Influence of the use of ethanol fuel on selected parameters of the gasoline engine

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Abstract. Main subject of this thesis is to contrast gasoline and ethanol fuel combustions by measuring effective parameters. Introduction to the research part comprises theoretical description of alternative fuels available for gasoline engines. Next, it was describe preparation to research, also research itself and the results analysis. Results contain graphs of parameters: the pressure in the engine cylinder, the rate of pressure changes in the cylinder (as a function of crank angle). Results also contain graphs of parameters torque, engine efficiency, concentration of toxic exhaust components (as a function of the air–fuel equivalence ratio (λ) and as a function of the spark advance angle). There parameters are shown for constant the crankshaft rotational speed, for constant throttle position. Research confirmed that the use of ethanol fuel does not cause significant losses or gains in terms of effective parameters.

1. Introduction

Due to the deteriorating condition of the natural environment, more and more attention has been paid to the influence of human activities on it. The automotive industry is one of the fields of activity where the greatest emphasis has been placed. Constructors of modern engines have to find solutions for many technical problems connected with each other to obtain given values of effective parameters and keeping low production costs [1–3]. At the same time, restrictions related to low emission of harmful substances and noise should be taken into account. The mechanical side is responsible for these features - construction and quality of the project as well as the engine management system controlling the operation of the associated ignition and power systems. To be able to meet high demands, it is necessary to use the most precise system that optimally uses the possibilities of the mechanical side of the structure in order to achieve the output parameters. Control of the internal combustion engine is one of the most complex control systems in the vehicle, it is necessary that the process of control system development be parallel to the design of a particular engine, and its capabilities allow the engine conditions to be recognized and the associated selection of parameters for the engine's controls. Only then it will be possible to create a competitive unit that achieves the assumptions consistent with the requirements of current standards and clients [4–8].

2. Aim

The article describes alternative fuels for modern spark-ignition engines, including gaseous and liquid fuels. Increased emphasis has placed on fuels based on alcohols, especially on ethanol, which is the subject of research in this article.

The purpose of the research is to examine the effect of feeding the engine with ethanol fuel. Effective parameters are taken into account. The ethanol fuel is E85 mixed with gasoline in a 1: 1 ratio. This gives a mixture of about 40% by volume of ethanol and 60% of a mixture of conventional petrol (Pb95) and that of 15% by volume of E85. The tested parameters for ethanol and conventional fuel are: the course of pressure changes in the cylinder as a function of the angle of crankshaft rotation, the course of cylinder pressure changes as a function of the crankshaft angle, torque, engine power, efficient engine effective, carbon monoxide concentration, hydrocarbons concentration, nitrogen oxide concentration.

3. Physicochemical properties of fuels used to power spark-ignition engine

The spark-ignition engine requires fuel with strictly defined properties for proper operation. Its power and ignition systems have properties and constraints related to their design and control, which are reflected in the physicochemical properties of the fuels which were used. The creation of the right amount of the mixture with the optimal composition, its appropriate distribution in the combustion chamber, ignition and the proper course of the combustion process depend on many factors. The limited efficiency of the combustion system determines the minimum stoichiometric constant and the calorific value of fuel for obtaining the stoichiometric mixture and maintaining the energy equivalent of conventional gasoline. This is conditioned by the fuel pressure and efficiency of the injectors, followed by the fuel pump and the diameters of the supply lines.

The octane number of the fuel speaks of its resistance to knocking combustion. This is a phenomenon of uneven, explosive combustion of fuel under the influence of pressure waves occurring in the combustion chamber. The higher the octane number, the earlier the ignition can be and the higher the compression ratio, which positively affects the efficiency of the engine.

Another important property is the volatility of fuel, affecting the good mixing of fuel with air. Volatility depends on two parameters - the higher the lower the boiling point temperature and the higher vapor pressure of a given fuel.

The viscosity of the fuel has a very large effect on the efficiency of the fuel system and the reproducibility of fuel dosing. Often when using alternative fuels, there is a need to reduce the effects of high viscosity by modifying the engine, or by preheating or chemical modification of the fuel. High viscosity also means difficulties in forming small drops, which in turn results in poor evaporation of the fuel, inefficient combustion process and high hydrocarbon emission.

The next parameters are ignition and auto-ignition temperatures. The first means the maximum storage temperature of fuel and speaks of the minimum temperature at which the fuel will ignite in open air from an open fire. The second value means the minimum temperature needed to initiate a self-sustaining flame.

The lubricity of fuel has a very large impact on the operation of the power system, primarily on the life of the fuel injectors.

These are the basic key parameters when assessing the already available and popular alternative fuels. In addition to these, there are other parameters, such as the flammability limit of a given fuel or its density, but in the area of currently used fuels, they are not large discrepancies and do not have a big impact on the processes of combustion processes.

Conventional gasoline is mainly a mixture of hydrocarbons containing from four to twelve carbon atoms with a density of about 0.74 g/cm^3, and in total it usually contains about one hundred different components. Light gasoline fractions are responsible for the ease of starting, but also the unfavorable formation of steam plugs in the fuel lines. The average fractions have a beneficial effect on the engine response to load changes. Heavy fractions cause deposits and bridges of spark plugs, which worsens combustion conditions. These fractions are also responsible for diluting the oil with fuel in case of cylinder-piston steam wear.

Table 1. Physicochemical properties of fuels used to power the spark-ignition engine [9–13].

	Heating value [MJ/kg]	Flammability limit λ	Research octane number	Stoichiometric ratio L_t
Pb95	42	0.4–1.4	95	14.7
Ethanol	26.8	0.3–2.1	108	9
E5	41.2	0.4–1.4	96	14.4
E10	40.5	0.4–1.4	97	14.1
E40	36	0.35–1.6	101	12.4
E85	29	0.3–2.0	109	9.9
Methanol	19.5	0.35–2.0	107	6.47
Butanol	36		100	11.2

4. Stand for experimental research

The research stand in the Institute of Vehicles at the Faculty of Automotive and Construction Machinery Engineering has been based on the 14K4F engine of the K16 type constructed by the Rover manufacturer.

Research stand consisted of the following elements [14–15]:

- The engine test bench - it enables precise motor control and determination of its working conditions and torque,
- The AVL CEB II exhaust gas analyzer allows the measurement of exhaust gas content and the air ratio,
- The lambda sensor (Innovate LC-1),
- A measuring cylinder and stopwatch, thanks to which it was measured out the time of consumption of fuel. These data have been used to calculate the unit fuel consumption and efficiency of the engine,
- A sparking plug with a pressure sensor that it allows pressure measurement in the engine cylinder and a crankshaft position sensor.

The combustion of alternative fuels requires the rework of the engine's control and power system. They have to solve certain technical problems: the problem of ensuring the proper composition of the mixture, location of tanks, installation weight and chemical aggressiveness of alternative fuels and higher operating costs.

The ethanol fuel discussed in this paper is a much less calorific fuel than gasoline. This means that with the same amount of air, inject more ethanol into the cylinder to obtain an energy equivalent of gasoline.

The problem is the limited efficiency of the injectors, because it is factory-fitted for conventional fuel. The efficiency of the fuel system can be increased by: higher fuel pressure, more efficient injectors or change of the control signal. Modification of the injector control signal was used during these tests. Different heating value, octane numbers and stoichiometric constants of mixtures are obtained depending on the ratios of ethanol and conventional gasoline in the mixture.

$$L_t = \frac{L_{t1} \cdot m_1 + L_{t2} \cdot m_2}{m_1 + m_2} \tag{1}$$

$$W_p = \frac{W_{p1} \cdot m_1 + W_{p2} \cdot m_2}{m_1 + m_2} \tag{2}$$

$$LO = \frac{LO_{p1} \cdot m_1 + LO_{p2} \cdot m_2}{m_1 + m_2} \tag{3}$$

L_t – constant stoichiometric fuel
W_p – heating value [MJ/kg]
LO – research octane number
m – mass of the fuel component [kg]

The tests have been carried out on E40 fuel. This is a mixture of 40% alcohol and 60% gasoline (Pb). It seems to be the maximum admixture of ethanol that allows combustion under any conditions in a mechanically unmodified engine. The original injectors have been left in the engine and the fuel pressure remained at the standard level. The engine tests with two fuels have been carried out for the conditions corresponding to vehicle driving under conditions set in the fourth gear with speeds of 60 and 75 km / h. This corresponds to speeds of 2300 rpm and 2900 rpm and loads of 35 Nm and 49 Nm. The rotational speed has been determined and then the throttle position (TPS) corresponding to these loads, which is 18.6% and 22.4%. This value remained constant during measurements. This allowed to precisely determine the impact of fuel use on the parameters tested. Engine torque has been read from the engine test bench display.

For each of the fuels, measurements have been made for different values of the air ratio λ in the range from 0.8 to 1.2 with a jump of 0.05. and for different spark advance angles. If we consider the efficiency and specific fuel consumption, the optimum spark advance angle in engine is the angle of 24°.

5. Results of studies

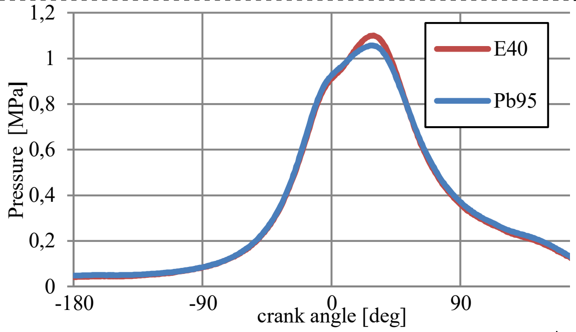

Figure 1. The pressure in the engine cylinder as a function of crank angle for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1, spark advance angle: α (Pb95) = 12°, α (E40) = 12°.

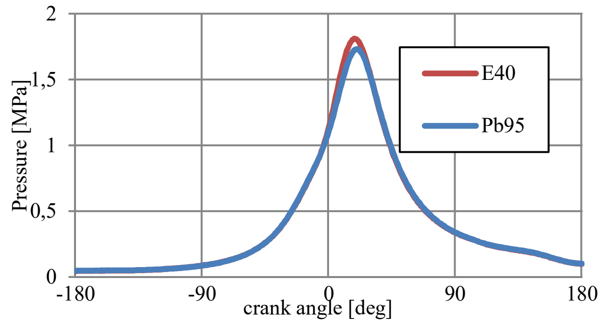

Figure 2. The pressure in the engine cylinder as a function of crank angle for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1, spark advance angle: α (Pb95) = 24°, α (E40) = 24°.

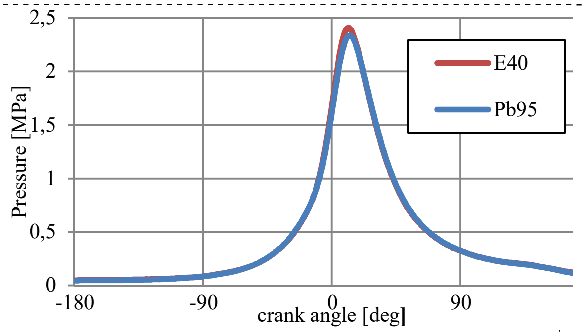

Figure 3. The pressure in the engine cylinder as a function of crank angle for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1, spark advance angle: α (Pb95) = 36°, α (E40) = 36°

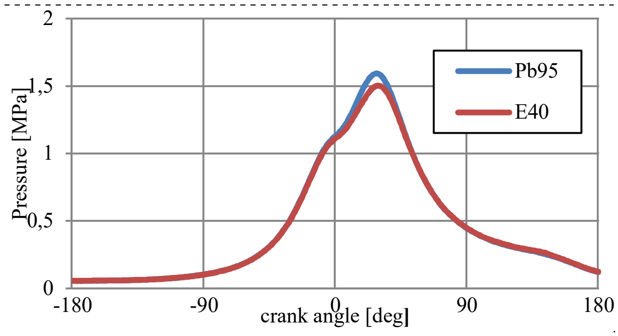

Figure 4. The pressure in the engine cylinder as a function of crank angle for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1, spark advance angle: α (Pb95) = 12°, α (E40) = 12°

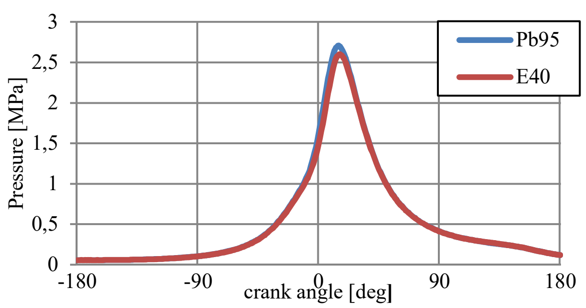

Figure 5. The pressure in the engine cylinder as a function of crank angle for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1, spark advance angle: α (Pb95) = 24°, α (E40) = 24°

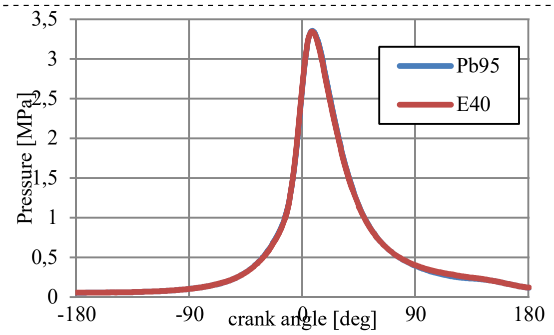

Figure 6. The pressure in the engine cylinder as a function of crank angle for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1, spark advance angle: α (Pb95) = 36°, α (E40) = 36°

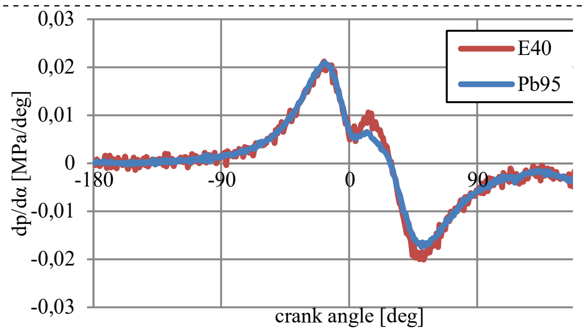

Figure 7. The rate of pressure changes in the cylinder as a function of crank angle for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1, spark advance angle: α (LO95) = 12°, α (E40) = 12°

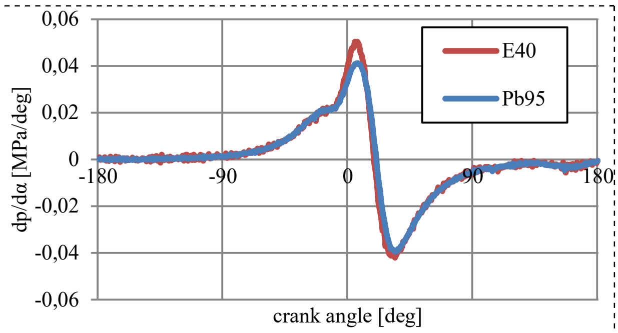

Figure 8. The rate of pressure changes in the cylinder as a function of crank angle for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1, spark advance angle: α (Pb) = 24°, α (E40) = 24°

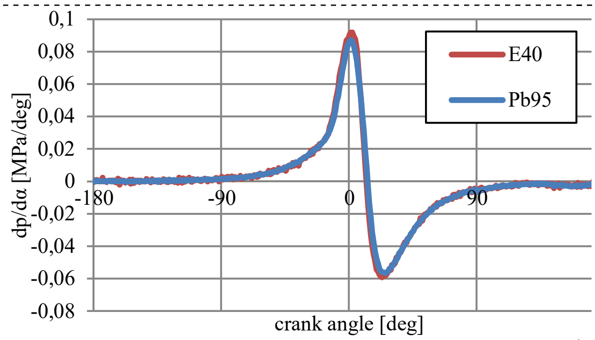

Figure 9. The rate of pressure changes in the cylinder as a function of crank angle for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1, spark advance angle: α (Pb) = 36°, α (E40) = 36°

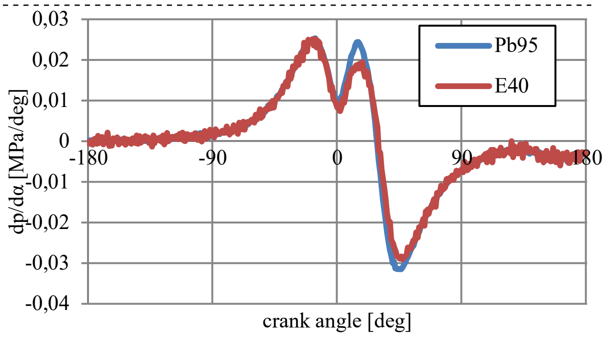

Figure 10. The rate of pressure changes in the cylinder as a function of crank angle for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1, spark advance angle: α (Pb) = 12°, α (E40) = 12°

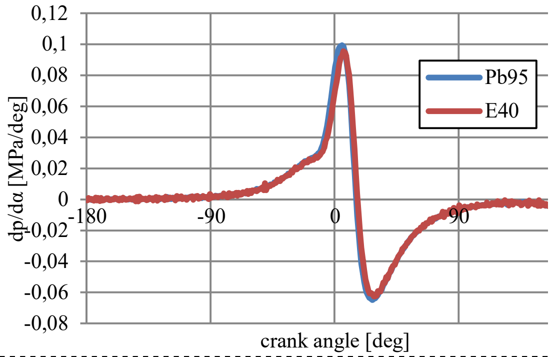

Figure 11. The rate of pressure changes in the cylinder as a function of crank angle for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1, spark advance angle: α (Pb) = 24°, α (E40) = 24°

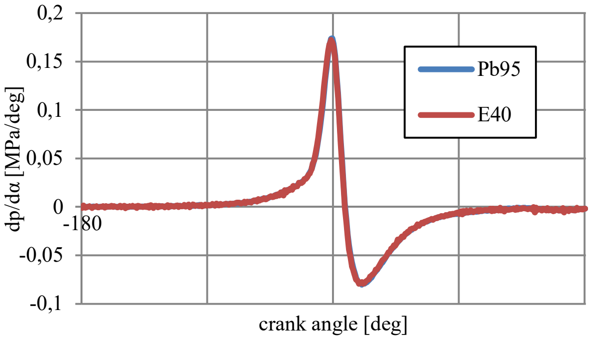

Figure 12. The rate of pressure changes in the cylinder as a function of crank angle for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1, spark advance angle: α (Pb) = 36°, α (E40) = 36°

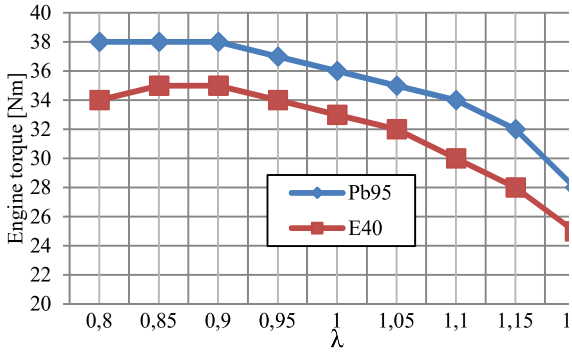

Figure 13. Engine torque as a function of the air–fuel equivalence ratio for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, α = opt

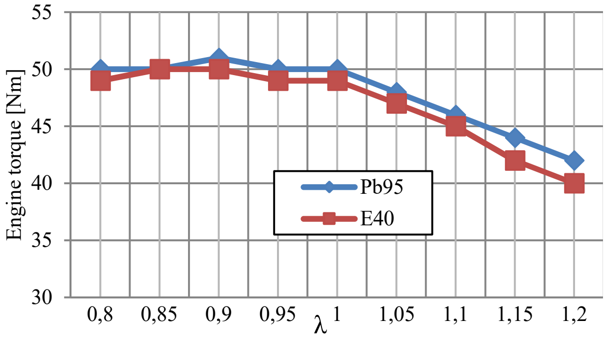

Figure 14. Engine torque as a function of the air–fuel equivalence ratio for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, α = opt

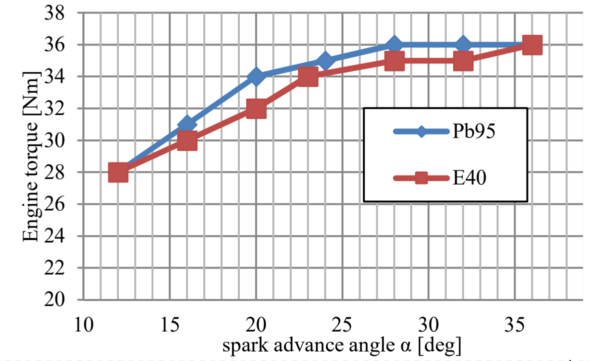

Figure 15. Engine torque as a function of the spark advance angle for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1

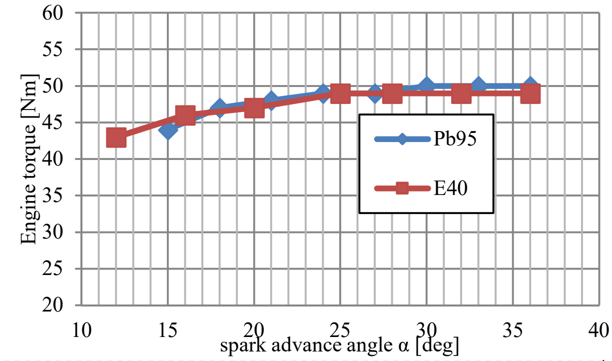

Figure 16. Engine torque as a function of the spark advance angle for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1

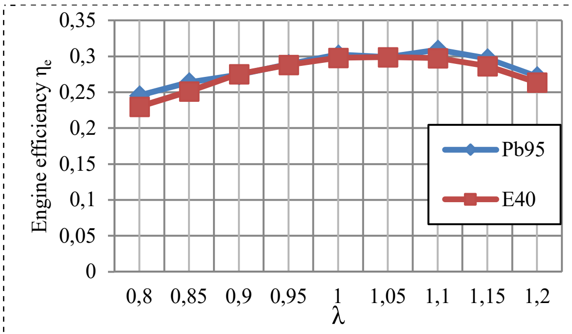

Figure 17. Engine efficiency as a function of the air–fuel equivalence ratio for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, α = opt

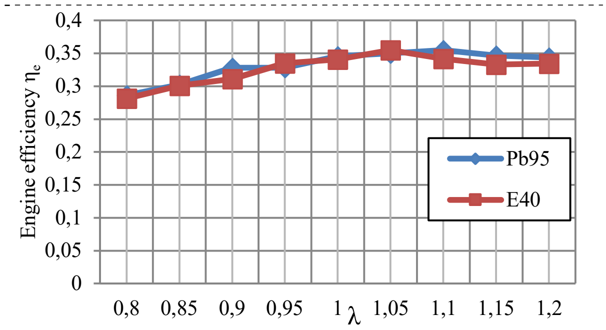

Figure 18. Engine efficiency as a function of the air–fuel equivalence ratio for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, α = opt

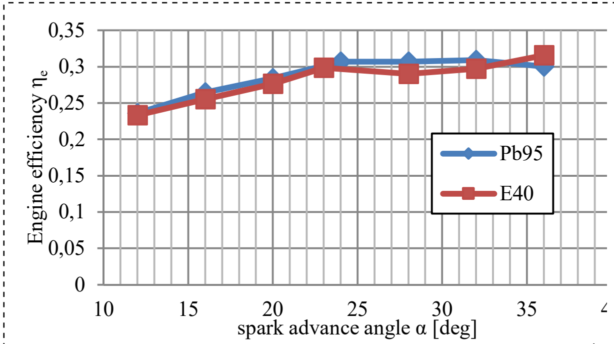

Figure 19. Engine efficiency as a function of the spark advance angle for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1

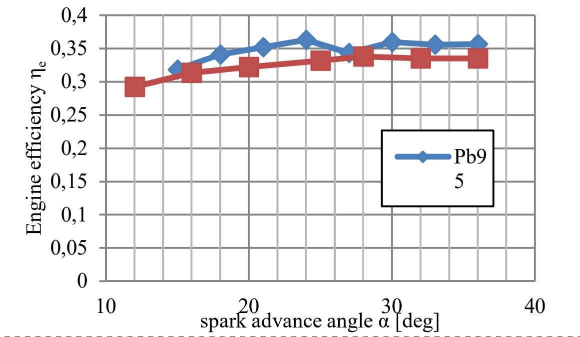

Figure 20. Engine efficiency as a function of the spark advance angle for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1

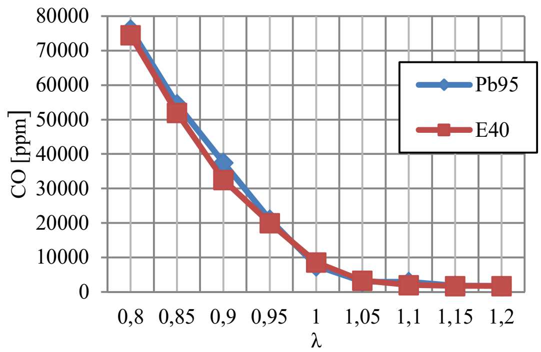

Figure 21. CO concentration for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, α = opt

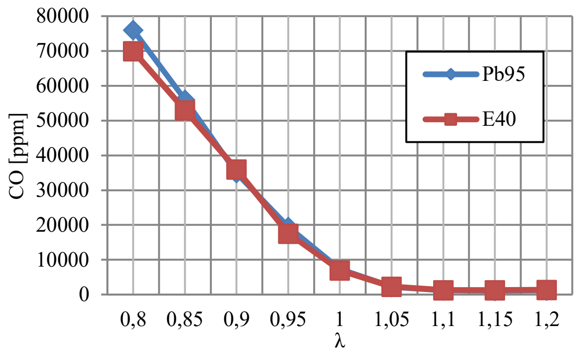

Figure 22. CO concentration for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, α = opt

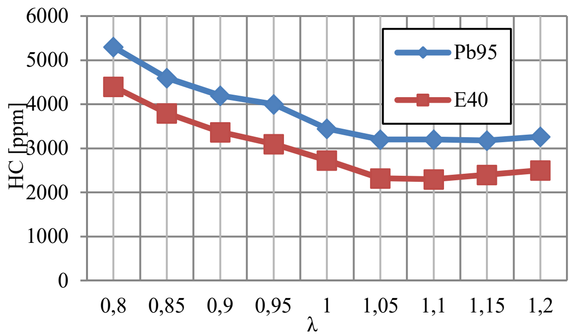

Figure 23. HC concentration for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, α = opt

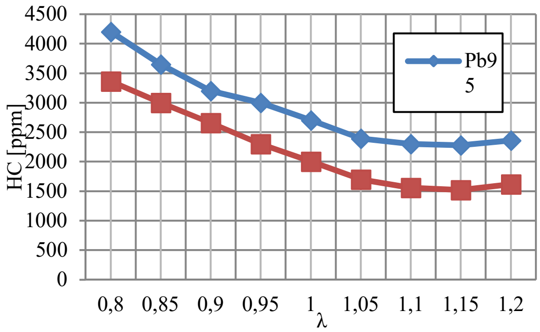

Figure 24. HC concentration for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, α = opt

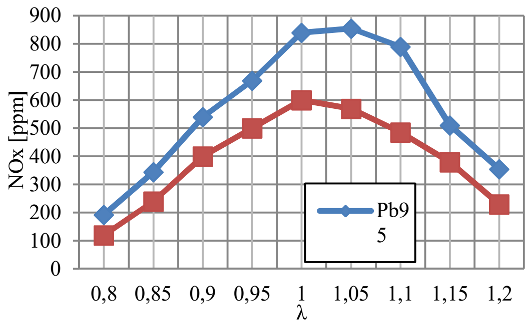

Figure 25. NO_x concentration for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, α = opt

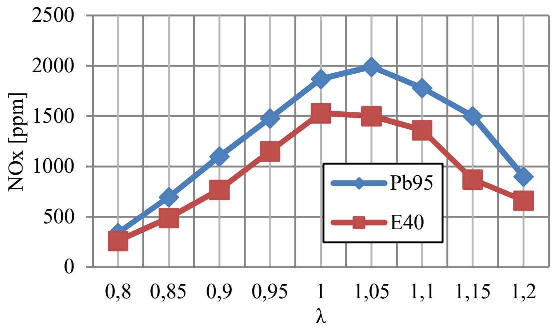

Figure 26. NO_x concentration for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, α = opt

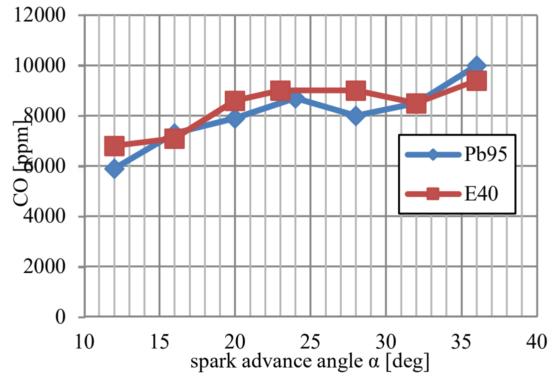

Figure 27. CO concentration for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1

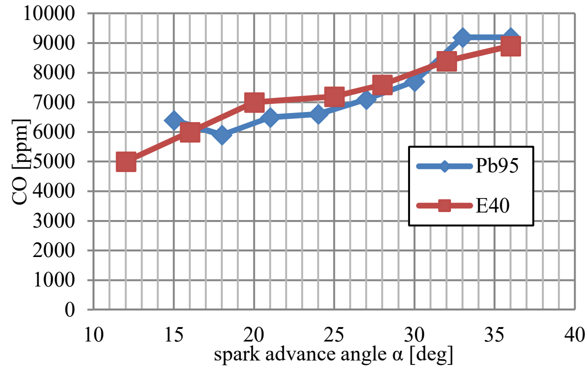

Figure 28. CO concentration for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1

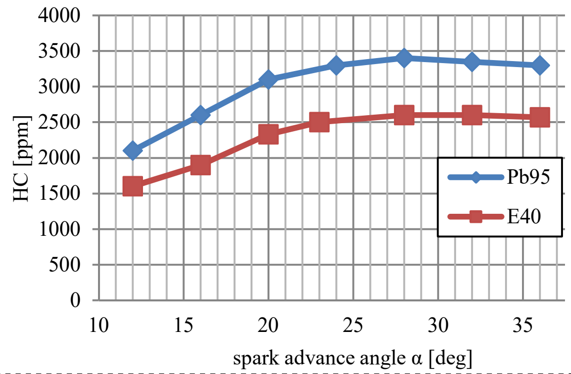

Figure 29. HC concentration for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1

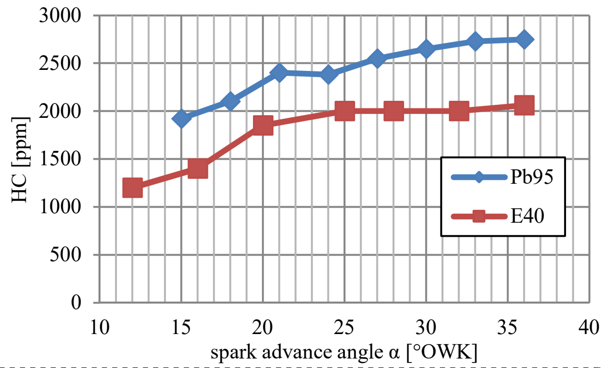

Figure 30. HC concentration for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1

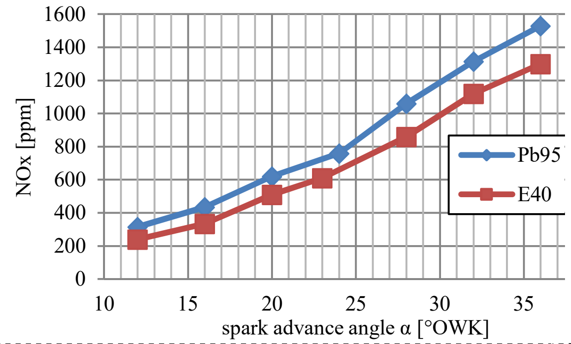

Figure 31. NO_x concentration for the crankshaft rotational speed n = 2300 rev / min, for throttle position TPS = 18,6%, λ = 1

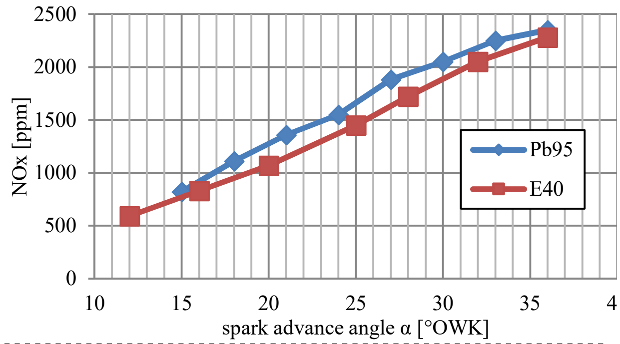

Figure 32. NO_x concentration for the crankshaft rotational speed n = 2900 rev / min, for throttle position TPS = 22,4%, λ = 1

6. Conclusions

The ethanol mixture results in a higher maximum pressure in the combustion chamber than gasoline at similar spark advance angle. The results are similar and the difference in results is about 5%.

Graphs of the rate of pressure changes in the cylinder show a higher burning rate of ethanol fuel. This is particularly visible in Figure 8.

We can see two local maximum pressure rate changes for low values of the ignition advance angle. This is the direct cause of uneven engine operation at these parameters (Fig. 7 and 10).

We can also see that the shape of the graph is more harmonious for gasoline on the graphs of the rate of pressure changes in the cylinder. It may be related to viscosity and so it is worse to spray the ethanol mixture (Figures 7–12).

The maximum efficiency has been obtained for the equivalence ratio (λ) in the range of 1.05-1.1. (Figures: 17–20).

During fueling the engine with ethanol, we can notice a decrease in the concentration of toxic substances. This is especially true for two toxic exhaust components - hydrocarbons (HC) and nitrogen oxides (NO_x). The hydrocarbon concentration difference for ethanol fuel and gasoline is constant. During adjusting the ignition timing at the speed n = 2900 rpm, a 30% reduction in the hydrocarbon concentration was obtained (Figure 30).

In the case of nitrogen oxides, the biggest difference has been found for the stoichiometric and poor mixtures. The greatest change in the concentration of nitrogen oxides has been noted during the regulation of the composition of the mixture. At a rotational speed of 2300 rpm and λ = 1.1, a 40% lower concentration of NO_x has been obtained (Figure 25).

At none of the measurement points, the concentration of hydrocarbons and nitrogen oxides with ethanol fuel has not been higher than with petrol.

The research have confirmed the positive effect of the ethanol mixture on the concentration of toxic substances, in particular on the concentration of nitrogen oxides.

It was shown that the effective parameters when powering the engine with ethanol and gasoline are comparable.

References

[1] Baczewski K, Kałdoński T 2005 *Paliwa do silników o zapłonie iskrowym* (Warszawa WKiŁ)
[2] Ambrozik A, Ambrozik T, Kurczyński D, Łagowski P 10-th European Conference of young research and science workers TRANSCOM 2013 *Impact of exhaust gas recirculation on basic parameters of the engine operation*" Słowacja, Žilina pp.17-21
[3] Bosch, Robert GmbH Gasoline Engine Management John Wiley & Sons 2006
[4] Maćkowski J 2006 *Wybrane problemy paliw samochodowych* (Gliwice WPŚ)
[5] Bielaczyc P, Klimkiewicz D, Szczotka A, Woodburn J Combustion Engines vol 2/2012 *A Comparison of the Exhaust Emission of a Vehicle Fuelled with Different Ethanol-Petrol Blends* pp. 57-65
[6] Merkisz J 1999 *Ekologiczne problemy silników spalinowych* vol 2 (Poznań WPP)
[7] Bielaczyc P, Woodburn J, Gandyk M, Szczotka A Combustion Engines vol 3/2016 *A Ethanol as an automotive fuel – a review* pp. 39-45
[8] Rychter T, Teodorczyk A 2006 *Teoria silników tłokowych* WKiŁ (Warszawa WKiŁ)
[9] Ambrozik A, Ambrozik T, Kurczyński D, Lagowski P, Trzensik E Solid State Phenomena vol 210/2013 *Cylinder Pressure Patterns in the SI Engine Fuelled by Methane and by Methane and Hydrogen Blends* pp. 40-49
[10] Żółty M, Stępień 2016 NAFTA-GAZ vol 9/2016 *Paliwa etanolowe w zastosowaniu do silników o zapłonie iskrowym* pp. 761-769
[11] Danek B 2012 Nafta-Gaz vol 10/2012 *Wpływ właściwości frakcji benzynowych na parametry składu frakcyjnego paliwa etanolowego E85* pp. 708–713
[12] Stępień Z 2015 Combustion Engines 2015 vol 54/3 *Wielokierunkowe badania wpływu paliw wysokoetanolowych na tworzenie osadów w silnikach z zapłonem iskrowym* pp. 608–618
[13] Pałuchowska M, Rogowska D 2009 Nafta-Gaz vol 1/2009 *Wpływ bioetanolu na nieaddytywne właściwości benzyny silnikowej*
[14] Rover Cars RAVE (Rover After Sales Literature) Information
[15] ECUMaster Digital ECU Tuner II – Instrukcja Użytkownika