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A STUDY OF THE ENVIRONMENTAL CHARACTERISTICS OF A GASOLINE ENGINE OPERATING ON UPGRADED BIOGAS

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ABSTRACT — *The paper presents a study of the environmental performance of a gasoline engine running on upgraded biogas. The parameters obtained are compared with those of the test running of the same engine on gasoline. The investigation of the operation on upgraded biogas involves conducting of multiple tests, providing corrective characteristics corresponding to various air-fuel ratios and ignition timing.*

Keywords: *air-fuel ratio, bio fuels, ecology, ignition timing, upgraded biogas*

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1. INTRODUCTUON

With the increasingly stringent environmental standards on exhaust gas set by EU legislation, the use of alternative fuel sources is increasing [3]. Biogas, which is basically a mixture of methane (60%), carbon dioxide (about 35%) and 5% other gases, is a type of alternative fuel. To achieve effective combustion, biogas must undergo an upgrading process which removes carbon dioxide and gases harmful to the engine [6]. The biogas that has undergone upgrading or purification is called upgraded biogas or biomethane.

There are several reasons for using biogas as alternative fuel, for example, reduced combustion noise, lower non-methane exhaust emissions even with cold start, considerably lower CO_2 emissions, high octane number, permitting applications in supercharged gasoline engines as well. Compared to gasoline, methane fuels have the following disadvantages: lower density, additional energy consumed for their compression, production and transportation loss of gas, and relatively few charging stations at the moment. The majority of all gas engines are spark-ignition internal combustion engines, with fuel injected in the intake manifold. Such engines have a few fundamental differences to be taken into account in the design of gas internal combustion engines:

- As compared to gasoline, biogas occupies a significant part of the intake volume. This requires a detailed dynamic modelling of the intake manifold mass flow [4];
- Although with gaseous fuels no fuel vapour condensation occurs on the cylinder walls, a similar dynamic effect is present due to the existence of substantial reverse flow at a certain point during the filling of the cylinder;
- As the fuel is gas, it can be injected while the intake valve is open without affecting the increase of HC emission in the exhaust.

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2. MATERIALS AND METHODS

The tests were conducted on a gasoline engine and provided for taking and analyzing various characteristics [5]. The experiments carried out aim at taking corrective parameters with different composition of the fuel-air mixture α, the variable parameter being Θ (the angle of ignition timing). The parameters were measured at frequencies of crankshaft rotation - 2000 min^{-1}, 3000 min^{-1}, 3500 min^{-1} and 4500 min^{-1}, and throttle opening of 100% (WOT). The external frequency-response characteristic of the tested engine was also taken and analyzed for operation on gasoline and biomethane respectively.

The quantity of the components of the internal combustion engine exhaust gas is measured using Applus gas analyzer of the company AutoLogic [2]. The gas analyzer employs NDIR measurement method which measures the concentration of HC, CO and CO_2 using the absorption of continuous infrared light by the gases to determine their concentration. The concentration of the elements in the gas volume is a function of the amount of gas molecules in a sample. The absorption of infrared light increases with the increase in the number of gas molecules passing through the light.

Table 1. Gas analyzer measuring range

	Dimension	**Range**	**Dispersing**	**Precision**
HC	***ppm***	0 ÷ 15 000	1	± 4 ppm
CO	***%***	0 ÷ 15	0,001	± 0,02 %
CO_2	***%***	0 ÷ 20	0,01	± 0,3 %
O_2	***%***	0 ÷ 25	0,01	± 0,1 %
NO_x	***ppm***	0 ÷ 5 000	1	± 20 ppm

The method for measuring NO_x and O_2 concentration uses chemical cells which generate voltage proportional to the gas of the sample cell.

The technical data and the measurement range of gas analyzer are shown in Tables 1 and 2 [1].

Table 2. Technical data of the Gas Analyzer

Parameter	**Dimension**	**Value**
Operating Temperature	***°C***	-20 ÷ 70
Altitude	***m***	-300 ÷ 3 000
Vibration Resistance	***Hz***	5 ÷ 1 000
Impact Resistance	***m***	1,22
Time Reporting	***sec***	8 measurement of NDIR
Supply	***V***	DC 5

3. RESULTS AND DISCUSSION

Figures 1 to 20 illustrate the variations of CH, CO, CO_2, NO_x and O_2 for various air ratios as a function of the angle of ESF at frequencies of crankshaft rotation of respectively n=2000 min^{-1}, n=3000 min^{-1}, n=3500 min^{-1} and n=4500 min^{-1}. Based on the graphs, it can be concluded that Θ has no impact on the concentration of the individual compounds, except for NO_x which mainly depends on the temperature of combustion. The highest CH content refers to rich air-gas mixtures, with CH concentrations of up to 160 ppm. The latter is due to the incomplete burning of the air-gas mixture, where the combustion takes place in the conditions of limited oxygen supply or pyrolysis of the fuel occurs. Also, in a rich air-gas mixture, the content of CO is the highest and is in the range of about 4 ÷ 5%. In rich mixtures, carbon monoxide fails to be oxidized to CO_2 due to slowing down of the reaction rate of oxidation, and the insufficient amount of free oxygen in the combustion chamber. The analysis of CO_2 indicates that the highest values of about 10% are achieved when $\alpha = 1,05$. This is due to the fact that with such an air-gas ratio, the air-gas mixture has the highest burning rate and the amount of oxygen is sufficient to ensure the complete combustion of the mixture in the engine cylinder, which provides for the maximum oxidizing of CO to CO_2. The negative effect of the complete combustion of lean air-gas mixtures is associated with the highest values of NOx in the range of 2000 ÷ 4000 ppm. With $\alpha = 1,05$ and $\alpha = 1,6$, the NOx concentration is influenced by the ESF angle as well since on the one hand, the increase in the latter leads to a rise in the temperature of combustion, and on the other hand, the air-gas mixture contains sufficient quantity of air to enable the molecules of O_2 and N_2 to dissociate and form nitrogen oxides.

In all diagrams, the parameters of rich air-fuel mixtures are indicated in red, the parameters of stoichiometric composition are shown in green and the parameters obtained for poor air-fuel mixtures are illustrated in blue.

Fig.1. Variation of O_2 depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 2000 min $^{-1}$

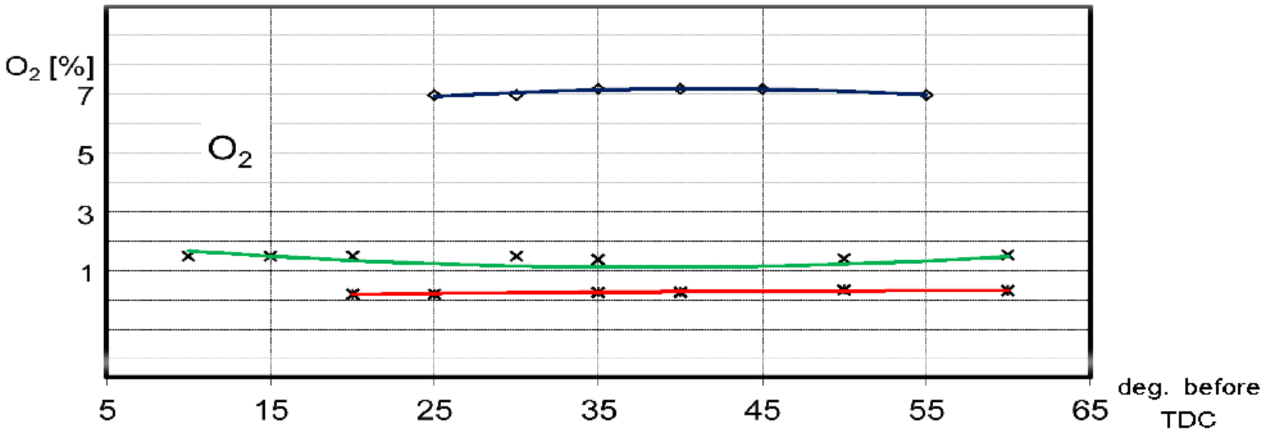


Fig. 2 Variation of NO_x depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 2000 min $^{-1}$

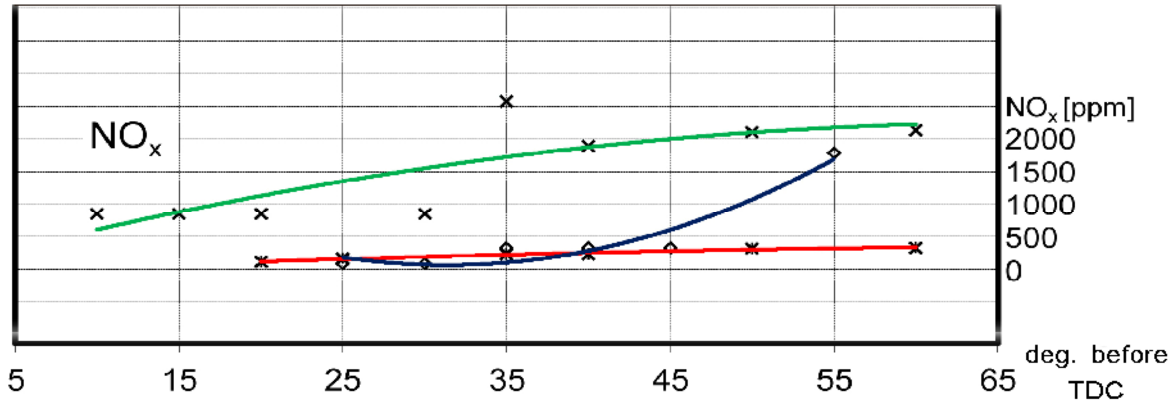


Fig. 3. Variation of CO_2 depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 2000 min $^{-1}$

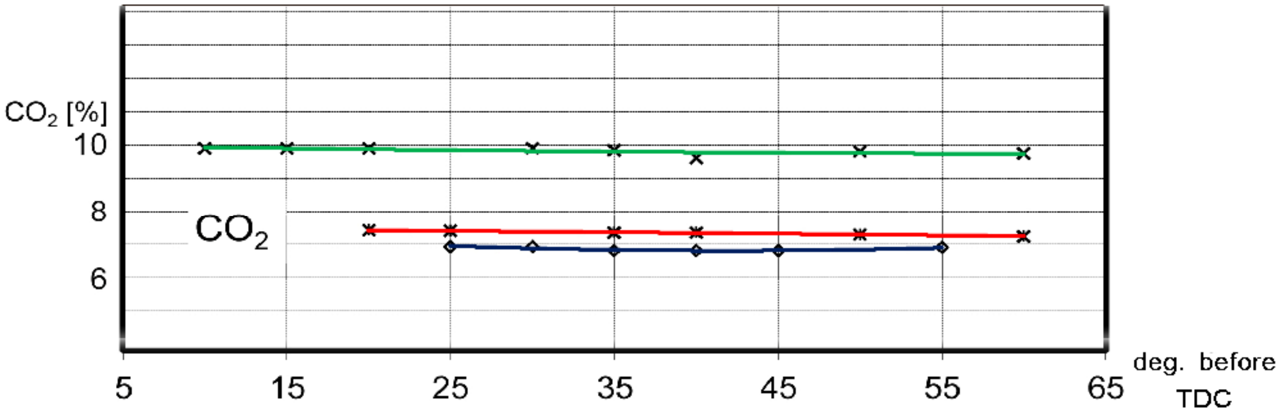


Fig. 4. Variation of CO depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 2000 min $^{-1}$

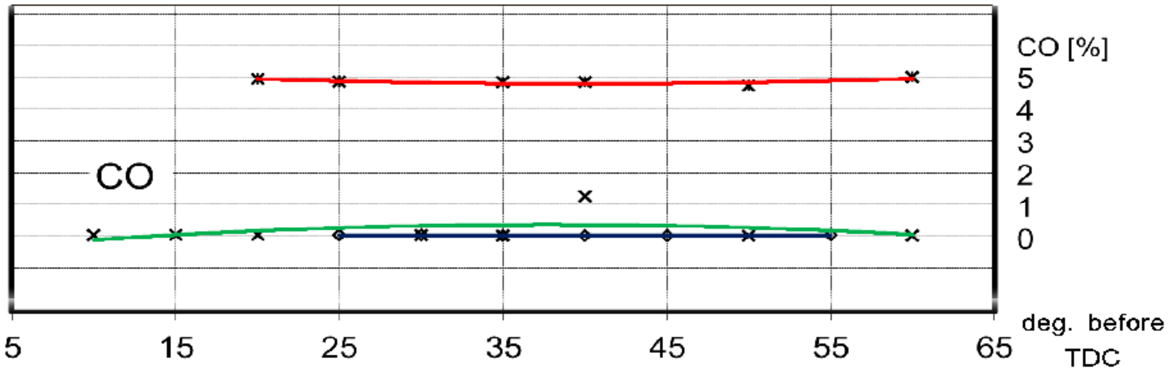
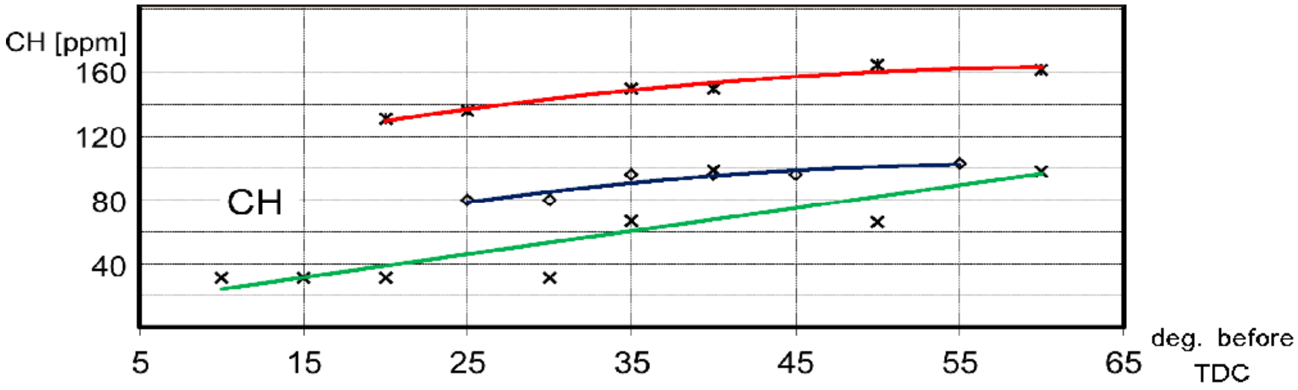


Fig. 5. Variation of CH depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 2000 min $^{-1}$



With optimal values of Θ and α, when n=2000 min $^{-1}$ – CH=67 ppm, when n=3000 min $^{-1}$ – CH=80 ppm, when n=3500 min $^{-1}$ – CH=82 ppm and when n=4500 min $^{-1}$ – CH=91 ppm.

With the increase in n as a result of an intensive heat transfer from the gases to the cylinder walls, the temperature and rate of the combustion decrease and part of the fuel in the layer next to the walls of the combustion chamber is not oxidized due to the termination of the oxidation reactions. CO levels are insignificant for the same controlling/corrective parameters and the corresponding speeds of rotation are: CO-2000=0,03%, CO-3000=0,18%, CO-3500=0,76% and CO-4500=0,06%, which indicate good combustion with almost complete oxidation of carbon monoxide. These amounts of CO result from the insufficient temperature for the full oxidation and CO_2 formation in the layer of fuel mixture near the walls of the combustion chamber.

Fig. 6. Variation of O_2 depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3000 min $^{-1}$

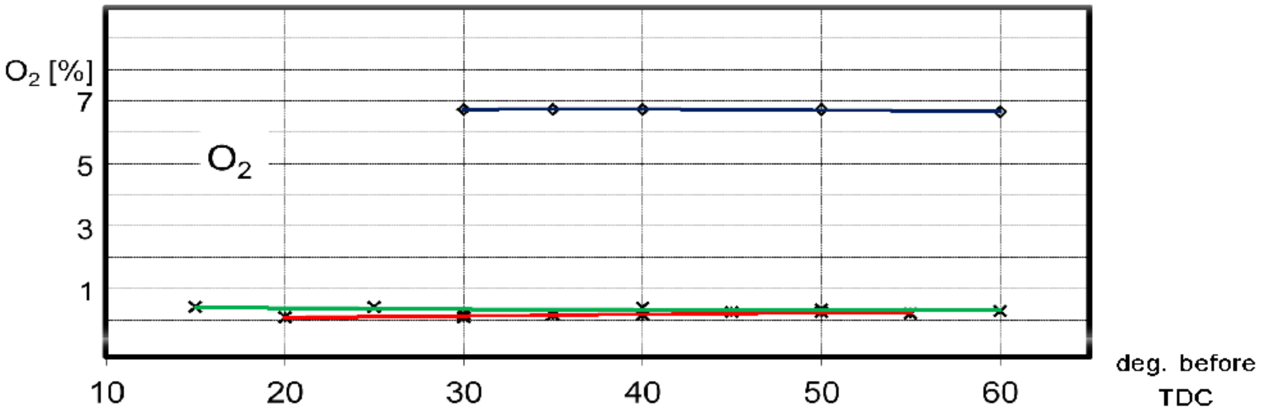


Fig. 7. Variation of NO_x depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3000 min $^{-1}$

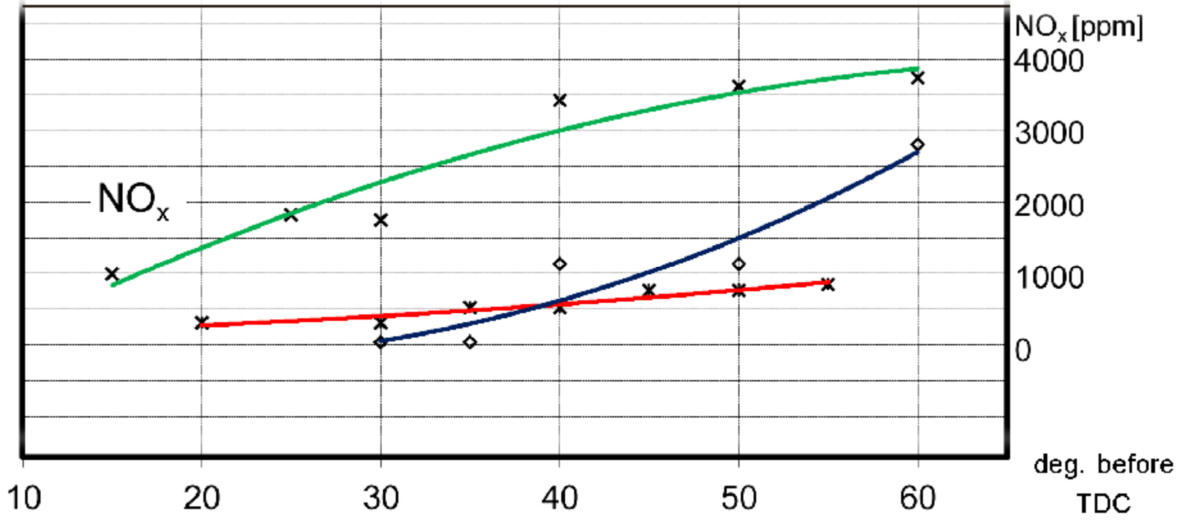


Fig. 8. Variation of CO_2 depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3000 min $^{-1}$

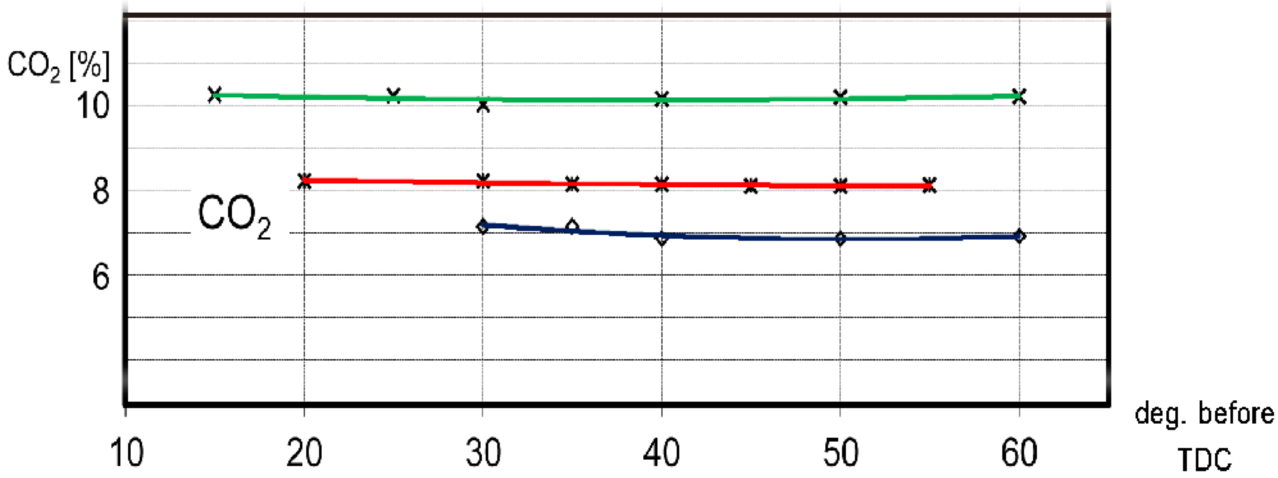


Fig. 9. Variation of CO depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3000 min $^{-1}$

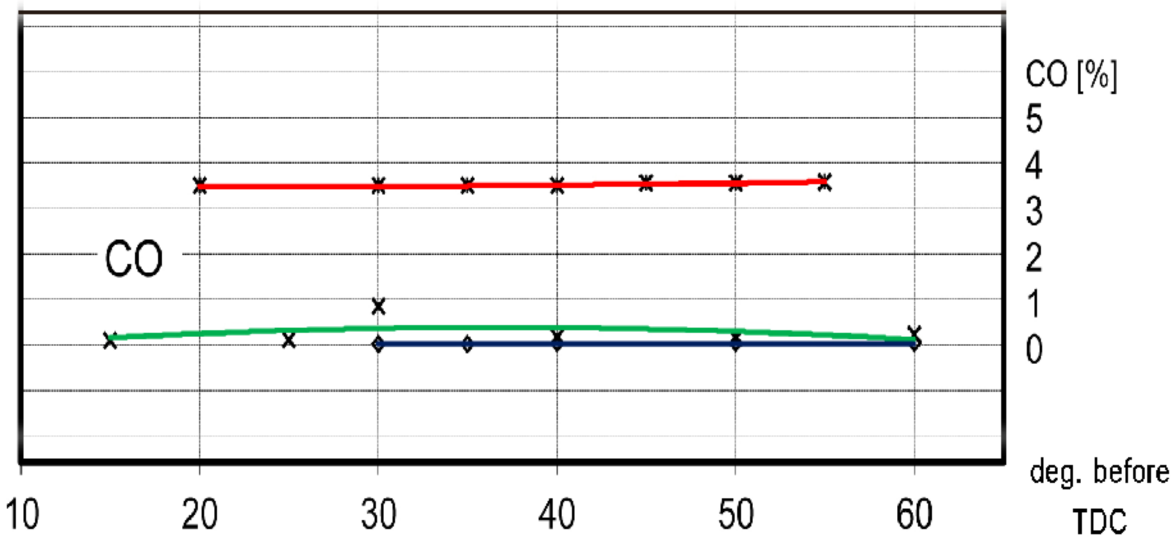
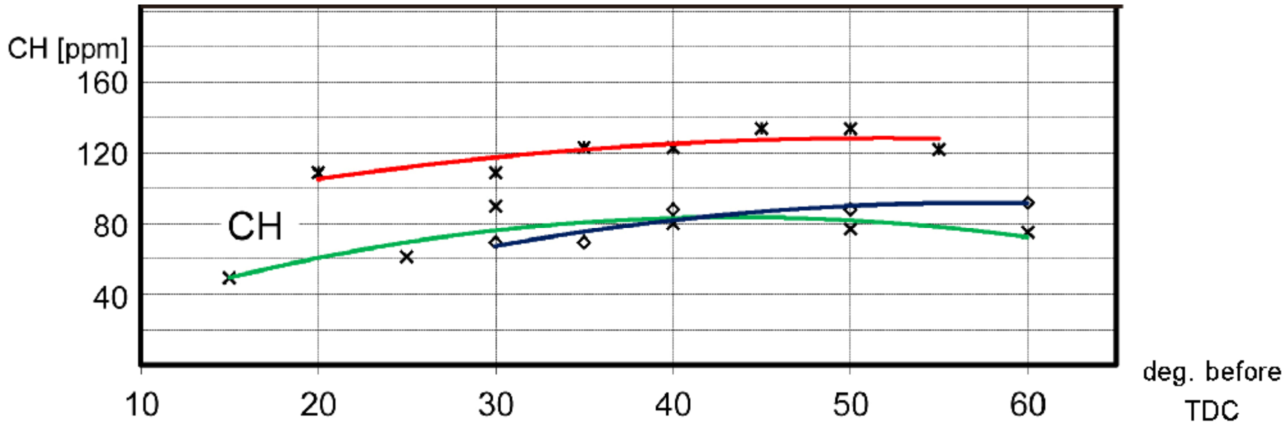


Fig. 10. Variation of CH depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3000 min $^{-1}$



The combustion process and the full oxidation of the gas fuel can also be evaluated by the levels of carbon dioxide in the exhaust gases, the maximum values in methane being 10 ÷ 10,5%. With the controlling / corrective parameters determined, the levels of CO_2 are as follows: at 2000 min^{-1} – CO_2=9,84%; at 3000 min^{-1} – CO_2=10,18%; at 3500 min^{-1} – CO_2=10,05% and at 4500 min^{-1} – CO_2=10,06%.

Fig. 11. Variation of O_2 depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3500 min $^{-1}$

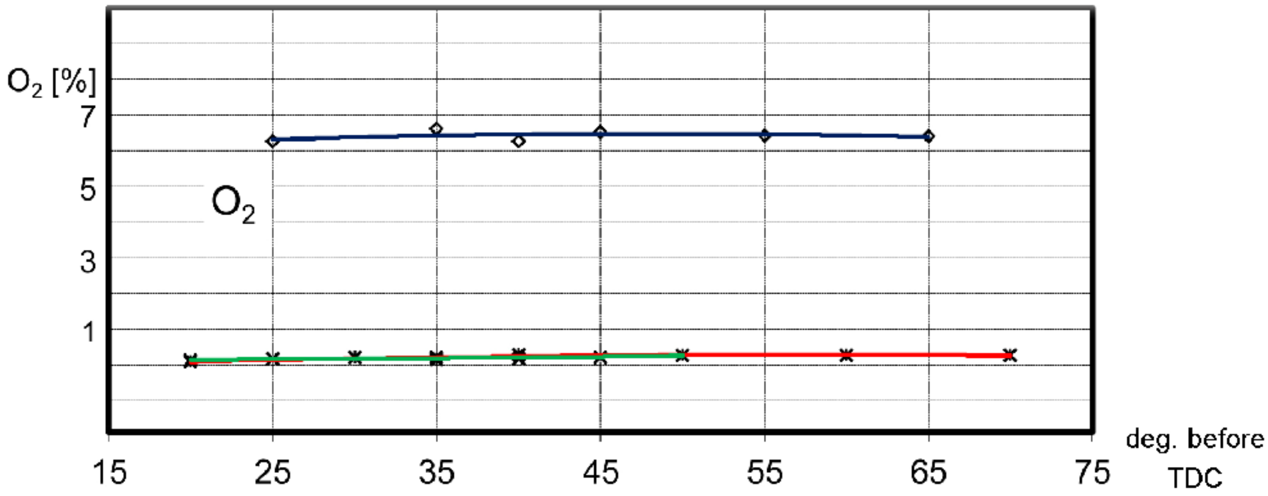


Fig. 12. Variation of NO_x depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3500 min $^{-1}$

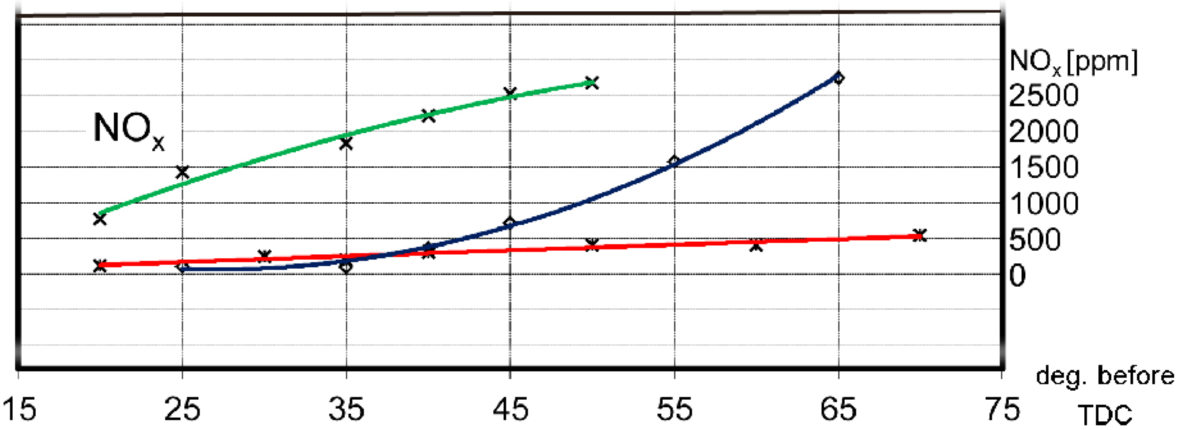


Fig.13. Variation of CO_2 depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3500 min $^{-1}$

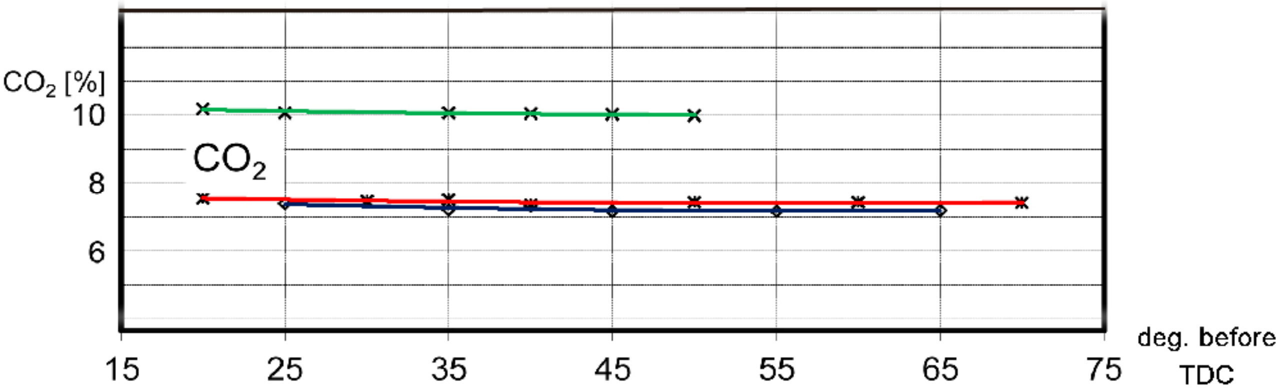


Fig. 14. Variation of CO depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3500 min $^{-1}$

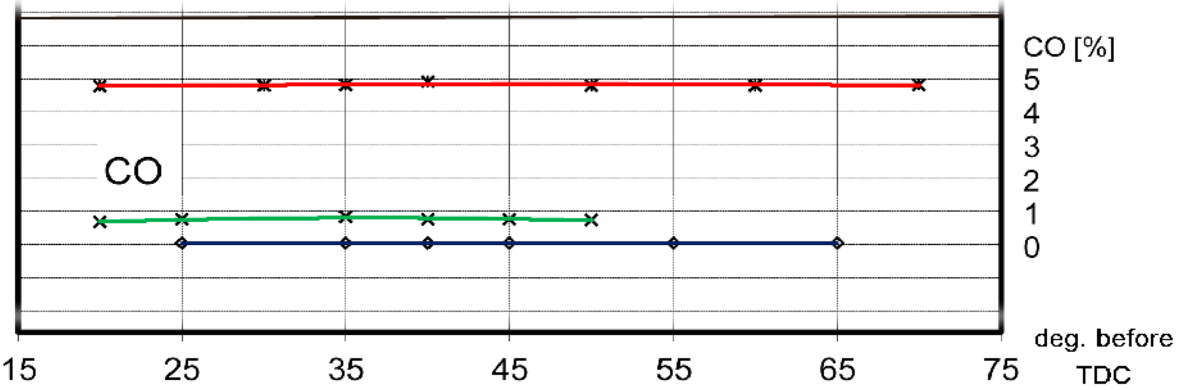


Fig. 15. Variation of CH depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 3500 min $^{-1}$

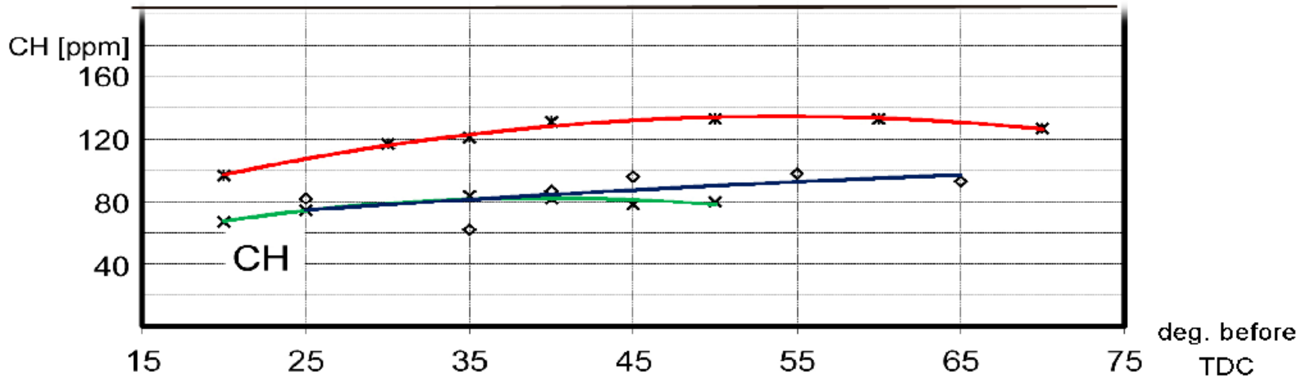


Fig. 16. Variation of O_2 depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 4500 min $^{-1}$

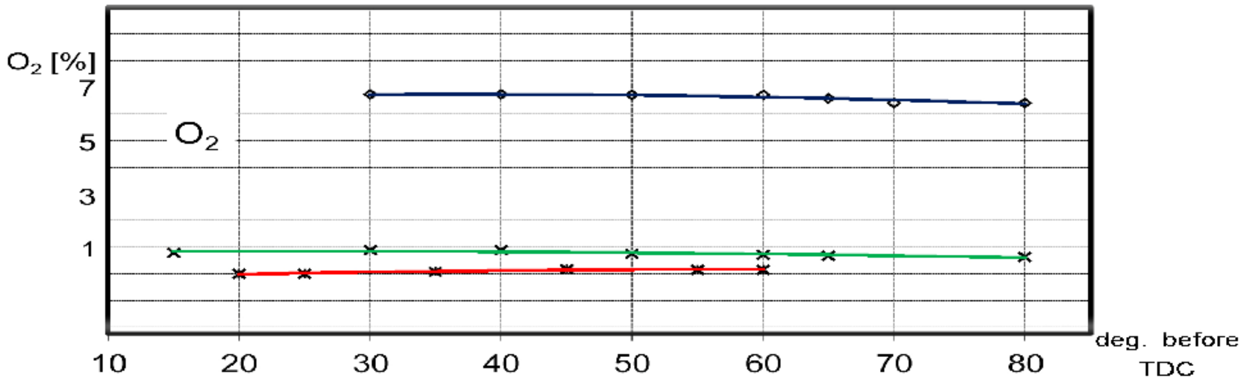


Fig. 17. Variation of NO_x depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 4500 min $^{-1}$

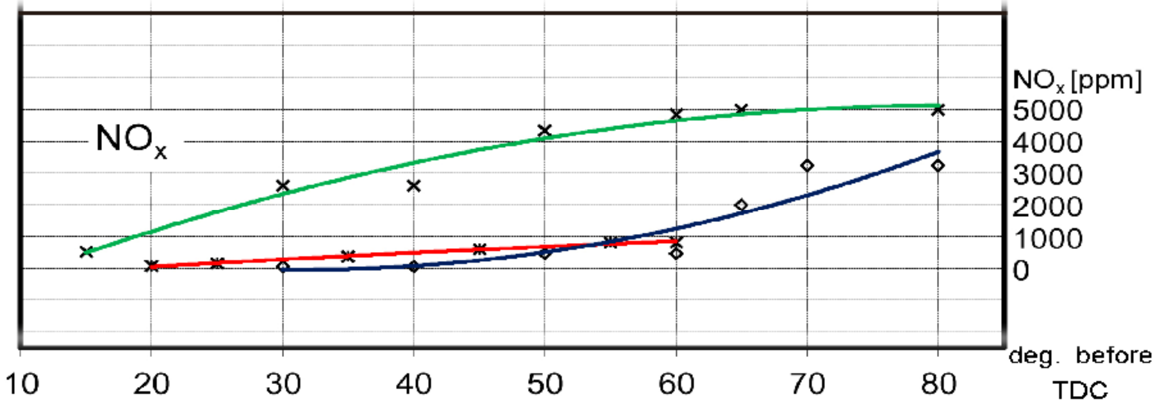


Fig. 18. Variation of CO_2 depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 4500 min $^{-1}$

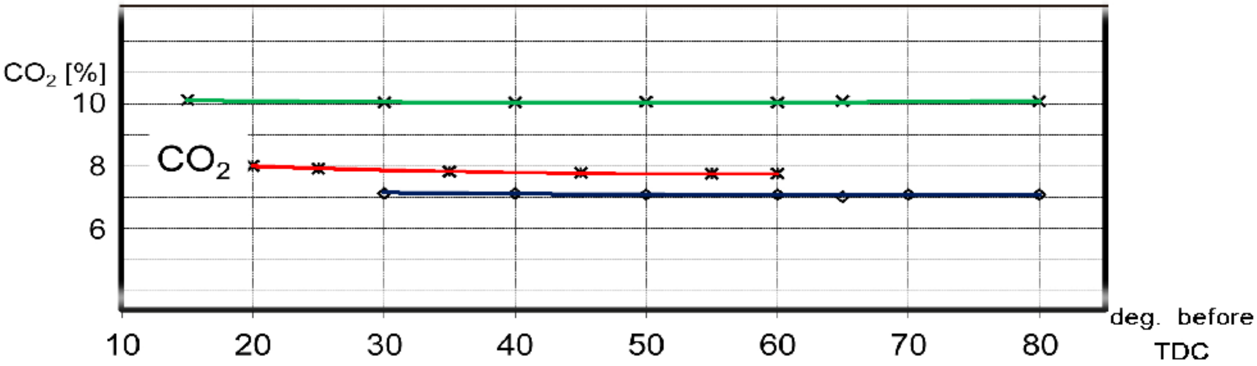


Fig. 19. Variation of CO depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 4500 min $^{-1}$

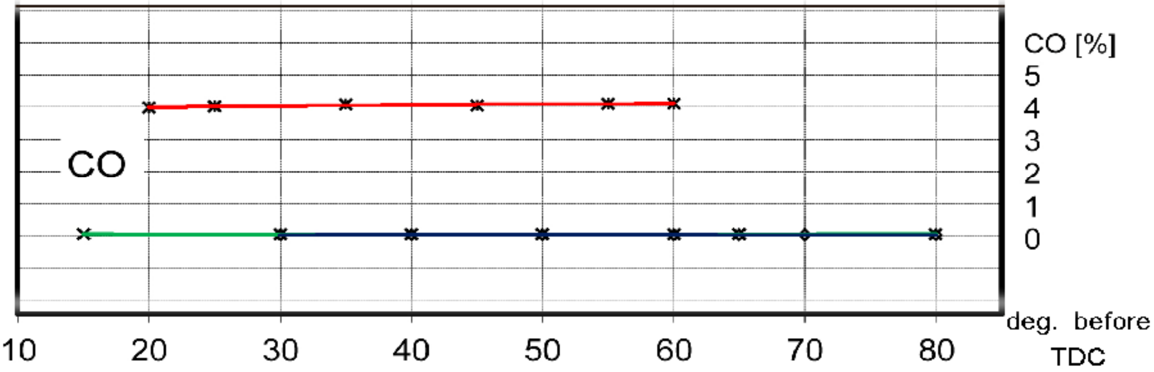
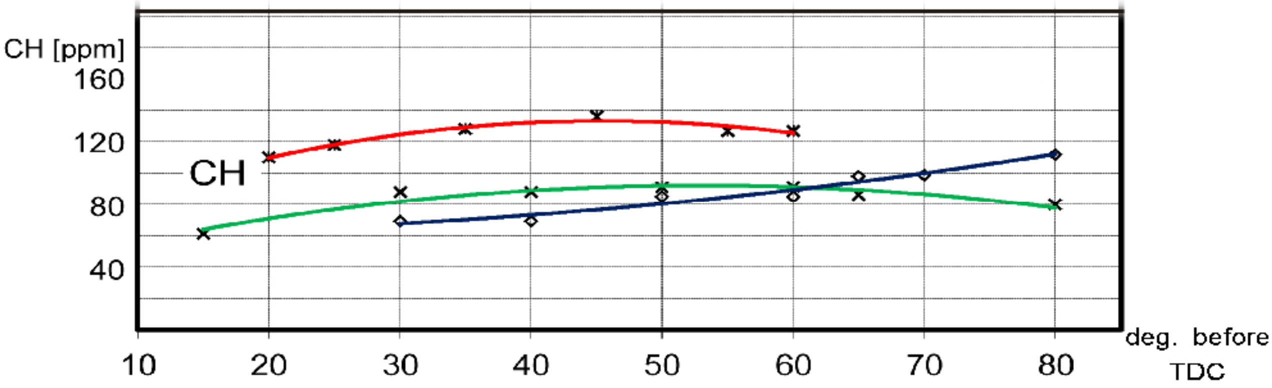


Fig. 20. Variation of CH depending on Θ (α=0,82 red lines; α=1,05 green lines; α=1,6 blue lines;) at 4500 min $^{-1}$



The only highly toxic substances which are formed by the complete combustion of hydrocarbon fuels are NO_x. At 2000 min $^{-1}$ – NO_x =2580 ppm; at 3000 min $^{-1}$ – NO_x =3430 ppm; at 3500 min $^{-1}$ – NO_x =2223 ppm and at 4500 min $^{-1}$ – NO_x =4350 ppm. This is normal because obtaining the optimum power-economic indicators requires more heat in the engine cylinder to achieve greater operational efficiency. Reduction the levels of nitrogen oxides can be achieved by applying some of the currently known methods for reduction of NOx concentration of NOx

The external speed curve is drawn for the optimum corrective parameters for both types of fuel - methane α = 1; gasoline α = 0,9 and optimum angle Θ at various speeds of rotation of the crankshaft.

4. CONCLUSION

As a result of the experimental studies, it should be noted that:

- When the internal combustion engine operates with optimal Θ and α, the concentration of CO in the exhaust gases is almost 0%, indicating a maximum completeness of the combustion process;
- When operating the engine with optimum values of Θ and α, the concentration of nitrogen oxides is found to increase (n=2000 min-1 – NO_x =2580 ppm; n=3000 min^{-1} – NOx =3430 ppm; n=3500 min^{-1} – NO_x=2223 ppm; n=4500 min^{-1} – NO_x =4350 ppm.), which is due to the increased heat release during the combustion process. Lowering the concentration of nitrogen oxides can be achieved by applying some of the existing well-proven methods.
- Reaching the maximum efficiency of combustion requires an increase in the angle of the ignition timing by 10÷20 ° as compared to the settings for gasoline depending on the frequency mode of the engine, which is due to the lower burning rate of biomethane compared to gasoline.
- Total CO_2 emissions are significantly reduced due to the use of gaseous fuel. In addition, emissions of non-methane hydrocarbons are reduced. Upgraded biogas (biomethane) is found to have the greatest potential as a fuel compared to other biofuels.
- Upgraded biogas can be used as fuel in the same way and with the same vehicles as natural gas.

5. REFERENCES

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