# Chapter 4
# Type Approval of Heavy-Duty Vehicles for Emission of Pollutants

## 4.1 Scope of Application and Rules of Type Approval

The new legislation divides vehicle type approvals into three categories:

- engine type as a separate technical unit,
- vehicle type with an engine approved as a separate technical unit,
- vehicle type with a non-approved engine.

Engine type approval is requested by its manufacturer. To assess regulatory compliance, type approval tests check the parameters listed in Table 4.1, with the exception of item 11 (engine installation on the vehicle). The approved engine type can be used in any vehicle, as long as the conditions for its installation (as stated in the certificate of approval) are met.

The manufacturer also applies for type approval for the vehicle. If the vehicle's engine has been type-approved as a separate technical unit, testing will be limited to checking the compliance of the engine's installation on the vehicle with the conditions stated in the certificate of approval (item 11 in Tab. 4.1). If the engine has not been type approved, then the tests listed in Table 4.1 will be performed. If the manufacturer provides a vehicle, it is his obligation to take out the engine for testing. During the tests either the vehicle's own systems (such as intake or exhaust) are used, or their parameters are simulated on the test bench.

Tests are carried out on a test bench, both for type approval of the engine as a separate technical unit, and of the vehicle with a non-approved engine.

As regards the scope of application, there has been one significant change over Directive 2005/55/EC. Namely, the new legislation applies also to vehicles/SI engines running on petrol. Thus far, such vehicles/engines were subject to Directive 70/220/EEC, and not 2005/55/EC, and the applicable requirements were limited to carbon monoxide concentration at engine idling speed, emissions from the crankcase and possibly OBD control. In the new legislation the scope of requirements is similar to those applicable to vehicles/engines running on other fuels.

J. Merkisz, J. Pielecha, and S. Radzimirski, *New Trends in Emission Control in the European Union*, Springer Tracts on Transportation and Traffic 4,
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The division of vehicles/engines into standard and EEV (enhanced environment-friendly vehicle) according to their respective emission levels, originally introduced in 2000, has now been abolished. The division resulted in different prescribed limits for each group.

**Table 4.1** Types of tests required under EC regulation for type approval of heavy-duty vehicles

| No. | Test type | SI engine | CI engine |
|---|---|---|---|
| 1 | Measurement of pollution emission in a steady-state test (WHSC) on an engine test bench | no | yes |
| 2 | Measurement of pollution emission in a transient test (WHTC) on an engine test bench | yes | |
| 3 | CO concentration and excess air coefficient measurement at engine idling speed (for in-service conformity verification) | yes | no |
| 4 | Measurement of emissions from the crankcase | yes | |
| 5 | Measurement of off-cycle emission | yes1) | |
| 6 | Durability test of pollution control devices | yes | |
| 7 | Measurement of fuel consumption and $CO_2$ emission | yes | |
| 8 | OBD test | yes | |
| 9 | Verification of the system designed to reduce emissions of nitrogen oxides | no | yes |
| 10 | Net power measurement | yes | |
| 11 | Verification of engine installation on the vehicle | yes | |

1) It is unclear whether or not the test applies to SI engines.

The new legislation applies to vehicles/engines running on the following fuels:

- for spark ignition (SI):
  - petrol (reference fuel E10),
  - LPG,
  - NG or biomethane,
  - ethanol (reference fuel E85),
- for compression ignition (CI):
  - diesel (reference fuel B7),
  - ethanol (reference fuel ED95).

Efforts have begun to include dual fuel vehicles (i.e. vehicles simultaneously running on two fuels: diesel and LPG or NG/biomethane) in the scope of legislation. It is expected that such inclusion will take effect approximately in 2013.

The symbols E10 and B7 mean that the fuels contain 10% of ethanol (by volume) or 7% of biodiesel (by volume), respectively; the symbol E85 denotes a mixture of ethanol (85% by volume) and petrol, while ED95 refers to ethanol (95% alcohol by mass) for CI engines. Thus, just like in the case of light-duty vehicles, the new legislation puts emphasis on alternative fuels. Attention should be drawn to the fact that the above content of ethanol and biodiesel for reference fuels, as prescribed in the new heavy-duty vehicles legislation, is greater than for light-duty vehicles (5% by volume and 5% by volume, respectively), which implies that the EU expects a significant growth of biocomponents' percentage in petrol and diesel.

**Table 4.2** Effective dates of each type approval variant in accordance with Euro VI legislation for heavy-duty vehicles

| Symbol | Threshold value for $NO_X$ (Tab.4.10) | Threshold value for PM (Tab.4.10) | Reagent quality and consumption requirements | NTA date | ANR date | Date by which registration is allowed |
|---|---|---|---|---|---|---|
| A | interim | efficiency monitoring | interim | 31.12.2012 | 31.12.2013 | 1.09.2015 |
| B | interim | interim | interim | 1.09.2014 | 1.09.2015 | 31.12.2016 |
| C | target | target | target | 31.12.2015 | 31.12.2016 | – |

In terms of fuel, there are now three kinds of type approvals:

- universal,
- for a limited range of fuel composition,
- for specific fuel composition.

Universal type approval is used for all CI engines, i.e. those running on diesel and ethanol, as well as for SI engines running on petrol. For gaseous fuels (LPG and NG/biomethane) universal type approval is granted only for self-adaptive engines supporting all commercially available fuels of a given kind, meeting the prescribed requirements. In this case the engine must meet the requirements when running on extreme reference fuels: A and B for LPG and GR and G25 for NG [10].

As for the second kind of type approval the required range of self-adaptation is smaller. Such approval can be granted only to NG engines. The engine is suitable for fuels in the composition range L or H [10].

The third of the above type approvals is available for engines that can be adapted to commercially available fuels only by adjusting the fuel supply system. Such approval can be granted for LPG and NG engines. Reference fuels are the same as for universal approval.

If the engine has been approved for a limited range of fuel composition or for a specific fuel composition, then it should be marked accordingly.

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

- threshold limits for nitrogen oxides in OBD test,
- threshold limits for PM in OBD test,

- requirements with regard to the reagent (Adblue) quality and consumption in the test of the system designed to reduce emissions of nitrogen oxides.

There are 3 type approval variants denoted with capital letters of the Latin alphabet, from A to C (Tab. 4.2).

The types of tests prescribed in the new legislation (Tab. 4.1) differ considerably from those used thus far. A general rule has been accepted that the measurement method in each test should be identical to the method determined in the corresponding GTR, if any. By 30 June 2011 three GTRs had been adopted with respect to the tests covered by the new legislation:

- GTR 4 on the methods of testing the emission of pollutants from CI engines and SI engines running on LPG and NG [6],
- GTR 5 on technical requirements for OBD systems in on-road vehicles [7],
- GTR 10 on off-cycle emission of pollutants [8].

## 4.2 Steady State Test and Transient Test

### *4.2.1 Operation Cycles and Prescribed Limits*

The tests used thus far (European Steady-state Cycle (ESC) and European Transient Cycle (ETC)) have been replaced with WHSC (World Harmonized Steady-state Cycle) and WHTC (World Harmonized Transient Cycle), respectively. The latter have been developed on the basis of the results of on-road tests of heavy-duty vehicles in certain EU states, Japan and the USA. They are global in character, unlike ESC and ETC, which were representative for traffic conditions in Europe. WHSC and WHTC tests were first introduced in GTR 4 [6].

The WHSC cycle used in the steady state test is a normalized cycle, i.e. one where both the speed and the torque of the tested engine are calculated on the basis of standard values of those parameters provided for in legislation.

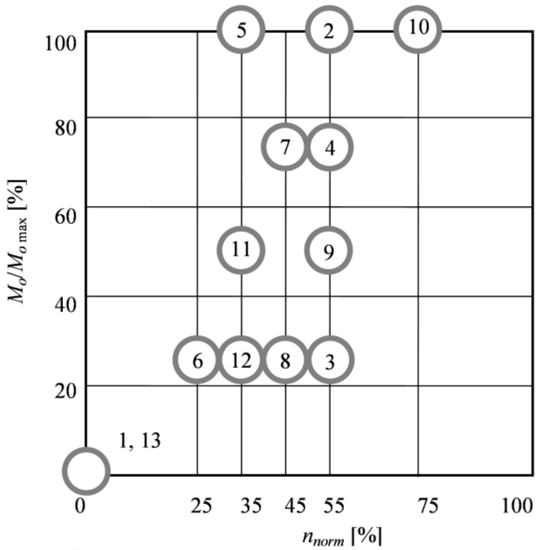
The WHSC cycle (just like the ESC) consists of 13 phases, but depending on the engine, there are differences in operating conditions (Fig. 4.1). One of such differences is that in the WHSC the measurements are made at 6 engine speeds (instead of 4). Another difference consists in the method of associating engine load with its speed. In the ESC for each of the three speeds (except for idling speed) there are four load values: 25%, 50%, 75% and 100%, which results in a total of 12 phases (plus the $13^{th}$ phase for idling speed). In the WHSC the load values are similar to those in the ESC (25%, 50%, 70% and 100% of the maximum load), but not all of them are used with every speed. The distribution is as follows: 4 loads of 25%, two loads of 50% and 70% each, and three loads of 100%. In total, there are 11 phases (plus two idling speed phases). The average speeds and loads (and thus powers) in the WHSC are lower than in the ESC, which affects the emission of pollutants.

To determine the actual values of engine speeds and loads, a denormalization of the values presented in Fig. 4.1 is required. Its first stage consists of determining full power curve (Fig. 4.2a). Subsequently, actual parameters are calculated using the following formulae:

$$n_{real} = n_{norm} \cdot (0{,}45\, n_{lo} + 0{,}45\, n_{pref} + 0{,}1\, n_{hi} - n_{idle}) \cdot 2.0327 + n_{idle} \tag{4.1}$$

$$M_{real} = (M_{norm} \cdot M_M)/100 \tag{4.2}$$

where: $n_{real}$ – actual engine speed [rpm],
$n_{norm}$ – normalized engine speed [%],
$n_{lo}$ – lowest engine speed at which 55% of the maximum power is generated ($N_{e\,\max}$) [rpm],
$n_{hi}$ – highest engine speed at which 70% of $N_{e\,\max}$ is generated [rpm],
$n_{idle}$ – idling speed [rpm],
$n_{pref}$ – speed at which the torque integral equals 51% of the torque integral in the range from $n_{idle}$ to $n_{95h}$ [rpm],
$n_{95h}$ – maximum speed at which 95% of $N_{e\,\max}$ is generated [rpm],
$M_{real}$ – actual torque [N·m],
$M_{norm}$ – normalized torque [%],
$M_M$ – maximum torque [N·m],
$N_{e\,\max}$ – effective power [kW] (Fig. 4.2a).




| Phase | $t_i$ [s] |
|---|---|
| 0 | – |
| 1 | 210 |
| 2 | 50 |
| 3 | 250 |
| 4 | 75 |
| 5 | 50 |
| 6 | 200 |
| 7 | 75 |
| 8 | 150 |
| 9 | 125 |
| 10 | 50 |
| 11 | 200 |
| 12 | 250 |
| 13 | 210 |

**Fig. 4.1** Normalized WHSC cycle and phase durations [2, 11]

The aforementioned differences between the WHSC and the ESC result in different operating conditions for individual engines (Fig. 4.3).

Another important difference between the WHSC and the ESC is related to the method of measurement and calculation of pollutant emission. In the ESC, in the case of gaseous pollutants, the average concentration, exhaust gas flow rate and engine power are determined. This determination is made on the basis of the results recorded during the last 30 seconds of operation in a given phase (i.e. once the working conditions have stabilized). The emission of pollutants in the entire test is determined as the weighted average from all 13 phases, using the weighting factor prescribed in the legislation. For particulate matter, one sample is collected on a single filter throughout the entire cycle. The sample collection must be organized (in terms of time, gas flow rate, dilution) in such a way that in each phase the actual weighting factor is equal to its prescribed value (within the allowed tolerances).

In the WHSC test, weighting factors for each phase are not used directly. The differences in the percentage of operating conditions are accounted for by diversifying the operation time in each phase. For gaseous pollutants, emissions are

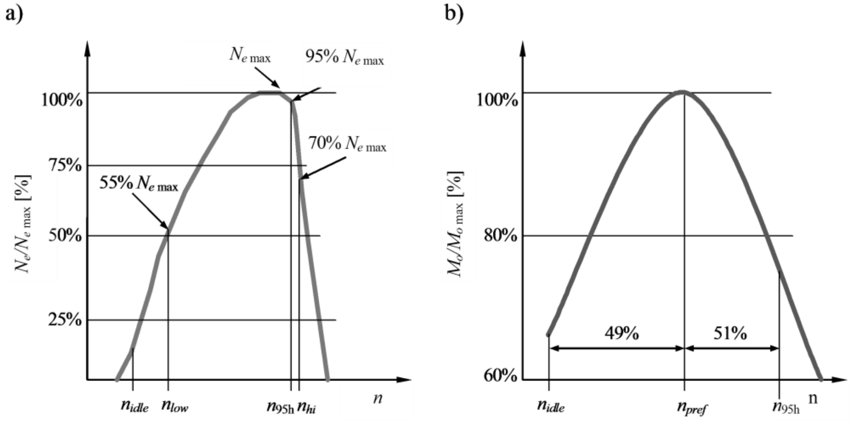



**Fig. 4.2** Definitions of engine speeds in the WHSC test: a) determination of $n_{lo}$, $n_{hi}$ and $n_{95h}$ on the basis of full power curve, b) determination of $n_{pref}$

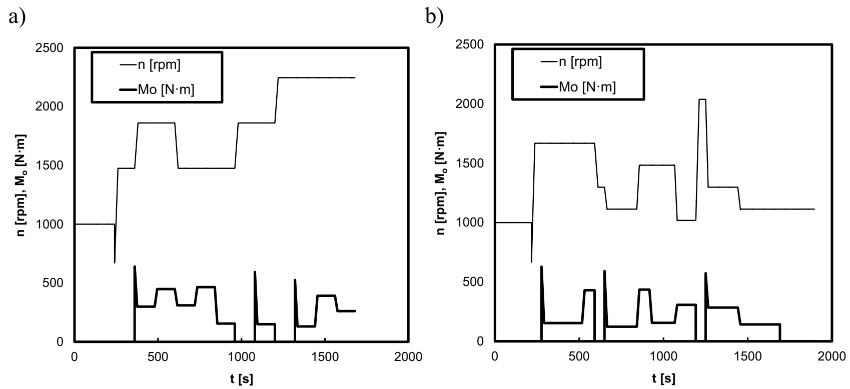



**Fig. 4.3** Comparison of ESC (a) and WHSC (b) for a selected engine

measured for the entire cycle, including transitions in operating conditions (engine speed and torque) in each phase. Therefore, the transition methodology is predefined. Transitions should be linear and should be completed in 20 seconds. Just like in the ESC, a PM sample is collected on one filter, but without any interruptions during the entire WHSC cycle. In the WHSC the operating conditions (engine speed, torque and temperature) are not stabilized, even though the cycle name (steady-state) suggests otherwise.

The emission of pollutants in the test measured in g/kWh is determined using the following formula:

$$e = \frac{m}{W_{real}} \tag{4.3}$$

where: $m$ – mass of the pollutant in the test [g],
$W_{real}$ – work in the test calculated on the basis of recorded engine speed and torque values [kWh].

Just like the WHSC, the WHTC is a normalized cycle (Fig. 4.4). "Denormalization" is carried out in the same way as in the WHSC.

The differences between the ETC and the WHTC result from the differences in:

- normalized engine speed and normalized torque (Tab. 4.3),
- the method for calculating a specific engine speed using normalized parameters.

In the case of the ETC the tested engine speed is determined using the following formula:

$$n_{rzecz} = 0{,}01\, n_{norm}\left(0{,}05\, n_{lo} + 0{,}95\, n_{hi} - n_{idle}\right) + n_{idle} \tag{4.4}$$

whereas in the case of the WHTC the formula is identical to the one presented above (4.1) for the WHSC.

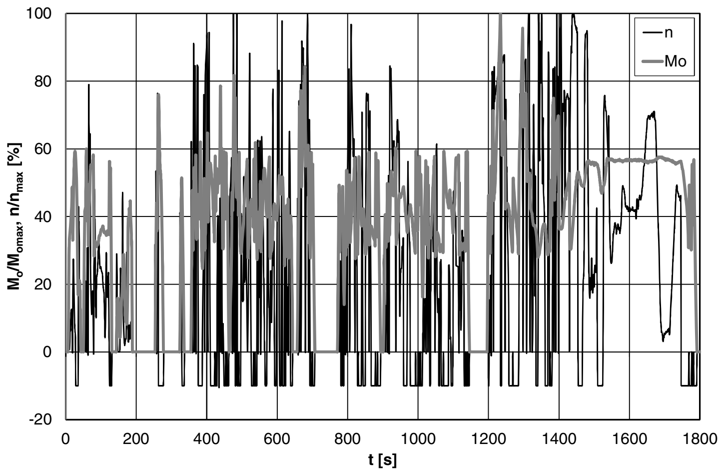



**Fig. 4.4** Normalized WHTC cycle

**Table 4.3** Normalized engine speed and torque for ETC and WHTC (fragment)

| Time [s] | ETC | | WHTC | |
|---|---|---|---|---|
| | Normalized engine speed $n/n_{max}$ [%] | Normalized engine torque $M_o/M_{o\ max}$ [%] | Normalized engine speed $n/n_{max}$ [%] | Normalized engine torque $M_o/M_{o\ max}$ [%] |
| .. | .... | .... | .... | ..... |
| 71 | 81.4 | 99.6 | 55.3 | 18.3 |
| 72 | 88.7 | 73.4 | 55.1 | 16.3 |
| 73 | 52.5 | 0 | 54.8 | 11.1 |
| 74 | 46.4 | 58.5 | 54.7 | 11.5 |
| 75 | 48.6 | 90.9 | 54.8 | 17.5 |
| 76 | 55.2 | 99.4 | 55.6 | 18.0 |
| 77 | 62.3 | 99.0 | 57 | 14.1 |
| 78 | 68.4 | 91.5 | 58.1 | 7.0 |
| 79 | 74.5 | 73.7 | 43.3 | 0 |
| 80 | 38.0 | 0 | 28.5 | 25.0 |
| .. | .... | .... | .... | .... |

The method for determining the tested engine torque on the basis of normalized values is the same for both cycles (maximum torque at a given engine speed multiplied by the normalized value).

For specific engines there are differences between the WHTC and the ETC in terms of speed and torque (Fig. 4.5). In the former, the average engine speed and torque are typically lower than in the latter. Just like in the case of the ESC and the WHSC, for certain engines there are considerable differences in measurement results in both tests (Fig. 4.7).

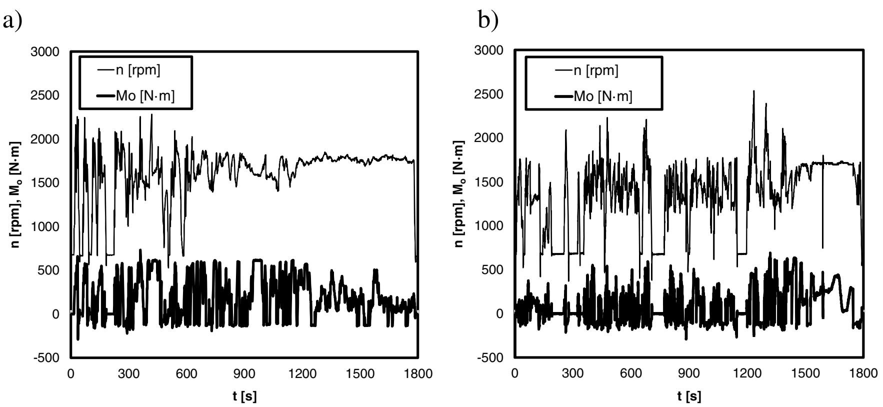



**Fig. 4.5** Comparison of operating conditions in the ETC (a) and the WHTC (b) in a hot start test [8]

The WHTC test consists of the following phases:

- phase 1 – cold start test; the engine is considered cold if the temperatures of oil, coolant and after-treatment system remain within the range of 20–30°C; one WHTC cycle is carried out (Fig. 4.5),
- phase 2 – hot soak period of 5 minutes,
- phase 3 – hot start test; one WHTC cycle is carried out (Fig. 4.5).

The share of the cold start test is 0.1, and the share of the hot start test is 0.9. The emission of pollutants *e* in g/kWh is determined using the following formula:

$$e = [(0{,}1\ m_{cold}) + (0{,}9\ m_{hot})]\ /\ [(0{,}1\ W_{cold}) + (0{,}9\ W_{hot})] \qquad (4.5)$$

where: $m_{cold}$ – compound mass determined in cold start test [g per phase],
$m_{hot}$ – compound mass determined in hot start test [g per phase],
$W_{cold}$ – work determined in cold start test [kWh per phase],
$W_{hot}$ – work determined in hot start test [kWh per phase].

In phase 1, emission of pollutants is significantly affected by the time required for achieving the normal engine temperature and by pollution control systems used (Fig. 4.6). The legislation does not stipulate detailed requirements with respect to engine warming method.

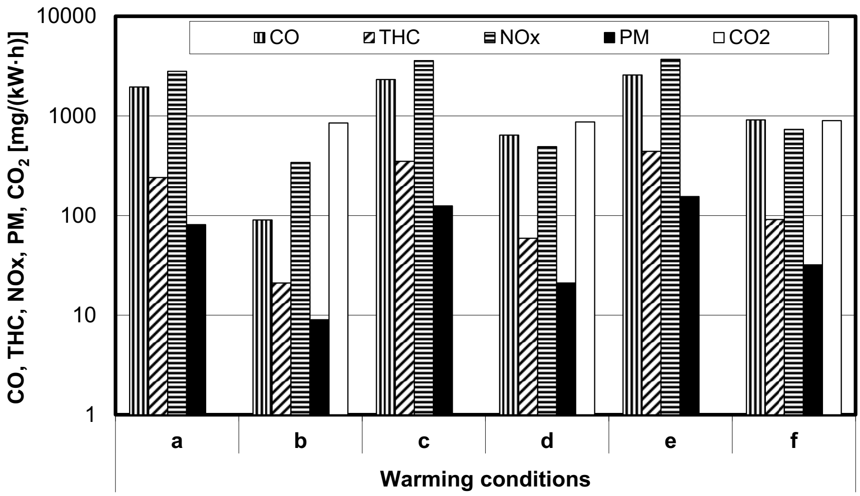



**Fig. 4.6** The effect of engine warming time (expressed as the time *t* necessary to heat the cooling agent to 90°C after start at 24°C) on specific emission of limited pollutants: a) t = 0 s (hot engine), measurement upstream of the pollution control system in the exhaust system, b) t = 0 s (hot engine), measurement downstream of the pollution control system in the exhaust system, c) t = 110 s, measurement upstream of the pollution control system in the exhaust system, d) t = 110 s, measurement downstream of the pollution control system in the exhaust system, e) t = 195 s, measurement upstream of the pollution control system in the exhaust system, f) t = 195 s, measurement downstream of the pollution control system in the exhaust system

Euro VI introduces an increased number of regulated pollutants, as compared to Euro V and EEV (Tab. 4.4). The new requirements also apply to:

- particle number (for CI and SI engines),
- ammonia (for CI and SI engines),
- particle mass for SI engines.

Additionally, there are the following differences:

- for CI engines, the requirements under Euro V and EEV in the ETC test apply to NMHC, while under Euro VI in the WHTC test they apply to THC,
- requirements regarding specific emissions of methane in Euro V and EEV in the ETC test only apply to SI engines running on NG, while under Euro VI in the WHTC test they apply to all SI engines.

Attention is drawn to the fact that in light-duty vehicles legislation, particulate matter mass is marked as PM and particle number is marked as PN, while in heavy-duty vehicles legislation these parameters are marked as "PM mass" and "PM number", respectively [5].

In case Euro VI as well as Euro V and EEV apply to the same pollutants, one cannot directly compare the respective limits prescribed therein, due to measurement methodology differences. On the basis of available data it is estimated that Euro VI requirements are in this case much more strict for CI engines, particularly as regards specific emissions of nitrogen oxides and PM mass. The same applies to carbon monoxide, whose values limits in Euro VI are the same, and in one case they are even higher. However, specific CO emissions from the same CI engine in WHSC and WHTC tests are on average greater than in ESC and ETC tests, respectively. For SI engines there is little data available to allow one to compare the severity of regulations under Euro VI on the one hand and Euro V and EEV on the other. Generally it can be claimed that the requirements applicable to nitrogen oxides and NMHC are more severe in Euro VI.

It should be stressed that in Regulation 595/2009 the limits identical to those in Table 4.4 were determined using ESC and ETC tests. However, the Regulation does not provide for requirements for WHSC and WHTC tests. They were planned to be introduced at a later date after correlation tests. The European Commission decided to remove ESC and ETC tests from its regulation and replaced them with WHSC and WHTC tests without adjusting the related prescribed limits. Therefore, it was assumed that the results in WHSC and WHTC tests are identical to those in ESC and ETC tests, which is not true for certain engines (Fig. 4.7).

Attention is drawn to the fact that in the new legislation the requirements applicable to emissions of hydrocarbons from light-duty and heavy-duty vehicles are expressed in a different way. For SI engines in light-duty vehicles the requirements apply to THC and NMHC, as opposed to NMHC and $CH_4$ in heavy-duty vehicles (Tab. 4.4). For CI engines in light-duty vehicles the prescribed limit refers to totalized emissions of THC and $NO_X$ (i.e. no separate limits for hydrocarbons), while for heavy-duty vehicles the requirements apply to THC (Tab. 4.4).

**Table 4.4** Prescribed limits of specific emission of pollutants under Euro V, EEV and Euro VI for heavy-duty vehicles

**Euro V**

| Test type (engine) | CO [mg/kWh] | THC [mg/kWh] | $NO_X$ [mg/kWh] | PM [mg/kWh] |
|---|---|---|---|---|
| ESC (CI) | 1500 | 460 | 2000 | 20 |

| | CO [mg/kWh] | NMHC [mg/kWh] | $CH_4$ [mg/kWh] | $NO_X$ [mg/kWh] | PM [mg/kWh] |
|---|---|---|---|---|---|
| ETC (SI, CI) | 4000 | 550 | 1100[1)] | 2000 | 30 |

**EEV**

| | CO [mg/kWh] | THC [mg/kWh] | $NO_X$ [mg/kWh] | PM [mg/kWh] |
|---|---|---|---|---|
| ESC (CI) | 1500 | 250 | 2000 | 20 |

| | CO [mg/kWh] | NMHC [mg/kWh] | $CH_4$ [mg/kWh] | $NO_X$ [mg/kWh] | PM [mg/kWh] |
|---|---|---|---|---|---|
| ETC (SI, CI) | 3000 | 400 | 650[1)] | 2000 | 20 |

**Euro VI**

| | CO [mg/kWh] | THC [mg/kWh] | $NO_X$ [mg/kWh] | $NH_3$ [ppm] | PM [mg/kWh] | PN [1/kWh] |
|---|---|---|---|---|---|---|
| WHSC (CI) | 1500 | 130 | 400 | 10 | 10 | $8,0\times10^{11}$ |
| WHTC (CI) | 4000 | 160 | 460 | 10 | 10 | $6,0\times10^{11}$ |

| | CO [mg/kWh] | NMHC [mg/kWh] | $CH_4$ [mg/kWh] | $NO_X$ [mg/kWh] | $NH_3$ [ppm] | PM [mg/kWh] | PN [1/kWh] |
|---|---|---|---|---|---|---|---|
| WHTC (CI) | 4000 | 160 | 500 | 460 | 10 | 10 | – |

[1)] Applies only to engines running on NG.

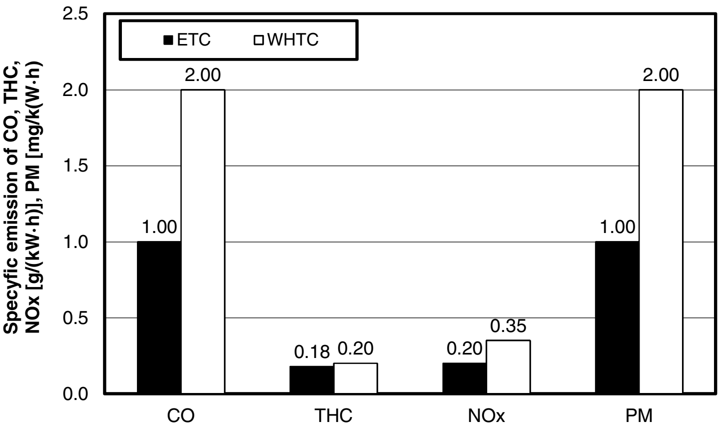



**Fig. 4.7** Comparison of specific emission of pollutants in ETC and WHTC tests from a selected CI engine running on diesel (based on [1])

When comparing the previous and the new legislation on heavy-duty vehicles one notices a significant difference in the formulation of requirements for hydrocarbons. As already mentioned, in the new legislation the type of limited hydrocarbons depends on the ignition type. Previously it depended on the test type:

- in the ESC test (applicable only to CI engines) – THC,
- in the ETC test – NMHC (for CI engines and SI engines running on LPG and NG) and $CH_4$ (only for SI engines running on NG).

In the new heavy-duty vehicles legislation the requirements applicable to particle mass and number apply to all vehicles fitted with SI and CI engines. This marks a significant difference as compared to the light-duty legislation, whereby the requirements for particle number apply to all vehicles fitted with SI engines (effective only under Euro 6), while the requirements for particle mass apply only to vehicles fitted with SI engines with direct fuel injection (effective both in Euro 5 and Euro 6).

## *4.2.2 Measurement Method and Test Equipment*

According to the new legislation, measurements of specific emission of pollutants in steady-state and transient tests are still to be carried out on an engine dynamometer (test bench) (Fig. 4.8). The brake used is an asynchronous AC motor with a small moment of inertia. Optimally, the brake's control system runs $n = f(t)$ of the operating cycle, the engine's electronic control system (ECS) runs $M_o = f(t)$, and an additional control software synchronizes both runs and calculates instantaneous power ($N_e = \pi n M_o/30$) and then integrates it to calculate work.

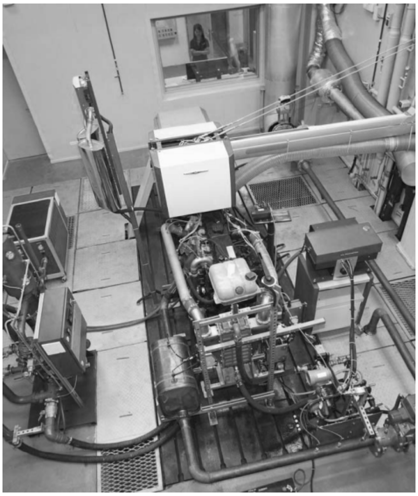


**Fig. 4.8** Engine dynamometer [4]

To reduce non-repeatability of test results caused by atmospheric conditions, requirements for the temperature and pressure of air sucked in by the engine have been introduced. On the basis of the measurement of those parameters the coefficient $f_a$ is calculated. For uncharged and mechanically supercharged CI engines, $f_a$ is calculated using the following formula:

$$f_a = (99/p_s) \cdot (T_a/298)^{0,7} \tag{4.6}$$

where: $p_s$ – dry air pressure at the intake system inlet [kPa],
$T_a$ – air temperature at the intake system inlet [K].

Formulae for other engines covered by the legislation are similar, but with different power indices. Atmospheric reference conditions have been identified as 99 kPa and 298 K. Atmospheric conditions are considered compliant if $f_a$ remains within the range from 0.96 to 1.06.

The mass of gaseous pollutants can be determined by measuring the concentration and flow rate of:

- raw exhaust gas,
- diluted exhaust gas.

In the first case, measurements include instantaneous pollutant concentrations in exhaust gas and instantaneous exhaust gas flow rate. A sample of raw exhaust gas for concentration measurement is taken from the engine exhaust system (Fig. 4.9). Mass emission of gaseous pollutants is calculated by means of the following formula:

$$m_{gas} = u\frac{1}{f}\sum_{i=1}^{i=n}(c_{gas,i} \cdot q_{mew,i}) \tag{4.7}$$

where: $m_{gas}$ – compound mass [g],
$u_{gas}$ – pollutant density to exhaust gas density ratio,
$c_{gas,i}$ – instantaneous pollutant concentration in exhaust gas [ppm],
$q_{mew,i}$ – exhaust gas flow rate in the $i^{th}$ measurement [kg/s],
$f$ – measurement frequency [Hz],
$n$ – number of measurements.

The $u_{gas}$ ratio for each fuel and pollutant is stated in the legislation.

The $q_{mew,i}$ value can be determined using the following methods:

- direct measurement of exhaust gas flow rate,
- measurement of air and fuel flow rate; $q_{mew,i}$ is the sum of those rates,
- measurement of air flow rate and the excess air coefficient λ.

Full flow measurement system (CVS) is used to measure pollutant mass on the basis of diluted exhaust gas flow rate and concentration. The system measures HC and $NO_X$ by continuous sampling, while CO is measured in bags (Figs. 4.10 and 4.11). Mass emission of gas pollutants is calculated using the following formula:

$$m_{gas} = u_{gas}\ c_{gas}\ m_{ed} \tag{4.8}$$

where: $m_{gas}$ – compound mass [g],
$u_{gas}$ – pollutant density to exhaust gas density ratio,
$c_{gas}$ – average pollutant concentration in exhaust gas [ppm],
$m_{ed}$ – total exhaust gas mass for the test [kg].

The $u_{gas}$ ratio for each fuel and pollutant is provided for in the legislation.

The $m_{ed}$ value is measured directly using critical flow venturis or a displacement pump.

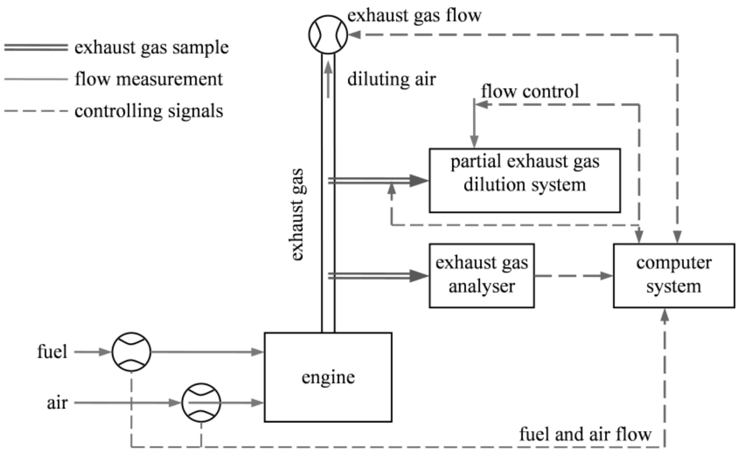



**Fig. 4.9** Layout of an undiluted exhaust gas measurement system [11]

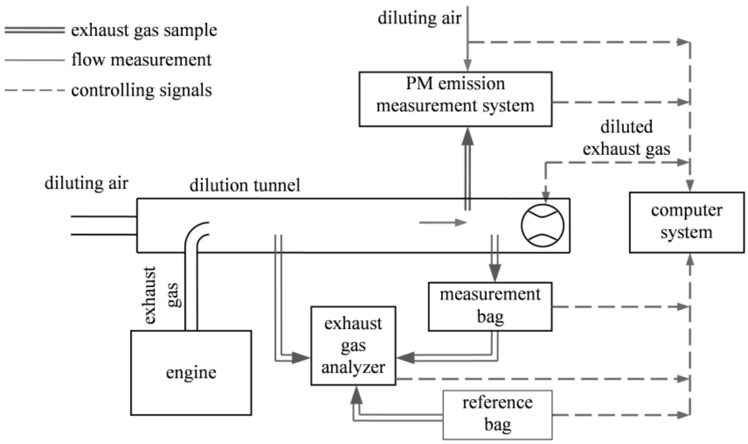



**Fig. 4.10** Layout of a full flow measurement system [11]

If specific emission of gaseous pollutants is measured in undiluted exhaust gas, PM emission is measured in a partial flow system (Figs. 4.9 and 4.12). If the said emission is measured in diluted exhaust gas, the PM sample is taken from the dilution tunnel (Fig. 4.10).

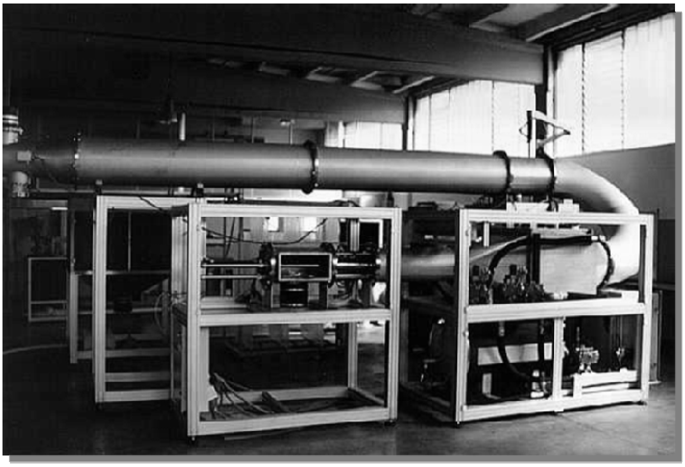


**Fig. 4.11** Full flow measurement system [4]

**Fig. 4.12** Partial flow system [4]

To determine PM mass, a sample is sent through a filter weighed before and after the test. The general formula for PM mass calculation looks as follows:

$$m_{\mathrm{PM}} = \frac{m_f \; m_{ed}}{1000 \, m_{sep}} \tag{4.9}$$

where: $m_{\mathrm{PM}}$ – PM mass exhausted during the test [mg],
$m_f$ – mass of particles collected on the filter (equal to the difference in filter weights before and after the test) [mg],
$m_{sep}$ – mass of exhaust gas sample passing through the filter [kg],
$m_{ed}$ – total mass of exhaust gas in the test [kg].

The concentration of pollutants in exhaust gas ($c_{gas}$) is determined by means of an analytical device consisting of adequate analyzers and ancillary units, similar to the one used in type I test for light-duty vehicles (Fig. 3.15). One fundamental change in the device results from the introduction of requirements regarding ammonia concentration (Tab. 4.4).

Ammonia concentration can be measured by two types of analyzers:

- laser diode spectrometer (LDS),
- Fourier Transformed Infrared (FTIR) spectrometer.

Measurement is made on a continuous basis. In the WHSC test it is assumed that the total average of instantaneous values of ammonia concentration constitutes the final result, compared against the prescribed limit amounting to 10 ppm. In the WHTC test the final result is calculated as follows:

$$c_{\mathrm{NH_3}} = 0.14 \, c_{\mathrm{NH_3},c} + 0.86 \, c_{\mathrm{NH_3},h} \tag{4.10}$$

where: $c_{\mathrm{NH_3}}$ – average ammonia concentration in the WHTC test [ppm],
$c_{\mathrm{NH_3},c}$ – average ammonia concentration in the cold start phase of the WHTC test, determined as the total average of instantaneous values [ppm],
$c_{\mathrm{NH_3},h}$ – average ammonia concentration in the hot start phase of the WHTC test, determined as the total average of instantaneous values [ppm].

Another significant change in the new legislation is related to the method of measuring the concentration of various hydrocarbons (non-methane, total and methane). The measurement system does not differ from the one used in type I test for light-duty vehicles and previously used for heavy-duty vehicles, discussed in detail in section 3.2. However, the calculation method differs considerably.

The hydrocarbon concentration measurement method for heavy-duty vehicles is determined in Directive 2005/55/EC [3] and in Regulation 49 (04 series of amendments) [11]. To some extent it has been copied from ISO 16183 [9]. The method is not fully clear. The legislation states that propane calibrated FID analyzer should be used if exhaust gas bypasses a separator. However, it fails to stipulate which method (Fig. 3.18) should be used for FID analyzer calibration if exhaust gas does pass through a separator. This applies in particular to the reference gas type. Some provisions imply that the gas in question should be propane (as is the case of analysis without the separator), but other regulations suggest to the contrary.

According to the aforementioned heavy-duty vehicles legislation, methane concentration is determined by measuring hydrocarbon concentration in exhaust gas passing through the separator and bypassing it, using the following formula:

$$c^{P}_{\mathrm{CH_4}} = \frac{c_W - (1 - E_E)\, c_{W/O}}{E_E - E_M} \tag{4.11a}$$

It is assumed that total hydrocarbon concentration is equal to the concentration measured in exhaust gas bypassing the separator:

$$c^{P}_{\mathrm{THC}} = c_{W/O} \tag{4.11b}$$

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

$$c^{P}_{\mathrm{NMHC}} = c_{W/O} - c^{P}_{\mathrm{CH_4}} = \frac{c_{W/O}(1 - E_M) - c_W}{E_E - E_M} \tag{4.11c}$$

For measurement systems of perfect parameters ($R_f = 1$, $E_E = 1$, $E_M = 0$, $k = 1$), the readings of the FID analyzer with exhaust gas passing through the separator correspond to the actual methane concentration. If the separator is bypassed, the said readings correspond to the actual THC concentration. The difference between the two readings is equal to NMHC concentration. In this case, the calculations of hydrocarbon concentrations made using simplified formulae (4.11) stated in the legislation do not differ from actual values. This applies to all hydrocarbon compositions.

## 4.3 Verification of Off-Cycle Emissions

The method for verifying off-cycle emissions is determined in GTR 10 [8]. The test in question (item 5 in Tab. 4.2) determines specific emission in steady-state conditions in three elementary operating fields, randomly selected from 9 or 12 fields constituting the verification range (Fig. 4.13). In each of those fields 5 points are measured. The engine is considered compliant:

**Table 4.5** Prescribed limits for off cycle emissions from heavy-duty vehicles

| Pollutant | Prescribed limit [mg/kWh] |
|---|---|
| CO | 2000 |
| THC | 220 |
| $NO_X$ | 600 |
| PM | 16 |

- for gaseous pollutants – if the average value from 5 measurements in each of the randomly selected elementary fields does not exceed the limit prescribed for the test,
- for PM mass – if the average value from all 15 measurements in three randomly selected elementary fields does not exceed the limit prescribed for the test.

The prescribed limit is calculated as follows:

$$NTE_{limit} = WHTC_{limit} + NTE_{component} \tag{4.13}$$

where: $NTE_{limit}$ – prescribed limit for off-cycle emission,
$WHTC_{limit}$ – prescribed limit for specific emission in the WHTC test,
$NTE_{component}$ – additional component.

The additional component ($NTE_{component}$) is determined using the following formula:

$$NTE_{component} = a\ WHTC_{limit} + b \tag{4.14}$$

The values $a$ and $b$ are pollutant-dependent.

The prescribed limits for off-cycle emission are presented in Table 4.5. They are greater than those for the WHSC by 20% (for THC) to 60% (for PM).

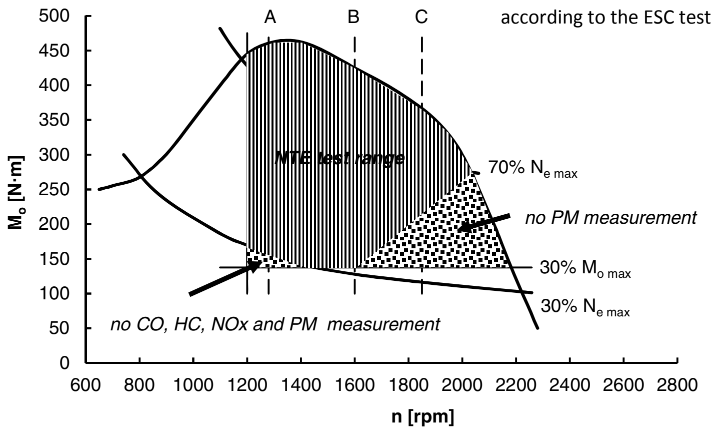



**Fig. 4.13** Operation field in off-cycle emission test for an engine of rated speed under 2400 rpm

## 4.4 Durability of Pollution Control Devices

Engine or vehicle manufacturer is required to run a durability test of pollution control devices (item 6 in Tab. 4.2), as part of the type approval process. The said test can be carried out either on the vehicle (on the road, on a test track or on a chassis dynamometer) or on the engine installed on an engine test bench. The vehicle's mileage should correspond to the vehicle's life (Tab. 4.6), which has been considerably extended in Euro VI as compared to Euro V. Upon the manufacturer's request, the mileage can be shortened on condition it is possible to accordingly extrapolate the emission deterioration factors. However, the said mileage must not be shorter than the minimum mileage stated in Table 4.6. If the test is carried out on an engine test bench, its conditions should correspond to the prescribed vehicle's mileage.

The test can be carried out for a family of vehicles or engines. If so, the results will apply to all types within the family.

The durability test involves the measurement of specific emission of pollutants in WHSC and WHTC tests after predefined mileages. On that basis, the relationship between specific emission and current mileage is determined using the linear regression method. If necessary, emission values for the mileage corresponding to the vehicle's life are determined by linear extrapolation.

As in the case of light-duty vehicles, two types of emission deterioration factors are allowed (multiplicative and additive). The manufacturer can choose the type of factors to use, separately for the WHSC and the WHTC.

The durability test for heavy-duty vehicles, as the type V test for light-duty vehicles, is carried out very rarely, because one can alternatively use fixed, multiplicative emission deterioration factors (Tab. 4.7). They are identical for engines fitted with CI and SI engines. Due to the extended mileage corresponding to the vehicle's life, the said factors have increased as compared to Euro V (except for emissions of PM mass).

Euro V legislation stated that the emission deterioration factor served the purpose of verifying whether or not the emission of pollutants remained within the prescribed limit throughout the vehicle's life. However, it did not provide for the details of such verification. The legislation on durability was interpreted in two ways. In accordance with the first one, emission specific values measured during engine type approval should be adjusted (i.e. totalized or multiplied) by the applicable deterioration factors and then compared to the prescribed limits. In accordance with the other interpretation, deterioration factors should be used for checking in-service conformity only. In this case, in order to verify the engine's compliance, values measured during audit tests should be adjusted by corresponding factors.

The new legislation clearly stipulates that emissions measured in WHSC and WHTC tests to be compared with the prescribed limits should be adjusted by the applicable deterioration factors.

**Table 4.6** Minimum and nominal mileages in the heavy-duty vehicles durability test prescribed in Euro V and Euro VI

| Vehicle category | Minimum mileage in durability test[1] [‘000 km] | Nominal vehicle mileage[)] [‘000 km] | Life of the vehicle corresponding to nominal mileage [years] |
|---|---|---|---|
| N1 | 100/160 | 100/160 | 5 |
| N2 | 125/188 | 200/300 | 6 |
| N3 of maximum laden mass ≤ 16,000 kg | 125/188 | 200/300 | 6 |
| N3 of maximum laden mass > 16,000 kg | 167/233 | 500/700 | 7 |
| M1 | –/160 | –/160 | 5 |
| M2 | 100/160 | 100/160 | 5 |
| M3 of maximum laden mass ≤ 7500 kg | 125/188 | 200/300 | 6 |
| M3 of maximum laden mass > 7500 kg | 167/233 | 500/700 | 7 |

[1)] The first figure applies to Euro V, the second to VI.

**Table 4.7** Alternative specific emission deterioration factors stipulated in Euro VI

| Test type | CO | THC | NMHC | $CH_4$ | $NO_X$ | $NH_3$ | PM | PN |
|---|---|---|---|---|---|---|---|---|
| Euro VI WHTC | 1.3 | 1.3 | 1.4 | 1.4 | 1.15 | 1.0 | 1.05 | 1.0 |
| Euro V ETC | 1.1 | 1.05 | 1.05 | 1.2 | 1.05 | – | 1.1 | – |
| Euro VI WHSC | 1.3 | 1.3 | 1.4 | 1.4 | 1.15 | 1.0 | 1.05 | 1.0 |
| Euro V ESC | 1.1 | 1.05 | – | – | 1.05 | – | 1.1 | – |

## 4.5 OBD Testing

The new legislation introduces considerable changes with regard to OBD testing (item 8 in Table 4.2). This analysis will be limited to the key changes introduced under Euro VI legislation as compared to Euro V. The first such change consists in the inclusion of all system or elements that affect the emission of pollutants. Previously, monitoring was not required if the malfunction of a given system or element did not result in specific emissions in excess of OBD threshold values.

System or element malfunctions are divided into classes, depending on their effect on emissions. The division is as follows:

- class A – malfunctions resulting in exceeding threshold values,
- class B1 – malfunctions that may result in exceeding threshold values, although their exact effect on specific emission is not adequately determined and therefore threshold values may not be exceeded in certain conditions,
- class B2 – malfunctions affecting specific emission but not beyond threshold values,
- class C – malfunctions that do not result in exceeding prescribed limits.

**Table 4.8** Specific emission threshold values [mg/kWh] for OBD tests

| Parameter | CI engines | | Engines[1] | |
|---|---|---|---|---|
| | $NO_X$ | PM (mass) | $NO_X$ | CO[2] |
| Euro V threshold | 7000 | 100 | – | – |
| Transition Euro VI threshold | 1500 | 25 | 1500 | – |
| Target Euro VI threshold | 1200 | 25 | 1200 | – |

[1] Applies to vehicles in categories M3, N2 of maximum laden mass above 7500 kg and N3, fitted with engines running on gaseous fuels (irrespectively of ignition type) and SI engines running on non-gaseous fuels.
[2] The CO threshold for Euro VI will be determined at a later date.

System or elements subject to monitoring include: electric components (e.g. sensors of temperature, pressure, fuel composition, etc.), particulate filters, selective catalytic reduction systems for nitrogen oxides, oxidation catalysts, exhaust gas recirculation systems (including fuel cooling), fuelling systems (including injectors), boost systems, valve variable timing systems, engine cooling systems, idling speed control systems. The regulation specifies the rules for monitoring each system or element.

Another change consists in reducing threshold values for nitrogen oxides. The target reduction is massive, which is why transition periods have been introduced (Tab. 4.8).

Just like in the case of light-duty vehicles, it is now required that the OBD system should determine the in-use performance ratio (IUPR) for each monitor.

## 4.6 Other Tests

Measurement of CO concentration and excess air coefficient at engine idling speed (item 4 in Table 4.1) provides emission data necessary for in-service technical inspections. The legislation applies to vehicles of maximum laden mass not greater than 7500 kg, fitted with SI engines running on petrol, ethanol, LPG and NG. The measurement method is similar to the one used in type II test for light-duty vehicles fitted with SI engines. Previously, measurement was obligatory for all heavy-duty vehicles running on petrol.

The requirements regarding crankcase emissions (item 4 in Table 4.1) vary depending on engine type.

For SI engines running on petrol and ethanol no toxic compounds can be emitted from the crankcase. The measurement method is similar to the one used in type III test for light-duty vehicles. It is unclear what measurement cycle should be used. For CI engines and SI engines running on LPG or NG, toxic compounds from the crankcase can be emitted on condition their amount is added to tailpipe emissions and the total amount remains within the prescribed limits. The measurement method is not clearly stated.

Fuel consumption and specific $CO_2$ emission (item 7 in Table 4.1) are measured in the WHSC test (if applicable) and in the WHTC test. Measured results are expressed in g/kWh.

Specific emission of $CO_2$ – just like specific emissions of limited pollutants – can be measured:

- in raw (undiluted) exhaust gas,
- in diluted exhaust gas in a full flow tunnel.

Testing methods are identical to those for limited pollutants.

Fuel consumption is measured directly, unlike for light-duty vehicles, where it is measured on the basis of specific emissions of carbon dioxide, carbon monoxide and hydrocarbons.

An approval granted to a heavy-duty vehicle type can be extended to some of its variants and versions (complete or completed) classified as light-duty. To extend the approval, specific emissions of carbon dioxide and fuel consumption are carried out in the manner prescribed for light-duty vehicles.

The new legislation introduces stricter requirements for systems used to control specific nitrogen oxide emissions from vehicles fitted with CI engines. Particular emphasis has been put on SCR systems requiring the use of a reagent (Adblue). If such a system is used, it is necessary to monitor reagent quality and consumption and to install a driver warning system. The performance of the system used to control specific nitrogen oxide emissions is tested separately (item 9 in Table 4.1).

The manufacturer should specify the minimum reagent concentration at which specific emission stays within the prescribed limits for nitrogen oxides, shown in Table 4.4, i.e. 400–460 mg/kWh. In practice, this requirement is difficult to meet for certain engines. Therefore, in the transition period (Tab. 4.2) emission of 900 mg/kWh is allowed.

The driver warning system should be activated if the difference between actual and assumed reagent consumption rate exceeds 20% (target value). In the transition period (Table 4.1) a difference of 50% is acceptable.

The net power measurement was thus far regulated in a separate Directive (80/1296/EEC), which becomes void. There are no significant differences as regards the testing procedure stipulated in the said directive and in UNECE Regulation 85, on which Euro VI legislation is based.

In accordance with the new legislation it is still possible to grant three kinds of type approvals, depending on the approved item:

- engine as a separate technical unit,
- vehicle with an engine approved as a separate technical unit,
- vehicle with regard to its engine.

Engine installation on the vehicle (item 11 in Table 4.1) is tested in the case of type approval of vehicles with engines approved as a separate technical unit. Thus far, engine installation on the vehicle was considered correct if intake system pressure, exhaust system overpressure, power used to drive additional equipment and exhaust system volume remained within the limits prescribed in the certificate of approval. In accordance with the new legislation the test will also include the performance of the OBD and the system used to control specific nitrogen oxide emissions.

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[9] International Standard ISO 16183 Heavy-duty engines – Measurement of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions

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