Article citation info:
MERKISZ, J., PIELECHA, J. Selected remarks about RDE test. *Combustion Engines*. 2016, **166**(3), 54-61. DOI:10.19206/CE-2016-340

Jerzy MERKISZ
Jacek PIELECHA

CE-2016-340

Selected remarks about RDE test

New test procedures for determining exhaust emission from passenger vehicles will be introduced in 2017. For several years, the European Commission has been developing new procedures, which aim is to perform tests in road conditions. The purpose is to determine the real values of emissions, which are not always reflected by the level of emissions obtained in the laboratory. Proper and accurate procedures for determining emissions in real traffic conditions (RDE – Real Driving Emission) have not yet been approved (as opposed to Heavy Duty Vehicles for which such conditions already exist), but there are proposals that are currently being analyzed by major research centers in Europe. There are many differences between those proposals such as determining road emission or research methodology related to emission measurement of hydrocarbons. The work compares the results of emissions measured in road tests using the latest legislative proposals related to passenger cars. The results are shown in relation to the used measurement method: classic method of determining exhaust emission; uses all measurement data determining the mass of harmful compounds and distance travelled during the test; method of averaging the measuring windows (MAW – moving average windows), also in the literature called EMROAD method, which determines the measurement windows (on the basis of carbon dioxide emissions from the WLTC test) and on its basis determines the road emission in RDE test; generalized method of instantaneous power (Power Binning), known in the literature as CLEAR – Classification of Emissions from Automobiles in Real driving, determines road emissions on the basis of generalized instantaneous power during the RDE test.

Key words: *exhaust emission, passenger cars, real driving tests*

1. Introduction

Emission standards are established for the control of pollutants emitted from motor vehicles throughout the world. Most regions also set the limits on carbon dioxide emissions, which are directly related to fuel consumption [1]. Exhaust emissions are measured in laboratory conditions (for passenger cars on the chassis dynamometer) in a fixed certification test. This part of the certification process of the vehicle is responsible for its "environmental performance" and is the same for all cars. The chassis test is responsible for the "most likely" road conditions, and performing the same tests for all vehicles allows for the comparison of the emission results between them. Nowadays, however, more and more attention is given to road tests (which is already reflected in the proposed European Union emissions regulations) known as RDE tests using PEMS type mobile research equipment (Portable Emission Measurement System). Recent research on emissions from vehicles in traffic conditions, performed with the use of mobile measurement systems, reflect the actual ecological performance of vehicles. Most attention is given to the possibility of using such tests to calibrate the engines in such a way to reduce emissions not only during the certification tests, but also in the entire range of engine operation. The authors of paper [11] pointed out that new research in real traffic conditions, currently simulated in various research tests (NEDC – New European Driving Cycle [16], CADC – Common Artemis Driving Cycles, WLTC – Worldwide Harmonized Light vehicles Test Cycle [15]), may increase the emissions of nitrogen oxides from road vehicles. They postulated that in order to reduce that increase it is necessary to make changes in the vehicles software, stating that these changes will be successful only for vehicles equipped with petrol engines. Vehicles fitted with compression-ignition engines will require further investments to increase the effectiveness of the exhaust gas aftertreatment through the use of new methods of reducing the concentration of nitrogen oxides (eg. using an SCR system – Selective Catalyst Reduction).

Authors of the article [9], who compared road emissions in real traffic conditions with the use of PEMS analyzers with results obtained using the program COPERT [12], arrived at the same conclusions. It was found that in the speed range of 20-120 km/h calculation results obtained by using the COPERT program are higher by about 10% for such quantities as fuel consumption and the emission of hydrocarbons to the values from road tests. However, with regard to the emission of nitrogen oxides the data from COPERT are understated by about 30%.

Comparative emission studies of Euro 5 emission class vehicles carried out in the laboratory on a chassis dynamometer [7], in various driving tests (e.g. NEDC, CADC and the WMTC – Worldwide Motorcycle Test Cycle) also confirmed the results previously stated. The authors used CADC and WMTC as tests in which the specificity of changes in speed corresponds to the test in real traffic conditions. It was found that for vehicles with petrol engines emissions of carbon monoxide does not exceed 1 g/km (permissible Euro 5 limit is also 1 g/km), emission of hydrocarbons does not exceed 10% of the limit (0.1 g/km) and the emission of nitrogen oxides is equivalent to approximately 20% of the limit value (0.06 g/km). The authors pointed out that vehicles with compression-ignition engines far exceed the permissible emission limits of nitrogen oxides – the obtained values exceed the exhaust emissions limit approximately 4 times (emission limit values for nitrogen oxides in Euro 5 is 0.18 g/km).

Studies in road conditions draw attention to significant emissions of particulate matter, mainly in the nanoparticle range from combustion engines also those powered by alternative fuels (e.g. natural gas) [13] (2015). The article highlights the significant mileage of the vehicles using alternative fuel, which in turn results in up to 8-fold increase in emitted particle number for vehicles with a mileage of 500,000 km compared to the vehicles with mileage of 75,000 km. The article confirmed in RDE tests, with different road traffic characteristics, that vehicles powered by compressed natural gas emit larger amounts of nitrogen oxides in comparison to vehicles powered by spark-ignition engines.

With regard to the accuracy of measurements in actual traffic conditions the final result depended on the operating conditions of the vehicle and the engine (including the speed of other vehicles, road surface, the capability of the driver and the driving style and other aspects of road traffic). These conditions are unpredictable and can significantly affect the outcome of the emissions measurement. From the data found, among others, in publications [6, 17], it follows that the greatest impact on the achieved emission results are: thermal state of the vehicle (engine), average speed, driving dynamics and road topography.

The impact of road conditions on the emission results was the subject of article [14], which studied SUVs with petrol engines and automatic transmission under the conditions of varying slope of the road. The authors have attempted to estimate the emission changes of individual components depending on the angle of road inclination. The authors demonstrated that the change in the road slope of 10% resulted in a 2-fold change in the emissions for vehicles with spark ignition engines and a 1.5-fold change in emissions for vehicles with compression-ignition engines.

Starting from 2017, the process of type approval of new passenger car models in the European Union will include a procedure for measuring emissions in real traffic conditions. EU regulation (715/2007/EC [5] and 692/2008 [4]) for RDE tests is a response to the results of studies [8, 10], relating to increased emissions of nitrogen oxides from vehicles equipped with compression ignition engines, despite such vehicles meeting the acceptable standards in laboratory tests. Under the new rules [3] for all new type approvals from September 2017, and in the case of newly registered car models from September 2019, the emissions of nitrogen oxides measured in traffic conditions will not be allowed to exceed 2.1 times the maximum limit (for Euro 6 that is 80 mg/km), or 168 mg/km. However, since January 2020 for a new type approval (and since January 2021 for new model registrations) this ratio will be reduced to 1.5, which means that the maximum emission of nitrogen oxides cannot exceed 120 mg/km (Fig. 1).

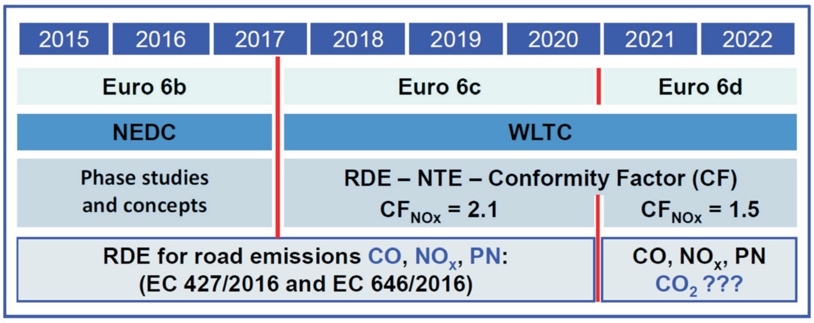


Fig. 1. RDE tests requirements in Europe [2, 3]

Parameters of road tests cannot be arbitrary, and to determine the emissions one of the proposed methods of measurement will be used [3]:

– method of moving average windows (MAW – Moving Average Windows); also referred to as EMROAD in the literature, developed by the JRC,
– method for categorizing power (Power Binning); in literature referred to as CLEAR – Classification of Emissions from Automobiles in Real driving, developed at the Graz University of Technology.

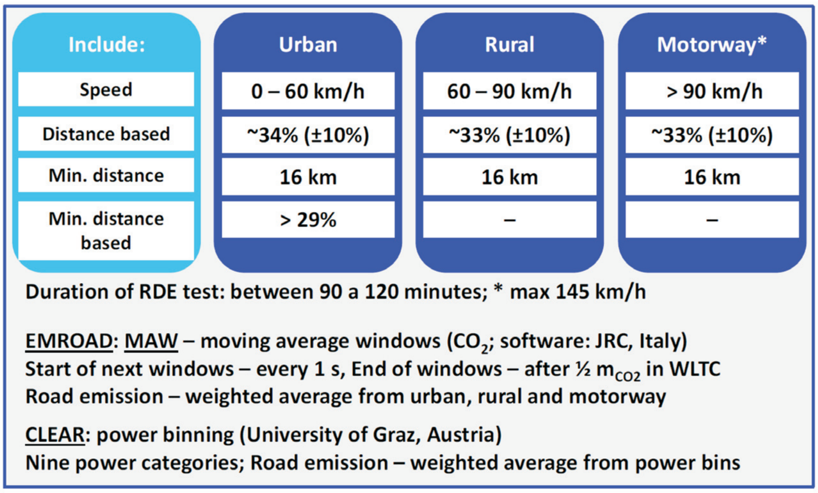


Fig. 2. Requirements of the test drive cycle [3]

The test route is selected in such a way that the test was carried out continuously, and the data was continuously recorded to achieve the minimum duration of the study. An external power supply provides electricity to the PEMS system, and not from a source receiving energy directly or indirectly from the tested vehicle engine. PEMS installation was carried out in such a way to ensure the least possible influence on the vehicle emission performance, its operation or on both of these factors. Efforts should be made to minimize the weight of the installed equipment, and potential changes in the aerodynamics of the test vehicle. RDE studies should be carried out on weekdays, on paved roads and streets (i.e. off-road driving is not permitted). Prolonged idling after the first ignition of the internal combustion engine at the start of the emission test is to be avoided (Fig. 2 and Fig. 3).

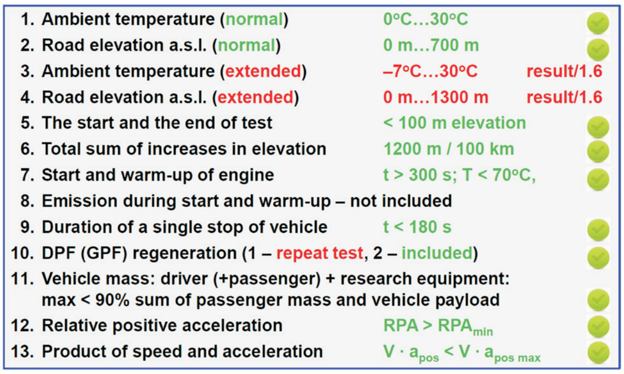


Fig. 3. Specific requirements of the test drive cycle [3]

2. Methodology

The tested objects were cars, the characteristics of their drive units are shown in Table 1. They were equipped with gasoline and diesel engines; characterized by exhaust emissions in line with the Euro 6 regulations. Despite the differences in the engine types and displacements, similar curb weight of vehicles was a common feature. The aim of the study was to determine the interdependence of the road emissions of compounds contained in vehicles exhaust gases (separately for the gasoline and diesel engines).

A Semtech DS mobile analyzer by Sensors and Engine Exhaust Particle Sizer 3090 were used for measuring the concentration of harmful substances in the exhaust gas. They facilitated the measurement of harmful gaseous compounds and particulate matter in accordance with the requirements of the standards mentioned earlier. Additionally data directly from the vehicle's diagnostic system and a GPS location signal were transmitted to the central unit of the analyzer.

Table 1. Characteristics of engine/vehicle used in testing

Parameter	Gasoline	Diesel
Cylinder number, arrangement	4, in series	4, in series
Displacement [cm^3]	1984	1968
Emission class	Euro 6	Euro 6
Max. power [kW] at [rpm]	169 / 4700–6200	135 / 4000
Max. torque [Nm] at [rpm]	350 / 1500–4400	380 / 1750–3000
Fuel injection	Direct injection	Common Rail
Vehicle curb weight [kg]	1349	1354

Table 2. Test route characteristics

Test parameters	Vehicle A Gasoline	Vehicle B Diesel	Relative difference $\frac{(A-B)\times 100\%}{½(A+B)}$
Total time [s]	5349	5209	2.65
Maximum speed [km/h]	147.9	133.3	11.36
Average speed [km/h]	33.73	34.51	–2.28
Distance [km]	50.116	49.936	0.43

Road emission measurements were made in the actual traffic conditions when driving in urban, rural and motorway roads; tests were performed three times, and the partial results presented are examples; the end results are the averages of all the results obtained (Table 2). Research route was chosen for a variety of driving conditions to take account of the varying: urban, rural and motorway topography and their impact on the value of the emission of gaseous components of exhaust gases. Analysis of changes in route elevation reveals a small variation, as well as elevation differences within values permitted by the norms (Fig. 4).

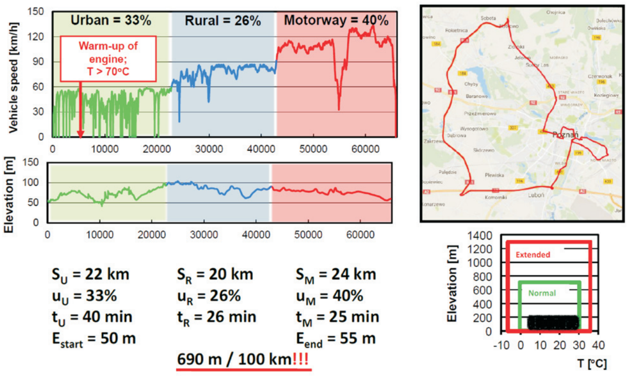


Fig. 4. Changes in road elevation and the vehicle speed (diesel engine) during the test

3. Result analysis

3.1. Analysis of all measurement data

The recorded changes of individual pollutants concentrations allowed to determine the relations characterizing the effect of the dynamic engine characteristics on harmful compounds emission, taking into account the results of the entire route measurement. The dynamic engine characteristics are included in an indirect way, using the distribution of the whole range of speeds and loads in real traffic conditions for making graphs of the emission intensity of the chosen components of combustion gases. This data was presented on the engine characteristic in the speed and load boxes (Fig. 5 and Fig. 6).

On the basis of the previously obtained measurements of harmful compounds emissions and using the knowledge of the distance traveled by the vehicle, instantaneous conformity factors values CF (Conformity Factor) were determined, which are defined as the ratio of road emission of the component, and the emissions specified by the legislation

$$(CF = b_{RDE}/b_{norm}).$$

The road emission values designated for the vehicle with the gasoline engine from the route tests are as follows (Fig. 7a): emission of carbon monoxide was 216 mg/km, emission of nitrogen oxides was 56 mg/km, emission of hydrocarbons was 83 mg/km, emission of carbon dioxide was 117 g/km. Compliance of road emissions with the specified Euro 6 limits was observed for all exhaust components tested. The values of the indicators were as follows (Fig. 7b): the conformity factor of carbon monoxide was 0.22, the conformity factor of nitrogen oxides was 0.89, the conformity factor of hydrocarbons was 0.83. The analysis of the data shows that the values of road emissions obtained in actual operation are not exceeded for vehicles with gasoline engines.

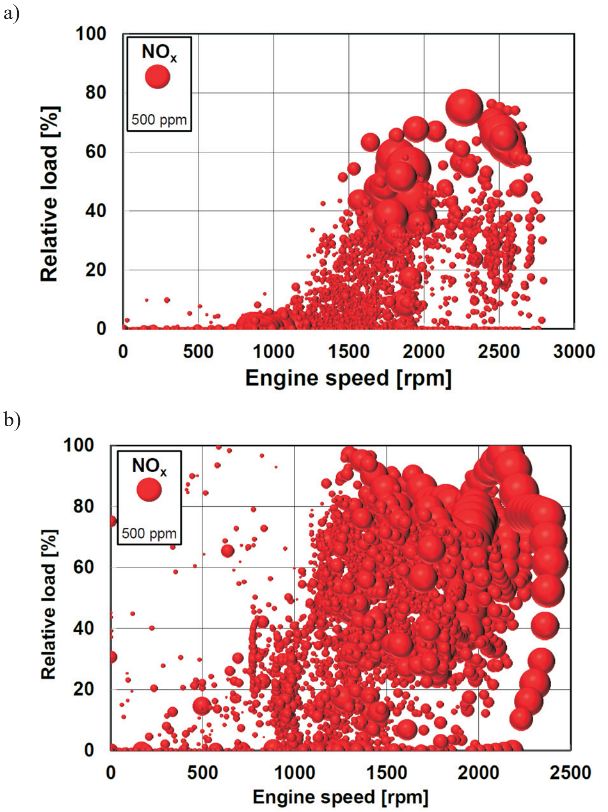


Fig. 5. The nitrogen oxides concentration relative to the engine operating parameters during the RDE test: a) gasoline engine, b) diesel engine

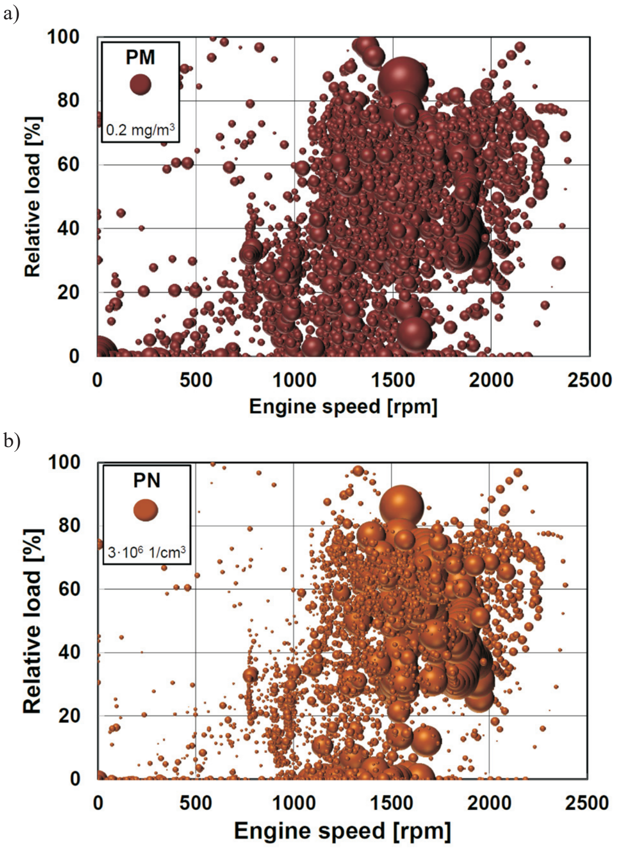


Fig. 6. Emission intensity by mass (a) and the number (b) of particles related to engine operating parameters during the RDE vehicle test (diesel engine)

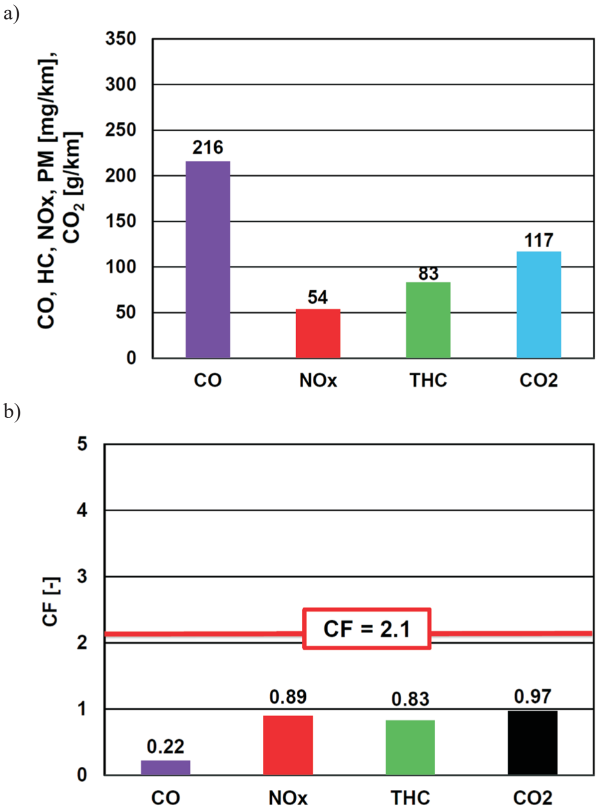


Fig. 7. Road emission values (a) and conformity factors (b) determined during road tests for a vehicle equipped with a gasoline engine (all results)

The road emission values determined for vehicle with a diesel engine from a drive on the test route are as follows (Fig. 8a): emission of carbon monoxide was 204 mg/km, emission of nitrogen oxides was 231 mg/km, emission of the sum of the nitrogen oxides and hydrocarbons was 296 mg/km, emitted particulate mass was 3.11 mg/km, and emitted particle number was $1.8 \cdot 10^{12}$ 1/km, emission of carbon dioxide was 148 g/km. Conformity factors specified for the vehicle fitted with a diesel engine are different in nature compared to those for an Gasoline engine. The emission values specified in Euro 6 standard were significantly exceeded for the of the value of sum of nitrogen oxides and hydrocarbons, as well as for nitrogen oxides alone and for particle number.

The values of the conformity factors were as follows (Fig. 8b): the conformity factor of carbon monoxide was 0.41, the conformity factor of nitrogen oxides was 2.89, the conformity factor of the sum of nitrogen oxides and hydrocarbons was 1.74, the conformity factor of particulate mass was 0.69, and the conformity factor of particle number was 2.99.

The analysis of the data shows that the road emission values obtained in actual operation do not exceeded the limits for vehicles with gasoline engines, while for diesel engines the emission of the sum of nitrogen oxides and hydrocarbons, emission of nitrogen oxides and the particle number (the latter rate due the regeneration of the particulate filter during testing) are all exceeded.

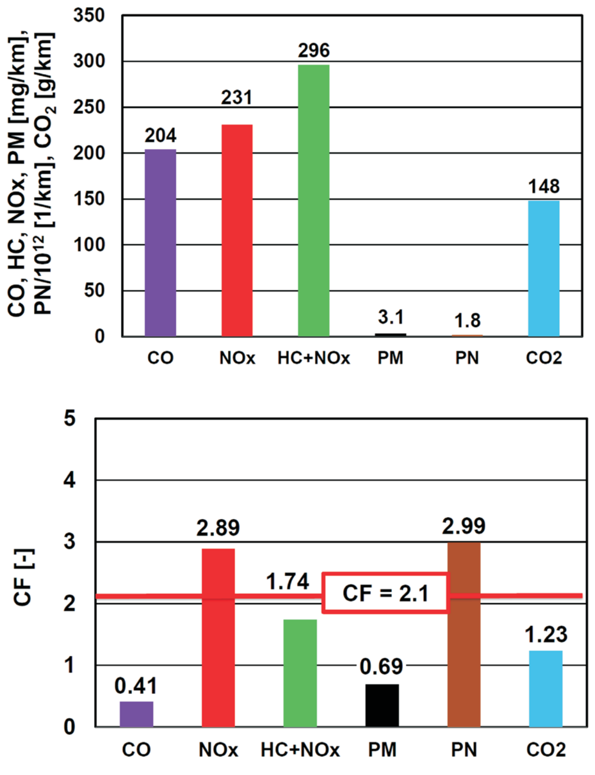


Fig. 8. Road emission values (a) and their respective conformity factors (b) determined during road tests for a vehicle equipped with a diesel engine (all results)

3.2. Moving average windows method

The first step in determining the road emissions with the new test procedure is to determine the validity of the test method (Fig. 9). The following issues must be considered:

– route length; for the conducted road tests the length was: 17.16, 13.69, 20.83 km, which adds up to 51.68 km (one of the values does not lie within the required test range),
– test duration, which has to be between 90 and 120 minutes; the conducted test took 87 minutes (thus the value does not meet the test requirements),
– time period during the test when the engine is not warmed up yet; the time for this test was 5 minutes (this value is acceptable for the test),
– the share of individual test stages in the whole test: urban drive was 33.20%, rural drive was 26.49%, and motorway drive was 40.31% (all obtained values meet the requirements of the test),
– the average speed in urban drive must be between 15 and 40 km/h; the test reached a value of 16.09 km/h (value lies within test limits),
– share of speed over 145 km/h on the motorway; this speed was not exceeded in the test (the value meets the test requirements),
– share of drive time with speed over 100 km/h on the motorway section must be at least 5 minutes; the test reached the value of 9.28 minutes (the value is acceptable),
– the share of time spent stationary during urban drive section must be between 6 and 30%; in test this value was 45.32% (the value does not meet the test requirements),
– the altitude difference between the starting and ending point of the test drive must be less than 100 m; the value reached in the test was 7.6 m (the value is acceptable).

a)

Trip characteristics	Urban	Rural	Motorway	Complete
Trip distance	> 16 km	> 16 km	> 16 km	
	16.58	11.54	23.18	51.30
Total trip duration				90-120 min
				89
Cold start duration				min 5 min.
				5
Distance share	29-44%	23-43%	23-43%	
	32.33	22.49	45.18	100.00
Average speed	15-40 km/h			
	14.69	72.85	118.35	34.58
Motorway speed above 145 km/h			< 3%	
			0,00	
Motorway speed above 100 km/h			>= 5 min	
			9.45	
Urban stop time				6-30%
				47.72
Start and end points elevation absolute difference				<= 100 m
				7.10
RPA	0.17	0.06	0.05	
95th percentile Speed*Acc	10.01	10.63	20.79	

b)

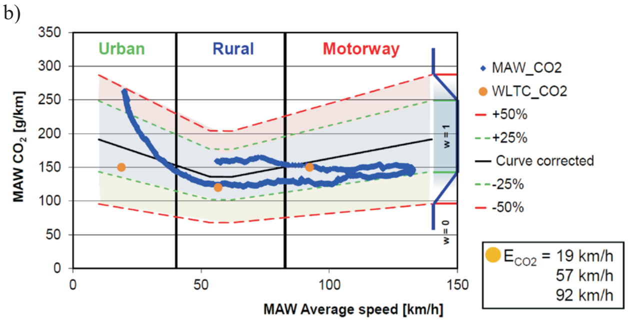


Fig. 9. Characteristics of the test route for a vehicle with a diesel engine (a) and CO_2 characteristic curve (b)

The obtained road emission values of pollutants (carbon monoxide and nitrogen oxides) for a vehicle with a gasoline engine were used to determine the conformity factors, whose maximum value as of 2020 will be 2.1 (factor value was obtained by dividing the measured road emission value by the emission limit b_{CO} equal to 1000 mg/km or by the emission limit of NO_x equal to 60 mg/km); The following values were obtained:

– road conformity factor of carbon monoxide: in the urban section – 0.092, in the rural section – 0.189, on the motorway – 0.229; average measured value during the test was 0.169 (Fig. 10a);
– road conformity factor of nitrogen oxides: in the urban section – 0.374, in the rural section – 0.726, on the motorway – 1.198; average measured value during the test was 0.762 (Fig. 10b).

For the vehicle with the diesel engine the following values were obtained:

– road conformity factor of carbon monoxide: in the urban section – 0.2, in the rural section – 0.174 on the motorway – 0.656; average measured value during the test was 0.342 (Fig. 11a);
– road conformity factor of nitrogen oxides: in the urban section – 1.165, in the rural section – 1.314, on the motorway – 4.391; average measured value during the test was 2.279 (Fig. 11b);

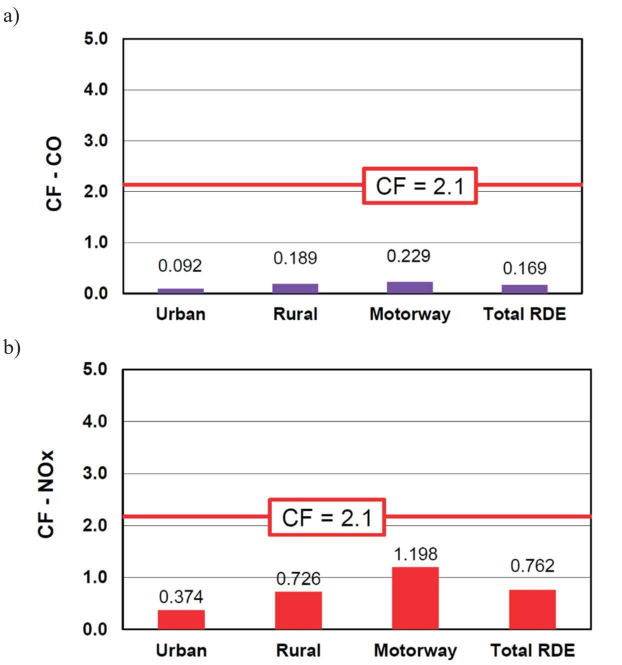


Fig. 10. Conformity factors of carbon monoxide (a) and nitrogen oxides (b) obtained in each test section for vehicle with a gasoline engine

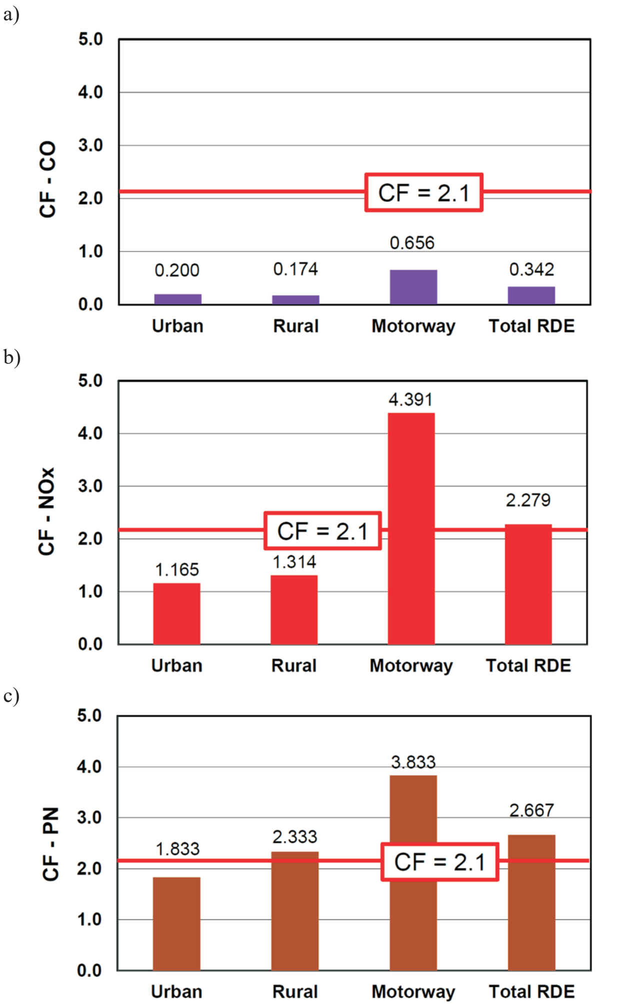


Fig. 11. Conformity factors of carbon monoxide (a) nitrogen oxides (b) and particle number (c) obtained in each test section for vehicle with a diesel engine

– road conformity factor of particle number: in the urban section – 1.833, in the rural section – 2.333, on the motorway – 3.833; average measured value during the test was 2.667 (Fig. 11c).

3.3. Power binning method

The power binning method uses pollutants emission concentrations, which are classified in accordance with the corresponding power at the wheels, and then using weighting factors to determine the emission values of the RDE test. Power bins and their corresponding share of time in the RDE test were established so as to be representative of each LDV (Table 3).

Table 3. Normalized shares of power for vehicle in an urban environment and the entire RDE test

Power bin	P_{norm} [–]		Share [%]	
	from (>)	to (≤)	urban	whole test
1		–0.1	21.98	18.5611
2	–0.	0.1	28.79	21.8580
3	0.1	1.0	44.00	43.4500
4	1.0	1.9	4.74	13.269
5	1.9	2.9	0.45	2.3767
6	2.9	3.7	0.045	0.4232
7	3.7	4.6	0.040	0.0511
8	4.6	5.5	0.004	0.0024
9	5.5		0.0003	0.0003

The values of P_{norm} are normalized using the equation:

$$P_{norm} = \frac{P_{RDE}\,[kW]}{P_{NEDC}\,[kW]} \quad (1)$$

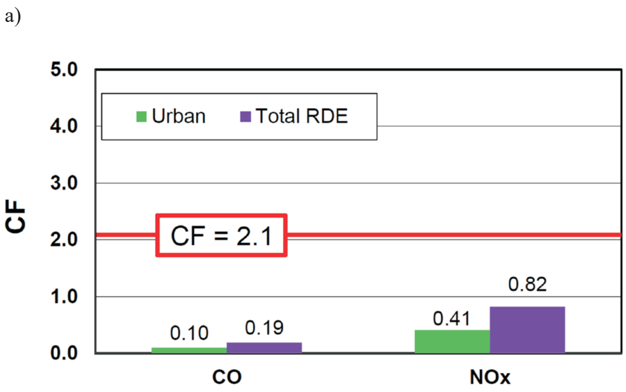
where: P_{RDE} – power at the wheels at that point in time of the RDE test [kW], and P_{NEDC} [kW] is the power at the wheels of the test vehicle in a type approval test on a chassis dynamometer.

The end emission result is achieved by determining the product of road emissions in every power bin and the share of time of each bin in the entire test drive (Fig. 12). For a vehicle with a gasoline engine the following estimates of road emissions (CF) were obtained: carbon monoxide – 0.10 (in the urban section), and 0.19 (whole RDE test) and the conformity factor of nitrogen oxides – 0.41 and 0.82, in the urban section of the test and the whole RDE test respectively. For a vehicle with a diesel engine the conformity factor values were as follows: carbon monoxide 0.23 and 0.35, nitrogen oxides 1.31 and 2.40 and particle number of 2.12 and 2.82, in the urban section alone and the whole test respectively.

4. Conclusions

By comparing the conformity factors (CF) of emissions in RDE tests the following values were obtained:

– For the vehicle with the gasoline engine: the obtained conformity factor values for carbon monoxide emission were 0.22, 0.17 and 0.19 (using all measurement data,



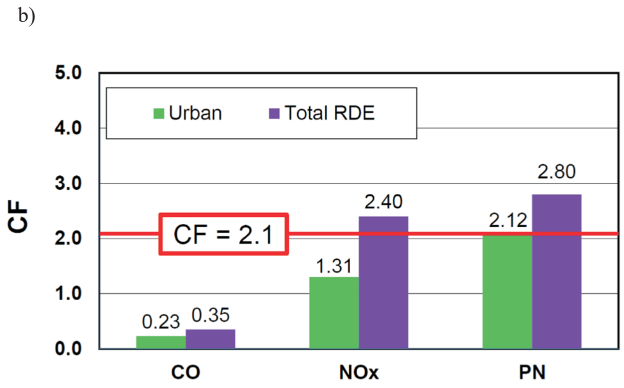


Fig. 12. Conformity factors of carbon monoxide and nitrogen oxides from gasoline vehicle (a) and carbon monoxide, nitrogen oxides and particle number for a diesel vehicle (b)

using the method of moving average windows and using the method of power binning respectively) – the resulting relative difference was 30%; for the emission of nitrogen oxides obtained values were 0.89, 0.76 and 0.82 (for the respective methods) – and the obtained relative difference was 17% (Fig. 13);

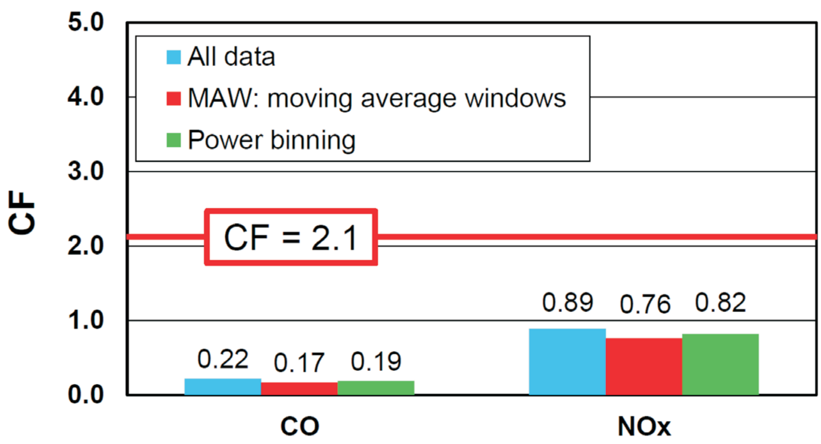


Fig. 13. Conformity factors of carbon monoxide and nitrogen oxides emissions from tests employing different methods of processing results (gasoline engine)

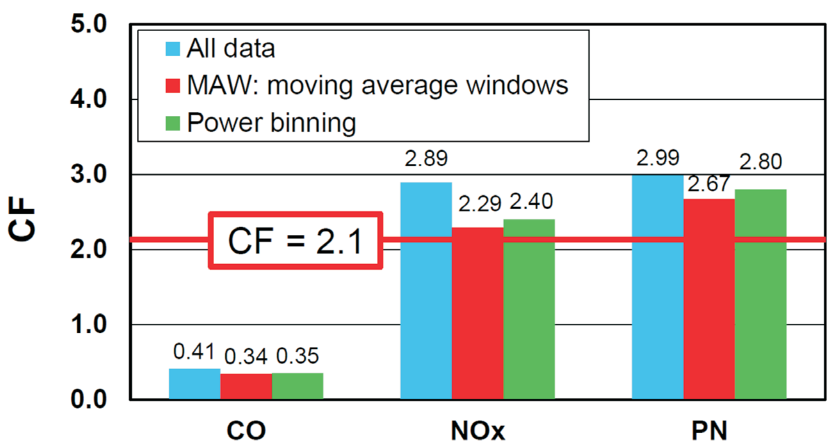


Fig. 14. Conformity factors of carbon monoxide, nitrogen oxides and particle number emissions from tests employing different methods of processing results (diesel engine)

– For the vehicle with the diesel engine: the obtained conformity factor values for carbon monoxide emission were 0.41, 0.34 and 0.35 (using respective methods) – the obtained relative difference was 20%, the obtained conformity factors of nitrogen oxides had a value of 2.89, 2.29 and 2.40 – the obtained relative difference was 27%, and the conformity factor value of particle number was 2.99, 2.67 and 2.80 – the obtained relative difference was 12% (Fig. 14).

Based on the pollutants emission results and conformity factors it should be concluded that road emission conformity factors of CO and NO_x are not exceeded for the vehicle powered by a gasoline engine, while for the vehicle powered by a diesel engine, it was found that limit values were exceeded for emission of nitrogen oxides (CF_{NOx} = 2.29–2.89, with the limitation CF_{NOx} = 2.1 for all result analysis methods) and for particle number (CF_{PN} = 2.67–2.99, with the limitation CF_{PN} = 2.1). It should be noted that the highest values of emission were obtained using all the measured data. This is mainly due to the fact that this method does not rejected any sections of the test (in the moving average windows method for example: stationary measurements lasting more than 3 minutes are discarded – and for this method the lowest values of emission were achieved). Using the method of power binning produced conformity factors that are between the minimum (moving average window method) and the maximum obtainable value from all the measurement data. However, this is the most complex method, as it requires knowledge of such things as: factors determining the power used in the test on a chassis dynamometer and road emissions of carbon dioxide in the various phases of the certification test for cars, specified by the Euro 6 norm.

Nomenclature

PB Power Binning
CADC Common Artemis Driving Cycles
CF Conformity Factor
CLEAR Classification of Emissions from Automobiles in Real driving
COPERT Computer Programme to calculate Emissions from Road Transport
EMROAD software (Excel add-in) used to analyze on-road emissions data measured with Portable Emissions Measurement Systems
HDV Heavy Duty Vehicles
MAW Moving Average Windows
NEDC New European Driving Cycle
PEMS Portable Emission Measurement System
RPA Relative Positive Acceleration
RDE Real Driving Emission
SCR Selective Catalyst Reduction
WLTC Worldwide Harmonized Light vehicles Test Cycle
WLTP Worldwide Harmonized Light vehicles Test Procedure
WMTC Worldwide Motorcycle Test Cycle

Bibliography

[1] Commission Regulation (EC) 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles, 2009.
[2] Commission Regulation (EU) 2016/427 of 10 March 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6), 2016.
[3] Commission Regulation (EU) 2016/646 of 20 April 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6), 2016.
[4] Commission Regulation (EC) 692/2008 of 18 July 2008 implementing and amending Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information, 2008.
[5] Commission Regulation (EC) 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information, 2007.
[6] Feist, M.D., Sharp C.A., Spears M.W. Determination of PEMS Measurement Allowances for Gaseous Emissions Regulated under the Heavy-Duty Diesel Engine In-Use Testing Program Part 1-Project Overview and PEMS Evaluation Procedures. SAE International Journal of Fuels and Lubricants, 2 (1), 2009, 435–454.
[7] Fontaras, G., Franco, V., Dilara, P., Martini, G., Manfredi, U. Development and Review of Euro 5 Passenger Car Conformity factors Based on Experimental Results Over Various Driving Cycles. Science of the Total Environment, 468–469, 2014, 1034–1042, doi:10.1016/ j.scitotenv.2013.09.043.
[8] Franco, V., Kousoulidou, M., Muntean, M., Ntziachristos, L., Hausberger, S., Dilara, P. Road Vehicle Conformity factors Development: A Review. Atmospheric Environment, 70, 2013, 84–97, doi:10.1016/j.atmosenv.2013.01.006.
[9] Kousoulidou, M., Fontaras, G., Ntziachristos, L., Bonnel, P., Samaras, Z., Dilara, P. Use of Portable Emissions Measurement System (PEMS) for the Development and Validation of Passenger Car Conformity factors. Atmospheric Environment, 64, 2013, 329–338, doi:10.1016/j.atmosenv.2012.09.062.
[10] Ligterink, N., Kadijk, G., van Mensch, P., Hausberger, S., Rexeis, M. Investigations and Real World Emission Performance of Euro 6 Light-Duty Vehicles. TNO Report, R11891, 2013, 1–53.
[11] May, J., Favre, C., Bosteels, D. Emissions from Euro 3 to Euro 6 Light-Duty Vehicles Equipped with a Range of Emissions Control Technologies. Association for Emissions Control by Catalyst, London 2013.
[12] Official Site of the COPERT 4 Model (2008), http://lat.eng.auth.gr/copert (accessed 11.07.2016).
[13] Pielecha, J., Merkisz, J., Jasiński, R., Gis, W. Real Driving Emissions Testing of Vehicles Powered by Compressed Natural Gas. SAE Technical Paper 2015-01-2022, 2015, doi:10.4271/2015-01-2022.
[14] Pielecha, J., Merkisz, J., Stojecki, A., Jasiński, R. Measurements of Particles Mass, Number and Size Distribution from Light-Duty Vehicles in Conditions of Variable Terrain Topography. 19th ETH-Conference on Combustion Generated Nanoparticles, Zurich 2015.
[15] UNECE Global Technical Regulation No. 15. Worldwide Harmonized Light Vehicles Test Procedure. UNECE, Geneva, Switzerland, 2015; http://www.unece.org/fileadmin/DAM/trans/ main/wp29/wp29r-1998agr-rules/ECE-TRANS-180a15e.pdf.
[16] UNECE Regulation No. 83 – Revision 5. Uniform Provisions Concerning the Approval of Vehicles with Regard to the Emission of Pollutants According to Engine Fuel Requirements; UNECE: Geneva, Switzerland, 2015; http://www.unece.org/fileadmin/DAM/trans/main/wp29 /wp29regs/r083r4e.pdf.
[17] Weiss, M., Bonnel, P., Hummel, R., Provenza, A., Manfredi, U. On-Road Emissions of Light-Duty Vehicles in Europe. Environmental Science and Technology, 45, 2011, 8575–8581.

Prof. Jerzy Merkisz, DSc., DEng. – Professor in the Faculty of Machines and Transport at Poznan University of Technology.

e-mail: *jerzy.merkisz@put.poznan.pl*

Jacek Pielecha, DSc., DEng. – Professor in the Faculty of Machines and Transport at Poznan University of Technology.

e-mail: *jacek.pielecha@put.poznan.pl*