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Analysis of particle emissions of passenger cars in RDE tests

Jerzy Merkisz[1,*], *Lukasz* Brzezinski[1], *Agnieszka* Magdziak[1], and *Kinga* Skobiej[1]

[1]Poznan University of Technology, Institute of Combustion Engines and Transport, Piotrowo Street 3, 60-965 Poznan, Poland

Abstract. The main issues addressed by the article are dimensional analysis of solid particles emitted by passenger cars operating in real driving conditions. It is a part of the current research trend focused on searching pro-ecological solutions related to determining the environmental impact of road transport. Special emphasis was placed on the comparison of the ecological parameters of passenger cars fuelled with petrol (conventional and hybrid) and diesel. All tests were carried out in accordance with the applicable requirements of the European Union. This approach will expand the knowledge base on the ecological properties of vehicles moving in urban, rural area and on highways.

1 Introduction

The latest research on pollutant emissions in real traffic conditions performed with the use of portable measurement devices [1] accurately reflects the ecological status of vehicles. The possibility of using such tests to calibrate drive units [2], in such a way as to limit the emission of pollutants not only during the test, but also in the whole range of engine operation [3] is one of the most focused aspects. Comparative tests carried out in laboratories [4] indicate that the operation of vehicles with gasoline engines meets the emission limits (also in hybrid propulsion systems [5, 6]), while also proving that vehicles with diesel engines significantly exceed the permissible nitrogen oxides emission limit [7]. The significant emission of particulate matter is pointed out, mainly in the nanoparticles range emitted also by internal combustion engines powered by alternative fuels (e.g. natural gas) as well as the dependence of the obtained research results from other test aspects, such as terrain topography [8]. The results of such tests do not currently yield specific values, but they are confirmed by articles describing several years of research [9] and comprehensive summaries of vehicle tests in real driving conditions [10, 11].

Starting from 1.09.2017, the type approval process for a new type of passenger car in the European Union includes a emissions measuring procedure in real driving conditions. The European Union Regulation (715/2007 [12] and 692/2008 [13]) on RDE tests is a response to the results of research [4] regarding the increased emission of nitrogen oxides from cars equipped with compression ignition engines, despite the fact that such vehicles met the appropriate emission standards in laboratory test conditions. According to the new

* Corresponding author: jerzy.merkisz@put.poznan.pl

rules [14, 15], in all new type approvals from 1.09.2017, or from 1.09.2019 in the case of new registrations of vehicles, the emission of nitrogen oxides measured in real driving conditions will not be permitted to exceed 2.1 times the maximum laboratory test limit (for the particle number this value will be 1.5). However, starting from January 1, 2020 for a new type approvals (and from January 1, 2021 for new registrations) this coefficient will be reduced to 1.5 for both emission categories (Fig. 1).

2015	2016	2017	2018	2019	2020	2021	2022
Euro 6b			Euro 6c			Euro 6d	
NEDC			WLTC				
Development and measurement phase			Conformity Factor (CF)				
			CF_{NOx} = 2.1, CF_{PN} = 1.5			$CF_{NOx, PN}$ = 1.5	
RDE for CO, NO_x, PN emissions: EC 427/2016 and EC 646/2016						CO, NO_x, PN and CO_2 ???	

Fig. 1. RDE test requirements in Europe [14, 15].

2 Research aim and methodology

The aim of the performed tests was to determine the average road emissions values of the number of solid particles and their dimensional distributions for each of the tested vehicles in the urban, rural and motorway driving sections. All vehicle tests were carried out using the same route, selected specifically so that the emission test requirements were met, and the correctness of the test data was ensured. The test route consisted of the urban part, the rural part and the motorway section. The total length of the test route was approx. 75 km. In the context of emission tests in real driving conditions, the EEPS 3090 analyzer from TSI Incorporated was used to measure the number of particles emitted as well as their size distribution. The mass spectrometer enabled the study of the size distribution and total number of emitted particles.

3 Test objects

Three vehicle models, differing in power system solutions, were tested. The first of the tested vehicles was equipped with a Diesel engine with a common-rail direct injection of diesel fuel, with a turbocharger and a displacement volume of 1.4 dm^3 (Fig. 2a). The second tested vehicle had an MPI gasoline engine with a displacement of 1.6 dm^3 (Fig. 2b). The last object was a hybrid vehicle, equipped with a spark-ignition engine with intermediate multi-point gasoline injection system (MPI) with a 1.8 dm^3 displacement, operating together with an electric motor in a parallel system (Fig. 2c). Detailed characteristics and specifications of the tested vehicles are presented in Table 2.

a) b) c)

Fig. 2. Vehicles prepared for RDE research; a) a vehicle with a Diesel engine, b) a vehicle with a gasoline engine, c) a hybrid vehicle.

Table 2. Drive system characteristics of the test vehicles.

Parameter	Diesel engine	Gasoline engine	Hybrid vehicle
Engine/fuel type	Diesel with a turbocharger/DI	SI/MPI	SI/MPI+ electric engine
Number of cylinders/valves	R4/8	R4/16	R4/16
Maximum power at engine speed [kW]/[rpm]	66/3800	97/6400	73/5200 (combustion), 100 (hybrid)
Torque [Nm]	205/1400-2800	160/4400	142/4000
Curb weight [kg]	1250	1240	1415

4 Results

The individual vehicle drives were characterized by a significant degree of similarity, which is visualized in Figure 3. Speed profiles for the three vehicles used in the tests have been shown in the same figure.

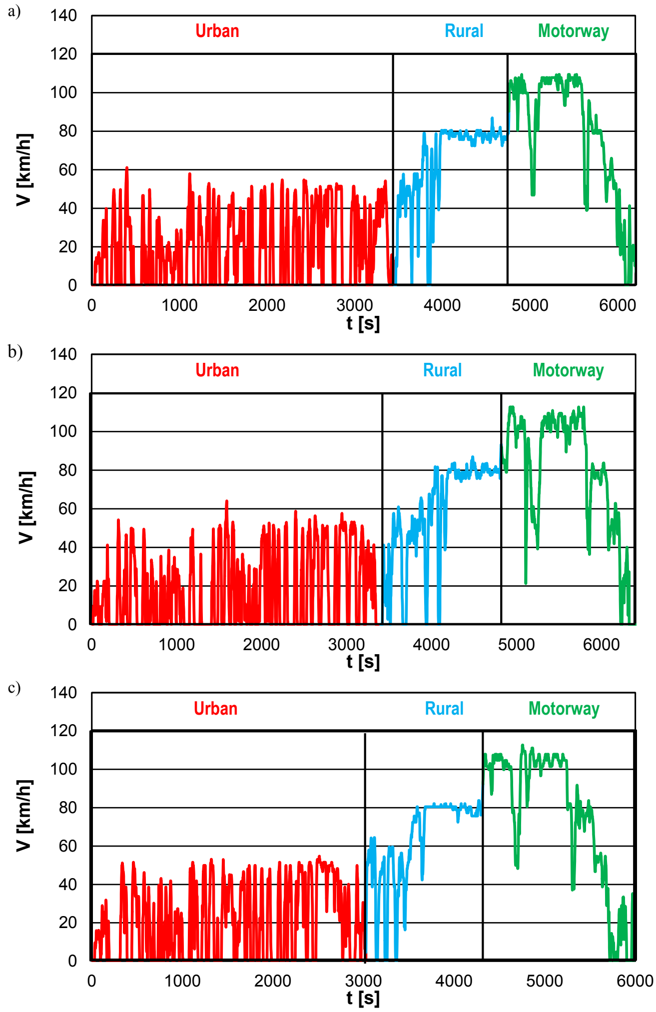

Fig. 3. Speed profiles in road tests for vehicles: a) powered with a Diesel engine, b) powered with a gasoline engine, c) with a hybrid engine.

The emission of solid particles from a Diesel engine vehicle with a particulate filter varies depending on the route taken. The highest particle number emission values were recorded in the case of driving through urban areas – the value of $1.4 \cdot 10^{12}$ km^{-1} was obtained, in the urban driving section this was $5.6 \cdot 10^{11}$ km^{-1}, and $4.2 \cdot 10^{11}$ km^{-1} for the motorway drive. The average particle number road emission obtained in the whole test was $8.1 \cdot 10^{11}$ km^{-1}.

Within the obtained size distributions of the particle number for a vehicle powered by a Diesel engine (Fig. 4) it was found that:

• in the urban driving section the most (about $7.5 \cdot 10^{6}$ cm^{-3}) particles are emitted in the size range of 34–60 nm; another local maximum (about $1.0 \cdot 10^{6}$ cm^{-3}) were particles with size of about 10 nm,

• in the rural driving section the most (about $1.8 \cdot 10^{6}$ cm^{-3}) of the emitted particles had a size of about 10 nm; another local maximum (about $6 \cdot 10^{5}$ cm^{-3}) were particles with size of about 40 nm,

• in the motorway driving section the most (about $1.5 \cdot 10^{6}$ cm^{-3}) of the emitted particles had a size of about 10 nm; another local maximum (about $7 \cdot 10^{5}$ cm^{-3}) were particles with size of about 40 nm.

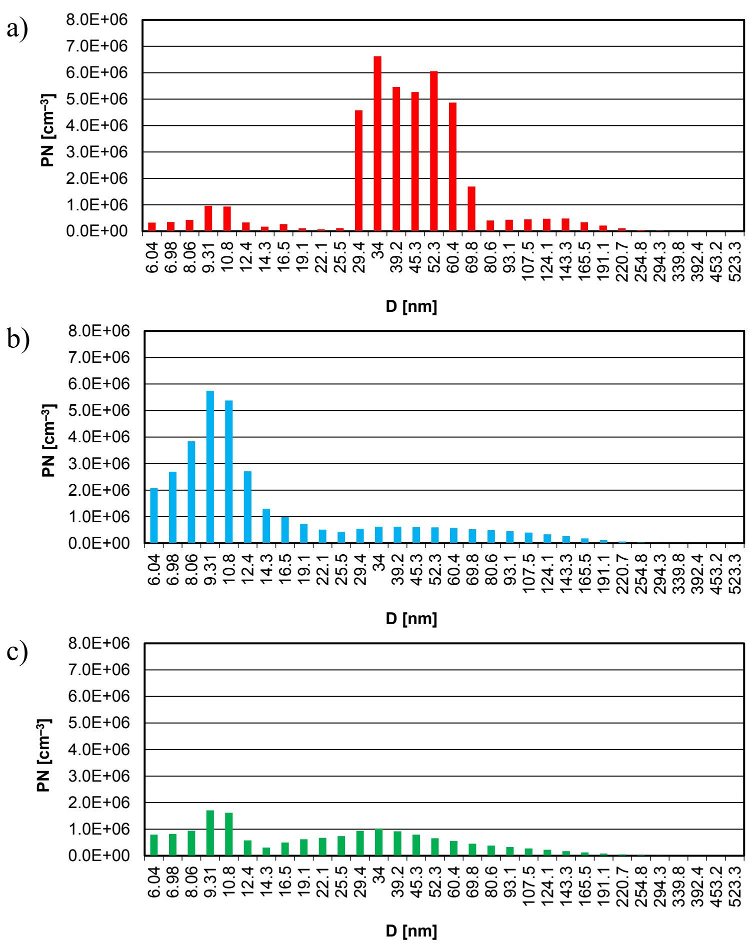

Fig. 4. Particle number size distributions for a vehicle with a Diesel engine with a particulate filter when driving in: a) urban, b) rural, c) motorway conditions.

The particle number emission from a vehicle with a gasoline engine varies depending on the route taken. The highest numerical emission values were obtained for vehicle travelling in urban areas $6.4 \cdot 10^{10}$ km^{-1}, for rural driving $9.2 \cdot 10^{10}$ km^{-1}, and $9.0 \cdot 10^{10}$ km^{-1} for motorway section. The average road emission of the number of particulates in the whole test was equal to $8.2 \cdot 10^{10}$ km^{-1}.

Within the obtained size distributions of the particle number for a vehicle powered by a gasoline engine (Fig. 5) it was found that:

- for the urban drive section the most emitted particles (about $7.5 \cdot 10^{6}$ cm^{-3}) are in the size range of 34–60 nm; another local maximum (about $1.0 \cdot 10^{6}$ cm^{-3}) was found for particles with size of about 10 nm,
- for the rural drive section the most (about $1.8 \cdot 10^{6}$ cm^{-3}) of the emitted particles had a size of about 10 nm; another local maximum (about $6 \cdot 10^{5}$ cm^{-3}) were particles with size of 40 nm,
- the majority of the emitted particles for the highway section (about $1.5 \cdot 10^{6}$ cm^{-3}) had a size of 10 nm; another local maximum (about $7 \cdot 10^{5}$ cm^{-3}) was found for particles sized 40 nm.

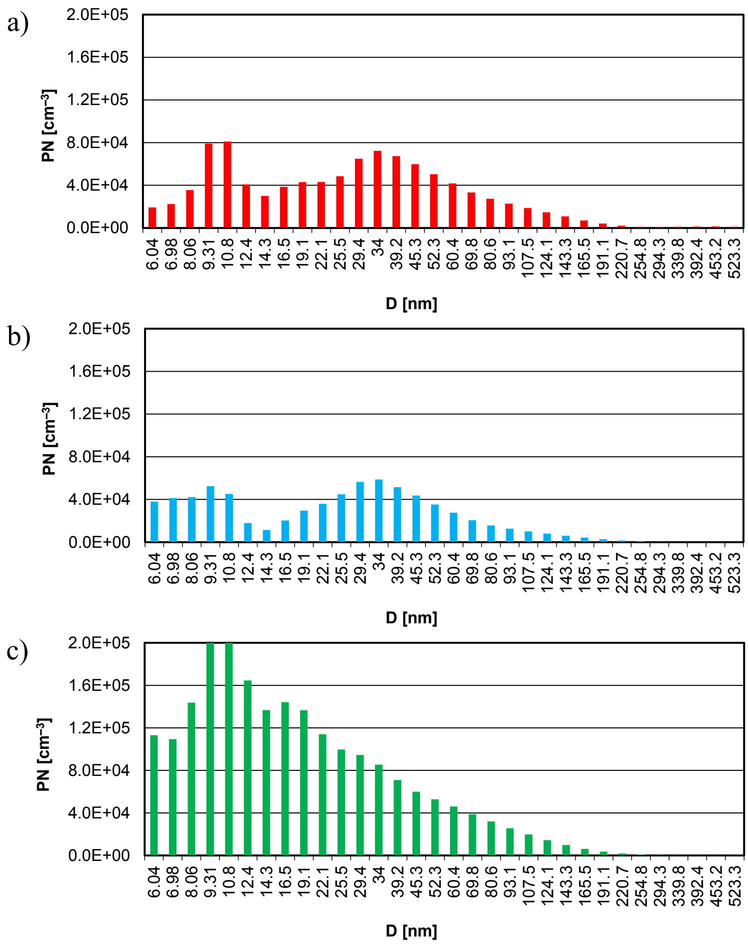

Fig. 5. Particle number size distributions for a vehicle with a gasoline engine when driving in: a) urban, b) rural, c) motorway conditions.

The particle number emission from a hybrid vehicle was dependent on the route taken. The highest numerical emission values were obtained for vehicle travelling in urban areas –

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emission value of $1.4 \cdot 10^{12}$ km^{-1}, while for rural drive section the emission was $5.2 \cdot 10^{11}$ km^{-1}, and $5.5 \cdot 10^{11}$ km^{-1} for the motorway section. The average road emission of the number of particulates in the whole test was equal to $8.4 \cdot 10^{11}$ km^{-1}.

Within the obtained size distributions of the particle number for a hybrid vehicle (Fig. 6) it was found that:

• for the urban drive section the most (about $6 \cdot 10^5$ cm^{-3}) of the emitted particles had a size in the range of 70–80 nm; another local maximum (about $1.5 \cdot 10^5$ cm^{-3}) was found for particles with the size of about 10 nm,

• for the rural drive section most of the particles emitted (about $0.8 \cdot 10^5$ cm^{-3}) were in the size range of 70–80 nm; another local maximum (about $0.5 \cdot 10^5$ cm^{-3}) was observed for particles the size of about 10 nm,

• for the motorway section the most (about $2.5 \cdot 10^5$ cm^{-3}) particles emitted have a size of about 10 nm.

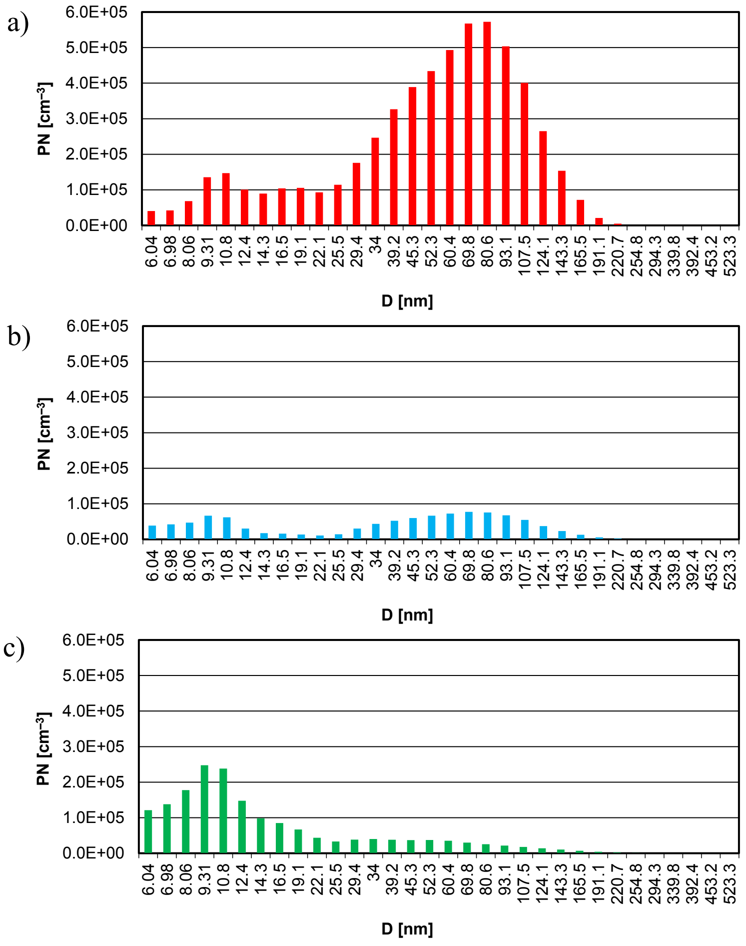

Fig. 6. Particle number size distributions for a hybrid vehicle when driving in: a) urban, b) rural, c) motorway conditions.

When comparing the particle number size distributions in the whole test, it should be noted that the largest concentration of the particle number was observed for the vehicle with a Diesel engine, where the number of particles with the characteristic diameter (30–60 nm) was about 10 times higher than for a hybrid vehicle and vehicle with a gasoline engine (Fig. 7).

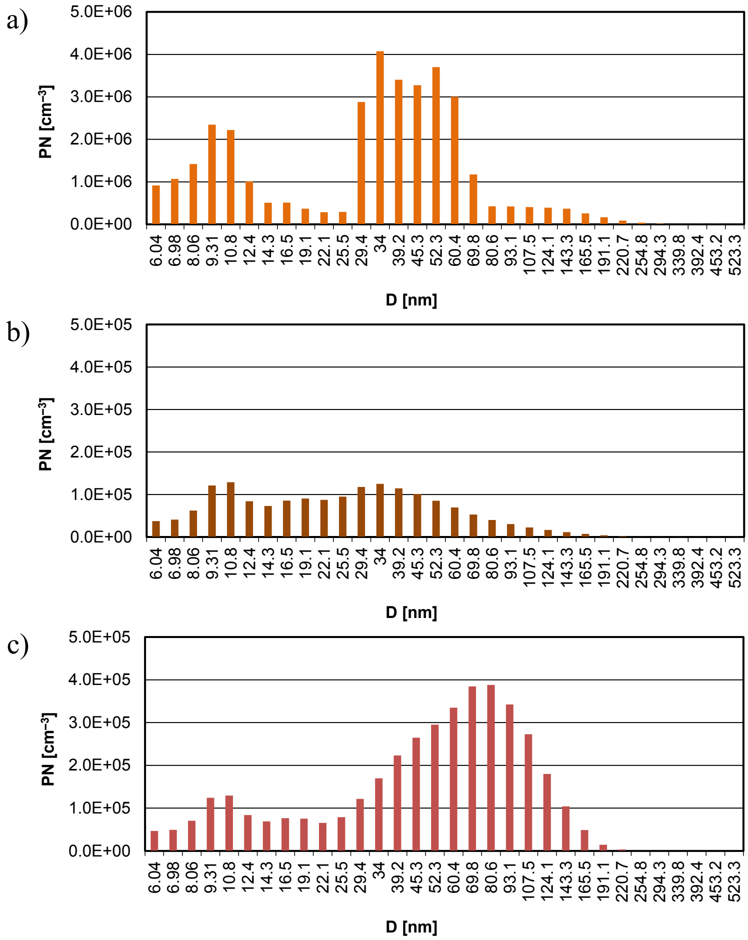

Fig. 7. Particle number size distributions in the whole test for vehicles: a) with a Diesel engine and particulate filter, b) with a gasoline engine, c) with a hybrid drive.

5 Conclusions

The nanoparticle emission from internal combustion engines applies to all types of engines: both for diesel and gasoline engines (including in hybrid systems). The presented research results showed that the highest numerical emission of nanoparticles occurs in diesel engines (in the RDE test this was $8.1\cdot10^{11}$ km^{-1}), and the smallest for a vehicle equipped with a gasoline MPI engine (in the RDE test this was $8.2\cdot10^{12}$ km^{-1}). Thus, it was 10 times lower than the value obtained for a diesel vehicle.

Also the particle size distribution is not the same for different types of engines:

- for a Diesel engine with a particulate filter the most common particle size range is 50–80 nm,
- for a gasoline engine the highest number of emitted particles are in the size range 30–50 nm,
- for a gasoline engine (in a hybrid system) this particle size range was 80–100 nm.

It should be noted that the smallest size particles were mostly emitted by the Diesel engines with a particulate filter (but their number was high), and the largest particles were emitted by the gasoline engine (in the hybrid drive system), which resulted from the high engine load in the periods of charging the vehicle battery with electricity.

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References

1. T. Bougher, I. Khalek, S. Trevitz, M. Akard, SAE Technical Paper 2010-01-1069 (2010)
2. D. Bergmann, *Developing the technology innovation process for further emissions reduction* (6th Integer Diesel Emissions Conference and Diesel Exhaust Fluid Forum, Atlanta, 2013)
3. J. Pielecha, J. Merkisz, J. Markowski, J. Jasinski, E3S Web of Conferences, **10** (2016)
4. G. Fontaras, V. Franco, P. Dilara, G. Martini, U. Manfredi, Sci. Total Environ. **468-469** (2014)
5. I. Pielecha, W. Cieslik, A. Szalek, Eksploat. Niezawodn. **20**, 16–23 (2018)
6. I. Pielecha, W. Cieslik, A. Szalek, Int. J. Precis. Eng. Manuf. **18**, 1633–1639 (2017)
7. N. Ligterink, G. Kadijk, P. van Mensch, S. Hausberger, M. Rexeis, TNO Report, R11891 (2013)
8. J. Merkisz, J. Pielecha, *Nanoparticle Emissions from Combustion Engines*, *Springer Tracts on Transportation and Traffic*, **8** (2015)
9. Y. Chen, J. Borken-Kleefeld, Atmos. Environ. **88**, 157–164 (2014)
10. A. Kufferath, M. Krüger, D. Naber, R. Maier, J. Hammer, International Vienna Motor Symposium (Wien, 2017)
11. S. Kruczynski, M. Slezak, W. Gis, Przemysl Chemiczny **95**, 1025–1028 (2016)
12. 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, European Commission (EC), Official J. European Union, L 171 (2007)
13. Commission Regulation (EC) 692/2008 of 18 July 2008 implementing and amending Regulation (EC) 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, European Commission (EC), Official J. European Union, L 199 (2008)
14. 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), Verifying Real Driving Emissions, Official J. European Union, L 109 (2016)
15. 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), Verifying Real Driving Emissions, Official J. European Union, L 82 (2016)