Analysis of the noise emission generated by a drive unit powered by mixtures of diesel oil and fatty acid methyl ester

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Abstract. The sound generated by drive units is one of the aspects that are addressed in sustainable transport development strategies. The regulations of the European Union, which indicate the ecological aspect of the use of internal combustion engines as one of the most important, also refer to the level of sound emission generated by these engines. The use of alternative fuels to power combustion engines allows not only to reduce the toxic components of exhaust gases, but also to reduce the noise they generate during operation. The manuscript presents the study of a drive unit powered by mixtures of diesel oil and fatty acid methyl esters, in which the software regulations of the control system were modified. Studies have shown a decrease in the level of sound emission when powered by alternative fuels.

1 Introduction

The development of the transport sector has significantly contributed to the increased use of non-renewable energy sources and negative impact on the natural environment. This has been noticed and regulated by law. The changes introduced in European and national law are aimed at limiting the negative impact of road transport on the natural environment. Pollution from the transport sector is more dangerous than emissions from industry. This is due to their dissemination at low altitudes [1]. The emission of automotive pollutants depends on many factors, such as those presented in Figure 1. The most important are legal regulations regarding ecological transport policy, protection of natural resources, environmental protection programs and anti-pollution measures. One of the applied solutions is the use of renewable fuels.

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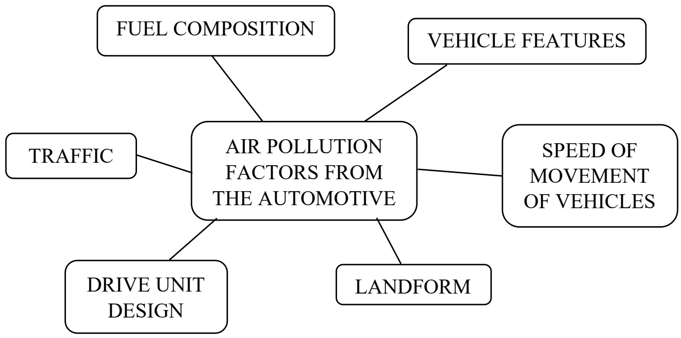

Fig. 1. Air pollution factors from the automotive sector.

The use of renewable energy sources to power internal combustion engines makes it possible to make the economy independent of fossil fuels and reduces the emission of toxic components contained in exhaust gases. The widest applications for the production of biofuels have vegetable oils. Among the alternative fuels of plant origin used to power diesel engines, the following can be distinguished: rapeseed oil, peanut oil, sunflower oil, soybean oil and animal fats [2, 3, 4]. Fuels of plant origin, called biofuels, undergo chemical processes in order to obtain physicochemical properties similar to those of diesel fuel. For structural, technical, technological and economic reasons, rapeseed oil is the most commonly used. Biogas produced from waste from fruit and vegetable processing and waste, as well as post-pyrolysis oil, i.e. a mixture formed in the process of thermal decomposition of organic substances from used car tires, can also be used to power diesel engines [5, 6]. Another raw material used as a source of biofuels are microalgae [7, 8]. Municipal waste, sewage and residual waste from the agricultural industry can also be used for the production of biofuels for the diesel engine [9, 10]. Diesel engines can also be fueled with used vegetable oil, i.e. post-frying waste, but this requires the use of a dual-fuel system, where the start-up takes place on diesel oil [11, 12]. The most popular and most commonly used is rapeseed oil.

In the literature, you can find research on internal combustion engines powered by alternative fuels, which concern the efficiency of engine operation, fuel consumption and individual components of exhaust gases, including particulate matter. Studies of the efficiency of the engine fueled with vegetable fuels showed changes in the engine's operating parameters, including an increase in fuel flow resistance, an increase in fuel density, a decrease in engine power and a decrease in overall engine efficiency [13, 14, 15]. Based on research on fuel consumption, an increase in the demand for fuel can be seen [16, 17, 18]. Fuel consumption, with the use of a 35% addition of fatty acid methyl esters to diesel fuel, increases by about 18% compared to pure diesel fuel [19, 20]. Changes in specific fuel consumption are noticeable already at a 5% percentage addition of biocomponent to diesel oil [21, 22, 23]. Another important parameter is the level of sound emission generated by the engine. The password emitted by the drive unit is an important ecological criterion, which is also considered in the Sustainable Transport Development Strategies presented by the European Commission.

The paper presents the course of testing the sound emission of a drive unit powered by mixtures of diesel oil and fatty acid methyl esters for five adjustments of the fuel injection controller and the analysis of the obtained results. The noise generated by the test object, as one of the important operating parameters, has been presented due to the sensitivity related to the change of the fuel mixture and the settings of the fuel injection controller.

2 Material and methods

The research material consisted of vegetable oils subjected to the process of transesterification, i.e. the exchange of chemically bound glycerin in the triacylglycerol molecule for added methyl alcohol in the presence of an alkaline or acid catalyst, commonly referred to as biocomponents. The description and composition of the tested mixtures are presented in Table 1.

Table 1. Composition of tested fuel mixtures.

Fuel mixture composition	symbol
diesel fuel without the addition of fatty acid methyl esters	ON
90% diesel oil 10% fatty acid methyl esters	BIO10
70% diesel oil 30% fatty acid methyl esters	BIO30
50% diesel oil 50% fatty acid methyl esters	BIO50

The tests were carried out for a compression-ignition drive unit, shown in Figure 2. The engine used for the tests is installed in vehicles with a maximum permissible weight not exceeding 3.5 t. It is characterized by direct fuel injection, the Common Rail system and electromagnetic injectors. The drive unit works with a turbocharger. The engine did not have a diesel particulate filter. The power unit was 16-valve and had a timing belt. The characteristics of the engine used for the tests are presented in Table 2.

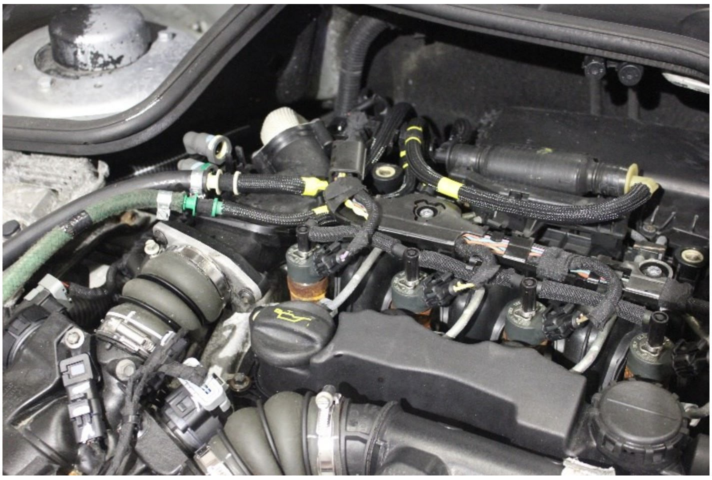

Fig. 2. Air pollution factors from the automotive sector.

Table 2. Engine characteristics.

engine typ	diesel engine
Fuel type	diesel oil
displacement	1560 cm^3
engine power	110 KM (81 kW) at 4000 rpm
maximum torque	240 Nm at 1750 rpm
number of cylinders	4
cylinder arrangement	In-line
cylinder diameter	73 mm
piston stroke	88,3 mm
number of valvers	16

fuel injection type	direct, common rail
recharge	turbocharging
injectors	electromagnetic
particulate filter	no

In the test facility, modifications were made to the electronic system, which were carried out by changing the factory software of the engine computer. The introduction of changes in the software of the fuel injection control system was aimed at verifying changes in the level of sound emission generated by the engine. Due to the specificity of the electronic system of the vehicle, each time the on-board computer was dismantled and mounted on a special stand, which is shown in Fig. 3. Before introducing changes to the computer software, a diagnostic measurement was performed in order to determine the possibility and legitimacy of increasing the engine parameters.

Fig. 3. Air pollution factors from the automotive sector.

Changes introduced in the vehicle computer software were made in accordance with the test schedule. The modifications consisted in increasing the fuel dose and increasing the air boost. The tests included four adjustments of the fuel injection controller, which are presented in Table 3.

Table 3. Vehicle computer software modification.

modification number	characteristic
I	Factory settings
II	Fuel dose increased by 2% and air boost increased by 50 hPa
III	Fuel dose increased by 4% and air boost increased by 50 hPa
IV	Fuel dose increased by 6% and air boost increased by 50 hPa

The sound emission tests were carried out while simulating the motion of the vehicle on a load chassis dynamometer. The sound emission level generated by the engine was determined using a sound level meter with a built-in spectral analyzer that meets the requirements of the IEC 61672-1:2002 and IEC 60651 standards. The sonometer used for the tests is shown in Figure 4.

Fig. 4. Sound level meter.

The assessment of the sound level depended on its duration and its level. These values were determined at the maximum load of the drive unit. The technical characteristics of the device are presented in table 4.

Table 4. Vehicle computer software modification.

microphone	1/2", capacitive, free field, pre-polarized
dynamic range	30dBA – 143 dB
linear range	80 dB
spectral analysis - octave bands	od 32Hz do 8kHz
spectral analysis - 1/3 octave bands	od 25Hz do 12,5kHz
simultaneous measurements	SPL, L_{eq}, S_{EL}, L_F, L_{max}, L_{min}, L_{pk}, L_{MPk}, L_N
time constants	S, F, I
integration time	from 1s to 99 hours
measurement error	$< 0,5\ dB$
operating temperature	-10°C - 50°C
operating humidity	25 - 90% RH
static pressure	65 - 108 kPa
thermal stabilization time	10 s

The principle of operation of the meter was based on the study of the acoustic signal, which in the form of a pressure wave reaches a condenser microphone with a linear frequency response. During the test, capacitance changes associated with diaphragm vibrations were converted into proper voltage changes. The resulting signal reached the amplifier and then to the output circuit through filtering circuits. When the signal reached the output circuit, it was possible to read the measurement result on the digital display of the device. The meter was equipped with correction filters, the feature of which is to adjust the characteristics of the transmitted sound to the characteristics of the human ear. Determination of the acoustic parameters of the drive unit was carried out using an indicative method aimed at determining the level of acoustic power. This method consisted in calculating the corrected sound power level and the sound power level in the frequency bands, based on the sound pressure level in the frequency bands and the sound level measured using the correcting filter.

3 Results

The obtained test results were statistically analyzed using the Statistica program. First, the basic statistical values were determined. Then, the Kolmogorov λ test was performed to verify the hypothesis that the population has a specific distribution. The test was possible because all hypothetical values of the distribution were known. Then, the hypothesis about the equality of the mean values of a series of samples was verified using the analysis of variance method. The test concerned the comparison of the average values of four mixtures and four adjustments of the engine control system software. In total, 10 tests were carried out, each time the value of the sound emission level generated by the engine was subjected to. The null hypothesis was that the mean values are equal. The significance levels for the mean value comparison test are shown in Table 5.

Table 5. Vehicle computer software modification.

regulation	**I**	**II**	**III**	**IV**
	0,0001	0,0001	0,0006	0,0001
fuel mixture	**ON**	**BIO10**	**BIO30**	**BIO50**
	0,0001	0,0001	0,0001	0,0001

The table contains the results of the significance level study, where $p = 0.0001$ means that the actual significance level is lower. In the conducted test, the basis for rejecting the hypothesis of equality of mean values was obtained. The performed analysis of variance allowed to obtain the results presented in Fig. 5.

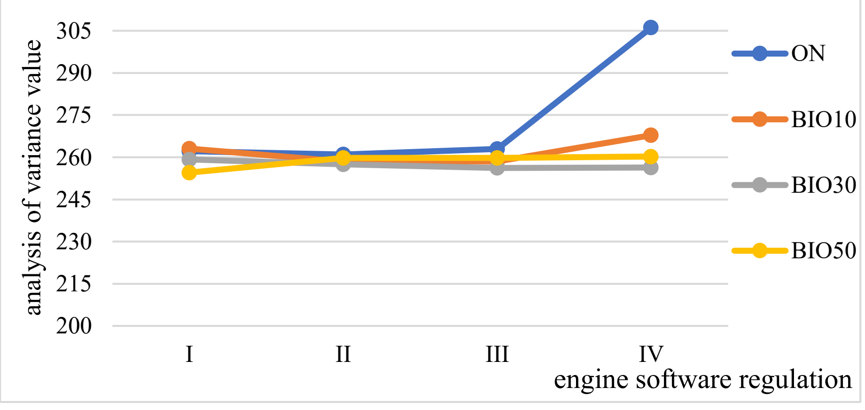

Fig. 5. The level of sound emission depending on the fuel mixture used and engine software adjustment.

According to the performed compatibility test, the one-dimensional distribution of the examined features can be considered normal. The population that was analyzed gave a 120-element sample n, which provided specific measurement results for the examined features x and y. x denotes the type of mixture used, and y the results of the drive unit sound level test for the appropriate software adjustments of the engine control system. Therefore, in the regression analysis, the independent variables are the software adjustments, and the dependent variables are the level of sound emissions generated by the engine. The interpretation of the regression function in the case of testing engines powered by alternative fuel concerns the usefulness of individual variables in the statistical model to predict the level of dependent variables. The paper presents an exemplary regression equation for one software adjustment of the engine control system. The values of the estimators a and b were determined by the least squares method, and the differences between the measurement values and their mean value and the values of specific functions were also calculated. On this basis, the regression line was estimated in the form:

$$y = 0,0292x + 121,788$$

The correlation coefficient for the above regression equation was r = -0.732. Testing the hypothesis H0: a = 0 gave $p < 0.0001$, which means that the examined relationship is statistically significant. Figure 6 shows a graph showing the linear regression for the analyzed case.

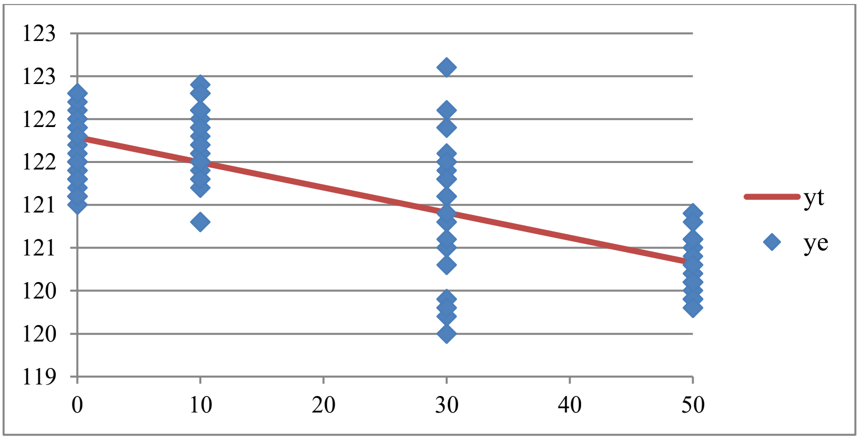

Fig. 6. Linear regression plot for the analyzed instance.

The conducted statistical analysis made it possible to obtain information on the examined dependencies. The analysis of the test results shows that the level of sound emission in the case of the diesel fuel mixture increased significantly for the fourth regulation of the engine control system software. In the case of the BIO30 mixture for regulation II and III, the noise level decreased, but with regulation IV it increased by 1.8% compared to the standard engine settings. For the BIO30 mixture, a decrease in the level of sound emission was noted in relation to changes in the drive unit computer software. In the case of the BIO50 mixture, the sound emission level increased with the change of engine control system adjustment.

4 Conclusions

The level of sound emission generated by internal combustion engines is one of the ecological aspects that are regulated by the provisions of European Union law. Regulations in this area indicate a nuisance for the natural environment and the need to reduce the sound emission generated by the engine. The research presented in the paper was aimed at determining the level of noise generated by an engine fueled with fuel mixtures with the addition of a biocomponent with variable adjustments of the engine software. The paper presents a fragment of the tests that the research object was subjected to. The obtained test results show that the level of sound emission slightly changes with the change of engine control system software. This change is minor compared to the axles that can be achieved with such modifications. Fueling the engine with mixtures of diesel oil and fatty acid methyl esters keeps the sound emission levels at an even level, in some cases even lowering them with variable adjustments of the engine software. Based on the obtained results, it can be concluded that the introduced modifications and the use of alternative fuel mixtures are justified from the point of view of environmental friendliness.

References

1. Pyza D., Systemy przewozowe- problemy obsługi, potencjał i jego utrzymanie, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa (2019)
2. Aspen D., Sparrevik M., Evaluating alternative energy carriers in ferry transportation using a stochastic multi-criteria decision analysis approach, Transportation Research Part D: Transport and Environment, 86 (2020)
3. Pattanaik P., DevMisra R., Effect of reaction pathway and operating parameters on the deoxygenation of vegetable oils to produce diesel range hydrocarbon fuels: A review, Renewable and Sustainable Energy Reviews, 73 (2017)
4. Masera K., Hossain A., Biofuels And Thermal Barrier: A Review On Compression Ignition Engine Performance, Combustion And Exhaust Gas Emission, Journal Of The Energy Institute, 92 (2019)
5. PrabhuaA., Avinasha A., Brindhadevi K., Pugazhendhi A., Performance and emission evaluation of dual fuel CI engine using preheated biogas-air mixture, Science of The Total Environment, 754 (2021)
6. Deheri C., Kumar S., Dhirendra A., Ambica N., Mohanty P., Fuel, 260 (2020)
7. Singh J., Commercialization petential of microalgae for biofuels production, Renewable and Substainable Energy Revews, 14 (2010)
8. Wierzbicki S., Biogas as a fuel for diesel engines, Jurnal of Kones Powertrain and Transport, 19, 3 (2012)
9. Jaglarz G., Generowicz A., Charakterystyki energetyczne odpadów komunalnych po procesach odzysku i recyklingu, Ekonomia i Środowisko, 2, 53 (2015)
10. Nigam P., Singh A., Production of liguid biofuel from renewable resource, Progress in Energy and Combustion Science, 37 (2011)
11. Ghobadian B., Rahimi H., Nikbakht A., Najafi G., Yusaf T., Diesel engine performance and exhaust emission analysis using waste cooking biodiesel fuels with an artificial neural network, Renewable Energy, 34 (2009)
12. Muślewski Ł., Markiewicz M., Pająk M., Kałaczyński T., Koral D., Analysis of the Use of Fatty Acid Methyl Esters as an Additive to Diesel Fuel for Internal Combustion Engines, Energies, 14 (2021)
13. Markiewicz M., Muślewski Ł., The Impact of Powering an Engine with Fuels from Renewable Energy Sources including its Software Modification on a Drive Unit Performance Parameters, Sustainability, 11, 23 (2019)
14. Markiewicz M., Muślewski Ł., Kaszkowiak J., Knopik L., Analysis of selected operating parameters of engine powered by mixture of biocomponents and diesel oil, Journal of KONES Powertrain and Transport, 25 (2018)
15. Markiewicz M., Pająk M., Muślewski Ł., Analysis of Exhaust Gas Content for Selected Biofuel-Powered Combustion Engines with Simultaneous Modification of Their Controllers, Materials, 14 (2021)
16. Monfijur M., Hyde M., Recent Developments on Internal Combustion Engine Performance and Emissions Fuelled With Biodiesel-Diesel-Ethanol Blends, Procedia Engineering, 105 (2015)
17. Likhanov V., Lopatin O., Research of high-speed diesel engines of small dimension on biofuel, Journal of Physics: Conference Series, 1399 (2019)

18. Markiewicz M., Muślewski Ł., Survey performance and emission parameters of diesel engine powered by diesel oil and fatty acid methyl esters using fuzzy logic techniques, Fuel, 277 (2020)
19. Likhanov V., Lopatin O., Yurlov A., Biofuel based on methanol and methyl ester of rapeseed oil for diesel engine, IOP Conference Series: Materials Science and Engineering, 734 (2020)
20. Markiewicz M., Muślewski Ł., Pająk M., Impact of Biocomponent Additive to Diesel Oil on Values of Selected Functional Parameters of Transport Means, Polish Journal of Environmental Studies, 29 (2020)
21. Mikulski M., Duda K., Wierzbicki S., Performance and emissions of a CRDI diesel engine fuelled with swine lard methyl esters–diesel mixture, Fuel, 164 (2016)
22. Zivkovic S., Veljković M., Environmental Impacts The Of Production And Use Of Biodiesel, Environmental Science And Pollution Research , 25 (2018)
23. Hossain N., Mahlia T., Saidur R., Latest development in microalgae-biofuel production with nano-additives, Biotechnology for Biofuels, 125 (2019)