Research of operating and ecological parameters of the SI engine fed by different fuel types

M Budzyński\textsuperscript{1} and K Śliwiński\textsuperscript{2}
\textsuperscript{1}Mechanical Faculty, Cracow University of Technology
\textsuperscript{2}Institute of Vehicles and Combustion Engines, Mechanical Faculty, Cracow University of Technology
\textsuperscript{1,2}ul. Jana Pawla II 37, 31-864 Krakow, Poland

1 E-mail: mrkbudzynski@gmail.com
2 E-mail: ksliwin@pk.edu.pl

Abstract. The purpose of the research is to evaluate the operational and ecological parameters of an engine fed by various types of fuel. The test stand constructed for this purpose was prepared to evaluate the engine work indicators for eight different types of motor gasolines from different manufacturers and with different octane number. The tests were performed on a Fiat 170A1 engine. Parameters that were measured directly in the test were: rotational speed, torque, fuel consumption, exhaust gas temperature, run of indicated pressure. The conducted research and comparative analysis of the obtained results confirmed that the type of fuel used does not significantly affect the obtained values of ecological and operating parameters. The higher fuel octane number with the compression ratio used in the research engine did not affect the higher values of the measured parameters.

1. Introduction

In connection with the growing environmental requirements, aimed at reducing the emission of harmful substances into the atmosphere, the process of fuel production is also subject to significant restrictions. Requirements characterizing fuels are specified in the European Union Directive 2009/28/WE from 23/04/2009. This document gives guidelines for quality parameters resulting from ecological requirements that were specified as a result of the European Auto / Oil program. In addition, fuel producers must comply the national specification for motor gasolines and the guidelines contained in the Worldwide Fuel Charter [2].

For vehicle users, an important parameter of gasoline is the octane number, which is a conventional indicator of fuel resistance to combustion anomalies, the value of which is expressed on a scale of 0-120. This value determines the resistance of fuel to the occurrence of uncontrolled auto-ignition of the fuel-air mixture inside the combustion chamber [7]. There is a distinction between Research Octane Number (RON) and Motor Octane Number (MON), which values are determined on the same principle, but they are distinguished by the test conditions. When buying fuel in the European Union, the octane value of fuel corresponds to the RON value, while in the United States, Canada and Australia, the method of determining the octane value of fuel is used, which is based on the average of RON and MON.

When reviewing the literature related to the analyzed issues, research should be distinguished in which the author drew attention to the exploitative properties of ethanol fuels [3]. As part of the
article, some researches about ethanol fuels in terms of ethanol content up to 100% (V/V) are quoted. They show a positive effect of ethanol in motor gasoline, which affect to the reduce a tendency to sediment formation in the combustion chambers and inlet valves.

European law allows the sale of E10 fuel (motor gasoline with 10% bioethanol), which is also in line with the provisions of Directive 2009/30/WE of April 23, 2009 in the area of quality requirements for motor gasolines with maximum oxygen content 3.7% (m/m) and from 5% to 10% (V/V) bioethanol[1].

Research was carried out on the octane number of fuels containing bioethanol in the range of 15-25% (V/V) and comparative 10% (V/V) [1]. These researches have shown that all octane number values obtained are within the norms limits of repeatability, and the obtained results can be used to validate the above-mentioned methods for motor gasolines with higher content of bioethanol from range 15% to 25% (V/V).

A review of test methods for fuels at research stands has also been carried out [5]. The continuous development of fuel production technologies and implement engine changes by manufacturers construction result in the emergence of new issues requiring accurate recognition. As a result, newer research procedures are being developed.

Researches have also been carried out, which compare the analysis of the results of European engine tests regarding the evaluation of the detergent properties of motor gasolines [4]. According to the analysis of the results of researches made on engines CEC F-05-93 and CEC F-20-98, it has been shown that assessments of fuel detergent properties made according to two different test methods are incomparable. Based on the result obtained by one test method it is impossible to conclude, predict or estimate the result obtained with the second research method.

A comparison of operating and ecological parameters of the spark-ignition engine which was fed by gasoline and Liquefied Petroleum Gas (LPG) was made[6]. As part of this study, the author stated that the engine supply by LPG is an interesting alternative to traditional power supply. On the one hand, there was a slight deterioration of dynamic parameters, on the other hand a significant reduction in the content of toxic components in the exhaust.

2. Aim and scope of the research
The purpose of the research is to evaluate the operational and ecological parameters of the engine fed by various types of petrol. Eight types of motor gasolines were evaluated. The fuels were characterized by different octane numbers and came from different manufacturers.

The paper includes an elaboration of the conducted research, their scope, and the test bench. The research involved eight different fuels from the four fuel distributors affordable on the Polish fuel market. The obtained results were used to analyze the impact of the fuel type on the work and ecological indicators reached by the engine. On their basis, comparative graphs were prepared, illustrating differences in the values of the examined parameters, and conclusions were drawn. The main source of powering motor vehicles is petroleum-derived fuels from the processing of crude oil. Fuels feeding spark-ignition engines must be characterized by appropriate properties that comply with the requirements of modern internal combustion engines.

3. Comparison of parameters declared by the manufacturer
When purchasing gasoline, fuel quality certificate cards were obtained at each station. The data from the cards were used for further analyses.

Eight different samples from four different petrol stations were analyzed:

**Petrol station A:**
- octane number 95 - gasoline in the research referred to as A95;
- octane number 100 - in the research referred to as A100;

**Petrol station B:**
- octane number 95 - in the research referred to as B95;
- octane number 98 - in the research referred to as \textbf{B98};

\textbf{Petrol station C}:
- octane number 95 - in the research referred to as \textbf{C95};
- octane number 98 - in the research referred to as \textbf{C98};

\textbf{Petrol station D}:
- octane number 95 - in the research referred to as \textbf{D95};
- octane number 98 - in the research referred to as \textbf{D98};

The quality certificates obtained at the petrol stations B and C prove that they were delivered from the same source. From the comparison of the values shown on the fuel quality certificates, the below comparison diagrams were obtained (Fig. 1, Fig. 2).

Individual fuels are characterized by a different motor octane number (MON) shown in Fig. 1. Comparing the values of the octane number and the motor octane number for the studied fuels, it can be ascertained that the D company's fuels are characterized by the highest motor octane number values in both the 95 and 98 octane fuel groups. This difference is about several percent. However, in the case of an engine fed by fuel with a bigger motor octane number at big constant load and big rotational speed, it is possible to obtain more favorable engine work parameters. The values of this parameter for pairs 95 and 98 octane fuels from B and C petrol stations are identical because they come from the same source.

![Figure 1. Comparison of values of the motor octane number of individual fuels.](image)

On the basis of the comparison presented in Fig. 2, it should be stated that in the case of fuels coming from the consortiums A, B and C, bigger density characterizes fuels with a bigger octane number. A reverse dependence occurs for the D group's fuels, where D95 fuel has a bigger density compared to D98 fuel. The value of this parameter does not determine how much fuel (by volume) is dosed into the combustion chamber. It is a parameter that can influence the results if its value is taken into account when creating the air-fuel mixture. The smaller density of fuel affects its bigger content in the mixture as compared to bigger density fuel, which may have an impact on the increased amount of heat released while burning the air-fuel mixture prepared in such a way.
Figure 2. Comparison density of tested fuels at 15° C.

From the information presented on the fuel quality cards, it can be concluded that the examination of the corrosive action on copper (Cu) plates for all the fuels was identical and the result of this test is marked with 1, which indicates that all the tested fuels meet the criteria set in the standards.

The content of resins for all eight tested fuels is identical and amounts to 1 mg /100 ml. The fuels are advertised as very clean, but it can be concluded that even small amounts of resins can be accumulated somewhere. However, no studies have been carried out in this area.

4. Methodology of research

For each of the fuels, measurements were made at four different values of ignition advanced angle, constant rotation speed equal to 3000 [1/min] and constant throttle plate angle equal to 35%. Parameters that were measured directly in the test were: rotational speed, torque, fuel consumption, exhaust gas temperature, run of indicated pressure. Parameters that were read over from the flue gas analyzer were concentrations of the following exhaust components: carbon monoxide (CO), carbon dioxide (CO$_2$), hydrocarbons (HC), nitrogen oxides (NO$_x$). Based on the measurements, such values as: brake specific fuel consumption (BSFC), effective engine power, mean indicated pressure and maximum indicated pressure were calculated.

4.1. Description of the test stand

The tests were carried out on an engine test bench type AMX211 with Eddy-current brake, equipped with apparatus for measuring the torque value and rotational speed value. The object of the research was a spark ignition engine Fiat 170 A1 of 900cm$^3$ engine capacity. In order to carry out the measurements, a Capelec gas analyzer CAP 3201 was used to measure the concentration of exhaust components.

4.2. Results and conclusions from the conducted research

Research on the influence of the value of ignition advanced angle on the run of the combustion process showed that by comparing the values of mean indicated pressure, torque, effective engine power and brake specific fuel consumption at four different ignition advance angle values (20°, 25°, 30°, 35°) before Top Dead Center (TDC) the engine reached its best work parameters for ignition advance angle 30° before TDC.
Selected runs of the curves of the tested parameters are shown in Fig. 3 and Fig. 4. Based on the results, it was established that this was the most advantageous determination value of the ignition advanced angle and therefore analysis and comparison of results were carried out for such a determination.

The comparison of the run of indicated pressure (Fig. 5) obtained for individual fuels at ignition advance angle value 30° before TDC indicates that the maximum pressure value for tested fuels was occurred at a similar crank angle. These values are obtained for the range (16 ÷ 18)° of crank angle.
after TDC. This can be suggested a similar run of heat release process for all tested fuels. The obtained pressure runs were averaged from two hundred samples. The tests showed differences between the maximum pressure values. The difference in the values of this parameter, for two extreme cases (for A100 and C95 fuels) is about 7%. It can be concluded that fuels with a bigger octane number, burned more slowly. Therefore, a lower value of maximum pressure was achieved. Higher values of pressures occurred for 95 octane fuel, the smallest value of maximum pressure was achieved for A100 fuel.

Figure 5. Comparison of the run of indicated pressure for tested fuels.

Analyzing the run of indicated pressure plots obtained for different fuels with the same value of ignition advance angle, there are some differences between the values of the maximum indicated pressure for fuels with the octane number 95 and 98 (Fig.5, Fig.6). Based on general theories, it can be concluded that the net calorific value of the mixture may have a significant influence on this. Another parameter that may affect this phenomenon is the higher octane number. It affects the occurrence of an extended combustion process for fuels with a higher octane number. Taking this into account, it can be
deduced that if there is no significant difference in the net calorific values of the tested fuels, the octane number has a significant impact on this phenomenon. It can be concluded that the octane value of fuel contributed to the reduction of the degree of burning out the mixture in the angular range to the point where the maximum pressure occurred, i.e. in the phase of factual combustion.

![Figure 6. Comparison of the values of the maximum indicated pressure for individual fuels (ignition advance angle 30° before TDC).](image)

![Figure 7. Comparison of the values of the brake specific fuel consumption for individual fuels (ignition advance angle 30° before TDC).](image)

By comparing the values of such parameters as the mean indicated pressure, torque, effective engine power or brake specific fuel consumption shown in Fig. 7, it can be stated that for each of the above parameters, the difference between the values of two boundary elements is around 5.5-7%.
The difference between the exhaust gas temperature values measured for the most favourable value of ignition advanced angle determined during the tests for individual fuels, is about 2%. Fig. 8 demonstrates how the temperature of exhaust changes with different fuels fed, depending on the value of the ignition advanced angle. When reducing of the value of ignition advanced angle, the temperature of the exhaust increases because the combustion process is extended to the exhaust gas outlet process. Therefore, heat losses occur, the combustion process does not proceed optimally, the obtained effective engine power values and torque values are lower than for the combustion process at the value of ignition advance angle 30° before TDC.

![Graph showing temperature of exhaust value for individual fuels as a function of the ignition advance angle.](image)

**Figure 8.** Comparison of the temperature of exhaust value for individual fuels as a function of the ignition advance angle.

By collating fuels with each other in terms of environmental effect, the least favourable properties are achieved by the B95 fuel, which shows a much bigger concentration of hydrocarbons (HC) in the exhaust compared to other fuels tested (Fig. 9). The remaining fuels of individual producers, regardless of the octane number, achieve a similar volume concentration of hydrocarbons (HC) in the exhaust. The concentration of hydrocarbons (HC) in the exhaust gas is affected by the temperature value of the combustion process, possibly also by fractional composition. The temperature of the combustion process can be deduced based on the exhaust gas temperature, assuming a similar run of the indicator pressure, the same ignition advance angle, the same air excess factor and a similar net calorific value of the fuel. Because these parameters are similar, it can be assumed that there is a difference in the fractional composition of the fuel. Based on the data obtained from the fuel quality cards, the same origin of fuels from the B and C petrol stations was found. The difference between values of concentration of hydrocarbon (HC) obtained while fed with these fuels, may indicate a deliberate or accidental change of the fuel composition in the tank at the petrol station.

The concentration of other toxic components of exhaust gases (carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NOₓ)), for all considered fuels was also tested. However, while comparing the results, no significant differences were noted.
Figure 9. Comparison of the values of the concentration of hydrocarbon for individual fuels (ignition advance angle 30° before TDC).

5. Summary
The aim of the research has been achieved, i.e. the assessment of the work and ecological parameters of the engine fed by different gasoline types. The built research test bench as well as the adopted methodology allowed all the assumed goals to be achieved. The engine work indicators, measurement of the concentration of basic toxic components of exhaust gases and the registration of high-frequency pressure runs in the combustion chamber of the working engine were measured.

Literature analysis showed that:

- In reference to the studies in which the author showed a positive effect of the increased volume of ethanol in gasoline [3], it can be concluded that the use of said fuel in a longer time perspective can have a positive effect on the condition of the combustion chamber and intake valves. This is related to the limitation of the tendency to form the deposit on them. In addition, the use of fuels with the participation of ethanol, reduces the emission of carbon monoxide and aromatic hydrocarbons.

- Referring to the research in which it was found that the work parameters achieved by the engine fed by LPG and petrol are similar to one another, one can state that feeding the tested engine with the mentioned fuel can be an interesting alternative in terms of: ecological and economic [6].

As part of the research, the following conclusions were drawn:

- Comparing the values of the octane number and the motor octane number for the studied fuels, it can be ascertained that the D company’s fuels are characterized by the highest motor octane number values in both the 95 and 98 octane fuel groups. This difference amounts to several percent. However, in the case of an engine fed by fuel with a bigger motor octane number at big, constant load and big rotational speed, it is possible to obtain more favorable engine operating parameters.

- The comparison of the run of indicated pressure (Fig. 5) obtained for individual fuels at ignition advance angle value 30° before TDC indicates that the maximum pressure value for tested fuels occurs at a similar crank angle. These values are obtained for the range (16 ÷ 18)° of crank angle after TDC. This is the evidence of similar run of heat release process for all tested fuels.
• With reduction of the value of ignition advance angle, the temperature of exhaust increases because the combustion process is extended to the exhaust gas outlet process. Therefore, heat losses occur, the combustion process does not proceed optimally, the obtained effective engine power values and torque values are lower than for the combustion process at the value of ignition advance angle equal 30° before TDC.

• The conducted research and comparative analysis of the obtained results allow the conclusion to be drawn - that the type of fuel used does not significantly affect the obtained values of ecological and work parameters of the engine. The difference between the values of such parameters as: torque, maximum pressure in the cylinder or concentrations of toxic components of exhaust gases while feeding the engine with the tested fuels amounts to about several percent. The higher value of the octane number, taking into account the compression ratio of the engine used in the research, did not affect the higher values of the measured parameters. The research results proved that only the recommended type of fuel should be used for a given type of engine, and it is not advisable to use more expensive fuels with a higher octane number, because the values of individual parameters obtained by feeding the engine with these fuels are similar to one another and have no major impact on the engine's operating and ecological parameters.

References

[1] Dybich K Badania wpływu zwiększonej zawartości bioetanolu w benzynie silnikowej na wartość liczby oktanowej, Nafta-Gaz 2016 nr 11 s. 975–983, DOI: 10.18668/NG.2016.11.12

[2] Jakóbiec J and Pałuchowska M Specyfikacje jakościowe benzynej silnikowej E10 Nafta-Gaz listopad 2011

[3] Pałuchowska M and Stępień Z Oceny paliw etanolowych w testach silnikowych i eksploatacyjnych Nafta-Gaz 2017 nr 2 s. 97–104, DOI: 10.18668/NG.2017.02.04

[4] Stępień Z Nieporównywalność ocen paliw w europejskich znormalizowanych testach silnikowych Nafta-Gaz 2017 nr 12

[5] Stępień Z, Oleksiak S and Dybich K Ocena właściwości użytkowych paliw na stanowiskach badawczych Nafta-Gaz 2009 nr 1

[6] Stoeck T and Kowlaski R Porównanie parametrów roboczych i ekologicznych silnika o zapłonie iskrowym zasilanego LPG oraz Benzyną Autobusy-Technika, Eksplotacja, Systemy Transportowe 4/2012

[7] Zając P Silniki Pojazdów Samochodowych Wydawnictwo Komunikacji i Łączności Warszawa 2009