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REAL DRIVING EMISSIONS – VEHICLE TESTS IN VARIABLE TERRAIN

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Abstract

This paper presents the results of tests conducted in real traffic conditions in a mountainous area, taking into account the natural topography characteristics. The tested vehicle was of SUV type (Sport Utility Vehicle) with gasoline and Diesel engine, complying with emission standard Euro 5. Using the portable system for measurement of harmful substances, measurements of pollution emissions were conducted. The results obtained confirmed the substantial changes in the emission of harmful components of exhaust fumes with the change of the road grade. In all considered cases, it was confirmed that with the increasing route grade, the road emissions of all harmful components of exhaust fumes increase, however this increase varies for different pollutants. The most sensitive for spark ignition engines is emission of particulate matter, which is associated mainly with the compression ignition engines.

For small changes of the road grade, the most sensitive seems to be road emission of carbon monoxide, for gasoline engines emission of particulate matter is specific, first, to all diesel engines, increase of the road grade to 10% caused on average twofold increase in the emission of harmful components of exhaust gases.

Keywords: *combustion engine, exhaust emissions, vehicle testing, Real Driving Emissions*

1. Introduction

In the applied models of total exhaust emissions from transport, the emission rate is adopted based on maximum admissible values prescribed in an exhaust emission homologation standard. In such a scenario, the results obtained from the models are only estimates, whose applicability may be restricted. It is thus necessary to seek new possibilities to assess vehicle exhaust emissions such as real-driving measurements. The measurements are performed under vehicle actual operating conditions and they use the PEMS (Portable Emission Measurement System) equipment [1-4]. The research carried out at Poznan University of Technology with the use of this method attempts to answer questions regarding the exhaust emissions, their variability and relation to the engine and vehicle operating parameters [5-7]. The paper presents several vehicles investigated for exhaust emissions under actual traffic conditions – RDE (Real Driving Emissions) [8-10].

The article estimates the emission of pollution in real traffic conditions, taking into account the influence of the selected elements of the road infrastructure (mainly the grade of the road), and comparing the results of the tests carried out in typical (flat) road conditions reflecting the type-approval tests. It was associated with the increasing speed of works over the change of the type-approval test for the passenger cars [11-13].

2. The aim and methodology of the research

The aim of the research was verification of the emission class of the vehicle of SUV category (Sport Utility Vehicle) with a spark ignition engine complying with Euro 5 standard, in real traffic conditions. Determining the emission class in real traffic conditions depending on the natural site topography and comparing it with normative values enabled determination of the index allowing the comparison of the emission of pollution in the conditions of diverse natural topography.

The measurements of road emissions were made in real traffic conditions (detailed characteristics – Tab. 1) on a flat route and in the mountainous area within the Silesia Voivodeship. Road profiles were diverse in terms of natural topography – the characteristics of the routes are given in Tab. 2.

Tab. 1. Characteristics of the research tests – flat route and mountainous route

Test parameters	Total time [s]	Maximum speed [km/h]	Average speed [km/h]	The route length [km]	The share of vehicle operating conditions		
					V = 0 [%]	V = const [%]	a > 0 [%]
Flat route	8724	110	61.47	131.29	32.59	23.79	32.95
Mountainous route	3732	73	44.14	45.76	35.49	24.24	40.13

Tab. 2. Test route characteristics in terms of natural site topography

Parameter	Height			Maximum grade	
	minimum [m]	average [m]	maximum [m]	increase [%]	reduction [%]
Flat route	228	275	356	5.9	–7.8
Mountainous route	439	637	930	28	25.2

3. Characteristics of the test routes

The selected test routes included different natural topography conditions so as to estimate the influence of the road surface inclination on the values of emissions of pollution in exhaust gases. Two routes varying in terms of average and local road grade were chosen in order to establish the change in pollution emissions for small and large values of the road grade. Grade (slope) of the road (or route incline) in the road or rail transport is defined as a difference in the height between two points of the road or railway related to the distance between these points.

Analysis of the flat route shows negligible changes in its height (Fig. 1), which also means insignificant changes in the road grade; the maximum difference amounted to 128 m. The mountainous route showed more variability of heights that is significant and the difference between the maximum and minimum height amounted to 491 m.

The characteristic of variability of the route was conducted by comparing the share of the negative and positive grade along the completely measured route. The characteristics were obtained by putting the grade values in order from the smallest (negative grade) to the largest (positive grade) and by assigning each single grade the value of the share in the whole route (Fig. 2). Summary of both characteristics of the measuring routes reflects the share of the local grade in the completely measured route. At the same time, the analysis of the data form Fig. 5 allows to determine whether negative or positive grade prevailed along the route. From the presented distribution of the grade for different test routes ensued that it was necessary to select different ranges of variability of the considered road grade for the test runs along the flat and mountainous route. For the flat route the variability of the grade ranged from –6% to 6%, and the range from –2% to 2% prevailed for 80 percent of the test duration time. Different conditions were observed in the mountainous areas: the range of variability from -2% to 2% prevailed for 30% of the test duration time, while the route grade higher than 2% (or smaller than -2%) occurred during 70% of the test duration time.

The tested vehicle was of SUV type (Sport Utility Vehicle) with automatic gearbox, equipped with gasoline engines (engine displacement of 3.6 dm^3 and the power of 206 kW) and Diesel engine (engine displacement of 2.0 dm^3 and the power of 125 kW). The vehicle used for tests complied with the Euro 5 emission standard.

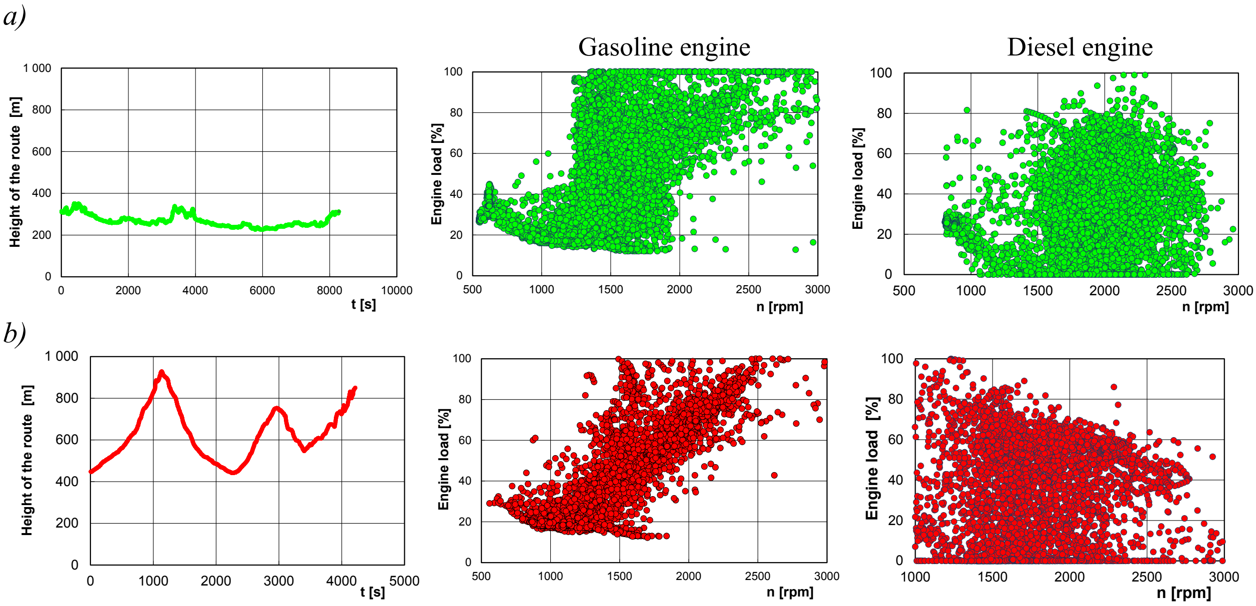

Fig. 1. Changes in the height of the route in: a) flat area, b) mountainous area

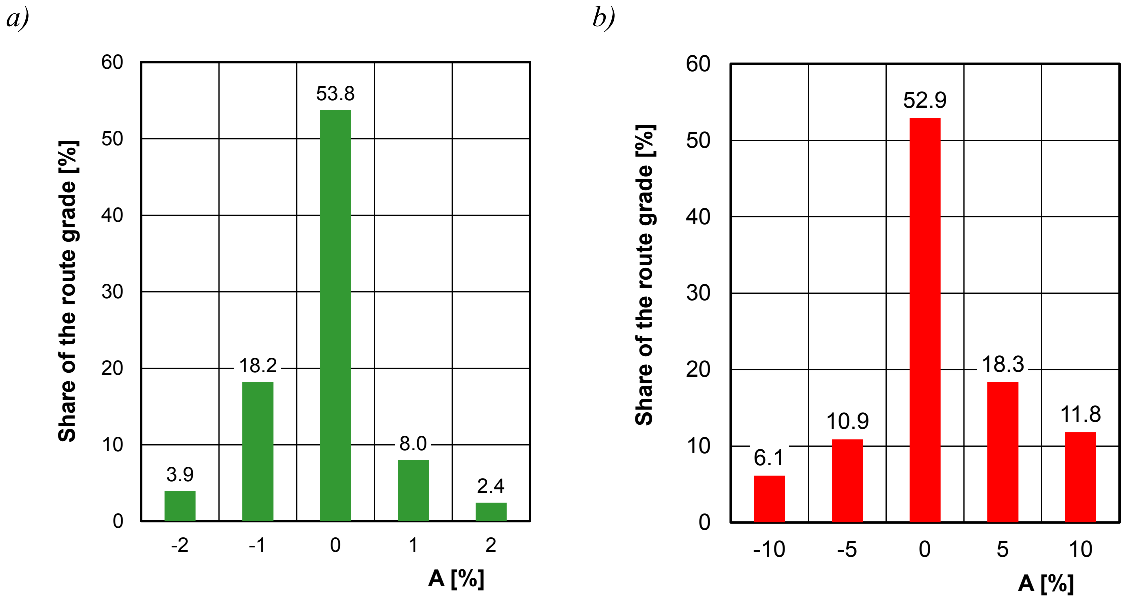

Fig. 2. Comparison of the share of the route grade: a) flat area, b) mountainous area

4. The obtained measurement results

Using the portable system for measurement of harmful substances, the emissions of carbon monoxide, hydrocarbons, nitrogen oxides, carbon dioxide and particulate matter in terms of its number and mass were conducted. In addition, among other things, engine speeds and loads were recorded – parameters read out from the on-board diagnostic system of the vehicle [14]. Recording the geographical localisation of the vehicle (with the use of a GPS) enabled visualisation of the test runs and determination of the route length. Data was recorded during the test run along the flat route, where the largest engine operational area for average loads and small engine speeds was obtained (Fig. 3a). In the mountainous area the situation was quite different: the largest operational area of the engine does not cover the driving conditions in the flat area – and it is determined by the line between the points describing the engine speed and engine load of: 1000 rpm and 20% and 2500 rpm and 100% respectively (Fig. 3b).

a) b)

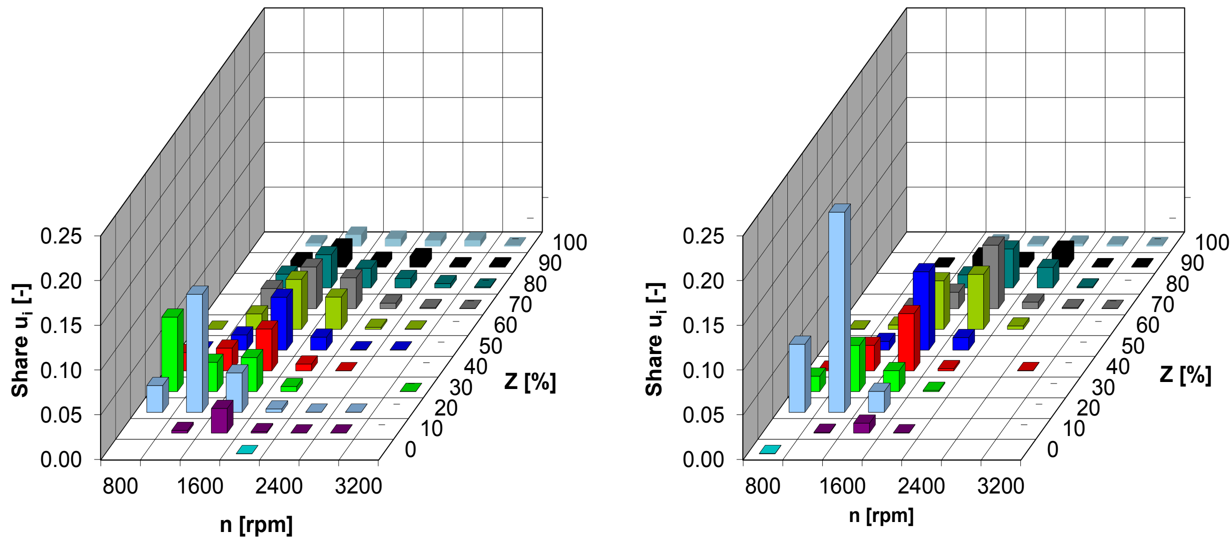

Fig. 3. Engine operational conditions against coordinates' engine speed-engine load during the road tests: a) flat route, b) mountainous area

The concentration of the carbon monoxide on the part of the flat route amounted to approximately 0.02% (for significant part of the route it was below this value, which means that it did not exceed 200 ppm – Fig. 4a (left)). Singular, dynamic engine operation conditions resulted in sudden increase of the concentration, due to which the concentration of emission of CO amounted to 40 mg/s. At the same time, the concentration of the carbon monoxide in the mountainous area amounted to approximately 0.01% (for significant part of the route it was below this value, which means that it did not exceed 100 ppm – Fig. 4a (right)). The change in the engine operation conditions resulted in a sudden increase of the concentration that, in consequence, caused an increase of CO emission concentration of up to 40 mg/s.

The concentration of hydrocarbons during the tests did not exceed 10-15 ppm (flat route – Fig. 4b, left) and 30 ppm in the mountainous area (Fig. 4b, right). Particular road conditions required constant increase of the fuel dose, which resulted in increased concentration of hydrocarbons. The values of emission rate of the discussed exhaust gas component, excluding initial and final phase, did not exceed the 2 mg/s (in the flat area), and in the mountainous area values amounting to 4-5 mg/s were observed.

In addition, concentration of the third gaseous component – nitrogen oxides – across the whole test along the flat route was very low. The obtained very small values of this component were the result of operation of a very efficient three-way catalytic converter (Fig. hc, left). The rate of emission of nitrogen oxides during whole test was minimal and did not exceed 1-2 mg/s. The dispersion of this value ensued from normal operation of the engine and no situations were observed, where the emission rate would significantly exceed the recorded values. In the mountainous area, the concentration of nitrogen oxides amounted to approximately 40 ppm (Fig. 4c, right). The rate of emission of nitrogen oxides during whole test was minimal and did not exceed 0.1-0.5 mg/s.

In case of particle concentration during the test along the flat route, given in milligrams per cubic meter, values ranging from 0.3 mg/m^3 were observed – for the initial part of vehicle operation, and then the concentration decreased – to the value of 0.2 mg/m^3 (Fig. 4d, left). The nature of the changes in emission rate for particulate matter was consistent with the changes in their concentration and only slightly exceeded the value of 0.1 mg/s, while usually it did not exceed 0.02 mg/s. Observing the recorded measurement of the particulate matter, it can be concluded that the obtained values changed in particular stages. In case of the test run along the mountainous route, in the initial phase the value of particulate concentration oscillated around 0.15 mg/m^3 with rising trend (Fig. 4d, right). In the next stage, the values of particle concentration rapidly decreased and kept at the minimum level. The last phase of the measurement was characterised by significant increase of the concentration, and despite certain variations, it can be defined as the phase of the highest concentration. The nature of the changes in emission rate for particulate matter was consistent with the changes in their concentration and only slightly exceeded the value of 0.1 mg/s.

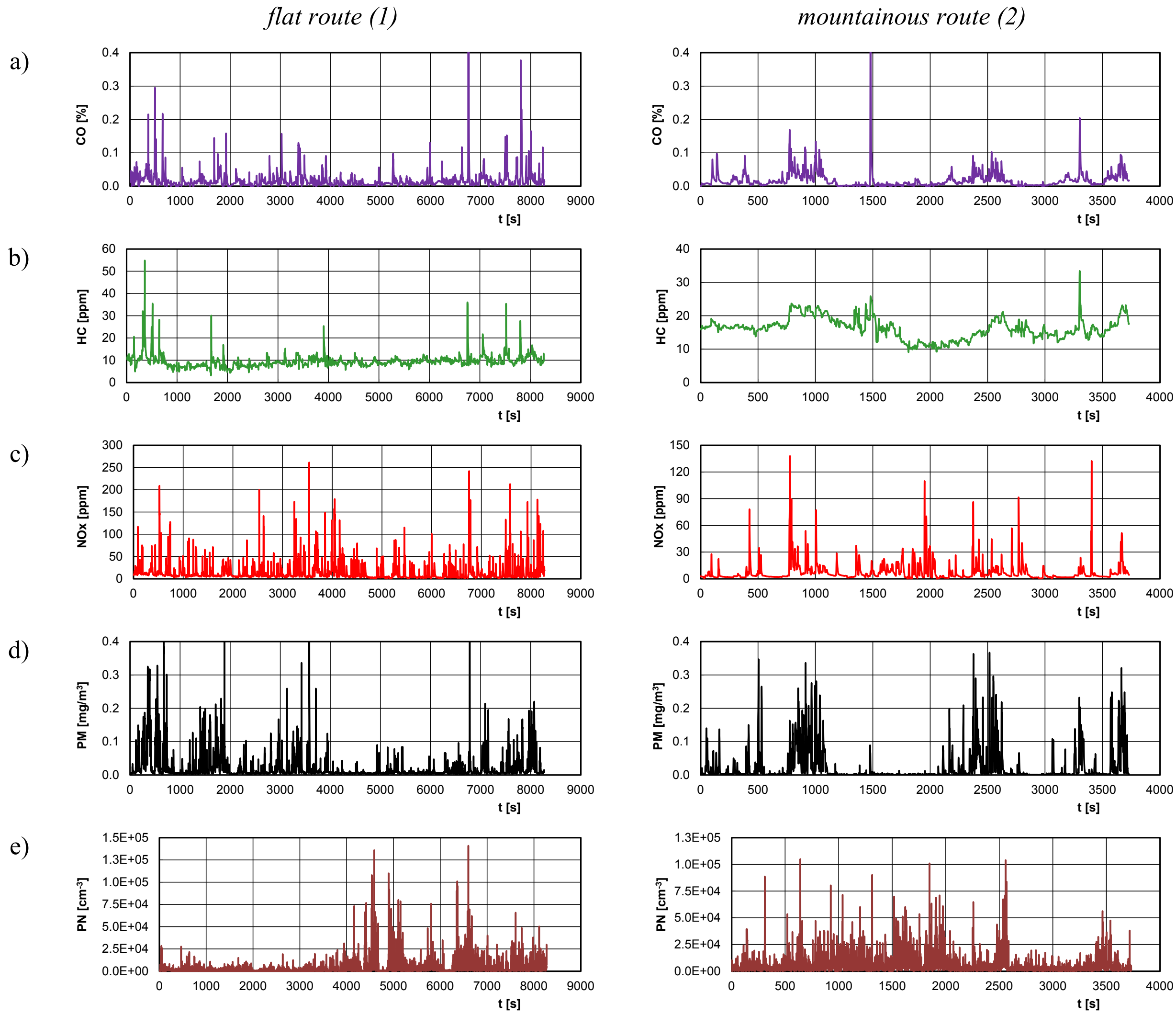

Fig. 4. Concentration while driving along flat route and mountainous route: a) carbon monoxide, b) hydrocarbons, c) nitrogen oxide, d) particulate mass, e) particulate number (gasoline engine)

During the test run along the flat route the nature of changes in the particle number was different from the nature of changes of particulate mass: in the initial phases of the test big particles in relatively small number were created, while in the second part of the route smaller particles were created (thus their number was bigger – Fig. 4e (left)) with definitely smaller mass. In case of the mountainous route – in the initial phases of the test big particles in relatively small number were created, while in the second part of the route smaller particles were created (thus their number was bigger – Fig. 4e (right)) with definitely smaller mass. Records of the rate of the particulate matter allowed assessment of their total number during the test run.

5. Emission factors

According to earlier articles concerning the determination of vehicle emission factors, the authors of this article propose the determination of emission factors for vehicles tested in varied terrain. An emission factor for a harmful compound can be defined as follows:

$$k_j = \frac{E_{real,j}}{E_{norm,j}}, \tag{1}$$

where:

j – harmful compound, for which an emission factor has been specified,

$E_{real,j}$ – emission of the chosen pollutant obtained in real driving conditions [g/km],

$E_{norm,j}$ – road emissions according to the exhaust emission standards [g/km] (based on [9]).

The obtained values of the emission factors for a vehicle fitted with a petrol engine in both flat and mountainous terrain for toxic compounds (CO, HC, NO_x, PM and PN) does not exceed the value of 1 (Fig. 4 and 5), while the average vehicle emission limit of carbon dioxide is exceeded, for vehicles in 2015 it is set as 130 g/km (although it is not subject to emission restrictions).

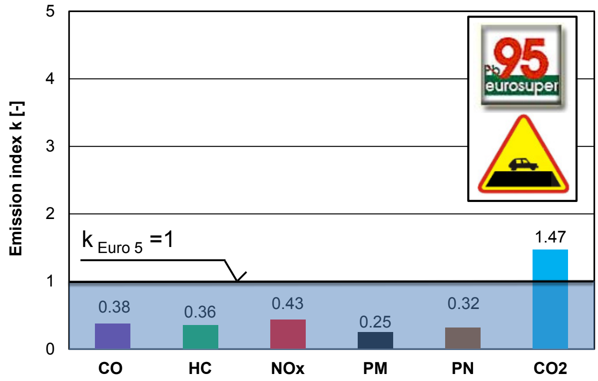

Fig. 5. Values of emission factors for a vehicle fitted with a petrol engine in Euro 5 emission class obtained in emission tests in flat terrain

The values of emission factors determined in tests carried out in the mountainous terrain on a vehicle fitted with a petrol engine are higher than their equivalents in the flat terrain tests for the following compounds: carbon monoxide, hydrocarbons and particulate matter number, which increased by 5%, 114%, and 106% respectively. The value of emission of nitrogen oxides has been slightly reduced, and its cause may be the higher exhaust gas temperature caused by increased strain on the engine, and consequently, a greater efficiency of the catalytic converter. The fuel consumption in mountainous terrain also increased, and was 30% higher with respect to the consumption in flat terrain.

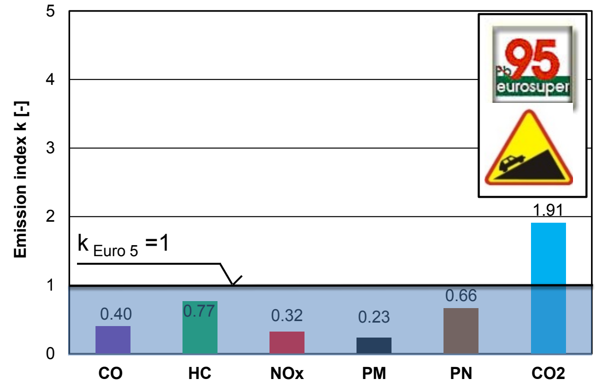

Fig. 6. Values of emission factors for a vehicle fitted with a petrol engine in Euro 5 emission class obtained in emission tests in mountainous terrain

Emission factors determined for a vehicle fitted with a diesel engine are different in nature. Significant excess in emission values in relation to the values specified by Euro 5 emission standards was found for hydrocarbons and nitrogen oxides. In flat terrain excess emission of hydrocarbons was more than 3-fold, and nitrogen oxides – more than 8-fold of the emission limit (Fig. 7). Even higher excess emission was found for tests performed in mountainous terrain, in relation to standards the emission of hydrocarbons was more than 5 times, and the emission of nitrogen oxides over 12 times that of the emission limit. The analysis of the data shows that the emission values obtained in real driving conditions are not exceeded for vehicles with gasoline engines, while for diesel engines road emission is exceeded for hydrocarbons and nitrogen oxides.

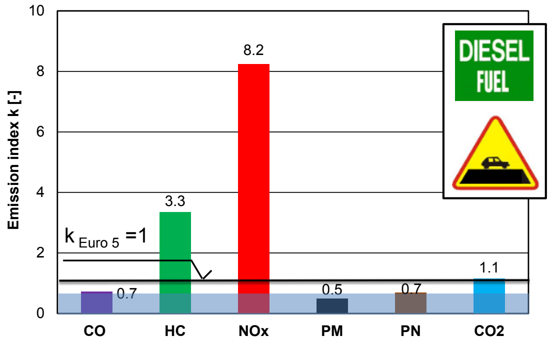

Fig. 7. Values of emission factors for a vehicle fitted with a diesel engine in Euro 5 emission class obtained in emission tests in flat terrain

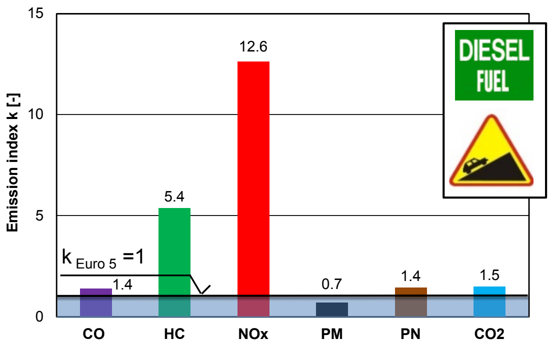

Fig. 8. Values of emission factors for a vehicle fitted with a diesel engine in Euro 5 emission class obtained in emission tests in mountainous terrain

6. Analysis of the obtained test results

In order to analyse the influence of the route grade on the increase of emission of pollution the whole route was divided into sections with specific values of the grade, for which were assigned values of pollution emission. For each section of the flat route grade (–2%, –1%, 0%, 1%, 2%) and mountainous route grade (–10%, –5%, 0%, 5%, 10%) values of the average road emission of every harmful component of the exhaust gases were determined. Then the values of road emissions of pollution for specific values of route grade were compared and the functional relations (of linear nature) were determined, indicating the value of road emission of pollution in relation to the route grade (Fig. 9).

In all considered cases, the same nature of dependencies was obtained: with the increasing route grade the road emissions of all harmful components of exhaust fumes increase, however this increase varies for different pollutants. Comparison of the relative values of coefficients of the obtained dependencies indicates multiplicity of changes of road emissions with the change of the road grade (the reference value defined for the road grade equal to zero). Fig. 11 shows the characteristics of emission changes of particular exhaust emission depending on the road grade for mountainous route.

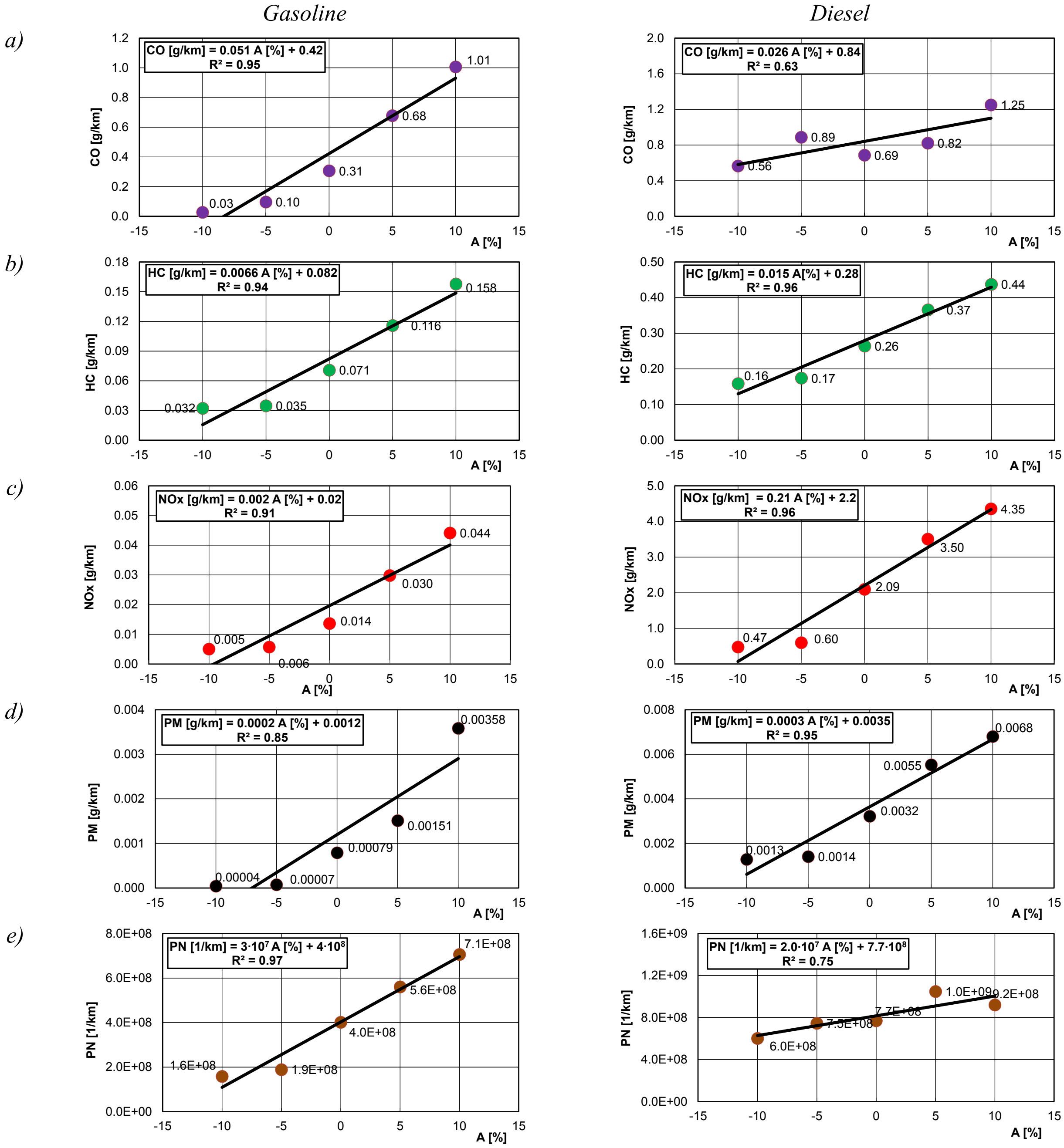

Fig. 9. The relation between the average road emission and the route grade for: a) carbon monoxide, b) hydrocarbons, c) nitrogen oxide, d) particle mass, e) particle number

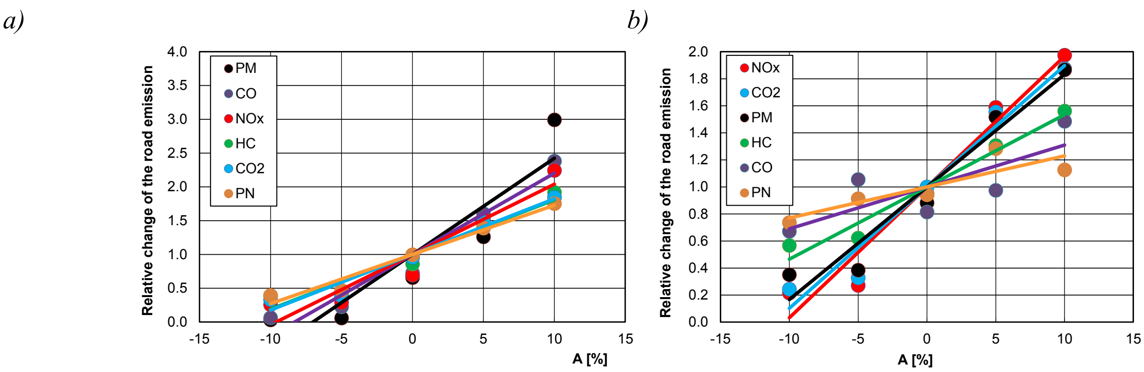

Fig. 10. Relative change of the road emission of pollution with the change of the route grade for vehicle with gasoline (a) and Diesel engine (b)

7. Conclusions

Comparison of the relative changes of road emissions depending on the road grade shows that for small changes of the road grade the most sensitive seems to be road emission of carbon monoxide. Taking into account bigger grades, it turns out that the most sensitive for gasoline engines is emission of particulate matter, which is specific, first, to all diesel engines. Studies carried out indicate that the increase of the road grade to 10% caused on average twofold increase in the emission of harmful components of exhaust gases. The obtained results confirmed significant effect of the diversified topography on the emission tests. This influence turned out to be significant enough to justify the need of including in the type-approval tests the coefficients correcting the road emission of pollutions in relation to the site topography.

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