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Ecological effects of changes in the ignition angle of a gasoline engine on exhaust harmful gases emissions

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Abstract. The present study reports the results from a real experiments of the impact of the ignition angle on the harmful exhaust gases emitted by a gasoline engine. The experiments were carried out with a BMW 318 gasoline engine equipped with a MegaSquirt 3 electronic control unit and TunerStudio MS software, as well as a Kane AUTOplus gas analyzer. The main emissions considered in the study include some greenhouse gases such as carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbons (HC). The emissions of harmful gases were measured at 7 different engine speeds and 9 different ignition angles. The obtained data were used to compile regression equations that describe the relationship between the ignition angle, engine speed and the harmful emissions levels. The obtained results and derived equations offer specific recommendations for optimization of the ignition angle to minimize harmful emissions and improve the environmental performance of gasoline engines.

Key words: gasoline engine, hazardous emissions, greenhouse gases, air pollution.

Introduction

In the context of today's environmental challenges, the reduction of harmful emissions from automobile engines represents a major issues for researchers and engineers. Gasoline engines, which are widely used in the automotive industry, generate significant amounts of harmful emissions such as carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbons (HC). These emissions have a significant impact on air quality and human health, as well on greenhouse gases concentration. Previous research has shown that ignition angle plays a key role in the combustion process in gasoline engines and therefore affects the amount and composition of harmful gases emitted (Heywood, 2018; Kanevski et al., 2024). However, optimally tuning the ignition angle to minimize harmful emissions remains a complex and challenging process, requiring a detailed study of the relationships between various engine parameters. The experimental studies of Karvountzis-Kontakiotis et al. (2018) and Zhao et al. (2019) highlight the importance of fine-tuning the ignition angle to reduce the CO_2, CO and HC emissions. They demonstrate that even small changes in ignition angle can lead to significant changes in emissions, necessitating a systematic optimization approach.

The present study aims to investigate the influence of ignition angle on the harmful gases emitted by a gasoline engine by analyzing data collected at different engine speeds and different ignition angles. Some correlation equations have been applied aiming at identify the optimal settings of the ignition system to minimize harmful emissions and improve the environmental performance of the engine.

Materials and methods

The present study focuses on the measurement of harmful emissions emitted by a gasoline engine at different ignition angles. The study was conducted using the following equipment and procedures:

Description of the experimental setup

1. Internal combustion engine:

Model: Gasoline engine from BMW 318

Technical characteristics: Four-cylinder, 1.8 liter, in-line internal combustion engine

2. Management system:

Model: Open hardware MegaSquirt 3 electronic engine control unit

Features: Allows precise adjustment of ignition angle and other engine parameters

3. Gas analyzer:

Model: Kane AUTOplus - Functions: Measures concentrations of major harmful emissions such as carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbons (HC)

4. Software: TunerStudio MS for setting and monitoring engine parameters (Fig. 1)

Features of TunerStudio MS: Intuitive user interface that allows quick and efficient tuning of engine parameters. Provides real-time data monitoring including engine RPM, coolant temperature, manifold pressure and other important parameters. Ignition Tuning and Fuel Maps: Tools to edit ignition and fuel maps that allow optimization of engine performance under various conditions.

Measurement procedures

1. Setting up the experimental setup: The engine is mounted on a laboratory bench (Fig.2), allowing monitoring of its main parameters and work processes. The MegaSquirt 3 electronic control unit is configured to control the ignition and other engine parameters, using the Tuner Studio MS software product for configuration.

2. Procedure for changing the ignition angle: Determination of the initial ignition angle according to the manufacturer's specifications. The ignition angle is changing in steps of 5 degrees in the range from 0 to +40 degrees.

3. Measurement of emissions: The measurements are carried out at different engine speeds: 800, 1000, 1200, 1400, 1600, 1800, and 2000 rpm. For each combination of ignition angle and rpm, the Kane AUTOplus gas analyzer records CO, CO_2 and HC concentrations. Measurements were repeated three times for each combination to ensure the accuracy and repeatability of results.

Control and calibration

The Kane AUTO-plus gas analyzer is calibrated before each series of measurements to ensure the accuracy of the measurements. The MegaSquirt 3 system is che-cked and adjusted for each new combination of parameters to ensure the stability of the experi-mental conditions.

Precision and Limitation of the Study

The precision of the measurements is guaranteed by multiple repetitions and the arithmetic mean of the obtained values. Limitations of the study include the influence of external factors such as ambient temperature and fuel quality, which may affect the results. This methodology provides a clear framework for conducting the experiments and provides reliable and valid data for the analysis of the influence of the ignition angle on harmful emissions from a gasoline engine.

4. Data Analysis: The collected data are analyzed using statistical methods to determine the correlation between ignition angle and emission levels. Linear regression equations are derived to describe the relationship between ignition angle and emissions at different engine speeds ($p<0.05$).

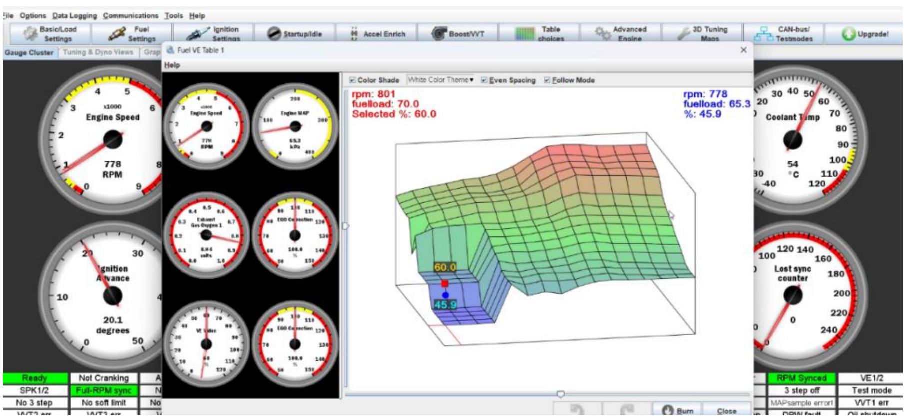

Fig. 1. Tuner Studio MS.

Fig. 2. Experimental stand for the research.

Results and Discussion

Experimental studies were conducted on the harmful emissions of carbon dioxide (CO_2), carbon monoxide (CO) and hydrocarbons (HC), released during the operation of a gasoline engine with internal combustion at 9 different ignition angles (from 0 to 40) and at 7 different engine speeds (from 800 rpm to 2000 rpm).

The results on the change in CO_2 emissions depending on the changes of the ignition angle and the engine revolutions are presented in Table 1 and Fig. 3. The analysis of the results led to the following conclusions: 1) CO_2 values are lowest (1.8 to 4.5%) at an ignition angle between 15-40 degrees and engine revolutions in the range of 800-2000 rpm; 2) The highest CO_2 values are at an ignition angle of 0-10 degrees and engine revolutions in the range of 1400-2000 rpm;

Correlation and regression analyses were used to process the results, aiming at describe the relationships between the emissions and engine properties. Correlation coefficients prove a strong dependence between the ignition angle and the measured CO_2 values ($p<0.05$). Figs. 4, 5 and 6 show the regression equations and their coefficients depending on the studied engine parameters.

Table 1. CO_2 emissions depending on the values of the ignition angle and engine speed.

CO_2		Engine RPM (RPM/min)						
		800	1000	1200	1400	1600	1800	2000
Ignition angle [degrees]	0	2.80	3.70	5.40	5.70	8.80	6.67	6.00
	5	2.71	3.79	4.60	5.06	8.69	3.86	4.59
	10	2.02	3.80	4.10	4.06	8.26	6.50	4.65
	15	2.02	3.07	4.17	4.46	6.34	4.25	4.47
	20	1.80	3.05	3.42	3.90	4.31	4.56	4.43
	25	1.60	3.13	3.11	3.84	5.01	4.60	4.23
	30	1.63	2.51	3.59	3.93	4.10	4.52	4.18
	35	1.55	2.50	3.75	4.81	3.16	4.44	4.15
	40	1.60	2.35	3.08	4.73	3.25	4.42	4.09

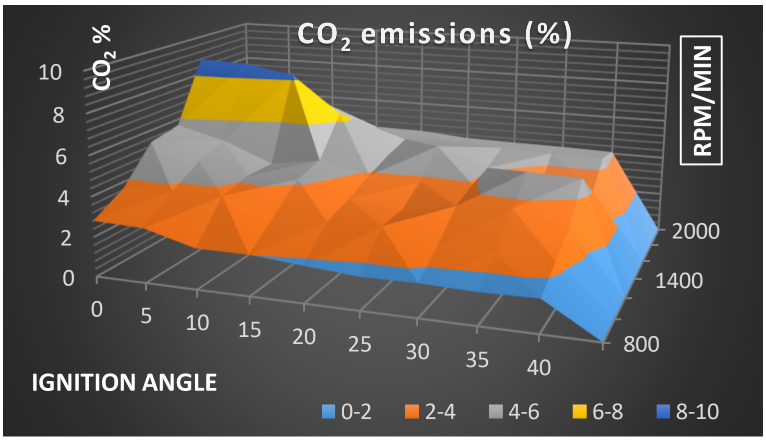

Fig. 3. Chart of CO_2 emissions at different ignition angles and different engine speeds.

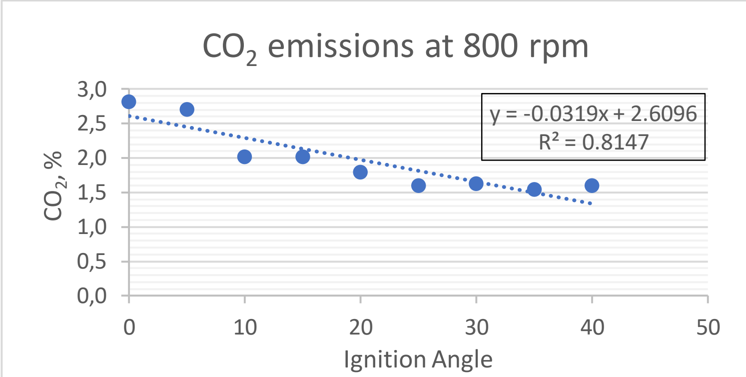

Fig. 4. Relationship between CO_2 emissions and different ignition angles at 800 rpm.

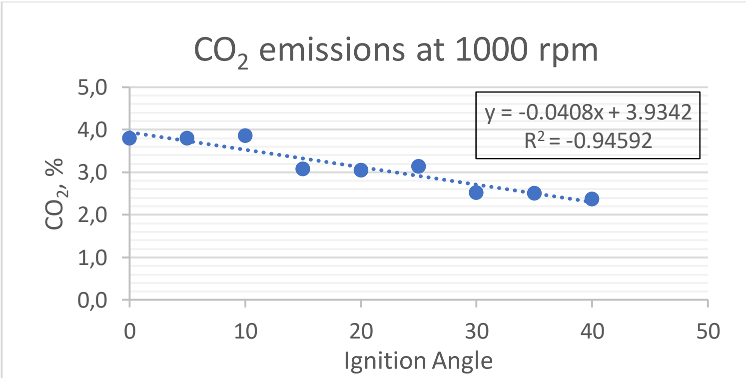

Fig. 5. Relationship between CO_2 emissions and different ignition angles at 1000 rpm.

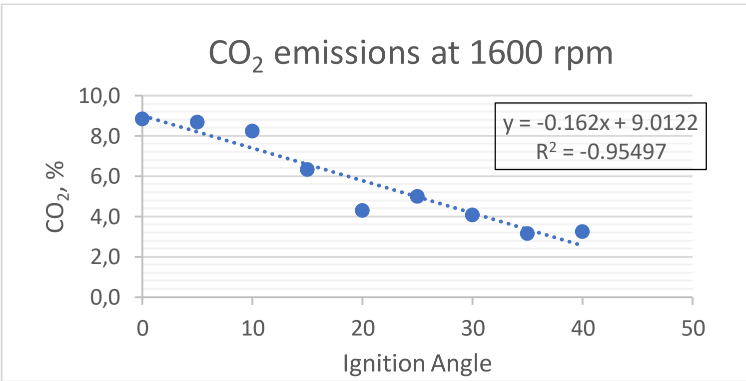

Fig. 6. Relationship between CO_2 emissions and different ignition angles at 1600 rpm.

Average values of the unburned hydrocarbons (HC) depending on the ignition angle and engine revolutions are presented in Table 2 and Fig. 7. Correlation equations were used to process the results, through which the correlation coefficients of the studied emissions.

The analysis of the results led to the following conclusions: 1) HC emissions are lowest (2000 to 4500 ppm) at an ignition angle in the range of 0-20 degrees and engine revolutions in the range of 800-1400 rpm; 2) HC emissions are highest at an ignition angle of 20-40 degrees and engine revolutions in the range of 1600-2000 rpm.

Correlation and regression analyses were used to process the results, aiming at describe the relationships between the HC emissions and engine properties. Correlation coefficients prove a strong dependence between the ignition angle and the measured HC values at engine speed of 1600-2000 ppm and medium dependence at lower speed ($p<0.05$). Linear regression equations were used to process the results, through which the regression coefficients of the studied HC emissions were obtained (Figs. 8, 9 and 10). It can be seen that R^2 = 0.75 at 1600 rpm which means that at about 75% of the total variance of the studied variable (HC emissions) could be explained by the studied factor (ignition angle), but this effect is less pronounced at a lower speed ($p<0.05$). This is in a good agreement with the literature data that the advance timing angle causes higher in cylinder peak pressure, which in turns pushes more of the fuel-air mixture into crevices (most significantly the space between the piston crown and cylinder walls) where the flame is quenched and mixture is left unburned (Zareei & Kakaee, 2013). Additionally, the temperature late in the cycle, when the mixture comes out of these crevices, is lower at more advance ignition timing. The later temperature means that the hydrocarbons and oxygen do not react. This increase the concentration of oxygen in the exhaust and unburned hydrocarbons.

Table 2. Emissions of unburned hydrocarbons (HC) depending on the values of the ignition angle and engine speed.

HC		Engine RPM (RPM/min)						
		800	1000	1200	1400	1600	1800	2000
Ignition angle [degrees]	0	4180.00	3701.00	4258.00	4314.00	2615.00	2965.00	3449.00
	5	4426.00	4482.00	4249.00	4487.00	2588.00	5403.00	5571.00
	10	4333.00	4448.00	3803.00	3857.00	2463.00	2425.00	5678.00
	15	4296.00	3832.00	3831.00	4072.00	2393.00	4908.00	5784.00
	20	4275.00	3793.00	3711.00	3864.00	4014.00	5019.00	5930.00
	25	4300.00	3609.00	3350.00	3872.00	2885.00	5075.00	5995.00
	30	4278.00	3876.00	3686.00	3915.00	4000.00	5083.00	8954.00
	35	4086.00	3796.00	3784.00	2592.00	3646.00	5105.00	5951.00
	40	4255.00	3970.00	3825.00	2754.00	3775.00	5144.00	6254.00

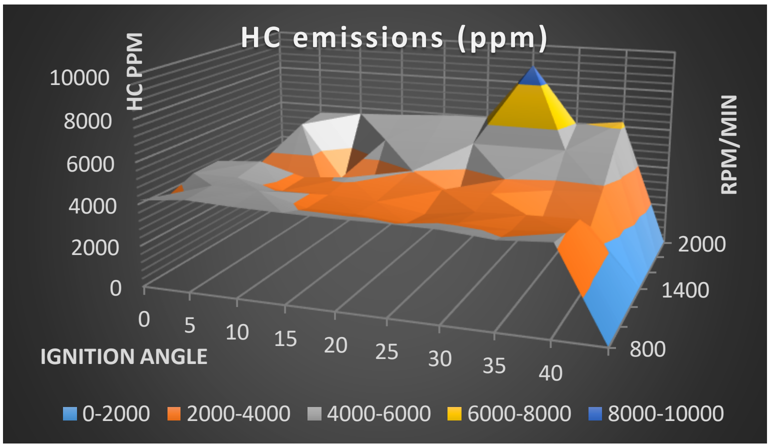

Fig. 7. Diagram of the HC at different ignition angles and different engine speeds.

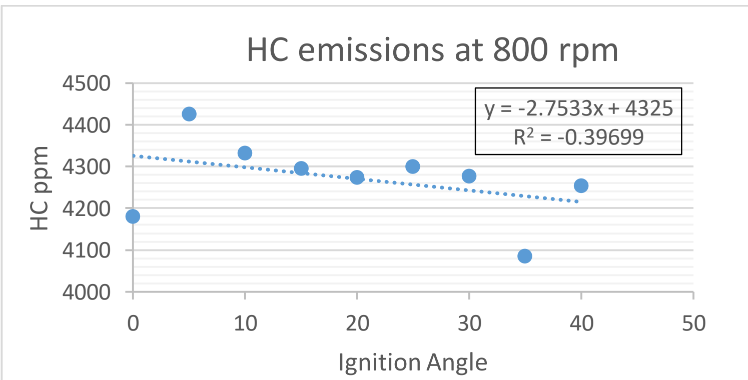

Fig. 8. Relationship between hydrocarbons (HC) and different ignition angles at 800 rpm.

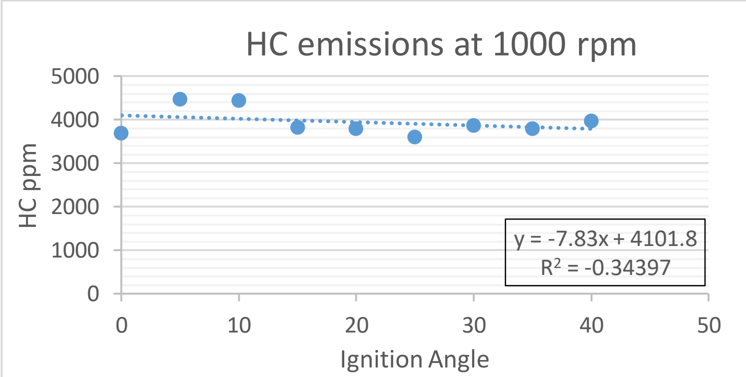

Fig. 9. Relationship between hydrocarbons (HC) and different ignition angles at 1000 rpm.

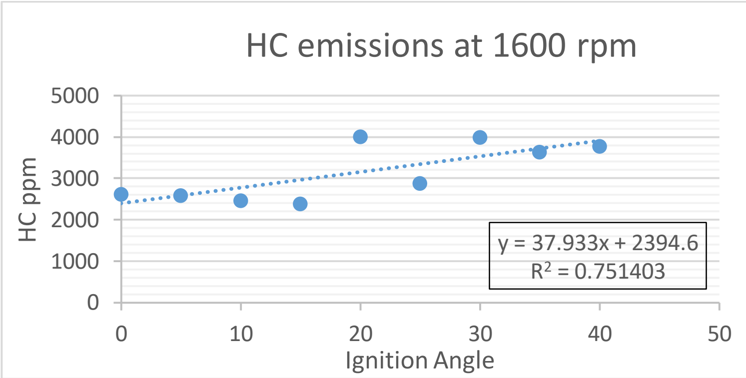

Fig. 10. Relationship between hydrocarbons (HC) and different ignition angles at 1600 rpm.

The average results of the measurements conducted on the carbon monoxide (CO) changes depending on the values of the ignition angle and engine revolutions are presented in Table 3 and Fig. 11. The analysis of the results led to the following conclusions: 1) CO values are the lowest (0.07 to 1%) at an ignition angle of 15-25 degrees and engine revolutions in the range of 800-1400 rpm; 2) CO values are highest (1.66-3.15%) at an ignition angle of 0-15 degrees and engine revolutions in the range of 1800-2000 rpm.

The correlation coefficients values prove a significant relation between the ignition angle and the measured CO emissions ($p<0.05$).

Linear regression equations were used to process the results, through which the regression coefficients of the studied emissions (Figs. 12, 13 and 14). The strongest impact on the CO content in exhaust gases was observed at engine speed of 1000 rpm where the changes in the ignition angle resulted in almost 87% of the total variance of the studied parameter (R^2=-0.86701).

Table 3. Emissions of carbon oxide (CO) depending on the values of the ignition angle and engine speed.

CO		Engine RPM (RPM/min)						
		800	1000	1200	1400	1600	1800	2000
Ignition angle [degrees]	0	0.10	0.36	0.04	0.14	0.43	2.56	3.15
	5	0.11	0.36	0.08	0.15	0.12	2.39	1.66
	10	0.08	0.28	0.08	0.10	0.10	0.11	1.68
	15	0.07	0.10	0.09	0.10	0.14	0.13	2.01
	20	0.07	0.11	0.08	0.08	0.04	0.15	2.08
	25	0.08	0.08	0.07	0.07	0.11	0.12	2.41
	30	0.07	0.09	0.09	0.06	0.02	0.14	2.36
	35	0.08	0.08	0.08	0.13	0.08	0.16	2.35
	40	0.08	0.08	0.08	0.14	0.07	0.20	2.64

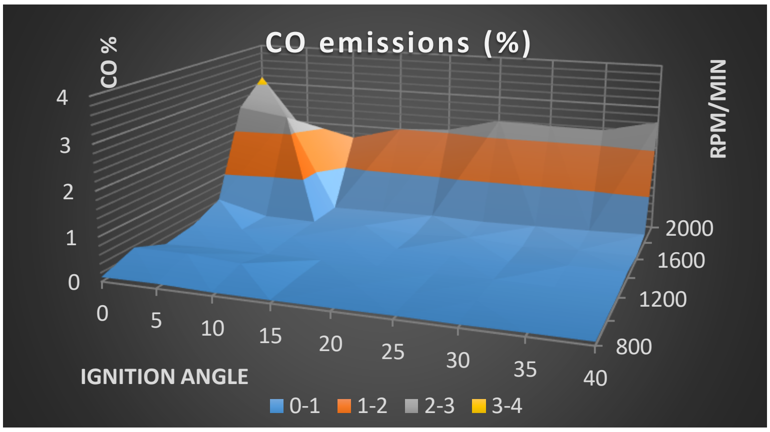

Fig. 11. Diagram of the HC at different ignition angles and different engine speeds.

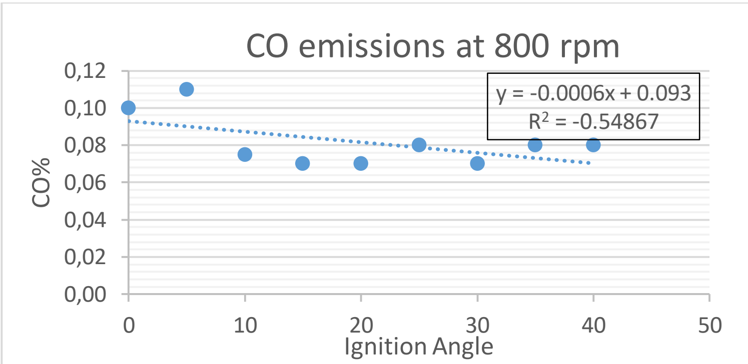

Fig. 12. Relationship between CO and different ignition angles at 800 rpm.

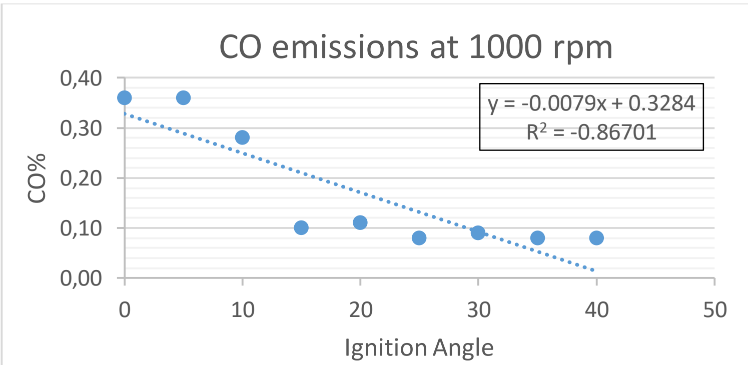

Fig. 13. Relationship between CO and different ignition angles at 1000 rpm.

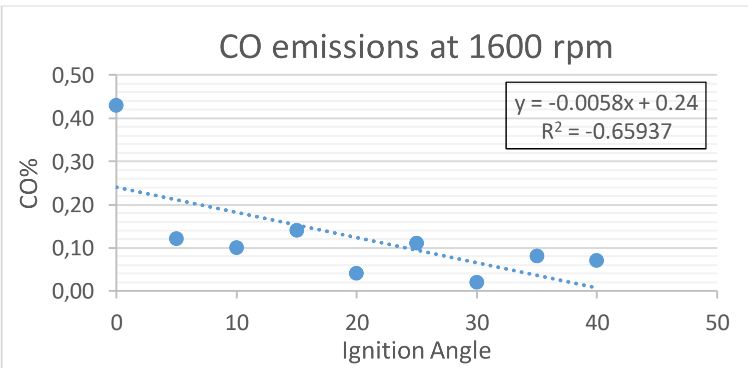

Fig. 14. Relationship between CO and different ignition angles at 1600 rpm.

Conclusions

Based on the conducted research and data analysis, the following conclusion are made: the optimal ignition angles, at which harmful CO_2, CO and HC emissions have minimal concentrations in the exhaust gases, are from 15 to 25 degrees. Regarding the engine speed, it can be concluded that less harmful emissions are derived between 800 and 1600 rpm.

The present study should alert the specialists working in the automotive industry to focus their expert potential to the optimization of the ignition angle of gasoline engines with internal combustion. This should affect both air quality and greenhouse gases levels at the atmosphere, as well as safety for the environment and human health.

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