Assessment of the emission of harmful car exhaust components in real traffic conditions

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Abstract. Until now, passenger cars before getting permission to sell were tested in the laboratory conditions in order to determine the amount of harmful gas compounds emission and average fuel consumption. However, studies have shown that, during real driving, emission results significantly differ from those obtained in the laboratory. For this purpose, in the European Union was created a new procedure for conducting of driving cycle WLTP (World Harmonized Light-Duty Procedure) taking into account road test (Real-Driving Emissions, RDE). The article presents selected results of pollutant emissions research using the HORIBA OBS 2200 road analysis system. The results show that emission in real traffic conditions can lead to exceeding vehicle emission standards. The largest exceeded emission limits occurred for the urban and motorway parts, while the smallest ones for the rural part. In relation to EURO 5, the limits for THC (exceeding by 9%) and CO (exceeding by 49%) were not included in the emission limit.

1. Introduction

In order to determine the exhaust emissions of car vehicles by September 2017, the NEDC test (New European Driving Cycle) was used, which was carried out only under controlled laboratory conditions, which ensured repeatability and comparability of results [7]. However, it turned out that the NEDC test often did not reflect the conditions that actually occurred while driving on public roads [2,4,12]. In order to improve the emission results and fuel consumption that may occur during driving in road conditions, new WLTP (World Harmonized Light-Duty Procedure) testing procedures have been created. Thanks to the new procedure, in addition to determining the emission volume during controlled road test on the chassis dynamometer, RDE road tests are also carried out, using mobile emission measurement systems – PEMS (Portable Emissions Measurement System) [4-6].

The actions taken have meant that new vehicle homologation tests more fully reflect the situations that take place on the roads, eg by delimiting the route to the urban, suburban and motorway sections. The test route is definitely longer and the test on the chassis dynamometer takes more than 10 minutes longer, not including the duration of road tests. Temperature conditions are also more similar to those prevailing in Europe. The test is more dynamic and better reflects acceleration and braking from reality [12].

The research part of the work concerns the assessment of pollutant emissions in exhaust gases during driving in real traffic conditions. The results obtained were compared with the requirements of the EURO 5 standard, which are valid for the car selected for tests.
2. “Real-driving emissions” test

The NEDC test, which was established in 1997, covers a distance of 11 km, lasts 20 minutes, while the average speed during its duration is 34 km/h [2]. The loss of credibility of the results of the NEDC test resulted from the fact that the development of car structures over the years caused that it neglected some important issues related to the performance of the vehicle itself. More and more newer models of cars have different equipment versions, but this test, for example, does not include the inclusion of additional devices (e.g., air conditioning), which undermines the emission values of exhaust components. It is also erroneous for this test to force each vehicle to have the same gear shifting points and that the ratio of urban driving to driving in non-urban areas was 66% to 34%, respectively [7,9].

The issues described above contributed to the development of a new procedure for conducting vehicle driving cycles – WLTP. This procedure delimits three types of vehicles, categorizing them with respect to the power/weight ratio. The WLTC (Worldwide Harmonized Light-Duty Vehicle Test Cycle) test is conducted for a given type of vehicle – a global harmonized light vehicle test cycle, during which the emission of gaseous exhaust gas pollutants (CO₂, NOₓ, THC, CO), particulate matter is measured (PM) and fuel consumption [8,11]. The test on the chassis dynamometer is supplemented by the RDE road test, whose task is to determine the emission of harmful exhaust components in traffic conditions. Conducting this type of road test is important because driving can take place in variable traffic, climatic conditions, or for different gradients, which significantly affects the emission results of exhaust emissions [3]. Therefore, due to occurrence of many variables and the dynamics of the RDE test, it was necessary to develop the road composition requirements (equal division into urban, rural and motorway sections), PEMS calibration, climatic conditions prevailing during the test and driving dynamics (e.g., acceptable range acceleration) so that the results are representative and reliable for each test [10].

2.1. PEMS

An important element of the new procedure is the measurement system enabling road tests. PEMS are equipped with the following sensors and methods for the measurement of pollutants in the car fumes: flame ionization detector (FID) for HC measurement, non-dispersive infrared spectrometer (NDIR) for CO and CO₂ measurement, non-dispersive ultraviolet (NDUV) for NO and NO₂ measurements. According to the EU Commission Regulation 2017/1151, acceptable deviations of PEMS measurements complied with results from a stationary analyser (on a chassis dynamometer) should not be greater than 15% for HC, CO, NO₅, and 10% for CO₂ [1].

PEMS can be installed in the trunk of the tested vehicle, while the measuring sensors with a flow meter are connected to the exhaust pipe. The exhaust gas pipe must be heated to 190 °C to avoid condensation of hydrocarbons. In addition, ambient temperature and humidity sensors, as well as a GPS transmitter are connected to the system. In order to obtain a full picture of the impact of the engine operation on the generated emission, the OBDII interface can be connected to the ECU of the vehicle [3,8,10].

![Horiba OBS-2200 PEMS, installed inside of the tested car](image1.jpg)

**Figure 1.** Horiba OBS-2200 PEMS, installed inside of the tested car

2.2. Selection of the test route
The selected stretch of road for testing should start from the urban part (driving speed does not exceed 60 km/h), then it should include the rural part (driving speed higher than in the urban area, but not more than 90 km/h) and should end with the motorway part (speed higher than 90 km/h). The described parts of the road should be equal, while their minimum lengths should be approx. 16 km. Travel time should be between 90 and 120 minutes. The ambient temperature must be between 0 and 30 °C. Road tests must be conducted on normal working days, excluding weekends [1]. The requirements for the RDE test conditions are summarized in Table 1.

### Table 1. Requirements and boundary conditions for RDE tests, based on [3]

| Parameter                              | Required values                                                                 |
|----------------------------------------|---------------------------------------------------------------------------------|
| Payload                                | <90% of maximum vehicle weight (including driver, passenger to operate the computer, measurements devices with power supply and auxiliary equipment) |
| Stop percentage                        | 6%-30% of urban time                                                            |
| Maximum speed                          | 145 km/h (160 km/h max. for 3% of motorway driving time)                         |
| Altitude                               | Moderate<br>Extended: 700-1300 m<br>Moderate: 0-30°C                             |
| Ambient temperature                    | Extended: (low) -7°C-0°C and (high) 30°C-35°C                                    |
| Altitude difference                    | No more than a 100 m altitude difference between start and finish               |
| Use of auxiliary systems               | Free to use as in real driving, also includes air conditioning and other systems (operation not recorded) |
| Dynamic boundary conditions            | Maximum: 95 percentile of V*a                                                  |
|                                       | Urban: 29%-44% of overall distance<br>Rural: 23%-43% of overall distance       |
| Composition of road                    | Urban: >16 km<br>Rural: >16 km<br>Motorway: 23%-43% of overall distance         |
| Distance                               | Urban: 15-40 km/h<br>Rural: 60-90 km/h                                         |
| Average velocity                       | Motorway: >90 km/h (100 km/h at least for 5 min of driving)                    |
| Conditions of temp. of vehicle         | first 5 minutes of test – „cold start” excluded from the analysis              |
| Time of measure                        | Normal weekdays in working hours, out of „peak” hours of congestions            |

Table 1 indicates the boundary conditions defined as extended. This means that if they occur for a specific time interval, all emissions are divided by the value of 1.6 before assessing them for compliance with the requirements of the Regulation [1].
3. Emission test using the PEMS

Research with the use of the PEMS (Horiba model OBS-2200), which is part of the equipment of Automotive Ecology Laboratory of the Department of Combustion Engines and Transport at the Faculty of Mechanical Engineering and Aeronautics of the Rzeszow University of Technology, was carried out in November 2017. In accordance with the provisions of the latest European Commission Regulation, the RDE test was started by comparing the measurement from the PEMS system with the AMA i60 stationary exhaust gas analysis system. Initial tests were carried out on a chassis dynamometer built in a climate chamber on a passenger car. The test results showed that differences in the emission values of pollutants in the NEDC test, measured using the PEMS and AMAi60 systems, were within the permissible deviations and were respectively: CO\(_2\) 6%, THC 6.1%, NO\(_x\) 14.2% and CO 14.4%. Therefore, further measurements of emissions in real traffic conditions can be considered as correct.

A vehicle with a gasoline engine complying with the EURO 5 standards was selected for road tests (Fig. 2). The engine of the vehicle is equipped with MPI injection system. The route selected for the road test is shown in Fig. 3.

![Figure 2. Selected vehicle to proceed road test with installed HORIBA OBS 2200 PEMS](image)

![Figure 3. Map with selected stretch of road test](image)
The aim of the tests conducted in road conditions was to determine the value of pollutant emissions in real traffic conditions for the selected region. The test route consisted of an urban, rural and motorway section. The average speed for individual parts of the road test was respectively: urban part 28 km/h, rural part 73 km/h, motorway part 101 km/h.

Table 2 presents a comparison of selected test parameters under NEDC stationary conditions and a test in real road conditions. In additions, the parameters of the completed road test were marked in accordance with the RDE test procedure.

Table 2. Selected NEDC parameters compared to real road test and RDE fulfillment

| Parameter                               | NEDC | Real test | RDE fulfillment |
|-----------------------------------------|------|-----------|-----------------|
| duration [s]                            | 1180 | 2965      | NO              |
| full distance [km]                      | 11.013 | 39.57     | NO              |
| average speed [km/h]                    | 33.6 | 48.4      |                 |
| maximum speed [km/h]                    | 120  | 124       | YES             |
| stop duration (%)                       | 23.7 | 14.1      | YES             |
| acceleration (%)                        | 20.9 | 28.2      |                 |
| deceleration (%)                        | 15.1 | 26.4      |                 |
| average positive acceleration (m/s²)    | 0.49 | 0.3       |                 |
| RPA                                     | 0.11 | 0.13      |                 |
| average deceleration (m/s²)             | -0.82 | -0.28    |                 |
| maximum acceleration (m/s²)             | 1.04 | 1.91      |                 |
| minimum deceleration (m/s²)             | -1.39 | -1.94    |                 |
| Ambient temperature [°C]                | 20 - 30 | 8.4      | YES             |
| cold start phase emission               | YES  | NO        | YES             |

3.1. Obtained results of research

The velocity chart obtained during the road test, taking into account particular parts of the route and the changes in the altitude of the road above sea level chart is shown in Fig. 4. The test was divided into individual parts (urban, rural, motorway) based on the obtained speed profiles and terrain characteristics.
Figure 4. Speed profile and altitude for road test with selected parts of road

Figure 5. Instantaneous emission of NO\textsubscript{x} and acceleration during road test
Emission values for the cold start engine were excluded from the analysis. Fig. 5 shows the instantaneous NO\textsubscript{x} emission combined with the acceleration of the vehicle. On the basis of the graph, it can be noticed that in cases of a sudden acceleration the emission of nitrogen oxides increases. The increment value is always different, i.e. its size is also influenced by other factors, including terrain height gradient, engine
speed, and gear ratio. Fig. 6 shows the instantaneous emission of carbon dioxide compared to the speed of the vehicle. On its basis, it can be noticed that for the high speed, CO₂ emission increase. This phenomenon is well illustrated by the part of driving on the motorway, where the emission is the largest. Fig. 7 shows the comparison of THC, NOx and CO emissions for selected parts of the test. The highest emission of hydrocarbons was obtained in the motorway section. The same applies to the emission of carbon monoxide. The emission of nitrogen oxides was comparable in the urban and motorway parts, while the lowest in the rural part. On Fig. 8, it can be noticed that the smallest speed was recorded for the urban part of the test. Of course, it has to do with the speed limits prevailing in the city and with the highest traffic density. A large number of accelerations and brakes in the urban part also contributed to the largest fuel consumption in relation to other parts. This state directly affected the high emission of harmful exhaust components in the urban part, in particular, nitrogen oxides. The smallest emission of harmful exhaust components for the test was obtained in the rural part.

Table 3. Values of average emission of selected toxic compounds of exhaust fumes for performed road test

| CO₂ [g/km] | THC [g/km] | NOₓ [g/km] | CO [g/km] |
|------------|------------|------------|-----------|
| 112.054    | 0.109      | 0.0503     | 1.491     |

According to the homologation requirements, the tested vehicle should meet the limits according to EURO 5 standards (PM limitation do not apply because the vehicle has an MPI injection system). As can be seen from table 3, the permissible values of carbon monoxide and hydrocarbon emission have been exceeded, which is mainly due to a different implementation of the road test in relation to the NEDC test.

4. Summary

The paper describes selected aspects of conducting RDE tests. When comparing the results of pollutant emissions for the tested vehicle with respect to the EURO 5 standard, presented in Table 3, the permissible values for the following exhaust components were exceeded: carbon oxides (CO) by 49% and for hydrocarbons (THC) by 9%. It should be noted, however, that for the tested car RDE test was not required due to the fact that this procedure was not valid for vehicles complying with the EURO 5 standard. However, it is also worthwhile carrying out for older vehicle structures in order to know the emission levels of pollutants they generate in real traffic conditions.

The exceedance of emission standards for specified components occurred mainly in the urban and motorway part. This can be associated with a rapid acceleration of the vehicle, and consequently too rich fuel mixture, which reduces NOx emissions and increases CO and THC emissions.

It should also be emphasized that RDE, as well as PEMS exhaust gas analysis systems, have some limitations. Modal emission measurement on the road over a longer period of time results in an increase in the analyzer response time (including through fluctuations in ambient temperature). Therefore, measurements of emissions during road tests are characterized by even larger margins of error (for NOx even up to 20-30% [3]) relative to emission measurement on stationary analyzers, despite the fact that PEMS analyzers meet similar requirements regarding measurement accuracy.

The new WLTP driving cycles procedure, as well as the RDE road test itself, applies to all new generations of cars put on sale after September 1, 2017. Currently sold models, for new procedures will be subject to September 1, 2018, with the exception of the RDE tests that apply will be from September 1, 2019. The results of nitrogen oxide emissions from the RDE test are compared with the so-called Conformity factor (CF), the value of which for new car models is currently 2.1. This means that even though NOx emissions from vehicles exceed 2.1 times, they will still meet the requirements of the standard (Euro 6). After 2020, the CF ratio will decrease to 1.5 for new car models, and from 2021 for all new cars. This state confirms that the introduced procedures, mainly in the aspect of road tests are still in development and require further research and improvement. The same applies to PEMS analyzers because currently, more and more companies are specializing in this type of instrumentation.
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