International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 20, Issue 6 (June, 2024), PP. 39-55

Determination and Global Modelling of Objective Functions in Environmentally Friendly Vehicles Using Sustainable Development Principles

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ABSTRACT:
The paper presents a scientific study on the influence of external factors such as ambient temperature, atmospheric pressure, air humidity and road traffic on the chemical noxious emissions from the thermal engine of a hybrid car. To obtain the results of the present research, the active type experiment was used (second-order compound factorial experiment method), the experimental data were obtained with the help of the portable apparatus, specific to the determination of chemical noxious substances in road vehicles at the Periodic Technical Inspection stations, in compliance with the principles of sustainable development (eco-driving of road vehicles; reduction of engine consumption; reduction of pollution with chemical noxious substances and other greenhouse gases; increase of the share of energy efficiency; support and development of a sustainable road transport system for the whole life cycle). Thus, both graphical and theoretical explanations of the changes in objective functions, in their relation to environmental and road traffic factors, are presented on a route (travel route on a national road - DN7), of a 4x4 car with a hybrid engine, a complex route comprising ramps and slopes, dangerous curves, road traffic heterogeneous with high volume and intensity, and a high-speed route located on the A1 - Sibiu motorway. The route totals 180 kilometres. The results obtained experimentally were processed by means of specialised software installed on a personal computer. At the end of the paper the results are presented, on the basis of which the conclusions of the experiment were established.
Keywords: *sustainable development, experimental research, hybrid car, objective function, environmental factors, road traffic.*

Date of Submission: 03-06-2024 Date of Acceptance: 14-06-2024

I. INTRODUCTION

Sustainable development [1] is that concept which defines in a new way how the world is understood, but also a method by which global issues are clarified [2, pp. 241-242]. The concept of sustainable development is not just about all the measures taken to protect the environment. Sustainable development means all those actions, taken as a whole, taken to build, develop the necessary conditions for daily activities in a sustainable and viable way [3, p. 43]. Until recently, industrial activities bore all the blame for polluting our planet. The rapid development of all branches of transport, especially road transport, the increase in global car production and the frequent use of environmentally unfriendly cars have tipped the balance of pollutants and harmful effects towards the negative, making transport activities major sources of chemical or noise pollution. Today, experts say that 72% of pollutants released into the atmosphere result from transport activities [3, p. 43]. Sustainability in transport derives from a complex system that aims to provide travel needs for today's generation without contaminating or damaging environmental factors or human health [4, pp. 211-220]. Given the need for maximum efficiency in the consumption of raw materials and energy, the transport system must now meet the economic, environmental and social prospects and mobility needs of future generations in the best possible way. In other words, specialists and researchers have the task of finding modern transport options that do not pollute the environment and do not harm human health, and this can be achieved by increasing the energy efficiency of fuels burned in the thermal engines of means of transport, using efficient and resource-efficient vehicles, using alternative energies for travel and, last but not least, constantly reducing waste of any kind resulting from the production or disposal of means of transport [3, p. 43], [5]. The gases released into the atmosphere by internal combustion engines have the ultimate effect of global warming, a phenomenon that has been occurring for the last 200 years and has become more acute in the last 20 years with industrial development and mankind's growing transport needs. Global warming is due to greenhouse gases (GHGs) and is the phenomenon of a continuous and constant increase in the average annual atmospheric air temperatures at the Earth's crust [6], [7]. According to the latest research, these temperatures have increased over the last 100 years by 0.74±0.18˚C. Experts predict global temperatures will rise by 1.4-5.8˚C by 2100. In order to reduce pollution, the European and EU authorities are constantly concerned that the transport sector, especially car transport, should release fewer harmful gases into the environment, which seriously affect human health, damage the life of biotopes and habitats, create and deepen global warming. To this end, they are coming up with strict legislative proposals to which all European countries must comply, whether or not they are part of the Schengen area. All legislative proposals in this direction become laws on the basis of which applicable rules and standards are set, which must be respected by all car manufacturers on the European continent. Exhaust emission standards are not an environmental label in the strictest sense, but require compliance with limit values set for air pollutants emitted by new cars. The maximum permissible exhaust gas content at European level is regulated by legislation. Romania has fully adapted its national legislation to the European legislation and has regulated by Order of the Minister of Transport, Construction and Tourism No 2133/2005, the way in which it is carried out and the rules on the periodic technical inspection of vehicles registered or recorded in Romania - RNTR 1 (Regulations on the certification of compliance of registered road vehicles with the technical rules on road safety, environmental protection and category of use according to their intended purpose by roadworthiness testing) [8], with subsequent additions and amendments. On the basis of these limit values, the ITP stations give permission for vehicles with thermal and hybrid engines to circulate on public roads.

II. DETERMINATION AND GLOBAL MODELLING OF OBJECTIVE FUNCTIONS ON HYBRID CARS

The main ***objective functions (response functions)***, which are shown on the right-hand side of Table 2, for which determinations and modelling have been done are as follows:

1) Exhaust emissions, carbon dioxide (CO_2); carbon monoxide (CO); flue gas oxygen (O_2); hydrocarbons (HmCn); nitrogen oxide (NO); stoichiometric ratio 14.7:1 (Air Flow Ratio) - AFR; Lambda value.

2) The average fuel consumption (gasoline) is determined by the cars Engine Control Unit (ECU) and permanently displayed on the cars onboard display.

The main ***influencing factors*** that are taken into account and that bring changes to the objective functions are:

➢ ***Ambient air temperature*** is a continuously varying quantity from one point to another, so depending on the location where it is measured it can differ greatly from the values reported at nearby weather stations. For example, on sunny summer days, the temperature measured at busy intersections is noticeably higher than that measured in a weather shelter. Temperature is expressed in degrees Celsius (°C). The ambient temperature has a major influence on the viscosity of oil in vehicle engines and aggregates. The higher the temperature, the less viscous the oil becomes and the easier it flows. At low temperatures, however, alkane hydrocarbons form a crystalline lattice which causes the oil to freeze, i.e. lose its ability to flow completely.

Decreased oil viscosity leads to:reducerea temperaturii şi a pierderilor datorate forţelor de frecare;

- ✓ fuel economy;
- ✓ starting the engine easier;
- ✓ increased viscosity leads to:
- ✓ lower oil consumption;
- ✓ better sealing between piston-seals-cylinder assembly;
- ✓ increased fuel consumption due to frictional forces creating resistance of rotating or translating parts.

Temperature affects every aspect of the car, from the performance of the engine and various systems to the comfort of the passengers and driver. According to research, the high operating temperature range of cars (-60ºC to +57ºC), the range of electrical/electronic components in cars (-40ºC to +125ºC) and in passenger compartments (-40ºC to +85ºC) affect the performance and reliability of all components.

➢ ***Atmospheric pressure*** is defined as the force exerted by atmospheric air on a unit area. It is one of the fundamental parameters in meteorology. The ground pressure distribution map allows the recognition of cyclonic and anticyclonic baric formations, whose genesis and life cycle are closely related to the weather. The map is almost unheard of in weather reports, but weather forecasting is based on the analysis of how many other parameters will evolve, at ground level, in the lower, middle and upper troposphere, at tropopause level and even in the lower stratosphere. Atmospheric pressure is measured with a barometer. Some barometers associate falling pressure with worsening weather and rising pressure with improving weather, which is not always true. Atmospheric processes are the combined and complex result of changes in all meteorological parameters. For example, on a beautiful summer day, a rise in temperature in the midday hours may cause a slight drop in atmospheric pressure. On the other hand, if atmospheric instability increases, the generation of storm clouds with strong vertical development is the cause of the sometimes sudden drop in atmospheric pressure. There are also situations, particularly in the cold season, where the occurrence of precipitation is not associated with a drop in ground level pressure but with processes taking place in the middle and upper troposphere. Atmospheric pressure is measured in millimetres column of mercury (mmHg), but in our experiment we will work by converting these into HectoPascals (hPa). The atmospheric pressure at sea level is approx. 760 mm column of mercury (101.325 Pascals). From the 760 mmHg value comes the name physical atmosphere. In conclusion, the atmospheric pressure that is capable of balancing a 760 mm column of mercury at a temperature of 0°C at sea level and latitude 45° is considered normal, equal to one atmosphere. An atmosphere, under these conditions, presses on 1 cm^2 of the earth's surface with a weight of about 1 kg, more precisely, with a mass of about 1,033 g. At meteorological stations, the millibar is used as the unit of measurement of atmospheric pressure. One millibar = 0.750 mm Hg (mm column of mercury). One atmosphere = 1.033 kg per 1 cm^2 = 1.013 bar = 760 mmHg. However, one bar = 1.019 Kg/cm^2 = 0.986 atmospheres = 760 mmHg. All atmospheric pressure data is reported in hectopascals, which is 100 times greater than Pa. In conversion, 760 mmHg = 1000 hPa. To convert atmospheric pressure from millimetres column of mercury to hectopascals, it is necessary to multiply the given value by 1.333. Studies show that if the air temperature remains constant and the atmospheric pressure changes with altitude, the maximum cylinder pressure decreases from 80-81 bar (at sea level) to 62-65 bar (for an altitude of 2,000 m) and the indicated cycle work of an internal combustion engine decreases by 9-10%. It is also known that an internal combustion engine operates abnormally when atmospheric pressure is low. The rarefied air, which is found in small quantities at altitude, is no longer the optimum quantity which, being allowed into the cylinders of the internal combustion engine together with the quantity of fuel injected, in both diesel and petrol injected engines ensures the ideal stoichiometric ratio of 14.7 parts of air to 1 kg of fuel. This favours rich fuel mixtures, and this is where the problems in engine operation start. In this case, engine power and efficiency decrease, fuel consumption and pollution may increase.

- ***Air humidity*** is the most common way to describe the water vapour content of the atmosphere. It tells us, as a percentage, how close to saturation the air mass is. Relative wetness is the ratio of the amount of water vapour in the air to the maximum amount of water vapour required to saturate at the same temperature and pressure. During the day, as the temperature increases, the relative humidity decreases, and in the evening and night the temperature decreases and the relative humidity increases. Air with a relative humidity of 50% contains half the amount of water vapour required for saturation, and air with 100% is said to be saturated, because further decreases in temperature or any additional supply of vapour would trigger condensation processes, i.e. dew point temperature. The humidity in our experiment will be taken in percentages (%). In almost all areas of Romania, in summer, the average relative humidity value of the air is maintained at values above 70%. Due to water vapour in the atmosphere, the average temperature of the Earth is between +15°C and -18°C.

- ***Road traffic*** has a direct influence on fuel consumption and emissions from cars. The basic characteristics of road traffic, such as volume, intensity, strength and capacity, directly influence fuel consumption and exhaust pollutants emitted into the atmosphere by motor vehicles. Queues at the end of large urban agglomerations, traffic jams on motorways or roads of all categories caused by traffic jams, roadworks, redevelopment, etc. also cause huge fuel consumption. They increase greenhouse gas emissions and create stress, dissatisfaction and distrust among the beneficiaries of road transport services. In order to find out the traffic values, road traffic will be monitored, the daily average of road traffic will be established and then all vehicles in traffic will be converted into standard vehicles.

The number of standard vehicles is calculated with the formula:

$$Nechiv. = N1 \; x \; C1 \; + N2 \; x \; C2 + \ldots Ni \; x \; Ci \; = \sum_{1}^{i} Ni \; x \; Ci \qquad (1)$$

where,

N is the number of standard vehicles in the time unit;

Ni - the number of vehicles in group *'i'* in the same time unit;

Ci - the equivalence coefficient for group *'i'* of physical vehicles, according to the table of equivalence coefficients in standard vehicles.

The vehicle equivalence coefficients in standard vehicles are given in Table 1.

Table 1: Equivalence coefficient values

Vehicle type	**Equivalation coefficient *(Ci)***
Cars with or without trailer	1
Minibuses, small buses, vans	1,2
Simple bus	2,5
Lorries with a payload exceeding 3 tonnes with trailer, buses with a trailer, tractor units with a trailer or semitrailer	3,5
Articulated bus	4

On the basis of the coefficients in Table 1, the calculation of the transformation of all vehicles into standard vehicles, which drove on the routes on which the experiments were conducted, at the respective dates and times, was carried out.

III. SPECIFIC CONDITIONS FOR CONDUCTING EXPERIMENTAL RESEARCH

The conditions under which the experimental determinations were carried out for the global modelling of the two objective functions, fuel consumption and exhaust gas emitted by the engine into the atmosphere, are similar to those carried out by the major light-duty car manufacturers for the approval of fuel consumption and pollutant emissions, WLTP (Worldwide Harmonized Light-Duty Vehicles Test Procedure). The procedure is a test method introduced by the European Union to globally harmonise fuel consumption and CO_2 emissions for passenger cars and light commercial vehicles on September 01, 2017, when the old NEDC (New Driving Cycle) fuel consumption approval method was replaced.

The following conditions were met during testing:

✓ The test was carried out on routes consisting of category 1-2 roads National Roads (DN) and motorway);

✓ Accelerations and decelerations were random, constant, in compliance with road traffic rules;

✓The average speed on the DN and motorway was adapted to the existing road traffic (in compliance with road traffic rules);

✓ The vehicle was equipped with a PEMS (Portable Emission Measurement System) measuring device, which measures carbon monoxide (CO), hydrocarbons (HmCn), carbon dioxide (CO_2), nitrogen oxide (NOx), oxygen in combustion gases (O_2) and Air Flow Ratio (AFR) - stoichiometric air fuel ratio (14.7:1);

✓Test times 30-60 minutes;

✓The data displayed on the on-board display and the routes on which the experiments were conducted were continuously monitored and video recorded;

✓Outdoor ambient temperature: +20 to +25°C;

✓All ancillary equipment that was switched on during the tests (air conditioning, headlights on, radio and navigation system on) was taken into account;

✓The minimum and maximum average fuel consumption results displayed on the vehicle's on-board display by the Engine Control Unit were correlated with the results returned by the KANE auto plus 5-1 gas analyser and the recordings of the two video cameras;

✓For accurate interpretation of the results, the times (hour/minute/second) of the cameras were correlated with those of the KANE auto plus, gas analyser 5-1.

Figure 1 shows the Toyota RAV 4 hybrid car, year of manufacture 2019, equipped with the experimental equipment.

Figure 1: Toyota RAV 4 hybrid car equipped with KANE auto plus 5-1 gas analyser, ready for testing

Figure 2 shows the data recording equipment.

Figure 2: Equipment used for data recording

The objective function determinations were carried out on national roads (DN7) Pitești - Sibiu and Sibiu Ring motorway - A1, a 180 km long mixed route.

IV. RESULTS AND DISCUSSIONS

To obtain the results of the present research, the active type experiment (second-order compound factorial experiment method) was used. In this experiment, determinations were performed for all objective functions. They were carried out on DN 7 - Black Hill, Pitesti city, Argeș county - Olt Valley - ring road (A1 motorway - Sibiu, based on an experiment carried out between Pitești - A1 Sibiu, on 07.09.2021. A combined route was used for this purpose, consisting of a winding route with ramps up and ramps down (Black Hill, Arges county), a normal route (Olt Valley, Ramnicu Valcea city – Sibiu city) and a motorway route (A1 Sibiu) - entrance from DN7 to Sibiu airport exit (Sibiu city ring motorway). The conditions under which the surveys were carried out were normal, on a route/itinerary 180 km long, with temperatures of the crossed areas in the range 22-24˚C, air humidity in the range 33-36%, atmospheric pressure in the range [1.026-1.027] hectopascals (hPa) and road traffic in the range 438 (motorway) -1.791 (National Road 7 – DN7) standard vehicles per hour. The experiment was carried out at lunchtime between 14:00 and 18:00 hour, when road traffic values are the highest, imposing some difficulty in traversing it due to congestion, traffic jams, high volume and intensity of vehicles, being a heterogeneous traffic (made up of different categories of vehicles). All these aspects have led to almost “bumper-to-bumper” traffic. The values of chemical noxides obtained with specific equipment were entered in a table. Based on them, graphs were drawn using specialized software.The most relevant results of the objective functions and influencing factors are presented in Table 2.

Table 2: Average results obtained on the route Pitești city- Sibiu city (DN 7) and motorway A1 Sibiu

Time (s)	Influencing factors				Objective functions (response functions)							Route (travel itinerary)
	Temperature (˚C)	Humidity (%)	Atmospheric pressure (hPa)	Road traffic (veh/hour)	CO_2 (%)	CO (%)	O_2 (%)	HmCn (ppm)	NOx (ppm)	AFR (Air Flow Ratio) 14,7:1	Average gasoline consumption (l/100 km)	
14:41:32 15:15:35	22.47	35.55	1027	1,791	7.47	0.02	10.45	6.50	1.28	5.91	6.14	DN7 (Black Hill, Pitești city, Argeș county)
15:57:48 17:28:46	22.93	40.68	1026.18	1,719	6.64	0.03	11.72	14.54	0.44	40	4.42	DN7 (Olt Valley, Rm. Vâlcea city - Sibiu city)
17:28:56 17:42:07	23.32	43	1026	438	12.9	0.04	3.82	26.77	3.59	10.8 8	4.71	Motorway A1 – Ring road Sibiu city

The graph in figure 3 shows an overview of all exhaust gases emitted into the atmosphere by the Toyota RAV 4 hybrid car.

On the graph, in the hourly interval [14:41-15:15] the exhaust gas situation is shown by driving the route on the Black Hill (DN7) - Argeș county. In the hourly interval [15:57 - 17:28] the exhaust gas situation is shown for the route on DN7, Olt Valley. In the hourly interval [17:28-17:42] the exhaust gas situation is presented by the route on the ring road of Sibiu city, motorway - A1.

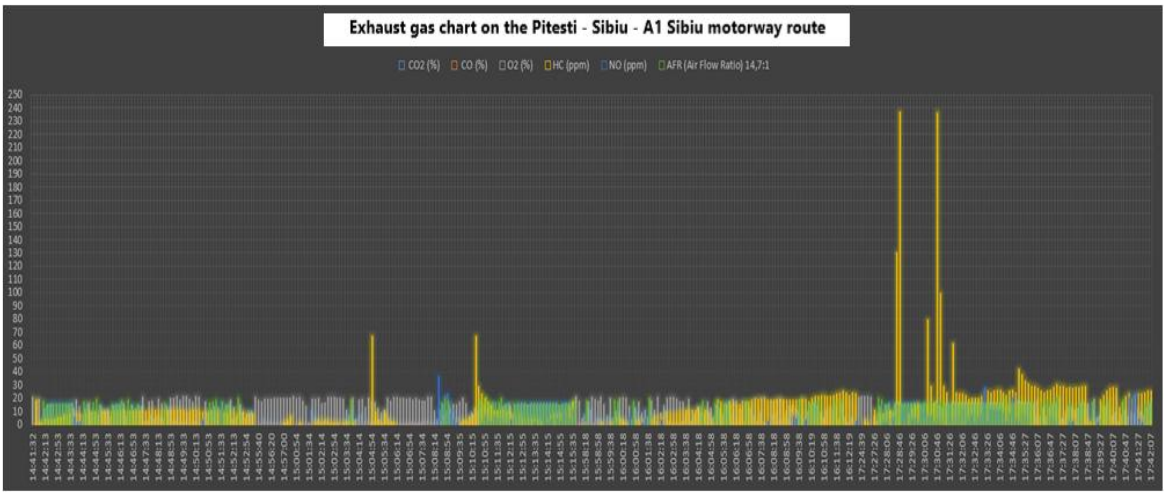

Figure 3: General picture of all exhaust gases on the Pitești - Sibiu (DN7) - A1 Sibiu motorway

Data processing was done using Minitab software. Analysis of the data presented in Table 2 shows the following:

A. Carbon monoxide (CO), (figure 4), is a product of the incomplete combustion of carbon based fossil fuels. In the surveys carried out, it is kept within the legal limits along most of the route/itinerary. The values frequently reached were below 0.1%, demonstrating that this category of noxious substances falls within the legal limit of 0.2%. The exception are two short exceedances of the legal limit, when maximum values of 0.41% and 0.42% respectively were reached for a short period of time (approx. 20 seconds), with a frequency of two occurrences over the whole distance of the route (figure 5). The low occurrence of overtaking is due to strong acceleration when overtaking other vehicles and when climbing ramps.

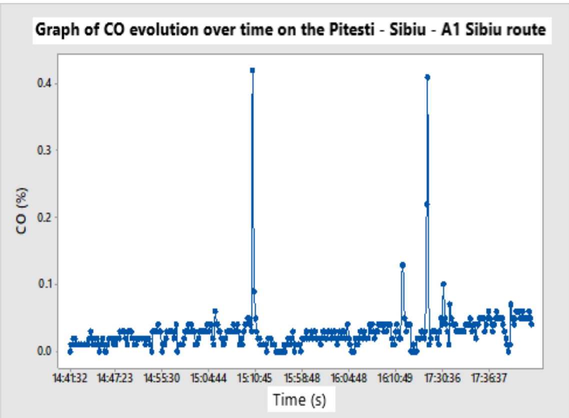

Figure 4: Graph of CO evolution over time on the Pitești – Sibiu – A1 Sibiu route

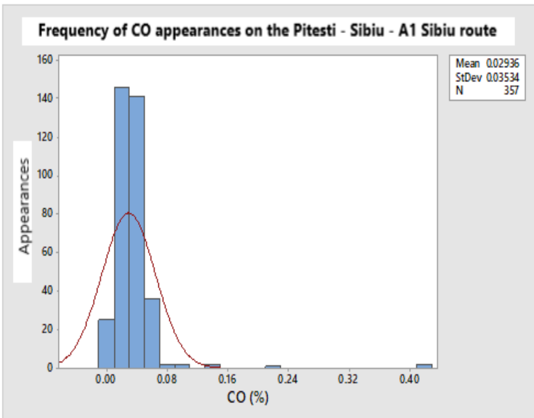

Figure 5: Frequency of CO appearances on the Pitești – Sibiu – A1 Sibiu route

As regards the evolution of this gas as a function of humidity and ambient temperature (figure 6), it reaches a maximum value of 0.42% at a humidity of 43% and an air temperature of 24˚C.

Over time, with the advent of internal combustion engines, less emphasis has been placed on the influence of intake temperature variation on pollution levels. At ambient temperatures above 23˚C and an atmospheric pressure in the range [1,026 - 1,026.5] hPa, CO reaches a maximum of 0.42% (figure 7). This is the effect of the influence of high temperature and humidity in the air increasing the CO emission values in the atmosphere.

Analysed in relation to average fuel consumption and atmospheric pressure (figure 8), CO remains in the range [0 - 0.15] % at an average petrol consumption of 5.5 l/100 km and an atmospheric pressure in the range [1,026.5 - 1,027] hPa.

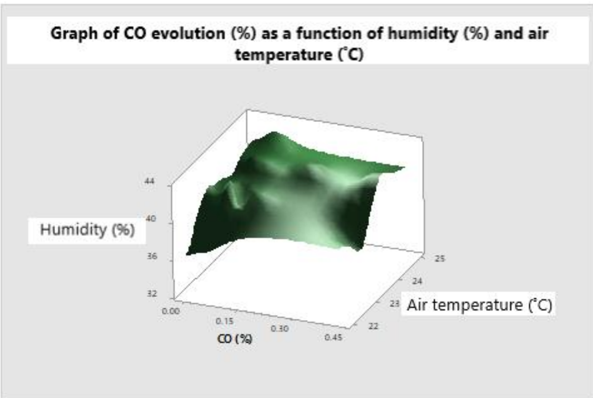

Figure 6: Graph of CO evolution (%) as a function of humidity (%) and air temperature (˚C) on the Pitești - Sibiu - A1 Sibiu route

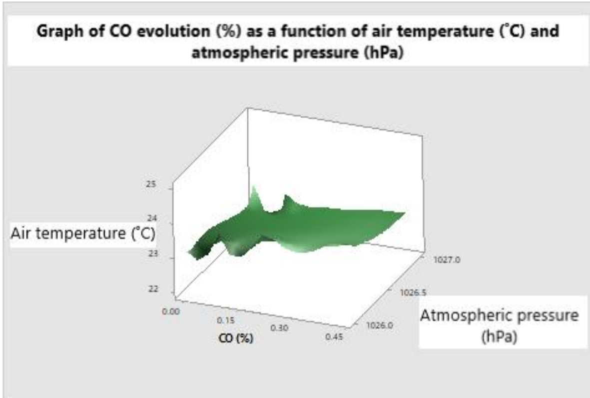

Figure 7: Graph of CO evolution (%) as a function of humidity (%) and atmospheric pressure (hPa) on the Pitești - Sibiu - A1 Sibiu route

It also reaches values of 0.12%, 0.20% and 0.35% respectively at air temperatures in the range [23 – 24] ˚C and average fuel consumption in the range [4.4 - 5] l/100 km (figure 9).

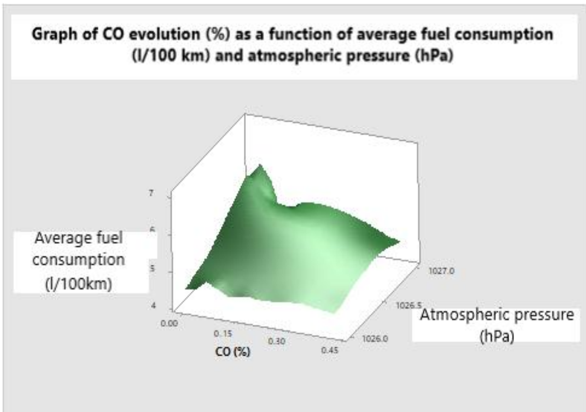

Figure 8: Graph of CO evolution (%) as a function of average fuel consumption (l/100 km) and atmospheric pressure (hPa) on the Pitești - Sibiu - A1 route

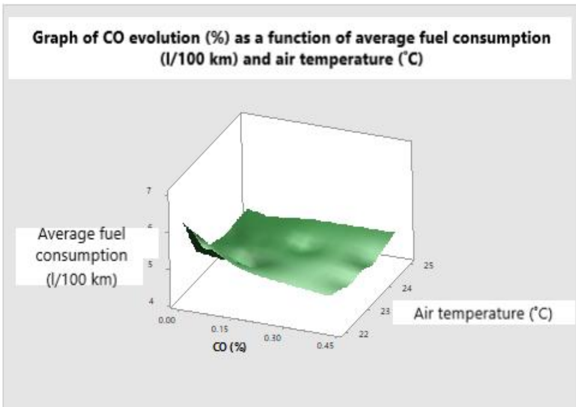

Figure 9: Graph of CO evolution (%) as a function of average fuel consumption (l/100 km) and air temperature (˚C) on the Pitești – Sibiu – A1

An internal combustion engine, especially those fitted to motor vehicles always operating at varying ambient temperatures, have a considerable influence on power and consumption performance. At an ambient humidity of 40% and a minimum average petrol consumption (4.4 l/100 km), CO reaches a maximum value of 0.42% (figure 10), while at a traffic speed of more than 1,500 vehicles/h and an average fuel consumption in the range [6 - 7] l/100 km it reaches minimum values of 0.02%. Carbon monoxide reaches a maximum value of 0.42% when average fuel consumption is at a minimum value of 4.4 l/100 km and traffic values are in the range [500 -1,719] vehicles/hour (figure 11).

I consider this to be due to the increase in ambient air temperature, which decreases the filling of the engine cylinders. It follows that the operation of internal combustion engines at high temperatures and high revs for long periods of time accelerates the oxidation process of the oil, degrading it and creating a malfunctioning engine mechanism. This directly influences fuel consumption and increases CO levels.

If traffic values are high, CO levels decrease with average fuel consumption. This is where the role of electric motors can be seen to support the combustion engine.

The high traffic volume (over 1,500 vehicles/hour), the speed of traffic and the heterogeneous nature of traffic, which leads to almost bumper-to-bumper traffic and vehicles driving in columns, substantially reduce fuel consumption. This is due to the hybrid vehicle's propulsion, often provided by electric motors, while the combustion engine is switched off. If road traffic is flowing at legal speeds, then the internal combustion engine runs continuously. In this case, CO levels are high and average fuel consumption increases (figure 11).

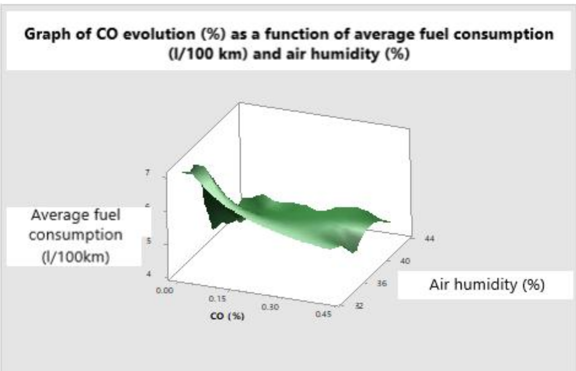

Figure 10: Graph of CO evolution (%) as a function of average fuel consumption (l/100 km) and air humidity (%) on the Pitești – Sibiu – A1 route.

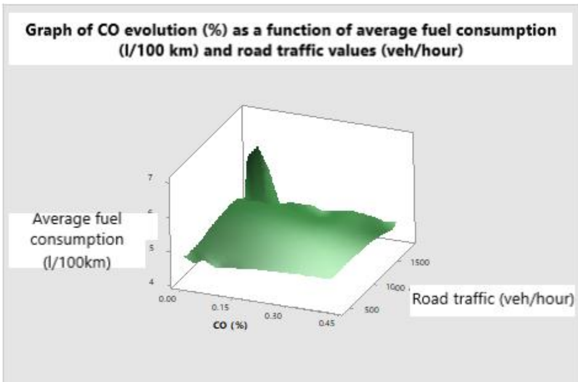

Figure 11: Graph of CO evolution (%) as a function of average fuel consumption (l/100 km) and road traffic values (vehicles/hour) on the Pitești – Sibiu -A1 route

At ambient temperatures of 24˚C and high road traffic values (above 1,500 vehicles/hour), the CO level reaches the maximum value of 0.42% (figure 12). It can be stated that from the point of view of this pollutant the internal combustion engine of the car meets the parameters of the European pollution standard Euro 6, being clean.

B. Carbon dioxide (CO_2) (figure 13 and 14), takes values in the range [0-17.3] % along the entire route. In European and national legislation, there is no stipulated maximum reference value. I therefore consider the maximum value emitted by the car engine to be normal emissions, specific to the Euro 6 pollution standard.

Research carried out at Periodic Technical Inspection stations, following discussions with specialists in the field, shows that the maximum values for carbon dioxide (CO_2) emissions from the car engine into the atmosphere are not taken into account or taken into account when checking vehicle emissions at these stations.

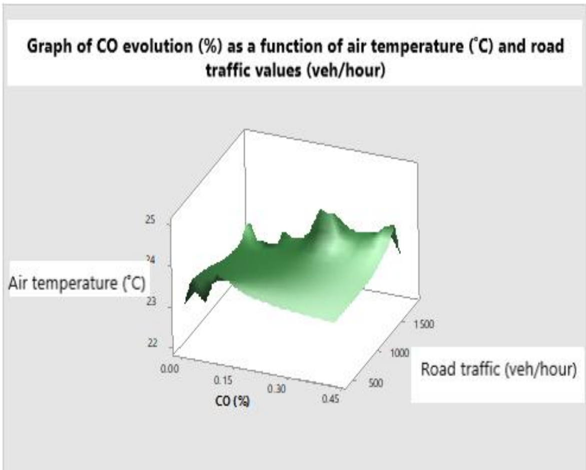

Figure 12: Graph of CO evolution (%) as a function of air temperature (˚C) and road traffic values (vehicles/hour) on the Pitești – Sibiu – A1 route

Analysing the CO_2 data obtained from Table 2, it appears that the maximum value was reached at high revs of the thermal engine, under load, when climbing ramps (on the Black Hill, in overtaking and on the motorway, when the thermal engine reaches revs in the range [2,000-3,000] crankshaft rotation/minute.

The frequently high values are also due to influencing factors. How these factors influence the CO_2 value is discussed in detail below. At an average fuel consumption of 7 l/100 km and air temperatures in the range [22 - 24] ˚C, CO_2 emissions are fluctuating, taking values in the range [0.1 - 17.3] % (figure 15).

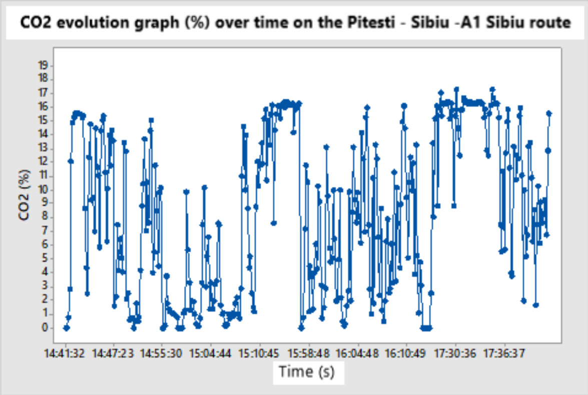

Figure 13: CO_2 evolution graph (%) over time on the Pitesti - Sibiu -A1 Sibiu route

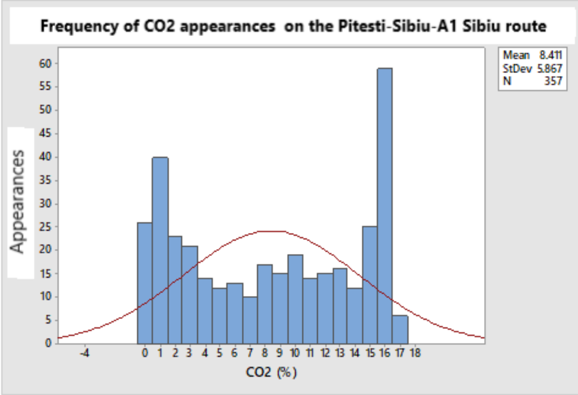

Figure 14: Frequency of CO_2 appareances on the Pitesti-Sibiu-A1 Sibiu route.

On the Black Hill section (a section with serpentines and tight curves), fuel consumption is maintained at the maximum value of 7 l/100 km and CO_2 values range from 0.1 to 17.3% (figure 15). As this route is travelled, the average fuel consumption decreases to 4.4 l/100 km (Olt Valley), then increases slightly to 4.7 l/100 km, while the CO_2 is in the range [0.2 -17.3] % at ambient temperatures in the range [23 -24] ˚C (figure 15).

On the A1 Sibiu motorway, CO_2 increases from range [1.7 - 17.3] % and average fuel consumption increases from 4.5 l/100 km to 4.8 l/100 km at ambient temperatures in the range [22 - 24] ˚C.

At environmental humidities in the range [32-37] %, average fuel consumption remains quite high (7 l/100 km - Black Hill, Arges county). Average fuel consumption drops to 4.7 l/100 km and CO_2 levels fluctuate between 0.1 and 17.3% (figure 16).

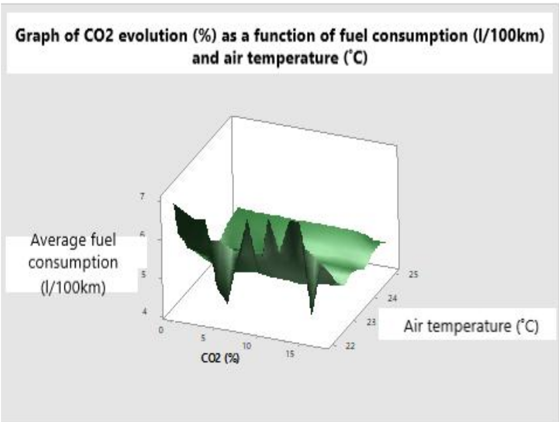

Figure 15: Graph of CO_2 evolution (%) as a function of fuel consumption (l/100km) and air temperature (˚C) on the Pitesti-Sibiu-A1 Sibiu route

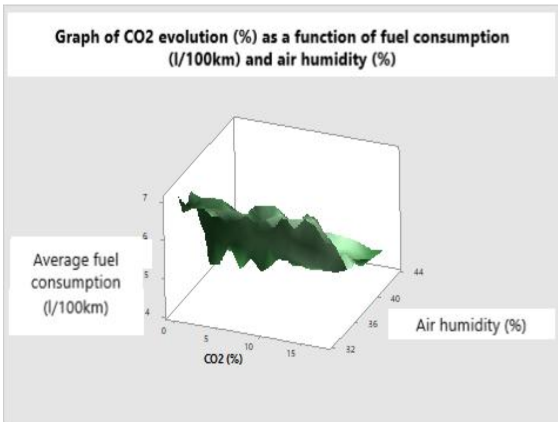

Figure 16: Graph of CO_2 evolution (%) as a function of fuel consumption (l/100km) and air humidity (%) on the Pitesti-Sibiu-A1 Sibiu route

At atmospheric pressures in the range [1.026 - 1.027] hPa, the average fuel consumption decreases from 7 l/100km to 4,7 l/100km, the CO_2 level oscillates in the range [0,1 - 17,3] % (figure 17).

At road traffic values above 1.500 vehicles/hour, the average fuel consumption reaches a maximum value of 7 l/100km, and CO_2 oscillates reaching maximum and minimum values in the range [0,1 - 17,3] % (figure 18).

Under low temperature and humidity conditions, CO_2 is also oscillating taking values in the range [0.1 - 17.3%]. At higher temperatures 23-24˚C, and an air humidity of 43% the CO_2 oscillation is lower (figure 19 and 20).

They occur due to the significant influence of high temperature and air humidity which affect the combustion principle in the engine cylinders increasing the amount of CO_2 removed into the atmosphere.

I consider that all these phenomena are due to the overheating of the fresh air charge which inevitably leads to the reduction of volumetric efficiency in the cylinder filling process.

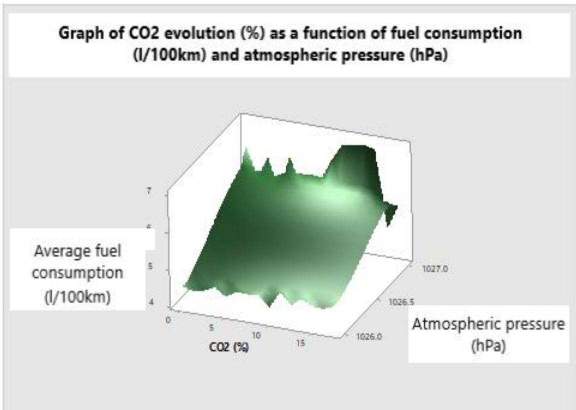

Figure 17: Graph of CO_2 evolution (%) as a function of fuel consumption (l/100km) and atmospheric pressure (hPa) on the Pitesti-Sibiu-A1 Sibiu route

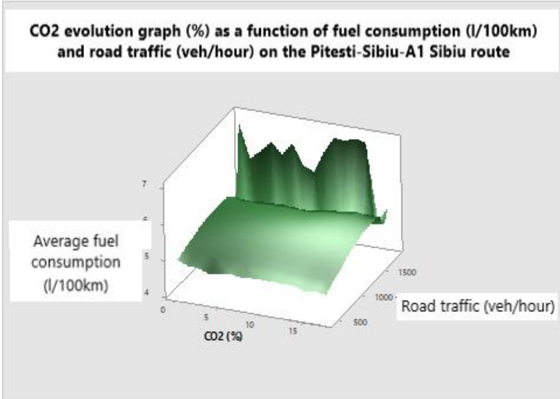

Figure 18: CO_2 evolution graph (%) as a function of fuel consumption (l/100km) and road traffic (vehicles/hour) on the Pitesti-Sibiu-A1 Sibiu route

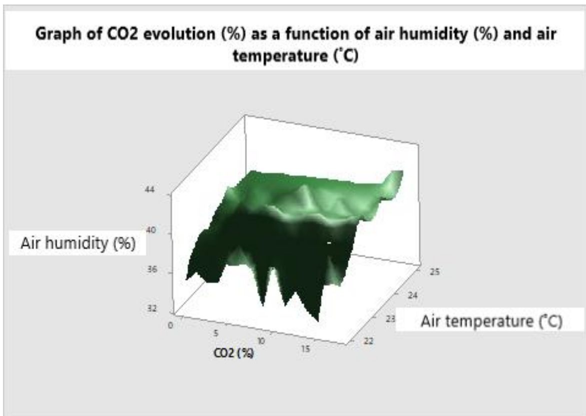

Figure 19: Graph of CO_2 evolution (%) as a function of air humidity (%) and air temperature (˚C) on the Pitesti-Sibiu-A1 Sibiu route

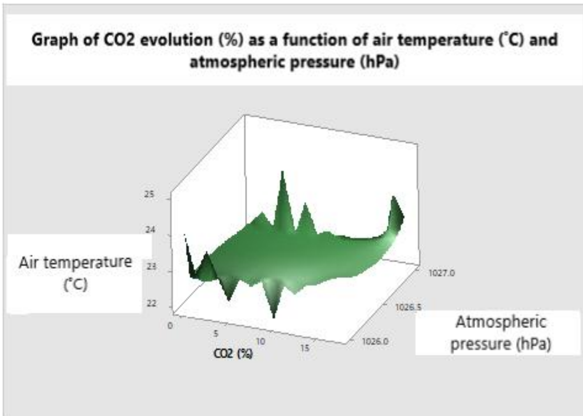

Figure 20: Graph of CO_2 evolution (%) as a function of air temperature (˚C) and atmospheric pressure (hPa) on the Pitesti-Sibiu-A1 Sibiu route

At road traffic values of over 1.500 vehicles/hour and an average fuel consumption of over 7 l/100 km, CO_2 takes values in the range [0-16] %. In this case, the high value of CO_2 is due to both high fuel consumption and heterogeneous road traffic which is a crowded one, where vehicle circulation was "bumper-to-bumper".

At high traffic values (over 1,500 vehicles/hour and air temperatures in the range [22-24] ˚C, CO_2 is maintained at maximum values (17,3%) (figure 21). From the point of view of this noxious the internal combustion engine of the car meets exactly the parameters of the European Euro 6 pollution standard, being clean at optimal temperature values (22˚C) and low traffic, but polluting at high values of air temperature (over 25˚C) and road traffic (over 1,500 vehicles/hour).

C. Hydrocarbons (HmCn), (figure 22 and 23), is within legal limits on most of the route/itinerary. The frequently reached values were below 30 -35 ppm, demonstrating that this category of noxious substances falls within the legal limit below 100 ppm. The exception was three short exceedances of the legal limit, when maximum values of 130 ppm and 237 ppm were reached on the Olt Valley, respectively, 236 ppm on A1 Sibiu ring motorway, for short periods of time (approx. 20-30 seconds), with one frequency, respectively two frequencies of occurrence over the entire distance of the route (figure 23).

I consider that the exceeding of the maximum values is due to high speed and incomplete combustion of petrol in the cylinders of the thermal engine. We also consider that the occurrence of maximum values may be due to the use of a fuel, a lower quality gasoline (e.g. Octane Number 95), or to improper functioning of the ignition or fuelling installations. The latter is ruled out because the car is new, has been serviced on time according to the manufacturer's requirements and no previous malfunctions or anomalies have been found in the operation of the two systems. In order to see if the occurrence of these short hydrocarbon emissions is due to the fuel, we propose to repeat the investigations under the same conditions but with a higher fuel (e.g. gasoline with an Octane Number of 99-100). At a fuel consumption in the range [7 - 4.4] l/100 km, a temperature in the range [22-24] ˚C (figure 24) and an environmental humidity in the range [33- 43] % (figure 25), hydrocarbons take legal values in the range [0 - 100] ppm.

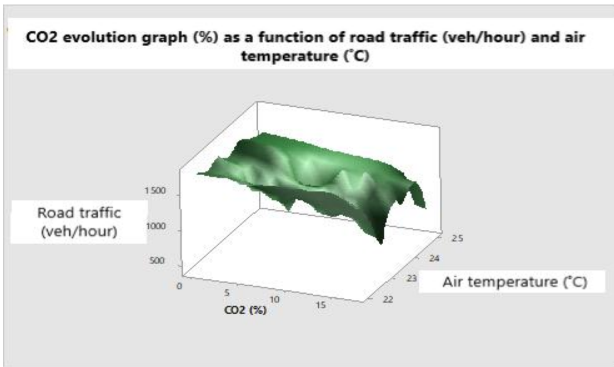

Figure 21: CO_2 evolution graph (%) as a function of road traffic (vehicles/hour) and air temperature (˚C) on the Pitesti-Sibiu-A1 Sibiu route

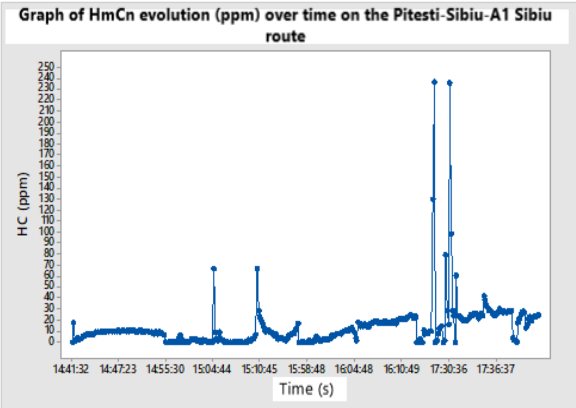

Figure 22: Graph of HmCn evolution (ppm) over time on the Pitesti-Sibiu-A1 Sibiu route

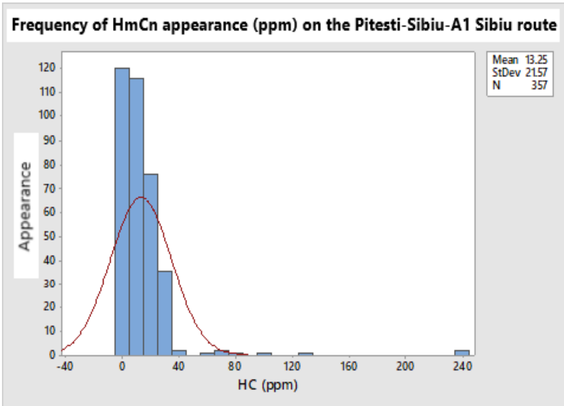

Figure 23: Frequency of HmCn appearance (ppm) on the Pitesti-Sibiu-A1 Sibiu route

I consider that at high ambient temperatures and humidity in which spark ignition engines operate, the way in which the cylinders are filled with fresh air is poor, resulting in abnormal combustion of the fuel mixture. Maximum values, above the maximum permissible value, are reached when the ambient temperature has a direct influence on the temperature of the compression end, delaying the fuel combustion front in the engine cylinders. This delay causes incomplete combustion resulting in a lot of unburned fuel being released into the atmosphere.

The process takes place at high air temperatures coupled with excessive humidity at high engine speeds in range [3,000 - 4,000] crankshaft rotations/minute.

Therefore, the temperature of the air admitted to the engine influences the temperature level per cycle and as a result has an influence on both the fuel atomisation through the viscosity of the gaseous medium in the combustion chamber at the time of injection and on the combustion speed and therefore on the formation of pollutant compounds.

On the other hand, it is known that as the temperature of the intake air increases, its density and the degree of uplevelling ηv of the engine decrease.

Finally, the mass of air remaining in the cylinder at the end of suction decreases, and under these conditions we can expect an incomplete combustion of the fuel which leads to a reduction in engine power on the one hand and an increase in the degree of pollution of the engine on the other. [9, pp. 1-2].

I agree with the specialists who state that high ambient temperatures always increase the temperature of the combustion process, which increases the tendency of the fuel mixture in the engine cylinders to burn with detonation.

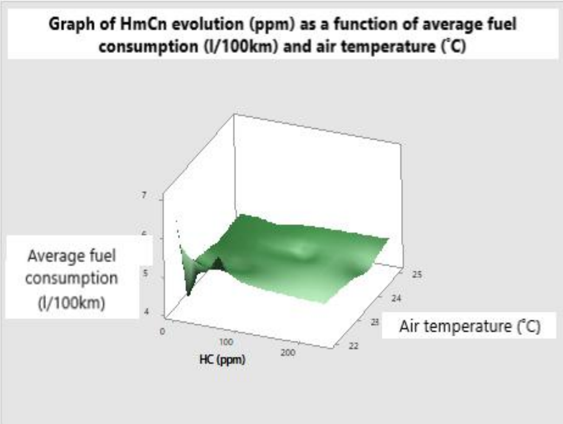

Figure 24: Graph of HmCn evolution (ppm) as a function of average fuel consumption (l/100km) and air temperature (˚C) on the Pitesti-Sibiu-A1 Sibiu route

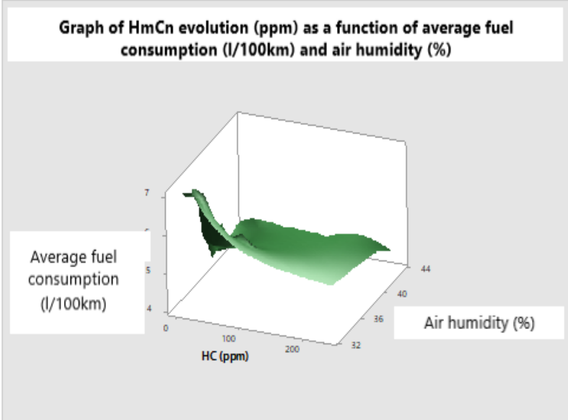

Figure 25: Graph of HmCn evolution (ppm) as a function of average fuel consumption (l/100km) and air humidity (%) on the Pitesti-Sibiu-A1 Sibiu route

This phenomenon is most noticeable on hot summer days when the air temperature is very high in the afternoon and the detonation in the engine cylinders becomes more powerful compared to the temperature of the air sucked into the engine at night. Experimentally, it has been found that the same engine sucking air at 50˚C (in the summer) needs 8 to 15 octane units less gasoline when sucking cold air at 0˚C (in the winter) [10, p. 96].

I affirm that the water vapour in the air sucked by the engine has a beneficial effect on the initial temperature by inhibiting the chemical reactions that create autoignition of the fuel mixture. The phenomenon of auto-ignition of the fuel mixture produces uncontrolled combustion in the cylinders of the thermal engine, combustion that does not occur at the right time, being incomplete. This results in a series of noxious emissions into the atmosphere with a high hydrocarbon content, i.e. unburned or incompletely burned gasoline. The phenomenon of unburned hydrocarbons released into the atmosphere is also specific to the operation of internal combustion engines when they are *cold*, i.e. when they are started up until the optimum operating temperature is reached.

At an average fuel consumption in the range [7 - 4,5] l/100 km, atmospheric pressures in the range [1.026-1.027] hPa, hydrocarbons take values in the range [0-100] parts per million (ppm). Fuel consumption has high values (7 l/100km) at atmospheric pressure values of 1.027 hPa (Black Hill). It reaches a minimum value of 4.4 l/100 km at a minimum atmospheric pressure of 1,026 hPa. The hydrocarbon value is maintained at legal values (max. 100 ppm).

The exception are the three short departures from the legal norms (Olt Valley = 130 ppm and 237 ppm and A1 Sibiu = 236 ppm) (figure 26). In my personal opinion, these departures can be due to the high values of road traffic which, on the Olt Valley, reached a maximum of 1,719 vehicles/hour (figure 27).

Also, the high humidity values of 44% and the ambient temperature of 24˚C, maximum values reached on the section Olt Valley - A1 Sibiu, may be the cause of the three short exceedances of the legal level of HmCn (figure 28).

Hydrocarbons are permanently present throughout the route, being below the maximum value allowed by law of 100 ppm (see figure 3). The yellow colour, which on the graph represents HmCn, is persistent on the Black Hill route, a route determined by the ascent of frequent ramps (left part of the graph in figure 3, max. 30 ppm), is less pronounced on the Olt Valley route (central part of the graph in figure 3, max 15 -20 ppm) and very pronounced on the A1 Sibiu route (right part of the graph in figure 3, A1 Sibiu, max. 45 ppm) where the car engine was running at full speed, under load.

The exception are the three exceedances of the legal maximum. From the point of view of this noxious the internal combustion engine of the car meets exactly the parameters of the European Euro 6 pollution standard, being clean at optimal temperature values (22˚C) and low traffic, but polluting at high values of air temperature (over 25˚C) and road traffic (over 1,500 vehicles/hour).

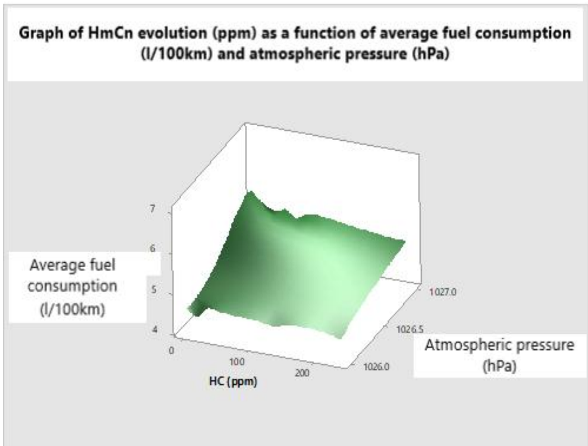

Figure 26: Graph of HmCn evolution (ppm) as a function of average fuel consumption (l/100km) and atmospheric pressure (hPa) on the Pitesti-Sibiu-A1 Sibiu route

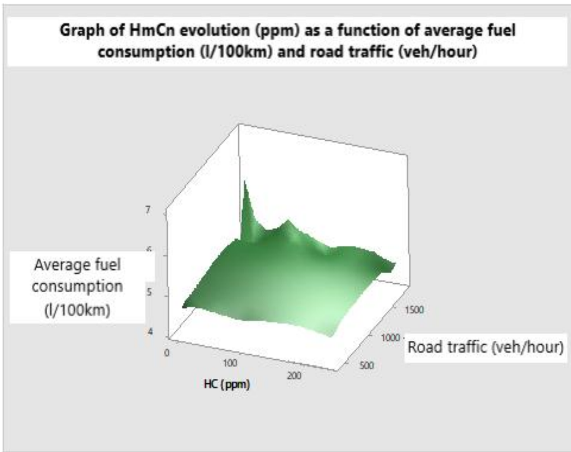

Figure 27: Graph of HmCn evolution (ppm) as a function of average fuel consumption (l/100km) and road traffic (vehicles/hour) on the Pitesti-Sibiu-A1 Sibiu route

D. Nitrogen oxides (NOx), (figure 29, and 30), is kept in the range [0-36] ppm along the whole route/itinerary (figure 29 and 30).

In European and national legislation, there is no stipulated maximum reference value. Therefore I consider the maximum value emitted by the car engine to be normal emissions, specific to the Euro 6 pollution standard. From personal research at the Periodic Technical Inspection stations and from discussions with specialists in the field, it appears that when checking vehicle emissions at these stations, the maximum values for nitrogen oxides (NOx) emitted by the car engine into the atmosphere are not taken into account. From the analysis of figure 30, there is a minimal occurrence of this gas, which shows that emissions are low.

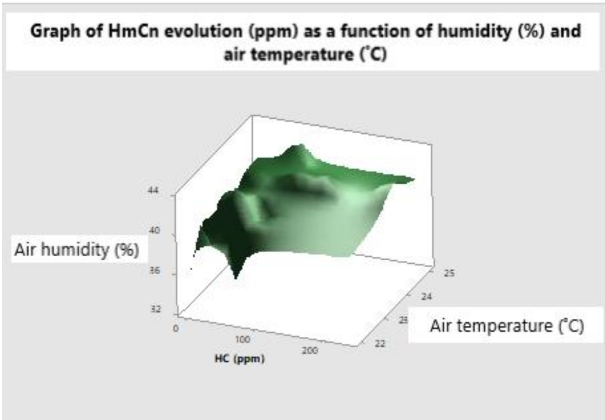

Figure 28: Graph of HmCn evolution (ppm) as a function of average humidity (%) and air temperature (˚C) on the Pitesti-Sibiu-A1 Sibiu route

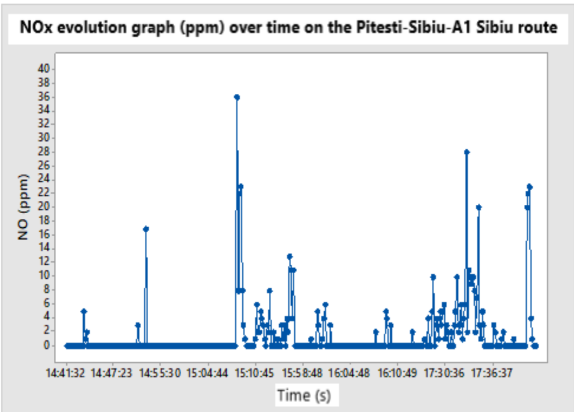

Figure 29: NOx evolution graph (ppm) over time on the Pitesti-Sibiu-A1 Sibiu route

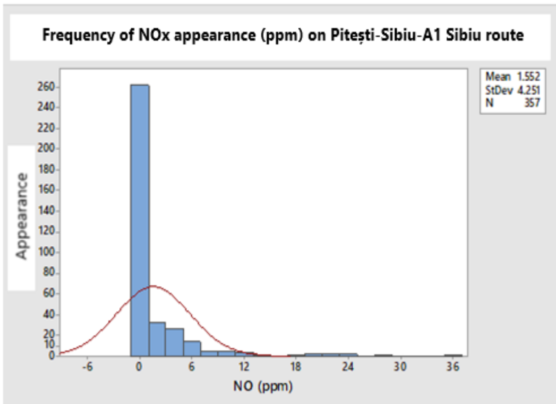

Figure 30: Frequency NOx appearance (ppm) on the Pitesti-Sibiu-A1 Sibiu route

I consider that this is due to the good functioning of the car's exhaust gas conversion system (catalytic converter), which defines a high quality of chemical transformations in terms of nitrogen oxides (NOx)removed by the engine.

Analyzing the influence of the main factors, it is found that at an air humidity in the range [33-43] % (figure 31), an air temperature in the range [22 - 24] ˚C (figure 32) and a road traffic value in the range [438 - 1.791] vehicles/hour (figure 33), low quantities of nitrogen oxide (NOx) are obtained, the maximum quantity of NOx eliminated into the atmosphere reaches maximum values of 36 ppm, its occurrence being reduced along the entire route. The most frequent occurrences of this gas were on the Black Hill route, Pitesti city, Argeș county, when climbing ramps and on the A1 Sibiu ring motorway, when the engine is running under load, at maximum speed and speed of the car (e.g. 130 km/h on the motorway). An increase in the nitrogen oxide (NOx) emissions, eliminated by the car engine, was also determined by the high air humidity, especially in the area of Sibiu city on the A1 motorway where the humidity reached a maximum value of 43% (figure 31).

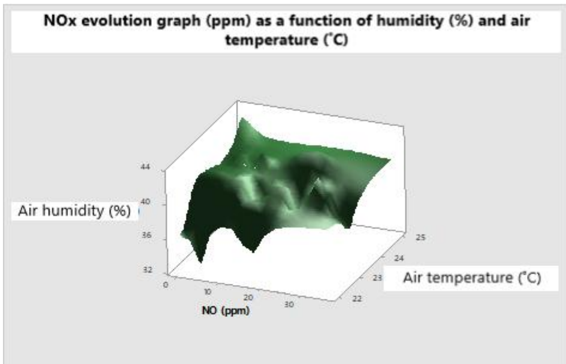

Figure 31: NOx evolution graph (ppm) as a function of humidity (%) and air temperature (˚C) on the Pitesti-Sibiu-A1

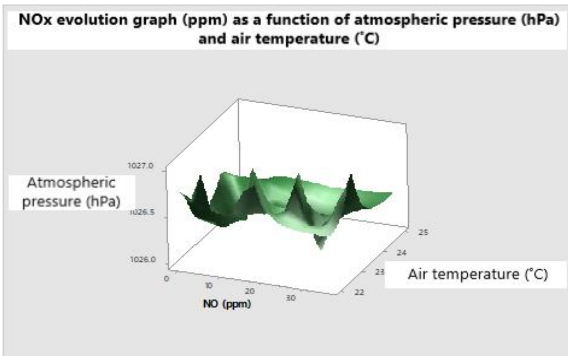

Figure 32: NOx evolution graph (ppm) as a function of atmospheric pressure (hPa) and air temperature (˚C) on the Pitesti-Sibiu-A1 Sibiu route

From the point of view of this noxious the internal combustion engine of the car meets exactly the parameters of the European Euro 6 pollution standard, being clean at optimal temperature values (22˚C) and low traffic, but polluting at high values of air temperature (over 25˚C) and road traffic (over 1,500 vehicles/hour).

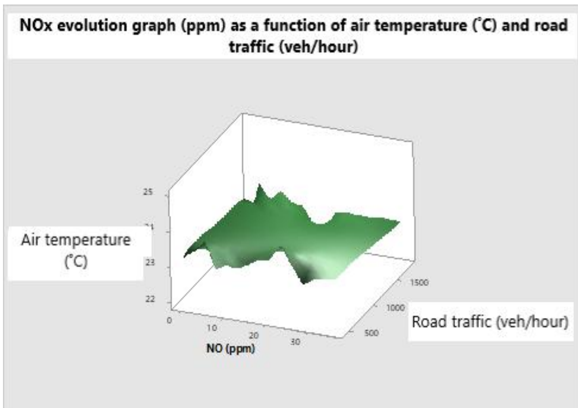

Figure 33: NOx evolution graph (ppm) as a function of air temperature (˚C) and road traffic (vehicles/hour) on the Pitesti-Sibiu-A1 Sibiu route

D. Oxygen (O_2), (figure 34 and 35), is one of the components of the exhaust gases released into the atmosphere by internal combustion engines of motor vehicles. Oxygen in the exhaust gas from motor vehicles is defined as the difference between the amount of oxygen in the exhaust gas and the amount of oxygen in the earth's atmosphere. Oxygen maintains and promotes the combustion of fuels in the cylinders of the thermal engines of motor vehicles and is not a toxic gas. It is found in the earth's atmosphere in the form of diatomic molecular oxygen (O_2) in a proportion of 20.5%. Its existence, to a greater or lesser extent in the exhaust gas composition, has a positive or negative influence on the level of chemical gas pollution of the ambient environment by the thermal engines of road vehicles.

In the modern cars, the oxygen in the exhaust gases is measured by two oxygen sensors (Lambda sonde), one mounted upstream of the catalytic converter and the second sensor mounted downstream of the catalytic converter, with the aim of making the catalytic conversion of the exhaust gases more efficient, thus substantially reducing pollution. The two sensors transmit the data to the ECU (Engine Control Unit), which automatically adjusts the air flow rate into the engine cylinders, establishing the oxidant fuel (air fuel) ratio, i.e. the stoichiometric ratio, *(Air Flow Ratio - AFR)*, (figure 36), which represents the amount of oxygen (air) required to be admitted into the cylinders of internal combustion engines, it represents the oxidant, the amount of oxygen that sustains combustion. It is known that a certain amount of oxygen is needed to ensure complete combustion of the fuel introduced into the engine (gasoline, diesel, liquefied petroleum gas - LPG, biofuels, etc). In this context, 14.7 parts of air (e.g. 1 kg of gasoline) are needed to burn one part (e.g. 14.7 kg of air) completely. If this ratio is kept at the exact value of 14.7:1, the mixture in the engine cylinders is said to be *stoichiometric ratio*.

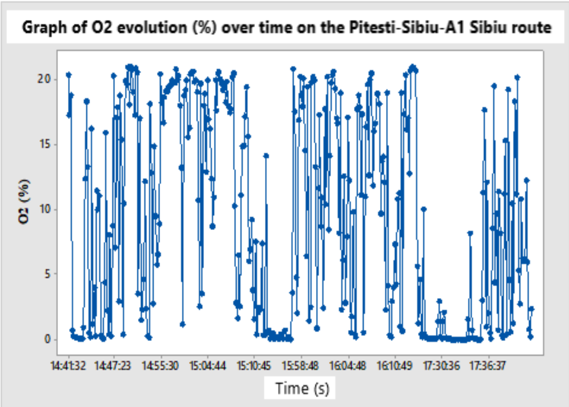

Figure 34: Graph of O_2 evolution (%) as a function of time on the Pitești-Sibiu-A1 Sibiu route

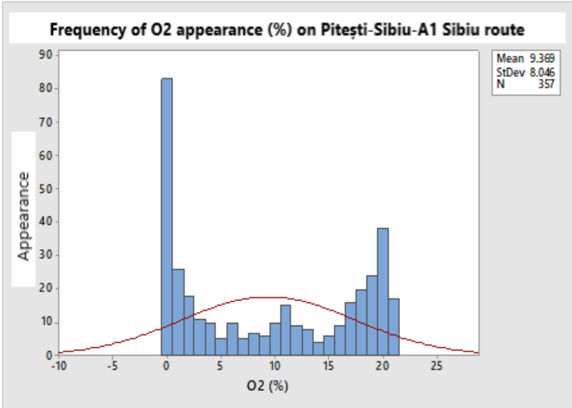

Figure 35: Frequency O_2 appearance (%) on Pitești-Sibiu-A1 Sibiu route

The notation used in the literature to evaluate the air-fuel ratio in the engine is the greek letter lambda *(λ)*. Lambda represents the ratio between the *Ideal stoichiometric dosage* and the *Actual dosage*.

$$Lambda\ (\lambda) = \frac{1}{Enrichment} = \frac{Ideal\ stoichiometric\ dosge}{Actual\ dosage} \qquad (2)$$

Thus, according to a relationship of the air-fuel mixture in the engine cylinders, we can have the following situations:

✓when **λ < 1, (0.8-0.9)**, we have a rich mixture, defined by the amount of fuel that is in excess, the amount of oxygen being insufficient for a complete combustion;

✓when **λ = 1**, we have an ideal stoichiometric ratio in which combustion is complete;

✓when **λ > 1, (1.2-1.3)**, we have a poor (lean) mixture, defined by the amount of oxygen that is in excess, the amount of fuel being insufficient for complete combustion.

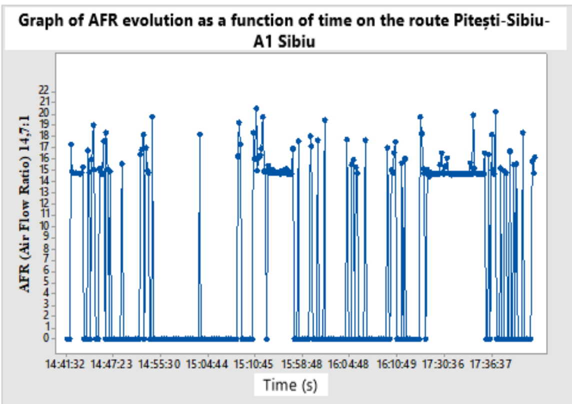

Figure 36: Graph of AFR evolution as a function of time on the Pitești-Sibiu-A1 Sibiu route

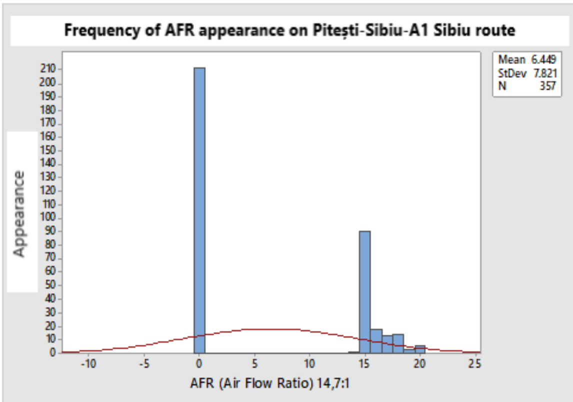

Figure 37: Frequency of AFR appearance on Pitești-Sibiu-A1 Sibiu route

Analysing the values presented on the two graphs (fig. 34 and fig. 36) it results that the oxygen has permanently taken values in the range of [1-22] %, which shows that a stoichiometric ratio with an optimal value of 14.7:1 has been ensured. In this context I state that the value ***λ = 1***, where an ideal *stoichiometric ratio* was obtained in which the combustion was complete. The Lambda probe functioned correctly transmitting continuously information to the ECU (Engine Control Unit).

The good functioning of the probe, also results from Fig. 36, where we show the AFR (Air Flow Ratio) values. Figure 35 shows the frequency of O_2 occurrences on the Pitești city - A1 motorway Sibiu city route. This also results in a high frequency of oxygen occurrences in the flue gas in the range [1-21] % (figure 34).

The optimum values obtained are due to the intervention of the Engine Control Unit which regulated the quantity of oxygen in the combustion gases, where it established a stoichiometric air-fuel ratio (AFR) at the ideal value of 14.7:1 (figure 36 and 37).

E. Fuel consumption (FC), (figure 38), represents the last objective function, set and displayed by the ECU (Engine Control Unit). It was monitored continuously, along the entire route with the help of a video camera. The data recorded precisely in time (hours, minutes, seconds) were recorded on video and then processed with the help of software on a Personal Computer (PC). On the basis of these data, the graph in figure 38 was created. The graph shows the evolution of the average fuel consumption on the Pitești - Sibiu - A1 motorway route. In this case, we have a stable average fuel consumption of 7 l/100 km, in the hourly interval [14:41-14:55], on the heaviest part of the climb of the specific ramps of the Black Hill - Pitești, Argeș county. After this route, the average fuel consumption gradually decreases to the minimum value of 4.4 l/100 km on the Olt Valley.

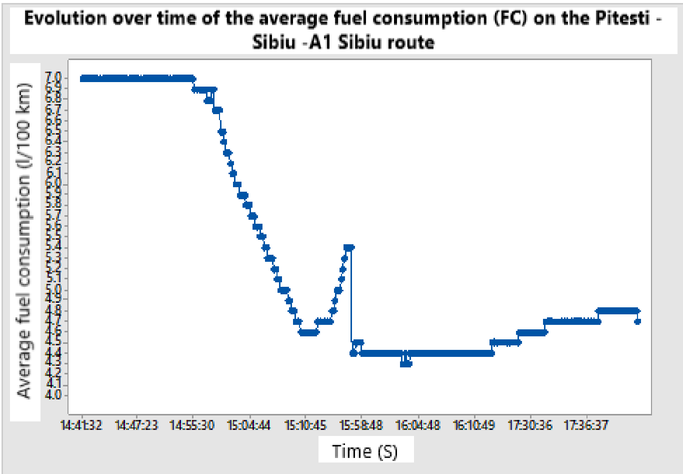

Figure 38: Graph of the evolution of the average fuel consumption (FC) as a function of time on the route Pitești-Sibiu-A1 Sibiu

The graph shows the evolution of the average fuel consumption on the Pitești city – Sibiu city A1 motorway route. In this case, we have a stable average fuel consumption of 7 l/100 km, in the hourly interval [14:41-14:55], on the heaviest part of the climb of the specific ramps of the Black Hill – Pitești city, Argeș couty. After this route, the average fuel consumption gradually decreases to the minimum value of 4.4 l/100 km on the Olt Valley. This is due to the intense, heterogeneous traffic conditions, which established the traffic in column (“bumper to bumper”), where the average speed did not exceed 45 km/h. Here the contribution of the electric motors can be observed, which due to the low speed of the vehicles, intervened, operating permanently and continuously along the entire route, limiting the operation of the thermal engine and therefore the average fuel consumption. On the A1 motorway the average fuel consumption increased from 4.5 l/100km to 4.8 l/100 km.

The increase is not significant, but it is due to the intervention of the thermal engine which contributed to the torque contribution necessary to drive the car at 130 km/h on the A1 Sibiu motorway.

V. CONCLUSIONS

Carbon monoxide (CO), hydrocarbons (HmCn) and nitrogen oxides (NOx), are kept within legal limits on both routes/itineraries on which the experiments were conducted. There are, however, small exceptions, where there were brief exceedances of about 20-30 seconds. An internal combustion engine, especially those fitted to motor vehicles, always operates at varying ambient temperatures which have a considerable influence on the power and consumption performance of the engine, and the short occurrences of overshoot are due to the following aspects:

- strong acceleration when overtaking other vehicles and climbing ramps;
- increase in ambient temperature, which reduces engine cylinder filling;
- when driving on the route with the engine below the optimum operating temperature in range [84-90] ˚C;

If traffic values are high, pollution levels and average fuel consumption drop. This is where the role of electric motors to support the combustion engine comes in. The high volume of traffic (more than 1,500-1,700 vehicles/hour), the speed of traffic and its heterogeneous nature, which results in almost ”bumper-to-bumper” traffic and vehicles driving in columns, substantially reduce fuel consumption. This is due to the hybrid vehicle's frequent propulsion by electric motors while the combustion engine is switched off. If road traffic is flowing at legal speeds, then the internal combustion engine runs continuously. In this case, exhaust gas levels are high and average fuel consumption increases.

From the analysed data, on both routes/itineraries, it appears that the CO_2 value frequently reached values in the range [3.5 - 17.3] %, which demonstrates its compliance with European level 6 standards. Carbon dioxide emissions are not regulated by legislation. However, we found that overheating of the fresh air charge inevitably leads to a reduction in volumetric efficiency in the cylinder filling process. The phenomenon is due to the influence of high temperature and air humidity affecting the combustion principle in the engine cylinders increasing the amount of CO_2 removed into the atmosphere. On both routes/itineration CO_2 took values in the range [0.1 - 17.3] %.

Hydrocarbons (HmCn) are permanently present throughout the route, but are below the maximum value of 100 ppm allowed by current legislation. The yellow colour shown on the graph in Figure 3 representing HmCn is persistent. Again, the exception is some short exceedances of about 20-40 seconds where the legal maximum was exceeded. The exceedance of the maximum permissible hydrocarbon (HmCn) values on both routes is due to high engine speeds and incomplete combustion of petrol in the cylinders of the thermal engine. The occurrence of maximum values may also be due to the use of a fuel, a lower quality petrol (e.g. Octane Number 95). Maximum values, above the maximum permissible limit, are reached when the ambient temperature has a direct influence on the temperature of the compression end, delaying the fuel combustion front in the engine cylinders. This delay causes incomplete combustion resulting in a lot of unburned fuel being released into the atmosphere. This occurs at high air temperatures in conjunction with excessive humidity at high engine speeds in range [3,000 - 4,000] crankshaft rotation/minute. This results in incomplete combustion at high engine speeds, decreasing engine power, increasing the level of unburned hydrocarbons (incompletely combusted fuels). High ambient humidity in spark ignition engines is however beneficial as it substantially reduces engine detonation. We agree with the specialists who say that it is advisable to introduce a quantity of water vapour into the engine intake stream. This also makes spark ignition engines work better when the air humidity is high (e.g. in the morning and at night when the humidity is higher and the air temperature absorbed by the engine is lower).

Emissions of nitrogen oxides (NOx) are not regulated by legislation. In both cases they occur minimally, demonstrating a well functioning exhaust gas conversion system of the car, which defines a high quality of catalytic transformation with regard to the nitrogen oxides removed by the engine.

The ECU (Engine Control Unit) and the Lambda probe ensured the correct operation of the thermal engine throughout the experimental research ensuring a proper stoichiometric ratio (AFR =14,7:1) by correct and timely regulation of the oxygen (O_2) level in the exhaust gas.

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