Chapter 3
Type Approval of Light-Duty Vehicles in Terms of Emission of Pollutants

3.1 Principles of Type Approval

Regulation 715/2007 determines two levels of requirements as regards emission of pollutants: Euro 5 and Euro 6. In its Regulation 692/2008 the European Commission divided each of those levels into two subsets marked with the letters "a" and "b" (Euro 5a, Euro 5b, Euro 6a, Euro 6b). This further division was introduced in connection with the change of the measurement methodology of PM emissions. The letter "a" denotes a method identical to the one used in Euro 4, while the letter "b" denotes a new method, suitable for measuring low PM values in exhaust gases. The first method was valid until 31.09.2011 for NTA and until 31.12.2012 for ANR, while the other one took effect thereafter.

In its regulation the European Commission additionally prescribes levels relating to the OBD system, marked as Euro 5+, Euro 6– and Euro 6–plus IUPR. Euro 6– and Euro 6–plus IUPR are exclusively applicable to vehicles with CI engines.

The effective dates of the new legislation for light-duty vehicles depend on three factors:

- prescribed level relating to the emission of pollutants,
- prescribed level relating to the OBD system,
- vehicle category and class.

There are a total of 25 combinations of the above factors, and thus 25 type approval variants. To easily identify the variant according to which the vehicle in question was approved, each variant is marked with capital letters of the Latin alphabet, from A to Y (Tab. 3.1). The letter is included in the type approval number. The effective dates for vehicles in categories M and N1 class I are stated in Tab. 3.1. For other vehicles affected by the new legislation, i.e. those in categories N1 class II, N1 class III and N2 those dates are usually postponed by a year.

The new legislation is applicable to the following light-duty vehicles:

- powered by internal combustion engines only,
- hybrid electric vehicles (HEVs),
- electric.

J. Merkisz, J. Pielecha, and S. Radzimirski, *New Trends in Emission Control in the European Union*, Springer Tracts on Transportation and Traffic 4,
DOI: 10.1007/978-3-319-02705-0_3, © Springer International Publishing Switzerland 2014

Depending on fuel type, vehicles powered by internal combustion engines and HEVs and covered by the new legislation are divided into:

Table 3.1 Symbols and effective dates of type approval variants according to the EU's new legislation for vehicles in categories M and N1 class I

Letter code	Requirement level relating to the emission of pollutants	Requirement level relating to the OBD system	Engine	NTA date	ANR date	Date by which registration is allowed
A	Euro 5a	Euro 5	SI, CI	1.09.2009	1.01.2011	31.12.2012
F	Euro 5b	Euro 5	SI, CI	1.09.2011	1.01.2013	31.12.2013
J	Euro 5b	Euro 5+	SI, CI	1.09.2011	1.01.2014	31.08.2014
N	Euro 6a	Euro 6–	CI	–	–	31.12.2012
Q	Euro 6b	Euro 6–	CI	–	–	31.12.2013
T	Euro 6b	Euro 6–plus IUPR	CI	–	–	31.05.2015
W	Euro 6b	Euro 6	SI, CI	1.09.2014	1.01.2015	–

- mono fuel vehicles equipped with:
  - SI engines running on: petrol, LPG, NG/biomethane, hydrogen,
  - CI engines running on diesel (B5),
- bi fuel vehicles equipped with SI engines running on petrol and LPG, petrol and NG/biomethane, petrol and hydrogen,
- flex fuel equipped with SI engines running on a mixture of petrol and ethanol (in any proportion) and CI engines running on a mixture of diesel and biodiesel.

Mono fuel vehicles powered by SI engines running on gaseous fuels (LPG, NG/biomethane, hydrogen) can be fitted with a petrol system, provided that the capacity of the petrol tank does not exceed 15 dm^3. The petrol system should be used for starting or emergency purposes only, to ensure mobility when the gaseous fuel is exhausted.

Bi fuel vehicles are those fitted with two separate systems (tanks) for storing two different fuels that can run on both of them and designed to run on only one fuel at a time. When switching from one fuel to the other the vehicle can run on both fuels for a very short time only. The legislation applies only to vehicles running on petrol and one of the aforementioned gaseous fuels. The vehicle can run on petrol or gaseous fuel. In the latter case running on petrol for a specified period of time is also allowed, typically after starting a cold or partially heated engine. Currently works are underway to develop a system where the choice of fuel in the gas mode depends not only on the engine temperature, but also on its load and speed.

Flex fuel vehicles can be powered with a mixture of two fuels of different compositions and physical and chemical properties, mixed in any proportion. Such vehicles are equipped with one fuel system (tank).

In accordance with Regulation 715/2007, the following reference fuels are used for testing:

- for mono fuel vehicles: petrol containing 5% (by volume) of ethanol marked with the symbol E5, diesel containing 5% (by volume) of biodiesel marked with the symbol B5, two kinds of LPG marked with the symbols A and B (varying in terms of propane content), two kinds of NG/biomethane marked with the symbols G20 and G25 (varying in terms of methane content), ethanol (85% by volume) with an addition of petrol marked with the symbol E85, hydrogen,
- for bi fuel vehicles: petrol (E5) and LPG, petrol (E5) and NG/biomethane, petrol (E5) and hydrogen,
- for flex fuel vehicles: petrol (E5) and ethanol (E85), diesel (B5) and biodiesel.

The legislation puts considerable emphasis on alternative fuels. To ensure comparability of conventional fuels with commercially available fuels, a 5% addition (by volume) of ethanol or biodiesel was introduced. The said percentage is planned to grow to 7 to 10% (by volume). The new legislation also applies to flex fuel vehicles for which one of the fuels is ethanol or biodiesel. The previous legislation did not apply to such vehicles.

The tests marked with number 1 to 8a, 9 and 11 were already in place in Euro 4 and earlier legislations (Tab. 3.2). In some of them changes to requirements and measurement methods were introduced. Also, there is a difference in the applicability of the test for specific vehicles. The new tests include measuring electricity consumption by electric vehicles (8b) and verification of the performance of the system for reducing nitrogen oxide emission (10). The first of these two tests has thus far been absent from EU legislation, but it was introduced in Regulation 101 [21] in 2005. Verification of the system that warns the driver and prevents operation if nitrogen oxide emission is exceeded is sometimes considered not to be a separate test, but rather part of the OBD system test. It is believed that it does constitute a separate test and is thus treated accordingly.

The principles of type approval and tests used for vehicles powered by an internal combustion or a hybrid electric engine only are identical. The only differences can be found in testing methodology for the emission of limited pollutants, carbon dioxide and fuel consumption.

Electric vehicles are only subject to electricity consumption testing (8b in Tab. 3.2). The other tests listed in Tab. 3.2 do not apply to those vehicles.

Neither requirements nor testing methods have been developed for vehicles powered by SI engines running on hydrogen, although the legislation formally applies to these vehicles as well. It is not likely that such requirements or tests will be developed in the near future. Therefore, this type of vehicles is excluded from this analysis.

Table 3.2 Test types according to Regulation 692/2008/EC required for type approval of light-duty vehicles

No.	Test type	Vehicles with SI engines (including hybrid)					Vehicles with CI engines (including hybrid)		Electric vehicles
		mono-fuel			bi-fuel	flex fuel	mono-fuel	flex fuel	
		petrol (E5)	LPG	NG/ biometan	petrol (E5) – LPG/ NG/ biometan	petrol (E5) – etanol (E85)	diesel (B5)	diesel (B5) – biodiesel	
1	I: measurement of pollution emission after cold start in ambient temperature from 20°C to 30°C in NEDC cycle on a chassis dynamometer:								
	– gaseous pollutants	yes	yes	yes	yes	yes	yes	yes[4)]	
	– particulate mass	yes (only DI engines)			yes (only DI engines running on petrol)	yes (only DI engines running on both fuels)	yes	yes[4)]	
	– particle number	yes	yes	yes	yes	yes	yes	yes[4)]	
2	II: Measurement of CO concentration and excess air coefficient at engine idle speed (for in-service conformity check)	yes	yes	yes	yes	yes			
3	III: measurement of vehicle crankcase emissions	yes	yes	yes	yes	yes			

Table 3.2 (*continued*)

4	IV: measurement of evaporative emissions	yes			yes	yes			
5	V: durability test of pollution control devices; durability test of 160,000 km	yes	yes	yes	yes	yes	yes	yes[4)]	
6	VI: Verifying low ambient temperature (–7°C) emissions after a cold start – UDC cycle	yes			yes	yes			
7	OBD test	yes	yes	yes	yes	yes	yes	yes[4)]	
8	a) Measurement of fuel consumption and CO_2 emission	yes	yes	yes	yes	yes	yes	yes[4)]	
	b) Electric energy consumption	yes[6)]	yes[6)]	yes[6)]	yes[6)]	yes[6)]	yes[6)]		yes
9	Smoke opacity measurement (for in-service conformity check)						yes	yes[4)]	
10	Verification of the nitrogen oxide emission control system	yes	yes	yes	yes	yes	yes	yes[4)]	
11	Net power measurement	yes	yes	yes	yes	yes	yes	yes[4)]	

1) For bi-fuel vehicles the tests in item 3, 4, 5 and 6 while running on petrol only.
2) For flex fuel vehicles (petrol E5 and ethanol E85) the tests in item 3, 4, 5 while running on petrol only; the test in item 6 while running on petrol only by 1.09.2015, and while running on both fuels thereafter.
3) For engines fitted with SI engines the test in item 1 as regards particle number is required under Euro 6; the prescribed values are to be set by 1.09.2014; it is unclear what types of fuel will be subject to this test.
4) For flex fuel (diesel and biodiesel) the principles of enforcing the test are currently being discussed. It is proposed that in the first stage the tests should apply only to diesel (B5).
5) If the vehicle is simultaneously classified as mono fuel and flex fuel, tests for both fuel systems should be used.
6) Only hybrid vehicles with off-vehicle charging of the energy storage system.

Table 3.3 Types of vehicles powered by a hybrid electric power train

Charging of the electricity storage system	Off-vehicle charging (OVC)		Not off-vehicle charging (NOVC)	
Operating mode switch	no	yes	no	yes

Tests applicable to hybrid electric vehicles depend on the method of charging the electricity storage system (Tab. 3.3).

HEVs without off-vehicle charging are subject to the tests applicable to vehicles powered by an internal combustion engine only. If the vehicle is fitted with an off-vehicle charging system, it is additionally subject to an electricity consumption test (Tab. 3.2).

It is not fully clear whether or not the new legislation also applies to electric vehicles fitted with an internal combustion engine used as a range extender, rather than for propulsion. Many companies have introduced such a solution or plan to do so in the immediate future. If one assumes that the new legislation also applies to such vehicles, then two sets of type approval tests are possible:

- principles, requirements and measurement methodology identical to those for vehicles powered by an internal combustion engine only,
- principles, requirements and measurement methodology identical to those for electric vehicles.

The legislation does not specify which of the above should be used for testing. Attention should be drawn to the fact that the use of measurement methodology applicable to vehicles powered by an internal combustion engine only is not technically reasonable, as it does not take into account that in the vehicles in question the internal combustion engine runs at intervals, and its working conditions (and thus emission of pollutants and fuel consumption) depend on the remaining battery power, etc.

Financial incentives referred to in 2.1 above can be offered in two cases:

- in the period from 2.07.2007 to 31.12.2010 for vehicles in categories M and N1 class I and in the period from 2.07.2007 to 31.12.2011 for vehicles in categories N1 classes II and III, N2 and the so-called vehicles designed to fulfill specific social needs providing Euro 5 limits are met (Tab. 3.4),
- in the period from 1.01.2011 to 31.08.2015 for vehicles in categories M and N1 class I and in the period from 1.01.2012 to 31.08.2016 for vehicles in categories N1 classes II and III and N2 providing Euro 6 limits are met (Tab. 3.4).

Table 3.4 Comparison of prescribed limits of pollution under Euro 4, Euro 5 and Euro 6

Category	Vehicle Class		CO [mg/km] SI	CO [mg/km] CI	THC [mg/km] SI	THC [mg/km] CI	NMHC [mg/km] SI	NMHC [mg/km] CI	NO_X [mg/km] SI	NO_X [mg/km] CI	THC + NO_X [mg/km] SI	THC + NO_X [mg/km] CI	PM[2] [mg/km] SI[1]	PM[2] [mg/km] CI	PN [km^{-1}] SI[5]	PN [km^{-1}] CI
							Euro 4									
M1 and M2 of MLM ≤ ≤ 2500 kg	–	all	1000	500	100	–	–	–	80	250	–	300	–	25	–	–
N1, M1 and M2 of 2500 kg < < MLM ≤ ≤ 3500 kg	I	RM ≤ 1305	1000	500	100	–	–	–	80	250	–	300	–	25	–	–
	III	1305 < RM ≤ 1760	1810	630	130	–	–	–	100	330	–	390	–	40	–	–
	IIII	1760 < RM	2270	740	160	–	–	–	110	390	–	460	–	60	–	–
							Euro 5[5] Euro 6									
M	–	all[6]	1000 1000	500 500	100 100	–	68 68	–	60 60	180 80	–	230 170	5.0/4.5 5.0/4.5	5.0/4.5 5.0/4.5	/[4]	6.0×10^{11} 6.0×10^{11}
	I	RM ≤ 1305	1000 1000	500 500	100 100	–	68 68	–	60 60	180 80	–	230 170	5.0/4.5 5.0/4.5	5.0/4.5 5.0/4.5	/[4]	6.0×10^{11} 6.0×10^{11}
N1	II	1305 < RM ≤ 1760	1810 1810	630	130 130	–	90 90	–	75 75	235 105	–	295 195	5.0/4.5 5.0/4.5	5.0/4.5 5.0/4.5	/[4]	6.0×10^{11} 6.0×10^{11}
	III[3]	1760 < RM	2270 2270	740	160 160	–	108 108	–	82 82	280 125	–	350 215	5.0/4.5 5.0/4.5	5.0/4.5 5.0/4.5	/[4]	6.0×10^{11} 6.0×10^{11}
N2	–	all	2270 2270	740	160 160	–	108 108	–	82 82	280 125	–	350 215	5.0/4.5 5.0/4.5	5.0/4.5 5.0/4.5	/[4]	6.0×10^{11} 6.0×10^{11}

1) Only applies to vehicles fitted with SI engines with direct injection, running on petrol.
2) The first value is effective until 31.09.2011 for NTA and until 31.12.2012 for ANR; the second value takes effect thereafter.
3) Also for all vehicles designed to fulfill specific social needs.
4) The prescribed limit will be set by 1.09.2014.
5) The numerator value applies to Euro 5, and the denominator value applies to Euro 6.

3.2 Type I Test

3.2.1 Limit Values

The basic differences between the new legislation and Euro 4 legislation in terms of exhaust emissions of limited pollutants consists in (Tab. 3.4):

- changed scope of application,
- introduction of requirements relating to new, previously unaddressed kinds of pollutants,
- reduced limits for limited (previously addressed) pollutants.

In Euro 4 legislation, the prescribed emission limits are expressed in g/km, while in Euro 5 and Euro 6 they are expressed in mg/km. There is also a different symbol denoting the sum of all hydrocarbons. In Euro 4 they were simply marked with HC. Due to the introduction of requirements for non-methane hydrocarbons the marking was changed to THC (total hydrocarbons). To facilitate comparability, Table 3.4 shows all limits in the same units (mg/km) and the sum of all hydrocarbons (total hydrocarbons) is marked with the same symbol (THC).

The new legislation provides two limits of PM emissions (Tab. 3.4). This change does not result from stricter requirements, but reflects a change of the measurement methodology. The first limit (5 mg/km) is used with the method used thus far (marked with the letter "a" in Tab. 3.1), while the other limit (4.5 mg/km) is used with the modified method, ensuring greater measurement accuracy of small particulates emission (marked with the letter "b" in Tab. 3.1).

One of the key factors affecting exhaust emissions is the vehicle total mileage. A typical relationship between these two parameters is presented in Fig. 3.1. Figure 3.1 shows that emissions gradually grow as the vehicle ages. Three phases of the said growth can be identified.

Phase 1 (mileage from 0 to 10,000 km) corresponds to the running-in period, during which emissions grow slightly, but nonetheless remain relatively low.

In phase 2 (mileage from 10,000 to 100,000 km) emission levels grow gradually in a fairly linear fashion. Towards the end of this stage the performance of pollution control devices (such as the catalytic converter or the EGR) drops dramatically. At this stage the emission level is expressed by means of the following formula:

$$e = e_{EI} + a\left(f - f_{EI}\right) \tag{3.1}$$

where: e – emission of pollutants at a given mileage [g/km],
e_{EI} – emission of pollutants at the end of stage 1 [g/km],
f – mileage [km],
f_{EI} – mileage at the end of phase 1 [km],
a – constant coefficient.

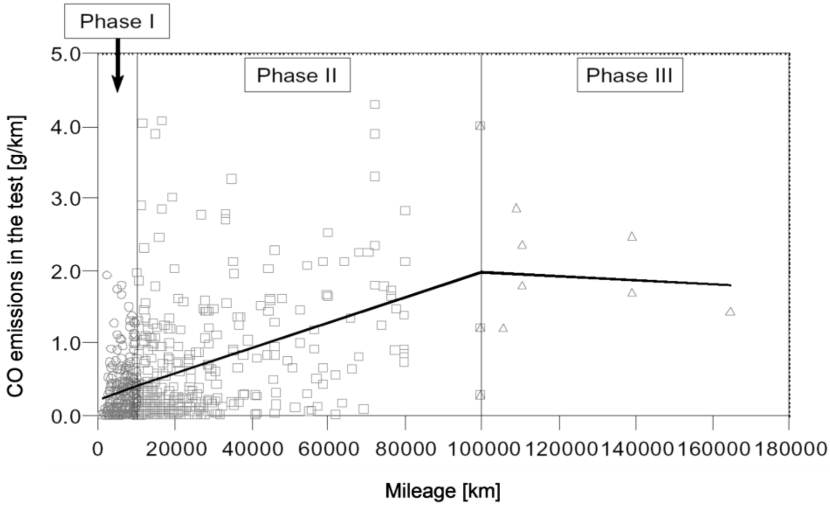


Fig. 3.1 Relationship between emissions and vehicle mileage [13]

In phase 3 (mileage above 100,000 km) emission tends to stabilize. Emissions can be significantly reduced by eliminating defects (e.g. adjustment or replacement of faulty pollution control devices).

The data in Fig. 3.1 refer to Euro 1 vehicles. For those vehicles phase 2 typically ends at a mileage of 100,000 to 120,000 km. According to [6], the relationship presented in the figure is also true for Euro 3 and Euro 4 vehicles; however, in their case phase 2 ends at a mileage of approximately 160,000 km (200,000 km for Euro 5 vehicles).

Pursuant to Directive 70/220/EEC (limited pollutant emissions), vehicles subjected to type approval tests must have a mileage of at least 3,000 km. The upper mileage limit is not specified, which is why high mileage vehicles are also eligible. In practice however, for reasons inferrable from Fig. 3.1, the mileage in question does not exceed 10,000 km (15,000 km at most). In Directive 80/1268/EEC (emission of carbon dioxide and fuel consumption) the maximum mileage was capped at 15,000 km.

In the new legislation mileage requirements were made uniform for all tests. They are identical to those specified in Directive 70/220/EEC, which means that the minimum mileage is 3,000 km, and the maximum mileage is not limited.

It is usually assumed that the vehicle compliance with exhaust emission requirements (Tab. 3.7) is controlled in type I test. This approach dates back to the period when the result of type approval tests compared against the prescribed limits was the emission at the early stage of the car's life cycle measured directly in type I test. However, in the early 1990s the above principle was changed. The new principle was that the prescribed limits were compared against emissions at the end of that period, which was conventionally (for type approval purposes) set at 80,000 km. Emission values compared against the prescribed limits (i.e. the result of type approval tests) were expressed as the product of the values measured in type I test and the emission deterioration factor (D). In order to determine the latter, a new test type was introduced. The conventional lifetime of a vehicle used to be 80,000 km from Euro 1 through to Euro 4. In the new legislation it is extended to 160,000 km. In the period preceding Euro 1 and then from Euro 1 to Euro 4 the measured emission value was the final value in type I tests.

Approximately since 2005 an increasing number of vehicles have been fitted with self-regenerating emission reducing systems, including in particular periodically regenerating systems. This term refers to systems (such as catalytic converters or particulate filters) that require a periodical regeneration process in less than 4,000 km of normal vehicle operation. If regeneration takes place at least once in a type I test, then it is considered to be “continuous”. In the case of vehicles with a periodically regenerating system, the final emission value in type I test is determined by multiplying the tested value by the regeneration coefficient (K).

Pursuant to the new legislation the value of emissions used for comparison against the prescribed limits (i.e. the result of type approval tests for limited exhaust pollutant emissions) is determined by means of the following formulae:

- if a multiplicative emission deterioration factor is used:

$$e_i^{TA} = D_i \, e_i^K = D_i \, K_i \, e_i^M \tag{3.2a}$$

- if an additive emission deterioration factor is used:

$$e_i^{TA} = e_i^K + D_i = K_i \, e_i^M + D_i \tag{3.2b}$$

where: e_i^{TA} – emission compared against the prescribed limit (result of type approval tests) [g/km],
e_i^M – emission measured in type I test [g/km],
e_i^K – final emission measured in type I test [g/km],
K_i – regeneration coefficient,
D_i – emission deterioration factor,
i – index denoting the pollutant.

Changes in the scope of application as regards type approval in terms of limited exhaust pollutant emissions, as introduced by the new legislation, include the following:

- car manufacturers are no longer allowed to choose the type approval method for N1 vehicles,
- vehicles powered by SI engines running on petrol with maximum laden mass exceeding 3500 kg are covered by the requirements,
- vehicles powered by SI engines running on LPG and NG and by CI engines running on diesel with maximum laden mass exceeding 3500 kg, but reference mass not greater than 2610 kg are classified as light-duty.

Pursuant to the earlier legislation car manufacturers could choose the type approval method for N1 vehicles running on diesel, NG and LPG. Such vehicles could be type approved either under light-duty vehicles legislation (Directive 70/22/EEC) or heavy-duty vehicles legislation (Directive 2005/55/EC). Car makers often chose to follow Directive 2005/55/EC, particularly for vehicles in N1 class III (Tab. 2.1) running on diesel, for the following reasons:

- easier extension of approvals,
- more relaxed requirements as regards limited exhaust pollutant emissions,
- more relaxed requirements as regards the OBD.

Approval of N1 vehicles powered by SI engines running on LPG or NG in accordance with heavy-duty vehicles legislation was not applied in practice, although it was formally allowed. This largely resulted from the fact that the testing method prescribed in the ETC test was not suitable for a large part of engines for such vehicles [14]. There were problems with execution of the operating cycle.

The option to choose the approval method is absent from the new legislation. All N1 vehicles are subject to approval in accordance with Regulation 715/2007. When assessing the importance of this change one should take into account the three following periods:

- from the effective date of light-duty vehicles legislation to the end of 2012 vehicles must meet Euro 5 requirements (type I test) instead of Euro V (ESC and ETC tests),
- from the beginning of 2013 to August 2014 or 2015 vehicles must meet Euro 5 requirements instead of Euro VI (WHSC and WHTC tests),
- from September 2014 or 2015 vehicles must meet Euro 6 requirements (type I test) instead of Euro VI.

Attention should be drawn to a significant difference between the prescribed pollution limits for light-duty and heavy-duty vehicles. For the former, limits are expressed in g/km, while for the latter they are expressed in g/kWh. For light-duty vehicles, the amount of emissions generated during the entire test and corresponding to the prescribed limit is in principle constant, irrespectively of the work, dimensions, weight, etc. For heavy-duty vehicles, however, the said value is not constant. It grows in proportion to the work done, and thus also to the vehicle size.

Tests show that the emission (expressed in mg/kWh) of pollutants from the same engine is greater in type I test than in ETC test. The relative difference depends on the pollutant type. It is usually the greatest for THC, and the lowest for NO_X. Some examples of such test results are presented in Fig. 3.2. The tests were organized as follows: an engine installed on an engine test bench underwent an ETC test, and then it was fitted in a N1 vehicle and underwent type I test. The approval emission limits were determined using the formula (3.2a) by multiplying the measured values by the corresponding emission deterioration factors.

Figure 3.2 shows that emission in type I test is greater than measured in ETC: by 2.3 to 2.9-fold for CO, by 2.8 to 3.5-fold for THC, by 1.4 to 1.5-fold for NO_X

and by 1.6 to 2.3-fold for PM. An analysis shows that on average and for all category N1 vehicles powered by CI engines running on diesel the Euro 5 requirements prescribed in Regulation 715/2007 are more stringent for all pollutants except for PM at the reference mass of 675 kg than Euro V requirements prescribed in Directive 2005/55/EC.

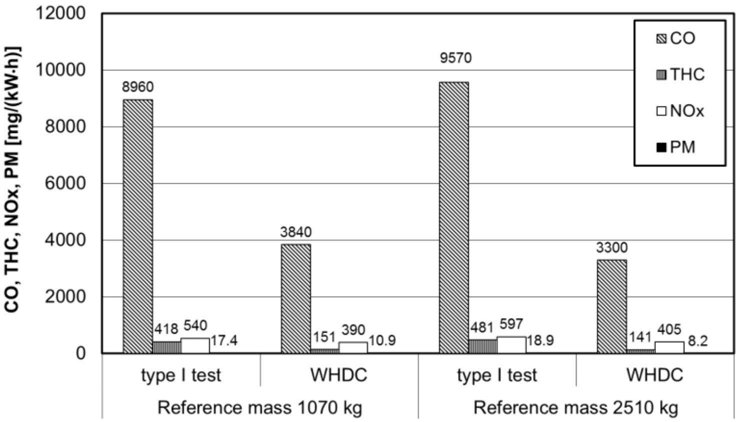


Fig. 3.2 Comparison of emissions from vehicles in N1 category powered by SI engines running on diesel in type I and WHDC tests [7]

A similar analysis comparing Euro 5 and Euro VI requirements shows that the former are less stringent (and thus easier to meet) for all N1 vehicles as regards nitrogen oxides and the sum of nitrogen oxides and hydrocarbons. This results from a radical reduction of the prescribed NO_X limit in Regulation 595/2009 as compared to the previous limit specified in Directive 2005/55/EC (from 3500 mg/km to 400 mg/km). As regards carbon monoxide, the situation is quite opposite. The prescribed limits for this particular pollutant are easier to meet in approvals done on the basis of Regulation 595/2009. For PM the severity of the requirements depends on the reference mass. For larger masses (vehicles in category N1 class III) the requirements provided for in both regulations are quite similar in terms of severity. For smaller masses (class I) the prescribed limits in Regulation 715/2007 are easier to meet, and thus less severe.

Euro 6 legislation significantly reduces the prescribed limit of nitrogen oxides, as compared to Euro 5 legislation with respect to vehicles with CI engines. As a result, the severity of requirements for this particular pollutant is greater [10]. For all vehicles in category N1 (except for small vehicles), the requirements become more stringent, or similar to Euro VI in the very least. For other pollutants the comparison is similar to that for Euro 5 and Euro VI.

The consequences of abolishing the freedom to choose the approval method for N1 vehicles with CI engines are ambiguous. For most vehicles the requirements become stricter, while for a small part of vehicles they are more relaxed. That relaxation concerns first and foremost the vehicles with a low reference mass (class I), which hardly ever were approved in accordance with heavy-duty vehicles legislation. For vehicles with a high reference mass (class III), for which such approval was common, the requirements become less severe mostly as regards the sum of hydrocarbons and nitrogen oxides (for a relatively short time they will also be less severe for nitrogen oxides alone). It is expected that abolishing the freedom to choose the approval method for N1 vehicles with CI engines will reduce emissions.

The new light-duty vehicles legislation also applies to vehicles in categories M1, M2 and N2 of maximum laden mass exceeding 3500 kg, but of reference mass not greater than 2610 kg, which thus far were classified as heavy-duty (chapter 2). In the previous legislation the requirements regarding exhaust emissions depended on the powertrain type.

In the case of engines running on petrol the requirements were stipulated in light-duty vehicles legislation (Directive 70/220/EEC). However, they did not cover driving cycle emissions, but only carbon monoxide concentration at idling speed. The introduction of the driving cycle requirements significantly stringency. It should be stressed, however, that the share of these vehicles among all vehicles in use and emissions is insignificant.

The requirements for vehicles in categories M1, M2 and N2 of maximum laden mass exceeding 3500 kg and reference mass not greater than 2610 kg running on diesel, LPG and NG were previously stipulated in heavy-duty vehicles legislation (Directive 2005/55/WE). In the case of diesel, the effect of their inclusion in the scope of Regulation 715/2007 is identical to the effect of abolishing the freedom to choose the approval method for N1 class III vehicles, as discussed above. In the case of vehicles running on LPG and NG there are no data enabling one to assess the consequences of their inclusion in the light-duty vehicles legislation.

As compared to Euro 4, the new legislation increases the number of pollutants subject to prescribed limits. The new requirements additionally apply to:

- non-methane hydrocarbons (NMHC) (only for vehicles with SI engines),
- particle number (PN) (for vehicles with CI engines and SI engines),
- particulate mass for vehicles with SI engines fitted with direct injection.

Attention should be drawn to the difference between particulates (as in PM) and particles (as in PN).

The definitions are as follows:

- particulate mass (PM) means components of the exhaust gas which are removed from the diluted exhaust gas at a maximum temperature of 325 K by means of the filters described in the legislation,
- particle number (PN) refers to particles of a diameter greater than 23 nm contained in the diluted exhaust gas after the removal of volatile components.

For vehicles powered by SI engines there are two parallel prescribed limits for hydrocarbons:

- total hydrocarbons (THC),
- non-methane hydrocarbons (NMHC).

The term “non-methane hydrocarbons” is understood as total hydrocarbons from which methane has been removed. Due to the measurement methodology used (by means of a FID analyzer), THC include not only hydrocarbons, but also other organic compounds, such as aldehydes, esters, etc. Therefore, emission of these compounds is also included in the measurement of NMHC [11].

The preamble to Regulation 715/2007 [17] explains that the introduction of separate prescribed limits for THC and NMHC emissions is aimed at facilitating market entry of vehicles powered by SI engines running on alternative gaseous fuels, including in particular NG and biomethane. Such vehicles are characteristic for a relatively low emission of nitrogen oxides, very low emission of PM and low emission of selected unlimited pollutants, such as benzene or PAH. Therefore, their broad use is desired for environmental purposes. Engines running on NG and biomethane differ from those running on petrol and LPG in terms of hydrocarbon emissions (Fig. 3.3). The fundamental difference can be seen in the share of methane in THC emissions. In the case of vehicles running on NG, methane constitutes approximately 70 to 90% of exhausted THC, while in vehicles running on petrol and LPG the corresponding percentage is approximately 10%.

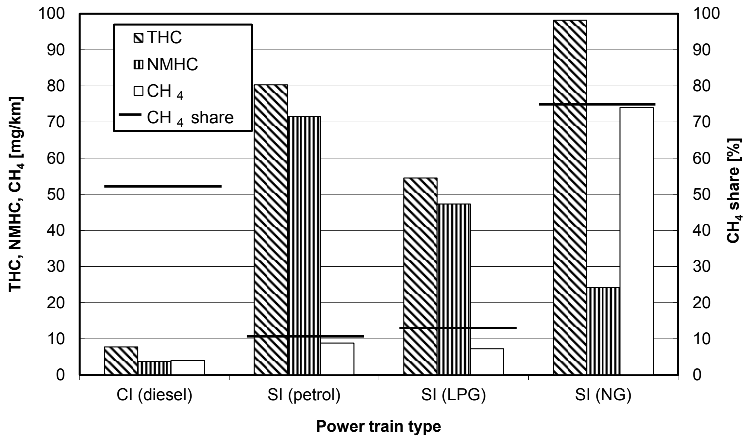


Fig. 3.3 Emission of hydrocarbons from vehicles running on different fuels (based on [19])

Methane, just like carbon dioxide, is classified as a greenhouse gas. The impact of individual gasses on climate change is conventionally expressed as CO_2 equivalent global warming potential (Tab. 3.5). Due to the high value of this potential for methane, the equivalent emission of greenhouse gases from vehicles running on NG and biomethane can be greater than from vehicles running on petrol, even though carbon dioxide emission is lower due to the lower carbon content in those two gaseous fuels.

At atmospheric concentrations methane is considered as neutral for human health. Furthermore, it is not a reactive compound contributing to smog formation.

Table 3.5 Global warming potential values for greenhouse gases exhausted from internal combustion engines, according to IPCC [12]

Greenhouse gas	20-year	100-year	500-year
CO_2	1	1	1
CH_4	56	21	6,5
N_2O	280	310	170
CO	–	–	–
VOC	–	–	–

Catalytic converters dedicated to vehicles with SI engines running on petrol are frequently characteristic for a low rate of methane conversion [13, 14]. The term "conversion rate" is defined as the difference in concentrations upstream and downstream of the converter, divided by the upstream concentration:

$$SK = 100 \cdot (c_p - c_z) / c_p \tag{3.3}$$

where: SK – conversion rate [%],
c_p – upstream concentration [ppm],
c_z – downstream concentration [ppm].

In some converters dedicated to vehicles with SI engines running on petrol methane conversion rate is approximately 10% [13]. Such converters cannot be used with engines running on NG or biomethane. As a result of works held in the recent years the said rate has been enhanced to some extent. The works have been two-dimensional.

The first dimension involved increasing the converter size in order to extend the so-called contact time.

The other dimension followed in order to improve methane conversion rate in three way catalytic converters is the optimization of the intermediate layer and the active metal layer.

Catalytic converters optimized for engines running on NG are characteristic for much better performance as compared to converters used with petrol engines. This has been confirmed by tests, as shown in Fig. 3.4. The tests were made using the same vehicle running on CNG, consecutively fitted with each converter. The converter optimized for CNG reduced methane emission by 45%. Also, emission of NMHC was reduced, as the conversion rate of light hydrocarbons (ethane, propane) increased. The average THC conversion rate amounted to 97% with the converter optimized for CNG and to 92% with the converter optimized for petrol.

Due to the high content and low conversion rate of methane, emission of THC from vehicles running on NG or biomethane is greater than in the case of vehicles running on petrol or LPG (Fig. 3.4). Therefore, if – as in Euro 4 legislation – only THC emission is limited, then the prescribed limit for this particular pollutant must be achievable for vehicles running on NG or biomethane. Otherwise an obstacle to the use of such vehicles would be created. Simultaneously however, the prescribed value will be too high for engines running on petrol or LPG. If limits for NMHC only are prescribed, then methane emission is not limited at all. Prescription of limits for methane alone results in the lack of limits for NMHC, which is unacceptable from the environmental perspective.

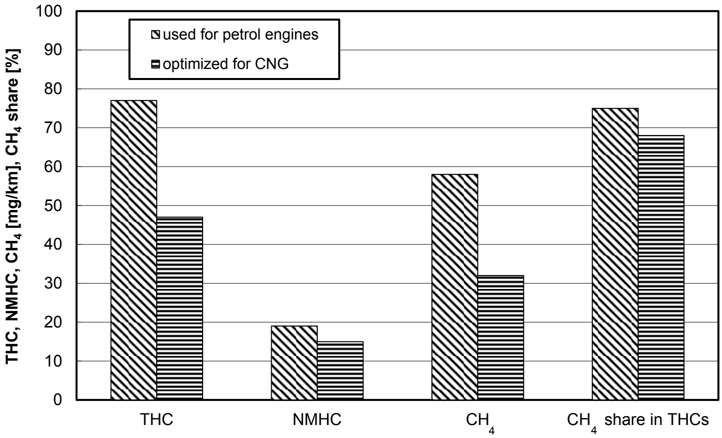


Fig. 3.4 Comparison of hydrocarbons emissions in type I test from a vehicle running on CNG fitted with a catalytic converter used for petrol engines and a converter optimized for CNG

Considering the above, it is necessary to group hydrocarbons by type and prescribe separate limits for each of them. The following three options were considered:

- total hydrocarbons and methane,
- total hydrocarbons and non-methane hydrocarbons,
- non-methane hydrocarbons and methane.

Each of the above options has some advantages and disadvantages. The disadvantage of the first option is identical as in the case of THC limit. Its introduction either results in an obstacle to the development of vehicles running on NG and biomethane, or establishes too relaxed requirements for vehicles running on petrol or LPG. For this reason the first option was rejected. The light-duty vehicle legislation incorporates the option “total hydrocarbons and non-methane total hydrocarbons”, while the heavy-duty vehicle legislation uses “non-methane hydrocarbons and methane”.

Introduction of prescribed limits for both pollutants, i.e. total hydrocarbons and non-methane hydrocarbons is a form of a compromise. In such a case, for vehicles running on petrol and LPG the deciding factor in meeting the requirements would be the NMHC emission, as the prescribed limit for this particular pollutant is by approximately 32% lower than for THC, while the share of methane in THC is approximately 10%. As regards vehicles running on NG and biomethane, whether or not the limits are observed will depend on the THC emission.

Particles, especially those smaller than approximately 0.1 µm, are now considered to be particularly hazardous to human health. Particulate filters are necessary to meet mass emission limits prescribed in the new legislation. Some of those filters do reduce the mass emission of particulate matter, but fail to adequately contain particles smaller than 0.1 µm. To prevent the use of such filters, particle number (PN) limits were also introduced, as mentioned above. In Euro 5 PN limits apply only to vehicles powered by CI engines. In Euro 6, vehicles with SI engines are also included. Tests show that PN emission from such vehicles without a particulate filter is sometimes greater than from vehicles powered by CI engines and fitted with a filter (Fig. 3.5). The requirements regarding particulate mass and particle number are identical for all vehicles affected by the new legislation, irrespectively of their size.

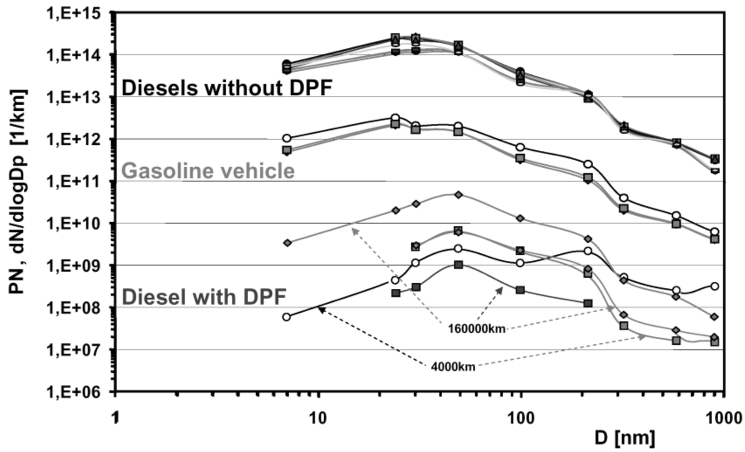


Fig. 3.5 Particle number emitted by selected vehicles [1]

Attention should be drawn to the fact that in the new legislation the prescribed emission limit is identical for all category M vehicles. A bus of maximum laden mass equal to 4500 kg must meet the same requirements (expressed in g/km) as a passenger car with a small engine. Thus far, the requirements for category M vehicles of maximum laden mass ranging from 2500 to 3500 kg were much more relaxed than those for vehicles not exceeding 2500 kg (Tab. 3.4).

In order to partially relax the limits for category M, the new legislation introduces the notion of the so-called vehicles designed to fulfill specific social needs. These include the following category M1 vehicles with CI engines:

- campers, ambulances, hearses of a reference mass exceeding 2,000 kg,
- vehicles carrying 7 or more passengers (including the driver) with a reference mass exceeding 2,000 kg,
- vehicles built specifically to accommodate wheelchair use inside the vehicle, with a reference mass exceeding 1760 kg.

For the above vehicles, Euro 5 limits are identical to those for category N1 class III vehicles (Tab. 3.4). It should be stressed that the group "vehicles designed to fulfill specific social needs" includes exclusively vehicles powered by CI engines. In this case there has been a discrepancy between political declarations in support of the use of alternative fuels, and the provisions of Regulation 715/2007. Reducing the scope of vehicles designed to fulfill specific social needs to those fitted with CI engines creates a kind of an obstacle to the development of such vehicles running on alternative fuels.

The relaxed requirements for vehicles designed to fulfill specific social needs will be phased out in Euro 6. Regulation 715/2007 does not provide for any Euro 6 waivers as regards the basic levels of emission from vehicles in category M.

In the late 1960s, when the first European legislation on the emission of pollutants was developed, the following proposals were made:

- introduction of identical requirements for all passenger cars, just like in the USA,
- no waivers.

The above proposals were not followed, also because European vehicles were much varied in terms of size, expressed e.g. by curb weight or maximum laden mass, or the vehicle footprint, as well as in terms of design variables and performance of the engine (displacement volume, torque, power) with equal size of the vehicle. As a result of the said diversity it was difficult to agree on a single limit for a given pollutant, because the interests of individual car makers were too divergent.

After approximately 50 years, the proposals to have uniform values and no waivers will largely materialize in Euro 6 legislation.

The reduction rate of the prescribed limits for pollutants in the new legislation as compared to Euro 4 depends on (Tab. 3.6):

- pollutant type,
- category,
- maximum laden mass,
- working principle (SI, CI).

As regards M1 vehicles with MLM $\leq$ 2500 kg and all N1 vehicles powered by an either SI or CI engine, the prescribed limits for CO and THC are the same in Euro 5 and Euro 6 and do not differ from those in Euro 4. However, there is a difference as regards NO_X. In the case of Euro 5 the prescribed limit of NO_X emissions was reduced by 25% as compared to Euro 4 for vehicles powered by SI engines and by 28 to 29% for vehicles powered by CI engines. Euro 6 brings about further reduction of NO_X emissions, but only for vehicles powered by CI engines (reduction by 56% as compared to Euro 5). Reduction of nitrogen oxide limits also translates into a reduction of prescribed limits for the sum of THC + NO_X (in place only for vehicles powered by CI engines). The largest emission reduction as compared to Euro 4 is observed in the case of PM (from 80% for M1 vehicles with MLM $\leq$ 2500 kg to 92% for N1 class III vehicles). The prescribed PM limits are identical for Euro 5 and Euro 6, which means that the above reduction rate is identical for both standards.

Table 3.6 Comparison of values measured in type I test in accordance with Euro 4, Euro 5 and Euro 6 requirements for category M vehicles with MLM ≤ 2500 kg

Pollutant	Measured values [g/km]				Reduction rate	
	Euro 4		Euro 5 and Euro 6*			
	SI	CI	SI	CI	SI	CI
CO	667	364	533	267	0.20	0.27
THC	67	–	62	–	0.08	–
NMHC	–	–	42	–	–	–
NO_X	53	200	30	131	0.44	0.35
THC + NO_X	–	240	–	167	–	0.30
PM	–	17	–	4	–	0.76

* Euro 6 only for vehicles powered by SI engines.

For category M vehicles with MLM > 2500 kg the change of the prescribed limits in comparison to Euro 4 requirements is much more profound than for M1 vehicles with MLM ≤ 2500 kg. The underlying reason is that Euro 4 values for the former (MLM > 2500 kg) were greater, while in Euro 5 and Euro 6 they are identical across the entire M category. The reduction rate depends on the vehicle reference mass. In Euro 4, in the 1305 kg < RM ≤ 1760 kg range the requirements were identical to those for category N1 class II, and vehicles with RM > 1760 kg were subject to the greater values applicable to class III. The reduction rate is as follows (smaller values apply to 1305 kg < RM ≤ 1760 kg, greater values apply to RM > 1760 kg):

- SI engines: 21% or 32% for CO, 23% or 38% for THC, 40% 44% for NO_X,
- CI engines: 21% or 32% for CO, 45% or 54% for NO_X, 41% or 50% THC + + NO_X, 88% or 92% for PM.

Vehicles in category M1 with > 2500 kg represent a small share of all vehicles. This group includes high-end, sport utility vehicles or armored vehicles, such as Audi A6, BMW X5, Chrysler Grand Cherokee, Ford Galaxy.

As already mentioned, the actual change of the requirements is determined not only by the prescribed limits, but also by other factors, such as control principles and measurement methods. When comparing Euro 5 and Euro 6 against Euro 4 one should first of all take into account that the conventional "life cycle" of a vehicle was increased from 80,000 km to 160,000 km. This increase significantly affects the values of the emission deterioration factor D (formula 3.2), which are increased in Euro 5 and Euro 6.

Table 3.6 shows a comparison of the values measured in type I test that must be met for a vehicle to comply with Euro 4, Euro 5 and Euro 6 requirements. The comparison was made for category M vehicles with MLM ≤ 2500 kg powered by

SI engines running on petrol and by CI engines running on diesel. The following assumptions were made for the purpose of the analysis:

- the regeneration coefficient K is 1, which means that the final emission value in type I test is equal to the measured value,
- the result of approval tests 20% below the prescribed limit (margin of 20%),
- fixed value of the emission deterioration factor, as determined in the legislation.

Due to increased values of emission deterioration factors, largely resulting from mileage growth in durability testing, in Euro 5 compliant vehicles CO and THC emissions measured in type I test should be lower than in the case of Euro 4, even though the prescribed limits are identical for both standards. The reduction of the measured value for both pollutants in the case of vehicles fitted with SI engines is 20% and 8%, respectively. Even greater reduction of CO emission is observed for vehicles with CI engines, where the difference between the deterioration factors is greater (1.1 for Euro 4 and 1.6 for Euro 5).

For THC, the difference between emission deterioration factors in Euro 5 and Euro 6 (and Euro 4 for vehicles with SI engines) is insignificant (1.3 and 1.2 respectively). However, in the case of these vehicles (other than those running on NG and biomethane) whether or not the limits are observed will depend first of all on NMHC emissions, rather than THC emissions. Therefore one should compare THC limits prescribed in Euro 4 against NMHC limits in Euro 5 and Euro 6. Assuming that the methane share in THC emission is 10%, the measured NMHC value for Euro 5 compliant vehicles should be by approximately 30% lower than for Euro 4 compliant vehicles.

The reduction rates of the measured NO_X values (44% for vehicles with SI engines and 35% for vehicles with CI engines) are significantly greater than the underlying prescribed limits (25% and 28%, respectively). Similarly to CO and THC emissions, this difference reflects a greater value of the *D* factor for Euro 5 as compared to Euro 4. The said difference is particularly great for vehicles with SI engines, where the factors are 1.6 and 1.2, respectively.

The above analysis illustrates that the new legislation puts particular emphasis on nitrogen oxide and particulate matter emissions from vehicles powered by CI engines. Figure 3.6 shows the severity of the new requirements, the criterion for assessing the severity is the prescribed limit reduction rate, calculated as the ratio between the limit upon the introduction of the first EU legislation for a given vehicle category or class and pollutant, and the currently applicable limit. For gaseous pollutants, there are two prescribed limits (maximum and minimum), because in the first legislation the limits depended on the vehicle reference mass. For each vehicle category or engine type limit ranges were prescribed (minimum value for the lowest mass and maximum value for the highest mass). For PM such variation did not apply, as a result of which only one reduction rate is presented.

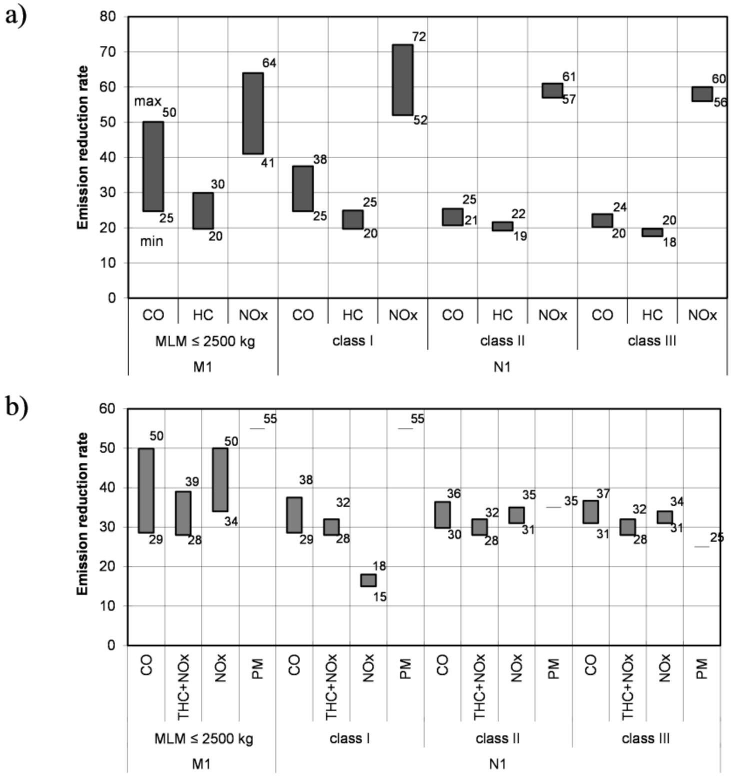


Fig. 3.6 Reduction of prescribed emission limits in the period from the first legislation to Euro 6: a) for vehicles powered by SI engines, b) for vehicles powered by CI engines

Taking into account the above factors one could conclude that the new legislation is clearly more stringent in terms of emission of pollutants from light-duty vehicles. This applies to all kinds of pollutants, including those whose limits have not changed.

3.2.2 Measurement Method and Test Equipment

The new legislation retains the general terms of measuring pollutants in type I tests:

- measurements are made on a chassis dynamometer in a driving cycle,
- ambient temperature in the test room is 20–30°C and the vehicle is conditioned in that temperature prior to testing,
- NEDC cycle is used,
- the cycle begins with a cold start,
- vehicles are divided into inertia classes, depending on their reference mass,

- CVS measuring system is used (sampling and volume measurement of exhaust gas),
- measurements are made using reference fuel.

Chassis dynamometer (roller test bench) allows making measurements while the vehicle is immobilized. The immobilization is necessary in order to connect the CVS. The wheels of the driving axle (axles) move on revolving rolls, coupled with a dynamometer brake used to generate resistance. The dynamometer should make it possible to simulate the vehicle mass and resistance to progress in accordance with applicable legislation.

Dynamometers with various kinds of structural solutions are used, such as:

- all-purpose dynamometers used to test both vehicles with a single driving axle and 4×4 vehicles, as well as those used to test vehicle with a single driving axle only,
- single-roller dynamometers, usually with roller diameter of 48” (~1200 mm) (Fig. 3.7) or two-roller dynamometers, usually with roller diameter of 360–506 mm (Fig. 3.8),
- dynamometers fitted with a hydraulic brake, using the principle of eddy currents, with a DC motor, or with an asynchronous AC motor,
- dynamometers with mechanical (flywheel based) or electric vehicle mass simulation,
- dynamometers of fixed or adjustable load curve.

The term “load curve” as used with respect to the chassis dynamometer is understood as resistance to progress expressed by means of force or torque as a function of driving speed. It is expressed by means of the following formula:

$$F_h = a + bv^2 \tag{3.5}$$

where: F_h – resistance to progress simulated on a dynamometer [N],
v – driving speed [km/h],
a, b – coefficients.

In the case of adjustable curve, the coefficients a and b can be adjusted independently of each other. If the curve is fixed, the coefficients depend on the dynamometer design.

The parameters of a fixed curve dynamometer are determined in the legislation. Namely, the range of possible absorbed resistance force should be in accordance with the following formula:

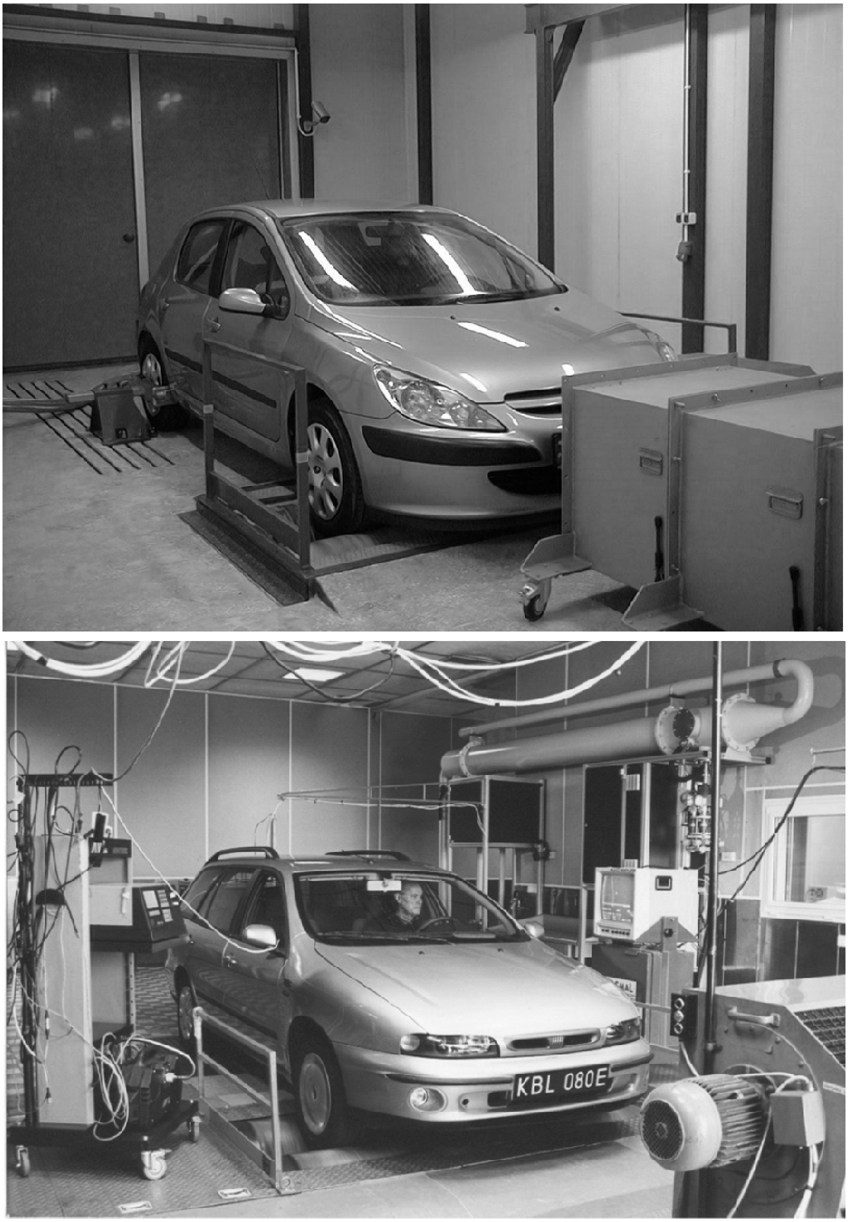
$$F_h = (a + bv^2) \pm 0{,}1F_{a80} \tag{3.6}$$

where: F_h – resistance to progress (absorbed) simulated on a dynamometer at a driving speed of v [N],
F_{a80} – resistance to progress absorbed at a driving speed of 80 km/h [N],
v – driving speed [km/h],
a, b – constant coefficients determined in the legislation.

a)

b)

Fig. 3.7 Single roller chassis dynamometer: a) Instytut Transportu Samochodowego (Motor Transport Institute) in Warsaw, b) BOSMAL Sp. z o.o. Instytut Badań i Rozwoju Motoryzacji (Automotive Research and Development Institute)



a)

b)

Fig. 3.8 Two-roller chassis dynamometer: a) Instytut Transportu Samochodowego (Motor Transport Institute) in Warsaw, b) BOSMAL Sp. z o.o. Instytut Badań i Rozwoju Motoryzacji (Automotive Research and Development Institute)

The term “absorbed resistance” is understood as the sum of resistance generated by the brake and internal resistance of the dynamometer. The coefficients a and b depend on the vehicle reference mass. Dynamometers of other profiles can also be used.

The legislation does not specify the design of chassis dynamometers. It merely determines the requirements that must be complied with (accuracy of force measurement by the brake ±5%, driving speed ±1 km/h, simulated mass ±20 kg).

Resistance to progress to be simulated on a chassis dynamometer are determined using one of the following methods:

- on the basis of road tests,
- by the so called “alternative method”.

The manufacturer can choose the method used to determine resistance to progress.

Resistance to progress determined on the road can be reproduced on adjustable curve chassis dynamometer only. Resistance on a level road at constant speed can be expressed with one formula:

$$F_d = F_n + F_r + F_p \tag{3.7}$$

where: F_d – total resistance on a level road [N],
F_n – rolling resistance of driving wheels [N],
F_r – rolling resistance of driven wheels [N],
F_p – air resistance [N].

In the case of a chassis dynamometer the rolling resistance of driving wheels is – due to the large diameter of the roll – close to the actual rolling resistance on the road. To properly simulate road resistance, a dynamometer should simulate air resistance and rolling resistance of driven wheels. In two-roll dynamometers, the roller diameter is smaller and there are two contact points for each wheel. As a result, the rolling resistance of powered wheels is much greater than on the road, by 60–85% on average (Fig. 3.9). Therefore, this type of dynamometers should simulate air resistance and a small portion of driven wheels rolling resistance.

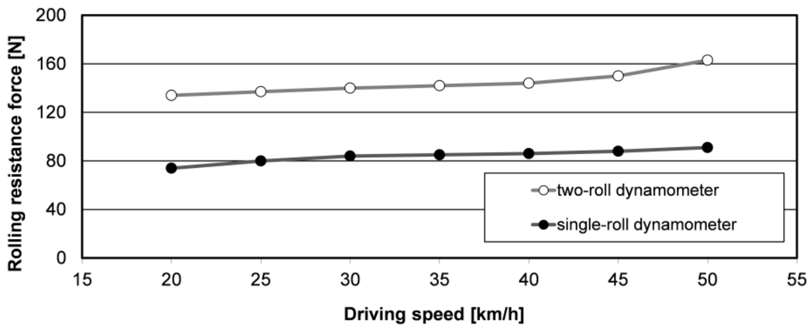


Fig. 3.9 Comparison of rolling resistance forces on a single-roll and two-roll chassis dynamometer

When the alternative method is used, the resistance on a chassis dynamometer is determined on the basis of the force or power absorbed at a driving speed of 80 km/h. It can be simulated on both adjustable and fixed curve dynamometers. To determine resistance at driving speeds other than 80 km/h using adjustable curve dynamometer, it is recommended to use the same coefficients a and b as used for defining that of a fixed curve dynamometer by means of the formula (3.6). For single roller dynamometers the rolling resistance of driving wheels is too low, which affects the total value of absorbed resistance. With fixed curve, resistance at speeds other than 80 km/h depends on the dynamometer design. As long as the dynamometer complies with the recommended design guidelines, they remain within the range specified by means of the formula (3.6).

Due to the diversity of dynamometer designs and load adjustment methods, the reproducibility of resistance to progress is inadequate, which negatively affects the reproducibility of pollutant emission results. A vehicle running on a chassis dynamometer requires external cooling, which is provided by means of an air blower. The previous legislation determined three methods of such cooling:

- cooling air speed equal to driving speed in the range of 10–120 km/h with a tolerance of ±5 km/h in the range of 10–50 km/h and ±10 km/h above 50 km/h,
- if requested by the manufacturer, cooling air speed equal to driving speed in the range of 0–50 km/h with a tolerance of ±5 km/h (at greater driving speeds the cooling air speed is not specified),
- if requested by the manufacturer, cooling air speed equal to 6 m/s (21.6 km/h).

The manufacturer could choose the option that best suited the vehicle presented for type approval.

The cooling method affects the emission of pollutants measured in type I tests (Fig. 3.10). Therefore, the new legislation provides for one method only, requiring variable cooling air speed equal to driving speed in the range of 10–120 km/h with a tolerance of ±5 km/h in the range of 10–50 km/h and ±10 km/h above 50 km/h. The above change was introduced in Regulation 83 [20] and will take effect from 2014. The postponed effective date allows laboratories to adjust testing equipment to new requirements.

In type I tests, emissions of pollutants are measured by means of the CVS system. Its working principles are as follows:

- tailpipe exhaust gas is continuously diluted with air; the flow rate of diluted exhaust gas should be constant,
- the total volume of diluted exhaust gas is measured for the entire test,
- a sample of diluted exhaust gas is taken for analysis; the ratio of the sample flow rate to air density should be constant,
- air used for dilution is also sampled; the ratio of the sample flow rate to air density should be constant.

Dilution of exhaust gas serves the purpose of preventing water vapour condensation in the CVS and in exhaust gas analyzers.

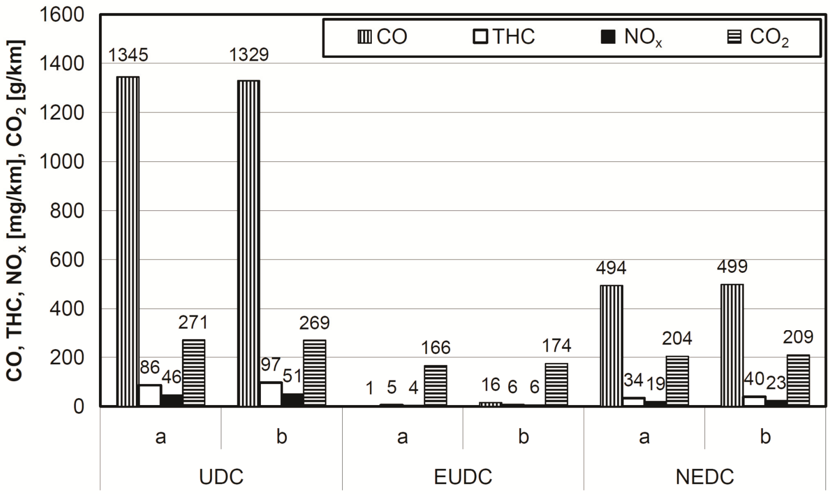


Fig. 3.10 The effect of the cooling method on emission of pollutants: a) cooling air speed equal to driving speed in the range of 10–120 km/h, b) constant cooling air speed equal to 21.6 km/h (on the basis of [18])

CVS systems used for testing can vary in terms of design. In vehicles fitted with SI engines, diluted exhaust gas is captured in flexible bags, from where it is taken for analysis of all gaseous pollutants, i.e. limited pollutants subject to type I test (CO, THC, NMHC, NO_X) and carbon dioxide (fuel consumption and carbon dioxide emission measurement test)). As far as vehicles fitted with CI engines are concerned, measurements of CO, NO_X and CO_2 concentrations are carried out in a manner identical to that used for SI engines (i.e. with exhaust gas samples in bags). In the case of THC, diluted exhaust gas is samples directly from the dilution tunnel (Fig. 3.11), and concentration level is measured on a continuous basis. The system used to deliver exhaust gas to the FID analyzer and the analyzer itself are heated up to a temperature of 190 ±10°C to prevent condensation of heavy hydrocarbons.

Concentration measurement is made by means of an analytical unit consisting of analyzers and ancillary equipment (Fig. 3.12).

The fundamental change in gaseous pollution concentration measurement methodology results from the introduction of requirements with regard to the NMHC emission for vehicles fitted with SI engines. The concentration of this particular pollutant is not analyzed directly; instead, it is measured on the basis of THC and CH_4. Therefore, in order to determine the NMHC emission, it is necessary to measure the concentration of CH_4. The division of hydrocarbons into the three above categories was not used in the previous legislation, which determined requirements for emissions of THC (marked as HC) for vehicles with SI engines and for the sum of THC and nitrogen oxides for vehicles fitted with CI engines.

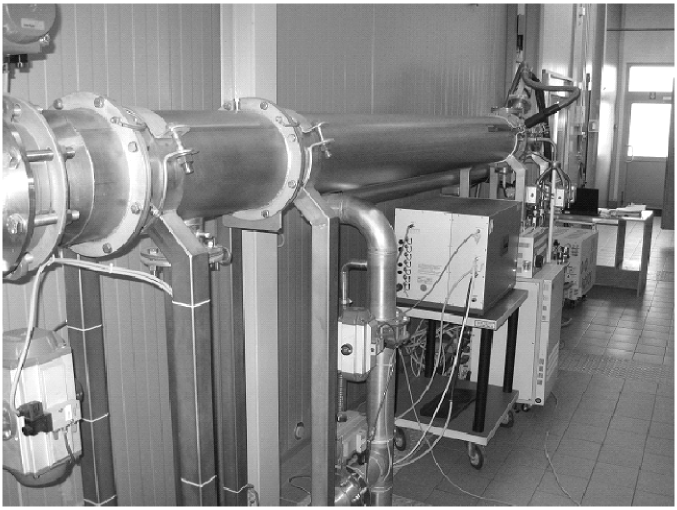


Fig. 3.11 CVS layout (*a*) and exhaust intake system of the CVS (*b*) BOSMAL Sp. z o.o. Instytut Badań i Rozwoju Motoryzacji (Automotive Research and Development Institute) [2]

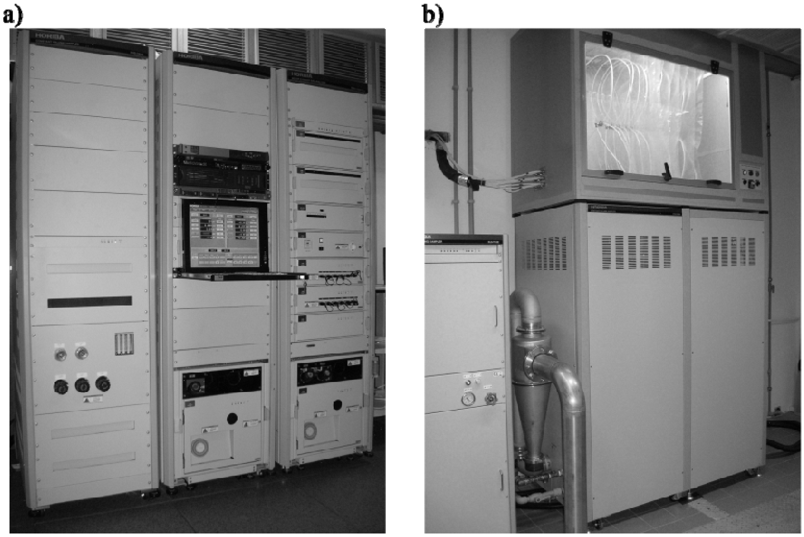


Fig. 3.12 Pollutant concentration measurement unit: a) exhaust gas analyser unit, b) insulated sampling bags [2]

Given the triple division of hydrocarbons into total hydrocarbons, non-methane hydrocarbons, and methane, the general principle for measuring their concentration is as follows. Each sample is analyzed twice. The first analysis is made by means of the FID analyzer in the way used for measuring HC before the division was introduced. The other analysis is also made by means of the FID analyzer, but only after NMHC have been removed from the sample by means of a special separator. The concentration of methane, non-methane hydrocarbons and total hydrocarbons is determined on the basis of the results of both analyses.

Figure 3.13 presents the layout of a hydrocarbon concentration measurement system. The system can be fitted with either one or two FID analyzers. If one analyzer is used, it is not possible to simultaneously analyze hydrocarbons passing through the separator and those bypassing it, which renders measurement more complicated. Therefore, systems with two analyzers are the preferred option.

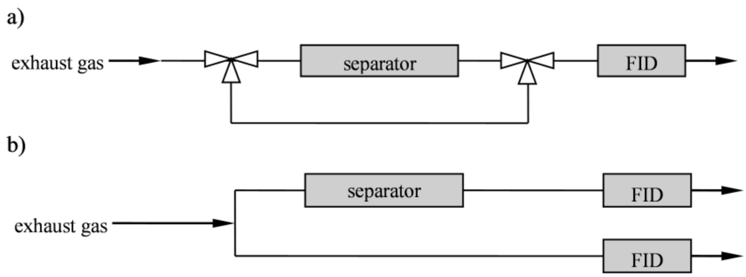


Fig. 3.13 Layout of exhaust HC concentration measurement system: a) single FID analyzer system, b) two FID analyzers system

In accordance with light-duty vehicles regulations, analyzers receiving exhaust gas from the separator should be calibrated with methane, while analyzers receiving exhaust gas bypassing the separator should be calibrated with propane. It is assumed that the concentration of total hydrocarbons is equal to the concentration measured in exhaust gas bypassing the separator:

$$c_{\mathrm{THC}}^{P} = c_{W/O} \tag{3.13a}$$

and the concentration of methane is equal to the concentration measured in exhaust gas passing through the separator:

$$c_{\mathrm{CH4}}^{P} = c_{W} \tag{3.13b}$$

Non-methane hydrocarbon concentration is calculated using the following formula:

$$c_{\mathrm{NMHC}}^{P} = c_{W/O} - R_f \cdot c_W \tag{3.13c}$$

The result of hydrocarbon concentration measurement depends on the following parameters of the measuring system:

- FID analyzer response factor for methane R_f,
- separator efficiency for methane (E_M),

- separator efficiency for ethane (E_E),
- ratio k of separator efficiency for propane (E_P) and ethane (E_E).

The above formulae for calculating hydrocarbon concentrations, as prescribed in light-duty vehicles legislation, are simplified. Therefore, the measured emission values for the said compounds vary from the actual values. This is particularly important for light-duty vehicles running on NG. In the case of those vehicles, the compliance with requirements for THC depends not only on the emission reduction system used, but also – and to a large extent – on the measurement equipment used by the type approval laboratory. For instance, the difference in THC concentrations measured by means of an analyzer of $R_f = 1$ and that of $R_f = 1.15$ amounts to 12%. For NMHC the discrepancy resulting from using simplified formulae may exceed 30%.

Emissions of gaseous pollutants in type I tests is determined using the following formula:

$$e_i = \frac{V \cdot \rho_i \cdot k_h \cdot c_i \cdot 10^{-6}}{d} \tag{3.14}$$

where: e_i – emission of the pollutant i [g/km],
ρ_i – density of the pollutant i in reference conditions [g/dm^3],
c_i – concentration of the pollutant i in diluted exhaust gas [ppm],
k_h – adjustment coefficient depending on air humidity (for nitrogen oxides only),
V – diluted exhaust gas volume corrected for reference conditions [dm^3],
d – distance travelled during the test [km].

The parameters c, V and d are determined through tests, while the density (ρ) of the pollutant in question is stated in the legislation. For carbon oxide and nitrogen oxides those values are identical for all light-duty vehicles, while the value for hydrocarbons depends on the fuel used for propulsion.

Since the introduction of the first European legislation on the emission of pollutants from petrol and diesel-powered engines in the 1970s it has been a general principle that the average composition of THC in exhaust gas (expressed as the ratio of hydrogen to carbon atoms in the molecule, or H/C ratio) is the same as in the fuel itself. Hydrocarbons in exhaust gas have been presented as CH_y, with y being equal to the estimated value of H/C. On the basis of known ratios, the density of THC in exhaust gas could be calculated. After the introduction of the limits for engines running on gaseous fuels (LPG and NG), the above principle has been used also with regard to those engines. Since reference petrol and reference diesel used for testing in accordance with the new legislation both contain biocomponents, the average composition of the fuels (and thus the HC ratio in exhaust gas) must also take into account the ratio of oxygen to carbon atoms in the molecule (O/C).

Fuels used for testing in accordance with Euro 5 legislation differ from one another in terms of H/C and O/C ratios, which causes considerable differences in THC densities (Tab. 3.7).

Table 3.7 Selected parameters of reference fuels and hydrocarbons in exhaust gas according to Euro 5 legislation

Fuel	Parameter				
	H/C	O/C	ρ_{THC} [g/dm^3]	coefficient a[1)]	coefficient b[1)]
Petrol (E5)	1.89	0.016	0.631	0.848	0.118
Diesel (B5)	1.86	0.005	0.622	0.861	0.116
LPG	2.525	0	0.649	0.825	0.1212
NG/biomethane	4	0	0.714	0.749	0.1336
Ethanol E85	2.74	0.385	0.932	0.574	0.1742

[1)] Coefficients used in the formula (3.17).

Table 3.8 Comparison of selected parameters of reference fuels and hydrocarbons in exhaust gas according to Euro 4 and Euro 5 legislation

Fuel	Parameter	Euro 4	Euro 5
Petrol (E5)	H/C	1.85	1.89
	O/C	0	0.016
	ρ_{THC} [g/dm^3]	0.619	0.631
	a[1)]	0.866	0.848
	b[1)]	0.1154	0.118

[1)] Coefficients used in the formula (3.17).

The introduction of biocomponents to conventional fuels caused only minor changes to THC density as compared to Euro 4. For petrol, the density grew by 2% (Tab. 3.8), and even less so for diesel. Further growth of THC density should be expected after 2012, due to the planned increase of biocomponent content in conventional fuels.

It should be stressed that THC density determined in accordance with the principles discussed above differs from the actual density, because the assumption of identical average composition of fuel and hydrocarbons in exhaust gas is not true. While the differences for petrol, diesel and LPG are relatively low (usually below 1.5%), they are clearly greater for NG/biomethane. The legislation assumes that for these two fuels HC in exhaust gases contain methane only (H/C = 4). However, the average actual share of methane is 70–90%, and can be even lower in certain vehicles. It is estimated that by assuming the methane-only density, the emission of THC has been inflated on average by 3.5%, and for some vehicles by over 5%.

The aforesaid principle of identical average THC composition in fuel and exhaust gas results in even more inflated emissions in the case of vehicles running on ethanol (E85). For this fuel it has been assumed that ethanol constitutes nearly 85% of THC – consequently, one deals here with the "emission of alcohols", even though the legislation formally mentions the "emission of hydrocarbons". Few as they may be, the tests of exhaust gas from vehicles running on E85 have shown that the share of alcohols is well below 50% and the emission of hydrocarbons measured in accordance with the legislation is inflated by over 10%.

The new EU legislation for light-duty vehicles assumes that the density of THC and NMHC is identical. As a consequence of this assumption, NMHC emissions measured in accordance with the legislation are greater than they really are. The resulting bias does not exceed 2% for conventional fuels and 4% for LPG.

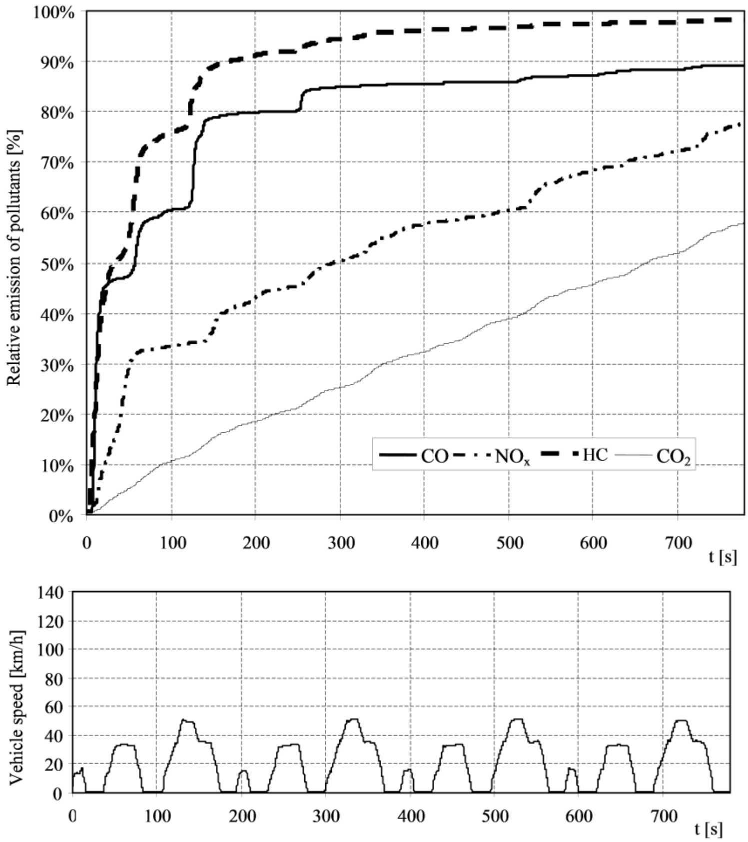


Fig. 3.14 Relative emission of pollutants as a function of time for a Euro 4 vehicle with an SI engine and three way catalyst in a UDC cycle in type I test (emission in NEDC cycle = 100%)

In the case of NG propulsion, the consequences are significant. For light-duty vehicles the statutory H/C ratio for NMHC is 4.00. Theoretically, it cannot be greater than 3.00. In fact, it is lower because NMHC contain not only ethane, but also compounds with the H/C ratio sometimes well below 3. It is estimated that for NG propulsion the average H/C ratio for NMHC in exhaust gas is approximately 2. Due to the density determination method stipulated in the legislation, the emission of NHMC from light-duty vehicles running on NG is inflated by approximately 14%.

For mono-fuel vehicles using petrol for start-up (petrol tank capacity must not exceed 15 dm^3) and for bi-fuel vehicles, emissions are calculated assuming that the density of THC and NMHC is the same as for gaseous fuel. In modern vehicles the bulk of those pollutants is emitted after a cold start in the warm up phase (Fig. 3.14). The new legislation limits the petrol running time for those vehicles to 60 seconds. Assuming that the total emission of HC in type I test is 100%, then approximately 65% of HC are emitted during the petrol running time (i.e. 60 seconds). The assumption of THC density typical of gaseous fuel inflates the emission of THC (Tab. 3.7). The bias is small for LPG (approx. 2%) and relatively high for NG (approx.10%).

An analysis shows that emission of NMHC from vehicles with SI engines running on NG/biomethane – if determined in accordance with light-duty vehicles legislation – is inflated as compared to the actual emission. In extreme cases, the difference could be as great as 40%. The same applies to THC emissions, although in this case the difference is smaller. Inflated emissions create a technical obstacle for the development of vehicles with SI engines running on NG/biomethane. To comply with statutory emission limits, such a vehicle must be fitted with a catalytic converter supporting greater hydrocarbon conversion, which is much more expensive than converters used in vehicles running on conventional fuels.

The measurement of PM emission by mass is carried out in a different manner. Diluted exhaust gas sample is captured directly in the tunnel and passes through retaining filter(s). The flow is forced by a pump. The volume of exhaust gas passing through filter(s) during the cycle is measured. Filter weight is checked before and after the test. PM emission is determined using the following formula:

$$e_{\mathrm{PM}} = \frac{V_{mix}\, m}{V_{ep}\, d} \tag{3.15}$$

where: e_{PM} – emission of PM [mg/km],
V_{ep} – volume of exhaust gas passing through filter(s) [dm^3],
V_{mix} – volume of exhaust gas passing through tunnel [dm^3],
m – PM mass deposited on filter(s) [mg],
d – distance travelled during the test [km].

Significant changes have been introduced with regard to the equipment used for measuring PM mass. The new legislation features two new limits for PM emissions from Euro 5 and Euro 6 vehicles (subsection 3.1). The difference between

Table 3.9 Comparison of selected conditions of PM mass measurement required by Euro 4 and Euro5/6

Euro 4 methodology	New Euro5/6 methodology
Particulate filter:	Particulate filter:
a) two filters,	a) one filter,
b) filter weight checking:	b) efficiency of at least 99% at exhaust gas speed of 35 cm/s,
– if $0.95(m_1 + m_2 \le m_1$, then $m = m_1$,	c) mass of particles deposited on the filter ≥ 20 μg.
– if $0.95(m_1 + m_2) > m_1$, to $m = m_1 + m_2$,	
– if $m_2 > m_1$, then the measurement is void,	
– results: measurement (m), first filter weight (m_1), second filter weight (m_2).	
	Diluting air filter:
	a) activated carbon filter (recommended), prefilter (recommended), proper filter (obligatory),
	b) proper filter (HEPA) efficiency not lower than 99.95% for PM.
	Weighing room conditions:
	a) temperature: 295 ±3 K,
	b) relative humidity: 45 ±8%.
	Correction of the mass of PM deposited on the filter reflecting the difference in buoyancy forces at calibration and at measurement:
	$m_c = m_p \cdot (1 - \rho_a / \rho_w)/(1 - \rho_a / \rho_m)$
	where: m_c, m_p – corrected mass, measured mass,
	ρ_a, ρ_w, ρ_m – density (air, weight, filter).
Filter balance:	Filter balance:
a) accuracy 5 μg,	a) accuracy 2 μg,
b) definition 1 μg.	b) definition 1 μg.

limits results from changes in the measurement methodology and equipment (Tab. 3.9). The said changes have been introduced in an attempt to improve measuring accuracy, as well as repeatability and reproducibility of results, first and foremost by introducing additional requirements regarding the equipment and by tightening the tolerances.

Apart from a more stringent limit on PM mass, Euro 5 and Euro 6 additionally limit the particle number (PN) [8]. Attempts are made to introduce a new method for measuring PN to testing engines and vehicles used for non-road purposes (such as aircraft).

The particle sampling system consists of the sampling probe tip (or sampling point) in the dilution system (full-flow – Fig. 3.15, or partial-flow – Fig. 3.16), particle transfer tube, particle pre-classifier (*4*) and a volatile particle remover upstream of the PN counter. The volatile particle remover must be fitted with a device for sample dilution (particle number diluters *6* and *8*) and particle evaporation (evaporation tube – *7*). The sampling probe or the sampling point (in gas flow measurement) must be placed in the dilution tract in such a way that samples can be taken from a homogenous mixture of diluted exhaust gas. The residence time (including the measuring time) should not exceed 20 seconds.

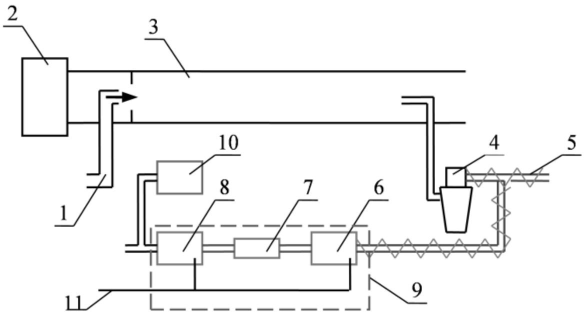


Fig. 3.15 Recommended layout of the PN sampling system – samples taken from a dilution system with full exhaust gas flow; *1* – engine exhaust system, *2* – air filter, *3* – dilution tunnel, *4* – pre-classifier, *5* – heated gas tract to connect additional equipment (e.g. particle mass classifier), *6* – 1st particle number diluter, *7* – evaporation tube, *8* – 2nd particle number diluter, *9* – volatile particle remover, *10* – PN counter, *11* – diluting air supply [15]

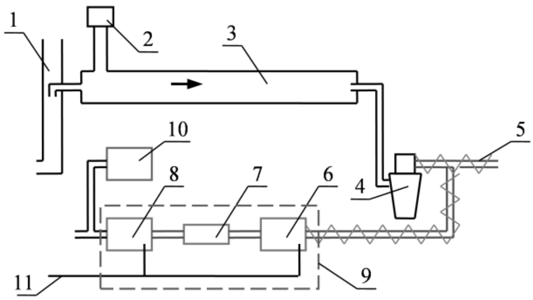


Fig. 3.16 Recommended layout of the PN sampling system – samples taken from a dilution system with partial exhaust gas flow; for key see Fig. 3.15 [15]

Gas sample captured by the PN distribution system must meet the following conditions: Reynolds number must be below 1700 and the residence time should not be greater than 3 seconds. The heated duct over which the diluted sample passes from the volatile particle remover to the orifice of the PN counter must meet the following conditions: internal diameter: at least 4 mm; sample pass-through time: 0.8 seconds or less.

The particle mass pre-classifier is installed upstream of the volatile particle remover. The diameter of the pre-classifier with a 50% cut-off point must be from 2.5 μm to 10 μm. In partial dilution systems it is allowed to use the same pre-classifier for PM mass and for PN.

The volatile particle remover must comprise the first particle number diluter (*6*), an evaporation tube (*7*) and the second particle number diluter (*8*), in series. The dilution consists in reducing the particle number in the sample fed into the particle concentration measurement unit to keep it below the upper threshold of the single particle count mode, and in suppressing nucleation in the sample.

The working temperature of the first particle diluter walls must be from 150°C to 400°C. The wall temperature should be maintained at a constant rated level with a tolerance of ±10°C. The diluter should be fed with filtered diluting air and should support dilution coefficients from 10 to 200.

All over the evaporation tube *7* the wall temperature must be equal to or higher than the temperature of the first particle number diluter (from 300°C to 400°C with a tolerance of ±10°C).

The second particle number diluter *8* should be fed with filtered diluting air and should support dilution coefficients from 10 to 30, so that the number of particles downstream of the second diluter is below the upper limit for counting particles and the gas temperature prior to its feeding into the counter is below 35°C.

The particle counter should:

- ensure counting accuracy of ±10% in the range from 1 cm^{-3} to the upper threshold of the single particle count mode,
- ensure readability of at least 0.1 particle per cm^3 at concentrations below 100 particles/cm^3,
- ensure linear response across the entire measurement range in the single particle count mode,
- have the t_{90} response time below 5 s,
- should have counting efficiencies at particle sizes of 23 nm (±1 nm) and 41 nm (±1 nm) electrical mobility diameter with an efficiency of 50% (±12%) and no less than 90%, respectively.

3.3 Other Tests

Type I test (item 2 in Table 3.2) is used to verify in-service emission data (during technical and roadside inspections). The test scope includes:

- at idling speed:
  - CO concentration in exhaust gas,
  - engine speed,
- at high idle speed ($n > 2{,}000$ rpm):
  - CO concentration in exhaust gas,
  - engine speed,
  - excess air coefficient (lambda).

The CO concentration measured in type approval tests must not exceed:

- 0.3% by volume at idling speed,
- 0.2% by volume at high idle speed.

For in-service vehicles CO concentrations should not exceed the values stated by the manufacturer, which in turn must not be greater than stated in the type approval. The excess air coefficient should be 1 ±0.03, unless the type approval test shows that another value is proper for the vehicle in question.

The measurement method is similar to the method prescribed in earlier legislation. The key difference relates to the calculation of the excess air coefficient, where the following formula applies:

$$\lambda = \frac{c_{CO_2} + \frac{c_{CO}}{2} + c_{O_2} + \left(\frac{y}{4} \times \frac{3{,}5}{3{,}5 + \frac{c_{CO}}{c_{CO_2}}} - \frac{z}{2} \right) \cdot \left(c_{CO_2} + c_{CO} \right)}{\left(1 + \frac{y}{4} - \frac{z}{2} \right) \times \left(c_{CO_2} + c_{CO} + K_1 \times c_{HC} \right)} \tag{3.16}$$

where: c_{CO}, c_{CO_2}, c_{O_2}, c_{HC} – respective concentrations of CO, CO_2, O_2, HC in exhaust gas [% by volume],

K_1 – ratio of hydrocarbon concentration measured by means of FID and NDIR analyzers,

y – ratio of hydrogen and carbon atoms in fuel (H/C),

z – ratio of oxygen and carbon atoms in fuel (O/C).

The values y(H/C) and z(O/C) for the reference petrol (E5) vary from the values prescribed in Euro 4 for bioethanol-free petrol.

Table 3.10 HC emissions from the powertrain in type IV test, by petrol composition

Type of emission	Type of fuel	
	E0[1)]	E5[2)]
Diurnal emissions	0.22	0.37
Warm soak emissions and hot soak emissions	0.07	0.07
Total emissions in type IV test	0.29	0.45

[1)] Ethanol content: 0%.

[2)] Ethanol content: 5% by volume.

Pursuant to the new legislation, type II test is used for all light-duty vehicles with SI engines. For bi-fuel vehicles, the test is performed while the vehicle runs on the same fuel as in the case of type I test, i.e.:

- for the parent vehicle: reference petrol and both reference gaseous fuels,
- for family members: reference petrol and one of the reference gaseous fuels.

Hybrid vehicles are tested with the combustion engine running. The manufacturer implements “service mode” to make the test possible.

Type III test (item 3 in Table 3.2) does not change. It applies only to vehicles with SI engines.

As before, type IV test (item 4 in Table 3.2) applies to vehicles with SI engines running on petrol. As compared to Euro 4, there is a difference resulting from the new division of vehicles into light-duty and heavy-duty. In accordance with the new legislation, the test also applies to vehicles of MLM > 3500 kg.

Powertrain emissions are conventionally divided into three types [3, 4, 9], namely:

- emissions resulting from daily ambient temperature changes (diurnal emissions),
- emissions caused after immobilization of warm or hot engine (warm soak emissions, hot soak emissions),
- running emissions.

Research shows that the introduction of 5–10% (by volume) of bioethanol to petrol causes significant increase in diurnal emissions of HC, as compared to petrol without the said addition (Tab. 3.10). It is attributable to greater vapor pressure and greater permeability of fuel vapors through plastic tank walls.

Type V test (item 5 in Table 3.2) has changed quite considerably. As per Regulation 692/2008 the distance induced to determine the deterioration factor grows from 80,000 km to 160,000 km. Another important change consists in the introduction of two types of deterioration factors:

- multiplicative, as used previously (in this case type I test results are multiplied by the factor),
- additive (in this case type I test results are added to the factor).

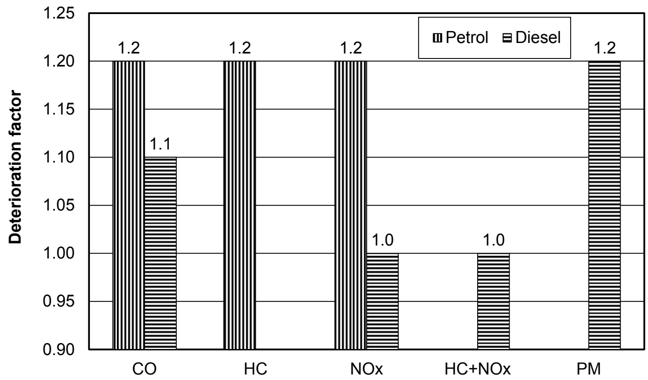
The car manufacturer has the right to choose the factor type.

In accordance with Regulation 692/2008, emission deterioration factors can be:

- determined on the basis of either the vehicle durability test, or the ageing test of pollution control devices (catalytic converter, particulate filter) in a bench cycle,
- accepted at the fixed value determined in the legislation, without testing.

The entire vehicle durability test can be carried out in a road cycle used previously, or in a new cycle, known as the standard road cycle. The new legislation (Regulation 692/2008) still allows using fixed emission deterioration factors instead of those determined through testing. In the case of vehicles with SI engines, the factors are the same in Euro 5 and Euro 6. For vehicles fitted with CI engines, fixed deterioration factors are determined for Euro 5 only. For Euro 6 they are to be determined at a later date. The values of fixed deterioration factors change as compared to the previously used ones (Fig. 3.17). For gaseous pollutants, they have grown for vehicles fitted with both CI and SI engines. Attention is drawn to high factor values for CO and NO_X emissions from vehicles fitted with SI engines and for CO emissions from vehicles fitted with CI engines. The growth of deterioration factors primarily results from increased mileage. For PM, the newly determined factor for vehicles with CI engines is lower than in Euro 4 (1.0 and 1.2, respectively). The underlying reason is that to comply with Euro 5 requirements particulate filters will be necessary which – as research proves – do not lose efficiency as mileage grows.

a)



b)

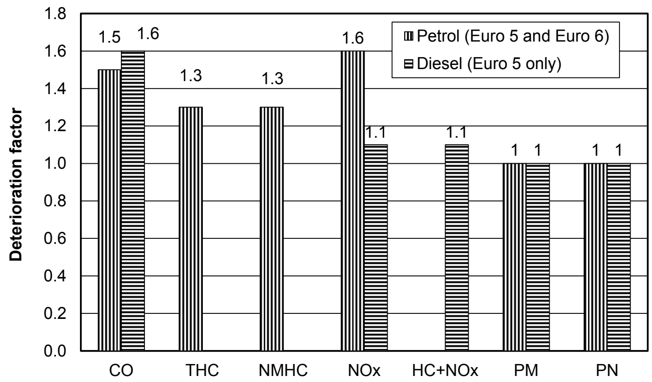


Fig. 3.17 Fixed emission deterioration factors for Euro 4 vehicles (a) and Euro 5/Euro 6 vehicles (b)

As in previous legislation, type VI test is used only for vehicles fitted with SI engines running on petrol (including bi-fuel vehicles). The purpose of the test is to determine pollutants' emission at a temperature of –7^{o}C, considered as representative for cold ambient temperatures in Europe. In type VI test (Fig. 3.18) only carbon monoxide and hydrocarbon emissions are limited. Changes introduced in the new legislation on type VI test (item 6 in Table 3.2) reflect the new method of dividing vehicles into light-duty and heavy duty (subsection 2.2). The said changes are as follows:

- the scope of application has been extended to include all light-duty vehicles of category M fitted with SI engines running on petrol; the same limit, equal to Euro 4's limit for M1 category vehicles of MLM ≤ 2500 kg, applies to all vehicles concerned;

- the scope of application has been extended to include light-duty vehicles of category N2 fitted with SI engines running on petrol; for these vehicles the limit is the same as for N1 class III vehicles.

In Euro 4, the requirements in type VI test were relatively relaxed. For a significant group of vehicles, emissions determined in type approval were below 50% of the limit [14]. In the new legislation, for M1 vehicles with MLM > 2500 kg the limits have been lowered by 45–50%. Limits for category M2 (previously exempt) have been introduced. As a result, it is considerably difficult for category M vehicles with high mass to meet the prescribed limits.

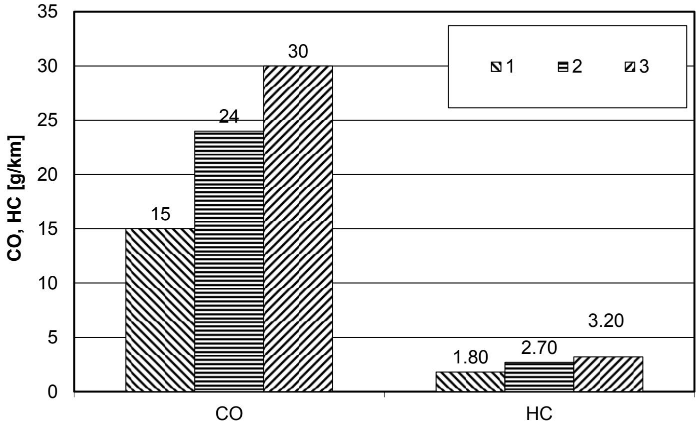


Fig. 3.18 Type VI test emission limits as per Euro 4, Euro 5 and Euro 6 legislation: Euro 4: 1 – category M1 with MLM ≤ 2500 kg and number of seats ≤ 6, N1 class I, 2 – category N1 class II, 3 – category M1 with MLM > 2500 kg or more than 6 seats, category N1 class III; Euro 5 and Euro 6: 1 – category M, category N1 class I, 2 – category N1 class II, 3 – category N1 class III, N2

As compared to Euro 4, the legislation on OBD performance has changed considerably (item 7 in Table 3.2). The key changes are as follows:

- threshold values, at which malfunction should be signaled, have been significantly reduced. This applies also to pollutants for which the prescribed limits have not changed; the ratio of threshold values to prescribed limits has also been reduced (Fig. 3.19),
- it is now required that the OBD system should specify for each monitor the in-use performance ratio (IUPR), i.e. the ratio of the instances in which the monitor was actually satisfied to the instances in which it theoretically should have been satisfied,
- for vehicles fitted with SI engines, the OBD system should monitor the catalytic converter in terms of emissions of not only HC, but also NO_X.

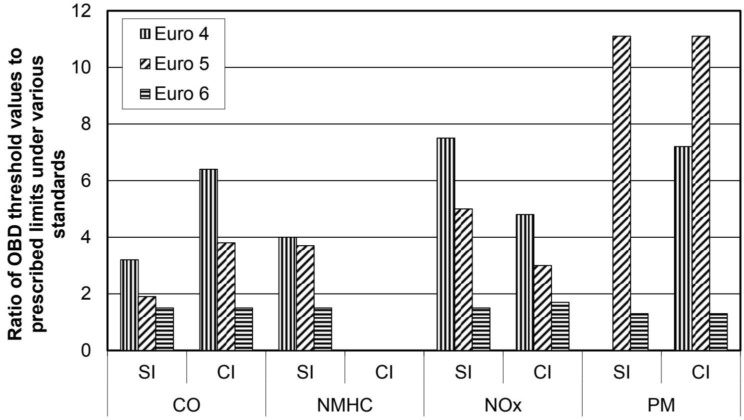


Fig. 3.19 Ratio of OBD threshold values to prescribed limits in type I test for category M vehicles

In the period between the introduction of Euro 5 legislation and complete Euro 6 legislation, threshold values are gradually reduced, while the required IUPR values grow. In the new legislation, the transition stages for OBD are marked as Euro 5+, Euro 6–, Euro 6–plus IUPR (Table 3.1).

Fuel consumption and CO_2 emission tests, as well as electric energy consumption tests (item 8 in Table 3.2) are by nature different from the other tests listed in Table 3.2. The purpose of these three tests is not to verify the vehicle's compliance with statutory requirements, but rather to determine the measured parameters in accordance with a unified measurement method, and also to confirm the correctness of data declared by the manufacturer. The determined values are subsequently used for purposes other than vehicle type approval [4, 5, 16].

The changes in the carbon dioxide emission and fuel consumption test (item 8a in Table 3.2) result from:

- the introduction of reference fuels with biocomponents,
- changes in type I test, as discussed in subsection 3.2.

The general formula for determining fuel consumption looks as follows:

$$\begin{aligned} FC &= \frac{1}{10}\cdot\frac{1}{a}\cdot\frac{1}{\rho}\cdot\left(a\, e_{HC} + 0{,}429\, e_{CO} + 0{,}273\, e_{CO_2}\right) = \\ &= \frac{b}{\rho}\cdot\left(a\, e_{HC} + 0{,}429\, e_{CO} + 0{,}273\, e_{CO_2}\right) \end{aligned} \tag{3.17}$$

where: FC – fuel consumption, dm^3/100 km for petrol, diesel, LPG and E85, and m^3/100 km for NG,

e_{CO_2} – emission of carbon dioxide [g/km],

e_{CO} – emission of carbon monoxide [g/km],

e_{HC} – emission of hydrocarbons [g/km],
ρ – fuel density at 15°C, g/dm^3 for petrol, diesel, LPG and E85, and g/m^3 for NG,
a – coefficient linked to carbon content in fuel,
b – coefficient linked to carbon content in fuel.

The density and the coefficients a and b for reference fuels introduced by the new legislation are presented in Table 3.15. Table 3.16 compares values in previous and in current legislation for vehicles running on petrol.

For hybrid vehicles, carbon dioxide emission and fuel consumption are determined similarly to emission of pollutants in type I test, discussed in detail in [14].

The electric energy consumption test (item 8b in Table 3.2) applies to:

- electric vehicles,
- hybrid vehicles with off-vehicle charging (OVC).

The measurement of electric energy consumption by electric vehicles consists of the 3 following phases:

- preliminary battery charging,
- driving cycle reproduction,
- battery charging.

The first operation in preliminary charging consists of discharging the batteries. Subsequently they are charged as recommended by the manufacturer for 12 hours. If they are not fully charged in 12 hours, that time can be extended, although its maximum value expressed in hours must not exceed three times the ratio of the batteries' capacity (Wh) to the charging power (W).

Within 4 hours after the completion of preliminary charging, a driving cycle, consisting of two NEDC cycles, is performed on a chassis dynamometer. The cycles' reproduction conditions are similar to those in type I test. One significant difference is that resistance to progress of the vehicle simulated on the dynamometer can be determined exclusively on the basis of on-road measurements. The alternative method for determining resistance cannot be used. The total distance travelled in the cycle is measured.

The charging of batteries starts within 30 minutes after the end of the driving cycle, and ends 24 hours after the completion of preliminary charging before the cycle. The charging time as well as the energy supplied from the power supply network are measured.

On-road electric energy consumption is determined using the following formula:

$$l_E = W / d \tag{3.18}$$

where: l_E – on-road electric energy consumption [Wh/km],
W – energy supplied from the network for charging [Wh],
d – distance travelled in the driving cycle [km].

For hybrid vehicles with off-vehicle charging (Table 3.5) the method for determining electric energy consumption is the same as for electric vehicles. It consists of measuring the electric energy supplied from the network in the charging process. The testing procedure is similar to the one used for these vehicles in type I test.

Verification of the system that warns the driver and prevents operation if nitrogen oxide emission is exceeded (item 10 in Table 3.2) – a new test introduced by Euro 5 and Euro 6 legislation – is required only for vehicles fitted with the SCR system for NO_X emission control using a reagent (*Adblue*). Such vehicles should be fitted with a driver warning system activated if:

- reagent quality is inadequate,
- reagent tank level is too low.

As an alternative, vehicles are to be fitted with sensors warning the driver if emission of nitrogen oxides is excessive. The vehicles must also have a system that prevents operation if the driver warning system detects excessive emission, e.g. by:

- disabling engine start after a period of time,
- disabling engine start after refueling,
- disabling refueling,
- limiting performance (maximum driving speed of 50 km/h).

The test consists in checking whether the vehicle is fitted with the warning and prevention systems and whether those systems comply with the regulations. Currently only a small percentage of vehicles are fitted with SCR systems.

The purpose of the engine power test (item 11 in Table 3.2) is to determine that power in accordance with the unified method and to confirm the correctness of data declared by the manufacturer. The scope of application of the net engine power test, as determined in the new legislation, is unclear. Directive 80/1269/EEC [17], regulating the said parameter, has been repealed. It follows from Regulation 715/2007 that engine power measurement should be one of the tests for light-duty vehicles. Pursuant to Regulation 692/2008 the scope of application of this test is limited to vehicles with CI engines.

3.4 Approval Extension

If a manufacturer produces a vehicle type as defined in Directive 2007/46 (Table 2.2) encompassing multiple variants, each of which comes in a number of versions, type approval tests are very labor and time consuming, and thus expensive. In certain cases, such tests would have to be carried out for dozens of vehicles, representing each type defined in Regulation 692/2008. To simplify the type approval process the legislation provides for the possibility of extension of one type approval (within the meaning of Regulation 692/2008) to other types, without additional tests.

The extensibility of type approval is of great practical importance. Some manufacturers obtain approvals for a vast majority of their vehicles by relying on extension, rather than no testing according to Regulation 692/2008.

The legislation provides for approval extension in the following ways:

- by introducing the notion of the vehicle family and by defining the conditions that each vehicle must meet to be considered a family member; type approval can be extended to include all such family members,
- by directly defining the conditions of approval (features that must be identical or remain within a predefined range).

The extension conditions vary from one test to another.

For type I, II and VI tests, extension can currently take place for a type, where:

- the reference mass is not greater than the reference mass of the approved type, or where such mass is greater but requires the use of equivalent inertia in the two inertia categories immediately above,
- for each transmission ratio w the following condition is true:

$$w = 100 \cdot \left| v_2 - v_1 \right| / v_1 \leq 8\%, \tag{3.19}$$

where: v_1 – driving speed at engine speed of 1000 rpm of the approved type [km/h],
v_2 – driving speed at engine speed of 1000 rpm of the type to which the approval is to be extended [km/h].

In the case of type IV tests, extension can be granted if the following features are identical in vehicles of both types:

- fuel feed system (carburettor, injector),
- fuel tank form,
- fuel tank and fuel piping materials,
- method for fuel vapor storage (vapor trap form, volume and material),
- trap purging method.

For type V test, the following must be identical:

- the vehicle (reference mass requirements are identical to those for type I test, and the total resistance to progress can be smaller or greater by no more than 5%),
- the engine (*inter alia,* engine cylinder capacity ±15%, fuel system, working principle),
- the pollution control system (catalytic converter, air injection into the exhaust system, exhaust gas recirculation).

As far as the OBD system is concerned, extension can be granted if the vehicle, to which the approval is to be extended, does not differ from the approved vehicle in terms of features included in the technical description required by the legislation. Differences are allowed for engine accessories, tires, equivalent inertia, overall gear ratio, transmission type and bodywork type.

For carbon dioxide emission and fuel consumption, the approval granted for a given type of vehicles within the meaning of Regulation 692/2008 can be extended to vehicles of the same or another type differing from the approved vehicle in terms of the following:

- reference mass,
- technically permissible maximum laden mass,
- type of bodywork:
  - for category M1 – saloon, hatchback, station wagon, coupe, convertible, multi-purpose,
  - for category N1 – lorry, van.

Extension is possible if the carbon dioxide emissions measured by the technical service do not exceed the type-approval value by more than

- 4% for vehicles of category M1,
- 6% for vehicles of category N1,

which means that in this particular case testing is required.

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