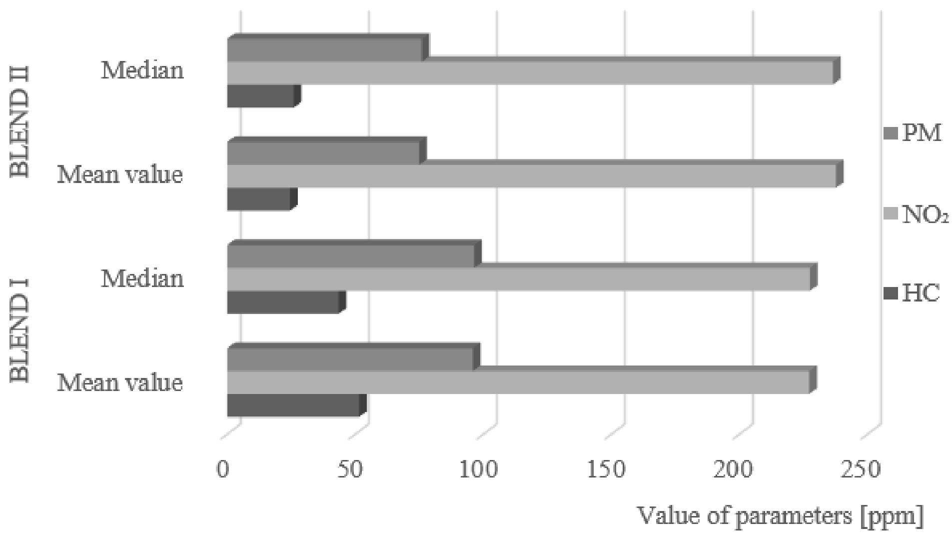

Fig. 7 Performance parameter values for engine

Statistical analysis of the obtained results of measurement of harmful substances in exhaust gases shows that the addition of methyl esters of fatty acids affects the concentration of individual components of exhaust gases. There is a decrease in carbon dioxide, oxygen, and hydrocarbons. During the tests, we also observed an increase in nitrogen oxides and a constant level of carbon oxides, which did not change depending on the changes in the blend supplying the engine. As other authors have pointed out, feeding diesel engines with methyl esters of fatty acids reduces the emission of toxic impurities of exhaust components, such as carbon oxides, hydrocarbons and solid particles *(Agarwal A. K., et al., 2013; Arapaki N., et al., 2007; Armas O., et al., 2010; Choi S., Oh Y., 2006; Fontaras G., et al., 2009; Knothe G., et al., 2006; Lapuerta M., et al., 2008)*. The exception is nitrogen oxides, showing an increase of a dozen or so percent over pure diesel.

CONCLUSIONS

On the basis of literature analysis and own study, performance parameters such as particulate matter in exhaust gases and toxic components of exhaust gases such as carbon monoxide, carbon dioxide, oxygen, hydrocarbons, and nitrogen monoxide were determined. Next, the values of these parameters were measured for tested blends. Obtained results of tests of performance parameters of engine justify the advisability of adding methyl esters of fatty acids to diesel fuel. The analysis of the test results allowed to determine the quantitative content of toxic components and particulate matter emitted during the combustion of individual blends. The study compares two blends: diesel fuel and a blend of 70% diesel fuel and 30% fatty acid methyl esters. The tests show that the use of 30% biodiesel additive reduces particulate matter in exhaust gases by about 20%. In the case of toxic components of exhaust gas, a significant increase in nitrogen oxides was noted during the tests, which increased by about 4.5%. Carbon dioxide remained at a similar level. During the tests, a decrease in oxygen and carbon monoxides was also observed. Hydrocarbons were the most sensitive to changes in the blend. Hydrocarbons decreased from 54 ppm to 9 ppm after the addition of biodiesel to diesel fuel.

REFERENCES

1. Agarwal, A. K., Srivastava, D. K., Dhar, A., Maurya, R. K., Shukla, P. CH., & Singh, A. P. (2013). Effect of fuel injection timing and pressure on combustion, emissions and performance characteristics of a single cylinder diesel engine. *Fuel, 111*.
2. Arapaki, N., Bekeas, E., Karavalakis, G., Tzirakis, E., Stournas, S., & Zannikos, F. (2007). Regulated and unregulated emission characteristics of diesel vehicle operating with diesel biodiesel blend. *SAE Technical Paper, No 1*.
3. Armas, O., Yehliu, K., & Boehman, A. (2010). Effect of alternative fuels on exhaust emission during diesel engine operation with matched combustion phasing. *Fuel, 89*.
4. Bala, B.K. (2005). Studies on biodiesels from transformation of vegetable oils for diesel engines. Energy Edu Sci Technol.
5. Choi, S. & Oh, Y. (2006). The emission effects by the use of biodiesel fuel. *International Journal of Modern Physics B., 20*.
6. Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport. Official Journal of the European Union L 123.
7. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union L 140.
8. Dzieniszewski, G. (2009). Selected ecological and economic aspects of supplying diesel engines with vegetable fuels (in Polish). *Inżynieria Rolnicza, 6(115)*.
9. Dzieniszewski, G. (2015). Ekologiczne problemy biopaliw (Ecological problems of biofuels). *Journal of Civil Engineering, Environment and Architecture*.
10. Fontaras, G., Karavalakis, G., Kousoulidou, M., Tzamkiozis, T., Ntziachristos, L., Bakeas, E., Stournas, S., & Samaras, Z. (2009). Effects of biodiesel on passenger car fuel consumption, regulated and non-regulated pollutant emissions over legislated and real-world driving cycles. *Fuel, 88*(9), 1608-1617.

11. Knothe, G., Sharp, C., & Ryan, T. (2006). Exhaust emission of biodiesel, petrodiesel, neat methyl esters and alkanes in a new technology engine. *Energy and Fuels, 20*.
12. Lapuerta, M., Armas, O., & Rodriguez-Fernandez, L. (2008). Effect of biodiesel fuels on diesel engine emission. *Progress in Energy and Combstion Science, 34*.
13. Leung, D., Luo, Y., & Chan, T. (2006). Optimization of exhaust emission of a diesel engine fuelled with biodiesel. *Energy and Fuels, 20*.
14. Markiewicz-Patalon, M., Kaszkowiak, E., Zbytek, Z., & Szymczak, M. (2017). Comparison of Calorific Values of Petroleum-Driver Fuels with Alternative Fuels of Vegetable Origin. In *Proceedings of 58th International Conference of Machine Design Departments* (pp. 222-225). p-ISBN: 978-80-213-2769-6.
15. Markiewicz-Patalon, M., Muślewski, Ł., Kaszkowiak, J., & Knopik, L. (2018). Analysis of selected operating parameters of engine powered by a mixture of biocomponents and diesel oil. *Journal of Kones Powertrain and Transport, 25*(4). ISNN 1231-4005.
16. Markiewicz-Patalon, M., Muślewski, Ł., Kaszkowiak, J., & Sójka, M. (2018). Analysis of efficiency of the vehicle transport facilities powered with diesel oil with additive of biocomponent. KONMOT, Kraków.
17. Markiewicz-Patalon, M., Muślewski, M., Kaszkowiak, J., & Landowski, B. (2017). Assessment of the suitability of the fuels with component power engines. *Journal of Kones Powertrain and Transport, 24*(4). p-ISSN: 1231-4005.
18. Merkisz, J. & Kozak, M. (2003). Influence of the blend composition of the biofuel and the conventional fuel on exhaust emissions (in Polish). *Eksploatacja i Niezawodność, 3*.
19. Piętak, A. & Radkowski, S. (2006). Wieloaspektowa analiza stosowania paliw alternatywnych w Polsce ze szczególnym uwzględnieniem biopaliw.
20. Pelkmans L. & Debal P. (2006). Comparison of on-road emission with emissions measured on chassis dynamometer test cycles. *Transportation Research, 11*.
21. Peterson C., Toberski J., Thompson J., & Chase C. (2000). The effect of biodiesel feedstock on regulated emission in chassis dynamometer tests of a pickup truck. *American Society of Agricultural of Biological Engineering, 43*(6).
22. Zając, P. (2009). Silniki pojazdów samochodowych. Wydawnictwo Komunikacji i Łączności. Warszawa.

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