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The Comparison of the Emissions from Light Duty Vehicle in On-road and NEDC Tests

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ABSTRACT

The investigations into the emissions from light-duty vehicles have been carried out on a chassis dynamometer (NEDC test in Europe and FTP75 test in the US). Such tests do not entirely reflect the real road conditions and that is why we should analyze the correlation of the laboratory versus on-road test results. The paper presents the on-road test results obtained in an urban and extra urban cycles. For these measurements a portable SEMTECH DS analyzer by SENSORS has been used. The device is an analyzer enabling an on-line measurement of the emission gases concentration in a real driving cycle under real road conditions. The road tests were performed on road portions of several kilometers each. The obtained results were compared with the results obtained for the same vehicle during the NEDC test on a chassis dynamometer. The comparative analysis was performed including the urban and extra-urban cycles. Additionally, a comparative analysis of the on-road tests was carried out considering the road portions corresponding to the individual NEDC parts (UDC and EUDC) in terms of time and distance. Additionally, an analysis of the exhaust emissions and fuel consumption was carried out in the driving cycle with respect to the terrain quality (mountain driving). Based on the performed research the authors noted that the emission under real road conditions significantly differs from the emissions on a chassis dynamometer.

INTRODUCTION

Environment protection against negative impact of the automotive industry requires constant efforts in the development in the modernization of combustion engines and methodology of investigating exhaust emissions. For many years the emission tests in Light Duty Vehicle have been carried out in compliance with the NEDC test [1]. The introduced legislative changes are mainly focused on limiting of the admissible emissions. At the same time we observe changes in the traffic characteristics across Europe - the cities are becoming more congested, driving parameters of vehicles change (average vehicle speed is reduced and the share of the acceleration phase in the city traffic grows). Hence, comes the question whether the conditions of the applicable homologation test fully reflect the real road conditions for LDV? The first tests performed in real traffic suggest that the emission level is much higher than that shown in the NEDC [2–7, 9, 10]. We, thus, have to debate on the necessity of a modification of the said homologation test. The results of the road tests should give us the answer whether any update of the NEDC test with an appropriate supplement is necessary or whether we need an entirely new test version.

TESTING METHODS

The tests were performed in two stages. The first was road emission tests (CO, HC, NO_x, CO_2) under real operating conditions. The second stage consisted in measuring the emissions from the same test object in the NEDC test carried out on a chassis dynamometer. A single tests was conducted. The measurement of the exhaust emissions was carried out in different real road conditions i.e. urban traffic, high speed driving and mountain driving (fig. 1). The tests were conducted on the main roads of the city in the afternoon hours and in congested urban areas. The road conditions were selected so as to reflect typical traffic. The test results were compared with the NEDC homologation cycle.

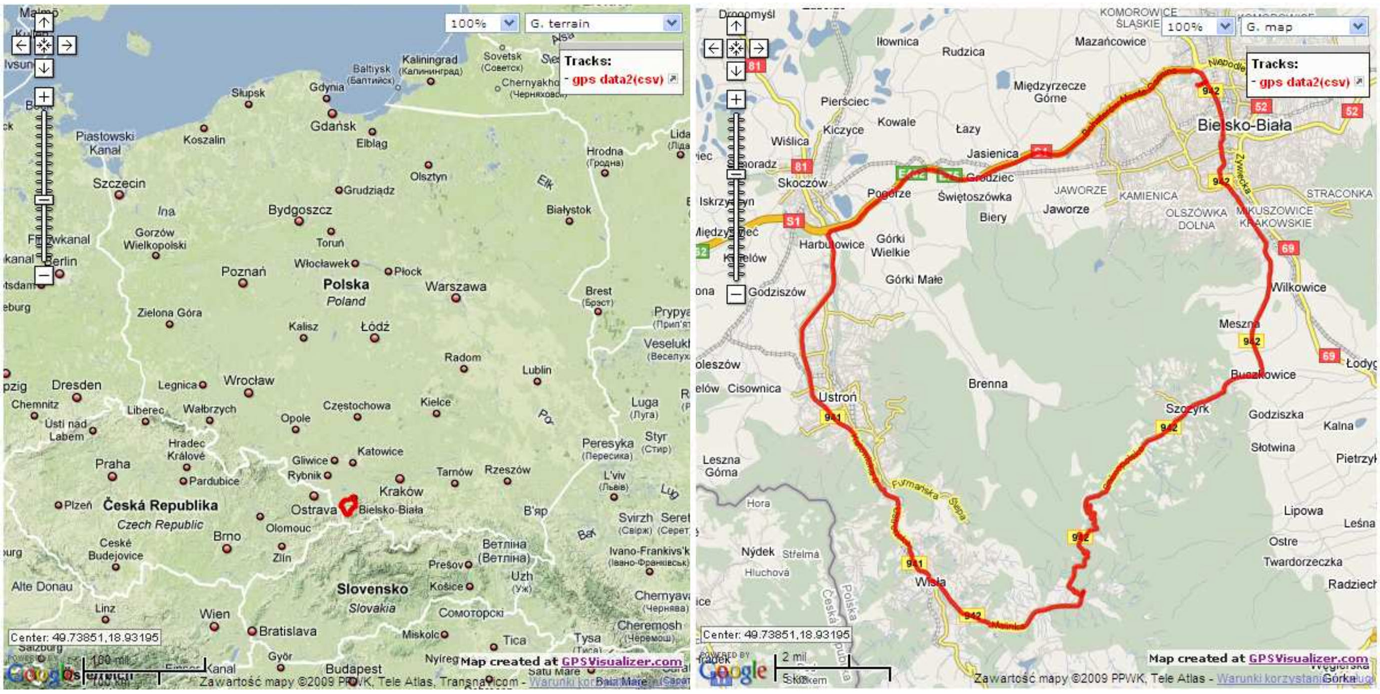

Fig. 1. The marked road used for the testing of exhaust emissions (read line) [created by www.GPSVisualizer.com]

The length of the test route was 76.044 km and was divided into urban and extra urban road portions in order to compare the emission level with the results obtained in the NEDC. The road portions corresponding in length and duration to the elementary UDC and EUDC tests (components of the NEDC). The list of the compared test cycles performed under real road conditions and on the chassis dynamometer have been shown in table 1. The average vehicle speeds have been included as well.

Table 1

Test cycles under comparison

Cycle	Cycle length [km]	Duration [s]	Average speed [km/h]
NEDC	11.007	1180	40.1
UDC	4.052	780	18.7
EUDC	6.955	400	62.6
Road tests	75.044	5788	47.3
Road tests urban cycle 780 s.	4.368	780	19.7
Road tests urban cycle 4.052 km	4.052	758	19.2
Road tests extra urban cycle 400s.	8.603	400	77.5
Road tests extra urban cycle 6.955 km	6.955	329	76.7

EXPERIMENTAL FACILITIES

The object of the tests was a car (model year 2006) fitted with a gasoline 4 cylinder 1.2 dm^3 engine, manual transmission, mileage reading – 100 000 km, OBD II protocol ISO-9141-2. In order to measure the concentration of emissions gases a portable SEMTECH DS analyzer by SENSORS was used [8]. The analyzer allowed the measurement of the concentration of emissions with a simultaneous measurement of mass flow rate of the exhaust gases. The exhaust gas introduced to the analyzer through a probe maintaining the temperature of 191^{o}C was then filtered out of particle matter and directed to the flame-ionizing detector (FID) where hydrocarbons concentration was measured. Then the exhaust gases were cooled down to the temperature of 4^{o}C and the measurement of the concentration of nitric oxides (NDUV analyzer), carbon monoxide, carbon dioxide (NDIR analyzer) and oxygen followed in the order as listed. It was possible to add data sent directly from the vehicle diagnostic system to the central unit of the analyzer and make use of the Satnav positioning system (tab. 2). In the test, the measurements of the toxic emissions were used and also, for comparison, signals from the on-board diagnostic system were registered, e.g. engine speed, load, vehicle speed, temperature of intake air [8]. Some of these signals served to specify time density maps presenting the share of the operating time of a vehicle in real operating conditions. The GPS signal was used in further visualization of the obtained data (fig. 2 and 3).

Table 2

Characteristics of a portable exhaust analyzer SEMTECH DS

Parameter	Measurement method	Accuracy
1. Emission		
CO	NDIR, range 0–8%	±3%
HC	FID, range 0–10 000 ppm	±2%
$NO_x = (NO + NO_2)$	NDUV, range 0–2500 ppm	±3%
CO_2	NDIR, range 0–20%	±3%
O_2	Electrochemical, range 0–25%	±1%
2. Data storage capacity	Over 10 hours at 1 Hz data acquisition rate	
3. Vehicle interface capacity	SAE J1850 (PWM), SAE J1979 (VPW) ISO 14230 (KWP-2000) ISO 15765 (CAN), ISO 11898 (CAN) SAE J1587, SAE J1939 (CAN)	

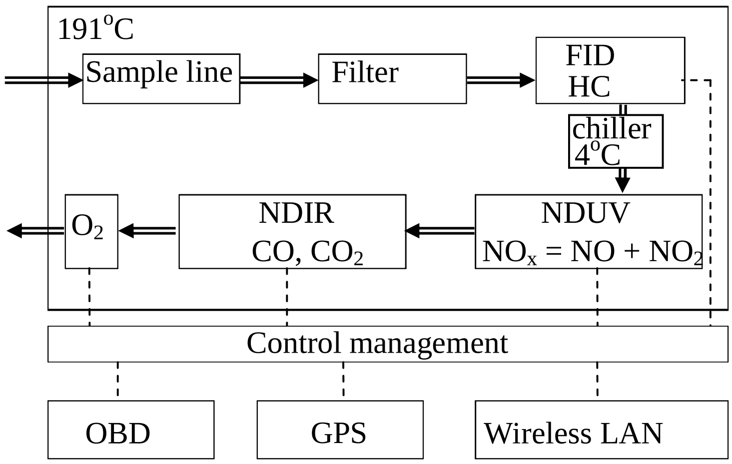

Fig. 2. A diagram of a portable analyzer SEMTECH DS; exhaust gas flow channels (===) and electrical connections circled (– – –) [8]

Chassis dynamometer emission tests were carried out at the BOSMAL Automotive R&D Centre's Emissions Testing Laboratory using the emissions chassis dynamometer Schenck 500/GS60. During the laboratory tests on a chassis dynamometer typical equipment for homologation tests was used i.e.: the CVS AVL CEC system, analyzer bench with NDIR analyzer for CO and CO_2 measurements, FID for HC and CLD for NO_x measurements. The specifications of the equipment installed in the emissions laboratory with chassis dynamometer has been listed in table 3.

Table 3

Emissions test equipment at the Bosmal laboratory with the R&D chassis dynamometer used for the investigations

Device	Type	Measurement range
Chassis dynamometer	Schenck 500GS60	0–200 km/h 0–1600 N
As set of analyzers:	AVL CEB 600	
Analyzer CO	Rosemount NGA 2000 NDIR	0–2500 ppm
Analyzer HC	Rosemount NGA 2000 HFID	0–10 000 ppm
Analyzer NOx	Rosemount NGA 2000 CLD	0–1000 ppm
Analyzer CO2	Rosemount NGA 2000 NDIR	0–20%
Analyzer CO	Rosemount NGA 2000 NDIR	0–10%
Analyzer HC	Rosemount NGA 2000 HFID	0–50 000 ppm
Analyzer NOx	Rosemount NGA 2000 CLD	0–10 000 ppm
Analyzer CO2	Rosemount NGA 2000 NDIR	0–20%
Analyzer CO2	Rosemount NGA 2000 NDIR	0–20%
Exhaust gases sampling system CFV-CVS	AVL CEC-Q20	1.5–22.5 m^3/min

Fig .3. View of SEMTECH DS analyzer fitted in a vehicle

TEST RESULTS AND ANALYSIS

The emissions were measured using the portable measurement system (CO, HC, NO_x and CO_2). The system also recorded the exhaust gas mass flow rate, the basic operating parameters of the engine (engine speed, engine load) and the vehicle route (speed, acceleration). Photographs 4–6 present the concentrations of toxic compounds, engine speed and vehicle speed overlain on the map with a marked vehicle route. A higher concentration of the emissions is seen in the initial phase of the test, which results from a lower initial (cold start) efficiency of the catalytic converter.

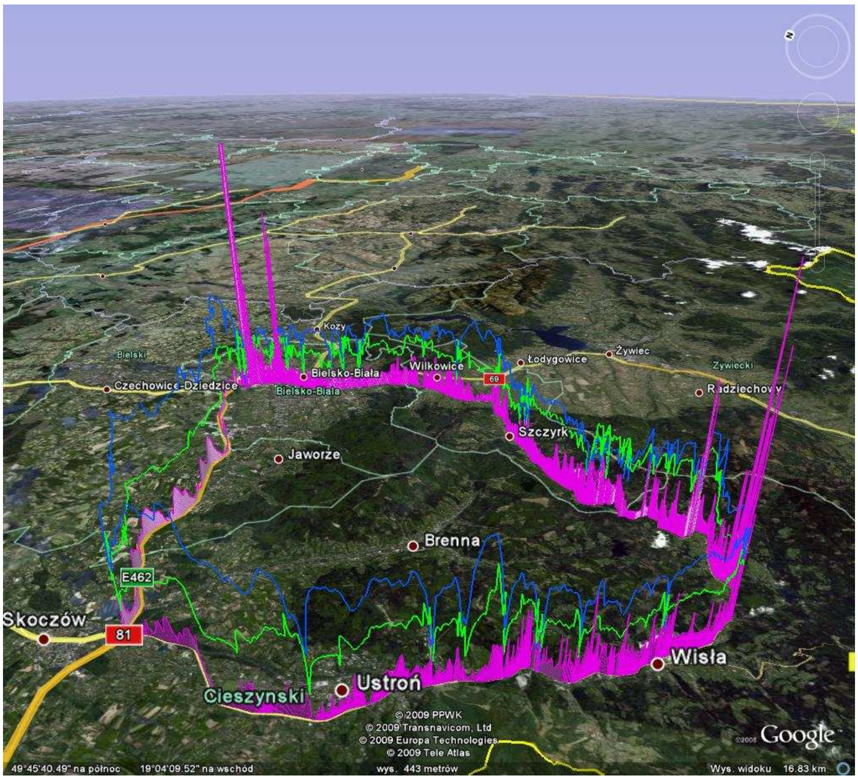

Fig. 4. Concentration of HC in the exhaust emissions under real road conditions; purple– HC, green – engine speed, blue – vehicle speed [created by www.GPSVisualizer.com]

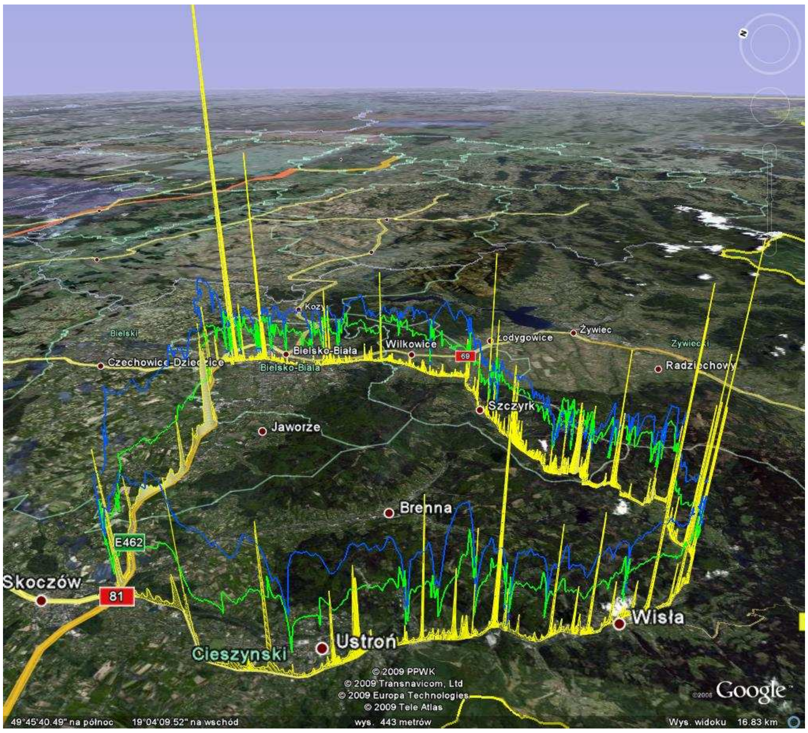

Fig. 5. Concentration of NO_x in the exhaust emissions under real road conditions; yellow – NO_x, green – engine speed, blue – vehicle speed [created by www.GPSVisualizer.com]

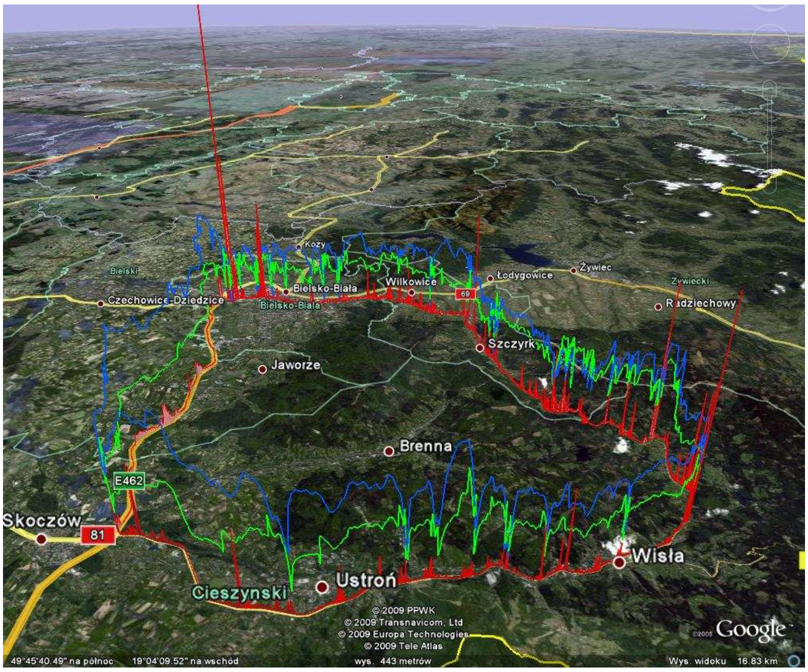

Fig. 6. Concentration of CO in the exhaust emissions under real road conditions; red – CO, green – engine speed, blue – vehicle speed [created by www.GPSVisualizer.com]

The data collected during the road tests were used to create characteristics showing the influence of the dynamic changes on the emissions. The parameters characterizing the dynamics of the vehicle were its speed and acceleration. Figure 7 shows the characteristics indicating the share of speeds and accelerations of the vehicle during the tests. From this characteristics it results that the most frequently used range of vehicle speeds is 10 to 24 m/s, and the acceleration from -0.2 to 1 m/s^2. The share of the engine operation at idle is also significant (vehicle stationary due to traffic conditions) and amounts to approximately 7%. Collectively the share of the said area and the operation at idle constitutes approximately 90% of the road test.

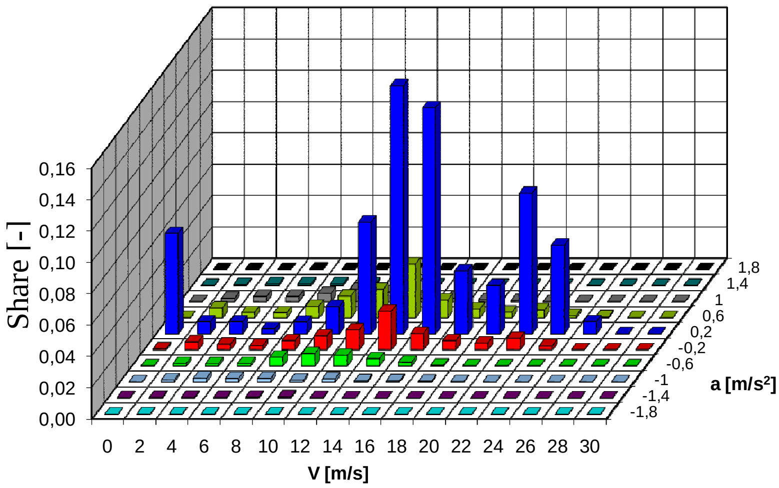

Fig. 7. Characteristics of the share of vehicle speeds and accelerations during the test

The distribution of the emission of CO and HC (expressed in mg/s) is very similar. The highest emissions were observed in the range of accelerations from -0.6 to 1,4 m/s^2 and the vehicle speed from 2 to 24 m/s (fig. 8 and 9). Characteristic is the fact that the emission of CO and HC clearly increases for higher vehicle accelerations. In the case of NO_x measurements two characteristic areas of higher emission have been observed (fig. 10). The first one occurs for the vehicle speed from 4 to 12 m/s and the acceleration from -0.6 to 1.8 m/s^2 and the second for the speed from 20 to 26 m/s and acceleration from -0.2 to 1 m/s^2.

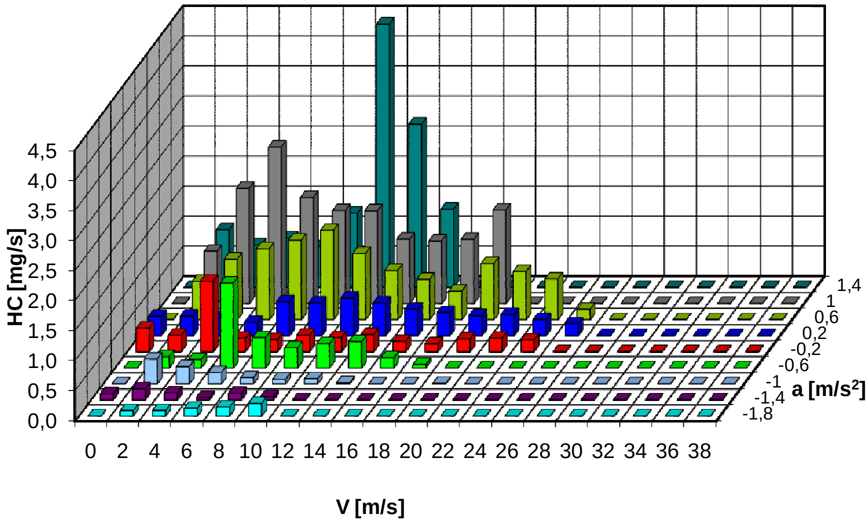

Fig. 8. The characteristics of HC emission in each speed and acceleration area under city traffic conditions

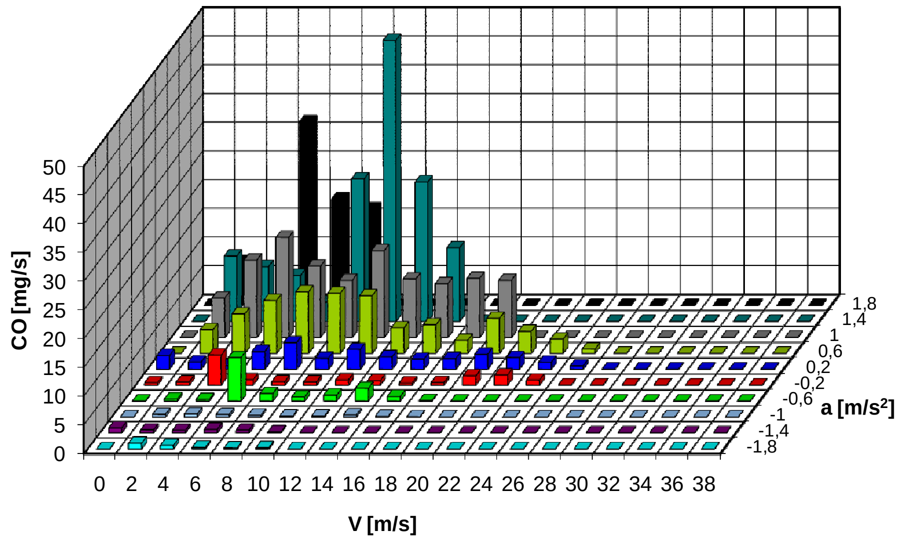

Fig. 9. The characteristics of CO emission in each speed and acceleration area under city traffic conditions

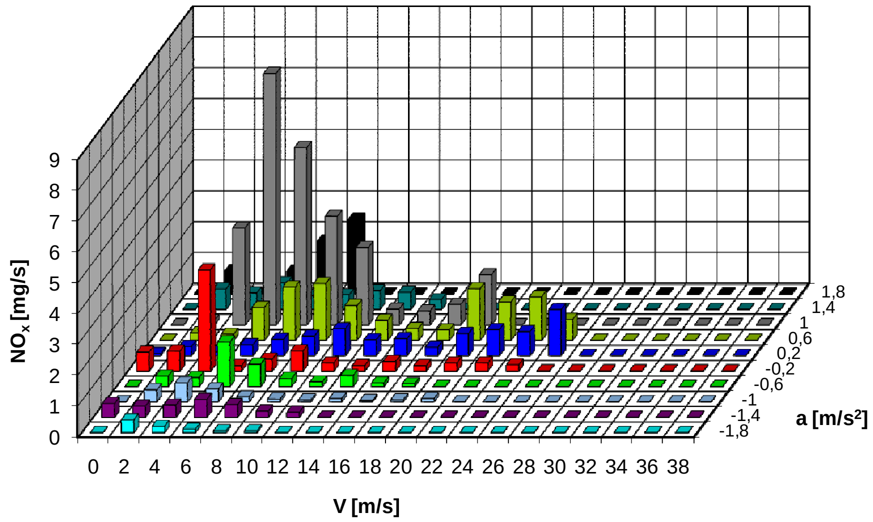

Fig. 10. The characteristics of NO_x emission in each speed and acceleration area under city traffic conditions

The graphic representation of the main areas where the highest (more than 3 times) emission of all the tested emissions was observed depending on the speed and acceleration of the vehicle has been shown in figure 11. The most frequently used speed and acceleration area has been shown there as well (constituting approximately 90% of the whole test). We can see that the area of the most frequently used vehicle speeds and accelerations partly overlaps with the area of highest emission CO, HC and NO_x.

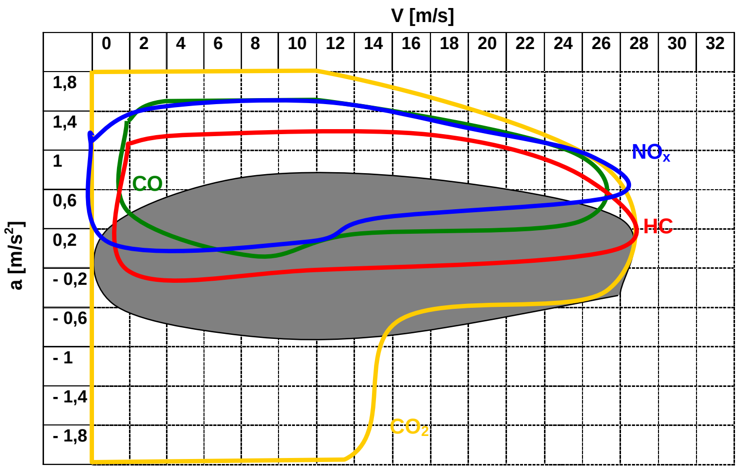

Fig. 11. The characteristics showing the areas of highest emissions on the map of vehicle speed and acceleration and the most frequently used area of vehicle speed and acceleration (gray area)

The comparison of the emissions in the whole road test has been shown in figure 12. The emissions under real road operation was clearly lower than the emissions recorded during the NEDC test with the exception of CO_2. The average emissions for the individual components in the NEDC tests is a result of three phases: warm up and cruise under urban and extra urban conditions. Hence, the analysis of these phases has been performed as well.

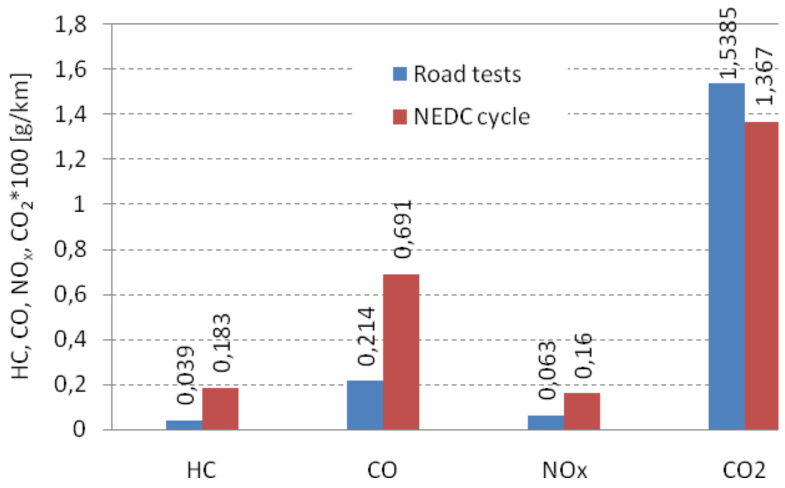

Fig. 12. The comparison of the emissions in the NEDC test

The results of the analysis of the city traffic emission tests have been shown in figure 13. It contains the results of the UDC cycle tests and two results of city traffic road tests. There were two variants of the road tests. The first variant of the road tests were the results of a road portion of duration extending for 400s, and the second 4.052 km. These variants were selected so that the city traffic road tests were similar in form to the UDC cycle which lasts 400s and has the length of 4.052 km (tab. 1). From this comparison it results that the emission of CO, HC and NO_x in the UDC test is higher than the emission obtained in the road tests but the emission of CO_2 (fuel consumption) is lower than in the UDC test. The smallest differences occur in the case of NO_x emission. The observed differences are significant even though the average cruising speeds of the cycles under comparison do not differ greatly (tab. 1). The obtained differences in the toxic emissions thus mainly result from the acceleration and velocity of the cruise in the individual cycles.

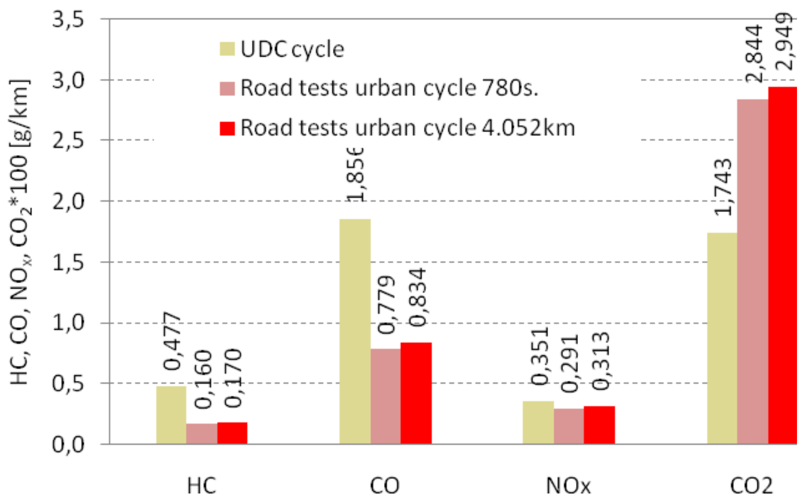

Fig. 13. The comparison of the toxic emissions in the city traffic cycles

A similar comparative analysis was done for the extra urban tests (fig. 14). The results of the emission EUDC tests were compared with the real road condition tests for two road variants - 400s and 6.955 km. Those variants were also selected to make the tests similar to the EUDC as it was done for the analysis of the urban cycles. In the road tests in the extra urban cycle the emission of CO, HC and CO_2 was higher than in the EUDC cycle but the emission of NO_x was lower. The smallest differences for the individual cycles were of the emission of NO_x (similarly to the urban tests) and HC. The road tests in the extra urban cycle were characterized by a higher average speed as opposed to EUDC (tab. 1), which definitely influenced the obtained results. Yet, a stronger influence on the results is credited to the dynamic parameters of the cruise.

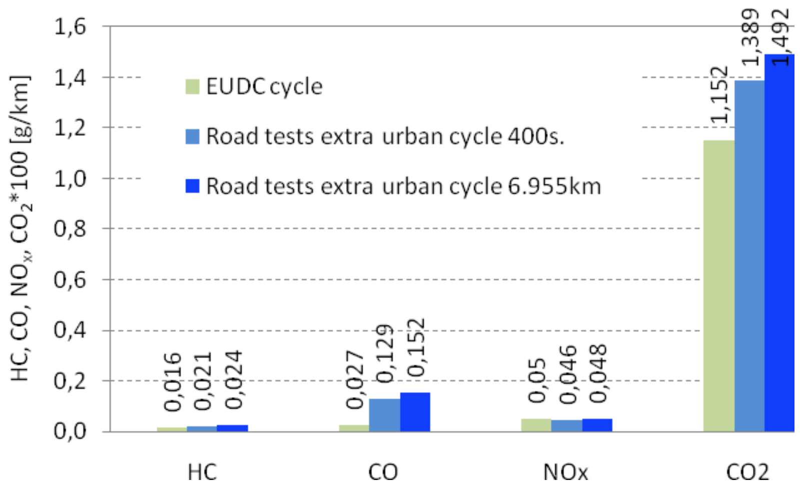

Fig. 14. The comparison of the emissions in the urban and extra urban cycles

CONCLUSIONS

The performed tests show differences between the exhaust emissions measured under real road operating conditions and the exhaust emissions measured under laboratory conditions in the NEDC cycle. These differences result from different vehicle cruising parameters (vehicle speed and acceleration) and, to a lesser extent, ambient conditions (temperature, humidity, wind). Within the last two decades changes in the traffic patterns in Europe have been observed. The amount of transported goods has grown rapidly leading to a higher congestion of the city roads. The vehicle cruising parameter patterns have also changed i.e. modern vehicles drive with higher speeds and accelerations. The here presented results may indicate that the real operating conditions of passenger vehicles in both urban and extra urban cycles do not fully correspond with those specified in the NEDC test. To that end, the authors suggest initiating a discussion whether the currently applicable test should undergo a modernization, for example through an addition of a supplement (following the American FTP75) reflecting the conditions that have not been not specified in the NEDC. Further investigations into the subject are necessary (incorporating traffic conditions of many cities and countries in both Europe and the U.S.) in order to fully resolve the issue.

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ABBREVIATIONS

CLD – Chemiluminescent Detector
CVS – Constant Volum System
CFS – Constant Flow System
EUDC – Extra Urban Drive Cycle
FID – Flame Ionization Detector (HFID – Heated FID)
FTP75 – Federal Test Procedure
GPS – Global Position System
LAN – Local Area Network
LDV – Light Duty Vehicle
NEDC – New European Drive Cycle
NDIR – Non Dispersive Infra Read
NDUV – Non-Dispersive Ultra-Violet
OBD – On Board Diagnostic
UDC – Urban Drive Cycle

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