Contributions Regarding the Study of Noxes in Automobiles Equipped with Spark Ignition Engines

Aurel Mihail Titu[1, *], Alina Bianca Pop[2], Mihai Banica[3]

Abstract: *Nowadays, internal combustion engines, with spark ignition, are still used in transport, and they are the focus of major car manufacturing companies that are looking for solutions to reduce polluting exhaust emissions and noise. The big car manufacturing companies present us with the latest technologies for obtaining performance engines and the methods of eliminating the noxes emitted by them. The spark ignition engine is considered the most polluting due to its spread in several fields of activity. For a correct analysis of internal combustion engines with spark ignition on the environment is the study of the emission of particles that represent the totality of the matter collected on a Teflon filter when the burnt gases pass through. The measurements conducted on vehicles of different brands and years of manufacture revealed how important the technical condition and the emissions emitted by them are. The main purpose of this scientific paper is to show how important the quality of the noxes resulting from the exhaust gases produced by internal combustion and spark ignition automobile engines is on the environment and implicitly on the population*

Keywords: *automobiles, noxes, spark ignition engines, the active type experiment*

1 INTRODUCTION

The term experiment or experimental determination is used in a rather precise sense to define an investigation in which the studied system is under the control of the investigator. This means that the objective of the investigation, the nature of the treatments or operations studied, and the measurement procedures investigated are established, at least with regard to the most important characteristics, by the investigator (Tițu et al., 2011).

Nowadays spark-ignition combustion engines are used more and more often in transport, and they are the focus of large car manufacturing companies that are looking for solutions to reduce polluting exhaust emissions and internal noise (Leach et al., 2020). Fuel producing companies are also of particular importance in reducing pollution, which in turn continuously improve the quality of the fuel composition to reduce pollution (Lion et al., 2020). Following some recent theoretical and experimental studies, it has been shown that the phenomenon of extinguishing the flame at the wall generates smaller amounts of HC (hydrocarbons) than was initially considered, other phenomena, such as the impossibility of flame propagation through the narrow spaces in the combustion chamber, absorption, and desorption in the oil film and in solid deposits, being the main generators of HC (hydrocarbons) (Gong et al., 2020). To reduce the risk of extinguishing the flame at the wall, different individual or combined measures can be taken:

- the concentration of HC reduced by impoverishing the mixture, until almost the limit of extinguishing the flame in the gas mass;
- increasing the pressure, especially the temperature of the gases burning near the wall by reducing the thickness of the boundary layer;
- ensuring oxygen and a high temperature for the components in the boundary layer by intensifying the oxidation reactions;
- reduction of the surface area of the combustion chamber and cylinder capacity;
- reducing the distance between the first segment and the piston head and reducing the bore/unit cylinder ratio, reducing the piston-cylinder clearance.

In spark-ignition engines, the noxes are determined by:

- the functional constructive solutions adopted for the realization and operation of internal combustion engines;
- the conditions in which the engine is operated, especially in the road case, characterized by a variability of loads and revolutions;
- the compositions and qualities of the fuel consist in establishing the achievement of a clean engine, for a clean environment (Awad, et al., 2018), (Lhuillier et al., 2020).

2 POLLUTIONS DUE TO MOTOR VEHICLES

Cars produce a strong pollution with noxes and are being considered the most serious polluter of the environment (Bovornkitti et al., 2019). The measurements proved the massive and systematic exceeding of the maximum allowed concentrations for many pollutants, the cause: vehicles (Dey et al., 2020). Euro 2 cars are far from "clean", in urban traffic (a lot of idling, sudden accelerations) the pollution increases strongly. We don't even need big scientific studies, because pollution is felt in the air we breathe, it can be seen on clothes and buildings, on vegetation and in the health of the population. To the exhaust noxes we add the pollution from the manufacturing process of the car, from the wear of the road, tires, brake pads, oil and especially that from the respective process resulting from its scrapping at the end of its "life" (Caballero-Calero et al., 2021). The consequences are affecting, in multiple ways, the health of people, as well as the flora and fauna of the respective area, as well as the built heritage (facades, monuments). These emitted noxes not only pollute chemically, photochemically, but also through aerosols, electrostatic and thermal pollution. The most important ways in which the vehicle pollutes the environment are noise and air pollution (Brodov et al., 2018). Noise pollution occurs because of the induction of oscillations in air masses that the auditory organ of humans and animals perceive as noises and vibrations (Guo et al., 2019), (Van Renterghem et al., 2020). In Romania, they are trying to align themselves with European pollution standards, which are imposed on domestic car manufacturers as well as importers. Currently, to register, they are accepted and approved by R.A.R (Romanian Auto Registry). As a complex phenomenon, transport pollution is not always a local one, influencing through its dynamic components of the environment (water, air) very extensive areas, the effects of which can be felt globally. The effects of transport pollution on the environment and the health of the population can be both direct and indirect. Automobiles equipped with an internal combustion engine are a source of chemical and noise pollution that harms both humans and the environment. Chemical exhaust pollution is caused by chemicals and compounds found in the exhaust gases of automobiles. Urban agglomerations due to intense road traffic have the disadvantage of polluting emissions with extremely high concentrations. The European Space Agency, with the help of the Envisat satellite, managed to map the emissions of nitrogen dioxide (NO_2) in Europe.

3 TYPES OF POLLUTANT EMISSIONS

Depending on the type of engine with which a car is equipped, petrol or diesel, its exhaust gases contain chemicals in different proportions. Table 1 summarizes the types of polluting substances in the exhaust gases and the main source depending on the type of engine.

Table 1. Types of pollutants in the exhaust gases and the main source according to the type of engine: (+) proportion too high, (-) smaller proportion

The polluting substance	Engine type	Primary Source/Origin
Hydrocarbons (HC)	(+) Gasoline; (-) Diesel	Incomplete combustion (rich gasoline mixture) Fuel absorption on the oil film, misses
Carbon monoxide (CO)	(+) Gasoline; (-) Diesel	Incomplete combustion
Nitrogen oxides (NOx)	(+) Gasoline; (-) Diesel	High combustion temperatures, excess oxygen (lean mixture)
Particulate matter (PM)	(-) Gasoline (only for direct injection engines); (+) Diesel	Incomplete combustion (rich mixture)

The harmful substances present in the atmosphere fall into two groups, depending on the nature of their origin. Thus, we have the primary substances, in gaseous or solid state, which are found directly in the exhaust gases of a car (HC, CO, NOx and PM) and secondary substances which are represented by photochemical smog and wet smog. The name smog comes from the English language by combining the words smoke (smoke) + fog (fog).

4 EUROPEAN STANDARDS CAR EMISSIONS

Diesel engines have stricter CO standards, but higher NOx emissions are allowed. Petrol powered vehicles are exempt from particulate matter (PM) by Euro 4 standards, but vehicles with direct injection engines will be subject to the maximum limit of 0.005 g/km for Euro 5 and Euro 6. For passenger cars the standards are defined depending on the distance they travel, i.e., g/km, for trucks (trucks) they are defined by the engine's energy production, i.e. g/kwh. In Europe, legislation limits the emissions of various polluting gases produced by motor vehicles according to the values presented above. All vehicles are built in accordance with this legislation and have in their structure an emission control system that eliminates or considerably reduces these emissions. The car subassemblies that filter the exhaust fumes are the catalysts and particle filters, their action also being controlled by the ECU. Strong exhaust gas emissions occur when the fuel is incompletely burned, the engine is improperly adjusted, when the engine is started or stopped, when traveling at low speed. In the absence of the catalyst, when the engines are operating in stationary mode, the CO content in the exhaust gases must not exceed 5%.

5 MEASUREMENTS OF NOXES

At the periodic technical inspection and at the checks carried out in traffic by the representatives of the traffic police and the Romanian Auto Registry, the first operation consists in checking the tightness of the evacuation of burnt gases. The next operation consists in determining the CO concentration using the gas analyser. For EURO2 vehicles, the concentration of CO when the engine is idling must not exceed 0.5% of the volume of burnt gases, and for vehicles equipped with EURO3 and 4, the percentage must not exceed 0.3%.

The Lambda sensor or "oxygen sensor" measures the amount of oxygen in the engine's exhaust gases. The vehicle's central computer uses the signals received from the Lambda sensor to adjust the mixture in order to obtain that ideal L=1 (14.8 kg of air with 1kg of unleaded gasoline). According to the legal regulations, the maximum permissible concentration of CO for motor vehicles without a catalyst, manufactured until 1986, the percentage is 4.5% of the volume of burnt gases, and for those manufactured after January 1, 1987, the percentage value must not exceed 3.5% of the volume of burnt gases. For vehicles equipped with diesel engines, the smoke index is measured after the engine has reached normal operating temperature, and the gas exhaust is perfectly sealed, and its path is clean. For EURO 4 and EURO 5 vehicles equipped with diesel engines, the smoke index is 1.5m, for those equipped with supercharged diesel engines, it is 3.5 and for normally aspirated engines, the smoke index is 2.5.

Modification of the combustion chamber (e.g. split combustion chamber) leads to a lowering of the noxes level. Increasing the compression ratio in combination with the use of lean mixtures contributes significantly to reducing the level of noxes. The recirculation of the exhaust gases, cooled in advance, means that the mixture of gases that do not contain oxygen (they are chemically inert) will reduce the rate of formation of nitrogen oxides (NOx) from the exhaust. The use of the combustion chamber divided according to the principle of stratification (rich mixture in the separate chamber, lean mixture in the main chamber) contributes to reducing the noxes of the compression ignition engine. Using lean mixtures when fuelling compression ignition engines results in lower exhaust gas emissions.

6 EXPERIMENTAL RESEARCH USING THE ACTIVE TYPE EXPERIMENT

To analyse the quality of exhaust from cars equipped with spark ignition engines, in this case study a factorial experiment was carried out with six influencing factors on two objective functions. The influencing factors of AFR (Air to fuel ratio (calculated according to Lambda) and Lambda (lambda sensor or oxygen sensor, measures the amount of oxygen in the engine exhaust gases), are the following: CO, CO_2, speed, temperature, O_2, CO_{corr}.

The factorial experiment allows us to create three-dimensional graphs, graphs that allow a fine interpretation of the input data and pertinent conclusions that are obtained on the researched object.

7 EXPERIMENTAL DATA PROCESSING

Data interpretation was done for each objective function correlated with two influencing factors, so the graphs obtained allow both the observation of the relationship between the objective factors AFR and Lambda as well as the influencing factors.

The six influencing factors are:

x_1 – engine speed (RPM)
x_2 – temperature (^{0}C)
x_3 – carbon monoxide (CO%)
x_4 – carbon dioxide (CO_2%)
x_5 – oxygen (O_2%)
x_6– corrected carbon monoxide (CO_{corr})

The objective functions on which the six factors will have influence are:

y_1 – AFR (Ait to fuel ratio calculated according to Lambda)
y_2– Lambda (Lambda sensor or oxygen sensor, measures the amount of oxygen in the exhaust gases of the engine).

To conduct the research, the data from the ITP station were collected, the collected data were entered into the table where you can see the values of the objective factors according to the influencing factors. The data was collected from different types of Euro 2-3-4-5 spark-ignition internal combustion engines with the same cylinder capacity of 1200-1600 cm^3.

Table 2. Table of factors

No.	Engine speed (RPM)	Temp.^{0}C	CO%	CO_2%	O_2 %	CO_{corr}%	AFR	Lambda
1	2220	89	0.1	14.8	0.62	0.1	15.24	1.03
2	710	72	0.1	14.7	0.64	0.1	15.24	1.03
3	2690	76	0.12	15	0.6	0.12	15.1	1.02
4	820	77	0.2	14.9	0.54	0.2	14.95	1.01
5	2900	46	0.2	14.8	0.18	0.2	14.8	1
6	800	69	0.07	13.9	1.18	0.09	15.54	1.05
7	2460	71	0.11	14.4	0.06	0.1	10.46	0.99
8	880	59	0.22	14.2	0.04	0.23	13.46	0.99
9	2170	63	0.1	12.7	0.24	0.1	14.95	1.01
10	730	62	0.1	12.8	0.22	0.1	14.95	1.01
11	2150	90	0.03	15.2	0.12	0.03	14.8	1
12	850	76	0.03	15.2	0.1	0.03	14.8	1
13	2190	85	0.12	15.1	0.62	0.12	15.1	1.02
14	830	85	0.04	15.4	0.2	0.04	14.95	1.01
15	6010	85	0.14	15.7	0.04	0.14	14.65	0.99
16	6010	85	0.23	15.6	0.08	0.23	14.65	0.99
17	2290	85	0.13	15.5	0.14	0.13	14.95	1.01
18	810	85	0.11	15.3	0.04	0.11	14.8	1

19	2170	83	0.12	1.4	0.32	0.12	14.95	1.01
20	920	83	0.08	15.4	0.08	0.08	14.8	1
21	2540	74	0.1	15.3	0.52	0.1	15.1	1.02
22	790	76	0.17	15.5	0.32	0.17	14.8	1
23	2770	71	0.1	15.1	0.14	0.1	14.8	1
24	770	75	0.1	14.6	0.56	0.1	15.24	1.03

Following the obtained experimental data (table 2), the most important graphs will be presented using the Statistica Stat Soft program. This program involves the introduction of certain indicators and the creation of the graphs presented below.

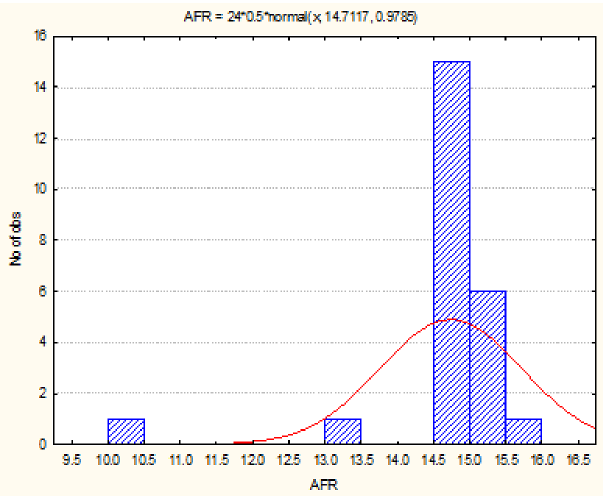

Fig. 1. Air to fuel ratio

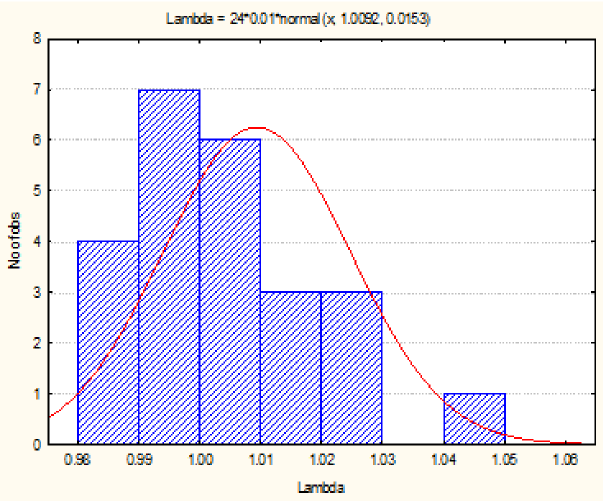

Fig. 2. Lambda sensor

In figure 1, AFR is represented, which takes values depending on Lambda, determining the amount of oxygen in the exhaust gases. As can be seen, the highest AFR values are between 14.5 and 15, that is, out of the 24 measurements of this indicator, 15 are between these values.

In figure 2 above is represented the Lambda Sensor that measures the amount of oxygen in the exhaust gases. As can be seen, 7 of the 24 measurements have values between 0.99 - 1, another 4 have values between 0.98 - 0.99, 1 has a value between -1.04 - 1.05, and the others taking values between 1 - 1.03.

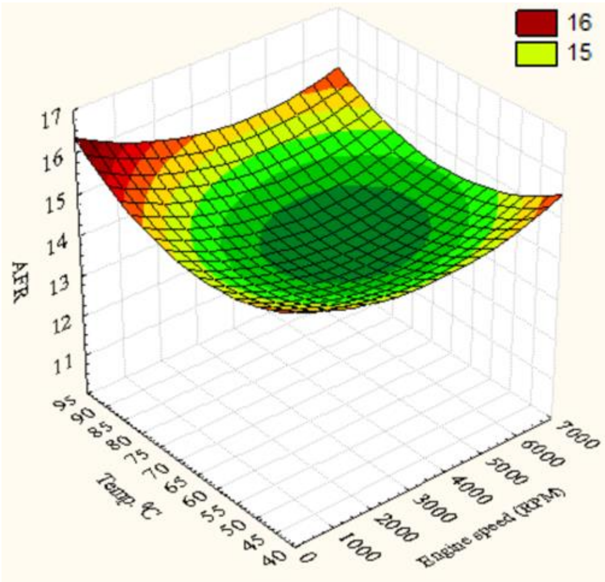

Fig. 3. Air to fuel ratio depending on speed and temperature

In figure 3, the AFR objective function is influenced by temperature and engine speed. An increase in the AFR can be observed with the increase in temperature and with the increase in speed. The maximum AFR values are between 16-17 at a temperature of 950 C and an engine speed at idle. The lowest AFR values are between 12-13 at a temperature of 90-95^0C and a speed of 2000-3000 rpm.

In figure 4, the AFR objective function is influenced by temperature and carbon monoxide. An increase in AFR can be observed with increasing temperature and increasing carbon monoxide. The maximum AFR values are between 16-18 at a temperature of 95^0C and a quantity of 0.24% carbon monoxide. The lowest AFR values are between 12 - 14 at a temperature of 40-45^0 C and the same amount of carbon monoxide, 0.24%.

In figure 5, the AFR objective function is influenced by temperature and the amount of oxygen. An increase in AFR to 22 can be observed when the engine temperature is between 40-45^0C and an increase in oxygen to 1.4%. The lowest value of the AFR is between 0-10 at a temperature of 60-70^0C and an amount of oxygen between -0.2-0%.

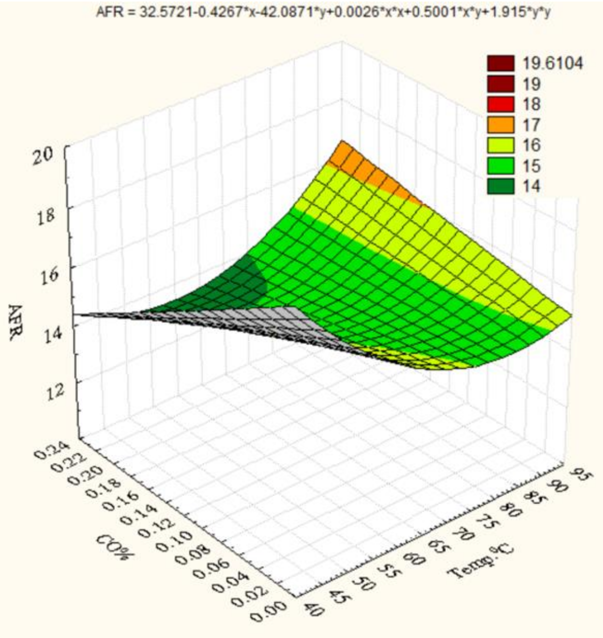

Fig. 4. Air to fuel ratio depending on temperature and carbon monoxide

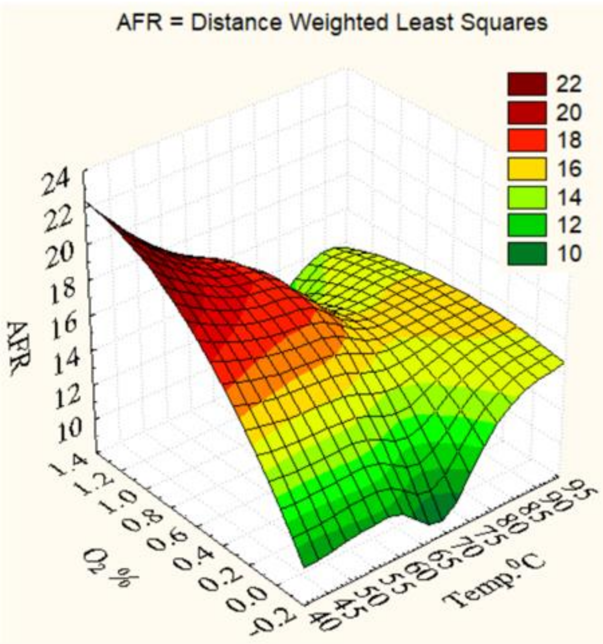

Fig. 5. Air to fuel ratio depending on temperature and oxygen

In figure 6, the AFR objective function is influenced by the speed and the amount of carbon monoxide. An increase in AFR to 15 can be observed with increasing engine speed and with increasing amount of carbon monoxide. The lowest value of the AFR is 13 with the increase in speed and the decrease in the amount of carbon monoxide.

In figure 7, the Lambda objective function is influenced by speed and temperature. We notice that Lambda Sensor values increase to 1 with increasing temperature and at an idling engine speed. The Lambda sensor takes minimum values at 0.92 with the increase in speed at an engine temperature between 40-45^{0}C.

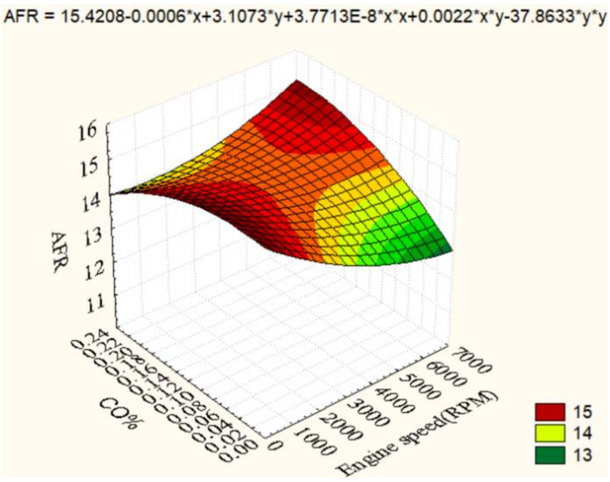

Fig. 6. Air to fuel ratio depending on speed and carbon monoxide

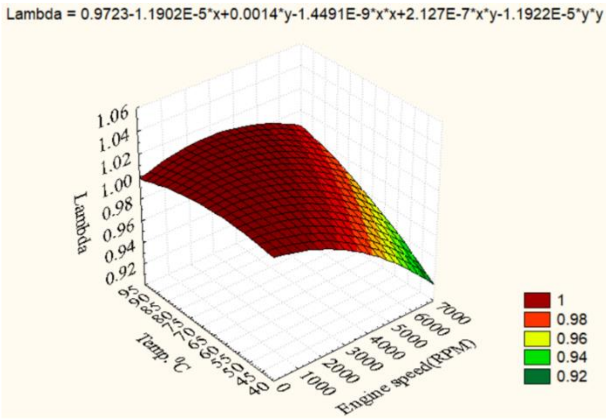

Fig. 7. Lambda sensor depending on speed and temperature

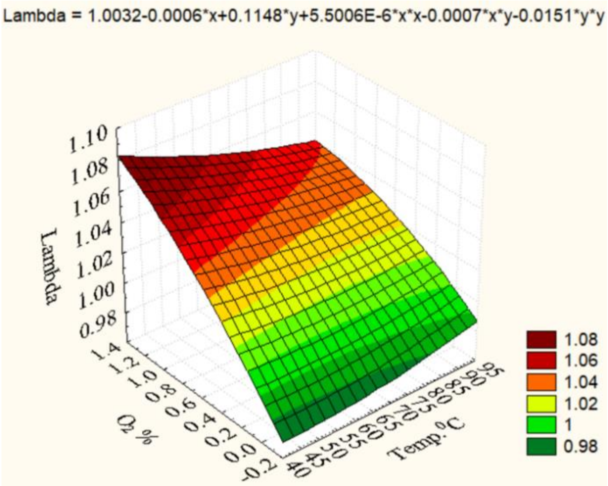

Fig. 8. Lambda sensor depending on temperature and oxygen

In figure 8, the Lambda objective function is influenced by temperature and the amount of oxygen. The maximum value of Sensor Lambda is observed at 1.08 at an engine temperature between 40-45^{0}C and at an increase in the amount of oxygen at 1.4%. Lambda sensor takes minimum values of 0.98 at an engine temperature between 40-45^{0}C and decreases in the amount of oxygen between -0.2-0 %.

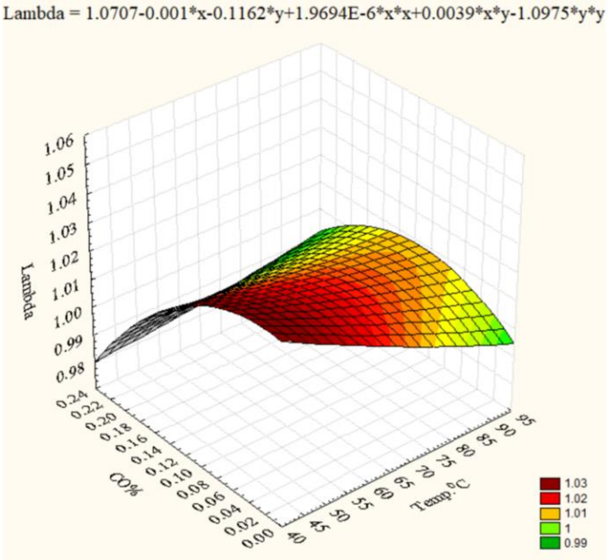

Fig. 9. Lambda sensor depending on temperature and carbon monoxide

In figure 9, the Lambda objective function is influenced by temperature and the amount of carbon monoxide. The maximum value of Sensor Lambda is 1.03 at an engine temperature between 40-45^{0}C and at a decrease in the amount of carbon monoxide between 0.02-0.04%. The Lambda sensor takes minimum values of 0.98 at an engine temperature of 40-45^{0}C and when the amount of carbon monoxide increases to 0.24%.

8 RESULTS AND DISCUSSION

AFR is the air-fuel ratio, being an important measure against pollution. The higher the AFR in the fuel, it is considered lean, and if the amount of AFR is lower, it is considered a rich mixture. The ideal mixture is 14.8 kg air/1 kg petrol. The AFR objective function does not significantly change its values regardless of the values of the influencing factors, thus it is between 14.5-16%. According to the data in the graphs presented, the AFR values are within normal parameters. Also called the oxygen sensor, the Lambda Sensor is of great importance in reducing polluting emissions from automobiles. This measures the amount of oxygen in the exhaust gases, transmitting to the central computer whether the mixture is rich ($\lambda < 1$), lean ($\lambda > 1$) or normal ($\lambda = 1$). Most values of the Lambda objective function oscillate between 0.98-1.03, being influenced by the influence functions, this function falling within the normal parameters. In conclusion, regardless of the parameters of the influencing factors, the values of the objective functions are within the parameters according to the Euro norms.

9 CONCLUSIONS

Although we are in a continuous development thanks to technology, we are too little aware of the impact technology has on the environment. Thanks to technology, new constituents appear that have a harmful effect on air pollution. One of the main sources of environmental pollution is transport. The impact of transport on the environment and the health of the population is a very complex issue, considering the fact that the long-term effect of different types of noxes has not yet been evaluated. Pollution destroys the environment due to its contamination with residual matter, industrial waste, exhaust gases, etc.

Air pollution by automobiles is achieved through the emissions of lead, aldehydes, carbon dioxide, and smoke that contribute to the formation and accentuation of the greenhouse effect. In order to increase the quality of exhaust fumes in engines with internal combustion and spark ignition, an important role is played by the Sensor Lambda, which measures the amount of oxygen in the exhaust gases, sending signals to the central computer about the composition of the air-fuel mixture (rich, normal, poor).

Another important factor in the quality of exhaust fumes is the quality of the fuel used in automobiles. In the case of a good quality fuel and if the air-fuel mixture (AFR) works within normal parameters, it follows that the exhaust noxes will also be found within normal parameters. Major car manufacturers use this type of experimental research to continuously improve the quality of their exhausts. As can be seen from the AFR histogram, it is within normal parameters according to Euro norms, so the air-fuel mixture is well done. A special importance for the AFR to be within normal parameters is the Lambda Sensor, i.e. the oxygen reader in the exhaust gases. In conclusion, the AFR objective function does not change its parameters regardless of any influence function as long as they are within normal operating parameters. The Lambda sensor plays a very important role in cars equipped with spark ignition engines, it is mounted on the gas exhaust pipe and is connected to the engine's central computer, with its help it reduces exhaust emissions, it detects the amount of oxygen in exhaust gases, i.e. with its help the amount of noxes is lower. Cars with euro one and euro two pollution standards are equipped with only one Lambda Sensor mounted before the catalyst, and those with euro 3-4-5-6 are equipped with 2 Lambda Sensors one before and one after the catalyst. In this work, we have followed the importance of the need to equip cars with Lambda Sensors, which play an important role in reducing pollution emissions.

Following this research, I noticed that the Lambda Sensor takes high values when the engine is cold and idling, therefore it is necessary to improve its performance.

For the good functioning of the Lambda Sensor, major car manufacturers are continuously researching to improve its quality, by manufacturing it from different compounds that heat up very quickly.

Sensor Lambda is made of ceramic with zirconium dioxide, thanks to this compound it heats up faster (30-60 s).

It is also equipped with a resistance that activates or deactivates automatically depending on the engine temperature.

The best strategy to control atmospheric pollution through the emission of exhaust gases involves methods that reduce these emissions before they are discharged into the atmosphere. These methods are those of collection, capture and reduction of these pollutants.

Reducing the gases emitted by automobiles is possible by recirculating gases or by using better quality fuel, but also by decomposing these gases with the help of catalysts and improving Lambda Sensor quality.

In conclusion, the reduction of pollutant emissions resulting from exhaust gases through the continuous improvement of fuel quality and other methods of collection, capture, of noxes have a major impact in protecting the environment and the population.

REFERENCES

[1] Awad, O.I., Mamat, R., Ibrahim, T.K., Hammid, A.T., Yusri, I. M., Hamidi, M.A. & Yusop, A.F. (2018). Overview of the oxygenated fuels in spark ignition engines: Environmental and performance. *Renewable and Sustainable Energy Reviews*, 91, 394-408

[2] Bovornkitti, S., Muchimwong, A., & Jarupongsakul, T. (2019). *Noxious Air Pollution*. TMJ, 19(2), 433-435

[3] Brodov, Y.M., Zhilkin, B.P. & Plotnikov, L.V. (2018). Influence of intake/exhaust channel lateral profiling on thermomechanics of pulsating flows. *Technical Physics*, 63(3), 319-324

[4] Caballero-Calero, O., Rull-Bravo, M., Platzek, D., Cárdenas, M. D., Fernández, R., Moure, A., ... & Martín-González, M. (2021). Tubular ring thermoelectric module for exhaust pipes: From Skutterudite nanopowders to the final device. *Energy*, 234, 121223

[5] Dey, S., & Mehta, N.S. (2020). Automobile pollution control using catalysis. *Resources, Environment and Sustainability*, 2, 100006

[6] Gong, C., Li, Z., Sun, J. & Liu, F. (2020). Evaluation on combustion and lean-burn limit of a medium compression ratio hydrogen/methanol dual-injection spark-ignition engine under methanol late-injection. *Applied Energy*, 277, 115622

[7] Guo, N., Liu, K., Zheng, S. & Xue, K. (2019). A systemic study on hydroforming process of exhaust pipe by FE simulation and experiment. International *Journal of Materials and Product Technology*, 59(1), 34-47

[8] Leach, F., Kalghatgi, G., Stone, R., & Miles, P. (2020). The scope for improving the efficiency and environmental impact of internal combustion engines. *Transportation Engineering*, 1, 100005

[9] Lion, S., Vlaskos, I. & Taccani, R. (2020). A review of emissions reduction technologies for low and medium speed marine Diesel engines and their potential for waste heat recovery. *Energy Conversion and Management*, 207, 112553

[10] Lhuillier, C., Brequigny, P., Contino, F. & Mounaïm-Rousselle, C. (2020). Experimental study on ammonia/hydrogen/air combustion in spark ignition engine conditions. *Fuel*, 269, 117448

[11] Ţiţu, M., Oprean, C., Boroiu, A., *Cercetarea experimentală aplicată în creşterea calităţii produselor şi serviciilor*, Editura AGIR, Bucuresti, 2011

[12] Van Renterghem, T., Vanhecke, K., Filipan, K., Sun, K., De Pessemier, T., De Coensel, B., ... & Botteldooren, D. (2020). Interactive soundscape augmentation by natural sounds in a noise polluted urban park. *Landscape and urban planning*, 194, 103705.

Authors addresses

[1]*Titu, Aurel Mihail, Professor, mihail.titu@ulbsibiu.ro*
[1]*"Lucian Blaga" University of Sibiu, Faculty of Engineering, Industrial Engineering and Management Department, 4, Emil Cioran Street, 101 Room, Sibiu, Romania*

[2]*Pop, Alina Bianca, Assistant, bianca.bontiu@gmail.com*
[2]*Department of Engineering and Management of Technology; Technical University of Cluj-Napoca, Northern University Centre of Baia Mare, Faculty of Engineering; 62A Victor Babes Street, 430083, Baia Mare, Maramures, Romania*

[3]*Banica, Mihai, Associate Professor, mihai.banica@imtech.utcluj.ro*
[3]*Department of Engineering and Management of Technology; Technical University of Cluj-Napoca, Northern University Centre of Baia Mare, Faculty of Engineering; 62A Victor Babes Street, 430083, Baia Mare, Maramures, Romania*

Contact person

[*]*Titu, Aurel Mihail, Professor, "Lucian Blaga" University of Sibiu, Faculty of Engineering, Industrial Engineering and Management Department, 4, Emil Cioran Street, 101 Room, Sibiu, Romania; mihail.titu@ulbsibiu.ro*