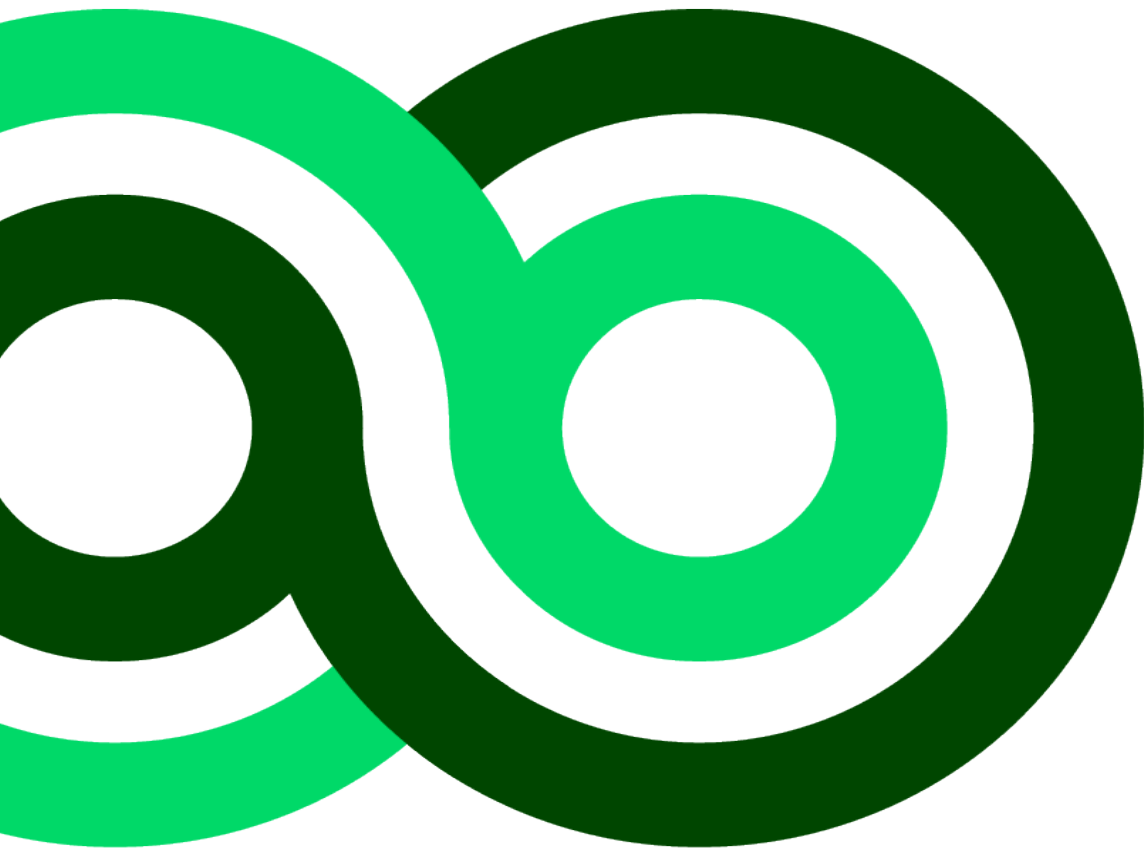


TEST PROCEDURE

Real World PEMS+





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VERIFYING REAL-WORLD ENVIRONMENTAL PERFORMANCE

1. INTRODUCTION

This test procedure describes the procedure to verify the vehicle's environmental performance under real-world driving conditions, such as the tailpipe emissions, fuel / energy consumption and driving range measurements with a Portable Emission Measurement System for the purposes of Green NCAP assessment (PEMS+) of light passenger and commercial vehicles.

1.1. PEMS+ TEST EQUIPMENT AND EXHAUST MASS FLOW

The exhaust mass flow shall be determined by Green NCAP accredited PEMS+ measurement equipment functioning independently from the vehicle.

2. RESERVED

3. RESERVED

4. GENERAL REQUIRMENTS

4.1. The PEMS+ test shall be representative for the vehicle's environmental performance operated on real-world driving routes under representative traffic conditions.

4.2. Reserved

4.3. The proposed test trip in urban, rural and motorway environments meeting the requirements of point 6. For the purpose of trip design, the urban, rural and motorway parts shall be selected based on a topographic map. The urban part of the trip should be driven on urban roads with a vehicle speed limit of 60 km/h or less. In case the urban part of the trip needs to be driven for a limited period of time on roads with a vehicle speed limit higher than 60 km/h, the vehicle shall be driven with vehicle speeds up to 60 km/h.

4.4. If for a vehicle the collection of ECU data, e.g. through the OBD interface, influences the vehicle's environmental performance, the PEMS+ test shall be considered as void. Such functionality shall be considered as a 'defeat device' as defined in Article 3(10) of Regulation (EC) 715/2007¹.

4.5. Reserved

4.6. Reserved

4.7. Compliance of the software tool used to verify the trip validity and calculate emissions in accordance with the provisions laid down in Appendices 4, 5, 7a and 7b shall be validated and certified by the tool provider. Where such software tool is incorporated in the PEMS instrument, proof of the validation shall be provided along with the instrument.

¹ OJ L171, 29.6.2007, p5

5. BOUNDARY CONDITIONS

5.1. Vehicle payload and test mass

- 5.1.1. The vehicle's basic payload shall comprise the driver, a witness of the test (if applicable) and the test equipment, including the mounting and the power supply devices.
- 5.1.2. For the purpose of testing some artificial payload may be added as long as the total mass of the basic and artificial payload is 70% of the sum of the “mass of the passengers” and the “pay-mass” defined in points 19 and 21 of Article 2 of Commission Regulation (EU) No 1230/2012².
- 5.1.3. The Test Mass for RDE shall be calculated according to the formula defined in the latest version of the *GNT_Overall_GNCAP_Test_Procedure_WG*.

5.2. Ambient conditions

- 5.2.1. Altitude conditions: lower than or equal to 1300 meters above sea level.
- 5.2.2. Ambient temperature conditions : $266.15\text{ K } (-7^{\circ}\text{C}) \leq T_{\text{Ambient}} \leq 308.15\text{ K } (35^{\circ}\text{C})$.
- 5.2.3. Any condition included in this range of temperature and altitude may be used for Green NCAP testing.
- 5.2.3.1. Exposure to extreme atmospheric conditions (heavy snowfall, storm, hail) and excessive amounts of dust should be avoided.
- 5.2.4. Reserved
- 5.2.5. Reserved
- 5.2.6. Reserved

5.3. Vehicle conditioning for cold engine-start testing

Before PEMS+ testing, the vehicle shall be preconditioned and conditioned in the following way:

- Warmed-up on the road for at least 20 minutes at a motorway operation in accordance with point 6.5 of this procedure.

Park the vehicle in the soak area with doors and bonnet closed and kept in engine-off status at an ambient temperature of $23^{\circ}\text{C} \pm 3^{\circ}\text{C}$ between 9 and 56h.

GPS vehicle speed shall be recorded during the conditioning at frequency of 1,0 Hz.

5.4. Dynamic conditions

The dynamic conditions encompass the effect of road grade, head wind and driving dynamics (accelerations, decelerations) and auxiliary systems upon energy consumption and emissions of the test vehicle. The verification of the normality of dynamic conditions shall be done after the test is completed, using the recorded PEMS data. This verification shall be conducted in 2 steps:

² OJ L 353, 21.12.2012, p. 31–79

- 5.4.1. The excess or insufficiency of driving dynamics during the trip shall be checked using the methods described in Appendix 7a.
- 5.4.1.1. For vehicles with a PWR higher than 90 W/kg point 4.1.1 “Verification of $v \times a_{pos_{[95]}}$ per speed bin” does not apply.
- 5.4.2. If the trip results are valid following the verifications in accordance with point 5.4.1, the methods for verifying the normality of the test conditions as laid down in Appendices 5, 7a and 7b shall be used.
- 5.4.3. Appendix 5 Verification of overall trip dynamics using the moving averaging window method is applicable only on an indicative basis, not limiting validity.
- 5.4.4. It is required to follow the Gear Shift Indicator (GSI) on the vehicle.
- 5.4.5. Accelerations during the test:
According to the latest version of *GNT_Emission_Robustness_WG*.

5.5. Vehicle condition and operation

5.5.1. Auxiliary systems

The air conditioning system or other auxiliary devices shall be operated in a way which corresponds to their possible use by a consumer at real-world driving on the road.

Cooling and heating systems for automatic air conditioning systems shall be activated (ON) during the performance of the tests, set to maintain 23°C in the vehicle’s occupant interior. (comfortable ambient temperature for a safe driving)

The air conditioning will be set between 21 °C and 23 °C.

The manual air condition is operated with A/C switch on, temperature ½ (middle position) and fan speed on 1/3 to ¼ with airflow on floor and windscreen. If necessary, the settings for temperature have to be readjusted.

The vehicle windows shall be closed when the air conditioning or heating are used.

The lights should be kept ON, this include: position lamps, low beam headlamps and the high beam headlamp when necessary if the visibility requires it.

The radio of the vehicle shall be kept ON.

5.5.2. Vehicles equipped with periodically regenerating systems

- 5.5.2.1. The instructions for vehicles equipped with periodic regeneration to be followed are those prescribed in latest version of the *GNT_Overall_GNCAAP_Test_Procedure_WG*.
- 5.5.2.2. Reserved
- 5.5.2.3. Reserved
- 5.5.2.4. Reserved
- 5.5.3. Reserved
- 5.5.4. Modifications that affect the vehicle aerodynamics are not permitted with the exception of the PEMS installation
- 5.5.5. The test vehicles shall not be driven with the intention to generate a passed or failed test due to extreme driving patterns that do not represent representative conditions of use. In case of need, verification of representative driving may be based on expert judgement made by

or on behalf of the accredited laboratory through cross-correlation on several signals, which may include exhaust flow rate, exhaust temperature, CO₂, O₂ etc. in combination with vehicle speed, acceleration and GPS data and potentially further vehicle data parameters like engine speed, gear, accelerator pedal position etc.

- 5.5.6. The vehicle shall be in good mechanical condition and shall have been run in and driven at least 3 000 km before the test. The odometer reading and the age of the vehicle used for PEMS+ testing shall be recorded.

6. TRIP REQUIREMENTS

- 6.1. The shares of urban, rural and motorway driving, classified by instantaneous vehicle speed as described in points 6.3 to 6.5, shall be expressed as a percentage of the total trip distance.
- 6.2. The trip shall always start with urban driving followed by rural and motorway driving in accordance with the shares specified in point 6.6. The urban, rural and motorway operation shall be run consecutively in accordance with point 6.12, but may also include a trip which starts and ends at the same point. Rural operation may be interrupted by short periods of urban operation when driving through urban areas. Motorway operation may be interrupted by short periods of urban or rural operation, e.g., when passing toll stations or sections of road works.
- 6.3. Urban operation is characterised by vehicle speeds lower than or equal to 60 km/h.
- 6.4. Rural operation is characterised by vehicle speeds higher than 60 km/h and lower than or equal to 90 km/h.
- 6.5. Motorway operation is characterised by vehicle speeds above 90 km/h.
- 6.6. The trip shall consist of approximately 34% per cent urban, 33% per cent rural and 33% per cent motorway driving classified by vehicle speed as described in points 6.3 to 6.5. "Approximately" shall mean the interval of ± 10 per cent points around the stated percentages. The urban driving shall however never be less than 29% of the total trip distance.
- 6.7. The vehicle speed shall not exceed 145 km/h. This maximum vehicle speed may be exceeded by a tolerance of 15 km/h for not more than 3% of the time duration of the motorway driving. Local vehicle speed limits remain in force during a PEMS test, notwithstanding other legal consequences. Violations of local vehicle speed limits per se do not invalidate the results of a PEMS test.
- 6.8. The average vehicle speed (including stops) of the urban driving part of the trip should be between 15 and 40 km/h. Stop periods, defined by vehicle speed of less than 1 km/h, shall account for 6-30 % of the time duration of urban operation. Urban operation shall contain

several stop periods of 10 s or longer. However, individual stop periods shall not exceed 300 consecutive seconds; else the trip shall be voided.

- 6.9. The vehicle speed range of the motorway driving shall properly cover a range between 90 and at least 110 km/h. The vehicle speed shall be above 100 km/h for at least 5 minutes.
- 6.10. The trip duration shall be between 90 and 120 minutes.
- 6.11. The start and the end point shall not differ in their elevation above sea level by more than 100 m. In addition, the proportional cumulative positive altitude gain shall be less than 1200 m/100km) and be determined according to Appendix 7b.
- 6.12. The minimum distance of each, the urban, rural and motorway operation shall be 16 km.
- 6.13. The average speed (including stops) during cold start period as defined in Appendix 4, point 4 shall be between 15 and 40 km/h. The maximum speed during the cold start period shall not exceed 60 km/h.
- 6.14. The vehicle speed in the motorway shall be kept between 110 -120 km/h

7. OPERATIONAL REQUIREMENTS

- 7.1. The trip shall be selected in such a way that the testing is uninterrupted and the data continuously recorded to reach the minimum test duration defined in point 6.10.
- 7.2. Electrical power shall be supplied to the PEMS by an external power supply unit and not from a source that draws its energy either directly or indirectly from the engine of the test vehicle.
- 7.3. The installation of the PEMS equipment shall be done in a way to influence the vehicle emissions or performance or both to the minimum extent possible. Care should be exercised to minimize the mass of the installed equipment and potential aerodynamic modifications of the test vehicle. The vehicle payload shall be in accordance with point 5.1.
- 7.4. PEMS+ tests shall be conducted on working days as defined for the Union in Council Regulation (EEC, Euratom) No 1182/71³
- 7.5. PEMS+ tests shall be conducted on paved roads and streets (e.g. off-road operation is not permitted).
- 7.6. At the test start as defined in point 5.1. of Appendix 1, the vehicle shall move within 15 seconds. The vehicle stop during the entire cold start period, as defined in point 4 of Appendix 4, shall be kept to the minimum possible and it shall not exceed in total 90 seconds. If the engine stalls during the test, it may be restarted, but the sampling shall not be interrupted. If the engine stops during the test, the sampling shall not be interrupted.

³ OJ L 124, 8.6.1971, p. 1

8. LUBRICATING OIL, FUEL AND REAGENT

- 8.1. The lubricant and reagent (if applicable) used for PEMS+ testing shall be within the specifications issued by the manufacturer for vehicle operation by the customer.
- 8.2. Physical fluid sample storage with certificate of analysis only in case of test results exceeding 0-star rating excessive thresholds
- 8.3. Fuel to be used is EURO 6 reference fuel for each type of vehicle.
- 8.4. For CNG vehicles the reference fuel is G20. Secondary fuel tank shall be also filled with reference fuel and full tank.

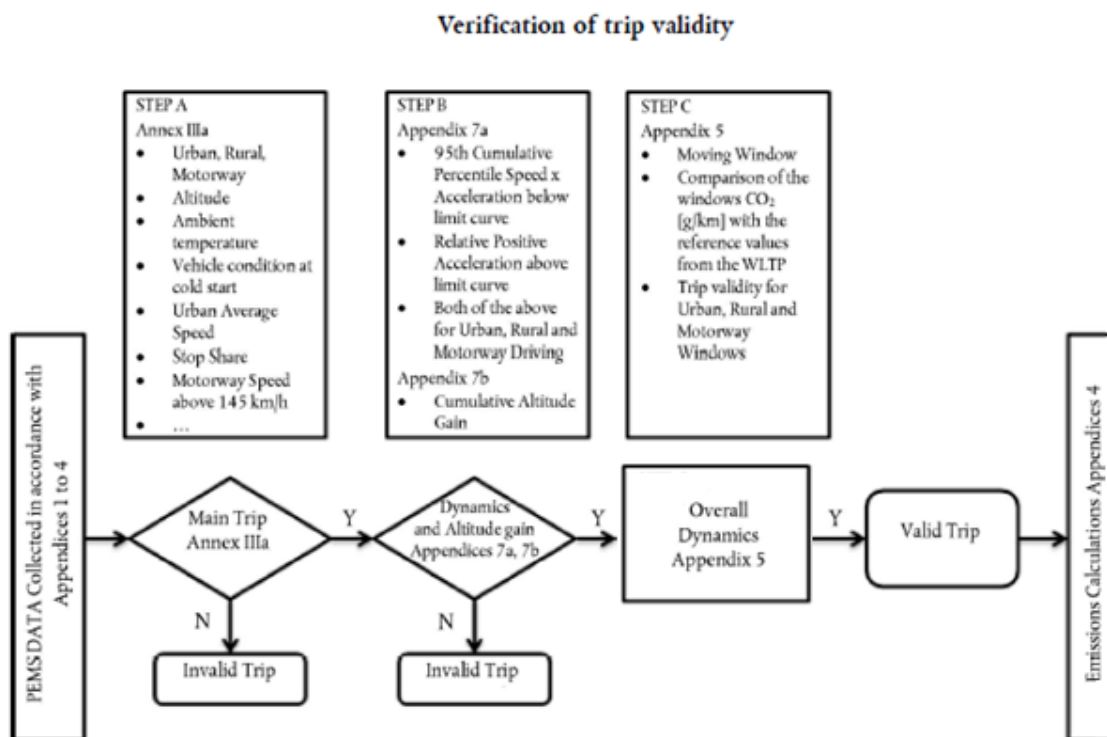
9. ENVIRONMENTAL PERFORMANCE AND TRIP EVALUATION

- 9.1. The test shall be conducted in accordance with Appendix 1.
- 9.2. The trip validity shall be verified in a three-step procedure as follows:
 - STEP A: The trip complies with the general requirements, boundary conditions, trip and operational requirements, and the specifications for lubricating oil, fuel and reagents set out in points 4 to 8;
 - STEP B: The trip complies with the requirements set out in Appendices 7a and 7b.
 - STEP C: The trip will be evaluated with the requirements set out in Appendix 5 but shall not invalidate a trip.

The steps of the procedure are detailed in Figure 1.

Figure 1

Verification of trip validity



If at least one of the requirements is not fulfilled, the trip shall be declared invalid (with exception of Appendix 5).

- 9.3. It shall not be permitted to combine data of different trips or to modify or remove data from a trip with exception of provisions for long stops as described in 6.8.
- 9.4. After establishing the validity of a trip in accordance with point 9.2, environmental performance results shall be calculated using the methods laid down in Appendix 4. The emissions calculations shall be made between test start and test end, as defined in Appendix 1, points 5.1. and 5.3. respectively.
- 9.5. Reserved
- 9.6. Gaseous pollutant and particle number emissions during cold start, as defined in point 4 of Appendix 4, shall be included in the normal evaluation in accordance with Appendices 4 and 5.
- 9.7. Energy consumption calculation
 - 9.7.1. Energy consumption for ICE , NOVC-HEV and OVC-HEV tested in CS mode
 - 9.7.1.1. Calculation of fuel consumption

The fuel characteristics required for the calculation of fuel consumption values shall be taken from Annex IX of *GNT_WLTC+_WG* procedure.

ρ_{fuel} is the test fuel density, kg/l. For gaseous fuels, fuel density at 15 °C;

HC_j are the emissions of hydrocarbon, g/km over a period j;

CO_j are the emissions of carbon monoxide, g/km over a period j;

$CO_{2,j}$ are the emissions of carbon dioxide, g/km over a period j;

FC_j is the fuel consumption of a specific fuel, l/100 km (or m³ per 100 km in the case of natural gas) over a period j;

j is the index for the considered period, where a period can be urban, rural, motorway phases or the total trip;

For a vehicle with a positive ignition engine fuelled with petrol (E10):

$$FC_j = \left(\frac{0.1206}{\rho_{fuel}} \right) \times [(0.829 \times HC) + (0.429 \times CO) + (0.273 \times CO_2)] \text{ in l/100 km}$$

For a vehicle with a positive ignition engine fuelled with CNG (G20):

$$FC_{norm,j} = \left(\frac{0.1336}{0.654} \right) \times [(0.749 \times HC) + (0.429 \times CO) + (0.273 \times CO_2)] \text{ in m}^3/100 \text{ km}$$

$$FC_{norm,j} = 0.1336 \times [(0.749 \times HC) + (0.429 \times CO) + (0.273 \times CO_2)] \text{ in kg/100 km}$$

For a vehicle with a compression engine fuelled with diesel (B7):

$$FC_j = \left(\frac{0.1165}{\rho_{fuel}} \right) \times [(0.858 \times HC) + (0.429 \times CO) + (0.273 \times CO_2)] \text{ in l/100 km}$$

- 9.7.1.2. Calculation of fuel energy consumption for ICE and NOVC-HEV

$EC_{fuel,j}$ is the fuel energy consumption in kWh/100km over a period j

For a vehicle with a positive ignition engine fuelled with petrol (E10):

$$EC_{petrol} = 8.64 \times FC_j$$

For a vehicle with a positive ignition engine fuelled with CNG (G20):

$$EC_{CNG} = 13.8925 \times FC_j$$

FC in kg/100km

For a vehicle with a compression engine fuelled with diesel (B7):

$$EC_{diesel} = 9.79 \times FC_j$$

9.7.2. Electric energy consumption of PEVs

9.7.2.1. Determination of electrical energy consumption at the vehicle's REESS

For the determination of the electric energy consumption based on the current and voltage determined according to Appendix 3 of Sub-Annex 8 Annex XXI to *GNT_WLTC+ WG* procedure, the following equations shall be used:

$$EC_{DC,j} = -\frac{\Delta E_{REESS,j}}{d_j} \times \frac{100}{1000}$$

where:

$EC_{DC,j}$ is the electric energy consumption over the considered period j based on the REESS depletion, kWh/100 km;

$\Delta E_{REESS,j}$ is the electric energy change of all REESSs during the considered period j, Wh;

d_j is the distance driven in the considered period j, km;

$\frac{100}{1000}$ is the conversion factor from Wh to kWh/100 km.

and

$$\Delta E_{REESS,j} = \sum_{i=1}^n \Delta E_{REESS,j,i}$$

where:

$\Delta E_{REESS,j,i}$ is the electric energy change of REESS i during the considered period j, Wh;

and

$$\Delta E_{REESS,j,i} = \frac{1}{3600} \times \int_{t_0}^{t_{end}} U(t)_{REESS,j,i} \times I(t)_{j,i} dt$$

where:

$U(t)_{REESS,j,i}$ is the voltage of REESS i during the considered period j determined according to Appendix 3 of Sub-Annex 8 Annex XXI to *GNT_WLTC+ WG* procedure, V;

t_0 is the time at the beginning of the considered period j, s;

t_{end} is the time at the end of the considered period j, s;

$I(t)_{j,i}$ is the electric current of REESS i during the considered period j determined according to Appendix 3 of Sub-Annex 8 to *GNT_WLTC+_WG* procedure, A;

i is the index number of the considered REESS;

n is the total number of REESS;

j is the index for the considered period, where a period can be urban, rural, motorway phases or the total trip;

$\frac{1}{3600}$ is the conversion factor from Ws to Wh.

In case the considered period is a given test cycle, $EC_{DC,j}$ can be expressed as $EC_{DC,test}$, where the index “test” is the identification of the considered test.

9.7.2.2. Grid to REESS output efficiency for PEV electric energy consumption calculations

The electric energy consumption over the considered period j based on the REESS depletion $EC_{DC,j}$ does not consider the energy losses occurring between the mains and the current and voltage measurement location according to Appendix 3 of Sub-Annex 8 to *GNT_WLTC+_WG* procedure.

The determination of the total electric energy consumption of PEVs shall consider the losses occurring between mains and the current and voltage measurement location according to Appendix 3 of Sub-Annex 8 to *GNT_WLTC+_WG* procedure.

According to *GNT_Real World Driving Range Test Procedure*:

E_{AC} is the electric energy delivered from the mains for a full recharge of the REESS in Wh, as described in *GNT_Real World Driving Range Test Procedure*.

$E_{DC-discharge}$ is the electric energy drawn from the battery in Wh, over the complete phase of REESS discharge procedure, calculated by the measured current and voltage, as described in *GNT_Real World Driving Range Test Procedure*.

For the calculation of the total electric energy consumption of PEV, the introduction of an efficiency factor is necessary. The “Grid to REESS output efficiency” describes the relation between the total REESS recharge energy from the mains and the total REESS output energy, as calculated in *GNT_Real World Driving Range Test Procedure*. The “grid to REESS output efficiency” is calculated as follows:

$$\eta_{grid-to-output} = \frac{E_{DC-discharge}}{E_{AC}}$$

where:

$\eta_{grid-to-output}$ is the “grid to REESS output efficiency” [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy, as calculated in *GNT_Real World Driving Range Test Procedure*.

9.7.2.3. Determination of the total electric energy consumption for PEV

The total electric energy consumption of PEVs for a given period is calculated according to the formula:

$$EC_{DC_total,j} = \frac{EC_{DC,j}}{\eta_{grid-to-output}}$$

where:

$EC_{DC_total,j}$ is the total electric energy consumption over the considered period j based on the REESS depletion and considering the electrical energy losses from the mains to the measurement location according to Appendix 3 of Sub-Annex 8 to *GNT_WLTC+ WG* procedure, kWh/100 km

$EC_{DC,j}$ is the electric energy consumption over the considered period j based on the REESS depletion, kWh/100 km;

$\eta_{grid-to-output}$ is the “grid to REESS output efficiency” [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy, as calculated in *GNT_Real World Driving Range Test Procedure*

j is the index for the considered period, where a period can be urban, rural, motorway phases or the total trip;

In case the considered period is a given test cycle, $EC_{DC,j}$ can be expressed as $EC_{DC,test}$ and $EC_{DC_total,j}$ can be expressed as $EC_{DC_total, test}$, where the index “test” is the identification of the considered test.

9.7.3. Energy consumption for OVC-HEVs tested in CD mode

9.7.3.1. Calculation of fuel consumption and equivalent fuel energy consumption

Calculation of fuel consumption shall be done in accordance with point 9.7.1.1. and the calculation of the equivalent energy consumption shall be done in accordance with point 9.7.1.2.

9.7.3.2. Calculation of electrical energy consumption

The determination of electrical energy consumption at the vehicle’s REESS shall be done in accordance with point 9.7.2.1.

When $EC_{DC,j}$ is negative then $EC_{DC,j}$ is equal to zero.

9.7.3.3. Calculation of total energy consumption for OVC-HEVs

The total energy consumption for OVC-HEVs shall be the sum of the energy consumption of fuel and electrical energy consumption from total REESS considering the grid to REESS output efficiency. The following equations shall be used:

$$EC_{total,j} = EC_{DC_total,j} + EC_{fuel,j}$$

where:

$EC_{total,j}$ is the total energy consumption, the sum of the fuel and electric energy consumption over a period j .

$EC_{DC_total,j}$ is the total electric energy consumption over the considered period j based on the REESS depletion and considering the electrical energy losses from the mains to the measurement location according to Appendix 3 of Sub-Annex 8 to *GNT_WLTC+ WG* procedure, kWh/100 km

$EC_{fuel,j}$ is the fuel energy consumption in kWh/100km and calculated in accordance with point 9.7.3.1.

j is the index for the considered period, where a period can be urban, rural, motorway phases or the total trip;

and

$$EC_{DC_total,j} = \frac{EC_{DC,j}}{\eta_{grid-to-output,PHEV}}$$

where:

$EC_{DC_total,j}$ is the total electric energy consumption over the considered period j based on the REESS depletion and considering the electrical energy losses from the mains to the measurement location according to Appendix 3 of Sub-Annex 8 to *GNT_WLTC+_WG* procedure, kWh/100 km

$EC_{DC,j}$ is the electric energy consumption over the considered period j based on the REESS depletion in kWh/100 km and calculated in accordance with point 9.7.3.2.

$\eta_{grid-to-output,PHEV}$ is the “grid to REESS output efficiency” [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy over the WLTC CD sequence, in accordance with paragraph 3.2 Sub-Annex 8 to *GNT_WLTC+_WG* procedure.

and

$$\eta_{grid-to-output,PHEV} = \frac{E_{DC,CD\ sequence}}{E_{AC}}$$

where:

$\eta_{grid-to-output,PHEV}$ is the “grid to REESS output efficiency” [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy over the WLTC CD sequence, in accordance with paragraph 3.2 Sub-Annex 8 to *GNT_WLTC+_WG* procedure.

$E_{DC,CD\ sequence}$ is the electric energy consumption over the WLTC CD sequence done in accordance with paragraph 4.3 Sub-Annex 8 to *GNT_WLTC+_WG* procedure), Wh;

E_{AC} is the recharged electric energy from the mains determined in accordance with paragraph 3.2.4.6. of Sub-Annex 8, Wh;

In case the considered period is a given test cycle, $EC_{DC,j}$ can be expressed as $EC_{DC,test}$, $EC_{DC_total,j}$ can be expressed as $EC_{DC_total,test}$ and $EC_{total,j}$ can be expressed as $EC_{total,test}$, where the index “test” is the identification of the considered test.

Appendix 1: Test procedure for vehicle environmental performance with a Portable Emissions Measurement System (PEMS)

1. INTRODUCTION

This Appendix describes the test procedure to determine environmental performance from light passenger and commercial vehicles (categories M1 and N1) using a Portable Emissions Measurement System (PEMS).

2. SYMBOLS, PARAMETERS AND UNITS

See separate list

3. GENERAL REQUIREMENTS

3.1. PEMS

The test shall be carried out with a PEMS, composed of components specified in points 3.1.1 to 3.1.5. If applicable, a connection with the vehicle ECU may be established to determine relevant engine and vehicle parameters as specified in point 3.2.

- 3.1.1. Analysers to determine the concentration of pollutants in the exhaust gas.
- 3.1.2. One or multiple instruments or sensors to measure or determine the exhaust mass flow.
- 3.1.3. A Global Positioning System to determine the position, altitude and, vehicle speed of the vehicle.
- 3.1.4. If applicable, sensors and other appliances being not part of the vehicle, e.g., to measure ambient temperature, relative humidity, air pressure, and vehicle speed.
- 3.1.5. An energy source independent of the vehicle to power the PEMS.

3.2. Test parameters

Test parameters as specified in Table 1 of this Appendix shall be measured at a constant frequency of 1,0 Hz or higher and recorded and reported in accordance with the requirements of Appendix 8 at a frequency of 1,0 Hz. If ECU parameters are available, these may be obtained at a substantially higher frequency but the recording rate shall be 1,0 Hz. The PEMS analysers, flow-measuring instruments and sensors shall comply with the requirements laid down in Appendices 2 and 3.

Table 1

Test parameters

Parameter	Recommended unit	Source ⁽⁸⁾
THC concentration ^(1,10)	ppm	Analyser

THC concentration ^(1,10)	ppm C ₁	Analyser
CH ₄ concentration ^(1,10)	ppm C ₁	Analyser
NMHC concentration ^(1,10)	ppm C ₁	Analyser ⁽⁶⁾
CO ₂ concentration ⁽¹⁾	ppm	Analyser
NO _x concentration ⁽¹⁾	ppm	Analyser ⁽⁷⁾
NO concentration ⁽¹⁾	ppm	Analyser
NO ₂ concentration ⁽¹⁾	ppm	Analyser ⁽¹¹⁾
PN concentration	#/m ³	Analyser
Exhaust mass flow rate	kg/s	EFM, any methods described in point 7 of Appendix 2
Ambient humidity	%	Sensor
Ambient temperature	K	Sensor
Ambient pressure	kPa	Sensor
Vehicle speed	km/h	Sensor, GPS, or ECU ⁽³⁾
Vehicle latitude	Degree	GPS
Vehicle longitude	Degree	GPS
Vehicle altitude ^(5,9)	M	GPS or Sensor
Exhaust gas temperature ⁽⁵⁾	K	Sensor
Engine coolant temperature ⁽⁵⁾	K	Sensor or ECU
Engine speed ⁽⁵⁾	rpm	Sensor or ECU
Engine torque ⁽⁵⁾	Nm	Sensor or ECU
Torque at driven axle ⁽⁵⁾	Nm	Rim torque meter
Pedal position ⁽⁵⁾	%	Sensor or ECU
Engine fuel flow ⁽²⁾	g/s	Sensor or ECU
Engine intake air flow ⁽²⁾	g/s	Sensor or ECU
Fault status ⁽⁵⁾	-	ECU
Intake air flow temperature	K	Sensor or ECU
Regeneration status ⁽⁵⁾	-	ECU

Engine oil temperature ⁽⁵⁾	K	Sensor or ECU
Actual gear ⁽⁵⁾	#	ECU
Desired gear (e.g. gear shift indicator) ⁽⁵⁾	#	ECU
Other vehicle data ⁽⁵⁾	unspecified	ECU

Notes:

- (1) to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
- (2) to be determined only if indirect methods are used to calculate exhaust mass flow rate as described in paragraphs 10.2 and 10.3 of Appendix 4
- (3) method to be chosen according to point 4.7
- (4) not applicable
- (5) to be determined only if necessary, to verify the vehicle status and operating conditions
- (6) may be calculated from THC and CH₄ concentrations according to point 9.2 of Appendix 4
- (7) may be calculated from measured NO and NO₂ concentrations
- (8) Multiple parameter sources may be used.
- (9) The preferable source is the ambient pressure sensor.
- (10) is not a mandatory measurement but subject to be reviewed in future. Green NCAP shall keep under review the procedures and be adapted to technical progress and data.
- (11) may be calculated by subtracting the NO concentration from NO_x concentration, if NO₂ is not directly measured

3.3. Preparation of the vehicle

The preparation of the vehicle shall include a general verification of the correct technical functioning of the test vehicle.

3.4. Installation of PEMS

3.4.1. General

The installation of the PEMS shall follow the instructions of the PEMS manufacturer and the local health and safety regulations. The PEMS should be installed as to minimise during the test electromagnetic interferences as well as exposure to shocks, vibration, dust and variability in temperature. The installation and operation of the PEMS shall be leak-tight and minimise heat loss. The installation and operation of PEMS shall not change the nature of the exhaust gas nor unduly increase the length of the tailpipe. To avoid the generation of particles, connectors shall be thermally stable at the exhaust gas temperatures expected during the test. It is recommended not to use elastomer connectors to connect the vehicle exhaust outlet and the connecting tube. Elastomer connectors, if used, shall have no contact with the exhaust gas to avoid artefacts at high engine load.

3.4.2. Permissible backpressure

The installation and operation of the PEMS sampling probes shall not unduly increase the pressure at the exhaust outlet in a way that may influence the representativeness of the measurements. It is thus recommended that only one sampling probe is installed in the same plane. If technically feasible, any extension to facilitate the sampling or connection with the exhaust mass flow meter shall have an equivalent, or larger, cross sectional area than the exhaust pipe.

3.4.3. Exhaust mass flow meter

Whenever used, the exhaust mass flow meter shall be attached to the vehicle's tailpipe(s) in accordance with the recommendations of the EFM manufacturer. The measurement range of the EFM shall match the range of the exhaust mass flow rate expected during the test. It is recommended to select the EFM in order to have the maximum expected flow rate during the test covering at least 75 % of the EFM full range. The installation of the EFM and any exhaust pipe adaptors or junctions shall not adversely affect the operation of the engine or exhaust after-treatment system. A minimum of four pipe diameters or 150 mm of straight tubing, whichever is larger, shall be placed at either side of the flow-sensing element. When testing a multi-cylinder engine with a branched exhaust manifold, it is recommended to position the exhaust mass flow meter downstream of where the manifolds combine and to increase the cross section of the piping such as to have an equivalent, or larger, cross sectional area from which to sample. If this is not feasible, exhaust flow measurements with several exhaust mass flow meters may be used. The wide variety of exhaust pipe configurations, dimensions and exhaust mass flow rates may require compromises, guided by good engineering judgement, when selecting and installing the EFM(s). It is permissible to install an EFM with a diameter smaller than that of the exhaust outlet or the total projected frontal area of multiple outlets, providing it improves measurement accuracy and does not adversely affect the operation or the exhaust after-treatment as specified in point 3.4.2. It is recommended to document the EFM set-up using photographs.

3.4.4. Global Positioning System (GPS)

The GPS antenna should be mounted, e.g. at the highest possible location, as to ensure good reception of the satellite signal. The mounted GPS antenna shall interfere as little as possible with the vehicle operation.

3.4.5. Connection with the Engine Control Unit (ECU)

If desired, relevant vehicle and engine parameters listed in Table 1 can be recorded by using a data logger connected with the ECU or the vehicle network through standards, such as ISO 15031-5 or SAE J1979, OBD-II, EOBD or WWH-OBD. If applicable, manufacturers shall disclose labels to allow the identification of required parameters.

3.4.6. Sensors and auxiliary equipment

Vehicle speed sensors, temperature sensors, coolant thermocouples or any other measurement device not part of the vehicle shall be installed to measure the parameter under consideration in a representative, reliable and accurate manner without unduly interfering with the vehicle operation and the functioning of other analysers, flow-measuring instruments, sensors and signals. Sensors and auxiliary equipment shall be powered independently of the vehicle. It is permitted to power any safety-related illumination of fixtures and installations of PEMS components outside of the vehicle's cabin by the vehicle's battery.

3.5. Emissions sampling

Emissions sampling shall be representative and conducted at locations of well-mixed exhaust where the influence of ambient air downstream of the sampling point is minimal. If applicable, emissions shall be sampled downstream of the exhaust mass flow meter, respecting a distance of at least 150 mm to the flow sensing element. The sampling probes shall be fitted at least 200 mm or three times the inner diameter of the exhaust pipe, whichever is larger, upstream of the point at which the exhaust exits the PEMS sampling installation into the environment. If the PEMS feeds back a flow to the tail pipe, this shall occur downstream of the sampling probe in a manner that does not affect during engine

operation the nature of the exhaust gas at the sampling point(s). If the length of the sampling line is changed, the system transport times shall be verified and if necessary corrected.

If the engine is equipped with an exhaust after-treatment system, the exhaust sample shall be taken downstream of the exhaust after- treatment system. When testing a vehicle with a branched exhaust manifold, the inlet of the sampling probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions of all cylinders. In multi-cylinder engines, having distinct groups of manifolds, such as in a 'V' engine configuration, the sampling probe shall be positioned downstream of where the manifolds combine. If this is technically not feasible, multi-point sampling at locations of well-mixed exhaust may be used, if approved by the Type Approval Authority. In this case, the number and location of sampling probes shall match as far as possible those of the exhaust mass flow meters. In case of unequal exhaust flows, proportional sampling or sampling with multiple analysers shall be considered.

If the engine is equipped with an exhaust after-treatment system, the exhaust sample shall be taken downstream of the exhaust after- treatment system. When testing a vehicle with a branched exhaust manifold, the inlet of the sampling probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions of all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a 'V' engine configuration, the sampling probe shall be positioned downstream of the point where the manifolds combine. If this is technically not feasible, multi- point sampling at locations of well-mixed exhaust may be used. In this case, the number and location of sampling probes shall match as far as possible those of the exhaust mass flow meters. In case of unequal exhaust flows, proportional sampling or sampling with multiple analysers shall be considered.

If hydrocarbons are measured, the sampling line shall be heated to $463 \pm 10 \text{ K}$ ($190 \pm 10 \text{ }^{\circ}\text{C}$). For the measurement of other gaseous components with or without cooler, the sampling line shall be kept at a minimum of 333 K ($60 \text{ }^{\circ}\text{C}$) to avoid condensation and to ensure appropriate penetration efficiencies of the various gases. For low pressure sampling systems, the temperature can be lowered corresponding to the pressure decrease provided that the sampling system ensures a penetration efficiency of 95 % for all regulated gaseous pollutants. If particles are sampled and not diluted at the tailpipe, the sampling line from the raw exhaust sample point to the point of dilution or particle detector shall be heated to a minimum of 373 K ($100 \text{ }^{\circ}\text{C}$). The residence time of the sample in the particle sampling line shall be less than 3 s until reaching first dilution or the particle detector.

All parts of the sampling system from the exhaust pipe up to the particle detector, which are in contact with raw or diluted exhaust gas, shall be designed to minimize deposition of particles. All parts shall be made from antistatic material to prevent electrostatic effects.

4. PRE-TEST PROCEDURES

4.1. PEMS leak check

After the installation of the PEMS is completed, a leak check shall be performed at least once for each PEMS-vehicle installation as prescribed by the PEMS manufacturer or as follows. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilization period all flow meters shall read approximately zero in the absence of a leak. Else, the sampling lines shall be checked and the fault be corrected.

The leakage rate on the vacuum side shall not exceed 0.5 per cent of the in-use flow rate for the portion of the system being checked. The analyser flows and bypass flows may be used to estimate the in-use flow rate.

Alternatively, the system may be evacuated to a pressure of at least 20 kPa vacuum (80 kPa absolute). After an initial stabilization period the pressure increase Δp (kPa/min) in the system shall not exceed:

$$\Delta p = \frac{p_e}{V_s} \times q_{vs} \times 0.005$$

Alternatively, a concentration step change at the beginning of the sampling line shall be introduced by switching from zero to span gas while maintaining the same pressure conditions as under regular system operation. If for a correctly calibrated analyser after an adequate period of time the reading is ≤ 99 per cent compared to the introduced concentration, the leakage problem shall be corrected.

4.2. Starting and stabilizing the PEMS

The PEMS shall be switched on, warmed up and stabilized according to the specifications of the PEMS manufacturer until key functional parameters, e.g., pressures, temperatures and flows have reached their operating set points before test start. To ensure correct functioning, the PEMS may be kept switched on or can be warmed up and stabilized during vehicle conditioning. The system shall be free of errors and critical warnings.

4.3. Preparing the sampling system

The sampling system, consisting of the sampling probe and sampling lines shall be prepared for testing by following the instruction of the PEMS manufacturer. It shall be ensured that the sampling system is clean and free of moisture condensation.

4.4. Preparing the Exhaust mass Flow Meter (EFM)

If used for measuring the exhaust mass flow, the EFM shall be purged and prepared for operation in accordance with the specifications of the EFM manufacturer. This procedure shall, if applicable, remove condensation and deposits from the lines and the associated measurement ports.

4.5. Checking and calibrating the analysers for measuring gaseous emissions

Zero and span calibration adjustments of the analysers shall be performed using calibration gases that meet the requirements of point 5 of Appendix 2. The calibration gases shall be chosen to match the range of pollutant concentrations expected during the PEMS+ test. To minimize analyser drift, one should conduct the zero and span calibration of analysers at an ambient temperature that resembles, as closely as possible, the temperature experienced by the test equipment during the trip.

4.6. Checking the analyser for measuring particle emissions

The zero level of the analyser shall be recorded by sampling HEPA filtered ambient air at an appropriate sampling point, usually at the inlet of the sampling line. The signal shall be recorded at a constant frequency which is a multiple of 1,0 Hz averaged over a period of 2 minutes; the final concentration shall be within the manufacturer's specifications, but shall not exceed 5 000 particles per cubic-centimetre.

4.7. Determining vehicle speed

Vehicle speed shall be determined by at least one of the following methods:

- (a) a GPS; if vehicle speed is determined by a GPS, the total trip distance shall be checked against the measurements of another method according to point 7 of Appendix 4.
- (b) a sensor (e.g., optical or micro-wave sensor); if vehicle speed is determined by a sensor, the vehicle speed measurements shall comply with the requirements of point 8 of Appendix 2, or alternatively, the total trip distance determined by the sensor shall be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the sensor shall deviate by no more than 4% from the reference distance.
- (c) the ECU; if vehicle speed is determined by the ECU, the total trip distance shall be validated according to point 3 of Appendix 3 and the ECU vehicle speed signal adjusted, if necessary, to fulfil the requirements of point 3.3 of Appendix 3. Alternatively, the total trip distance as determined by the ECU can be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the ECU shall deviate by no more than 4% from the reference.

4.8. Check of PEMS set up

The correctness of connections with all sensors and, if applicable, the ECU shall be verified. If engine parameters are retrieved, it shall be ensured that the ECU reports values correctly (e.g., zero engine speed [rpm] while the combustion engine is in key-on-engine-off status). The PEMS shall function free of errors and critical warnings.

5. ENVIRONMENTAL PERFORMANCE TEST

5.1. Test start

Test start (see Figure App.1.1) shall be defined by either:

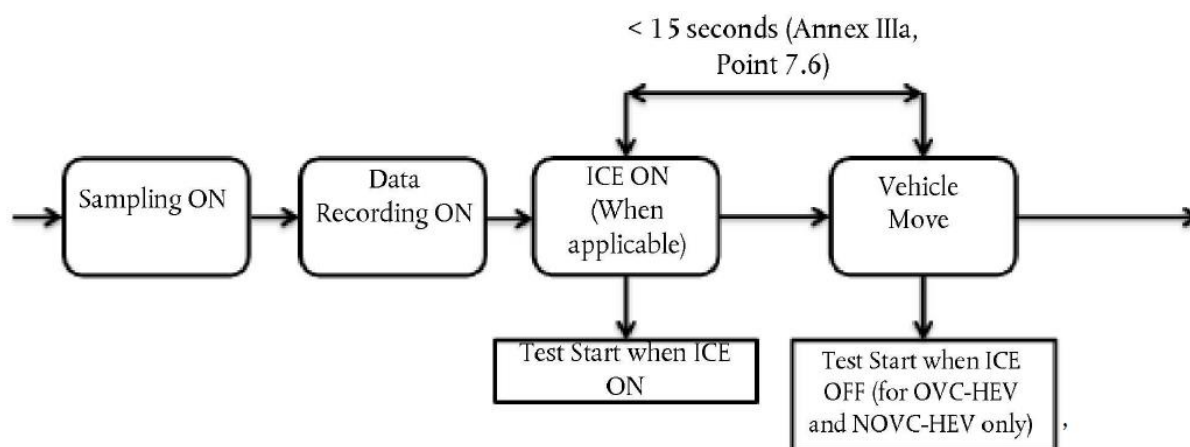
- the first ignition of the internal combustion engine;
- or the first movement of the vehicle with speed greater than 1 km/h for OVC-HEVs and NOVC-HEVs starting with the internal combustion engine off.

Sampling, measurement and recording of parameters shall begin prior to the test start. Before the test start it shall be confirmed that all necessary parameters are recorded by the data logger.

To facilitate time alignment, it is recommended to record the parameters that are subject to time alignment either by a single data recording device or with a synchronised time stamp.

Figure App.1.1

Test Start Sequence



5.2. Test

Sampling, measurement and recording of parameters shall continue throughout the on-road test of the vehicle. The engine may be stopped and started, but emissions sampling and parameter recording shall continue. Any warning signals, suggesting malfunctioning of the PEMS, shall be documented and verified. Parameter recording shall reach a data completeness of higher than 99 %. Measurement and data recording may be interrupted for less than 1 % of the total trip duration but for no more than a consecutive period of 30 s solely in the case of unintended signal loss or for the purpose of PEMS system maintenance. Interruptions may be recorded directly by the PEMS. It is not permissible to introduce interruptions in the recorded parameter via the pre-processing, exchange or post-processing of data. If conducted, auto zeroing shall be performed against a traceable zero standard similar to the one used to zero the analyser. If necessary, it is strongly recommended to initiate PEMS system maintenance during periods of zero vehicle speed.

5.3. Test end

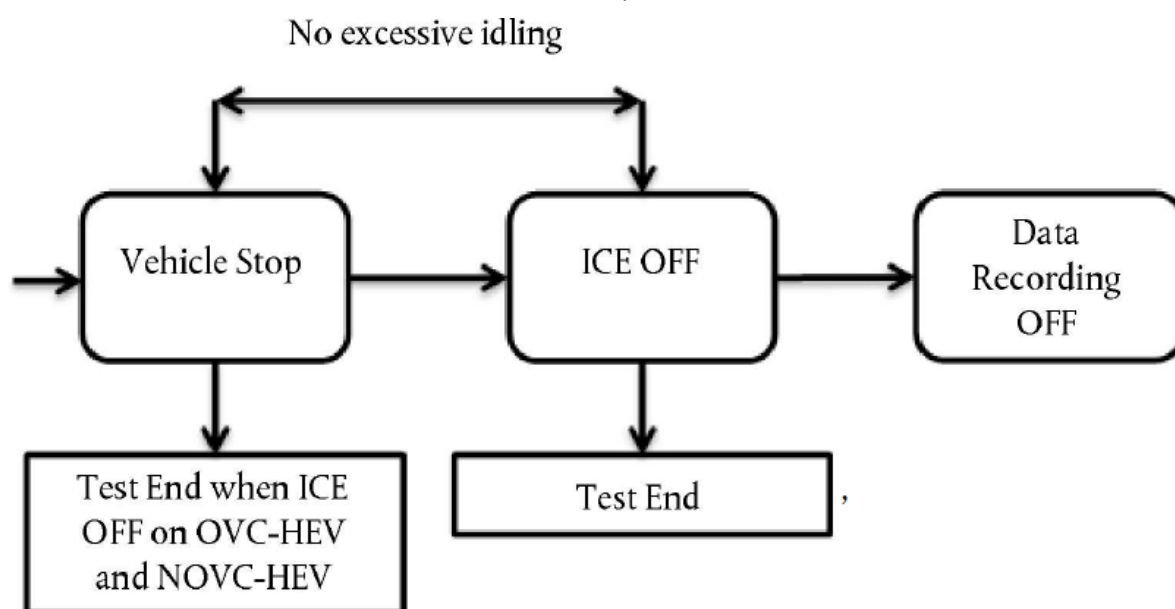
The end of the test (see Figure App.1.2) is reached when the vehicle has completed the trip and either when:

- the internal combustion engine is switched off; or:
- for OVC-HEVs and NOVC-HEVs finishing the test with the internal combustion engine off, the vehicle stops and the speed is lower than or equal to 1 km/h.

Excessive idling of the engine after the completion of the trip shall be avoided. The data recording shall continue until the response time of the sampling systems has elapsed. For vehicles with a signal detecting regeneration (see line 42 in the Transparency List 1 in Appendix 5 of Annex II to Regulation (EU) 2017/1151), the OBD-check shall be performed and documented directly after data recording and before any further driven distance is driven.

Figure App.1.2

Test End Sequence



6. POST-TEST PROCEDURE

6.1. Checking the analysers for measuring gaseous emissions

The zero and span of the analysers of gaseous components shall be checked by using calibration gases identical to the ones applied under point 4.5 to evaluate the analyser's zero and response drift compared to the pre-test calibration. It is permissible to zero the analyser prior to verifying the span

drift, if the zero drift was determined to be within the permissible range. The post-test drift check shall be completed as soon as possible after the test and before the PEMS, or individual analysers or sensors, are turned off or have switched into a non-operating mode. The difference between the pre-test and post-test results shall comply with the requirements specified in Table 2.

Table 2

Permissible analyser drift over a PEMS test

"Pollutant	Absolute Zero response drift	Absolute Span response drift ⁽¹⁾
CO ₂	≤2000 ppm per test	≤2% of reading or ≤2000 ppm per test, whichever is larger
CO	≤75 ppm per test	≤2% of reading or ≤75 ppm per test, whichever is larger
NO _x	≤5 ppm per test	≤2% of reading or ≤5 ppm per test, whichever is larger
NO/NO ₂	≤5 ppm per test	≤2% of reading or ≤5 ppm per test, whichever is larger
CH ₄	≤10 ppmC ₁ per test	≤2% of reading or ≤10 ppmC ₁ per test, whichever is larger
THC	≤10 ppmC ₁ per test	≤2% of reading or ≤10 ppmC ₁ per test, whichever is larger

⁽¹⁾ If the zero drift is within the permissible range, it is permissible to zero the analyser prior to verifying the span drift.

If the difference between the pre-test and post-test results for the zero and span drift is higher than permitted, all test results shall be voided and the test repeated.

6.2. Checking the analyser for measuring particle emissions

The zero level of the analyser shall be recorded in accordance with point 4.6.

6.3. Checking the on-road emission measurements

The span gas concentration that was used for the calibration of the analysers in accordance with paragraph 4.5 at the test start shall cover at least 90 % of the concentration values obtained from 99 % of the measurement of the valid parts of the emissions test. It is permissible that 1 % of the total number of measurements used for evaluation exceeds the used span gas by up to a factor of two. If these requirements are not met, the test shall be voided.

Appendix 2: Specifications and calibration of PEMS components and signals

1. INTRODUCTION

This appendix sets out the specifications and calibration of PEMS components and signals.

2. SYMBOLS, PARAMETERS AND UNITS

See separate list

3. LINEARITY VERIFICATION

3.1. General

The accuracy and linearity of analysers, flow-measuring instruments, sensors and signals, shall be traceable to international or national standards. Any sensors or signals that are not directly traceable, e.g., simplified flow-measuring instruments shall be calibrated alternatively against chassis dynamometer laboratory equipment that has been calibrated against international or national standards.

3.2. Linearity requirements

All analysers, flow-measuring instruments, sensors and signals shall comply with the linearity requirements given in Table 1. If air flow, fuel flow, the air-to-fuel ratio or the exhaust mass flow rate is obtained from the ECU, the calculated exhaust mass flow rate shall meet the linearity requirements specified in Table 1.

Table 1

Linearity requirements of measurement parameters and systems

"Measurement parameter/instrument	$ \chi_{\min} \times (a_1 - 1) + a_0 $	Slope a_1	Standard error SEE	Coefficient of determination r^2
Fuel flow rate ⁽¹⁾	≤1% max	0.98 - 1.02	≤2%	≥0.990
Air flow rate ⁽¹⁾	≤1% max	0.98 - 1.02	≤2%	≥0.990
Exhaust mass flow rate	≤2% max	0.97 - 1.03	≤3%	≥0.990
Gas analysers	≤0.5% max	0.99 - 1.01	≤1%	≥0.998
Torque ⁽²⁾	≤1% max	0.98-1.02	≤2%	≥0.990
PN analysers ⁽³⁾	≤5% max	0.85-1.15 ⁽⁴⁾	≤10%	≥0.950

⁽¹⁾ optional to determine exhaust mass flow

⁽²⁾ optional parameter

⁽³⁾ The linearity check shall be verified with soot-like particles, as these are defined in point 6.2

⁽⁴⁾ To be updated based on error propagation and traceability charts.

3.3. Frequency of linearity verification

The linearity requirements pursuant to point 3.2 shall be verified:

- (a) for each gas analyser at least every twelve months or whenever a system repair or component change or modification is made that could influence the calibration;
- (b) for other relevant instruments, such as exhaust mass flow meters and traceably calibrated sensors, whenever damage is observed, as required by internal audit procedures, by the instrument manufacturer or by instrument manufacturer but no longer than one year before the actual test.

The linearity requirements pursuant to point 3.2 for sensors or ECU signals that are not directly traceable shall be performed with a traceably calibrated measurement device on the chassis dynamometer once for each PEMS-vehicle setup.

3.4. Procedure of linearity verification

3.4.1. General requirements

The relevant analysers, instruments and sensors shall be brought to their regular operating condition according to the recommendations of their manufacturer. The analysers, instruments and sensors shall be operated at their specified temperatures, pressures and flows.

3.4.2. General procedure

The linearity shall be verified for each regular operating range by executing the following steps:

- (a) The analyser, flow-measuring instrument or sensor shall be set to zero by introducing a zero signal. For gas analysers, purified synthetic air or nitrogen shall be introduced to the analyser port via a gas path that is as direct and short as possible.
- (b) The analyser, flow-measuring instrument or sensor shall be spanned by introducing a span signal. For gas analysers, an appropriate span gas shall be introduced to the analyser port via a gas path that is as direct and short as possible.
- (c) The zero procedure of (a) shall be repeated.
- (d) The linearity shall be verified by introducing at least 10, approximately equally spaced and valid, reference values (including zero). The reference values with respect to the concentration of components, the exhaust mass flow rate or any other relevant parameter shall be chosen to match the range of values expected during the emissions test. For measurements of exhaust mass flow, reference points below 5% of the maximum calibration value can be excluded from the linearity verification.
- (e) For gas analysers, known gas concentrations in accordance with point 5 shall be introduced to the analyser port. Sufficient time for signal stabilisation shall be given.
- (f) The values under evaluation and, if needed, the reference values shall be recorded at a constant frequency which is a multiple of 1,0 Hz over a period of 30 seconds.
- (g) The arithmetic mean values over the 30 seconds period shall be used to calculate the least squares linear regression parameters, with the best-fit equation having the form:

$$y = a_1x + a_0$$

where:

y is the actual value of the measurement system

a_1	is the slope of the regression line
x	is the reference value
a_0	is the y intercept of the regression line

The standard error of estimate (SEE) of y on x and the coefficient of determination (r^2) shall be calculated for each measurement parameter and system.

- (h) The linear regression parameters shall meet the requirements specified in Table 1.

3.4.3. *Requirements for linearity verification on a chassis dynamometer*

Non-traceable flow-measuring instruments, sensors or ECU signals that cannot directly be calibrated according to traceable standards, shall be calibrated on a chassis dynamometer. The procedure shall follow as far as applicable, the requirements of Annex 4a to UN/ECE Regulation No 83. If necessary, the instrument or sensor to be calibrated shall be installed on the test vehicle and operated according to the requirements of Appendix 1. The calibration procedure shall follow whenever possible the requirements of point 3.4.2; at least 10 appropriate reference values shall be selected as to ensure that at least 90% of the maximum value expected to occur during the PEMS+ test is covered.

If a not directly traceable flow-measuring instrument, sensor or ECU signal for determining exhaust flow is to be calibrated, a traceably calibrated reference exhaust mass flow meter or the CVS shall be attached to the vehicle's tailpipe. It shall be ensured that the vehicle exhaust is accurately measured by the exhaust mass flow meter according to point 3.4.3 of Appendix 1. The vehicle shall be operated by applying constant throttle at a constant gear selection and chassis dynamometer load.

4. ANALYSERS FOR MEASURING GASEOUS COMPONENTS

4.1. Permissible types of analysers

4.1.1. *Standard analysers*

The gaseous components shall be measured with analysers specified in points 1.3.1 to 1.3.5 of Appendix 3, Annex 4A to UN/ECE Regulation No 83, 07 series of amendments. If an NDUV analyser measures both NO and NO₂, a NO₂/NO converter is not required.

4.1.2. *Alternative analysers*

Any analyser not meeting the design specifications of point 4.1.1 is permissible provided that it fulfils the requirements of point 4.2. The test laboratory shall ensure that the alternative analyser achieves an equivalent or higher measurement performance compared to a standard analyser over the range of pollutant concentrations and co-existing gases that can be expected from vehicles operated with permissible fuels under moderate and extended conditions of valid PEMS+ testing as specified in points 5, 6 and 7. Upon request, the manufacturer of the analyser shall submit in writing supplemental information, demonstrating that the measurement performance of the alternative analyser is consistently and reliably in line with the measurement performance of standard analysers. Supplemental information shall contain:

- (a) a description of the theoretical basis and the technical components of the alternative analyser;

- (b) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 over the expected range of pollutant concentrations and ambient conditions of the type-approval test defined in Annex XXI to the Regulation (EU) 2017/1151 as well as a validation test as described in point 3 of Appendix 3 for a vehicle equipped with a spark-ignition and compression-ignition engine; the manufacturer of the analyser shall demonstrate the significance of equivalency within the permissible tolerances given in point 3.3 of Appendix 3.
- (c) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 with respect to the influence of atmospheric pressure on the measurement performance of the analyser; the demonstration test shall determine the response to span gas having a concentration within the analyser range to check the influence of atmospheric pressure under moderate and extended altitude conditions defined in point 5.2. Such a test can be performed in an altitude environmental test chamber.
- (d) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 over at least three on-road tests that fulfil the requirements.
- (e) a demonstration that the influence of vibrations, accelerations and ambient temperature on the analyser reading does not exceed the noise requirements for analysers set out in point 4.2.4.

Approval authorities may request additional information to substantiate equivalency or refuse approval if measurements demonstrate that an alternative analyser is not equivalent to a standard analyser.

4.2. Analyser specifications

4.2.1. General

In addition to the linearity requirements defined for each analyser in point 3, the compliance of analyser types with the specifications laid down in points 4.2.2 to 4.2.8 shall be demonstrated by the analyser manufacturer. Analysers shall have a measuring range and response time appropriate to measure with adequate accuracy the concentrations of the exhaust gas components at the applicable emissions standard under transient and steady state conditions. The sensitivity of the analysers to shocks, vibration, aging, variability in temperature and air pressure as well as electromagnetic interferences and other impacts related to vehicle and analyser operation shall be limited as far as possible.

4.2.2. Accuracy

The accuracy, defined as the deviation of the analyser reading from the reference value, shall not exceed 2% of reading or 0.3% of full scale, whichever is larger.

4.2.3. Precision

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than 1% of the full-scale concentration for a measurement range equal or above 155 ppm (or ppmC₁) and 2% of the full-scale concentration for a measurement range of below 155 ppm (or ppmC₁).

4.2.4. Noise

The noise shall not exceed 2 % of full scale. Each of the 10 measurement periods shall be interspersed with an interval of 30 seconds in which the analyser is exposed to an appropriate span gas. Before each sampling period and before each span period, sufficient time shall be given to purge the analyser and the sampling lines.

4.2.5. Zero response drift

The drift of the zero response, defined as the mean response to a zero gas during a time interval of at least 30 seconds, shall comply with the specifications given in Table 2.

4.2.6. Span response drift

The drift of the span response, defined as the mean response to a span gas during a time interval of at least 30 seconds, shall comply with the specifications given in Table 2.

Table 2

Permissible zero and span response drift of analysers for measuring gaseous components under laboratory conditions

"Pollutant	Absolute Zero response drift	Absolute Span response drift
CO ₂	≤1000 ppm over 4 h	≤2% of reading or ≤1000 ppm over 4 h, whichever is larger
CO	≤50 ppm over 4 h	≤2% of reading or ≤50 ppm over 4 h, whichever is larger
PN	5000 particles per cubic centimetre over 4h	According to manufacturer specifications
NO _x	≤5 ppm over 4 h	≤2 % of reading or ≤5 ppm over 4 h, whichever is larger
NO/NO ₂	≤5 ppm over 4 h	≤2 % of reading or ≤5 ppm over 4h, whichever is larger
CH ₄	≤10 ppmC ₁	≤2% of reading or ≤10 ppmC ₁ over 4 h, whichever is larger
THC	≤10 ppmC ₁	≤2% of reading or ≤10 ppmC ₁ over 4 h, whichever is larger";

4.2.7. Rise time

The rise time, defined as the time between the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$; see point 4.4), shall not exceed 3 seconds.

4.2.8. Gas drying

Exhaust gases may be measured wet or dry. A gas-drying device, if used, shall have a minimal effect on the composition of the measured gases. Chemical dryers are not permitted.

4.3. Additional requirements

4.3.1. General

The provisions in points 4.3.2 to 4.3.5 define additional performance requirements for specific analyser types and apply only to cases, in which the analyser under consideration is used for PEMS+ emission measurements.

4.3.2. Efficiency test for NO_x converters

If a NO_x converter is applied, for example to convert NO₂ into NO for analysis with a chemiluminescence analyser, its efficiency shall be tested by following the requirements of point 2.4 of Appendix 3 of Annex 4a to UN/ECE Regulation No 83, 07 series of amendments. The efficiency of

the NO_x converter shall be verified no longer than one month before the environmental performance test.

4.3.3. Adjustment of the Flame Ionisation Detector (FID)

(a) Optimization of the detector response

If hydrocarbons are measured, the FID shall be adjusted at intervals specified by the analyser manufacturer by following point 2.3.1 of Appendix 3 of Annex 4a to UN/ECE Regulation No 83, 07 series of amendments. A propane-in-air or propane-in-nitrogen span gas shall be used to optimize the response in the most common operating range.

(b) Hydrocarbon response factors

If hydrocarbons are measured, the hydrocarbon response factor of the FID shall be verified by following the provisions of point 2.3.3 of Appendix 3 of Annex 4a to UN/ECE Regulation No 83, 07 series of amendments, using propane-in-air or propane-in-nitrogen as span gases and purified synthetic air or nitrogen as zero gases, respectively.

(c) Oxygen interference check

The oxygen interference check shall be performed when introducing a FID into service and after major maintenance intervals. A measuring range shall be chosen in which the oxygen interference check gases fall in the upper 50 per cent. The test shall be conducted with the oven temperature set as required. The specifications of the oxygen interference check gases are described in point 5.3.

The following procedure applies:

(i) The analyser shall be set at zero;

(ii) The analyser shall be spanned with a 0 per cent oxygen blend for positive ignition engines and a 21 per cent oxygen blend for compression ignition engines;

(iii) The zero response shall be rechecked. If it has changed by more than 0.5 per cent of full scale, steps (i) and (ii) shall be repeated;

(iv) The 5 per cent and 10 per cent oxygen interference check gases shall be introduced;

(v) The zero response shall be rechecked. If it has changed by more than ±1 per cent of full scale, the test shall be repeated;

(vi) The oxygen interference E_{O_2} shall be calculated for each oxygen interference check gas in step (iv) as follows:

$$E_{O_2} = \frac{(c_{ref,d} - c)}{c_{ref,d}} \times 100$$

where the analyser response is:

$$c = \frac{(c_{ref,d} \times c_{FS,b})}{c_{m,b}} \times \frac{c_{m,b}}{c_{FS,d}}$$

where:

$c_{ref,b}$ is the reference HC concentration in step (ii) [ppmC₁]

$C_{ref,d}$ is the reference HC concentration in step (iv) [ppmC₁]

$C_{FS,b}$ is the full-scale HC concentration in step (ii) [ppmC₁]

$C_{FS,d}$ is the full-scale HC concentration in step (iv) [ppmC₁]

$C_{m,b}$ is the measured HC concentration in step (ii) [ppmC₁]

$C_{m,d}$ is the measured HC concentration in step (iv) [ppmC₁]

(vii) The oxygen interference E_{O_2} shall be less than ± 1.5 per cent for all required oxygen interference check gases.

(viii) If the oxygen interference E_{O_2} is higher than ± 1.5 per cent, corrective action may be taken by incrementally adjusting the air flow (above and below the manufacturer's specifications), the fuel flow and the sample flow.

(ix) The oxygen interference check shall be repeated for each new setting.

4.3.4. Conversion efficiency of the non-methane cutter (NMC)

If hydrocarbons are analysed, a NMC can be used to remove non-methane hydrocarbons from the gas sample by oxidizing all hydrocarbons except methane. Ideally, the conversion for methane is 0 per cent and for the other hydrocarbons represented by ethane is 100 per cent. For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emissions (see point 9.2 of Appendix 4). It is not necessary to determine the methane conversion efficiency in case the NMC-FID is calibrated according to method (b) in point 9.2 of Appendix 4 by passing the methane/air calibration gas through the NMC.

(a) Methane conversion efficiency

Methane calibration gas shall be flown through the FID with and without bypassing the NMC; the two concentrations shall be recorded. The methane efficiency shall be determined as:

$$E_M = 1 - \frac{C_{HC(w/NMC)}}{C_{HC(w/oNMC)}}$$

where:

$C_{HC(w/NMC)}$ is the HC concentration with CH₄ flowing through the NMC [ppmC₁]

$C_{HC(w/o NMC)}$ is the HC concentration with CH₄ bypassing the NMC [ppmC₁]

(b) Ethane conversion efficiency

Ethane calibration gas shall be flown through the FID with and without bypassing the NMC; the two concentrations shall be recorded. The ethane efficiency shall be determined as:

$$E_E = 1 - \frac{C_{HC(w/NMC)}}{C_{HC(w/oNMC)}}$$

where:

$C_{HC(w/NMC)}$ is the HC concentration with C_2H_6 flowing through the NMC [ppmC₁]

$C_{HC(w/o\ NMC)}$ is the HC concentration with C_2H_6 bypassing the NMC [ppmC₁]

4.3.5. Interference effects

(a) General

Other gases than the ones being analysed can affect the analyser reading. A check for interference effects and the correct functionality of analysers shall be performed by the analyser manufacturer prior to market introduction at least once for each type of analyser or device addressed in points (b) to (f).

(b) CO analyser interference check

Water and CO₂ can interfere with the measurements of the CO analyser. Therefore, a CO₂ span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range of the CO analyser used during the test shall be bubbled through water at room temperature and the analyser response recorded. The analyser response shall not be more than 2 per cent of the mean CO concentration expected during regular on-road testing or ± 50 ppm, whichever is larger. The interference check for H₂O and CO₂ may be run as separate procedures. If the H₂O and CO₂ levels used for the interference check are higher than the maximum levels expected during the test, each observed interference value shall be scaled down by multiplying the observed interference with the ratio of the maximum expected concentration value during the test and the actual concentration value used during this check. Separate interference checks with concentrations of H₂O that are lower than the maximum concentration expected during the test may be run and the observed H₂O interference shall be scaled up by multiplying the observed interference with the ratio of the maximum H₂O concentration value expected during the test and the actual concentration value used during this check. The sum of the two scaled interference values shall meet the tolerance specified in this point.

(c) NO_x analyser quench check

The two gases of concern for CLD and HCLD analysers are CO₂ and water vapour. The quench response to these gases is proportional to the gas concentrations. A test shall determine the quench at the highest concentrations expected during the test. If the CLD and HCLD analysers use quench compensation algorithms that utilize H₂O or CO₂ measurement analysers or both, quench shall be evaluated with these analysers active and with the compensation algorithms applied.

(i) CO₂ quench check

A CO₂ span gas having a concentration of 80 to 100 per cent of the maximum operating range shall be passed through the NDIR analyser; the CO₂ value shall be recorded as A. The CO₂ span gas shall then be diluted by approximately 50 per cent with NO span gas and passed through the NDIR and CLD or HCLD; the CO₂ and NO values shall be recorded as B and C, respectively. The CO₂ gas flow shall then be shut off and only the NO span gas shall be passed through the CLD or HCLD; the NO value shall be recorded as D. The per cent quench shall be calculated as:

$$E_{CO_2} = \left[1 - \left(\frac{C \times A}{(D \times A) - (D \times B)} \right) \right] \times 100$$

where:

A is the undiluted CO₂ concentration measured with the NDIR [%]

B is the diluted CO₂ concentration measured with the NDIR [%]

C is the diluted NO concentration measured with the CLD or HCLD [ppm]

D is the undiluted NO concentration measured with the CLD or HCLD [ppm]

Alternative methods of diluting and quantifying of CO₂ and NO span gas values such as dynamic mixing/blending are permitted upon approval of the approval authority.

(ii) Water quench check

This check applies to measurements of wet gas concentrations only. The calculation of water quench shall consider dilution of the NO span gas with water vapour and the scaling of the water vapour concentration in the gas mixture to concentration levels that are expected to occur during an emissions test.

A NO span gas having a concentration of 80 per cent to 100 per cent of full scale of the regular operating range shall be passed through the CLD or HCLD; the NO value shall be recorded as *D*. The NO span gas shall then be bubbled through water at room temperature and passed through the CLD or HCLD; the NO value shall be recorded as *C*. The analyser's absolute operating pressure and the water temperature shall be determined and recorded as *E* and *F*, respectively. The mixture's saturation vapour pressure that corresponds to the water temperature of the bubbler *F* shall be determined and recorded as *G*. The water vapour concentration *H* [%] of the gas mixture shall be calculated as:

$$H = \frac{G}{E} \times 100$$

The expected concentration of the diluted NO-water vapour span gas shall be recorded as *D_e* after being calculated as:

$$D_e = D \times \left(1 - \frac{H}{100}\right)$$

For diesel exhaust, the maximum concentration of water vapour in the exhaust gas (in per cent) expected during the test shall be recorded as *H_m* after being estimated, under the assumption of a fuel H/C ratio of 1.8/1, from the maximum CO₂ concentration in the exhaust gas *A* as follows:

$$H_m = 0.9 \times A$$

The per cent water quench shall be calculated as:

$$E_{H_2O} = \left(\left(\frac{D_e - C}{D_e} \right) \times \left(\frac{H_m}{H} \right) \right) \times 100$$

where:

D_e is the expected diluted NO concentration [ppm]

C is the measured diluted NO concentration [ppm]

H_m is the maximum water vapour concentration [%]

H is the actual water vapour concentration [%]

(iii) Maximum allowable quench

The combined CO₂ and water quench shall not exceed 2 per cent of full scale.

(d) Quench check for NDUV analysers

Hydrocarbons and water can positively interfere with NDUV analysers by causing a response similar to that of NO_x. The manufacturer of the NDUV analyser shall use the following procedure to verify that quench effects are limited:

- (i) The analyser and chiller shall be set up by following the operating instructions of the manufacturer; adjustments should be made as to optimise the analyser and chiller performance.
- (ii) A zero calibration and span calibration at concentration values expected during emissions testing shall be performed for the analyser.
- (iii) A NO₂ calibration gas shall be selected that matches as far as possible the maximum NO₂ concentration expected during emissions testing.
- (iv) The NO₂ calibration gas shall overflow at the gas sampling system's probe until the NO_x response of the analyser has stabilised.
- (v) The mean concentration of the stabilized NO_x recordings over a period of 30 s shall be calculated and recorded as NO_{x,ref}.
- (vi) The flow of the NO₂ calibration gas shall be stopped and the sampling system saturated by overflowing with a dew point generator's output, set at a dew point of 50 °C. The dew point generator's output shall be sampled through the sampling system and chiller for at least 10 minutes until the chiller is expected to be removing a constant rate of water.
- (vii) Upon completion of (iv), the sampling system shall again be overflowed by the NO₂ calibration gas used to establish NO_{x,ref} until the total NO_x response has stabilized.
- (viii) The mean concentration of the stabilized NO_x recordings over a period of 30 s shall be calculated and recorded as NO_{x,m}.
- (ix) NO_{x,m} shall be corrected to NO_{x,dry} based upon the residual water vapour that passed through the chiller at the chiller's outlet temperature and pressure.

The calculated NO_{x,dry} shall at least amount to 95% of NO_{x,ref}.

(e) Sample dryer

A sample dryer removes water, which can otherwise interfere with the NO_x measurement. For dry CLD analysers, it shall be demonstrated that at the highest expected water vapour concentration H_m the sample dryer maintains the CLD humidity at ≤ 5 g water/kg dry air (or about 0.8 per cent H₂O), which is 100 per cent relative humidity at 3.9 °C and 101.3 kPa or about 25 per cent relative humidity at 25 °C and 101.3 kPa. Compliance may be demonstrated by measuring the temperature at the outlet of a thermal sample dryer or by measuring the humidity at a point just upstream of the CLD. The humidity of the CLD exhaust might also be measured as long as the only flow into the CLD is the flow from the sample dryer.

(f) Sample dryer NO₂ penetration

Liquid water remaining in an improperly designed sample dryer can remove NO₂ from the sample. If a sample dryer is used in combination with a NDUV analyser without an NO₂/NO converter upstream,

water could therefore remove NO₂ from the sample prior to the NO_x measurement. The sample dryer shall allow for measuring at least 95 per cent of the NO₂ contained in a gas that is saturated with water vapour and consists of the maximum NO₂ concentration expected to occur during emission testing.

4.4. Response time check of the analytical system

For the response time check, the settings of the analytical system shall be exactly the same as during the emissions test (i.e. pressure, flow rates, filter settings in the analysers and all other parameters influencing the response time). The response time shall be determined with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0.1 second. The gases used for the test shall cause a concentration change of at least 60 per cent full scale of the analyser.

The concentration trace of each single gas component shall be recorded. The delay time is defined as the time from the gas switching (t_0) until the response is 10 per cent of the final reading (t_{10}). The rise time is defined as the time between 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$). The system response time (t_{90}) consists of the delay time to the measuring detector and the rise time of the detector.

For time alignment of the analyser and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 per cent of the final reading (t_{50}).

The system response time shall be ≤ 12 s with a rise time of ≤ 3 seconds for all components and all ranges used. When using a NMC for the measurement of NMHC, the system response time may exceed 12 seconds.

5. GASES

5.1. Calibration and span gases for PEMS+ test

5.1.1. General

The shelf life of calibration and span gases shall be respected. Pure as well as mixed calibration and span gases shall fulfil the specifications of Sub-Annex 5 of Annex XXI to Regulation (EU) 2017/1151.

5.1.2. NO₂ calibration gas

In addition, NO₂ calibration gas is permissible. The concentration of the NO₂ calibration gas shall be within two per cent of the declared concentration value. The amount of NO contained in the NO₂ calibration gas shall not exceed 5 per cent of the NO₂ content.

5.1.3. Multicomponent mixtures

Only multicomponent mixtures which fulfil the requirements of point 5.1.1. shall be used. These mixtures may contain two or more of the components. Multicomponent mixtures containing both NO and NO₂ are exempted of the NO₂ impurity requirement set out in points 5.1.1 and 5.1.2.

5.2. Gas dividers

Gas dividers, i.e., precision blending devices that dilute with purified N₂ or synthetic air, can be used to obtain calibration and span gases. The accuracy of the gas divider shall be such that the concentration of the blended calibration gases is accurate to within ± 2 per cent. The verification shall be performed at between 15 and 50 per cent of full scale for each calibration incorporating a gas divider. An additional verification may be performed using another calibration gas, if the first verification has failed.

Optionally, the gas divider may be checked with an instrument which by nature is linear, e.g. using NO gas in combination with a CLD. The span value of the instrument shall be adjusted with the span gas directly connected to the instrument. The gas divider shall be checked at the settings typically used and the nominal value shall be compared with the concentration measured by the instrument. The difference shall in each point be within ± 1 per cent of the nominal concentration value.

5.3. Oxygen interference check gases

Oxygen interference check gases consist of a blend of propane, oxygen and nitrogen and shall contain propane at a concentration of 350 ± 75 ppmC₁. The concentration shall be determined by gravimetric methods, dynamic blending or the chromatographic analysis of total hydrocarbons plus impurities. The oxygen concentrations of the oxygen interference check gases shall meet the requirements listed in Table 3; the remainder of the oxygen interference check gas shall consist of purified nitrogen.

Table 3

Oxygen interference check gases

	Engine type	
	Compression ignition	Positive ignition
O ₂ concentration	$21 \pm 1\%$	$10 \pm 1\%$
	$10 \pm 1\%$	$5 \pm 1\%$
	$5 \pm 1\%$	$0.5 \pm 0.5\%$

6. ANALYSERS FOR MEASURING PARTICLE NUMBER EMISSIONS

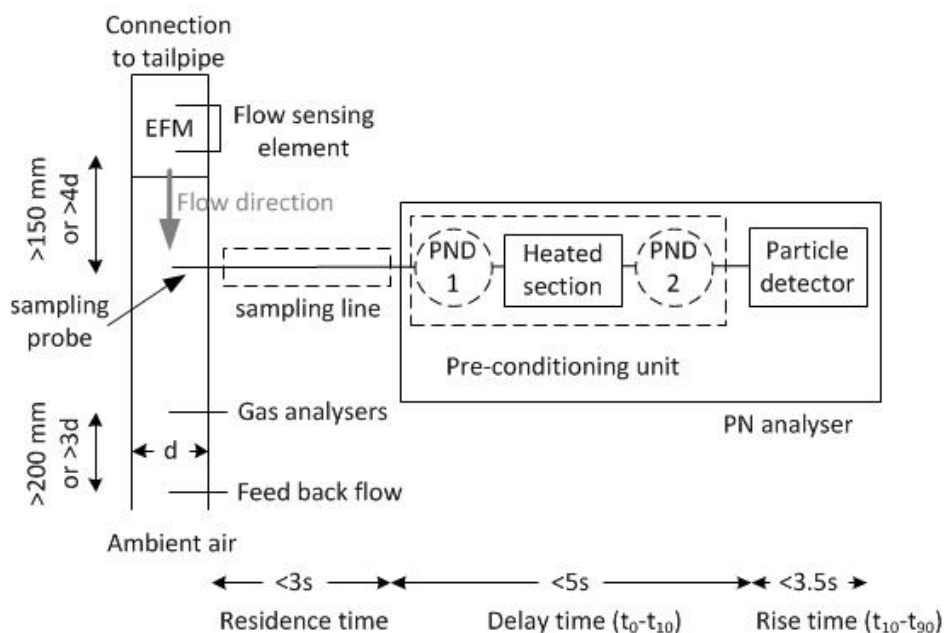
This sections will define future requirement for analysers for measuring particle number emissions, once their measurement becomes mandatory.

6.1. General

PN analyser shall consist of a pre-conditioning unit and a particle detector that counts with 50% efficiency from approximately 23 nm. It is permissible that the particle detector also pre-conditions the aerosol. The sensitivity of the analysers to shocks, vibration, aging, variability in temperature and air pressure as well as electromagnetic interferences and other impacts related to vehicle and analyser operation shall be limited as far as possible and shall be clearly stated by the equipment manufacturer in its support material. The PN analyser shall only be used within its manufacturer's declared parameters of operation.

Figure 1

Example of a PN analyser setup: Dotted lines depict optional parts. EFM = Exhaust mass Flow Meter, d = inner diameter, PND = Particle Number Diluter.



The PN analyser shall be connected to the sampling point via a sampling probe which extracts a sample from the centreline of the tailpipe tube. As specified in point 3.5 of Appendix 1, if particles are not diluted at the tailpipe, the sampling line shall be heated to a minimum temperature of 373 K (100 °C) until the point of first dilution of the PN analyser or the particle detector of the analyser. The residence time in the sampling line shall be less than 3 s.

All parts in contact with the sampled exhaust gas shall be always kept at a temperature that avoids condensation of any compound in the device. This can be achieved, e.g. by heating at a higher temperature and diluting the sample or oxidizing the (semi)volatile species.

The PN analyser shall include a heated section at wall temperature $\geq 573\text{K}$. The unit shall control the heated stages to constant nominal operating temperatures, within a tolerance of $\pm 10\text{ K}$ and provide an indication of whether or not heated stages are at their correct operating temperatures. Lower temperatures are acceptable as long as the volatile particle removal efficiency fulfils the specifications of 6.4.

Pressure, temperature and other sensors shall monitor the proper operation of the instrument during operation and trigger a warning or message in case of malfunction.

The delay time of the PN analyser shall be $\leq 5\text{ s}$.

The PN analyser (and/or particle detector) shall have a rise time of $\leq 3.5\text{ s}$.

Particle concentration measurements shall be reported normalised to 273 K and 101.3 kPa. If necessary, the pressure and/or temperature at the inlet of the detector shall be measured and reported for the purposes of normalizing the particle concentration.

PN systems that comply with the calibration requirements of the UNECE Regulations 83 or 49 or GTR 15 automatically comply with the calibration requirements.

6.2. Efficiency requirements

The complete PN analyser system including the sampling line shall fulfil the efficiency requirements of Table 3a.

Table 3a

PN analyser (including the sampling line) system efficiency requirements

d_p [nm]	Sub-23	23	30	50	70	100	200
E(d_p) PN analyser	To be determined	0.2 – 0.6	0.3 – 1.2	0.6 – 1.3	0.7 – 1.3	0.7 – 1.3	0.5 – 2.0

Efficiency E(d_p) is defined as the ratio in the readings of the PN analyser system to a reference Condensation Particle Counter (CPC)'s ($d_{50}=10\text{nm}$ or lower, checked for linearity and calibrated with an electrometer) or an Electrometer's number concentration measuring in parallel monodisperse aerosol of mobility diameter d_p and normalized at the same temperature and pressure conditions.

The efficiency requirements will need to be adapted, in order to make sure that the efficiency of the PN analysers remains consistent with the margin PN. The material should be thermally stable soot-like (e.g. spark discharged graphite or diffusion flame soot with thermal pre-treatment). If the efficiency curve is measured with a different aerosol (e.g. NaCl), the correlation to the soot-like curve must be provided as a chart, which compares the efficiencies obtained using both test aerosols. The differences in the counting efficiencies have to be taken into account by adjusting the measured efficiencies based on the provided chart to give soot-like aerosol efficiencies. The correction for multiply charged particles should be applied and documented but shall not exceed 10%. These efficiencies refer to the PN analysers with the sampling line. The PN analyser can also be calibrated in parts (i.e. the pre-conditioning unit separately from the particle detector) as long as it is proven that PN analyser and the sampling line together fulfil the requirements of Table 3a. The measured signal from the detector shall be >2 times the limit of detection (here defined as the zero level plus 3 standard deviations).

6.3. Linearity requirements

The PN analyser including the sampling line shall fulfil the linearity requirements of point 3.2 in Appendix 2 using monodisperse or poly-disperse soot-like particles. The particle size (mobility diameter or count median diameter) should be larger than 45 nm. The reference instrument shall be an Electrometer or a Condensation Particle Counter (CPC) with $d_{50}=10\text{ nm}$ or lower, verified for linearity. Alternatively, a particle number system compliant with UNECE Regulation 83.

In addition, the differences of the PN analyser from the reference instrument at all points checked (except the zero point) shall be within 15% of their mean value. At least 5 points equally distributed (plus the zero) shall be checked. The maximum checked concentration shall be the maximum allowed concentration of the PN analyser.

If the PN analyser is calibrated in parts, then the linearity can be checked only for the PN detector, but the efficiencies of the rest parts and the sampling line have to be considered in the slope calculation.

6.4. Volatile removal efficiency

The system shall achieve $>99\%$ removal of $\geq 30\text{ nm}$ tetracontane ($\text{CH}_3(\text{CH}_2)_{38}\text{CH}_3$) particles with an inlet concentration of $\geq 10,000$ particles per cubic-centimetre at the minimum dilution.

The system shall also achieve a $>99\%$ removal efficiency of poly-disperse alkane (dekane or higher) or emery oil with count median diameter $>50\text{ nm}$ and mass $>1\text{ mg/m}^3$.

The volatile removal efficiency with tetracontane and/or poly-disperse alkane or oil have to be proven only once for the instrument family. The instrument manufacturer though has to provide the maintenance or replacement interval that ensures that the removal efficiency does not drop below the technical requirements. If such information is not provided, the volatile removal efficiency has to be checked yearly for each instrument.

7. INSTRUMENTS FOR MEASURING EXHAUST MASS FLOW

7.1. General

Instruments, sensors or signals for measuring the exhaust mass flow rate shall have a measuring range and response time appropriate for the accuracy required to measure the exhaust mass flow rate under transient and steady state conditions. The sensitivity of instruments, sensors and signals to shocks, vibration, aging, variability in temperature, ambient air pressure, electromagnetic interferences and other impacts related to vehicle and instrument operation shall be on a level as to minimize additional errors.

7.2. Instrument specifications

The exhaust mass flow rate shall be determined by a direct measurement method applied in either of the following instruments:

- (a) Pitot-based flow devices;
- (b) Pressure differential devices like flow nozzle (details see ISO 5167);
- (c) Ultrasonic flow meter;
- (d) Vortex flow meter.

Each individual exhaust mass flow meter shall fulfil the linearity requirements set out in point 3. Furthermore, the instrument manufacturer shall demonstrate the compliance of each type of exhaust mass flow meter with the specifications in points 7.2.3 to 7.2.9.

It is permissible to calculate the exhaust mass flow rate based on air flow and fuel flow measurements obtained from traceably calibrated sensors if these fulfil the linearity requirements of point 3, the accuracy requirements of point 8 and if the resulting exhaust mass flow rate is validated according to point 4 of Appendix 3.

In addition, other methods that determine the exhaust mass flow rate based on not directly traceable instruments and signals, such as simplified exhaust mass flow meters or ECU signals are permissible if the resulting exhaust mass flow rate fulfils the linearity requirements of point 3 and is validated according to point 4 of Appendix 3.

7.2.1. Calibration and verification standards

The measurement performance of exhaust mass flow meters shall be verified with air or exhaust gas against a traceable standard such as, e.g. a calibrated exhaust mass flow meter or a full flow dilution tunnel.

7.2.2. Frequency of verification

The compliance of exhaust mass flow meters with points 7.2.3 and 7.2.9 shall be verified no longer than one year before the actual test.

7.2.3. Accuracy

The accuracy of the EFM, defined as the deviation of the EFM reading from the reference flow value, shall not exceed ± 3 percent of the reading, 0,5 % of full scale or $\pm 1,0$ per cent of the maximum flow at which the EFM has been calibrated, whichever is larger.

7.2.4. Precision

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given nominal flow, approximately in the middle of the calibration range, shall not exceed 1 per cent of the maximum flow at which the EFM has been calibrated.

7.2.5. Noise

The noise shall not exceed 2 per cent of the maximum calibrated flow value. Each of the 10 measurement periods shall be interspersed with an interval of 30 seconds in which the EFM is exposed to the maximum calibrated flow.

7.2.6. Zero response drift

The zero-response drift is defined as the mean response to zero flow during a time interval of at least 30 seconds. The zero-response drift can be verified based on the reported primary signals, e.g., pressure. The drift of the primary signals over a period of 4 hours shall be less than ± 2 per cent of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

7.2.7. Span response drift

The span response drift is defined as the mean response to a span flow during a time interval of at least 30 seconds. The span response drift can be verified based on the reported primary signals, e.g., pressure. The drift of the primary signals over a period of 4 hours shall be less than ± 2 per cent of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

7.2.8. Rise time

The rise time of the exhaust flow instruments and methods should match as far as possible the rise time of the gas analysers as specified in point 4.2.7 but shall not exceed 1 second.

7.2.9. Response time check

The response time of exhaust mass flow meters shall be determined by applying similar parameters as those applied for the emissions test (i.e., pressure, flow rates, filter settings and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the exhaust mass flow meter. The gas flow switching shall be done as fast as possible, but highly recommended in less than 0.1 second. The gas flow rate used for the test shall cause a flow rate change of at least 60 per cent full scale of the exhaust mass flow meter. The gas flow shall be recorded. The delay time is defined as the time from the gas flow switching (t_0) until the response is 10 per cent (t_{10}) of the final reading. The rise time is defined as the time between 10 per cent and 90 per cent response ($t_{90} - t_{10}$) of the final reading. The response time (t_{90}) is defined as the sum of the delay time and the rise time. The exhaust mass flow meter response time (t_{90}) shall be ≤ 3 seconds with a rise time ($t_{90} - t_{10}$) of ≤ 1 second in accordance with point 7.2.8.

8. SENSORS AND AUXILIARY EQUIPMENT

Any sensor and auxiliary equipment used to determine, e.g., temperature, atmospheric pressure, ambient humidity, vehicle speed, fuel flow or intake air flow shall not alter or unduly affect the performance of the vehicle's engine and exhaust after-treatment system. The accuracy of sensors and auxiliary equipment shall fulfil the requirements of Table 4. Compliance with the requirements of Table 4 shall be demonstrated at intervals specified by the instrument manufacturer, as required by internal audit procedures or in accordance with ISO 9000.

Table 4

Accuracy requirements for measurement parameters

Measurement parameter	Accuracy
Fuel flow ⁽¹⁾	± 1% of reading ⁽³⁾
Air flow ⁽¹⁾	± 2% of reading
Vehicle speed ⁽²⁾	± 1.0 km/h absolute
Temperatures ≤600 K	± 2 K absolute
Temperatures >600 K	± 0.4% of reading in Kelvin
Ambient pressure	± 0.2 kPa absolute
Relative humidity	± 5% absolute
Absolute humidity	± 10% of reading or, 1 gH ₂ O/kg dry air, whichever is larger
Accelerator pedal position	±0.3 % (relative to full scale value)

⁽¹⁾ optional to determine exhaust mass flow

⁽²⁾ This requirement applies to the vehicle speed sensor only; if vehicle speed is used to determine parameters like acceleration, the product of vehicle speed and positive acceleration, or RPA, the vehicle speed signal shall have an accuracy of 0,1 % above 3 km/h and a sampling frequency of 1 Hz. This accuracy requirement can be met by using the signal of a wheel rotational speed sensor.

⁽³⁾ The accuracy shall be 0.02 per cent of reading if used to calculate the air and exhaust mass flow rate from the fuel flow according to point 10 of Appendix 4.

Appendix 3: Validation of PEMS and non-traceable exhaust mass flow rate

1. INTRODUCTION

This appendix describes the requirements to validate under transient conditions the functionality of the installed PEMS as well as the correctness of the exhaust mass flow rate obtained from non-traceable exhaust mass flow meters or calculated from ECU signals.

2. SYMBOLS, PARAMETERS AND UNITS

See separate list

3. VALIDATION PROCEDURE FOR PEMS

3.1. Frequency of PEMS validation

To validate the installed PEMS once for each PEMS-vehicle combination either before the PEMS+ test or, alternatively, after the completion of the test.

3.2. PEMS validation procedure

3.2.1. PEMS installation

The PEMS shall be installed and prepared according to the requirements of Appendix 1. The PEMS installation shall be kept unchanged in the time period between the validation and the PEMS+ test.

3.2.2. Test conditions

The validation test shall be conducted on a chassis dynamometer in accordance with the *GNT_WLTC+_WG* procedure. It is not recommended to feed the exhaust flow extracted by the PEMS during the validation test back to the CVS in order to avoid contamination. If the flow is not fed back to the CVS, the CVS results shall be corrected for the extracted exhaust mass. If the exhaust mass flow rate is validated with an exhaust mass flow meter, it is recommended to cross-check the mass flow rate measurements with data obtained from a sensor or the ECU.

3.2.3. Data analysis

The total distance-specific emissions [g/km] measured with laboratory equipment shall be calculated in accordance to Sub-Annex 7 of Annex XXI to Regulation (EU) 2017/1151. The emissions as measured with the PEMS shall be calculated in accordance with point 9 of Appendix 4, summed to give the total mass of pollutant emissions [g] and then divided by the test distance [km] as obtained from the chassis dynamometer. The total distance-specific mass of pollutants [g/km], as determined by the PEMS and the reference laboratory system, shall be evaluated against the requirements specified in point 3.3. For the validation of NO_x emission measurements, humidity correction shall be applied in accordance with Sub-Annex 7 of Annex XXI to Regulation (EU) 2017/1151.

3.3. Permissible tolerances for PEMS validation

The PEMS validation results shall fulfil the requirements given in Table 1. If any permissible tolerance is not met, corrective action shall be taken and the PEMS validation shall be repeated.

Table 1

Permissible tolerances

Parameter [Unit]	Permissible absolute tolerance
Distance [km] ⁽¹⁾	250 m of the laboratory reference
THC ⁽²⁾ [mg/km]	15 mg/km or 15% of the laboratory reference, whichever is larger
CH ₄ ⁽²⁾ [mg/km]	15 mg/km or 15% of the laboratory reference, whichever is larger
NMHC ⁽²⁾ [mg/km]	20 mg/km or 20% of the laboratory reference, whichever is larger
PN ⁽²⁾ [# /km]	1·10 ¹¹ p/km or 50% of the laboratory reference ⁴ whichever is larger
CO ⁽²⁾ [mg/km]	150 mg/km or 15% of the laboratory reference, whichever is larger
CO ₂ [g/km]	10 g/km or 10% of the laboratory reference, whichever is larger
NO _x ⁽²⁾ [mg/km]	15 mg/km or 15% of the laboratory reference, whichever is larger
NO/ NO ₂ [mg/km]	15 mg/km or 15% of the laboratory reference, whichever is larger

⁽¹⁾ only applicable if vehicle speed is determined by the ECU; to meet the permissible tolerance it is permitted to adjust the ECU vehicle speed measurements based on the outcome of the validation test

⁽²⁾ parameter only mandatory if measurement is done in PEMS+ tests in the framework of Green NCAP

⁽³⁾ PMP system

4. VALIDATION PROCEDURE FOR THE EXHAUST MASS FLOW RATE DETERMINED BY NON-TRACEABLE INSTRUMENTS AND SENSORS

4.1. Frequency of validation

In addition to fulfilling the linearity requirements of point 3 of Appendix 2 under steady-state conditions, the linearity of non-traceable exhaust mass flow meters or the exhaust mass flow rate calculated from non-traceable sensors or ECU signals shall be validated under transient conditions for each test vehicle against a calibrated exhaust mass flow meter or the CVS.

4.2. Validation procedure

The validation shall be conducted on a chassis dynamometer under type approval conditions, as far as applicable. As reference, a traceably calibrated flow meter shall be used. The ambient temperature can be any within the range specified in point 5.2. The installation of the exhaust mass flow meter and the execution of the test shall fulfil the requirement of point 3.4.3 of Appendix 1.

4.3. Requirements

The linearity requirements given in Table 2 shall be fulfilled. If any permissible tolerance is not met, corrective action shall be taken and the validation shall be repeated.

Table 2

Linearity requirements of calculated and measured exhaust mass flow

Measurement parameter/system	a_0	Slope a_1	Standard error SEE	Coefficient of determination r^2
Exhaust mass flow	$0.0 \pm 3.0 \text{ kg/h}$	1.00 ± 0.075	$\leq 10\% \text{ max}$	≥ 0.90

Appendix 4: Determination of emissions

1. INTRODUCTION

This Appendix describes the procedure to determine the instantaneous mass and particle number emissions [g/s; #/s] that shall be used for the subsequent evaluation of a PEMS+ trip and the calculation of the final emission result.

2. SYMBOLS, PARAMETERS AND UNITS

See separate list

3. TIME CORRECTION OF PARAMETERS

For the correct calculation of distance-specific emissions, the recorded traces of component concentrations, exhaust mass flow rate, vehicle speed, and other vehicle data shall be time corrected. To facilitate the time correction, data which are subject to time alignment shall be recorded either in a single data recording device or with a synchronised timestamp following point 5.1 of Appendix 1. The time correction and alignment of parameters shall be carried out by following the sequence described in points 3.1 to 3.3.

3.1. Time correction of component concentrations

The recorded traces of all component concentrations shall be time corrected by reverse shifting according to the transformation times of the respective analysers. The transformation time of analysers shall be determined according to point 4.4 of Appendix 2:

$$C_{i,c}(t - \Delta t_{t,i}) = C_{i,r}(t)$$

where:

$C_{i,c}$ is the time-corrected concentration of component i as function of time t

$C_{i,r}$ is the raw concentration of component i as function of time t

$\Delta t_{t,i}$ is the transformation time t of the analyser measuring component i

3.2. Time correction of exhaust mass flow rate

The exhaust mass flow rate measured with an exhaust flow meter shall be time corrected by reverse shifting according to the transformation time of the exhaust mass flow meter. The transformation time of the mass flow meter shall be determined according to point 4.4 of Appendix 2:

$$q_{m,c}(t - \Delta t_{t,m}) = q_{m,r}(t)$$

where:

$q_{m,c}$ is the time-corrected exhaust mass flow rate as function of time t

$q_{m,r}$ is the raw exhaust mass flow rate as function of time t

$\Delta t_{t,m}$ is the transformation time t of the exhaust mass flow meter

In case the exhaust mass flow rate is determined by ECU data or a sensor, an additional transformation time shall be considered and obtained by cross-correlation between the calculated exhaust mass flow rate and the exhaust mass flow rate measured following point 4 of Appendix 3.

3.3. Time alignment of vehicle data

Other data obtained from a sensor or the ECU shall be time-aligned by cross-correlation with suitable emission data (e.g., component concentrations).

3.3.1. Vehicle speed from different sources

To time align vehicle speed with the exhaust mass flow rate, it is first necessary to establish one valid vehicle speed trace. In case vehicle speed is obtained from multiple sources (e.g., the GPS, a sensor or the ECU), the vehicle speed values shall be time aligned by cross-correlation.

3.3.2. Vehicle speed with exhaust mass flow rate

Vehicle speed shall be time aligned with the exhaust mass flow rate by cross-correlation between the exhaust mass flow rate and the product of vehicle speed and positive acceleration.

3.3.3. Further signals

The time alignment of signals whose values change slowly and within a small value range, e.g. ambient temperature, can be omitted.

4. COLD START

Cold start for the purposes of PEMS+ is the period from the test start until the point when the vehicle has run for 5 minutes. If the coolant temperature is determined, the cold start period ends once the coolant is at least 70 °C for the first time but no later than 5 minutes after test start.

5. EMISSION MEASUREMENTS DURING STOP OF THE COMBUSTION ENGINE

Any instantaneous emissions or exhaust flow measurements obtained while the combustion engine is deactivated shall be recorded. In a separate step, the recorded values shall afterward be set to zero by the data post processing. The combustion engine shall be considered as deactivated if two of the following criteria apply: the recorded engine speed is <50 rpm; the exhaust mass flow rate is measured at <3 kg/h; the measured exhaust mass flow rate drops to <15% of the typical steady-state exhaust mass flow rate at idling.

6. CONSISTENCY CHECK OF VEHICLE ALTITUDE

In case well-reasoned doubts exist that a trip has been conducted above of the permissible altitude as specified in point 5.2 and in case altitude has only been measured with a GPS, the GPS altitude data shall be checked for consistency and, if necessary, corrected. The consistency of data shall be checked by comparing the latitude, longitude and altitude data obtained from the GPS with the altitude indicated by a digital terrain model or a topographic map of suitable scale. Measurements that deviate by more than 40 m from the altitude depicted in the topographic map shall be manually corrected and marked.

7. CONSISTENCY CHECK OF GPS VEHICLE SPEED

The vehicle speed as determined by the GPS shall be checked for consistency by calculating and comparing the total trip distance with reference measurements obtained from either a sensor, the validated ECU or, alternatively, from a digital road network or topographic map. It is mandatory to correct GPS data for obvious errors, e.g., by applying a dead reckoning sensor, prior to the consistency check. The original and uncorrected data file shall be retained and any corrected data shall be marked. The corrected data shall not exceed an uninterrupted time period of 120 s or a total of 300 s. The total trip distance as calculated from the corrected GPS data shall deviate by no more than 4% from the reference. If the GPS data do not meet these requirements and no other reliable vehicle speed source is available, the test results shall be voided.

8. CORRECTION OF EMISSIONS

8.1. Dry-wet correction

If the emissions are measured on a dry basis, the measured concentrations shall be converted to a wet basis as:

$$c_{\text{wet}} = k_w * c_{\text{dry}}$$

where:

c_{wet} is the wet concentration of a pollutant in ppm or per cent volume

c_{dry} is the dry concentration of a pollutant in ppm or per cent volume

k_w is the dry-wet correction factor

The following equation shall be used to calculate k_w :

$$k_w = \left(\frac{1}{1 + \alpha \times 0.005 \times (c_{\text{CO}_2} + c_{\text{CO}})} - k_{w1} \right) \times 1.008$$

where:

$$k_{w1} = \frac{1.608 \times H_a}{1000 + (1.608 \times H_a)}$$

where:

H_a is the intake air humidity [g water per kg dry air]

c_{CO_2} is the dry CO₂ concentration [%]

c_{CO} is the dry CO concentration [%]

α is the molar hydrogen ratio

8.2. Correction of NO_x for ambient humidity and temperature

NO_x emissions shall not be corrected for ambient temperature and humidity.

8.3. Correction of negative emission results

Negative intermediate results shall not be corrected. Negative final results shall be set to zero.

8.4. Reserved

9. DETERMINATION OF THE INSTANTANEOUS GASEOUS EXHAUST COMPONENTS

9.1. Introduction

The components in the raw exhaust shall be measured with the measurement and sampling analysers described in Appendix 2. The raw concentrations of relevant components shall be measured in accordance with Appendix 1. The data shall be time corrected and aligned in accordance with point 3 of this Appendix.

9.2. Calculating NMHC and CH₄ concentrations

For methane measurement using a NMC-FID, the calculation of NMHC depends on the calibration gas/method used for the zero/span calibration adjustment. When a FID is used for THC measurement without a NMC, it shall be calibrated with propane/air or propane/N₂ in the normal manner. For the calibration of the FID in series with a NMC, the following methods are permitted:

- (a) the calibration gas consisting of propane/air bypasses the NMC;
- (b) the calibration gas consisting of methane/air passes through the NMC.

It is strongly recommended to calibrate the methane FID with methane/air through the NMC.

In method (a), the concentrations of CH₄ and NMHC shall be calculated as follows:

$$c_{CH_4} = \frac{c_{HC(w/oNMC)} \times (1 - E_M) - c_{HC(w/NMC)}}{(E_E - E_M)}$$

$$c_{NMHC} = \frac{c_{HC(w/NMC)} - c_{HC(w/oNMC)} \times (1 - E_E)}{r_h \times (E_E - E_M)}$$

In method (b), the concentration of CH₄ and NMHC shall be calculated as follows:

$$c_{CH_4} = \frac{c_{HC(w/NMC)} \times r_h \times (1 - E_M) - c_{HC(w/oNMC)} \times (1 - E_E)}{r_h \times (E_E - E_M)}$$

$$c_{NMHC} = \frac{c_{HC(w/oNMC)} \times (1 - E_M) - c_{HC(w/NMC)} \times r_h \times (1 - E_M)}{(E_E - E_M)}$$

where:

$c_{HC(w/oNMC)}$ is the HC concentration with CH₄ or C₂H₆ bypassing the NMC [ppmC₁]

$c_{HC(w/NMC)}$ is the HC concentration with CH₄ or C₂H₆ flowing through the NMC [ppmC₁]

r_h is the hydrocarbon response factor as determined in point 4.3.3.(b) of Appendix 2

E_M is the methane efficiency as determined in point 4.3.4.(a) of Appendix 2

E_E is the ethane efficiency as determined in point 4.3.4(b) of Appendix 2

If the methane FID is calibrated through the cutter (method b), then the methane conversion efficiency as determined in point 4.3.4.(a) of Appendix 2 is zero. The density used for calculating the NMHC mass shall be equal to that of total hydrocarbons at 273.15 K and 101.325 kPa and is fuel-dependent.

10. DETERMINATION OF EXHAUST MASS FLOW RATE

10.1. Introduction

The calculation of instantaneous mass emissions according to points 11 and 12 requires determining the exhaust mass flow rate. The exhaust mass flow rate shall be determined by one of the direct measurement methods specified in point 7.2 of Appendix 2. Alternatively, it is permissible to calculate the exhaust mass flow rate as described in points 10.2 to 10.4.

10.2. Calculation method using air mass flow rate and fuel mass flow rate

The instantaneous exhaust mass flow rate can be calculated from the air mass flow rate and the fuel mass flow rate as follows:

$$q_{mew,i} = q_{maw,i} + q_{mf,i}$$

where:

$q_{mew,i}$ is the instantaneous exhaust mass flow rate [kg/s]

$q_{maw,i}$ is the instantaneous intake air mass flow rate [kg/s]

$q_{mf,i}$ is the instantaneous fuel mass flow rate [kg/s]

If the air mass flow rate and the fuel mass flow rate or the exhaust mass flow rate are determined from ECU recording, the calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust mass flow rate in point 3 of Appendix 2 and the validation requirements specified in point 4.3 of Appendix 3.

10.3. Calculation method using air mass flow and air-to-fuel ratio

The instantaneous exhaust mass flow rate can be calculated from the air mass flow rate and the air-to-fuel ratio as follows:

$$q_{mew,i} = q_{maw,i} \times \left(1 + \frac{1}{A/F_{st} \times \lambda_i}\right)$$

where:

$$A/F_{st} = \frac{138.0 \times \left(1 + \frac{\alpha}{4} \cdot \frac{\varepsilon}{2} + \gamma\right)}{12.011 + 1.008 \times \alpha + 15.9994 \times \varepsilon + 14.0067 \times \delta + 32.0675 \times \gamma}$$

$$\lambda_i = \frac{\left(100 - \frac{c_{CO} \times 10^{-4}}{2} - c_{HCw} \times 10^{-4}\right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{CO} \times 10^{-4}}{3.5 \times c_{CO2}} - \frac{\varepsilon}{2} - \frac{\delta}{2}}{1 + \frac{c_{CO} \times 10^{-4}}{3.5 \times c_{CO2}}}\right) \times (c_{CO2} + c_{CO} \times 10^{-4})}{4.764 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \times (c_{CO2} + c_{CO} \times 10^{-4} + c_{HCw} \times 10^{-4})}$$

where:

$q_{maw,i}$	is the instantaneous intake air mass flow rate [kg/s]
A/F_{st}	is the stoichiometric air-to-fuel ratio [kg/kg]
λ_i	is the instantaneous excess air ratio
c_{CO2}	is the dry CO ₂ concentration [%]
c_{CO}	is the dry CO concentration [ppm]
c_{HCw}	is the wet HC concentration [ppm]
α	is the molar hydrogen ratio (H/C)
β	is the molar carbon ratio (C/C)
γ	is the molar sulphur ratio (S/C)
δ	is the molar nitrogen ratio (N/C)
ε	is the molar oxygen ratio (O/C)

Coefficients refer to a fuel $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$ with $\beta = 1$ for carbon-based fuels. The concentration of HC emissions is typically low and may be omitted when calculating λ_i .

If the air mass flow rate and air-to-fuel ratio are determined from ECU recording, the calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust mass flow rate in point 3 of Appendix 2 and the validation requirements specified in point 4.3 of Appendix 3.

10.4. Calculation method using fuel mass flow and air-to-fuel ratio

The instantaneous exhaust mass flow rate can be calculated from the fuel flow and the air-to-fuel ratio (calculated with A/F_{st} and λ_i according to point 10.3) as follows:

$$q_{mew,i} = q_{mf,i} \times (1 + A/F_{st} \times \lambda_i)$$

The calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust gas mass flow rate in point 3 of Appendix 2 and the validation requirements specified in point 4.3 of Appendix 3.

11. CALCULATING THE INSTANTANEOUS MASS EMISSIONS OF GASEOUS COMPONENTS

The instantaneous mass emissions [g/s] shall be determined by multiplying the instantaneous concentration of the pollutant under consideration [ppm] with the instantaneous exhaust mass flow rate [kg/s], both corrected and aligned for the transformation time, and the respective u value of Table 1. If measured on a dry basis, the dry-wet correction according to point 8.1 shall be applied to the instantaneous component concentrations before executing any further calculations. If occurring, negative instantaneous emission values shall enter all subsequent data evaluations. Parameter values shall enter the calculation of instantaneous emissions [g/s] as reported by the analyser, flow-measuring instrument, sensor or the ECU. The following equation shall be applied:

$$m_{\text{gas},i} = u_{\text{gas}} \cdot c_{\text{gas},i} \cdot q_{\text{mew},i}$$

where:

$m_{\text{gas},i}$ is the mass of the exhaust component “gas” [g/s]

u_{gas} is the ratio of the density of the exhaust component “gas” and the overall density of the exhaust as listed in Table 1

$c_{\text{gas},i}$ is the measured concentration of the exhaust component “gas” in the exhaust [ppm]

$q_{\text{mew},i}$ is the measured exhaust mass flow rate [kg/s]

gas is the respective component

i number of the measurement

Table 1

Raw exhaust gas u values depicting the ratio between the densities of exhaust component or pollutant i [kg/m³] and the density of the exhaust gas [kg/m³]⁽⁶⁾

Fuel	ρ_e [kg/m ³]	Component or pollutant i							
		NO	NO ₂	NO _x	CO	HC	CO ₂	O ₂	CH ₄
		ρ_{gas} [kg/m ³]							
		2.053	2.053	2.053	1.250	⁽¹⁾	1.9636	1.4277	0.716
		u_{gas} ^(2,6)							
Diesel (B7)	1.2943	0.001586	0.001586	0.001586	0.000966	0.000482	0.001517	0.001103	0.000553
Ethanol (ED95)	1.2768	0.001609	0.001609	0.001609	0.000980	0.000780	0.001539	0.001119	0.000561
CNG ⁽³⁾	1.2661	0.001621	0.001621	0.001621	0.000987	0.000528 ⁽⁴⁾	0.001551	0.001128	0.000565

Propane	1.2805	0.001603	0.001603	0.001603	0.000976	0.000512	0.001533	0.001115	0.000559
Butane	1.2832	0.001600	0.001600	0.001600	0.000974	0.000505	0.001530	0.001113	0.000558
LPG ⁽⁵⁾	1.2811	0.001602	0.001602	0.001602	0.000976	0.000510	0.001533	0.001115	0.000559
Petrol (E10)	1.2931	0.001587	0.001587	0.001587	0.000966	0.000499	0.001518	0.001104	0.000553
Ethanol (E85)	1.2797	0.001604	0.001604	0.001604	0.000977	0.000730	0.001534	0.001116	0.000559

- (1) depending on fuel
(2) at $\lambda = 2$, dry air, 273 K, 101.3 kPa
(3) u values accurate within 0.2% for mass composition of: C=66-76%; H=22-25%; N=0-12%
(4) NMHC on the basis of CH_{2.93} (for THC the u_{gas} coefficient of CH₄ shall be used)
(5) u accurate within 0.2% for mass composition of: C₃=70-90%; C₄=10-30%
(6) u_{gas} is a unitless parameter; the u_{gas} values include unit conversions to ensure that the instantaneous emissions are obtained in the specified physical unit, i.e., g/s

12. CALCULATING THE INSTANTANEOUS PARTICLE NUMBER EMISSIONS

The instantaneous particle number emissions [particles/s] shall be determined by multiplying the instantaneous concentration of the pollutant under consideration [particles/cm³] with the instantaneous exhaust mass flow rate [kg/s], both corrected and aligned for the transformation time. If applicable, negative instantaneous emission values shall enter all subsequent data evaluations. All significant digits of intermediate results shall enter the calculation of the instantaneous emissions. The following equation shall apply:

$$PN_i = c_{PN,i} q_{mew,i} / \rho_e$$

where:

PN_i is the particle number flux [particles/s]

$c_{PN,i}$ is the measured particle number concentration [#/m³] normalized at 0°C

$q_{mew,i}$ is the measured exhaust mass flow rate [kg/s]

ρ_e is the density of the exhaust gas [kg/m³] at 0°C (Table 1).

13. RESERVED

Appendix 5: Verification of overall trip dynamics using the moving averaging window method

1. INTRODUCTION

The Moving Averaging Window method is used to verify the overall trip dynamics. The test is divided in sub-sections (windows) and the subsequent analysis aims at determining whether the trip is valid for PEMS+ purposes. The dynamics of the windows is verified by comparing their CO₂ distance-specific emissions with a reference curve obtained from the vehicle CO₂ emissions measured in accordance with the WLTP procedure.

2. SYMBOLS, PARAMETERS AND UNITS

See separate list

3. MOVING AVERAGING WINDOWS

3.1. Definition of averaging windows

The instantaneous emissions calculated in accordance with Appendix 4 shall be integrated using a moving averaging window method, based on the reference CO₂ mass. The principle of the calculation is as follows: The PEMS+ distance-specific CO₂ mass emissions are not calculated for the complete data set, but for sub-sets of the complete data set, the length of these sub-sets being determined so as to match always the same fraction of the CO₂ mass emitted by the vehicle over the WLTP cycle. The moving window calculations are conducted with a time increment Δt corresponding to the data sampling frequency. These sub-sets used to calculate the vehicle on-road CO₂ emissions and its average speed are referred to as “averaging windows” in the following sections. The calculation described in the present point shall be run from the first data point (forward).

The following data shall not be considered for the calculation of the CO₂ mass, the distance and the vehicle average speed in the averaging windows:

- The periodic verification of the instruments and/or after the zero drift verifications;
- Vehicle ground speed is smaller than 1 km/h.;

The calculation shall start from when vehicle ground speed is higher than or equal to 1 km/h and include driving events during which no CO₂ is emitted and where the vehicle ground speed is higher than or equal to 1 km/h. The mass emissions $M_{CO_2,j}$ shall be determined by integrating the instantaneous emissions in g/s as specified in Appendix 4.

Figure 1

Vehicle speed versus time - Vehicle averaged emissions versus time, starting from the first averaging window

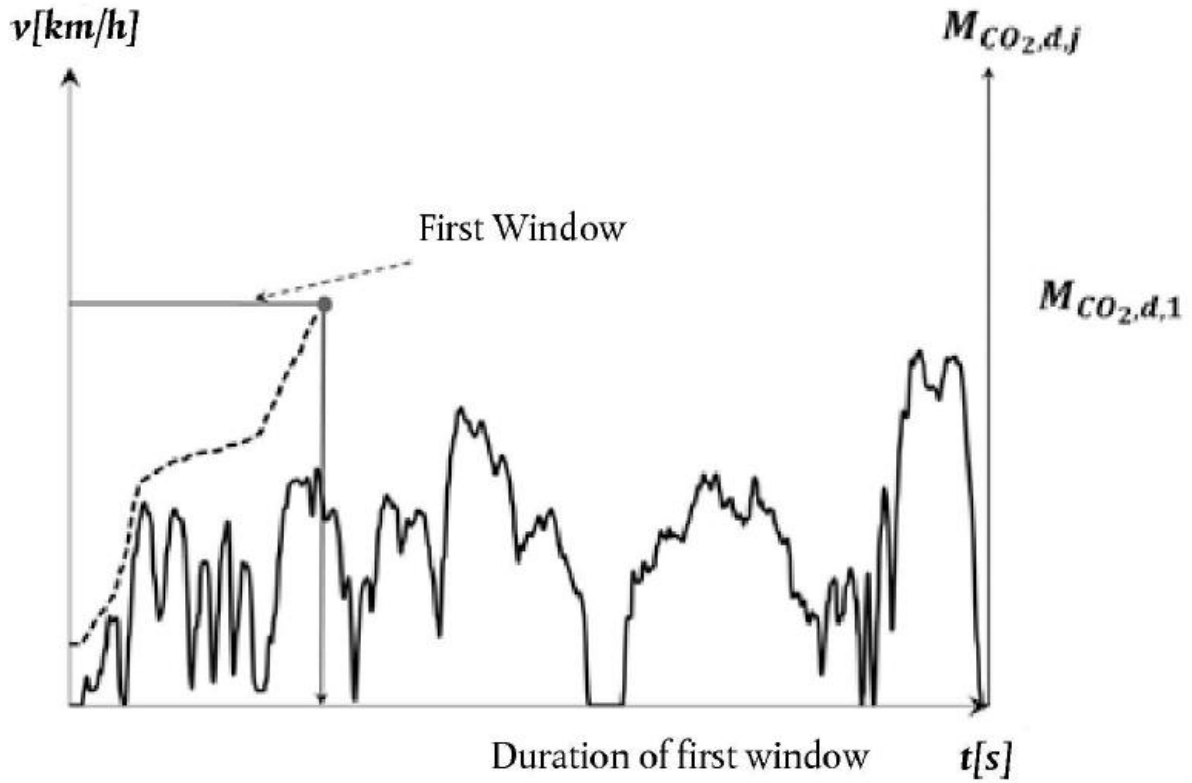
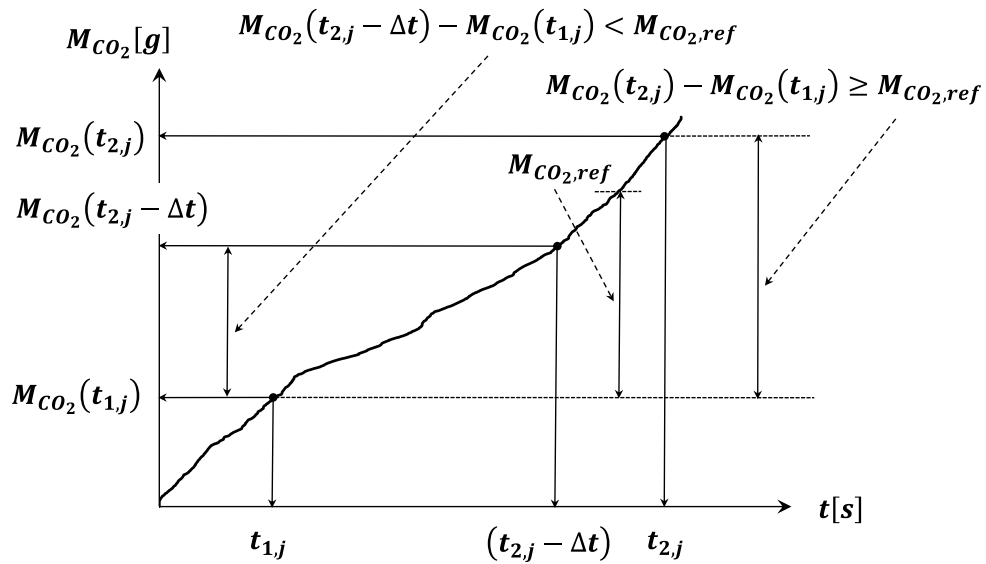


Figure 2

Definition of CO₂ mass based on averaging windows



The duration $(t_{2,j} - t_{1,j})$ of the j^{th} averaging window is determined by:

$$M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j}) \geq M_{CO_2,ref}$$

where:

$M_{CO_2}(t_{i,j})$ is the CO₂ mass measured between the test start and time $(t_{i,j})$ [g];

$M_{CO_2,ref}$ is the half of the CO₂ mass emitted by the vehicle over the WLTP procedure considering the Certificate of Conformity values

For Green NCAP testing purposes, the reference CO₂ mass shall be obtained from point 12 of the Transparency list 1 of Appendix 5 of Annex II to Regulation (EU) 2017/1151 with interpolation between vehicle H and vehicle L (if relevant) as defined in Sub-Annex 7 of Annex XXI to Regulation (EU) 2017/1151, using Test mass and Road load coefficients (f0, f1 & f2) obtained from the Certificate of Conformity for the individual vehicle as defined in Annex IX to Regulation (EU) 2017/1151. The value for OVC-HEV vehicles in case not included in the Transparency list above is to be obtained from the WLTC+ Cold test conducted using the Charge Sustaining mode according to *GNT_WLTC+_WG* procedure.

$t_{2,j}$ shall be selected such as:

$$M_{CO_2}(t_{2,j} - \Delta t) - M_{CO_2}(t_{1,j}) < M_{CO_2,ref} \leq M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j})$$

where Δt is the data sampling period.

The CO₂ masses are calculated in the windows by integrating the instantaneous emissions calculated as specified in Appendix 4.

3.2. Calculation of window parameters

The following shall be calculated for each window determined in accordance with point 3.1.

- The distance-specific CO₂ emissions $M_{CO_2,d,j}$;
- The average vehicle speed \bar{v}_j

4. EVALUATION OF WINDOWS

4.1. Introduction

The reference dynamic conditions of the test vehicle are defined from the vehicle CO₂ emissions versus average speed measured at type approval on the Type 1 test and referred to as 'vehicle CO₂ characteristic curve'.

4.2. CO₂ characteristic curve reference points

The distance-specific CO₂ emissions to be considered in this paragraph for the definition of the reference curve shall be obtained from point 12 of the Transparency list 1 of Appendix 5 of Annex II to Regulation (EU) 2017/1151 with interpolation between vehicle H and vehicle L (if relevant) as defined in Sub-Annex 7 of Annex XXI to Regulation (EU) 2017/1151, using Test mass and Road load coefficients (f0, f1 & f2) obtained from the Certificate of Conformity for the individual vehicle as defined in Annex IX to Regulation (EU) 2017/1151. The value for OVC-HEV vehicles in case not included in the Transparency list above is to be that obtained from the WLTC+ test conducted using the Charge Sustaining mode according to *GNT_WLTC+_WG* procedure.

The reference points P_1 , P_2 and P_3 required to define the vehicle CO₂ characteristic curve shall be established as follows:

4.2.1. Point P_1

$\overline{v_{P1}} = 18,882 \text{ km/h}$ (average vehicle speed of the Low Vehicle speed phase of the WLTP cycle)

M_{CO_2,d,P_1} = Vehicle CO₂ emissions over the Low Vehicle speed phase of the WLTP cycle [g/km]

4.2.2. Point P_2

$\overline{v_{P2}} = 56,664 \text{ km/h}$ (Average Speed of the High Vehicle Speed phase of the WLTP cycle)

M_{CO_2,d,P_2} = Vehicle CO₂ emissions over the High Vehicle speed phase of the WLTP cycle [g/km]

4.2.3. Point P_3

$\overline{v_{P3}} = 91,997 \text{ km/h}$ (Average Speed of the Extra High Vehicle Speed phase of the WLTP cycle)

M_{CO_2,d,P_3} = Vehicle CO₂ emissions over the Extra High Vehicle speed phase of the WLTP cycle [g/km]

4.3. CO₂ characteristic curve definition

Using the reference points defined in section 4.2, the characteristic curve CO₂ emissions are calculated as a function of the average vehicle speed using two linear sections (P_1, P_2) and (P_2, P_3). The section (P_2, P_3) is limited to 145 km/h on the vehicle speed axis. The characteristic curve is defined by equations as follows:

For the section (P_1, P_2):

$$M_{CO_2,d,CC}(\bar{v}) = a_1 \bar{v} + b_1$$

$$\text{with: } a_1 = (M_{CO_2,d,P_2} - M_{CO_2,d,P_1}) / (\overline{v_{P2}} - \overline{v_{P1}})$$

$$\text{and: } b_1 = M_{CO_2,d,P_1} - a_1 \overline{v_{P1}}$$

For the section (P_2, P_3):

$$M_{CO_2,d,CC}(\bar{v}) = a_2 \bar{v} + b_2$$

$$\text{with: } a_2 = (M_{CO_2,d,P_3} - M_{CO_2,d,P_2}) / (\overline{v_{P3}} - \overline{v_{P2}})$$

$$\text{and: } b_2 = M_{CO_2,d,P_2} - a_2 \overline{v_{P2}}$$

Figure 3

Vehicle CO₂ characteristic curve

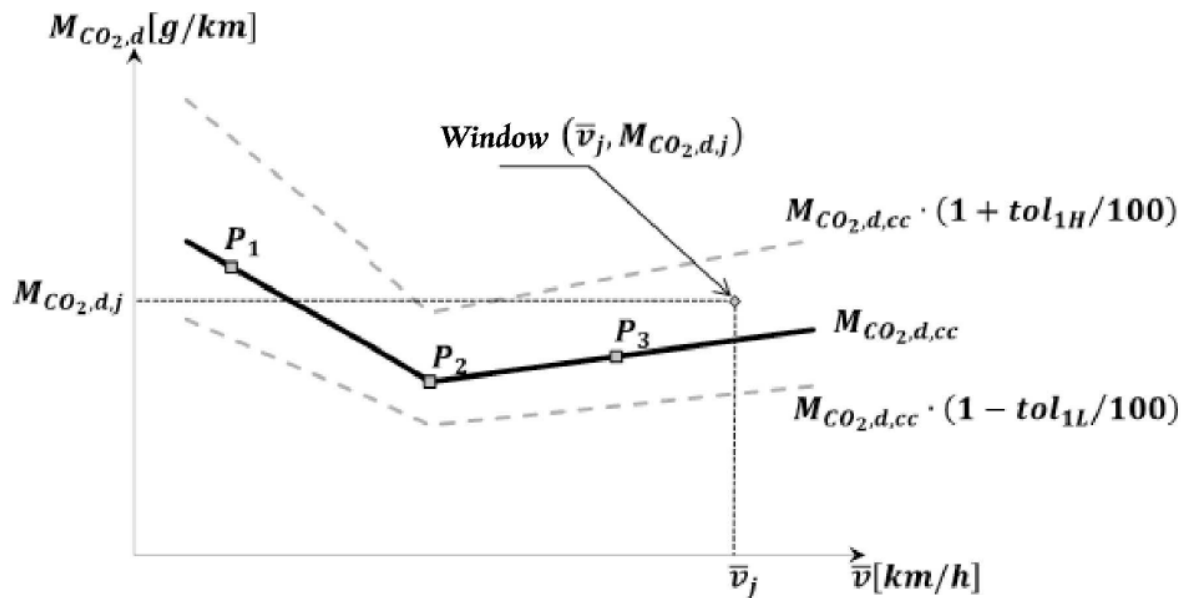
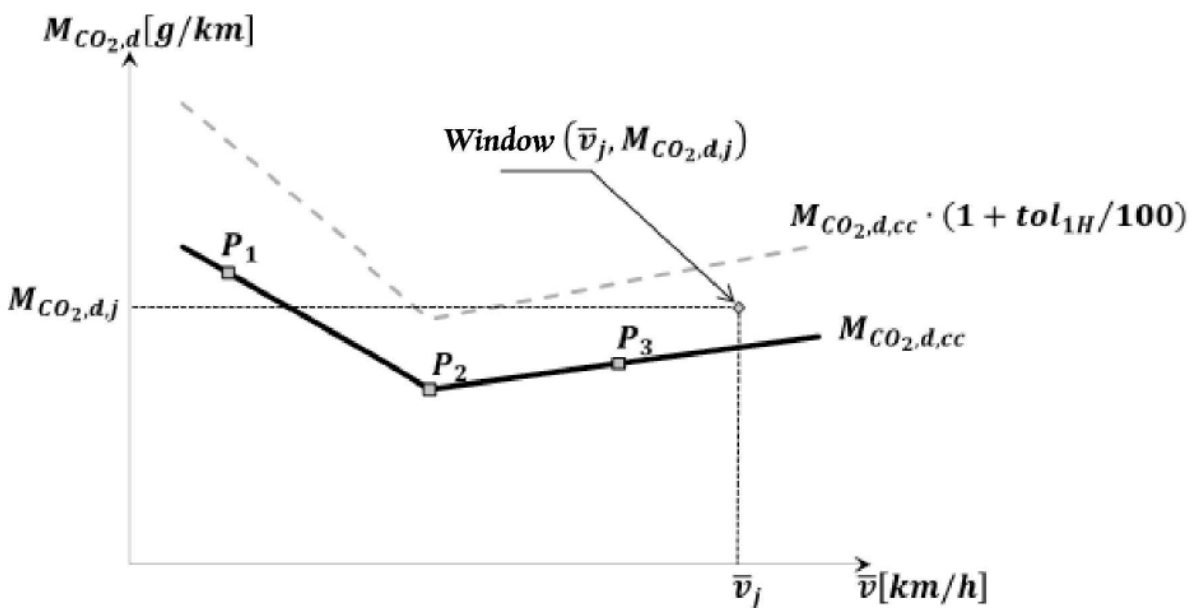


Figure 4

Vehicle CO₂ characteristic curve: urban, rural and motorway driving definitions



4.4. Urban, rural and motorway windows

4.4.1. Urban windows

Urban windows are characterized by average vehicle speeds \bar{v}_j lower than 45 km/h.

4.4.2. Rural windows

Rural windows are characterized by average vehicle speeds \bar{v}_j greater than or equal to 45 km/h and lower than 80 km/h.

4.4.3. Motorway windows

Motorway windows are characterized by average vehicle speeds \bar{v}_j greater than or equal to 80 km/h and lower than 145 km/h.

Figure 5

Vehicle CO₂ characteristic curve: urban, rural and motorway driving definitions (Illustrated for ICE and NOVC-HEV vehicles)

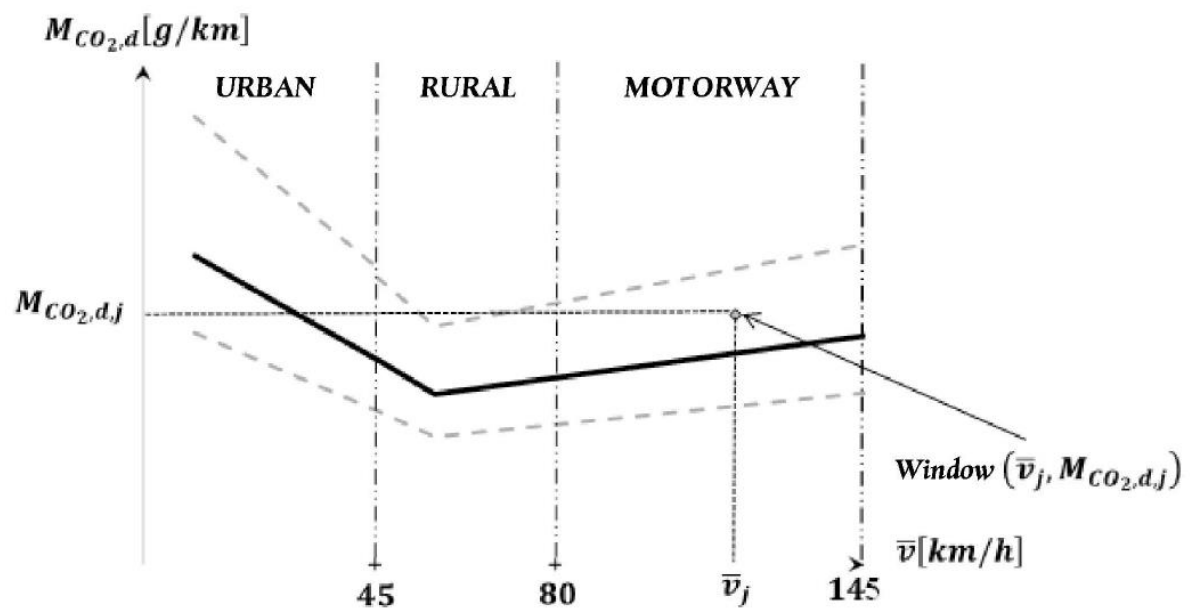
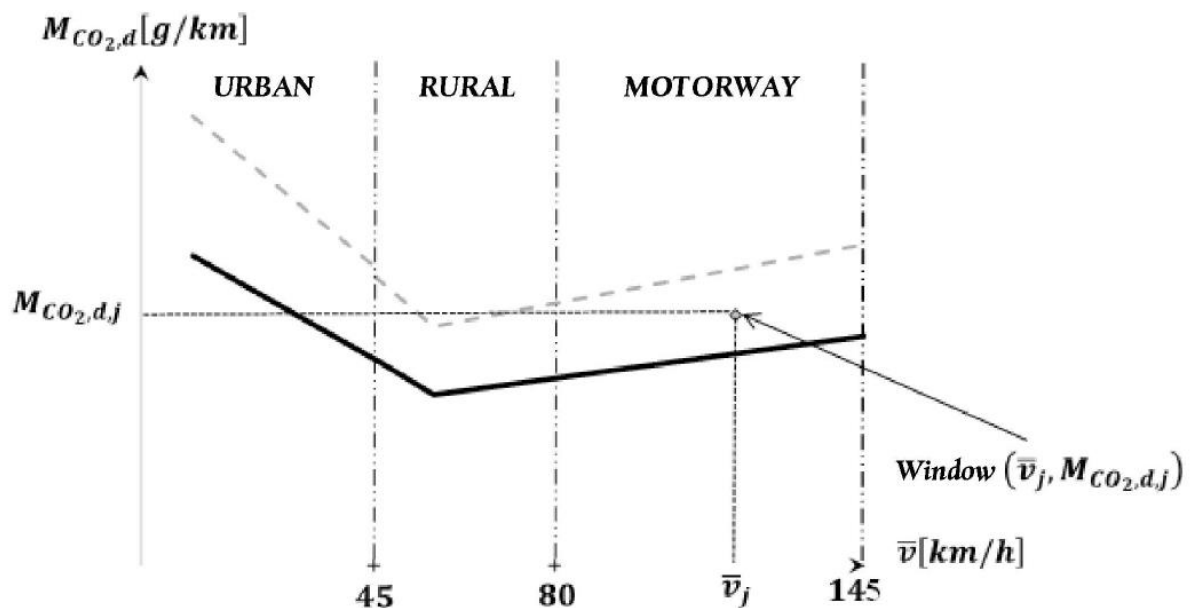


Figure 6

Vehicle CO₂ characteristic curve: urban, rural and motorway driving definitions (Illustrated for OVC-HEV vehicles)



4.5. Verification of trip validity

4.5.1. Tolerances around the vehicle CO₂ characteristic curve

The upper tolerance of the vehicle CO₂ characteristic curve is $tol_{1H} = 45\%$ for urban driving and $tol_{1H} = 40\%$ for rural and motorway driving. The lower tolerance of the vehicle CO₂ characteristic curve is $tol_{1L} = 25\%$ for ICE and NOVC-HEV vehicles and $tol_{1L} = 100\%$ for OVC-HEV vehicles.

4.5.2. Verification of test validity

The test is valid when it comprises at least 50 % of the urban, rural and motorway windows that are within the tolerances defined for the CO₂ characteristic curve. For NOVC-HEVs and OVC-HEVs, if the minimum requirement of 50 % between tol_{1H} and tol_{1L} is not met, the upper positive tolerance tol_{1H} may be increased by steps of 1 %.

Appendix 6: Reserved

Appendix 7: Reserved

Appendix 7a: Verification of trip dynamics

1. INTRODUCTION

This Appendix describes the calculation procedures to verify the trip dynamics by determining the excess or absence of dynamics during urban, rural and motorway driving.

2. SYMBOLS, PARAMETERS AND UNITS

See separate list

3. TRIP INDICATORS

3.1. Calculations

3.1.1. Data pre-processing

Dynamic parameters like acceleration, ($v \cdot a_{pos}$) or RPA shall be determined with a vehicle speed signal of an accuracy of 0,1 % for all vehicle speed values above 3 km/h and a sampling frequency of 1 Hz. This accuracy requirement is generally fulfilled by distance calibrated signals obtained from a wheel (rotational) speed sensor. Otherwise, acceleration shall be determined with an accuracy of 0,01 m/s² and a sampling frequency of 1 Hz. In this case the separate vehicle speed signal, in ($v \cdot a_{pos}$), shall have an accuracy of at least 0,1 km/h.

The correct speed trace builds the basis for further calculations and binning as described in paragraph 3.1.2 and 3.1.3.

3.1.2. Calculation of distance, acceleration and $v \cdot a$

The following calculations shall be performed over the whole-time based vehicle speed trace (1 Hz resolution) from second 1 to second t_t (last second).

The distance increment per data sample shall be calculated as follows:

$$d_i = v_i/3.6, \quad i = 1 \text{ to } N_t$$

where:

d_i is the distance covered in time step i [m]

v_i is the actual vehicle speed in time step i [km/h]

N_t is the total number of samples

The acceleration shall be calculated as follows:

$$a_i = (v_{i+1} - v_{i-1})/(2 \cdot 3.6), \quad i = 1 \text{ to } N_t$$

where:

a_i is the acceleration in time step i [m/s²]. For $i = 1$: $v_{i-1} = 0$, for $i = N_t$: $v_{i+1} = 0$.

The product of vehicle speed per acceleration shall be calculated as follows:

$$(v \cdot a)_i = v_i \cdot a_i/3.6, \quad i = 1 \text{ to } N_t$$

where:

$(v \cdot a)_i$ is the product of the actual vehicle speed per acceleration in time step i [m^2/s^3 or W/kg].

3.1.3. Binning of the results

After the calculation of a_i and $(v \cdot a)_i$, the values v_i , d_i , a_i and $(v \cdot a)_i$ shall be ranked in ascending order of the vehicle speed.

All datasets with $v_i \leq 60 km/h$ belong to the “urban” vehicle speed bin, all datasets with $60 km/h < v_i \leq 90 km/h$ belong to the “rural” vehicle speed bin and all datasets with $v_i > 90 km/h$ belong to the “motorway” vehicle speed bin.

The number of datasets with acceleration values $a_i > 0.1 m/s^2$ shall be bigger or equal to 100 in each vehicle speed bin.

For each vehicle speed bin the average vehicle speed \bar{v}_k shall be calculated as follows:

$$\bar{v}_k = (\sum_i v_{i,k}) / N_k, i = 1 \text{ to } N_k, k = u, r, m$$

where:

N_k is the total number of samples of the urban, rural, and motorway shares.

3.1.4. Calculation of $v \cdot a_{pos-[95]}$ per vehicle speed bin

The 95th percentile of the $v \cdot a_{pos}$ values shall be calculated as follows:

The $(v \cdot a)_{i,k}$ values in each vehicle speed bin shall be ranked in ascending order for all datasets with $a_{i,k} > 0.1 m/s^2$ and the total number of these samples M_k shall be determined.

Percentile values are then assigned to the $(v \cdot a_{pos})_{j,k}$ values with $a_{i,k} \geq 0.1 m/s^2$ as follows:

The lowest $v \cdot a_{pos}$ value gets the percentile $1/M_k$, the second lowest $2/M_k$, the third lowest $3/M_k$ and the highest value $M_k/M_k = 100\%$.

$(v \cdot a_{pos})_{k-[95]}$ is the $(v \cdot a_{pos})_{j,k}$ value, with $j/M_k = 95\%$. If $j/M_k = 95\%$ cannot be met, $(v \cdot a_{pos})_{k-[95]}$ shall be calculated by linear interpolation between consecutive samples j and $j+1$ with $j/M_k < 95\%$ and $(j+1)/M_k > 95\%$.

The relative positive acceleration per vehicle speed bin shall be calculated as follows:

$$RPA_k = \sum_j (\Delta t \cdot (v \cdot a_{pos})_{j,k}) / \sum_i d_{i,k}, j = 1 \text{ to } M_k, i = 1 \text{ to } N_k, k = u, r, m$$

where:

RPA_k is the relative positive acceleration for urban, rural and motorway shares in [m/s^2 or $kWs/(kg \cdot km)$]

Δt is a time difference equal to 1 second

M_k is the sample number for urban, rural and motorway shares with positive acceleration

N_k is the total sample number for urban, rural and motorway shares

4. VERIFICATION OF TRIP VALIDITY

4.1. Verification of $v \cdot a_{pos_95}$ per vehicle speed bin (with v in [km/h])

If $\bar{v}_k \leq 74.6 \text{ km/h}$ and $(v \cdot a_{pos})_{k-95} > (0.136 \cdot \bar{v}_k + 14.44)$ are fulfilled, the trip is invalid.

If $\bar{v}_k > 74.6 \text{ km/h}$ and $(v \cdot a_{pos})_{k-95} > (0.0742 \cdot \bar{v}_k + 18.966)$ are fulfilled, the trip is invalid.

4.2. Verification of RPA per vehicle speed bin

If $\bar{v}_k \leq 94.05 \text{ km/h}$ and $RPA_k < (-0.0016 \cdot \bar{v}_k + 0.1755)$ is fulfilled, the trip is invalid.

If $\bar{v}_k > 94.05 \text{ km/h}$ and $RPA_k < 0.025$ is fulfilled, the trip is invalid.

Appendix 7b: Procedure to determine the cumulative positive elevation gain of a PEMS trip

1. INTRODUCTION

This Appendix describes the procedure to determine the cumulative elevation gain of a PEMS trip.

2. SYMBOLS, PARAMETERS AND UNITS

See separate list

3. GENERAL REQUIREMENTS

The cumulative positive elevation gain of a PEMS+ trip shall be determined based on three parameters: the instantaneous vehicle altitude $h_{GPS,i}$ [m above sea level] as measured with the GPS, the instantaneous vehicle speed v_i [km/h] recorded at a frequency of 1 Hz and the corresponding time t [s] that has passed since test start.

4. CALCULATION OF CUMULATIVE POSITIVE ELEVATION GAIN

4.1. General

The cumulative positive elevation gain of a PEMS+ trip shall be calculated as a three-step procedure, consisting of (i) the screening and principle verification of data quality, (ii) the correction of instantaneous vehicle altitude data, and (iii) the calculation of the cumulative positive elevation gain.

4.2. Screening and principle verification of data quality

The instantaneous vehicle speed data shall be checked for completeness. Correcting for missing data is permitted if gaps remain within the requirements specified in Point 7 of Appendix 4; else, the test results shall be voided. The instantaneous altitude data shall be checked for completeness. Data gaps shall be completed by data interpolation. The correctness of interpolated data shall be verified by a topographic map. It is recommended to correct interpolated data if the following condition applies:

$$|h_{GPS}(t) - h_{map}(t)| > 40m$$

The altitude correction shall be applied so that:

$$h(t) = h_{map}(t)$$

where:

$h(t)$	-	vehicle altitude after the screening and principle verification of data quality at data point t [m above sea level]
$h_{GPS}(t)$	-	vehicle altitude measured with GPS at data point t [m above sea level]
$h_{map}(t)$	-	vehicle altitude based on topographic map at data point t [m above sea level]

4.3. Correction of instantaneous vehicle altitude data

The altitude $h(0)$ at the start of a trip at $d(0)$ shall be obtained by GPS and verified for correctness with information from a topographic map. The deviation shall not be larger than 40 m. Any instantaneous altitude data $h(t)$ shall be corrected if the following condition applies:

$$|h(t) - h(t - 1)| > (v(t)/3.6 * \sin 45^\circ)$$

The altitude correction shall be applied so that:

$$h_{corr}(t) = h_{corr}(t - 1)$$

where:

$h(t)$	-	vehicle altitude after the screening and principle verification of data quality at data point t [m above sea level]
$h(t-1)$	-	vehicle altitude after the screening and principle verification of data quality at data point t-1 [m above sea level]
$v(t)$	-	vehicle speed of data point t [km/h]
$h_{corr}(t)$	-	corrected instantaneous vehicle altitude at data point t [m above sea level]
$h_{corr}(t-1)$	-	corrected instantaneous vehicle altitude at data point t-1 [m above sea level]

Upon the completion of the correction procedure, a valid set of altitude data is established. This data set shall be used for the calculation of the cumulative positive elevation gain as described in Point 13.4.

4.4. Final calculation of the cumulative positive elevation gain

4.4.1. Establishment of a uniform spatial resolution

The total distance d_{tot} [m] covered by a trip shall be determined as sum of the instantaneous distances d_i . The instantaneous distance d_i shall be determined as:

$$d_i = \frac{v_i}{3.6}$$

Where:

d_i	-	instantaneous distance [m]
v_i	-	instantaneous vehicle speed [km/h]

The cumulative elevation gain shall be calculated from data of a constant spatial resolution of 1 m starting with the first measurement at the start of a trip $d(0)$. The discrete data points at a resolution of 1 m are referred to as way points, characterized by a specific distance value d (e.g., 0, 1, 2, 3 m...) and their corresponding altitude $h(d)$ [m above sea level].

The altitude of each discrete way point d shall be calculated through interpolation of the instantaneous altitude $h_{corr}(t)$ as:

$$h_{int}(d) = h_{corr}(0) + \frac{h_{corr}(1) - h_{corr}(0)}{d_1 - d_0} * (d - d_0)$$

Where:

$h_{int}(d)$	-	interpolated altitude at the discrete way point under consideration d [m above sea level]
--------------	---	---

$h_{corr}(0)$	-	corrected altitude directly before the respective way point d [m above sea level]
$h_{corr}(1)$	-	corrected altitude directly after the respective way point d [m above sea level]
d	-	cumulative distance traveled until the discrete way point under consideration d [m]
d_0	-	cumulative distance travelled until the measurement located directly before the respective way point d [m]
d_1	-	cumulative distance travelled until the measurement located directly after the respective way point d [m]

4.4.2. Additional data smoothing

The altitude data obtained for each discrete way point shall be smoothed by applying a two-step procedure; d_a and d_e denote the first and last data point respectively (Figure 1). The first smoothing run shall be applied as follows:

$$road_{grade,1}(d) = \frac{h_{int}(d + 200m) - h_{int}(d_a)}{(d + 200m)} \quad \text{for } d \leq 200m$$

$$road_{grade,1}(d) = \frac{h_{int}(d + 200m) - h_{int}(d - 200m)}{(d + 200m) - (d - 200m)} \quad \text{for } 200m < d < (d_e - 200m)$$

$$road_{grade,1}(d) = \frac{h_{int}(d_e) - h_{int}(d - 200m)}{d_e - (d - 200m)} \quad \text{for } d \geq (d_e - 200m)$$

$$h_{int,sm,1}(d) = h_{int,sm,1}(d - 1m) + road_{grade,1}(d), d = d_a + 1 \text{ to } d_e$$

$$h_{int,sm,1}(d_a) = h_{int}(d_a) + road_{grade,1}(d_a)$$

Where:

$road_{grade,1}(d)$	-	smoothed road grade at the discrete way point under consideration after the first smoothing run [m/m]
$h_{int}(d)$	-	interpolated altitude at the discrete way point under consideration d [m above sea level]
$h_{int,sm,1}(d)$	-	smoothed interpolated altitude, after the first smoothing run at the discrete way point under consideration d [m above sea level]
d	-	cumulative distance travelled at the discrete way point under consideration [m]
d_a	-	reference way point at a distance of zero meters [m]
d_e	-	cumulative distance travelled until the last discrete way point [m]

The second smoothing run shall be applied as follows:

$$road_{grade,2}(d) = \frac{h_{int,sm,1}(d + 200m) - h_{int,sm,1}(d_a)}{(d + 200m)} \quad \text{for } d \leq 200m$$

$$road_{grade,2}(d) = \frac{h_{int,sm,1}(d + 200m) - h_{int,sm,1}(d - 200m)}{(d + 200m) - (d - 200m)} \quad \text{for } 200m < d < (d_e - 200m)$$

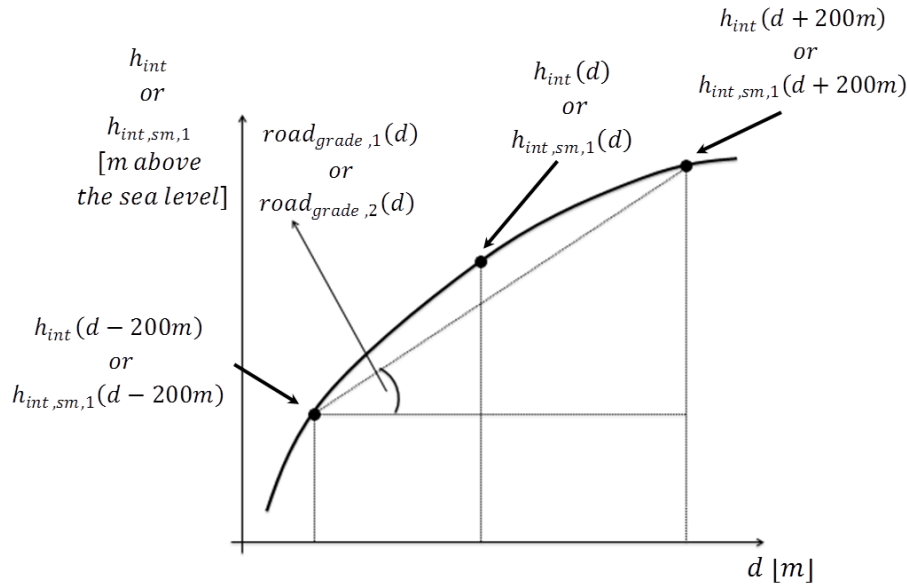
$$road_{grade,2}(d) = \frac{h_{int,sm,1}(d_e) - h_{int,sm,1}(d - 200m)}{d_e - (d - 200m)} \quad \text{for } d \geq (d_e - 200m)$$

Where:

- $road_{grade,2}(d)$ - smoothed road grade at the discrete way point under consideration after the second smoothing run [m/m]
- $h_{int,sm,1}(d)$ - smoothed interpolated altitude, after the first smoothing run at the discrete way point under consideration d [m above sea level]
- d - cumulative distance travelled at the discrete way point under consideration [m]
- d_a - reference way point at a distance of zero meters [m]
- d_e - cumulative distance travelled until the last discrete way point [m]

Figure 1

Illustration of the procedure to smooth the interpolated altitude signals



4.4.3. Calculation of the final result

The positive cumulative elevation gain of a total trip shall be calculated by integrating all positive interpolated and smoothed road grades, i.e. $road_{grade,2}(d)$. The result should be normalized by the total test distance d_{tot} and expressed in metres of cumulative elevation gain per one hundred kilometres of distance.

The positive cumulative elevation gain of the urban part of a trip shall then be calculated based on the vehicle speed over each discrete way point:

$$v_w = 1 / (t_{w,i} - t_{w,i-1}) \cdot 60^2 / 1000$$

Where:

v_w - waypoint vehicle speed [km/h]

All datasets with $v_w \leq 60$ km/h belong to the urban part of the trip.

Integrate all of the positive interpolated and smoothed road grades that correspond to urban datasets.

Integrate the number of 1m waypoints which correspond to urban datasets and divide by

1000 to calculate urban test distance d_{urban} [km].

The positive cumulative elevation gain of the urban part of trip shall then be calculated by dividing the urban elevation gain by the urban test distance, and expressed in metres of cumulative elevation gain per one hundred kilometres of distance.

5. NUMERICAL EXAMPLE

Tables 1 and 2 show how to calculate the positive elevation gain on the basis of data recorded during an on-road test performed with PEMS. For the sake of brevity an extract of 800m and 160s is presented here.

5.1. Screening and principle verification of data quality

The screening and principle verification of data quality consists of two steps. First, the completeness of vehicle speed data is checked. No data gaps related to vehicle speed are detected in the present data sample (see Table 1). Second, the altitude data are checked for completeness; in the data sample, altitude data related to seconds 2 and 3 are missing. The gaps are filled by interpolating the GPS signal. In addition, the GPS altitude is verified by a topographic map; this verification includes the altitude $h(0)$ at the start of the trip. Altitude data related to seconds 112 -114 are corrected on the basis of the topographic map to satisfy the following condition:

$$h_{GPS}(t) - h_{map}(t) < -40m$$

As result of the applied data verification, the data in the fifth column $h(t)$ are obtained.

5.2. Correction of instantaneous vehicle altitude data

As a next step, the altitude data $h(t)$ of seconds 1 to 4, 111 to 112 and 159 to 160 are corrected assuming the altitude values of seconds 0, 110 and 158 respectively since for the altitude data in these time periods the following condition applies:

$$|h(t) - h(t - 1)| > (v(t)/3.6 * \sin 45^\circ)$$

As result of the applied data correction, the data in the sixth column $h_{corr}(t)$ are obtained. The effect of the applied verification and correction steps on the altitude data is depicted in Figure 2.

5.3. Calculation of the cumulative positive elevation gain

5.3.1. Establishment of a uniform spatial resolution

The instantaneous distance d_i is calculated by dividing the instantaneous vehicle speed measured in km/h by 3.6 (Column 7 in Table 1). Recalculating the altitude data to obtain a uniform spatial resolution of 1 m yields the discrete way points d (Column 1 in Table 2) and their corresponding altitude values $h_{int}(d)$ (Column 7 in Table 2). The altitude of each discrete way point d is calculated through interpolation of the measured instantaneous altitude h_{corr} as:

$$h_{int}(0) = 120.3 + \frac{120.3 - 120.3}{0.1 - 0.0} * (0 - 0) = 120.3000$$

$$h_{int}(520) = 132.5 + \frac{132.6 - 132.5}{523.6 - 519.9} * (520 - 519.9) = 132.5027$$

5.3.2. Additional data smoothing

In Table 2, the first and last discrete way points are: $d_a=0m$ and $d_e=799m$, respectively. The altitude data of each discrete way point is smoothed by applying a two steps procedure. The first smoothing run consists of:

$$road_{grade,1}(0) = \frac{h_{int}(200m) - h_{int}(0)}{(0 + 200m)} = \frac{120.9682 - 120.3000}{200} = 0.0033$$

chosen to demonstrate the smoothing for $d \leq 200m$

$$road_{grade,1}(320) = \frac{h_{int}(520) - h_{int}(120)}{(520) - (120)} = \frac{132.5027 - 121.0}{400} = 0.0288$$

chosen to demonstrate the smoothing for $200m < d < (599m)$

$$road_{grade,1}(720) = \frac{h_{int}(799) - h_{int}(520)}{799 - (520)} = \frac{121.2000 - 132.5027}{279} = -0.0405$$

chosen to demonstrate the smoothing for $d \geq (599m)$

The smoothed and interpolated altitude is calculated as:

$$h_{int,sm,1}(0) = h_{int}(0) + road_{grade,1}(0) = 120.3 + 0.0033 \approx 120.3033m$$

$$h_{int,sm,1}(799) = h_{int,sm,1}(798) + road_{grade,1}(799) = 121.2550 - 0.0220 = 121.2330m$$

Second smoothing run:

$$road_{grade,2}(0) = \frac{h_{int,sm,1}(200) - h_{int,sm,1}(0)}{(200)} = \frac{119.9618 - 120.3033}{(200)} = -0.0017$$

chosen to demonstrate the smoothing for $d \leq 200m$

$$road_{grade,2}(320) = \frac{h_{int,sm,1}(520) - h_{int,sm,1}(120)}{(520) - (120)} = \frac{123.6809 - 120.1843}{400} = 0.0087$$

chosen to demonstrate the smoothing for $200m < d < (599)$

$$road_{grade,2}(720) = \frac{h_{int,sm,1}(799) - h_{int,sm,1}(520)}{799 - (520)} = \frac{121.2330 - 123.6809}{279} = -0.0088$$

chosen to demonstrate the smoothing for $d \geq (599m)$

5.3.3. Calculation of the final result

The positive cumulative elevation gain of a trip is calculated by integrating all positive interpolated and smoothed road grades, i.e. values in the column $road_{grade,2}(d)$ in Table 2. For the entire data set the total covered distance was $d_{tot}=139.7$ km and all positive interpolated and smoothed road grades were of 516m. Therefore, the positive cumulative elevation gain reached $516*100/139.7=370m/100km$.

Table 1

Correction of instantaneous vehicle altitude data

Time t [s]	$v(t)$ [km/h]	$h_{GPS}(t)$ [m]	$h_{map}(t)$ [m]	$h(t)$ [m]	$h_{corr}(t)$ [m]	d_i [m]	Cum. d [m]
0	0.00	122.7	129.0	122.7	122.7	0.0	0.0
1	0.00	122.8	129.0	122.8	122.7	0.0	0.0
2	0.00	-	129.1	123.6	122.7	0.0	0.0
3	0.00	-	129.2	124.3	122.7	0.0	0.0
4	0.00	125.1	129.0	125.1	122.7	0.0	0.0
...
18	0.00	120.2	129.4	120.2	120.2	0.0	0.0
19	0.32	120.2	129.4	120.2	120.2	0.1	0.1
...
37	24.31	120.9	132.7	120.9	120.9	6.8	117.9
38	28.18	121.2	133.0	121.2	121.2	7.8	125.7
...
46	13.52	121.4	131.9	121.4	121.4	3.8	193.4
47	38.48	120.7	131.5	120.7	120.7	10.7	204.1
...
56	42.67	119.8	125.2	119.8	119.8	11.9	308.4
57	41.70	119.7	124.8	119.7	119.7	11.6	320.0
...
110	10.95	125.2	132.2	125.2	125.2	3.0	509.0
111	11.75	100.8	132.3	100.8	125.2	3.3	512.2
112	13.52	0.0	132.4	132.4	125.2	3.8	516.0
113	14.01	0.0	132.5	132.5	132.5	3.9	519.9
114	13.36	24.30	132.6	132.6	132.6	3.7	523.6
...
149	39.93	123.6	129.6	123.6	123.6	11.1	719.2
150	39.61	123.4	129.5	123.4	123.4	11.0	730.2
...
157	14.81	121.3	126.1	121.3	121.3	4.1	792.1
158	14.19	121.2	126.2	121.2	121.2	3.9	796.1
159	10.00	128.5	126.1	128.5	121.2	2.8	798.8
160	4.10	130.6	126.0	130.6	121.2	1.2	800.0

- denotes data gaps

Table 2

Calculation of road grade

d [m]	t_0 [s]	d_0 [m]	d_1 [m]	h_0 [m]	h_1 [m]	$h_{int}(d)$ [m]	$road_{grade,1}(d)$ [m/m]	$h_{int,sm,1}(d)$ [m]	$road_{grade,2}(d)$ [m/m]
0	18	0.0	0.1	120.3	120.4	120.3	0.0035	120.3	-0.0015
...
120	37	117.9	125.7	120.9	121.2	121.0	-0.0019	120.2	0.0035
...
200	46	193.4	204.1	121.4	120.7	121.0	-0.0040	120.0	0.0051
...
320	56	308.4	320.0	119.8	119.7	119.7	0.0288	121.4	0.0088
...

520	113	519.9	523.6	132.5	132.6	132.5	0.0097	123.7	0.0037
...
720	149	719.2	730.2	123.6	123.4	123.6	-0.0405	122.9	-0.0086
...
798	158	796.1	798.8	121.2	121.2	121.2	-0.0219	121.3	-0.0151
799	159	798.8	800.0	121.2	121.2	121.2	-0.0220	121.3	-0.0152

Figure 2

The effect of data verification and correction - The altitude profile measured by GPS $h_{GPS}(t)$, the altitude profile provided by the topographic map $h_{map}(t)$, the altitude profile obtained after the screening and principle verification of data quality $h(t)$ and the correction $h_{corr}(t)$ of data listed in Table 1

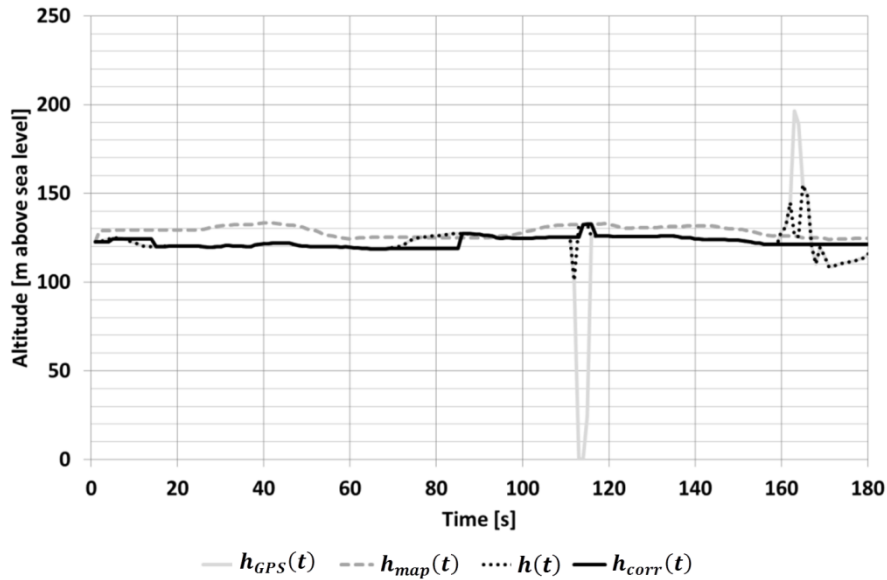


Figure 3

Comparison between the corrected altitude profile $h_{corr}(t)$ and the smoothed and interpolated altitude $h_{int,sm,1}$

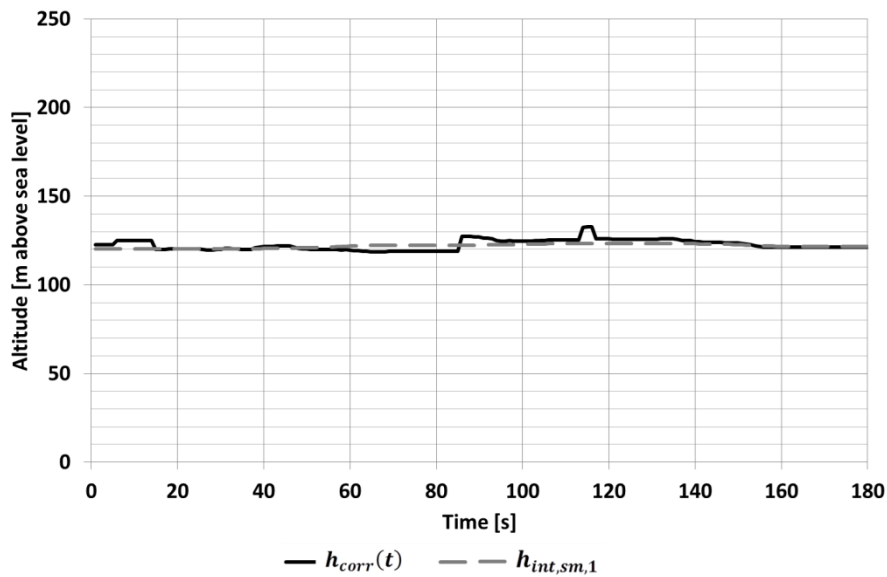


Table 3

Calculation of the positive elevation gain

d	t_0	d_0	d_1	h_0	h_1	$h_{int}(d)$	$road_{grade,1}(d)$	$h_{int,sm,1}(d)$	$road_{grade,2}(d)$
0	18	0.0	0.1	120.3	120.4	120.3	0.0035	120.3	-0.0015
...
120	37	117.9	125.7	120.9	121.2	121.0	-0.0019	120.2	0.0035
...
200	46	193.4	204.1	121.4	120.7	121.0	-0.0040	120.0	0.0051
...
320	56	308.4	320.0	119.8	119.7	119.7	0.0288	121.4	0.0088
...
520	113	519.9	523.6	132.5	132.6	132.5	0.0097	123.7	0.0037
...
720	149	719.2	730.2	123.6	123.4	123.6	-0.0405	122.9	-0.0086
...
798	158	796.1	798.8	121.2	121.2	121.2	-0.0219	121.3	-0.0151
799	159	798.8	800.0	121.2	121.2	121.2	-0.0220	121.3	-0.0152

Appendix 8: Reserved

Appendix 9: Reserved

Appendix 10: On-road measurement of N₂O

1. SCOPE AND REFERENCES

The purpose of this procedure is to describe the method of measuring on-road of laughing gas (N₂O) emissions, performed as a part of the Green NCAP PEMS+ test program.

The measurements will be carried out during the onroad PEMS+ tests described in the latest version of the *GNT_Overall_GNCAp_Test_Procedure_WG*.

2. TEST PARAMETER

Table 1 of Appendix 1 is expanded with the test parameter N₂O:

Parameter	Recommended unit	Source
N ₂ O concentration ⁽¹⁾	ppm	Analyser

Notes:

⁽¹⁾ to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4

3. SPECIFICATIONS AND CALIBRATION OF PEMS COMPONENTS AND SIGNALS

The linearity requirements for gas analysers apply to the N₂O analyser. Those are listed in Table 1 Appendix 2.

4. ANALYSERS FOR MEASURING NITROUS OXIDE CONCENTRATIONS (N₂O)

4.1. Permissible types of analysers

4.1.1. Standard analysers

On-road emissions of nitrous oxide (N₂O) shall be measured with nondispersive infrared analysers (NDIR).

4.1.2. Alternative analysers

Any analyser not meeting the design specifications of point 4.1.1 of this Appendix is permissible provided that it fulfils the requirements of point 4.2 of this Appendix. The test laboratory shall ensure that the alternative analyser achieves an equivalent or higher measurement performance compared to a standard analyser over the range of pollutant concentrations and co-existing gases that can be expected from vehicles operated with permissible fuels under moderate and extended conditions of valid PEMS+ testing as specified in points 4 to 9. Upon request, the manufacturer of the analyser shall submit in writing supplemental information, demonstrating that the measurement performance of the alternative analyser is consistently and reliably in line with the measurement performance of standard analysers. Supplemental information shall contain:

- a description of the theoretical basis and the technical components of the alternative analyser;
- a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 of this Appendix over the expected range of pollutant concentrations and ambient conditions of the type-approval test defined in point 4.2 as well as a validation test as described in in Appendix 3 for a vehicle equipped with a spark-ignition and compression-ignition engine; the manufacturer of the analyser shall demonstrate the significance of equivalency within the permissible tolerances given in Appendix 3.

- (c) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 of this Appendix with respect to the influence of atmospheric pressure on the measurement performance of the analyser; the demonstration test shall determine the response to span gas having a concentration within the analyser range to check the influence of atmospheric pressure under moderate and extended altitude conditions defined in point 4. Such a test can be performed in an altitude environmental test chamber.
- (d) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 of this Appendix over at least three on-road tests that fulfil the requirements.
- (e) a demonstration that the influence of vibrations, accelerations and ambient temperature on the analyser reading does not exceed the noise requirements for analysers set out in point 4.2.5 of this Appendix.

Approval authorities may request additional information to substantiate equivalency or refuse approval if measurements demonstrate that an alternative analyser is not equivalent to a standard analyser.

4.2. Analyser specifications

4.2.1. General

In addition to the linearity requirements defined for each analyser in Table 2 of Appendix 2, the compliance of analyser types with the specifications laid down in points 4.2.2 to 4.2.8 to this Appendix shall be demonstrated by the analyser manufacturer. Analysers shall have a measuring range and response time appropriate to measure with adequate accuracy the concentrations of the exhaust gas components at the applicable emissions standard under transient and steady state conditions. The sensitivity of the analysers to shocks, vibration, aging, variability in temperature and air pressure as well as electromagnetic interferences and other impacts related to vehicle and analyser operation shall be limited as far as possible.

4.2.2. Measuring range

The analysers shall have a measuring range compatible with the accuracy required to measure the concentrations of the exhaust gas sample compounds. A typical N₂O measuring low range may be 0 – 100 ppm; a typical N₂O measuring high range may be 0 – 1000 ppm.

4.2.3. Accuracy

The accuracy, defined as the deviation of the analyser reading from the reference value, shall not exceed 2% rel. of reading or 20 ppm abs., whichever is larger.

4.2.4. Precision

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than 1% of the full-scale concentration for a measurement range. equal or above 155 ppm and 2% of the full-scale concentration for a measurement range of below 155 ppm.

4.2.5. Noise

The noise shall not exceed 2 % of full scale. Each of the 10 measurement periods shall be interspersed with an interval of 30 seconds in which the analyser is exposed to an appropriate span gas. Before each sampling period and before each span period, sufficient time shall be given to purge the analyser and the sampling lines.

4.2.6. Zero response drift

The drift of the zero response, defined as the mean response to a zero gas during a time interval of at least 30 seconds, shall comply with the specifications given in Table 2 in 4.2.7 of this Appendix.

4.2.7. Span response drift

The drift of the span response, defined as the mean response to a span gas during a time interval of at least 30 seconds, shall comply with the specifications given in Table 2 in 4.2.7 of this Appendix.

Table 2 Permissible zero and span response drift of N₂O analysers for measuring gaseous components under laboratory conditions

Pollutant	Absolute Zero response drift	Absolute Span response drift
N ₂ O	≤20 ppm abs. over 8 h	≤20 ppm abs. over 8 h or 2% rel. over 8 h, whichever is greater

4.2.8. Measuring frequency

The N₂O concentration shall be measured at a constant frequency of 1,0 Hz or higher.

4.2.9. Rise time

The rise time, defined as the time between the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$; see point 4.4 of this Appendix), shall not exceed 3 seconds.

4.2.10. Gas drying

Exhaust gases may be measured wet or dry, whereby the manufacturer's specifications are to be considered. A gas-drying device, if used, shall have a minimal effect on the composition of the measured gases. Chemical dryers are not permitted.

4.3. Additional requirements

4.3.1. General

The provisions in points 4.3.2 of this Appendix define additional performance requirements for specific analyser types and apply only to cases, in which the analyser under consideration is used for PEMS+ emission measurements.

4.3.2. Interference effects

(a) General

Other gases than the ones being analysed can affect the analyser reading. A check for interference effects and the correct functionality of analysers shall be performed by the analyser manufacturer prior to market introduction at least once for each type of analyser or device addressed in point (b).

(b) N₂O analyser interference check

Water and CO₂ can interfere with the measurements of the N₂O analyser. Therefore, a CO₂ span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range of the N₂O analyser used during the test shall be bubbled through water at room temperature and the analyser response recorded. The analyser response shall not be more than 2 per cent of the mean N₂O concentration expected during regular on-road testing or ±2 ppm, whichever is larger. The interference check for H₂O and CO₂ may be run as separate procedures. If the H₂O and CO₂ levels used for the

interference check are higher than the maximum levels expected during the test, each observed interference value shall be scaled down by multiplying the observed interference with the ratio of the maximum expected concentration value during the test and the actual concentration value used during this check. Separate interference checks with concentrations of H₂O that are lower than the maximum concentration expected during the test may be run and the observed H₂O interference shall be scaled up by multiplying the observed interference with the ratio of the maximum H₂O concentration value expected during the test and the actual concentration value used during this check. The sum of the two scaled interference values shall meet the tolerance specified in this point.

4.4. Response time check of the analytical system

For the response time check, the settings of the analytical system shall be exactly the same as during the emissions test (i.e. pressure, flow rates, filter settings in the analysers and all other parameters influencing the response time). The response time shall be determined with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0.1 second. The gases used for the test shall cause a concentration change of at least 60 per cent full scale of the analyser.

The concentration trace of each single gas component shall be recorded. The delay time is defined as the time from the gas switching (t_0) until the response is 10 per cent of the final reading (t_{10}). The rise time is defined as the time between 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$). The system response time (t_{90}) consists of the delay time to the measuring detector and the rise time of the detector.

For time alignment of the analyser and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 per cent of the final reading (t_{50}).

The system response time shall be ≤ 12 s with a rise time of ≤ 3 seconds for all components and all ranges used.

5. GASES

5.1. Calibration and span gases for PEMS+ test

- N₂O in nitrogen (tolerance: ± 2 per cent or 0.25 ppm, whichever is greater)
- Nitrogen for purge and zero calibration (Purity: ≤ 1 ppm C1, ≤ 1 ppm CO, ≤ 400 ppm CO₂, ≤ 0.1 ppm NO, ≤ 0.1 ppm N₂O, ≤ 0.1 ppm NH₃)

6. VALIDATION OF PEMS AND NON-TRACEABLE EXHAUST MASS FLOW RATE

Table 1 of Appendix 3 "VALIDATION OF PEMS AND NON-TRACEABLE EXHAUST MASS FLOW RATE" is to be expanded with the permissible tolerance for N₂O:

Table 3 Permissible tolerances

Parameter [Unit]	Permissible absolute tolerance
N ₂ O ⁽²⁾ [mg/km]	15 mg/km or 15% of the laboratory reference, whichever is larger

7. DETERMINATION OF EMISSIONS

Table 1 of Appendix 4 is to be expanded with density and raw exhaust gas u values for N_2O :

Table 4 Raw exhaust gas u values depicting the ratio between the densities of exhaust component or pollutant i [kg/m^3] and the density of the exhaust gas [kg/m^3]⁽⁶⁾

Fuel	ρ_e [kg/m^3]	Component or pollutant i
		N_2O
		ρ_{gas} [kg/m^3]
		1.964
		$u_{gas}^{(2,6)}$
Diesel (B7)	1.2943	0,001517
Ethanol (ED95)	1.2768	0,001538
CNG ⁽³⁾	1.2661	0,001551
Propane	1.2805	0,001533
Butane	1.2832	0,001533
LPG ⁽⁵⁾	1.2811	0,001533
Petrol (E10)	1.2931	0,001518
Ethanol (E85)	1.2797	0,001534

(2) at $\lambda = 2$, dry air, 273 K, 101.3 kPa

(6) u_{gas} is a unitless parameter; the u_{gas} values include unit conversions to ensure that the instantaneous emissions are obtained in the specified physical unit, i.e., g/s

8. DETERMINATION OF AVERAGE N_2O CONCENTRATION IN PPM/TEST_{PHASE} AND PPM/TEST

Besides the determination of emissions as shown in point 11 of Appendix 4, the N_2O emissions are also to be expressed in average N_2O emission concentration per test phase in ppm/test_{phase}.

The average concentration of N_2O (ppm/test_{phase}) shall be calculated using one of the following equations, depending on the character of the measurement:

$$C_{N_2O_{mean_phase}} = \frac{1}{n_{phase}} \sum_{i=n_{phase_start}}^{i=n_{phase_end}} C_{N_2O_i}$$

where:

C_{N_2O} is the instantaneous N_2O concentration, ppm;

n is the number of measurements in the respective test phase.

n_{phase_start} is the measurement number at the start of the respective phase

n_{phase_end} is the measurement number at the end of the respective phase

or

$$C_{N_2O_{mean_phase}} = \frac{\int_{t_{1phase}}^{t_{2phase}} C_{N_2O} dt}{t_{2phase} - t_{1phase}}$$

where:

$\int_{t_{1phase}}^{t_{2phase}} C_{N_2O} dt$ is the integral of the recording of the continuous N₂O analyser over the test phase duration (t_{2phase}-t_{1phase});

C_{N_2O} is the instantaneous N₂O concentration, ppm;

The test average N₂O emissions in ppm/test are calculated as follows:

$$C_{N_2O_{mean_test}} = \frac{1}{n} \sum_{i=1}^{i=n} C_{N_2O_i}$$

where:

C_{N_2O} is the instantaneous N₂O concentration, ppm;

n is the number of measurements during the entire test.

or

$$C_{N_2O_{mean_test}} = \frac{\int_{t_1}^{t_2} C_{N_2O} dt}{t_2 - t_1}$$

where:

$\int_{t_1}^{t_2} C_{N_2O} dt$ is the integral of the recording of the continuous N₂O analyser over the entire test duration (t₂-t₁);

C_{N_2O} is the instantaneous N₂O concentration, ppm;