STUDY OF EMISSIONS DURING ROAD TEST USING ON-BOARD MEASURING METHOD FOR LIGHT DUTY DIESEL VEHICLES

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ABSTRACT

The paper presents the results of exhaust emission tests of diesel vehicles fitted with diesel particulate filters under real road conditions. The tests were carried out in portions of about a dozen kilometers in length under city traffic conditions. The SEMTECH portable analyzer from SENSORS was used to measure the exhaust emissions. The measurements of particulates matter emission used particle counter and mass spectrometer. The above results were used for defining the vehicle emissions rate which can be used for the classification of car fleets, that differ among one another in the date of manufacture hence the exhaust emissions requirements.

Keywords: exhaust emission, road tests, Diesel engines, Diesel particulate filters

1. INTRODUCTION

These days one can observe a strong trend to deal with environmental perils from the automotive industry in global terms. The regulations that allow the operation of vehicles (homologation tests and production conformity tests), periodical technical check-ups and other laws directly and indirectly related to the production, operation and management of products of civilization treat the problem of environmental protection on a full scale [1]. Over the years in each country there were different systems of tests and vehicle exhaust emission control, however, for some time there has been a well-developed unification. A growing number of cars in the world and the pollution of the environment result in higher requirements as far as the emission of exhaust components is concerned. The present level of technical and technological advancement in all the branches of industry, including all types of transport, causes increased requirements for the production of tools for emission measurement. In order for these requirements to be fulfilled to the necessary extent according to the regulations which change from time to time, it was necessary for the industry to concentrate on this issue. The studies on the emission of exhaust components are a complex process. Contemporary emission analyzers require special laboratory conditions and the homologation procedures include engine and chassis dynamometer tests which do not reflect the real on-road emissions. The latest results of studies conducted under the real conditions show that in the case of some emission components certain emissions are higher by several hundred per cent. Thus, there is a trend to legislate the measurement of the emission under real operating conditions [2].

2. TESTING METHODS

The purpose of the research was to verify the emission characteristics of a vehicle with a diesel engine (meeting Euro 4 standard) under real traffic conditions. The research was at the same time an attempt at creating an on-board system for measuring of the exhaust emissions level. The determination of the emission characteristics in on-road conditions and comparing it with the results obtained on a test-bed in a type-approval test enabled determining of the emission factor. The emission factor obtained was used to answer the question whether the emission in on-road conditions is comparable with the emission obtained during a type-approval test. It is at the same time a verification of driving conditions in a type-approval test (developed several decades ago) and the real traffic conditions.

The measurement of the emission level was carried out in the road conditions in the city of Poznan (Fig. 1). The tests were conducted on the main roads of the city in the afternoon with a moderate traffic.

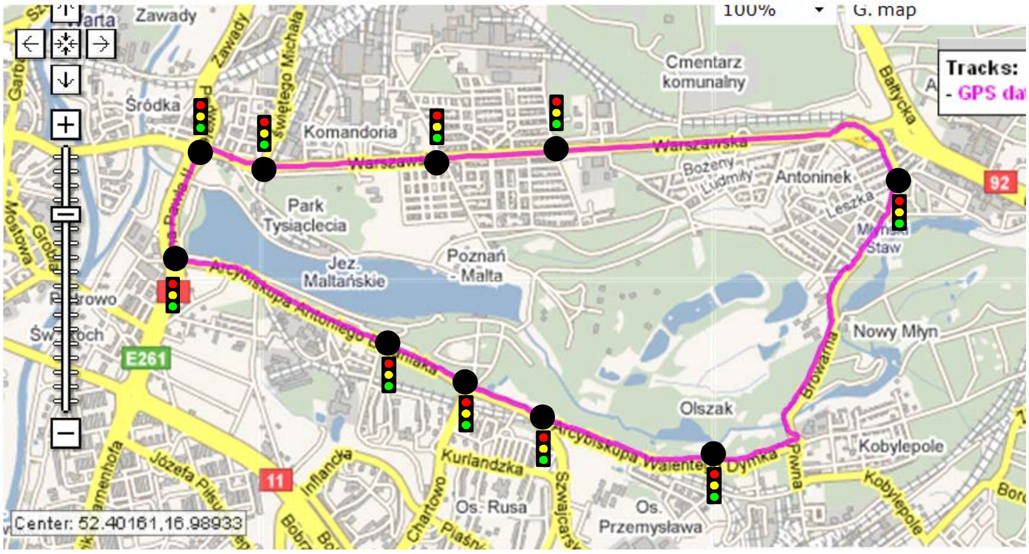

Figure 1. The route used to test the emission level of a vehicle (city of Poznan, Poland)
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The conditions were selected in such a way as to enable a comparison of the tests results with the NEDC homologation test (Fig. 2) – with reference to which the emission level indexes were introduced. The specified route was characterized by parameters similar to the NEDC test in terms of the road length, driving time and average speed value (Table 1). The tests measured the concentration of CO, HC, NOx and then with the use of GPS and diagnostic system data the road emissions were specified.

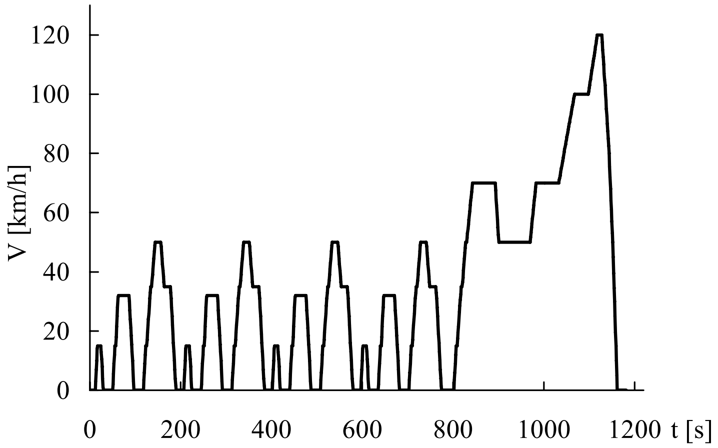

Figure 2. NEDC European homologation test for passenger vehicles [3]

Table 1. Characteristics of the test and comparison with the NEDC test

Test parameter	Diesel	NEDC
Total duration [s]	1110	1180
Max speed [km/h]	105	120
Average speed [km/h]	34.2	33.6
Length [m]	11,780	11,007

3. EXPERIMENTAL SET UP

Vehicle

The object of the tests was Chevrolet Captiva fitted with a 2.0 dm^3 diesel engine (European standard, Sulfur < 10 ppm); manual transmission, 4 cylinder, 110 kW@4000 rpm, torque: 320 Nm@2000 rpm, catalytic converter, diesel particulate filter, OBD II protocol CAN 2.0b, mileage: 10,000 km, vehicle weight: 1700 kg. The tested vehicle was homologated according to Euro 4 standard.

Measurement instruments

a) Portable gas analyzer – Semtech DS

In order to measure the concentration of the individual emissions a portable analyzer for emission testing - SEMTECH DS by SENSORS Inc. [4, 5] was used. The analyzer allowed the measurement of the concentration of the individual 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°C was then filtered out of particle matter and directed to the flame-ionizing detector (FID) where hydrocarbons concentration was measured. Then the exhaust gas was cooled down to the temperature of 4°C and the measurement of the concentration of NOx (NDUV analyzer), CO, CO_2 (NDIR analyzer) and O_2 followed in the listed order. It is possible to add data acquired directly from the vehicle diagnostic system to the central unit of the analyzer and make use of the GPS signal (Table 2).

Table 2. Characteristics of a portable exhaust analyzer SEMTECH DS

Parameter	Measurement method	Accuracy
1. Emission		
CO	NDIR, range 0–1000 ppm	±3%
HC	FID, range 0–10,000 ppm	±2%
NOx	NDUV, range 0–2500 ppm	±3%
CO2	NDIR, range 0–20%	±3%
O2	Electrochemical, range 0–25%	±1%
2. Data storage capacity	Over 10 hours at 1 Hz data acquisition rate	
3. Vehicle interface capacity	SAEJ1850 (PWM), SAEJ1979 (VPW), ISO 14230 (KWP-2000), ISO 15765 (CAN), ISO 11898 (CAN) SAEJ1587, SAEJ1939 (CAN)	

In the tests the measurements of exhaust emission were performed and, for comparison, signals such as engine speed, load, vehicle speed, engine temperature from an on-board diagnostic system were registered [6, 7]. Some of these signals served to specify the time density maps presenting the share of the operating time of a vehicle under the real operation. GPS signal was used for further visualization of the obtained data (Fig. 3 and 4).

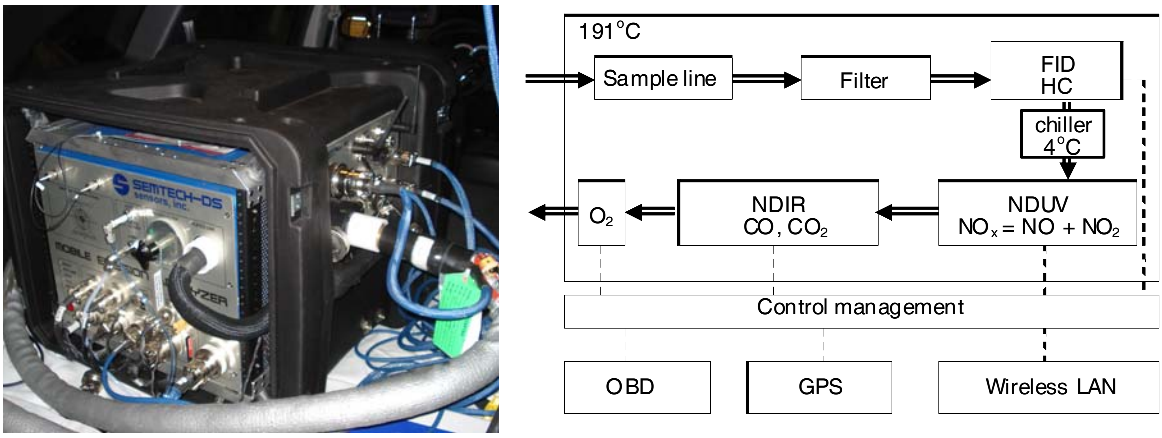

Figure 3. View and diagram of a portable analyzer SEMTECH DS; exhaust gas flow channels (===) and electrical connections circled (– – –)

Figure 4. View of SEMTECH DS analyzer fitted in a vehicle

b) AVL Particle Counter 489

Condensation particle counters (CPCs) accurately measure PN concentration of the exhaust emissions. It is a fact, the GRPE Particle Measurement Program (PMP) has recently completed the light-duty, inter-laboratory correlation exercise (LD ILCE) and concluded that PN measurements using a CPC plus thermodilution are 20 times more sensitive and much less variable than the traditional method (i.e., gravimetric filter analysis). As a result, the measurement of solid PN emissions has been proposed for Euro 5 Regulation 83. Proposed ECE Regulations 83 and 49 mandate that only the number concentrations of solid particles are measured. Therefore, nucleation mode particles (i.e. nanoparticles) formed by the condensation of volatile compounds found in the engine exhaust gases must be suppressed or eliminated. As a result, the proposed regulations specify a particle sampling and measurement system shown in Fig. 5.

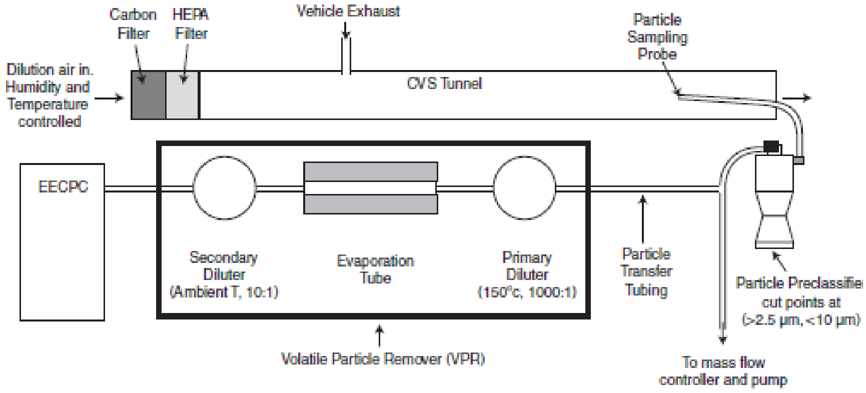

Figure 5. Proposed Regulation 83 Particle Sampling and Measurement System [8]

Exhaust gas is sampled from a CVS tunnel and diluted with HEPA filtered compressed air using the AVL Chopper Diluter. Inside the evaporation tube the diluted exhaust gas is heated to a degree that causes the volatile emission components to vaporize, leaving behind nothing other than solid particles. After that, the exhaust gas is diluted once again using a porous tube diluter and fed into the condensation particle counter (CPC). In the CPC, butanol is condensed on to the particles inside the exhaust gas to enlarge them so that they become visually detectable. The enlarged particles are then counted based on the scattered light pulses generated when the particles pass through the laser beam. This makes it possible to determine the number of particles per volume unit. The evaporation tube is a tube heated to a maximum temperature of 350°C using heating cartridges, in which the volatile particles from the primarily diluted exhaust gas are vaporized. The secondary diluter is a porous tube diluter with a dilution ratio that is determined by the flow rates through MFC1 and MFC2. The secondary diluter is immediately followed by a stabilization chamber from which the diluted exhaust gas is sampled for the CPC. The aerosol to be measured enters the CPC by the sample inlet. Inside the heated saturator, lined with a piece of wick soaked in butanol, the butanol vaporizes and in its vapor state mixes with the aerosol. In the cooled condenser, the butanol vapor is cooled down until it becomes supersaturated and ready to condense on the aerosol particles (heterogeneous condensation). This temperature is just slightly below the temperature at which homogeneous condensation (condensation without condensation nuclei) occurs. Butanol that condenses on the condenser walls is drained off either by a water remover or it flows back to the butanol-soaked pieces of wick when the water remover is turned off. The so enlarged particles enter the counting device via a nozzle. This nozzle consists of a laser diode, a focusing lens, a collecting lens and a photodetector. The laser beam is exactly focused on the point above the nozzle. Whenever a particle enters through the nozzle, the laser light is scattered and the scattered light is caught by the collecting lens and focused on the photodetector. The entire optics is kept at a higher temperature than the saturator in order to prevent the butanol from condensing on the lenses. In order to control the volume flow through the CPC, a critical orifice is used with the difference in pressure upstream and downstream of the orifice, the absolute pressure and the pressure downstream of the nozzle being measured and monitored in order to ensure correct flow through the CPC (Fig. 6) [9].

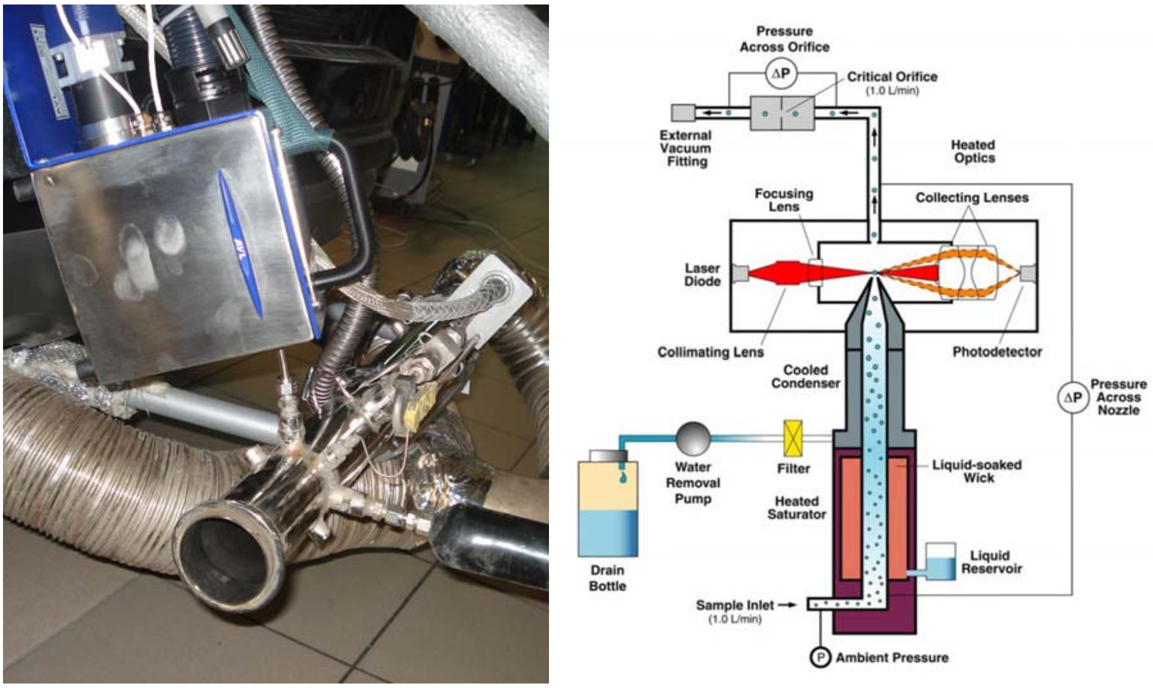

Figure 6. View and diagram of the condensation particle counter [9]

c) Engine Exhaust Particle Sizer TM Spectrometer (TSI 3090)

A schematic of the EEPS spectrometer is shown in Figure 7. Particles enter the instrument as part of the aerosol inlet flow through a cyclone with a 1 µm cut. Next, the particles pass through an electrical diffusion charger in which ions are generated. These mix with the particles and electrically charge them to provide a predictable charge level based on particle size. The charger is mounted inline with the analyzer column and located at the top of the instrument. Particles then enter the sizing region through an annular gap, where they meet a stream of particle free sheath air. The sizing region is formed by the space between two concentric cylinders. The outer cylinder is built from a stack of sensing electrode rings that are electrically insulated from each other. The electrodes are connected to a very sensitive charge amplifier, also called an electrometer, with an input near ground potential. The inner cylinder is connected to a positive high voltage supply, which forms the high voltage electrode. This creates an electric field between the two cylinders. While the positive charged particles stream with the sheath air from the top to the bottom of the sizing region, they are also repelled from the high voltage electrode and travel towards the sensing electrodes. Particles that land on the sensing electrodes transfer their charge. The generated current is amplified by the electrometers, digitized, and read by a microcontroller. The data are processed in real time to obtain 10 particle size distributions per second.

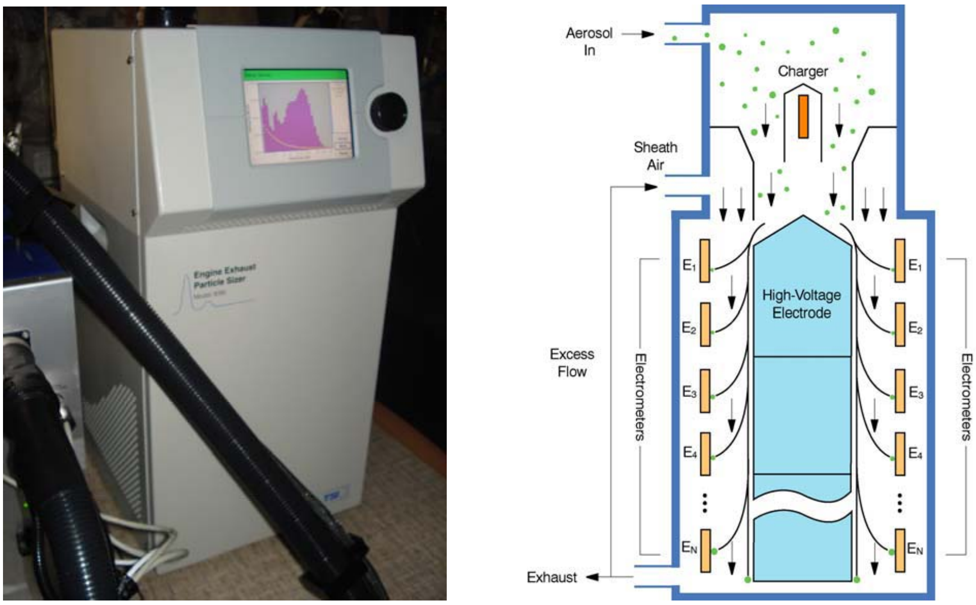

Figure 7. View and schematic diagram of the 3090 EEPS Spectrometer [10]

4. EXPERIMENTAL RESULTS AND ANALYSIS

The obtained data were used to specify dependence characteristics for the influence of dynamic engine properties on exhaust emissions. The dynamic engine properties were indirectly taken into account, using all the speed range and the range of acceleration calculated for city traffic to prepare a matrix of emission intensity. The data used were averaged within each speed and acceleration range, which generated characteristics of vehicle operation in each range (Fig. 8) and characteristics of emission matrices of exhaust. The greatest share of the engine operation in the studied traffic conditions was obtained for minimum and medium speed and zero vehicle acceleration.

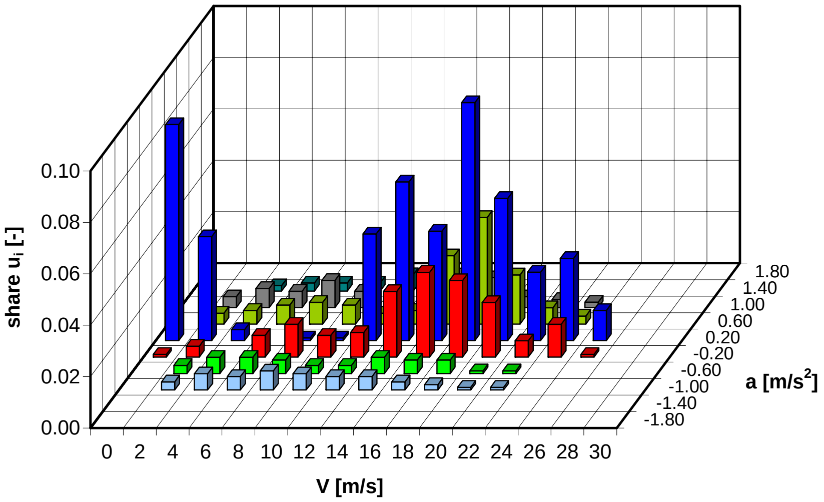

Figure 8. Characteristics of the use of the vehicle operation time in each speed and acceleration range under city traffic conditions

Maximum intensity of emission of carbon monoxide (Fig. 9) and hydrocarbons (Fig. 10) expressed in grams per second falls within the area of maximum vehicle speeds and accelerations within the range of 0.0 to 1.2 m/s^2 which are convergent for both exhaust components. The area of an increased emission of nitric oxides (Fig. 11) falls within the range of increased speeds of a vehicle and increased acceleration of a vehicle i.e. a considerable engine load.

The mass emission of particles (Fig. 12) is ambiguous – for minimum vehicle speed the emission amounts to 15 mg/m^3 and decreases along with the increase of vehicle speed (5–10 µg/m^3), and then for high speed values (above 20 m/s) it increases to 15-20 µg/m^3 again. The measurements of particle quantity showed a different distribution than particle mass.

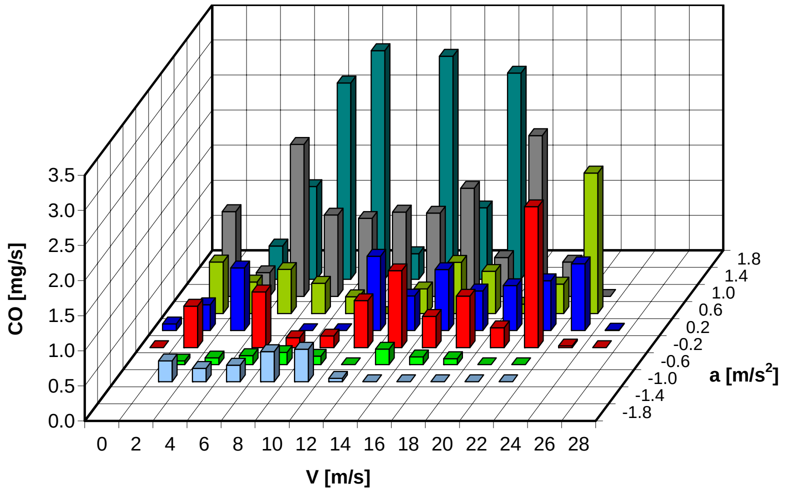

Figure 9. CO emission in each speed and acceleration range under city traffic conditions

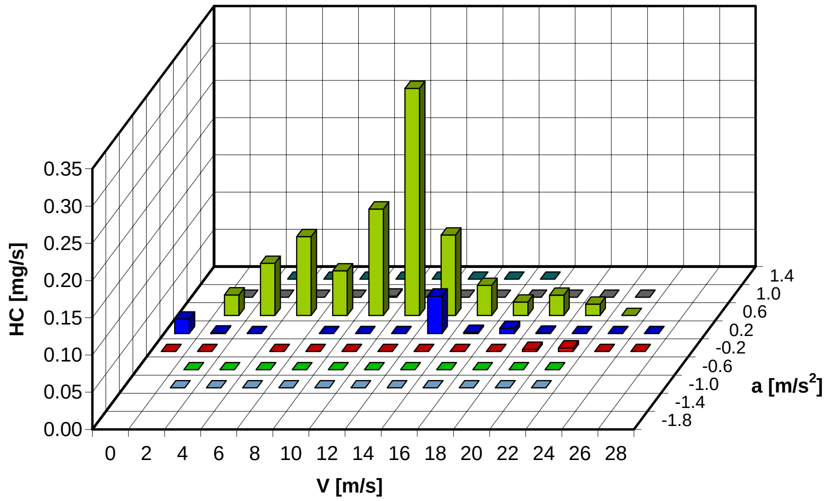

Figure 10. HC emission in each speed and acceleration range under city traffic conditions

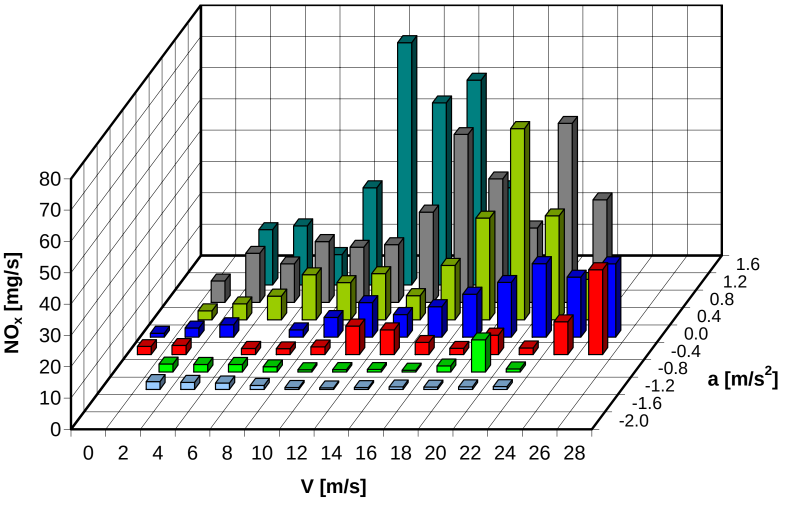

Figure 11. NOx emission in each speed and acceleration range under city traffic conditions

The highest quantity of particles (Fig. 12 and 13) was generated in the vehicle operating conditions of rather low driving speed (2–6 m/s) and average acceleration (0–1 m/s^2) and with the increasing speed the quantity of particles was decreasing. Such distribution of particle mass and quantity is characteristic of vehicles fitted with diesel particulate filter that can be subject to periodic regeneration. In the tests conducted over the specific road section partial regeneration was not activated. It resulted mainly from the short distance covered by the vehicle as well as from the high performance of the diesel particulate filter. Too low the temperature of exhaust gases (in the exhaust gas measurement point it did not exceed 250°C) was the reason of the lack of diesel particulate filter regeneration.

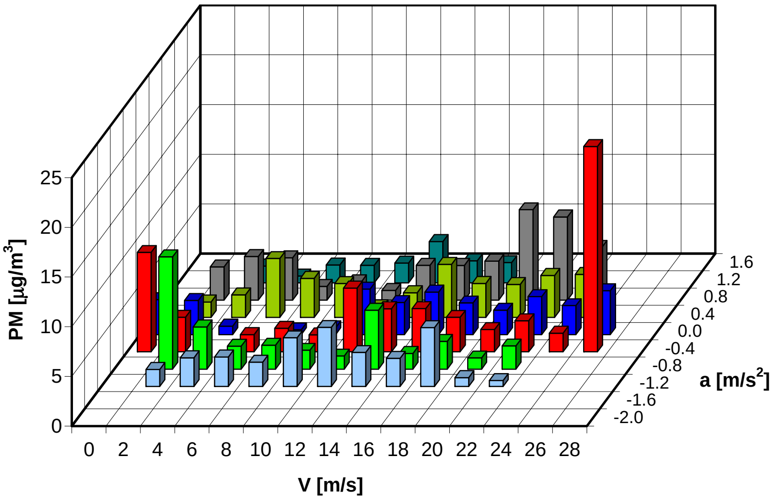

Figure 12. Particle mass emission in each speed and acceleration range under city traffic conditions

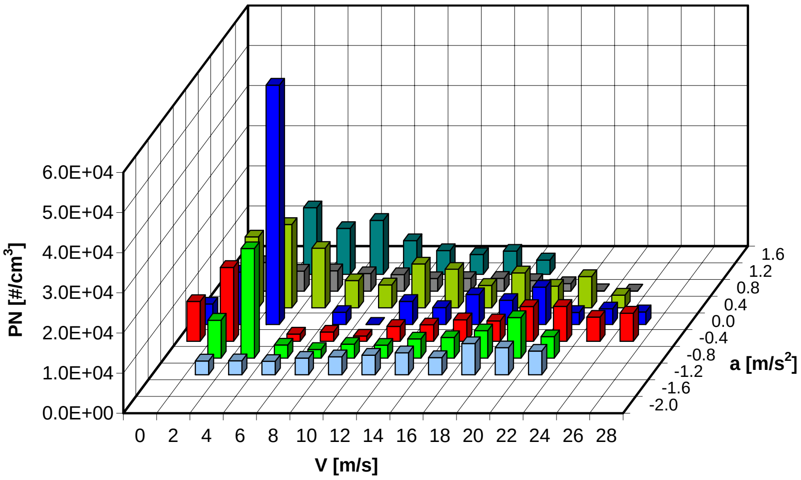

Figure 13. Particle number emission in each speed and acceleration range under city traffic conditions

The obtained results of a vehicle driving time in the conditions determined by its speed, acceleration and intensity of exhaust emissions in the European homologation test (NEDC). This comparison was used subsequently to specify the value of the emission increase from a vehicle under real conditions in relation with the conditions of a vehicle operation in the homologation test (Fig. 14).

Having compared the participation of driving time of a vehicle within the areas of vehicle speed and acceleration in the road and homologation test a similarity of both of the obtained characteristics can be observed. Compatibility of the compared characteristics for a breakdown of the occurrence of the vehicle driving time share has been maintained. In the NEDC test the share of a vehicle drive at minimum speed and zero acceleration is bigger. However, for real conditions the area of the used speeds and acceleration of a vehicle is bigger. However, the relative comparison of the values reveals the discrepancies reaching the values above 100% for the same ranges of vehicle speed and acceleration.

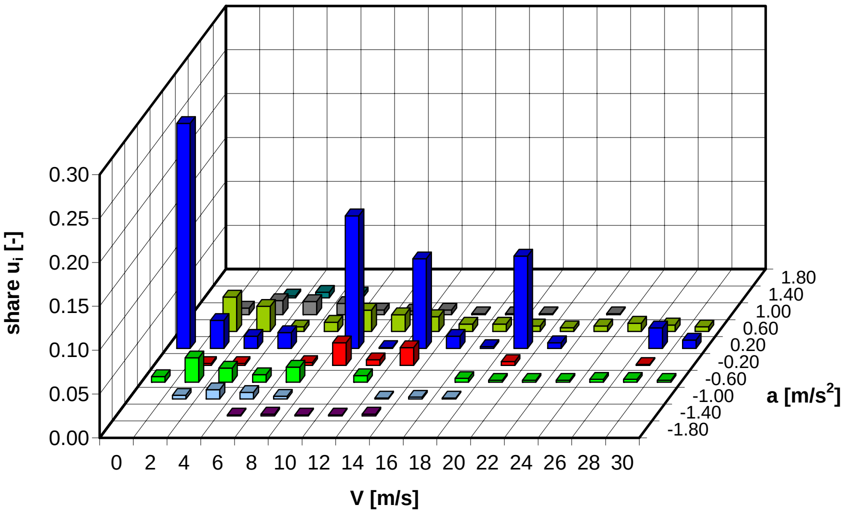

Figure 14. Characteristics of the use of vehicle operating time in each range of speed and acceleration for the conditions of the NEDC test

5. QUANTITY INDEXES OF EMISSION LEVEL

With the use of values of the collective emission of the exhaust components and the values recorded from the GPS system the road length during the test was determined and then the average road emission was specified for each exhaust emission (Fig. 15). The remaining road emission values exceed these values. That means a higher road emission of a vehicle during operation than during a homologation test.

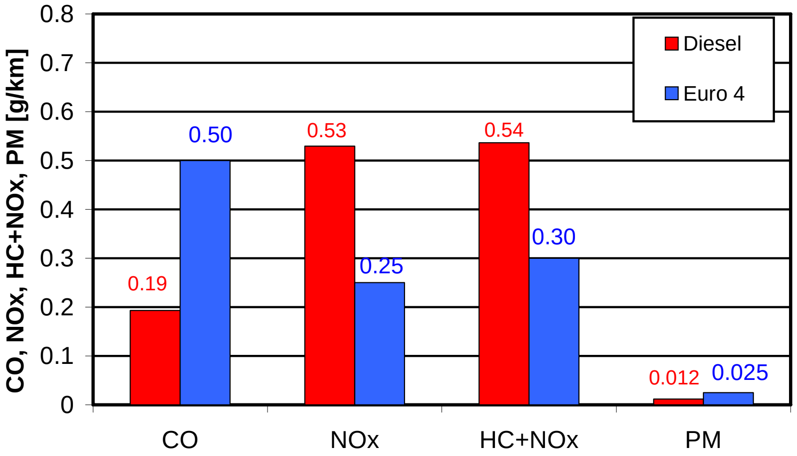

Figure 15. A comparison of road emission values and Euro 4 standard (PM approx.)

Based on the presented information, e.g. the characteristics of share of a vehicle operating time in each section of speed and acceleration and the characteristics of emission intensity, a multiplication factor of the emission increase (or decrease) under the real traffic conditions can be calculated in relation to the homologation test. The index of a vehicle emission level (for a given exhaust component) was defined as follows:

$$k_j = \frac{E_{road,\,j}}{E_{NEDC,j}}, \qquad (1)$$

where:

j – exhaust compound for which emission level index was set forth,

$E_{road,j}$ – emission intensity obtained under the real conditions ([g/s] or [g/km]),

$E_{NEDC,j}$ – emission intensity obtained in the NEDC test ([g/s] or [g/km]) (emission limits: [8, 11]).

The emission intensity under the real conditions can be calculated through the characteristics of a vehicle driving time breakdown ($u_{a,V}$) and the characteristics of emission intensity for j-th exhaust compound $e_{j(a,V)}$ expressed in grams per second:

$$E_{road,j} = \sum_a \sum_V \left(u_{a,V} \cdot e_{j(a,V)}\right). \qquad (2)$$

If the information concerning the exhaust emission in the NEDC test is missing, acceptable values according to the Euro emission standard can be assumed binding for a specific vehicle. The acceptable emission values for a specific compound expressed in g/km can be recalculated for the emission intensity values (in g/s) if the duration and the distance covered in the homologation test are known. Such relations served to establish the emission level indexes for the exhaust components of a tested vehicle (Fig. 16).

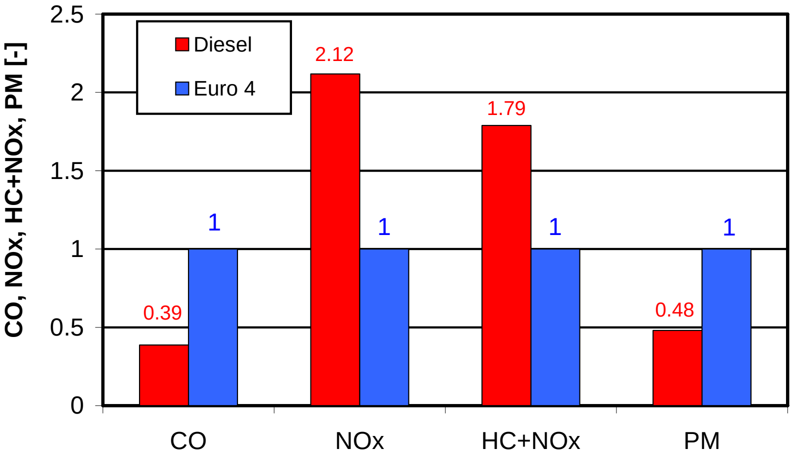

Fig. 16. Comparison of vehicle emission factor

CONCLUSION

The analysis of the data proves that the emission values obtained in the NEDC homologation test for a tested vehicle (in accordance with Euro 4 standard) and the values under real operation differ from each other. These differences in the case of some components are significant and amount to:

a) CO emission is 60% lower,

b) emission of nitric oxides is 120% higher,

c) emission of hydrocarbons and nitric oxides is 80% higher,

d) emission of particulate matter is 50% lower.

The obtained data enabled to define the vehicle emission factor that can be used to classify fleets of vehicles in relation to exhaust emissions that differ e.g. in production date (emission limits, vehicle mileage or operating conditions).

The results of the tests carried out under the real conditions show that in the case of some exhaust emissions this emission is several hundred per cent higher. Therefore, one can observe a trend to legislate the exhaust emission measurement under real operating conditions of vehicles in Europe.

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