Comparison of Real Driving Emissions tests

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Abstract. The article presents the issues concerning the specific distance emission test results comparison of the exhaust gases from vehicles with Diesel engines. The tests in real driving conditions included: (in the first stage) the test on the proposed test route, based on the type approval test parameters and (in the second stage) testing in accordance with the European Union guidelines, where the research route was divided into urban, rural and motorway sections. The obtained results – in various test conditions – were used to compare the measured values of specific distance emissions, carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides and the particle number. Not performing the road conditions measurements of particulate mass is in line with the requirements of the RDE tests, in which the focus was placed mainly on the assessment of nitrogen oxides and the particle number. The performed tests allowed making a comparison between the specific distance emission test results of exhaust components and the values obtained in the type approval test. These tests were also used to verify the legitimacy of performing full RDE tests and validating the specific distance emission results obtained in the proposed tests.

1. Introduction

Internal combustion engines will continue to dominate as the main power source of means of transport [1]. It has been predicted that in 2050 they will be used in 74% of drive systems, including increasingly popular hybrid systems. Due to the dynamic development of electric propulsion and hybrid systems, carbon dioxide emissions are expected to be reduced by 90% [2].

Making changes to vehicle type approval testing procedures is also an attempt to drastically reduce the problem of exceeding the legal emission limit values. Previous vehicle laboratory tests did not provide adequate information on the actual operating conditions of the engines used. Adapting to the real world and responding to it was the intention behind the introduction of the European regulations 715/2007/EC [3] and 692/2008 [4]. The breakthrough occurred when the decision on the mandatory use of RDE tests, i.e. in real driving conditions, was made. The regulations include incentives for vehicle manufacturers, among others, to make changes to their companies and products as soon as they are introduced.

The degree of the RDE procedures development is already so advanced that from September 2017 (EU 427/2016 [5] and EU 646/2016 [6]), in addition to laboratory testing, the type approval process also includes a procedure for measuring the pollutant emissions during actual driving. The European Union regulation on the use of RDE testing is a response to the study revealing increased nitrogen oxides emissions from cars equipped with compression ignition engines, despite the fact that such vehicles comply with the acceptable standards in laboratory test conditions. According to the new rules, for all new approvals starting from 1.09.2017, and for new car model registrations from 1.09.2019, the nitrogen oxides emission measured in road conditions will not exceed 2.1 times the maximum laboratory test limit (Fig. 1) [7]. As a consequence, the main focus of the article is on the emission of nitrogen oxides from passenger cars powered by different types of internal combustion engines with variable displacement.

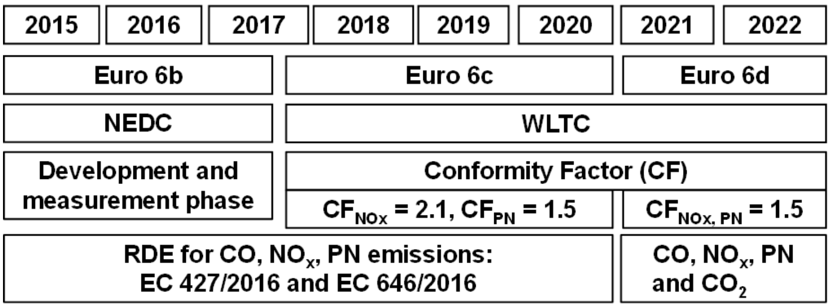


Figure 1. Requirements for type approval tests and real operating conditions for passenger vehicles in 2015-2022 [7]

2. Exhaust emission tests in real driving conditions

Recent research on pollutant emissions in real driving conditions performed using mobile devices [8, 13] reflects the state of ecological vehicles very accurately. Most attention is paid to the possibility of using such research to calibrate engines [10, 11], in such a way so as to limit emissions not only during the emission test [12, 13], but also over the whole engine operating range [14, 15]. Comparative laboratory testing conducted on chassis dynamometers [16] has revealed the compliance of vehicles, with gasoline and Diesel engines, with the exhaust emissions standards. However, tests carried out in real driving conditions have shown that vehicles with Diesel engines significantly exceed the nitrogen oxides emissions limits [17, 18]. Attention is drawn to the importance of particulate exhaust emissions, mainly in the form of nanoparticles emitted from internal combustion engines (gasoline engines with direct fuel injection, as well as Diesel engines equipped with a particulate filter (DPF)) [19, 20, 21]. The results of such studies are currently not presented independently, but have been confirmed by publications which encompass investigations spanning several years [22, 23] and comprehensive summaries of vehicles tested in real driving conditions [24-27].

3. Research aim

The tests in real driving conditions included: (in the first stage) the test on the proposed test route, based on the type approval test parameters and (in the second stage) testing in accordance with the European Union guidelines, where the research route was divided into urban, suburban and motorway sections. The obtained results – in various test conditions – were used to compare the obtained values of specific distance emissions, carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides and the particle number.

4. Research methodology

4.1. Road test research routes

4.1.1. Route 1

The first research route led through the main city streets, but in addition some roads with the velocity limit of 90 km/h were used; tests were carried out in the afternoon hours during moderate road congestion. The average velocity was comparable to the type approval test (NEDC). The test began with a hot engine start. The velocity is shown in Fig. 2. The detailed characteristics of the route are presented in Table 1, in which the data of the other test routes were also given.

4.1.2. Route 2
The second research route ran initially in the urban area (hot start), with the larger part of it being a rural route, with a velocity limit of 90 km/h. This route was characterized by a higher average velocity than route 1, reaching about 60 km/h. The maximum difference in elevation was about 60 m, and the length was about 60 km (detailed characteristics in Table 1).

4.1.3. Route 3
The third research route was chosen in accordance with the RDE requirements, and it was divided into three sections: urban, rural and motorway. The lengths and shares of individual sections were in line with the requirements specified in EU standards 2016/247 [5] and EU 2016/646 [6]. The test had about 80 km distance and the average velocity was about 45 km/h.

The difference in the research routes resulted mainly from the various shares of the urban, rural and motorway sections. The largest share of the urban part was on the route 1, on the route 2 the largest share was the rural part, and on the route 3 the share of these parts was similar to each other (Figure 2); detailed characteristics of test routes are given in Table 2.

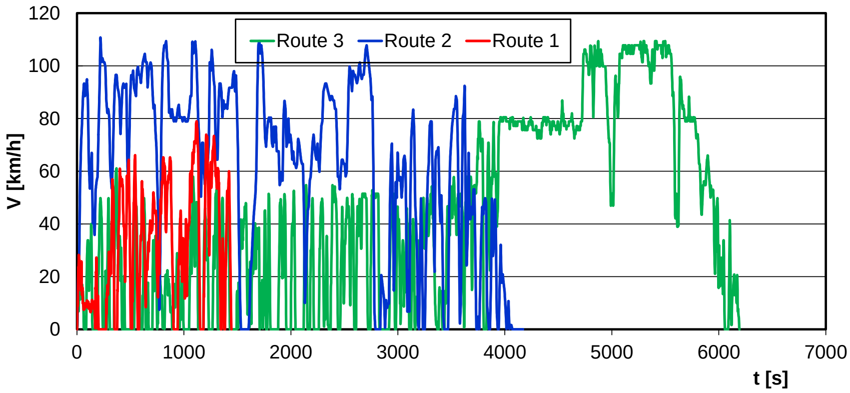


Figure 2. Velocity of individual route tests

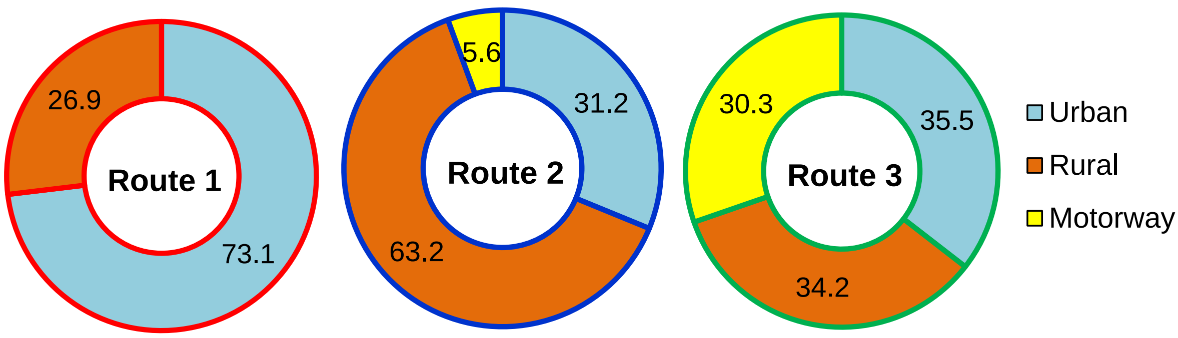


Figure 3. Share of urban, rural and motorway sections in research routes

Table 1. Detailed characteristics of the test routes

Test parameter	Route 1	Route 2	Route 3
Duration [s]	1496	4170	6120
Maximum velocity [km/h]	87	92	120
Average velocity [km/h]	32.1	61.5	45.1
Distance [km]	11.7	59.3	78.1
Stop share [%]	27	3.6	26.3

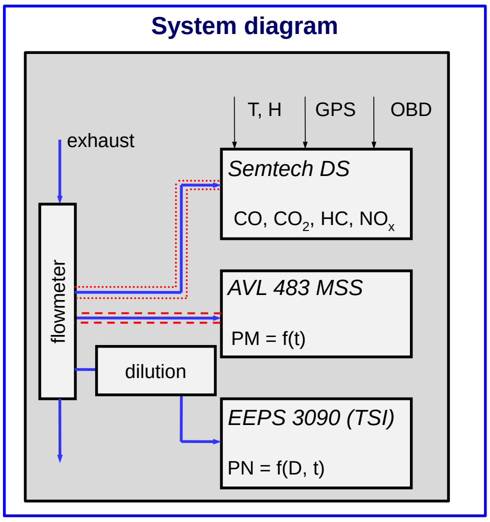
Table 2. Comparison of the RDE test route parameters (route 3) with the legal requirements

Test parameter	Value	Expected value	Meets standard
Test distance (U/R/M) [km]	27.7/26.6/23.7	16/16/16	yes/yes/yes
Test duration [min]	104	90–120	yes
Share of test stages (U/R/M) [%]	35.5/34.2/30.3	29–44/23–43/23–43	yes/yes/yes
Average velocity (urban) [km/h]	23.6	15–40	yes
Stop share (urban) [%]	26.3	6–30	yes
RPA (U/R/M) [m/s^2]	0.214/0.05/0.052	min: 0.138/0.048/0.025	yes/yes/yes
$V \cdot a_{+\_95}$ [m^2/s^3]	12.01/23.11/17.44	max: 17,61/24.91/26.99	yes/yes/yes
U – urban, R – rural, M – motorway			
RPA – relative positive acceleration			

4.2. Exhaust emission measurement

The testing apparatus is presented in Figure 4. A portable Semtech DS analyser was used for the measurement of exhaust emissions from vehicles. It allowed measurements of carbon monoxide, hydrocarbons and nitrogen oxides. In terms of benchmarking and quality control, zero-span checks were performed before and after each measurement. Linearisations of the equipment were carried out every three months. Post-processing plausibility checks were made on all data, focusing on carbon dioxide, to ensure that the data collected was realistic. A portable AVL condensation particle counter was used to measure the particle number. The emissions measurement equipment had a maximum mass of 69 kg (Gas PEMS – 25 kg, PM/PN PEMS – 23 kg), together with an additional power supply (generator) – 21 kg.

a) b)



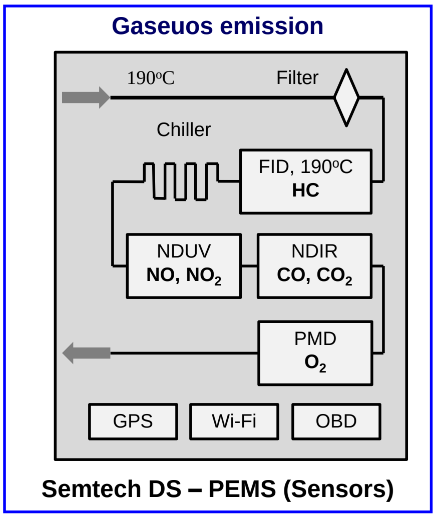


Figure 4. The measuring systems used for testing in real driving conditions

4.3. Test vehicle

A passenger car with a 30,000 km mileage was used for the research tests, it was equipped with a Euro 6 emission class charged Diesel engine with a displacement of 1.4 dm^3. The exhaust gas aftertreatment system was as typical for Diesel engines with direct common rail fuel injection i.e. a dual-function catalytic converter and a diesel particulate filter. The choice of such a research object was dictated by the fact that in the European Union more than 30% of new cars meet the latest exhaust emission limits (Euro 5 and Euro 6), while RDE tests refer to the latest vehicles.

5. Results

The performed exhaust emission tests using three different test routes allowed to compare the obtained specific distance emissions results of gaseous compounds and particulate matter, and at the same time allowed to answer the question about the possibility of estimating exhaust emissions in exhaust emissions tests that do not meet the requirements set for RDE tests. Exhaust emission measurements were repeated 5 times in each test, and the presented final emission results are average values shown along the indicated standard deviation.

Although the nature of the routes varied significantly, the research results were presented in a way that would allow for a direct comparison. The relative emission of individual harmful compounds (m_i/M) was used for this purpose relative to the total relative time of the research test (t_i/T) as well as to the relative total test route distance (s_i/S).

Figure 5 presents a comparison of emission values of harmful compounds in relation to the total emission of these compounds depending on the tests duration. The comparison shows that the emission of carbon monoxide increased proportionally to the duration of the test regardless of the type of the test route used (all curves are close to each other and lie on the diagonal of the graph). A slightly different character was observed for hydrocarbons and nitrogen oxides: the largest initial increase is observed on route 2, and the smallest on route 3. With respect to the number of particulates, the fastest emission increase was observed on route 3, and the slowest on route 1. This is in line with the fact that route 1 was characterized by the largest share of the urban driving section and the lack of a motorway section.

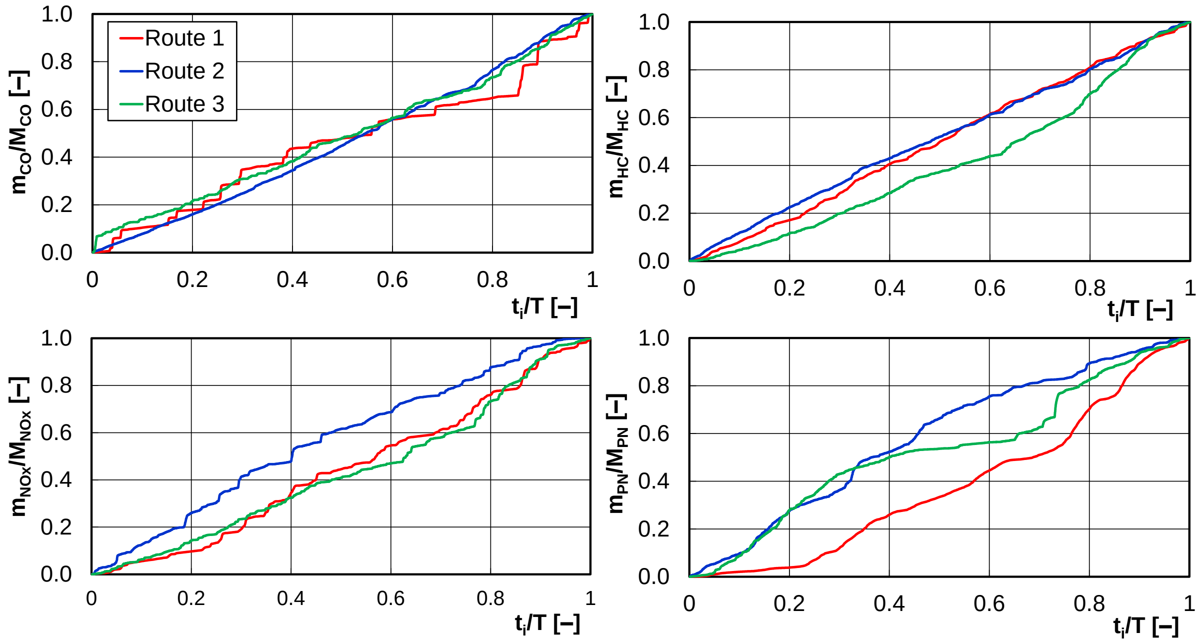


Figure 5. Relative exhaust emission compounds as a function of the relative tests duration

The test distance is a much better indicator than the test time, because it is not affected by the vehicle's stops during the test (as opposed to the test time, which increases regardless of whether the vehicle is moving or not). The characteristics shown in Figure 6 differ significantly from those in Figure 5. In the case of carbon monoxide emission, the effect of the length of individual phases is clearly visible, not just their share in the whole test. The fastest increase in the emission of this compound is observed on route 3 (test in accordance with the RDE requirements), and the slowest on route 2 (driving mainly in the rural route). The relative emission of hydrocarbons provides a similar trend for all research routes (small deviation on route 2). For the relative emission of nitrogen oxides the fastest increase was observed on route 3, and the slowest on route 2 (uniform engine load during the test). The largest differences were noted for the relative number of solid particles, where on route 3, more than half of all particles were emitted during the first 20% of the test length. In the remaining tests (route 1 and 2) the relative increase in the number of particles corresponded to the relative distance traveled in the test.

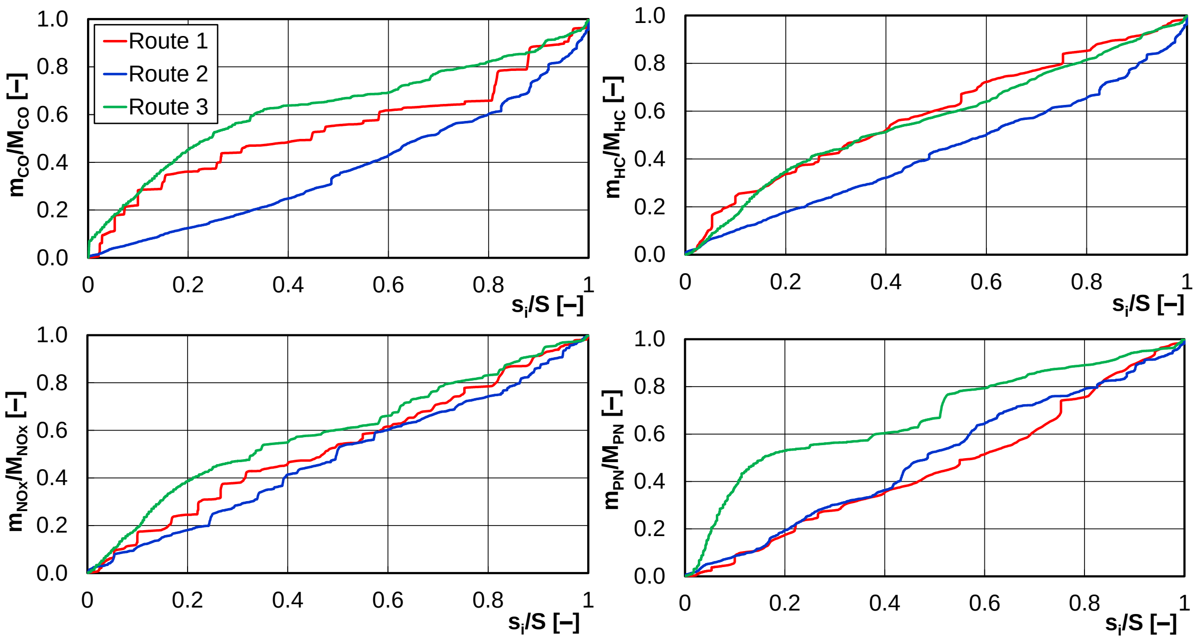


Figure 6. Relative exhaust emission compounds as a function of the relative tests distance

Because the above comparison method provided a very good analytical material, it was decided that the relative exhaust emission (the current value of the compound's specific distance emission related to the final value obtained in the test) should also be compared. It is a quantity that is directly subject to emission standards, and at the same time makes the mass of the emitted components independent of the test total distance.

In the first approach (Fig. 7), the relative specific distance emission of the compounds was compared depending on the relative test duration. The comparison shows that the largest specific distance emission of carbon monoxide was achieved on route 3 after about 2-3% of the entire test time. On route 1, the (instantaneous) specific distance emission for the test duration from the beginning to 30% of its total time was about 3-4 times greater than the final value. The instantaneous specific distance emission value of carbon monoxide on route 3 was practically constant. Another emission characteristic was observed for specific distance emissions of hydrocarbons: the highest instantaneous value was reached on the route 1, and on the route 3 the values at the beginning of the test were about twice as high as the final value. This means that during the motorway part, the hydrocarbon specific distance emission was smaller than in the urban part. On route 3, the character of hydrocarbon specific distance emissions was close to the emission of carbon monoxide and was practically proportional to the distance travelled (due to small – almost invariable, engine load). Considering the relative emission of nitrogen oxides, about double value obtained from the urban and rural parts on route 3 compared to motorway part should be noted. This means that more nitrogen oxides are emitted during dynamic urban traffic conditions than in motorway conditions (exhaust aftertreatment systems work optimally at higher exhaust gas temperature). A similar character was observed during the measurement of the number of solid particles. On the research route 1 (mainly urban), the relative emission of the number of particulates has continuously increased, which means that the increase in their number was greater than the increase in the test duration. On route 2, only the initial rapid increase in the number of emitted particles was observed, after which the value was almost constant. On the research route 3, the relative specific distance emission of the number of particulates was about 4 times higher in the urban part than in the remaining stages of the test.

When comparing the results of the relative exhaust emission as a function of the relative distance of tests, it should be noted that the values obtained in the initial test phases differ significantly from the final values (Fig. 8). However, as the relative distance increases, they coincide with the final value. In the case of relative specific distance emissions of carbon monoxide on route 3, 20% relative distance, the relative emission decreased about 5 times (from $b_{CO}/B_{CO} = 10$ to a value of 2).

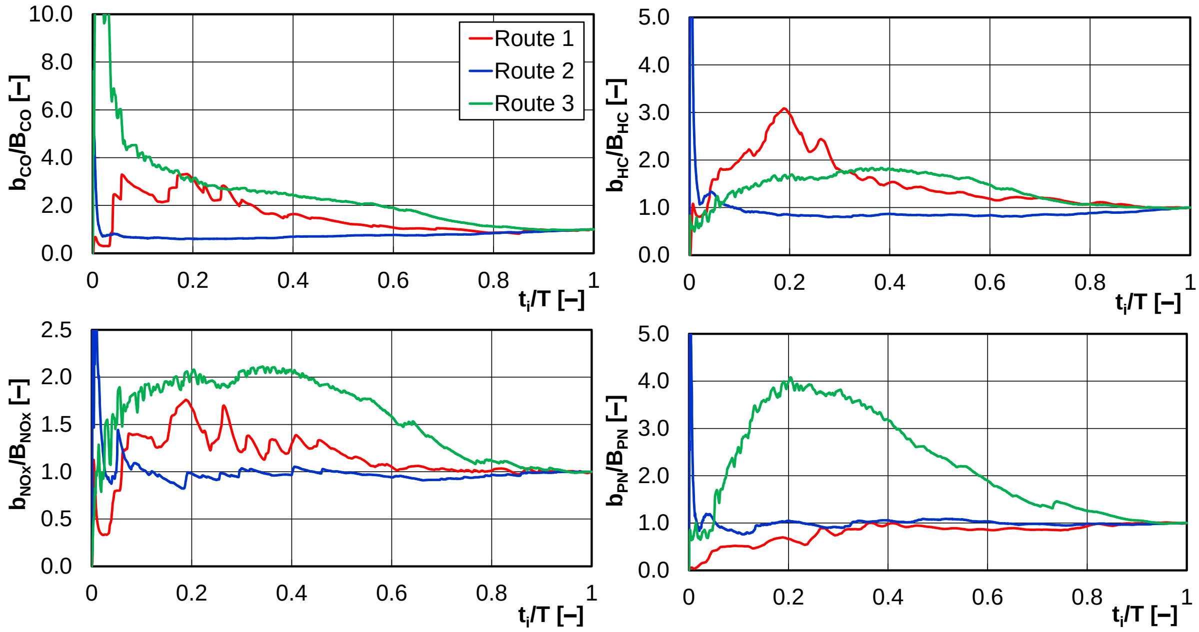


Figure 7. Relative specific distance emission as a function of the tests relative duration.

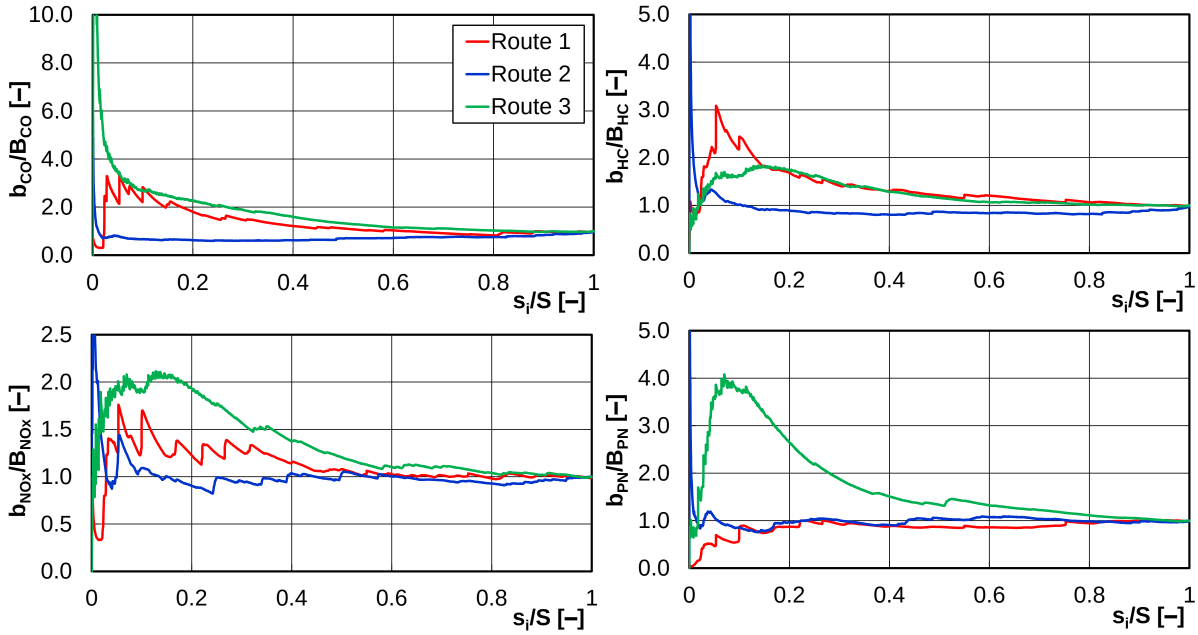


Figure 8. Relative specific distance emission as a function of the relative distance of the tests

Also in the case of relative specific distance emissions of hydrocarbons on route 2 (the majority of the route ran through areas where only partial engine load was used), the values of this parameter were not significantly large. The exception was the beginning of the test where – as is apparent from the velocity – the route began with a temporary stop. In the case of the relative specific distance emission of nitrogen oxides, regardless of the type of route, an increase in the discussed parameter was initially observed, but in the range of a relative distance of 0.8, these values differed little from each other. Similar values were obtained for the relative specific distance emission of the number of solid particles. On route 1, this specific distance emission was increasing up to the relative distance value of 0.2, and then the increase in the number of particles was proportional to the increase in the distance. Therefore, the relative specific distance emission was maintained around the value of 1.

In conclusion, it should be noted in the above analysis that as the test distance increased, the value of the specific distance emission of each compound was tending towards the final value. The graphs also show that the nature of the changes presented in Fig. 8 depend mainly on the type of the test section (urban, rural, motorway), and at the same time on their order. The type of route, in which the first stage was the urban part (route 3), was characterized by much higher values of relative specific distance emissions of each compound in this part than in the remaining parts of the test. A characteristic element of the results from Figure 8 is also the fact that after about 60% of the total test distance, the value of the specific distance emission of each compound only slightly deviates from its final value.

A detailed analysis of the above phenomenon (Fig. 9), shows that for a relative test distance (s_i/S) of 0.2, the relative change in specific distance emissions is the highest and ranges from 30% (route 2) to even 200% (route 3). However, for a relative distance of 0.6 and 0.8, these differences are much smaller and amount to 30% for route 2, and for route 3 only 10%. It should be noted that the biggest differences were observed (mostly) in the changes in carbon monoxide emissions, and the smallest differences were observed for the emission of nitrogen oxides. Based on the analysis, one can pose a thesis, that it would be possible to shorten the test distance by about 20%, and the obtained results would not significantly differ from the final values obtained in this research.

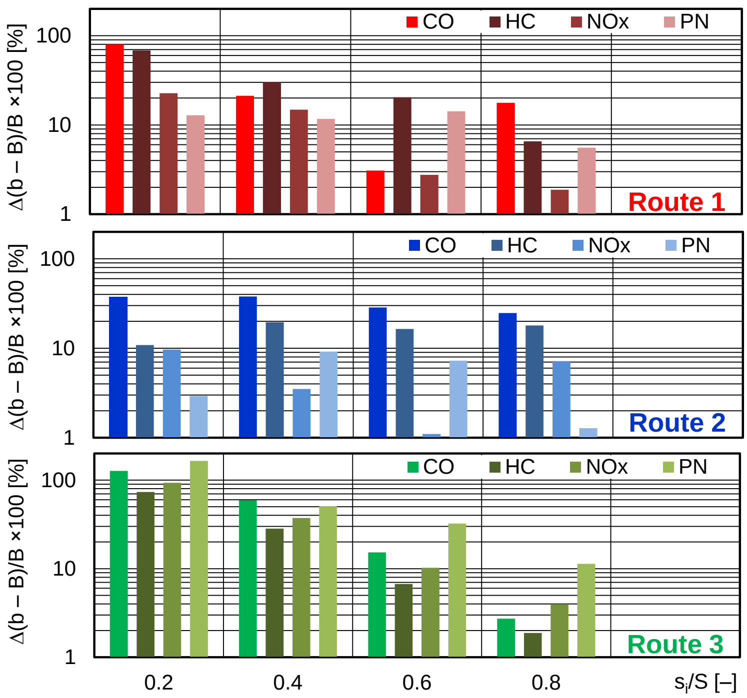


Figure 9. Relative change of specific distance exhaust emissions in relation to their final value (logarithmic scale) as a function of relative test distance

The summary of the conducted analysis ends in the determination of the specific distance emissions value of individual harmful compounds for all research routes (Fig. 10). The analysis of specific distance emissions of carbon monoxide and hydrocarbons shows that their highest value was obtained for route 1, and the smallest for route 3. This is mainly due to the fact that route 1 consists mainly of urban driving, where the lack of adequate temperature of the catalytic converter prevented the oxidation of these compounds. In addition, dynamic traffic conditions prevented a fixed flue gas flow, which resulted in a 30% more emissions on route 1 than on route 3. The opposite situation was observed for the specific distance emissions of nitrogen oxides: the smallest value was obtained for route 1 (mainly urban) and the highest value for route 3 (compliant with the RDE test requirements). The largest differences in values on test routes were recorded for specific distance emissions of the particle number. On route 1, the value was about 40% lower than for the test on route 3.

The measurement uncertainties have also been indicated in Figure 10: they were the largest for the route 1 measurements due to the smaller number of measurement data. On the other hand, considering harmful compounds, the largest uncertainty was observed for the measurement of the particle number (uncertainty of measurement in the range of 28% – 15%, respectively for measuring route 1 and 3).

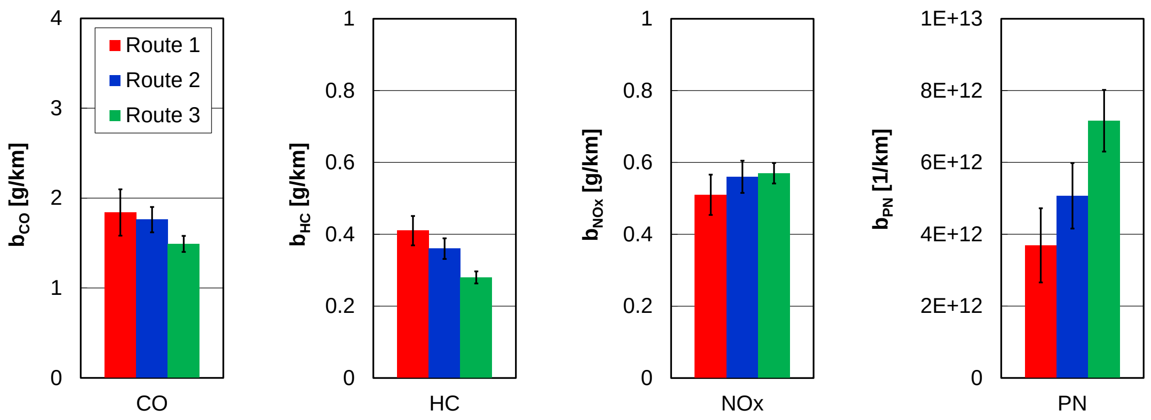


Figure 10. Specific distance exhaust emissions for various test routes

6. Conclusions

The qualitative and quantitative analysis of exhaust emissions in various test drives resulted from road toxicity tests comparison. This comparison shows that the relative value of the specific distance emissions is closer related to the test distance than to its duration. Values of specific distance emissions determined in various drive tests depend mainly on the type of test and they are higher (for carbon monoxide and hydrocarbons) in those tests than in the RDE test designed in accordance with the requirements of relevant standards. Such a situation occurs when these tests are shorter and the urban and rural part has a larger share in the whole research test. The opposite situation occurs for specific distance emissions of nitrogen oxides and the number of solid particles. The analysis of the research also confirmed that it is possible to shorten the tests distance by about 20% without a significant change in the results of specific distance exhaust emission measurements.

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