Article citation info:
Markiewicz M, Kaszkowiak J, Hujo L. The effect of ethanol in gasoline on exhaust gas components emitted by spark ignition engines. Combustion Engines. 0000;XXX(X):xx-xx. https://doi.org/10.19206/CE-206029

Marietta MARKIEWICZ
Jerzy KASZKOWIAK
Lubomir HUJO

Combustion Engines
Polish Scientific Society of Combustion Engines

The effect of ethanol in gasoline on exhaust gas components emitted by spark ignition engines

ARTICLE INFO

Received: 25 April 2025
Revised: 27 May 2025
Accepted: 7 June 2025
Available online: 5 August 2025

Fuels of natural origin are the most frequently used source of power for spark ignition engines. Their exhaustibility causes the search for alternative sources, which are plant-derived fuels. The paper presents tests of the amount of exhaust gas components in a spark ignition engine powered by mixtures of gasoline and ethyl alcohol. Pure ethanol and gasoline without biocomponent additives were used as research material. The experiments were performed using an exhaust gas analyzer and a particle analyzer during tests on a chassis dynamometer. The drive unit used for the tests was powered by mixtures with various ethanol content, from 10% to 100%. The analysis of the conducted tests showed a reduction in the amount of the formation of exhaust gas components hazardous to the natural environment.

Key words: *petrol engine, biofuels, engine, environmental protection, noise emission*

1. Introduction

The most commonly used source of power for spark ignition engines are fuels of natural origin. Exhaustibility of these fuels makes it necessary to seek new solutions, such as alternative fuels. Emission of exhaust gas components and soot particles to the natural environment is another important argument in favor of alternative fuel application. The kind of fuel mixture to be used depends on the design of the drive unit. The fuel which is most frequently used for spark ignition engines is ethanol. Application of biofuels in drive units is one of the methods to reduce greenhouse gas emission. This is set out in Directive 2009/28/WE of the EU Parliament and of the Council of 23 April 2009 on the promotion and application of energy from renewable sources. Ecological aspects connected with the application of fuels from different renewable sources are very important for the sustainable development of transport [7, 27]. Constantly growing transport increases the demand for energy, which subsequently leads to an increase in fuel consumption by 3% annually [37]. This, in turn, causes pollution of the natural environment by emission of exhaust gas components such as carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides, and solid particles.

Despite the benefits of using ethanol as a fuel additive, its use is also associated with a number of potential risks to the durability and reliability of fuel systems and engine lubrication. Ethanol has hygroscopic properties, meaning it has the ability to absorb moisture from the environment. The presence of water in the fuel system can lead to phase separation in the fuel mixture, corrosion of metal components, and problems with engine starting. Furthermore, ethanol may have a harmful effect on plastics and elastomers commonly used in vehicle fuel systems, such as seals, fuel lines, and membranes. These materials may swell, harden, become brittle, or even cause the fuel system to leak. Additionally, the use of ethanol-gasoline blends can lead to increased dilution of lubricating oil in the engine's crankcase. Fuel entering the oil reduces its viscosity and lubricating properties, leading to faster oil degradation and the need for more frequent oil changes. In extreme cases, this can result in reduced engine durability and increased wear of its components [5, 10, 12, 25, 36].

The most popular blend of ethanol and gasoline is E85 bioethanol, containing 85% ethanol and 15% unleaded gasoline [30, 32, 33]. The components of the above-mentioned blend need to comply with current norms. In the case of ethanol, it is EN 15376 norm, and for unleaded gasoline, EN 228 norm. An important reference when discussing the impact of ethanol in fuels on the operation of internal combustion engines, including exhaust emissions, is the document "Ethanol Guidelines" developed by the Worldwide Fuel Charter Committee. This document provides recommendations regarding the quality of ethanol as a fuel additive (e.g., water, sulfur, metal, and contaminant content), insights into the effects of ethanol on exhaust emissions and engine performance (such as knock resistance and cold start behavior), the durability of materials in the fuel system (e.g., corrosion, elastomer swelling), as well as potential technical issues related to engine fueling [33]. E85 is recommended for flexible fuel vehicle FFV engines whose design is adjusted to this kind of fuelling. Bioethanol E85 is a collarless liquid obtained from the fermentation of plants such as corn, sugar cane, or sugar beets [3, 16, 22, 30, 42]. The most popular plants used for the production of bioethanol in Europe are corn products and sugar beets. As a result of their fermentation, a water solution of ethanol (about 15%) and other alcohols is obtained. Pure ethanol comes from a distillation process whose outcome is a rectified spirit containing 96% ethanol and 4% water [15]. Ethanol for industrial purposes is obtained from synthesis gas as a result of direct synthesis. The substance is a chemically clean ethanol. Results of tests of bioethanol provided by the literature indicate that, compared to gasoline, it is characterized by [2, 17, 29]:

- lower calorific value
- lower need for air during fuel combustion
- higher octane number

Table 1. Selected properties of the fuel blends [12, 40]

Properties	Gasoline	Mixture of 85% ethanol and 15% unleaded gasoline	Ethanol
Density	720–775 km/m^3	785 km/m^3	794 km/m^3
Calorific value	42.3–43.5 MJ/kg	29 MJ/kg	26.8 MJ/kg
Test octane number	95	105	120–135
Motor octane number	85	90	100–106
Air excess coefficient	14.7–14.7	9.7	3.5–17
Vaporation heat	350 kJ/kg	780 kJ/kg	855–870 kJ/kg

– lower ignition energy
– higher susceptibility to corrosion and melting of the engine rubber elements.

The properties of fuel blends determine their suitability to be used as a power source for the drive unit. They are also determinants of optimization for the exhaust gas components, the engine performance and its functional qualities. The fuel is supposed to provide an engine with proper efficiency and performance parameters as well as compliance with emissivity norms in its life cycle. Although the basic fuel for a spark engine has always been gasoline, the environment-friendly approach involves the need to search for alternative fuel sources, for instance, such as ethanol or a mixture of 85% ethanol and 15% unleaded gasoline [13, 22, 35, 41]. The most significant differences between these mixtures are presented in Table 1.

Literature provides results of tests conducted for drive units fueled with gasoline and ethanol blends [9, 20, 21, 23, 26, 32]. Authors of numerous publications claim that because of the design, only mixtures with 10% of ethanol are suitable for spark ignition engines. In order to reduce the risk of damage to the drive unit, it is necessary to modify the computer control system. Modifications of the engine computer control systems are supposed to adjust the engine to a given fuel mixture, and they are applied to the fuel injection system by changing the intake valve opening timing [8, 11, 14]. Tests of drive units fueled with E85 mixtures indicate problems with the engine startup in low temperatures. Literature provides results of tests of the exhaust gas components, which were conducted in real road conditions [4, 7, 8, 31]. Test results concerning vehicles powered with gasoline and ethanol blends show a reduction in emission of the exhaust gas components, including: carbon dioxide, carbon monoxide, nitrogen oxides, and hydrocarbons. Moreover, the tests indicate an increase in the fuel consumption by app. 30% [1, 24, 26, 41].

The idea of using alternative fuels was imposed by pro-ecological strategies introduced by the European Union. The European Parliament and Council directive number 2018/8421 imposes a requirement to comply with the norms regarding exhaust gas emission from transport by the member states. The major goal set out in the directive is to reduce greenhouse gas emission by 40% up to 2030 in reference to 2005. Currently, there are exhaust emission norms that need to be complied with in the territory of the European Union. Recently, a new exhaust emission norm – Euro 6D ISC FCM has been introduced. Each successively introduced exhaust gas emission norm reduces nitrogen oxides and carbon dioxide emissions to the environment by motor vehicles. The current norm allows a spark ignition engine vehicle to emit 60 mg NO_x per kilometer. Whereas, in the case of carbon dioxide emission, the regulations provide for its reduction down to 95 g/km. The European Union legislation on harmful exhaust gas component reduction are being constantly modified. The European Commission announced the introduction of the next Euro 7 norm that would rigorously reduce the emission of carbon monoxide, nitrogen oxides, and solid particles. The norm is also supposed to impose strict requirements for vehicles to be equipped with filters and catalyzers. The changes to be introduced are supposed to reduce the negative impact of transport on the natural environment, which involves taking actions to promote the application of ecological transport forms. [5, 6, 19, 24, 34].

The introduction of exhaust emission standards and the requirement to reduce the emission of harmful substances released from spark-ignition engines during combustion necessitate the design and implementation of new fueling solutions for power units. Regulations introduced by the European Union and its member states are intended to ensure sustainable development in transportation. Research findings reported in the literature indicate a reduction in exhaust gas components and particulate matter emissions from engines fueled with gasoline-ethanol blends [1, 4, 8, 9, 11, 14, 18, 20–23, 26, 28, 31, 32, 37]. The studies were conducted for various computer-controlled engine management systems, aiming to improve engine performance and reduce its environmental impact. Researchers are seeking solutions that would enable the achievement of goals outlined in the European Union's sustainable transport development documents while maintaining high vehicle performance parameters. The use of ethanol as a bio-component in small amounts (up to 10%) has little effect on exhaust composition and does not require engine recalibration. However, for ethanol content above 10%, engine adjustments, particularly of fuel dosage, are recommended due to the adverse effects of an overly lean air-fuel mixture, which can lead, among other things, to an increase in hydrocarbon content in the fuel [38, 39, 43].

This study aims to verify the exhaust gas components emitted to the natural environment by a spark ignition engine fueled with different blends of gasoline and ethanol, and for different adjustments of the engine computer control system.

2. Materials and methods

The conditions of the tests were similar to real road traffic. The tests were carried out for a spark ignition engine with a multipoint ignition fueled with a blend of gasoline and ethanol.

The material used in the tests was ethyl alcohol and unleaded gasoline. The gasoline used in the tests had no bio-component additives. Proportions of the blends are presented in Table 2.

Table 2. Proportions of mixtures used in tests

No.	Mixture composition	Denotation
1	100% unleaded gasoline	PB100
2	90% gasoline 10% ethanol	BIO10
3	70% gasoline 30% ethanol	BIO30
4	50% gasoline 50% ethanol	BIO50

The material used in the tests was unleaded gasoline and dehydrated ethyl alcohol with maximum 1% water content which is obtained from a biomass. A sample blend is shown in Fig. 1. The properties of the individual tested blends are presented in Table 3.

Fig. 1. Fuel blend used in tests

Table 3. Selected properties of the tested fuel mixtures

Properties	PB100	BIO10	BIO30	BIO50
Density	0.72–0.77 g/cm³	0.81 g/cm³	0.85 g/cm³	0.72 g/cm³
Calorific value	42.3–43.5 MJ/kg	40–42 MJ/kg	36 MJ/kg	34 MJ/kg
Test octane number	95	96	99	99.5
Air excess coefficient	14.7–14.7	13.2	12.2	10.6
Vaporation heat	350–400 kJ /kg	350–400 kJ/kg	350–400 kJ/kg	350–400 kJ/kg

The research object was a vehicle powered with 8 valve engine with spark ignition and multipoint injection, whose cylinder capacity was 1242 cm^3, power 44 kW, and maximum torque 102 Nm. It was a drive unit that met the Euro 4 standard. The tested drive unit is presented in Fig. 2. It was chosen due to its widespread use in motor vehicles (numerous cars make are equipped with this type of drive unit). The unit selected for testing was not equipped with an exhaust gas cleaning system; the authors wanted to obtain the most reliable engine emissions results possible.

The tests were carried out with the use of a gasoline and ethyl alcohol blend. The research subject was to analyze the effect of ethanol content change on the values of exhaust gas components emitted to the natural environment by the drive unit. Technical specifications of the engine are presented in Table 4.

Fig. 2. Drive unit used in the tests

The tests were carried out with the use of a gasoline and ethyl alcohol blend. The research subject was to analyze the effect of ethanol content change on the values of exhaust gas components emitted to the natural environment by the drive unit.

Table 4. Specifications of the investigated engine

Engine type	Inline, Spark ignition
Engine capacity	1242 cm^3
Number of cylinders	4
Number of cylinder valves	2
Timing system	OHV
Engine power	44 kW
Torque	102 Nm for 2500 rpm
Engine placement	Diagonally in the vehicle front
Compression ratio	9.8
Type of fueling system	Multipoint injection

Prior to the experiment, the engine oil, oil filter, air filters, and fuel were changed in the drive unit. The supply system was adjusted so as to allow a noninvasive fuel change. Those adjustments were applied to the fuel supply system. An additional fuel tank was connected. A special 5 dm^3 tank was used. The fuel excess returned to the external fuel tank through a special return pipe. After each fuel change, the engine worked for about 10 minutes in order to remove the remaining fuel from the fuel filter and the supply system. Prior to measurements, the engine had been heated up until the temperature of the liquid coolant reached 75°C. The ambient temperature was 15°C and the pressure was 1004 hPa.

The experiment was supposed to determine the amount of exhaust gases generated by a spark injection engine fueled with a mixture of gasoline and ethyl alcohol in different proportions. The tests were carried out on a chassis dynamometer with an eddy current brake, under conditions reproducing real traffic. Required loads were applied to the vehicle. Exhaust gas and solid particle analyzers were connected to the vehicle to determine the content of exhaust components that were emitted to the environment. Measurements of the exhaust component concentration were carried out by an exhaust gas analyzer to define the amount of exhaust gas components discharged to the environment in the form of gases. The goal was to determine the values of such compounds as: hydrocarbons (HC), oxygen (O_2), carbon dioxide (CO_2), and carbon monoxide (CO). From the perspective of emissions from spark-ignition engines, nitrogen oxides and nitrogen dioxide are also important components; however, these are the subject of discussion in a separate study. A solid particle analyzer using an optical method was applied to measure particles larger than 100 mm. During its operation, an engine produces particles of carbon and absorbs smaller ones, i.e., soot. The distribution of solid particle dimensions, that is, their number, was determined using an electronic particle counter. All the measurements were performed for a spark ignition engine under the conditions of maximal loads.

The tests were carried out on a single-axle chassis dynamometer equipped with a DynoTech DS04 2WD eddy current brake. The support roller diameter was 323.9 mm, and the dynamometer was electronically controlled. During the measurements, the room temperature was 15°C, with fluctuations of less than 1°C. Atmospheric pressure remained at 1000.4 hPa, with variations of less than 5 hPa throughout the testing period. Measurements were conducted until the tested parameters stabilized.

3. Results

3.1. Statistical analysis

The results obtained from the tests were statistically analyzed and verified for their significance from the point of view of the drive unit functioning.

The test results were statistically analyzed (variance analysis) by means of the Statistica program, with the use of the Tukey test. The content of solid particles in the exhaust gases decreased along with an increase in ethanol to reach a minimum of 30% ethanol content. An increase in the solid particle content was found for an increase in ethanol up to 50%. Differences in the amount of solid particles were statistically significant for all ethanol content levels in the fuel. Such changes of the solid particle amount is probably the effect of lean mixture for higher content of ethanol (the demand for oxygen drops). A drop in the content of solid particles would probably be maintained for an increasing content of ethanol in fuel. The curve of solid particle amount change is presented in Fig. 3.

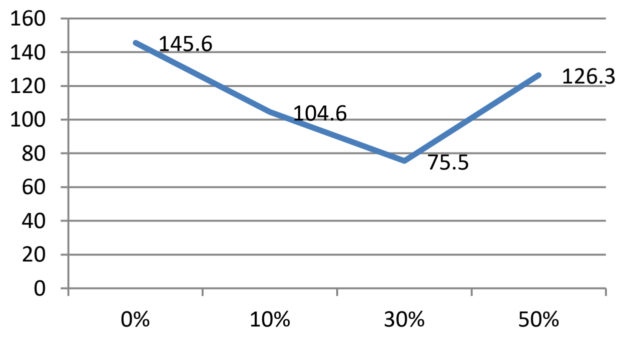


Fig. 3. Amount of solid particles depending on ethanol content in fuel

The content of carbon monoxide was decreasing along with an increase in the content of ethanol in fuel. For 30% and 50% of ethanol content, the differences were found statistically insignificant. This indicates more complete fuel combustion for an increasing content of ethanol. The value changes of carbon monoxide content in exhaust gases is presented in Fig. 4.

CO_2 content in exhaust gases slightly decreased with the increasing ethanol content. Differences occurred only when the level of ethanol content reached 50%. A drop in the percentage share of carbon dioxide in the exhaust gases is probably the effect of air excess in the fuel air mixture (engine setting correction needed). The content of carbon dioxide in exhaust gases is presented in Fig. 5.

The content of oxygen increased with an increase in ethanol content in the fuel. The value differences were statistically significant for all ethanol content levels in the fuel. This is due to a smaller demand for oxygen during combustion of ethanol than combustion of gasoline. The value change curve for oxygen content in exhaust gases is presented in Fig. 6.

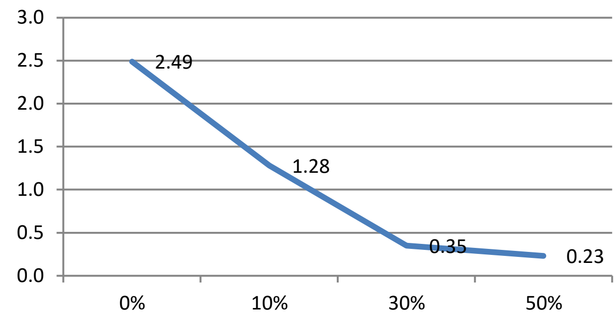


Fig. 4. Dependence of carbon monoxide content change in exhaust gases on the ethanol content in fuel

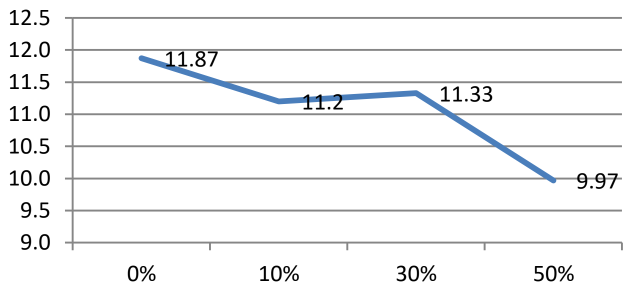


Fig. 5. CO_2 content in exhaust gases depending on the content of ethanol in fuel

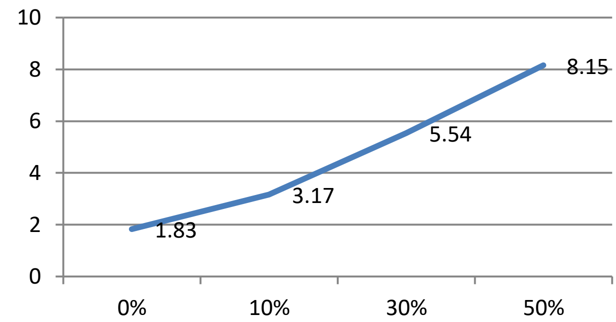


Fig. 6. Value change curve for oxygen content in exhaust gases

The content of hydrocarbons in the fuel changed with the increasing content of ethanol. For fuel without ethanol, the amount of hydrocarbons was 331 ppm. on average, and it decreased down to 254.8 ppm for 10% of ethanol content (statistically significant difference). Next, it increased for ethanol content up to 332.6 ppm averagely and differed significantly statistically from the amount of hydrocarbons in the fuel with no ethanol additive. For 50% of ethanol content, a statistically significant drop in the amount of solid particles was found, though with a value lowest within the analyzed range. The value change curve for hydrocarbon content in exhaust gases is presented in Fig. 7.

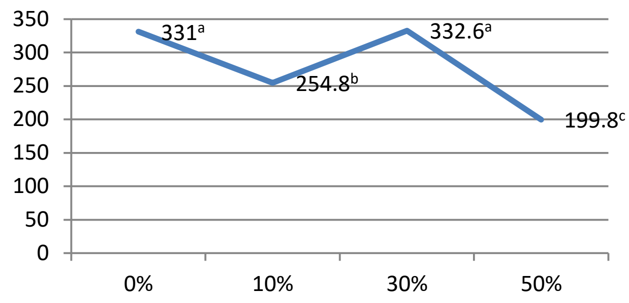


Fig. 7. Value change curve for hydrocarbon content in exhaust gases depending on the ethanol content

3.2. Assessment model for the drive unit quality of functioning

In this study, parameters were identified (concentrations of the exhaust components), to be later evaluated for their impact on the research object functioning quality. In the developed model, X stands for one-dimensional vectors which were accepted to be random variables. The analyzed parameters represent performance of spark ignition engines fueled with gasoline and ethanol blends. Then, the vector assumes the following form:

$$X_i = < X_1, X_2, X_3, X_4, X_5 > \quad (1)$$

where the form vector components are: X_1 – solid particles contained in exhaust gases, X_2 – carbon monoxide, X_3 – carbon dioxide, X_4 – oxygen, X_5 – hydrocarbons.

For the research object used, the random variable is in the form:

$$Z_x = \sum_{i=1}^{p} \alpha_i X_i \quad (2)$$

where: $\alpha_i \geq 0, \sum_{i=1}^{p} \alpha_i = 1$, α_i, i = 1,2,…, p – stand for the values of weights for particular parameters, Z_X – is a random variable, being a finite mixture of variables: X_i, i = 1,2,…,p.

MOA (multi criteria optimizations analysis) was used for the above case. AHP method (Analytic Hierarchy Process) was used for determination of heights for particular parameters. In order to perform measurements of uncountable criteria, the assessment was rendered in a numerical form, according to an accepted grading scale that is presented in Table 5.

Based on the prepared grading scale, a reversed comparison in pairs was made. The grades were presented in the form of a square matrix. First, a matrix was built to define the significance degree for the criteria in reference to the assumed goal, in the following form:

Table 5. Grading scale accepted for the analysis

Grade	Definition	Explanation
1	Equal significance	The effect of compared parameters is the same
3	Slight dominance	One parameter is slightly more important than the other
5	Significant dominance	Significant dominance of one parameter over the other
7	Large dominance	Distinct dominance of one parameter over the other
9	Absolute dominance	Dominance of one parameter over the other is of absolute character
2,4,6,8	Intermediate values	If a compromise between two adjacent grades is needed

$$q = \begin{bmatrix} 1 & q_{1,2} & \cdots & q_{1,n} \\ \frac{1}{q_{1,2}} & 1 & \cdots & q_{2,n} \\ \vdots & 0 & 1 & \vdots \\ \frac{1}{q_{1,n}} & \frac{1}{q_{2,n}} & \cdots & 1 \end{bmatrix} \quad (3)$$

Next, a matrix was created to indicate the significance degree of the accepted decision variants in reference to each subcriterion from the directly higher level, defined as a matrix of normalized grades in the form:

$$q = \begin{bmatrix} 1 & \frac{q_{1,2}}{\sum_{i=1}^{n} q_{i,2}} & \cdots & \frac{q_{1,n}}{\sum_{i=1}^{n} q_{i,n}} \\ \frac{q_{2,1}}{\sum_{i=1}^{n} q_{i,2}} & 1 & \cdots & \frac{q_{2,n}}{\sum_{i=1}^{n} q_{i,n}} \\ \vdots & 0 & 1 & \vdots \\ \frac{q_{n,1}}{\sum_{i=1}^{n} q_{i,2}} & \frac{q_{n,2}}{\sum_{i=1}^{n} q_{i,2}} & \cdots & 1 \end{bmatrix} \quad \textbf{(4)}$$

Then, a mean value of the priority vectors was calculated for an element of each matrix verse of normalized grades which determined the relative weight (significance). The sum of priorities was equal to 1. Next, measures of the comparison consistence and the value of eigen vector were calculated, and the inconsistence index and coefficient were constructed. The sum of partial priorities for a given decision variant was determined to be its global priority, which means that the variant with the highest priority is considered to be the best. The share of priorities of a given variant in the main goal through implementation of the analysed parameters is presented in Table 6.

Table 6. Determination of significance (weights) for the analyzed parameters

Denotation	Explanation	Weight
α_1	exhaust gas solid particles	0.215
α_2	carbon monoxide	0.143
α_3	carbon dioxide	0.558
α_4	oxygen	0.046
α_5	hydrocarbons	0.038

Tests of the drive unit were carried out in 24 hour time intervals, ten repetitions for each parameter. Based on the tests, the values of each parameter were determined for each time interval, The values determined for the considered parameters were recoded so that the minimal value would reflect the worst level, whereas the maximal value would represent the most desired one. For transparency and unambiguity of the results, the values on the analyzed set were normalized onto interval <0–10>, using the following dependency:

$$10 \times \frac{(X_i - X_{min})}{(X_{max} - X_{min})} \quad (5)$$

The results were used to determine mean values and variability intervals (minimal and maximal values) from the time intervals for particular measurement groups. The test results for further analyses of each fuel blend are presented in Table 7.

Table 7. The values of the considered parameter set for he analyzed fuel mixtures

Parameter	Mean value	Maximal value	Minimal value
Unleaded gasoline			
Solid particles	145.6	152.0	139.0
Carbon monoxide	2.49	4.71	0.02
Carbon dioxide	11.87	12.90	9.10
oxygen	1.83	5.26	0.20
hydrocarbons	331	464	216
90% unleaded gasoline and 10% ethanol			
Solid particles	104.6	107.0	10.0
Carbon monoxide	1.28	4.04	0.15
Carbon dioxide	11.2	13.6	9.4
oxygen	3.17	6.81	0.43
hydrocarbons	25.8	292.0	209.0
70% unleaded gasoline and 30% ethanol			
Solid particles	75.5	91.0	69.0
Carbon monoxide	0.35	0.44	0.13
Carbon dioxide	11.33	13.90	8.80
oxygen	5.54	9.01	3.30
hydrocarbons	332.6	577.0	194.0
50% unleaded gasoline and 50% ethanol			
Solid particles	126.3	150.0	103.0
Carbon monoxide	0.23	0.99	0.06
Carbon dioxide	9.97	13.00	5.90
oxygen	8.15	11.48	4.18
hydrocarbons	199.8	287.0	110.0

The test results were normalized based on the data included in Table 7, according to dependency 5. The vector components obtained for particular blends from the parameter normalized results are presented in Table 8.

Table 8. Normalized results for particular components of the form vector

Parameters	Fuel blends			
	PB100	BIO10	BIO30	BIO50
Solid particles	5.0769	5.2000	2.9545	4.9574
Carbon monoxide	6.1407	3.1619	7.0968	1.8279
Carbon dioxide	7.2895	4.2857	4.9608	5.7324
Oxygen	3.2213	4.2947	3.9229	5.4384
Hydrocarbons	4.6371	5.5181	3.4621	5.0734

Determination of the vector components enabled to provide a geometric interpretation of the drive unit parameter mean value for blends of gasoline and ethanol. In this case, it was unleaded gasoline with no ethanol additive that was accepted to be the reference point. A comparison of gasoline and ethanol blends with the reference point is presented in Fig. 8. The vector components were marked as X with indexes defining the parameter number. In the case of the compared blends, the vector components were also marked as X with their indexes denoting a given fuel blend, in the following order: X_{A1}–A_5 for BIO10 blend, X_{B1}–B_5 for BIO30 blend, X_{C1}–C_5 for BIO50 blend.

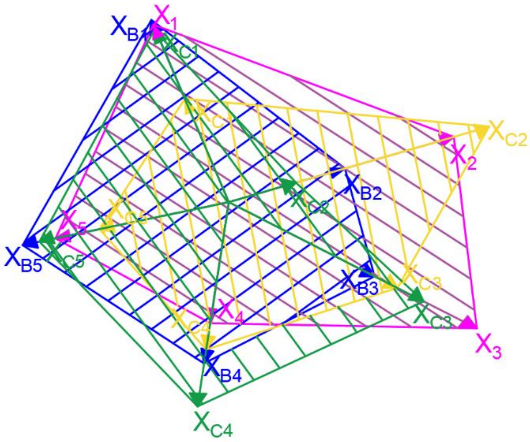


Fig. 8. Comparison of vector components for blends of gasoline and ethanol with the reference point

A random variable was defined for the tested drive unit on the basis of the vector components determined for each fuel blend, in the following form:

$$Z_x = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 \quad (6)$$

The values of a random variable defined for the fuel blends are presented in Fig. 9.

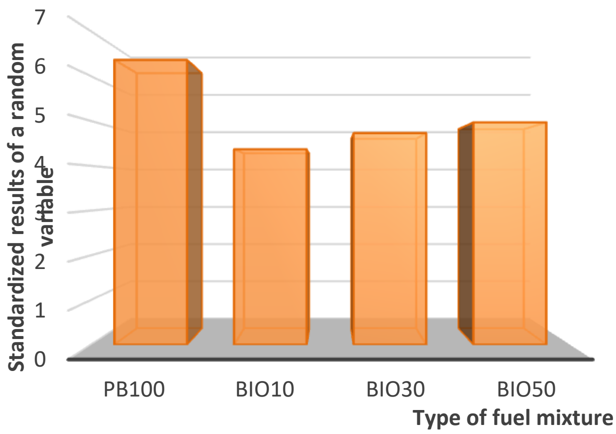


Fig. 9. Standardized random variables defined for the tested fuel blends

A graphic interpretation of a random variable, determined for the analyzed fuel blends, allows to perform a complete analysis of each vector component, consistently with significance defined on the basis of the accepted weights. The diagram presented in Fig. 4 shows that BIO10 blend achieved the lowest results, compared to the reference point, whereas BIO50 blend the highest. It means that application of ethanol in gasoline has a positive effect on the drive unit exhaust gas emission reduction.

5. Conclusions

Based on the tests, it can be said that an additive of ethanol to gasoline does have an impact on the exhaust components emitted by the considered spark ignition engine. An analysis of the component values shows that the best blend is that of 70% gasoline and 30% ethanol. According to the analysis, the composition of the blend has the largest impact on the carbon dioxide criterion, whereas the lowest on hydrocarbons. Value changes of the analyzed parameters are presented in the form of vectors which allows their simultaneous analysis. Application of ethanol additive to gasoline reduced the drive unit emission of exhaust gases into the environment. The test results confirm advisability of using alternative fuel for powering drive units of spark ignition engines. From the point of view of natural resources exhaustibility, the use of alternative solutions for fueling spark ignition engines is a good solution. Blends of gasoline with ethanol exhibit similar or better characteristics as compared to pure gasoline which fully justifies their application. The results obtained from the conducted tests indicate the advisability of using ethanol as a bio-component in fuel, both due to its renewable nature and its positive impact on the exhaust composition of spark-ignition engines.

Nomenclature

AHP	analytic hierarchy process
CO	carbon monoxide
CO_2	carbon dioxide
HC	hydrocarbons
MOA	multi criteria optimizations analysis
O_2	oxygen

Bibliography

[1] Almaid L, Sales L, Sodre J. Fuel consumption and emissions from a vehicle operating with ethanol, gasoline and hydrogen produced on board. Int J Hydrogen Energ. 2015; 40(21):6988-6994. https://doi.org/10.1016/j.ijhydene.2015.03.167

[2] Baena L, Gomez M, Calderon J. Aggressiveness of a 20% bioethanol–80% gasoline mixture on autoparts: I behavior of metallic materials and evaluation of their electrochemical properties. Fuel. 2012;95:320-328. https://doi.org/10.1016/j.fuel.2011.12.002

[3] Balat M, Balat H, Cahide O. Progress in bioethanol processing. Prog Energ Combust. 2008;34(5):551-573. https://doi.org/10.1016/j.pecs.2007.11.001

[4] Balki M, Sayin C, Canakci M. The effect of different alcohol fuels on the performance, emission and combustion characteristics of a gasoline engine. Fuel. 2014;115:901-906. https://doi.org/10.1016/j.fuel.2012.09.020

[5] Bielaczyc P, Klimkiewicz D, Szczotka A, Woodburn J. A comparison of the exhaust emission of a vehicle fuelled with different ethanol-petrol blends. Combustion Engines. 2012; 149(2):57-65. https://doi.org/10.19206/CE-117041

[6] Costa R, Filho F, Moreira T, Baeta J, Guzzo M, Souza J. Exploring the lean limit operation and fuel consumption improvement of a homogeneous charge prechamber torch ignition system in an SI engine fueled with a gasoline-bioethanol blend. Energy. 2020;197:114-123. https://doi.org/10.1016/j.energy.2020.117300

[7] Costa R, Sodre J. Hydrous ethanol vs. gasoline-ethanol blend: Engine performance and emissions. Fuel. 2010;89(2): 287-293. https://doi.org/10.1016/j.fuel.2009.06.017

[8] Costagliola M, Iannaccone S, Prati M. Combustion efficiency and engine out emissions of a S.I. engine fueled with alcohol/gasoline blends. Appl Energ. 2013;111:1162-1171. https://doi.org/10.1016/j.apenergy.2012.09.042

[9] Deng X, Chen Z, Wang X, Zhen H, Xie R. Exhaust noise, performance and emission characteristics of spark ignition engine fuelled with pure gasoline and hydrous ethanol gasoline blends. Case Studies in Thermal Engineering. 2018;12: 55-63. https://doi.org/10.1016/j.csite.2018.02.004

[10] Dhaliwal JS, Negi MS, Kapur GS, Kant S. Compatibility studies on elastomers and polymers with ethanol blended gasoline. Journal of Fuels. 2014:1-8. https://doi.org/10.1155/2014/429608

[11] Duc K, Duy V, Dinh L, Viet T, Anh T. Performance and emission characteristics of a port fuel injected, spark ignition engine fueled by compressed natural gas. Sustainable Energy Technologies and Assessments. 2019;31:383-389. https://doi.org/10.1016/j.seta.2018.12.018

[12] Elfasakhany A. Engine performance evaluation and pollutant emissions analysis using ternary bioethanol–iso-butanol–gasoline blends in gasoline engines. J Clean Prod. 2016;139:1057-1067. https://doi.org/10.1016/j.jclepro.2016.09.016

[13] Elfasakhany A. Investigations on the effects of ethanol–methanol–gasoline blends in a spark ignition engine: Performance and emissions analysis. Engineering Science and Technology, an International Journal. 2015;18(4):713-719. https://doi.org/10.1016/j.jestch.2015.05.003

[14] Fernandez J, Arnal J, Gomez J, Lacelle N, Dorado M. Performance tests of a diesel engine fueled with pentanol/diesel fuel blends. Fuel. 2013;107:866-872. https://doi.org/10.1016/j.fuel.2013.01.066

[15] Galadima A, Muraza O. Catalytic upgrading of bioethanol to fuel grade biobutanol: a review. Ind Eng Chem Res. 2015; 54(29):7181-7194. https://doi.org/10.1021/acs.iecr.5b01443

[16] Ghobadian B, Rahimi H, Tavakauli T, Khatami M. Production of bioethanol and sunflower methyl ester and investigation of fuel blend properties. J Agric Sci Technol. 2008;10: 225-232.

[17] Grzelak P, Chłopek Z, Szczepański K. Properties of substitute motor fuels produced from ethanol in biorefineries. Combustion Engines. 2024;198(3):41-47. https://doi.org/10.19206/CE-184488

[18] Harbi A, Alabduly A, Alkhedhair A, Alqahtani N, Albishi M. Effect of operation under lean conditions on NO_x emissions and fuel consumption fueling an SI engine with hydrous ethanol–gasoline blends enhanced with synthesis gas. Energy. 2022;238(A):121-129. https://doi.org/10.1016/j.energy.2021.121694

[19] Hassan A, Rawashdeh H, Muhtaseb A, Abu Jrai A, Ahmad R, Zeaiter J. Impact of changing combustion chamber geometry on emissions, and combustion characteristics of a single cylinder SI (spark ignition) engine fueled with ethanol/gasoline blends. Fuel. 2018;231:197-203. https://doi.org/10.1016/j.fuel.2018.05.045

[20] Iliev S. A comparison of ethanol and methanol blending with gasoline using a 1D engine model. Procedia Engineer. 2015;100:1013-1022. https://doi.org/10.1016/j.proeng.2015.01.461

[21] Iodice P, Senatore A, Langella G, Amoresano A. Effect of ethanol–gasoline blends on CO and HC emissions in last generation SI engines within the coldstart transient: an experimental investigation. Appl Energ. 2016;179:182-190. https://doi.org/10.1016/j.apenergy.2016.06.144

[22] Jakliński P, Czarnigowski J, Ścisłowski K. Study of the effect of ignition crank angle and mixture composition on the performance of a spark-ignition engine fueled with ethanol. Combustion Engines. 2024;197(2):56-63. https://doi.org/10.19206/CE-174888

[23] Jamrozik A, Tutak W, Gruca M, Pyrc M. Performance, emission and combustion characteristics of CI dual fuel engine powered by diesel/ethanol and diesel/gasoline fuels. J Mech Sci Technol. 2018;32:2947-2957. https://doi.org/10.1007/s12206-018-0551-8

[24] Jhang S, Lin Y, Chen K, Lin S, Batterman S. Evaluation of fuel consumption, pollutant emissions and well-to-wheel GHGs assessment from a vehicle operation fueled with bioethanol, gasoline and hydrogen. Energy. 2020;209:118436. https://doi.org/10.1016/j.energy.2020.118436

[25] Kass M, Janke C, Connatser RM, Lewis S, Baustian J, Wolf L et al. Performance of vehicle fuel system elastomers and plastics with test fuels representing gasoline blended with 10% ethanol (E10) and 16% isobutanol (iBu16). SAE Int J Fuels Lubr. 2020;13(2):137-150. https://doi.org/10.4271/04-13-02-0008

[26] Lodice P, Senatore A, Langella G, Amoresano A. Ethanol in gasoline fuel blends: effect on fuel consumption and engine out emissions of SI engines in cold operating conditions. Appl Therm Eng. 2018;130:1081-1089. https://doi.org/10.1016/j.applthermaleng.2017.11.090

[27] Masum B, Masjuki HH, Kalam H, Fattah I, Palash S, Abedin M. Effect of ethanol–gasoline blend on NO_x emission in SI engine. Renew Sust Energ Rev. 2013;24:209-222. https://doi.org/10.1016/j.rser.2013.03.046

[28] Mourad M, Mahmoud K. Investigation into SI engine performance characteristics and emissions fuelled with ethanol/butanol-gasoline blends. Renew Energ. 2019;143:762-771. https://doi.org/10.1016/j.renene.2019.05.064

[29] Muhammad M. Comparison of the properties and yield of bioethanol from mango and orange waste. Arid Zone Journal of Engineering, Technology and Environment. 2017; 13(6):779-789.

[30] Nwufo O, Nwafor O, Igbokwe J. Effects of blends on the physical properties of bioethanol produced from selected Nigerian crops. International Journal of Ambient Energy. 2016;37:10-15. https://doi.org/10.1080/01430750.2013.866907

[31] Roso V, Santos N, Alvarez C, Filho F, Pujatti F, Valle R. Effects of mixture enleanment in combustion and emission parameters using a flexfuel engine with ethanol and gasoline, Appl Therm Eng. 2019;153:463-472. https://doi.org/10.1016/j.applthermaleng.2019.03.012

[32] Singh P, Ramadhas A, Mathai R, Sehgal A. Investigation on combustion, performance and emissions of automotive engine fueled with ethanol blended gasoline. SAE Int J Fuels Lubr. 2016;9(1):215-223. https://doi.org/10.4271/2016-01-0886

[33] Szlachetka M, Wendeker M. Model research of injection of gasoline and E85 into the engine intake pipe. Combustion Engines. 2012;151(4):55-63. https://doi.org/10.19206/CE-117021

[34] Turkcan A, Ozsezen A, Canakci M. Experimental investigation of the effects of different injection parameters on a direct injection HCCI engine fueled with alcohol–gasoline fuel blends. Fuel Process Technol. 2014;126:487-496. https://doi.org/10.1016/j.fuproc.2014.05.023

[35] Taghavifar H, Kaleji B, Kheyrollahi J. Application of composite TNA nanoparticle with bi-ethanol blend on gasoline fueled SI engine at different lambda ratios. Fuel. 2020;277: 1-12. https://doi.org/10.1016/j.fuel.2020.118218

[36] Thakur A, Kaviti A, Mehra R, Mer K. Progress in performance analysis of ethanolgasoline blends on SI engine. Renew Sust Energ Rev. 2017;69:324-340. https://doi.org/10.1016/j.rser.2016.11.056

[37] Thangavelu S, Ahmed A, Ani F. Review on bioethanol as alternative fuel for spark ignition engines. Renew Sust Energ Rev. 2016;56:820-835. https://doi.org/10.1016/j.rser.2015.11.089

[38] Tutak W, Jamrozik A, Bereczky A, Lukacs K. Effects of injection timing of diesel fuel on performance and emission of dual fuel diesel engine powered by diesel/E85 fuels. Transport. 2018;33(3):633-646. https://doi.org/10.3846/transport.2018.1572

[39] Tutak W. Bioethanol E85 as a fuel for dual fuel diesel engine. Energ Convers Manage. 2014;86:39-48. https://doi.org/10.1016/j.enconman.2014.05.016

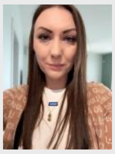
[40] Wang X, Chen Z, Ni J, Liu S, Zhou H. The effects of hydrous ethanol gasoline on combustion and emission characteristics of a port injection gasoline engine. Case Studies in Thermal Engineering. 2015;6:147-154. https://doi.org/10.1016/j.csite.2015.09.007

[41] Yao Y, Tsai J, Wang I. Emissions of gaseous pollutant from motorcycle powered by ethanol–gasoline blend. Appl Energ. 2013;102:93-100. https://doi.org/10.1016/j.apenergy.2012.07.041

[42] Yusuf A, Inambao F. Bioethanol production from different Matooke peels species: a surprising source for alternative fuel. Case Studies in Thermal Engineering. 2019;13:100357. https://doi.org/10.1016/j.csite.2018.11.008

[43] Zhuang Y, Hong G. Primary investigation to leveraging effect of using ethanol fuel on reducing gasoline fuel consumption. Fuel. 2013;105:425-431. https://doi.org/10.1016/j.fuel.2012.09.013

Marietta Markiewicz, DSc. DEng. – Faculty of Mechanical Engineering, Bydgoszcz University of Science and Technology, Poland.
e-mail: *marmar000@pbs.edu.pl*



Jerzy Kaszkowiak, DEng. – Faculty of Mechanical Engineering, Bydgoszcz University of Science and Technology, Poland.
e-mail: *jerzy.kaszkowiak@pbs.edu.pl*

Prof. Lubomir Hujo, DEng. – Mechanical Engineering Technologies and Materials, Trenčianska Univerzita Alexandra Dubčeka, Slovakia.
e-mail: *lubomir.hujo@tnuni.sk*