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# Measurement of vehicle emissions in real road conditions Part II. Results and analysis

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**Abstract.** This article presents the results of experimental studies of harmful components contained in the exhaust gases from internal combustion engines in cars. The experimental studies were conducted according to a predetermined methodology and conditions for conducting a specific section of the street network.

## INTRODUCTION

In our previous article [1] we present the methodology of measurements, types of cars and fuels used in the experiment. There we define the conditions for conducting measurements. In this article we present and analyze the data from the processing of the information obtained and show some experimental results.

Determining the exact amount of harmful components in the exhaust gases of internal combustion engines of cars in operating conditions is particularly important for the environment and human health, especially in large cities with ever-growing fleets and accompanying congestion on the street network.

It is necessary to pay attention both to the technical condition of the car fleet and to the quality of the fuels used in internal combustion engines.

The amount of harmful components in the exhaust gases depends on the technical condition of cars and their engines, as well as on the quality of the fuels used in internal combustion engines. As already mentioned in the previous article, the cars used in the study are in technically correct condition, and the quality of the fuels used is not the subject of this study.

The development of affordable, innovative and intelligent methods and technologies for the purpose of constant monitoring and control of emissions emitted by internal combustion engines of cars in operation, they will only increase the environmental safety of cars and at the same time reduce the harmful effects on people and the environment.

## PREREQUISITES AND MEANS FOR SOLVING THE PROBLEM

The purpose of this research is to determine the amounts of harmful emissions and components in the exhaust gases from the internal combustion engine of a car in operating conditions.

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Measurement and determination of the exact amount of harmful emissions in the exhaust gases is performed with a specialized gas analyzer (for vehicles with forced ignition - petrol engine) of the Italian company BRAIN BEE model AGS-200 [2] and Smokemeter (for cars with self-ignition - diesel internal combustion engine) OPACIMETER FOR DIESEL ENGINES again to a company BRAIN BEE model OPA-100 [2]. During the study, in parallel with the equipment for determining the amount of average components in the exhaust gases, diagnostic equipment was used to monitor the main indicators of the internal combustion engine of the company TEXA model IDC5 [3]. The quantities of harmful components in both liquid fuels (petrol and diesel) and gaseous fuels (LPG and CNG) were studied.

## RESULTS AND DISCUSSION

In Table 1 presents a short sample of the studied indicators of a car powered by gasoline, and are studied and presented further in the article LPG and CNG, as the presented data are both from the gas analyzer and from the diagnostic equipment. The studied indicators are identical for all three types of fuel as the car is the same (three-fuel Citroen Jumpy-EURO4 Emission Standard).

**TABLE 1.** Researched indicators of gasoline internal combustion engines.

| GAS ANALYZER | | | | | | | | OBD DIAGNOSTICS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| № | Engine speed | Lambda | CO | T | CO2 | O2 | HC | Engine speed | Upstream Oxigen sensor 1 | Downstream Oxigen sensor 2 | Intake manifold pressure | Engine load | Gear shift position | Vehicle speed |
| | rpm | λ | %Vol | C° | %Vol | %Vol | ppm Vol | rpm | mV | mV | mbar | Nm | -- | km/h |
| 4 | 690 | 1,005 | 0,01 | 100 | 14,9 | 0,12 | 1 | 672 | 98 | 702 | 328 | 0 | N | 0 |
| 5 | 690 | 1,005 | 0,01 | 100 | 15 | 0,12 | 1 | 992 | 683 | 702 | 920 | 10 | N | 0 |
| : | : | : | : | : | : | : | : | : | : | : | : | : | : | : |
| 122 | 1810 | 1,626 | 0,01 | 102 | 9,1 | 8,12 | 0 | 1344 | 761 | 117 | 920 | 99 | 1 | 8 |
| 123 | 1950 | 1,638 | 0,01 | 102 | 9 | 8,19 | 0 | 1824 | 585 | 293 | 406 | 33 | N | 15 |
| 124 | 1460 | 1610 | 0,01 | 102 | 9,3 | 8,08 | 0 | 1568 | 780 | 546 | 920 | 125 | 2 | 19 |
| : | : | : | : | : | : | : | : | : | : | : | : | : | : | : |
| 198 | 750 | 1,717 | 0,18 | 102 | 6,6 | 7,03 | 0 | 704 | 741 | 117 | 359 | 0 | N | 5 |
| 199 | 740 | 1,874 | 0,19 | 102 | 5,9 | 7,69 | 0 | 704 | 683 | 117 | 343 | 0 | N | 1 |

**Figure 1a** shows the measurement in real conditions with the gas analyzer and the variation between the change in $CO^2$ content and the Air-Fuel Ratio (Lambda) depending on the engine speed, and **Figure 1b** shows the variation between CO and HC depending on the engine speed of gasoline. The direct variation between the change of the Air-Fuel Ratio and $CO^2$ depending on the engine speed is impressive (Fig. 1.a).

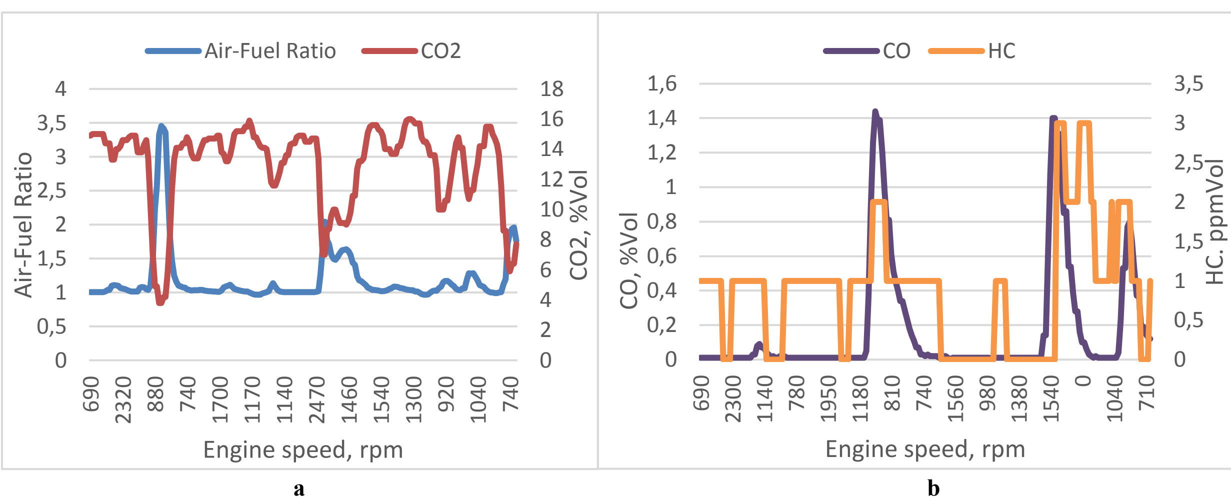
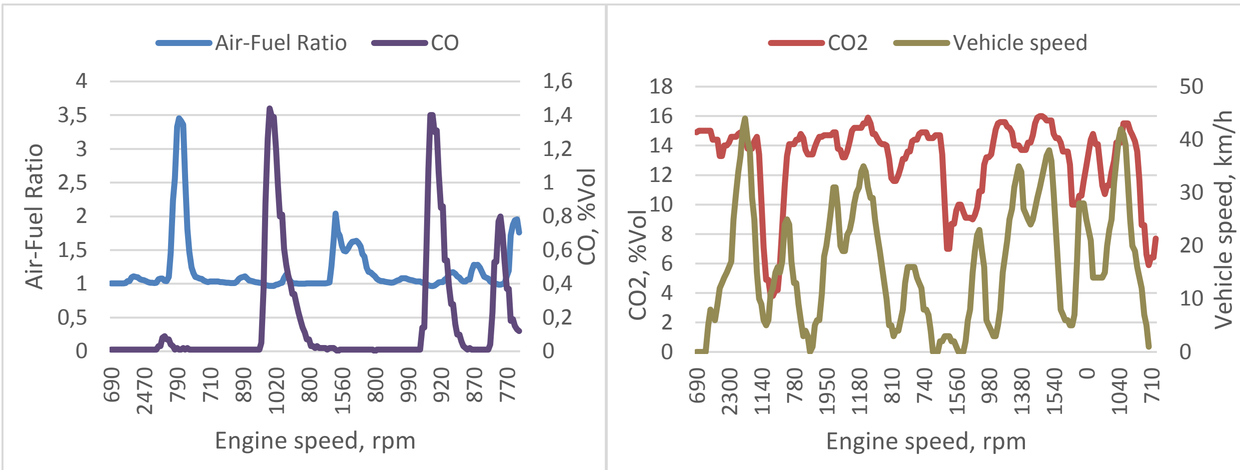



**FIGURE 1.** Variation of $CO^2$ and Air-Fuel Ratio, CO and HC content depending on Engine speed Engine on gasoline

**Figure 2a** shows the measurement and the variation between the change in CO content and the Air-Fuel Ratio (Lambda), and **Figure 2b** shows the relationship between $CO^2$ and the speed of the vehicle, both depending on the speed of the engine with gasoline.




a b

**FIGURE 2.** Variation of CO and Air-Fuel Ratio, CO and Vehicle speed content depending on Engine speed. Engine on gasoline

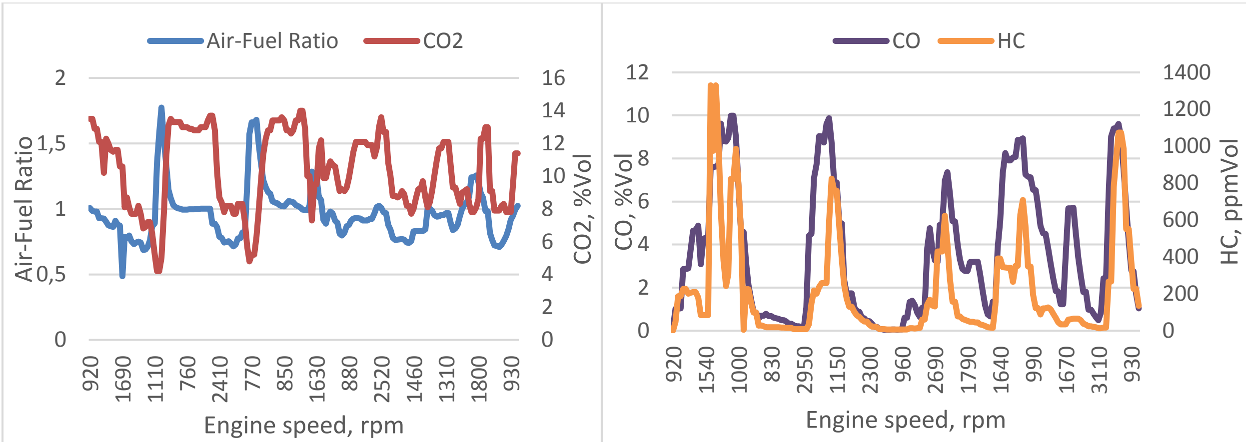
Here the connection between $CO^2$ and Vehicle speed is most clearly noticed, as a function of Engine speed (Fig. 2.b), which corresponds to the dependences presented in Figure 1a.

In Table 2 presents a short sample of the studied indicators of a car engine powered by LPG, as the presented data are both from the gas analyzer and from the diagnostic equipment.

**TABLE 2.** Researched indicators of gasoline internal combustion engines, powered by LPG.

| GAS ANALYZER | | | | | | | | OBD DIAGNOSTICS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| № | Rpm | Lambda | CO | T | CO2 | O2 | HC | Engine speed | Upstream Oxigen sensor 1 | Downstream Oxigen sensor 2 | Intake manifold pressure | Engine load | Gear shift position | Vehicle speed |
| | 1/min | λ | %Vol | C° | %Vol | %Vol | ppm Vol | rpm | mV | mV | mbar | Nm | -- | km/h |
| 8 | 920 | 1,006 | 0,14 | 102 | 13,5 | 0,21 | 1 | 960 | 878 | 800 | 655 | 39 | 1 | 5 |
| 9 | 870 | 0,985 | 1,02 | 102 | 13,5 | 0,38 | 48 | 832 | 917 | 878 | 515 | 35 | 1 | 6 |
| : | : | : | : | : | : | : | : | : | : | : | : | : | : | : |
| 68 | 1790 | 0,752 | 8,74 | 102 | 8,2 | 0,27 | 258 | 1728 | 0 | 234 | 218 | -16 | 4 | 42 |
| 69 | 1630 | 0,737 | 9,61 | 102 | 8,2 | 0,22 | 258 | 1280 | 0 | 98 | 218 | -12 | 4 | 35 |
| 70 | 1360 | 0,714 | 9,87 | 102 | 7,7 | 0,17 | 586 | 1216 | 939 | 39 | 218 | -14 | 4 | 31 |
| : | : | : | : | : | : | : | : | : | : | : | : | : | : | : |
| 189 | 1090 | 0,846 | 4,13 | 103 | 7,8 | 0,53 | 550 | 864 | 449 | 761 | 390 | 0 | N | 6 |
| 190 | 930 | 0,917 | 2,81 | 103 | 7,8 | 0,87 | 372 | 832 | 59 | 741 | 359 | 0 | N | 0 |

**Figure 3a** again shows a measurement in real conditions with the gas analyzer and the variation between the change in $CO^2$ content and the Air-Fuel Ratio (Lambda) depending on engine speed, and **Figure 3b** shows the variation between CO and HC depending on engine speed which is powered by LPG.

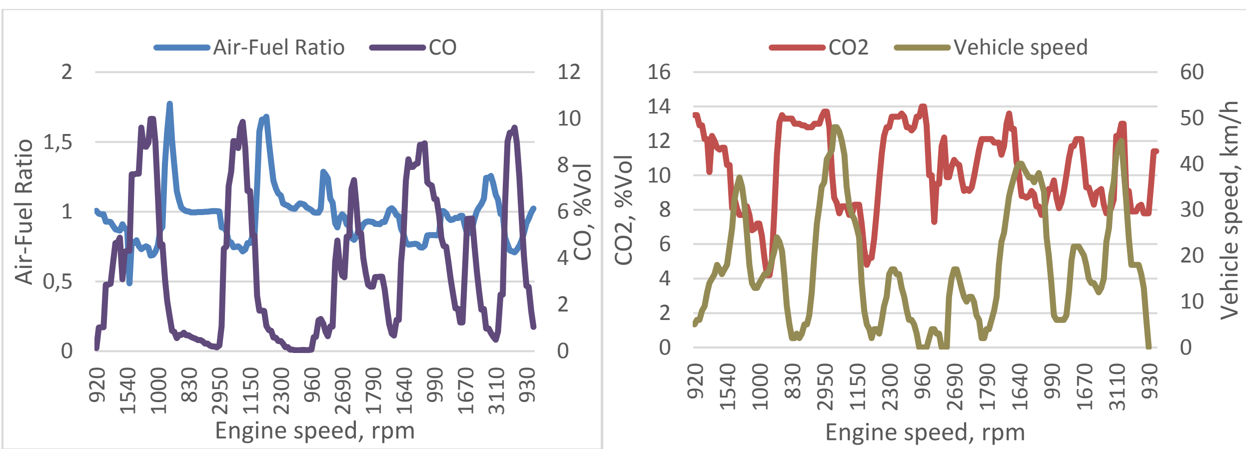



**a** **b**

**FIGURE 3**. Variation of $CO^2$ and Air-Fuel Ratio, CO and HC content depending on Engine speed, rpm. Engine on LPG

When working with LPG on internal combustion engines, there is a direct variation between CO and HC depending on Engine speed (Fig. 3b), as the values of HC when driving with LPG are many times higher than when operating on internal combustion engines with gasoline.

**Figure 4a** shows the variation between the change in CO content and the Air-Fuel Ratio (Lambda), and **Figure 4b** shows the variation between $CO^2$ and vehicle speed, both depending on the engine speed at engine on LPG.




**a** **b**

**FIGURE 4.** Variation of CO and Air-Fuel Ratio, CO and Vehicle speed, km/h content depending on Engine speed, rpm. Engine on LPG

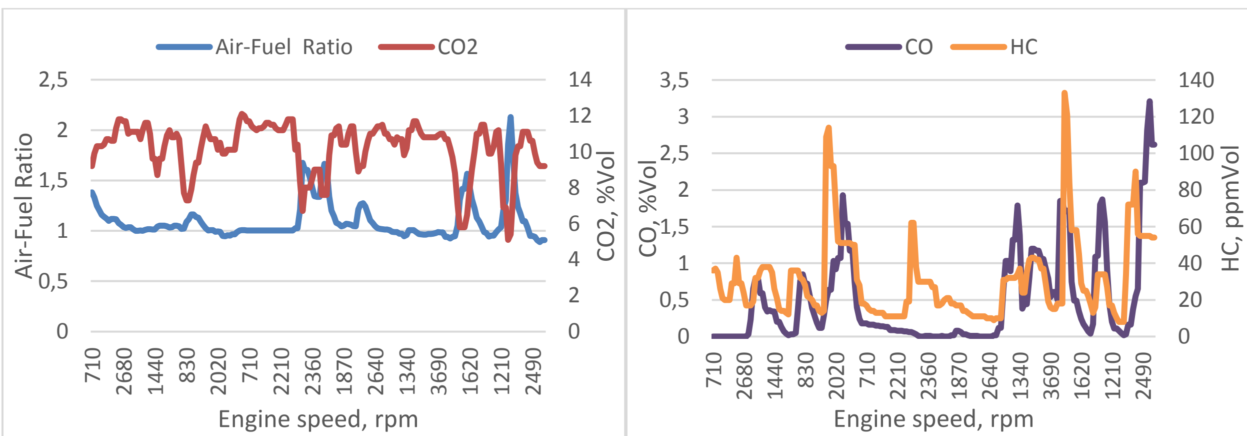
In contrast to the values of the studied indicators in the operation of gasoline on internal combustion engines, there is no variation between the levels of $CO^2$ and Vehicle speed, as the values are approximately the same but in different modes of operation of the engine (Fig.4.b). There is a clear increase in the amount of CO, as well as the direct connection between the CO and the Air-Fuel Ratio (Lambda) **Figure 4a**.

In **Table 3** presents a short sample of the studied indicators of a car powered by car engine powered by CNG, as the presented data are both from the gas analyzer and from the diagnostic equipment.

**TABLE 3.** Researched indicators of gasoline internal combustion engines, powered by CNG.

| GAS ANALYZER | | | | | | | | OBD DIAGNOSTICS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| № | Rpm | Lambda | CO | T | CO2 | O2 | HC | Engine speed | Upstream Oxigen sensor 1 | Downstream Oxigen sensor 2 | Intake manifold pressure | Engine load | Gear shift position | Vehicle speed |
| | 1/min | λ | %Vol | C° | %Vol | %Vol | ppm Vol | rpm | mV | mV | mbar | Nm | -- | km/h |
| 4 | 2270 | 1,207 | 0 | 103 | 10,3 | 3,06 | 26 | 1632 | 858 | 468 | 733 | 27 | N | 5 |
| 5 | 1620 | 1,16 | 0 | 103 | 10,3 | 2,36 | 21 | 1312 | 819 | 663 | 764 | 87 | 1 | 7 |
| : | : | : | : | : | : | : | : | : | : | : | : | : | : | : |
| 119 | 2490 | 1,027 | 0 | 104 | 11,4 | 0,45 | 10 | 2560 | 858 | 780 | 920 | 161 | 2 | 34 |
| 120 | 2780 | 1,02 | 0,02 | 104 | 11,4 | 0,35 | 9 | 2208 | 839 | 566 | 593 | 137 | 3 | 37 |
| 121 | 2520 | 1,016 | 0,02 | 104 | 11,5 | 0,29 | 10 | 2112 | 858 | 683 | 920 | 149 | 3 | 39 |
| : | : | : | : | : | : | : | : | : | : | : | : | : | : | : |
| 182 | 2490 | 0,95 | 2,1 | 104 | 10,6 | 0,49 | 55 | 2144 | 59 | 839 | 218 | -20 | 2 | 34 |
| 183 | 2490 | 0,95 | 2,1 | 104 | 10,6 | 0,49 | 55 | 1504 | 0 | 663 | 234 | -12 | N | 31 |

**Figure 5a** shows a real-time measurement with the gas analyzer and the variation between the change in $CO^2$ content and the Air-Fuel Ratio (Lambda) depending on the engine speed, and **Figure 5b** shows the variation between CO and HC depending on the engine speed which is CNG powered.



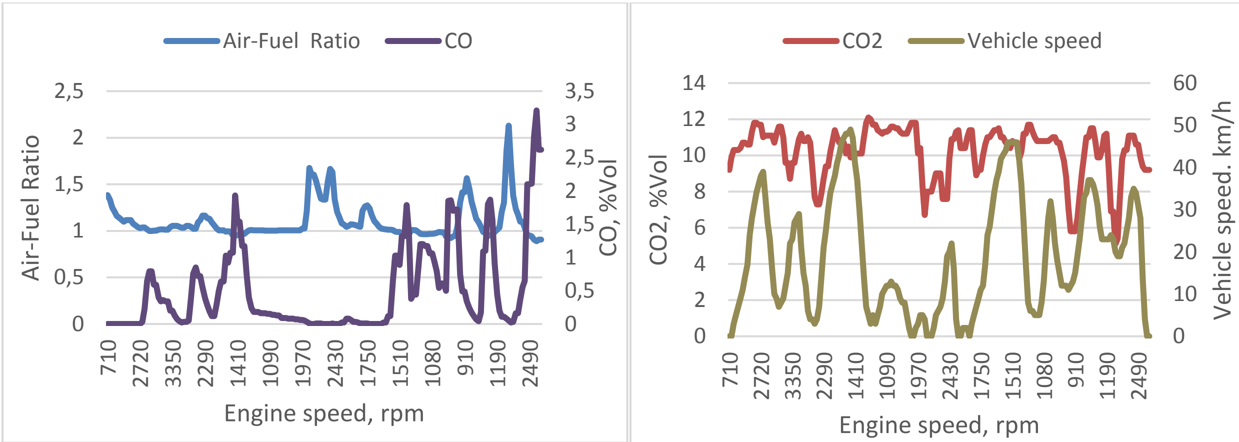

a

b

**FIGURE 5**. Variation of $CO^2$ and Air-Fuel Ratio, CO and HC content depending on Engine speed, Engine on CNG.

It is observed here weak connection between Air-Fuel Ratio и CO2 (фиг.5.a), but as with the operation of LPG on internal combustion engines, a large connection can be seen between CO and HC content depending on Engine speed (Fig. 5.b), but the amount of HC is about ten times smaller.

**Figure 6a** shows the measurement in real conditions with the gas analyzer and the variation between the change in CO content and the Air-Fuel Ratio (Lambda) depending on engine speed, and **Figure 6b** shows the variation between $CO^2$ and vehicle speed depending on speed on internal combustion engines at engine on LPG. The clear connection between the studied indicators is impressive.




**a** **b**

**FIGURE 6.** Variation of CO and Air-Fuel Ratio, CO and Vehicle speed, km/h content depending on Engine speed. Engine on CNG

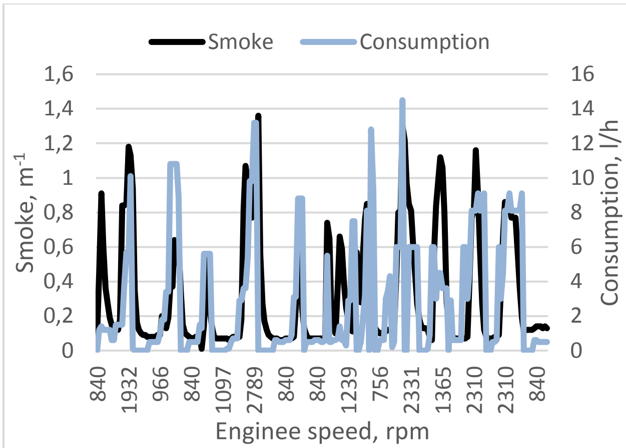
Here we see a connection between CO[2] and Vehicle speed, as a function of Engine speed (Fig. 6.b), which corresponds to the dependencies shown in **Figure 5a**, which can be seen when running an internal combustion engine with gasoline (Fig. 2.b).

**Table 4** presents a brief sample of the studied indicators of a diesel-powered internal combustion engine (Skoda Fabia - EURO4 Emission Standard), both from the opacimeter and from the diagnostic equipment. The studied indicators differ due to the specifics of the information provided by the diagnostic equipment, as well as the measured components, as in diesel cars smoke is mainly measured.

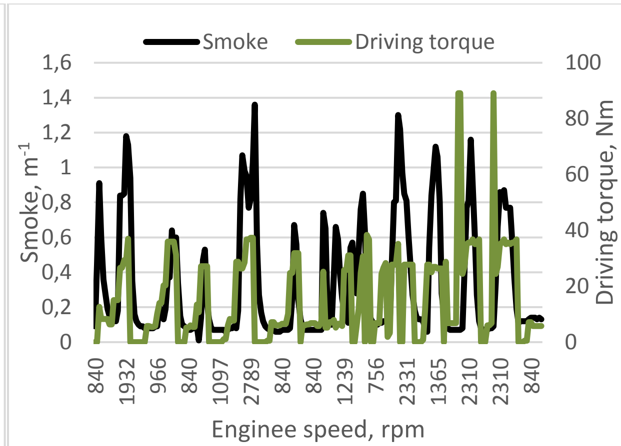
**TABLE 4.** Researched indicators diesel internal combustion engines.

| SMOKEMETER | | | | OBD DIAGNOSTICS | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| № | Engine speed rpm | PM m-1 | Oil.temp °C | Engine speed rpm | Col.temp °C | Veh.sped km/h | Bat.volt V | Driv.troq Nm | Consum l/h |
| 1 | 850 | 0,09 | 91 | 840 | 89,1 | 0 | 13,68 | 0 | 0 |
| 2 | 1580 | 0,45 | 91 | 1323 | 89,1 | 0 | 13,83 | 0 | 1,2 |
| 3 | 1380 | 0,91 | 91 | 1323 | 89,1 | 4 | 13,83 | 12,63 | 1,4 |
| : | : | : | : | : | : | : | : | : | : |
| 178 | 1020 | 0,08 | 96 | 1113 | 90,9 | 24 | 13,91 | 24,43 | 3 |
| 179 | 1290 | 0,39 | 96 | 1680 | 90,9 | 18 | 13,83 | 26,9 | 4,5 |
| 180 | 2090 | 0,77 | 96 | 2310 | 90,9 | 25 | 13,91 | 35,09 | 8,1 |
| : | : | : | : | : | : | : | : | : | : |
| 215 | 840 | 0,14 | 97 | 840 | 91,8 | 0 | 13,91 | 5,76 | 0,5 |
| 216 | 860 | 0,13 | 97 | 840 | 91,8 | 0 | 13,91 | 5,76 | 0,5 |

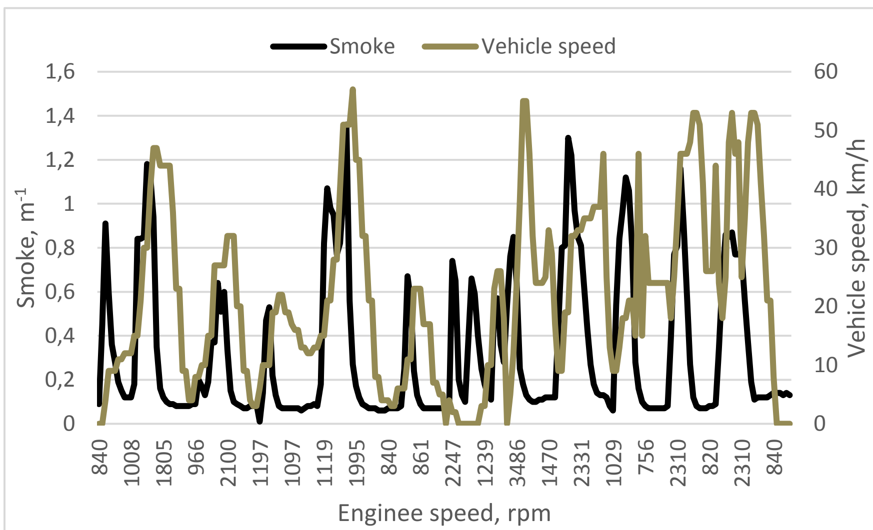
**Figure 7a** shows a real-time measurement with an opacimeter and the variation between smoke content change and fuel consumption as a function of engine speed, and **Figure 7b** shows the variation between smoke quantity and Driving torque, **Figure 7c** shows the change in the smoke and the speed of the car as a function of the engine speed, which is powered by diesel.




**a**




**b**




**c**

**FIGURE 7. a** -Variation of Smoke and Consumption; **b** – Smoke and Driving torque; **c** – Smoke and Vehicle speed, content depending on Engine speed. Engine on diesel

There is a strong content between fuel consumption and smoke in relation to engine speed, which is quite expected for the operation of the engine, the same trend is observed in the increase of smoke associated with Driving torque, which is directly dependent on the cost of fuel, which also depends on the speed of the car.

## CONCLUSIONS

No values at NO were observed during the study, as the emission standard of cars assumes values that are below the possible (measurement resolution) for measurement with the used gas analyzer.

Working to improve air quality and cleanliness in the city is a strategic priority set for city governments and engineers. Therefore, the main measures in all programs are aimed at improving air quality and reducing air pollution from both road traffic and all major sources. The only correct approach is to take timely and appropriate measures to control air quality in large cities by identifying in advance the main risk sources of increasing environmental pollution and taking action to reduce pollution.

The development of accessible methodologies, through the use of innovative and intelligent approaches and technologies to continuously monitor and control emissions from engines through the exhaust gases of cars in operation and from cars themselves, will improve the environmental safety of cars in general and in at the same time they will reduce the harmful effects on people and the environment.

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