Council of the European Union

Brussels, 14 September 2022
(OR. en)

12421/22
ADD 3

ENT 124
MI 661
ENV 879

COVER NOTE

From:	Secretary-General of the European Commission, signed by Ms Martine DEPREZ, Director
date of receipt:	13 September 2022
To:	General Secretariat of the Council
No. Cion doc.:	[…](2022) XXX draft - D 082562/3 - ANNEX III
Subject:	ANNEX to the Commission Regulation amending Commission Regulation (EU) 2017/1151 as regards the emission type approval procedures for light passenger and commercial vehicles

Delegations will find attached document […](2022) XXX draft - D 082562/3 - ANNEX III.

Encl.: […](2022) XXX draft - D 082562/3 - ANNEX III

EUROPEAN
COMMISSION

Brussels, XXX
D082562/03
[…](2022) XXX draft

ANNEX 3

ANNEX

to the

Commission Regulation

amending Commission Regulation (EU) 2017/1151 as regards the emission type approval procedures for light passenger and commercial vehicles

ANNEX III

'ANNEX IIIA

1. ABBREVIATIONS

Abbreviations refer generically to both the singular and the plural forms of abbreviated terms.

CLD	—	ChemiLuminescence Detector
CVS	—	Constant Volume Sampler
DCT	—	Dual Clutch Transmission
ECU	—	Engine Control Unit
EFM	—	Exhaust mass Flow Meter
FID	—	Flame Ionisation Detector
FS	—	full scale
GNSS	—	Global Navigation Satellite System
HCLD	—	Heated ChemiLuminescence Detector
ICE	—	Internal Combustion Engine
LPG	—	Liquid Petroleum Gas
NDIR	—	Non-Dispersive InfraRed analyser
NDUV	—	Non-Dispersive UltraViolet analyser
NG	—	Natural Gas
NMC	—	Non-Methane Cutter
NMC-FID	—	Non-Methane Cutter in combination with a Flame-Ionisation Detector
NMHC	—	Non-Methane HydroCarbons
OBD	—	On-Board Diagnostics
PEMS	—	Portable Emissions Measurement System
RPA	—	Relative Positive Acceleration
SEE	—	Standard Error of Estimate
THC	—	Total HydroCarbons
VIN	—	Vehicle Identification Number
WLTC	—	Worldwide harmonized Light vehicles Test Cycle

2. DEFINITIONS

2.1. For the purposes of this Annex, the following definitions shall apply in terms of generic issues:

2.1.1. "Vehicle type with regard to Real Driving Emissions" means a group of vehicles which do not differ with respect to the criteria constituting a "PEMS test family" as defined in point 3.3.1.

2.1.2. “Declared Maximum RDE” means the emission values, which must necessarily be lower than the applicable emission limits, declared optionally by the manufacturer and used for checking compliance against lower emission limits

2.2. For the purposes of this Annex, the following definitions shall apply in terms of test equipment:

2.2.1. "Accuracy" means the difference between a measured value and a reference value, traceable to a national or international standard and describes the correctness of a result (Figure 1).

2.2.2. “Adapter” means in the context of this annex mechanical parts that allow the connection of the vehicle to a commonly used or standardized measurement device connector .

2.2.3. "Analyser" means any measurement device that is not part of the vehicle but installed to determine the concentration or the amount of gaseous or particle pollutants.

2.2.4. "Calibration" means the process of setting a measurement system's response so that its output agrees with a range of reference signals.

2.2.5. “Calibration gas" means a gas mixture used to calibrate gas analysers.

2.2.6. "Delay time" means the difference in time between the change of the component to be measured at the reference point and a system response of 10 per cent of the final reading (t10) with the sampling probe being defined as the reference point (Figure 2).

2.2.7. "Full scale" means the full range of an analyser, flow-measuring instrument or sensor as specified by the equipment manufacturer or the highest range used for the specific test.

2.2.8. "Hydrocarbon response factor" of a particular hydrocarbon species means the ratio between the reading of a FID and the concentration of the hydrocarbon species under consideration in the reference gas cylinder, expressed as $ppmC_1$.

2.2.9. "Major maintenance" means the adjustment, repair or replacement of a component or module that could affect the accuracy of a measurement.

2.2.10. "Noise" means two times the root mean square of ten standard deviations, each calculated from the zero responses measured at a constant frequency which is a multiple of 1.0 Hz during a period of 30 seconds.

2.2.11. "Non-methane hydrocarbons" (NMHC) means the Total Hydrocarbons (THC) minus the methane (CH_4) contribution.

2.2.12. "Precision" means the degree to which repeated measurements under unchanged conditions show the same results (Figure 1).

2.2.13. "Reading" means the numerical value displayed by an analyser, flow-measuring instrument, sensor or any other measurement devise applied in the context of vehicle emission measurements.

2.2.14. "Reference value" means a value traceable to a national or international standard (Figure 1).

2.2.15. "Response time" (t90) means the difference in time between the change of the component to be measured at the reference point and a system response of 90 per cent of the final reading (t90) with the sampling probe being defined as the reference point, whereby the change of the measured component is at least 60 per cent full scale (FS) and takes place in less than 0.1 second. The system response time consists of the delay time to the system and of the rise time of the system as depicted in Figure 2.

2.2.16. "Rise time" means the difference in time between the 10 per cent and 90 per cent response of the final reading (t10 to t90) as depicted in Figure 2.

2.2.17. "Sensor" means any measurement device that is not part of the vehicle itself but installed to determine parameters other than the concentration of gaseous and particle pollutants and the exhaust mass flow.

2.2.18. "Set point" means the target value a control system aims to reach.

2.2.19. "Span" means to adjust an instrument so that it gives a proper response to a calibration standard that represents between 75 per cent and 100 per cent of the maximum value in the instrument range or expected range of use.

2.2.20. "Span response" means the mean response to a span signal over a time interval of at least 30 seconds.

2.2.21. "Span response drift" means the difference between the mean response to a span signal and the actual span signal that is measured over a defined time period after an analyser, flow-measuring instrument or sensor has been accurately spanned.

2.2.22. "Total hydrocarbons" (THC) means the sum of all volatile compounds measurable by a flame ionization detector (FID).

2.2.23. "Traceable" means the ability to relate a measurement or reading through an unbroken chain of comparisons to a national or international standard.

2.2.24. "Transformation time" means the time difference between a change of concentration or flow (t0) at the reference point and a system response of 50 per cent of the final reading (t50) as depicted in Figure 2.

2.2.25. "Type of analyser", also referred to as "analyser type" means a group of analysers produced by the same manufacturer that apply an identical principle to determine the concentration of one specific gaseous component or the number of particles.

2.2.26. "Type of exhaust mass flow meter" means a group of exhaust mass flow meters produced by the same manufacturer that share a similar tube inner diameter and function on an identical principle to determine the mass flow rate of the exhaust gas.

2.2.27. "Verification" means the process of evaluating whether the measured or calculated output of an analyser, flow-measuring instrument, sensor or signal or method agrees with a reference signal or value within one or more predetermined thresholds for acceptance.

2.2.28. "Zero" means the calibration of an analyser, flow-measuring instrument or sensor so that it gives an accurate response to a zero signal.

2.2.29. "Zero gas" means a gas containing no analyte, which is used to set a zero response on an analyser.

2.2.30. "Zero response" means the mean response to a zero signal over a time interval of at least 30 seconds.

2.2.31. “Zero response drift" means the difference between the mean response to a zero signal and the actual zero signal that is measured over a defined time period after an analyser, flow-measuring instrument or sensor has been accurately zero calibrated.

Figure 1

Definition of accuracy, precision and reference value

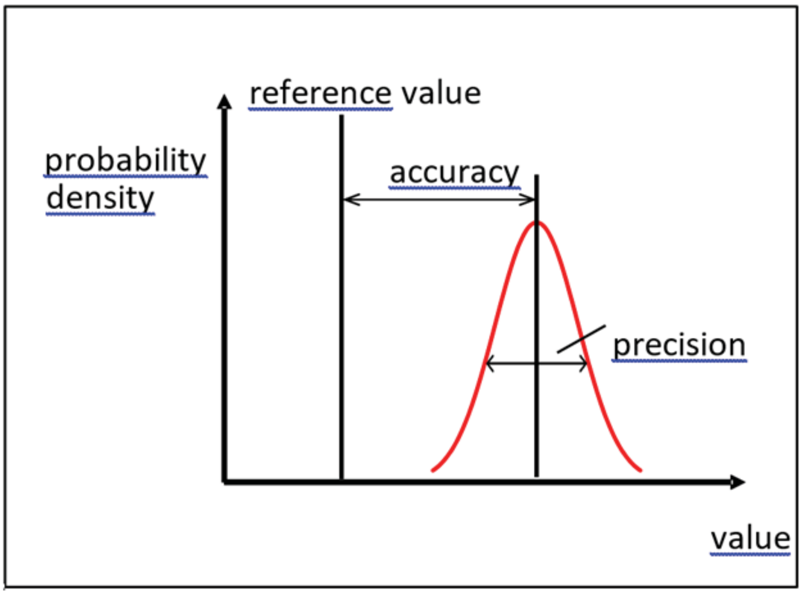
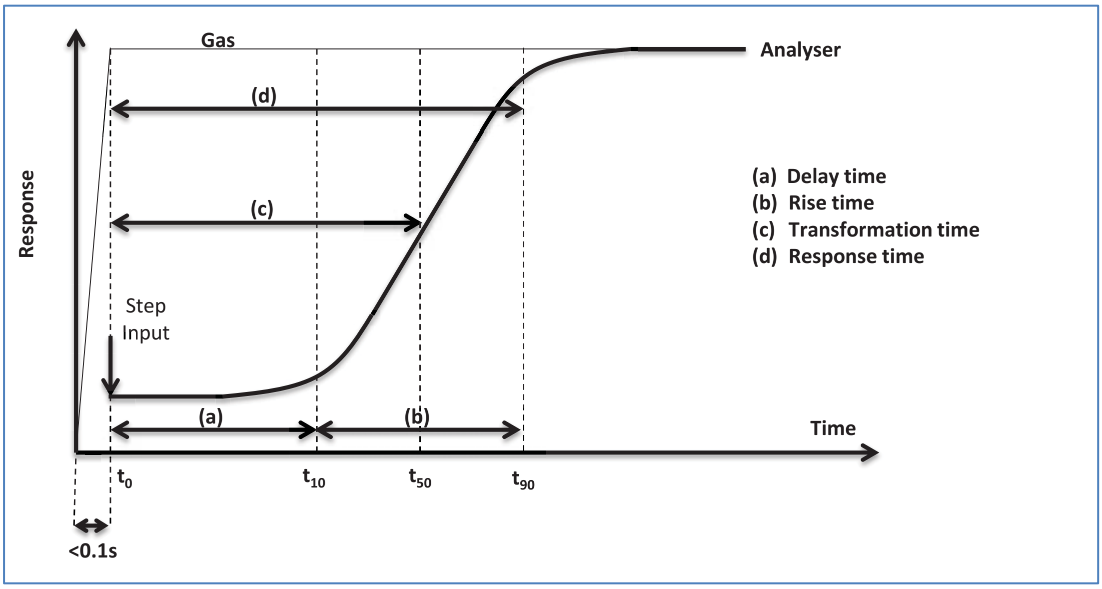


Figure 2

Definition of delay, rise, transformation and response times



2.3. For the purposes of this Annex, the following definitions shall apply in terms of vehicle characteristics and driver:

2.3.1. “Actual mass of the vehicle" means the mass in running order plus the mass of the fitted optional equipment to an individual vehicle.

2.3.2. "Auxiliary devices" means energy consuming, converting, storing or supplying non-peripheral devices or systems which are installed in the vehicle for purposes other than the propulsion of the vehicle and are therefore not considered to be part of the powertrain.

2.3.3. "Mass in running order" means the mass of the vehicle, with its fuel tank(s) filled to at least 90 per cent of its or their capacity/capacities, including the mass of the driver, fuel and liquids, fitted with the standard equipment in accordance with the manufacturer's specifications and, when they are fitted, the mass of the bodywork, the cabin, the coupling and the spare wheel(s) as well as the tools.

2.3.4. *"*Maximum Permissible Test mass of the vehicle" means the sum of the actual mass of the vehicle and 90 per cent of the difference between the technically permissible maximum laden mass and the actual mass of the vehicle (Figure 3).

2.3.5. "Odometer" means an instrument indicating to the driver the total distance driven by the vehicle since its production.

2.3.6. "Optional equipment" means all the features not included in the standard equipment which are fitted to a vehicle under the responsibility of the manufacturer, and that can be ordered by the customer.

2.3.7. "Power-to-test mass-ratio" corresponds to the ratio of the rated engine power of the internal combustion engine over the test mass (i.e. the actual mass of the vehicle plus the mass of the measurement equipment and the mass of additional passengers or payload, if any).

2.3.8. “Power-to-mass-ratio” is the ratio of rated power to the mass in running order.

2.3.9. "Rated engine power (Prated)" means maximum net power of the engine or motor in kW as per the requirements of UN Regulation No. 85[1].

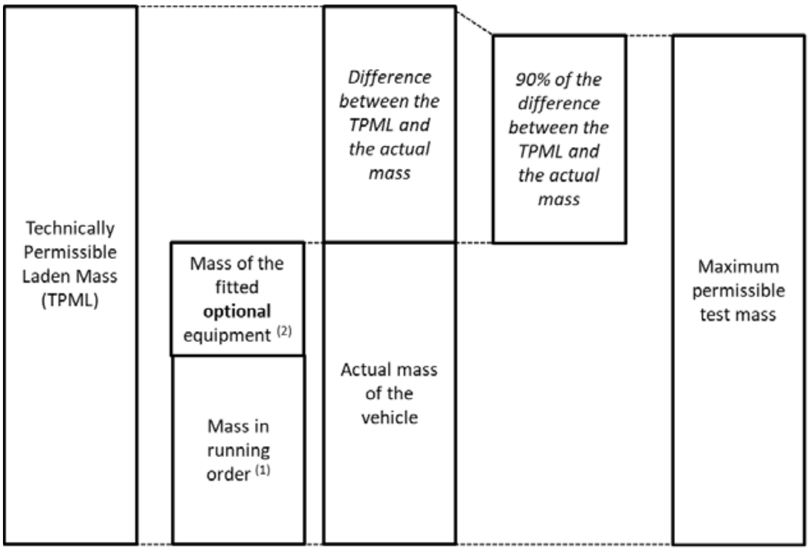
2.3.10. "Technically permissible maximum laden mass" means the maximum mass allocated to a vehicle on the basis of its construction features and its design performances.

2.3.11. "Vehicle OBD information" means information relating to an on-board diagnostic system for any electronic system on the vehicle

[1] Regulation No 85 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of internal combustion engines or electric drive trains intended for the propulsion of motor vehicles of categories M and N with regard to the measurement of net power and the maximum 30 minutes power of electric drive trains (OJ L323, 7.11.2014, p.52)

Figure 3

Mass definitions



(1) means the mass of the vehicle, with its fuel tank(s) filled to at least 90 per cent of its or their capacity/capacities, including the mass of the driver, fuel and liquids, fitted with the **standard equipment** in accordance with the manufacturer's specifications and, when they are fitted, the mass of the bodywork, the cabin, the coupling and the spare wheel(s) as well as the tools.

(2) means all the features not included in the standard equipment which are fitted to a vehicle under the responsibility of the manufacturer, and that can be ordered by the customer.

2.3.12. "Flex fuel vehicle" means a vehicle with one fuel storage system that can run on different mixtures of two or more fuels.

2.3.13. "Mono-fuel vehicle" means a vehicle that is designed to run primarily on one type of fuel.

2.3.14. "Not off-vehicle charging hybrid electric vehicle" (NOVC-HEV) means a hybrid electric vehicle that cannot be charged from an external source.

2.3.15. "Off-vehicle charging hybrid electric vehicle" (OVC-HEV) means a hybrid electric vehicle that can be charged from an external source.

2.4. For the purposes of this Annex, the following definitions shall apply in terms of Calculations

2.4.1. "Coefficient of determination" (r^2) means:

$$r^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - a_0 - (a_1 \times x_i))^2}{\sum_{i=1}^{n}(y_i - \overline{y})^2}$$

where:

a_0 is the axis intercept of the linear regression line

a_1 is the slope of the linear regression line

x_i is the measured reference value

y_i is the measured value of the parameter to be verified

$\overline{y}$ is the mean value of the parameter to be verified

n is the number of values

2.4.2. "Cross-correlation coefficient" (r) means:

$$r = \frac{\sum_{i=1}^{n-1}(x_i - \overline{x}) \times (y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n-1}(x_i - \overline{x})^2} \times \sqrt{\sum_{i=1}^{n-1}(y_i - \overline{y})^2}}$$

where:

x_i is the measured reference value

y_i is the measured value of the parameter to be verified

$\overline{x}$ is the mean reference value

$\overline{y}$ is the mean value of the parameter to be verified

n is the number of values

2.4.3. "Root mean square" (x_{rms}) means the square root of the arithmetic mean of the squares of values and defined as:

$$x_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}$$

where:

x_i is the measured or calculated value

n is the number of values

2.4.4. "Slope" of a linear regression (a_1) means:

$$a_1 = \frac{\sum_{i=1}^{n}(x_i - \overline{x}) \times (y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

where: x_i is the actual value of the reference parameter

y_i is the actual value of the parameter to be verified

$\overline{x}$ is the mean value of the reference parameter

$\overline{y}$ is the mean value of the parameter to be verified

n is the number of values

2.4.5. "Standard error of estimate" (SEE) means:

$$SEE = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \acute{y})^2}{n-2}}$$

where:

$\acute{y}$ is the estimated value of the parameter to be verified

y_i is the actual value of the parameter to be verified

n is the number of values

2.5. For the purposes of this Annex, the following definitions shall apply in terms of other items

2.5.1. "Cold start period" means the period from the test start as defined in point 2.6.5 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. In the case that measuring the coolant temperature is not feasible, on request of the manufacturer and with approval of the approval authority, instead of using the coolant temperature, the engine oil temperature may be used.

2.5.2. "Deactivated internal combustion engine" means an internal combustion engine for which one of the following criteria apply:

- the recorded engine speed is < 50 rpm;

- or when the engine speed is not recorded, the exhaust mass flow rate is measured at < 3 kg/h.

2.5.3. "Engine control unit" means the electronic unit that controls various actuators to ensure the optimal performance of the engine.

2.5.4. "Extended factor" means a factor which accounts for the effect of extended ambient temperature or altitude conditions upon pollutant emissions.

2.5.5. "Particle number emissions" (PN) means the total number of solid particles[2] *emitted from the vehicle exhaust quantified according to the dilution, sampling and measurement methods as specified in this Annex.*

2.6. For the purposes of this Annex, the following definitions shall apply in terms of Testing Procedure

2.6.1. "Cold start PEMS trip" means a trip with conditioning of the vehicle prior to the test as described in paragraph 5.3.2.

2.6.2. "Hot start PEMS trip" means a trip without conditioning of the vehicle prior to the test as described in paragraph 5.3.2, but with a warm engine with coolant temperature above 70 °C. In the case that measuring the coolant temperature is not feasible, on request of the manufacturer and with approval of the approval authority, instead of using the coolant temperature, the engine oil temperature may be used.

2.6.3. "Periodically regenerating system" means a pollutant emissions control device (e.g. catalytic converter, particulate trap) that requires a periodical regeneration

2.6.4. "Reagent" means any product other than fuel that is stored on-board the vehicle and is provided to the exhaust after-treatment system upon request of the emission control system.

2.6.5. "Test start" means (Figure 4) whichever occurs first from:

- the first activation of the internal combustion engine;

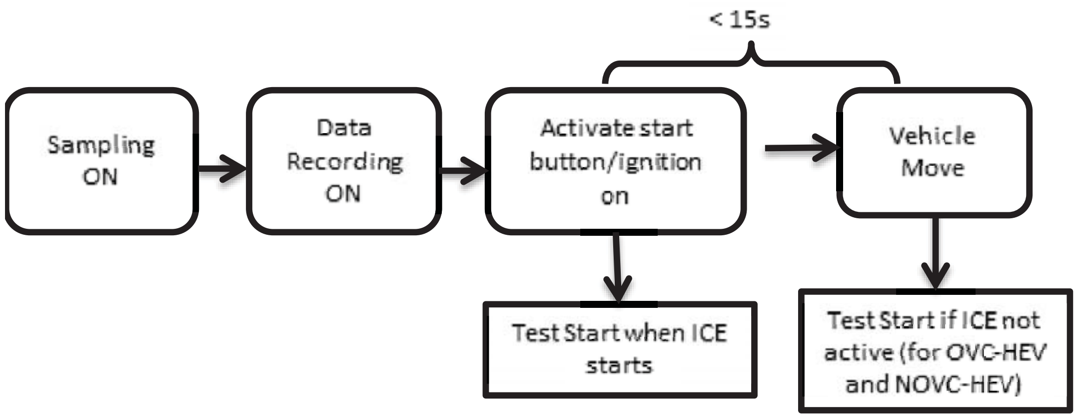
- the first movement of the vehicle with speed greater than 1 km/h for OVC-HEVs and NOVC-HEVs.

Figure 4

Test start definition

---

[2] The term *"particle"* is conventionally used for the matter being characterised (measured) in the airborne phase (suspended matter), and the term "particulate" for the deposited matter.



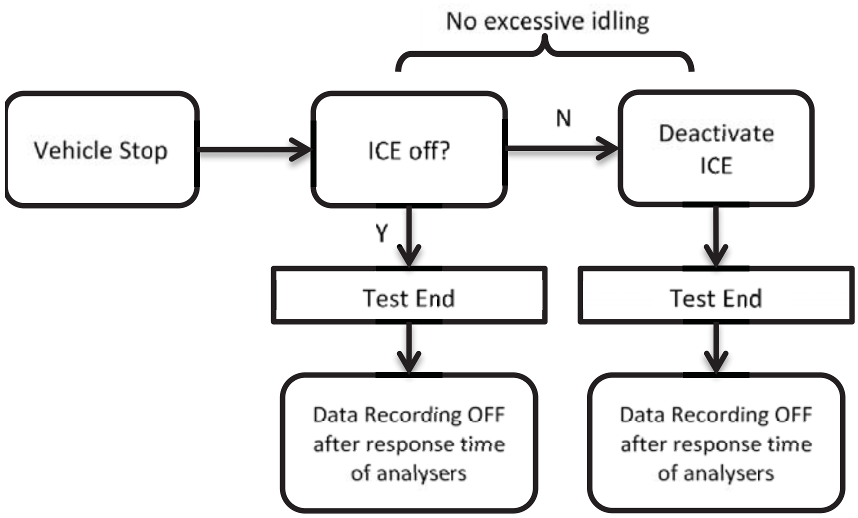
2.6.6. *"Test end" means (Figure 5) that the vehicle has completed the trip and whichever occurs last from:*

- the final deactivation of the internal combustion engine;

- the vehicle stops and the speed is lower than or equal to 1 km/h for OVC-HEVs and NOVC-HEVS finishing the test with deactivated internal combustion engine.

Figure 5

Test end definition



2.6.7. *"Validation of PEMS" means the process of evaluating on a chassis dynamometer the correct installation and functionality within the given accuracy limits of a Portable Emissions Measurement System and exhaust mass flow rate measurements as obtained from one or multiple non-traceable exhaust mass flow meters or as calculated from sensors or ECU signals.*

3. General requirements

3.1. Compliance requirements

For vehicle types approved according to this Annex, the final RDE emission results calculated according to this Annex at any possible RDE test performed in accordance with the requirements of this Annex, shall not be higher than any of the relevant Euro 6 emission limits laid down in Table 2 of Annex I to Regulation (EC) No 715/2007. The manufacturer shall confirm compliance with this Regulation by completing the RDE compliance certificate set out in Appendix 12.

The manufacturer may declare compliance with lower emission limits by declaring lower values called "Declared Maximum RDE", either for NOx or PN or both, in the Manufacturer's RDE certificate of compliance found in Appendix 12 and the Certificate of Conformity of each vehicle. These Declared Maximum RDE values shall be used for checking the compliance of cars when applicable, including for tests performed during In-service Conformity and Market Surveillance.

The RDE performance shall be demonstrated by performing the necessary tests in the PEMS test family on the road operated over their normal driving patterns, conditions and payloads. The necessary tests shall be representative for vehicles operated on their real driving routes, with their normal load. The requirements of emission limits shall be fulfilled for the urban operation and the complete PEMS trip.

The RDE tests required by this Annex provide a presumption of conformity. The presumed conformity may be reassessed by additional RDE tests. Verification of compliance shall be made in accordance with the rules of in-service conformity.

3.2. Facilitation of PEMS testing

Member States shall ensure that vehicles can be tested with PEMS on public roads in accordance with the procedures under their own national law, while respecting local road traffic legislation and safety requirements.

Manufacturers shall ensure that vehicles can be tested with PEMS. This shall include:

(a) constructing the exhaust pipes in order to facilitate sampling of the exhaust, or making available suitable adapters for exhaust pipes for testing by the authorities;

(b) in case the exhaust pipe construction does not facilitate sampling of the exhaust, the manufacturer shall also make available to independent parties, adapters for purchase or rent via their spare parts or service tools network (e.g. RMI portal), through authorised dealers or via a contact point on the referred publicly accessible website;

(c) providing guidance available online, without the need of registration or login, on how to attach a PEMS to vehicles;

(d) granting access to ECU signals relevant to this Annex, as mentioned in Table A4/1 of Appendix 4; and

(e) making the necessary administrative arrangements.

3.3. Selection of vehicles for PEMS testing

PEMS tests shall not be required for each *'vehicle type with regards to Real Driving Emissions'*. Several vehicle emission types may be put together by the vehicle manufacturer to form a '*PEMS test family*' in accordance with the requirements of paragraph 3.3.1., which shall be validated in accordance with the requirements of paragraph 3.4.

Symbols, parameters and units

N	—	Number of vehicle emission types
NT	—	Minimum number of vehicle emission types
PMR_H	—	highest power-to-mass-ratio of all vehicles in the PEMS test family
PMR_L	—	lowest power-to-mass-ratio of all vehicles in the PEMS test family
V_eng_max	—	maximum engine volume of all vehicles within the PEMS test family

3.3.1. PEMS test family building

A PEMS test family shall comprise finished vehicles of a manufacturer with similar emission characteristics. Vehicle emission types may be included in a PEMS test family only as long as the vehicles within a PEMS test family are identical with respect to the characteristics in all the administrative and technical criteria listed below.

3.3.1.1. Administrative criteria

(a) The approval authority issuing the emission type approval in accordance with this Annex ('authority')

(b) The manufacturer having received the emission type approval in accordance with this Annex ('manufacturer').

3.3.1.2. Technical criteria

(a) Propulsion type (e.g. ICE, NOVC-HEV, OVC-HEV)

(b) Type(s) of fuel(s) (e.g. petrol, diesel, LPG, NG, …). Bi- or flex-fuelled vehicles may be grouped with other vehicles, with which they have one of the fuels in common.

(c) Combustion process (e.g. two stroke, four stroke)

(d) Number of cylinders

(e) Configuration of the cylinder block (e.g. in-line, V, radial, horizontally opposed, …)

(f) Engine volume

The vehicle manufacturer shall specify a value V_eng_max (= maximum engine volume of all vehicles within the PEMS test family). The engine volumes of vehicles in the PEMS test family shall not deviate more than – 22 % from V_eng_max if V_eng_max ≥ 1500 ccm and – 32 % from V_eng_max if V_eng_max < 1500 ccm.

(g) Method of engine fuelling (e.g. indirect or direct or combined injection)

(h) Type of cooling system (e.g. air, water, oil)

(i) Method of aspiration such as naturally aspirated, pressure charged, type of pressure charger (e.g. externally driven, single or multiple turbo, variable geometries …)

(j) Types and sequence of exhaust after-treatment components (e.g. three-way catalyst, oxidation catalyst, lean NOx trap, SCR, lean NOx catalyst, particulate trap)

(k) Exhaust gas recirculation (with or without, internal/external, cooled/non-cooled, low/high pressure)

3.3.1.3. Extension of a PEMS test family

An existing PEMS test family may be extended by adding new vehicle emission types to it. The extended PEMS test family and its validation must also fulfil the requirements of paragraphs 3.3. and 3.4. This may require the PEMS testing of additional vehicles to validate the extended PEMS test family according to paragraph 3.4.

3.3.1.4. Alternative PEMS test family definition

As an alternative to the provisions of paragraph 3.3.1.1 and 3.3.1.2. the vehicle manufacturer may define a PEMS test family that is identical to a single vehicle emission type or a single WLTP IP-family. In this case, only one vehicle has to be tested from the family in either a hot or a cold test, at the choice of the authority and there is no need to validate the PEMS test family as in paragraph 3.4.

3.4. Validation of a PEMS test family

3.4.1. General requirements for validating a PEMS test family

3.4.1.1. The vehicle manufacturer shall present a representative vehicle of the PEMS test family to the authority. The vehicle shall be subject to a PEMS test carried out by a Technical Service to demonstrate compliance of the representative vehicle with the requirements of this Annex.

3.4.1.2. The authority shall select additional vehicles according to the requirements of paragraph 3.4.3. for PEMS testing carried out by a Technical Service to demonstrate compliance of the selected vehicles with the requirements of this Annex. The technical criteria for selection of an additional vehicle according to paragraph 3.4.3. shall be recorded with the test results.

3.4.1.3. With agreement of the authority, a PEMS test can also be driven by a different operator witnessed by a Technical Service, provided that at least the tests of the vehicles required by paragraphs 3.4.3.2. and 3.4.3.6. and in total at least 50 per cent of the PEMS tests required for validating the PEMS test family are driven by a Technical Service. In such case the Technical Service remains responsible for the proper execution of all PEMS tests pursuant to the requirements of this Annex.

3.4.1.4. A PEMS test result of a specific vehicle may be used for validating different PEMS test families under the following conditions:

- the vehicles included in all PEMS test families to be validated are approved by a single authority according to this Annex and this authority agrees to the use of the specific vehicle's PEMS test results for validating different PEMS test families;

- each PEMS test family to be validated includes a vehicle emission type, which comprises the specific vehicle.

3.4.2. For each validation, the applicable responsibilities are considered to be borne by the manufacturer of the vehicles in the respective family, regardless of whether this manufacturer was involved in the PEMS test of the specific vehicle emission type.

3.4.3. Selection of vehicles for PEMS testing when validating a PEMS test family

When selecting vehicles from a PEMS test family, it shall be ensured that the following technical characteristics relevant for pollutant emissions are covered by a PEMS test. A particular vehicle selected for testing can be representative for different technical characteristics. For the validation of a PEMS test family, vehicles shall be selected for PEMS testing as follows:

3.4.3.1. For each combination of fuels (e.g. petrol-LPG, petrol-NG, petrol only), on which some vehicles of the PEMS test family can operate, at least one vehicle that can operate on such combination of fuels shall be selected for PEMS testing.

3.4.3.2. The manufacturer shall specify a value PMR_H (= highest power-to- mass-ratio of all vehicles in the PEMS test family) and a value PMR_L (= lowest power-to- mass-ratio of all vehicles in the PEMS test family). At least one vehicle configuration representative for the specified PMR_H and one vehicle configuration representative for the specified PMR_L of a PEMS test family shall be selected for testing. The power-to- mass ratio of a vehicle shall not deviate by more than 5 per cent from the specified value for PMR_H, or PMR_L for the vehicle to be considered as representative for this value.

3.4.3.3. At least one vehicle for each transmission type (e.g., manual, automatic, DCT) installed in vehicles of the PEMS test family shall be selected for testing.

3.4.3.4. At least one vehicle per each configuration of driven axles shall be selected for testing if such vehicles are part of the PEMS test family.

3.4.3.5. For each engine volume associated with a vehicle in the PEMS test family at least one representative vehicle shall be tested.

3.4.3.6. At least one vehicle in the PEMS test family shall be tested in hot start testing.

3.4.3.7. Notwithstanding the provisions in paragraphs 3.4.3.1. to 3.4.3.6., at least the following number of vehicle emission types of a given PEMS test family shall be selected for testing:

Number of vehicle emission types in a PEMS test family (N)	*Minimum number of vehicle emission types selected for PEMS cold start testing (NT)*	*Minimum number of vehicle emission types selected for PEMS hot start testing*
1	1	1[2]
From 2 to 4	2	1
from 5 to 7	3	1
from 8 to 10	4	1
from 11 to 49	$NT = 3 + 0.1 \times N$[1]	2
more than 49	$NT = 0.15 \times N$[1]	3

[1] NT shall be rounded to the next higher integer number

[2] When there is only one vehicle emission type in a PEMS test family, the type approval authority shall decide whether the vehicle shall be tested in hot or cold start.

3.5. Reporting for type approval

3.5.1. The vehicle manufacturer shall provide a full description of the PEMS test family, which shall include the technical criteria described in paragraph 3.3.1.2. and submit it to the authority.

3.5.2. The manufacturer attributes a unique identification number of the format MS-OEM-X-Y to the PEMS test family and communicates it to the authority. Here MS is the distinguishing number of the Member State issuing the EC type-approval[3], OEM is the 3 character manufacturer, X is a sequential number identifying the original PEMS test family and Y is a counter for its extensions (starting with 0 for a PEMS test family not extended yet).

3.5.3. The authority and the vehicle manufacturer shall maintain a list of vehicle emission types being part of a given PEMS test family on the basis of emission type approval numbers. For each emission type all corresponding combinations of vehicle type approval numbers, types, variants and versions as defined in sections 0.10 and 0.2 of the vehicle's EC certificate of conformity shall be provided as well.

3.5.4. The authority and the vehicle manufacturer shall maintain a list of vehicle emission types selected for PEMS testing in order validate a PEMS test family in accordance with point 3.4, which also provides the necessary information on how the selection criteria of point 3.4.3 are covered. This list shall also indicate whether the provisions of point 3.4.1.3 were applied for a particular PEMS test.

3.6. Rounding requirements:

Rounding of data in the data exchange file, defined in Appendix 7, section 10, is not permitted. In the pre-processing file, the data may be rounded to the same order of magnitude of the accuracy of the measurement of a respective parameter.

The intermediate and final emission test results, as calculated in Appendix 11, shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure. Preceding steps in the calculations shall not be rounded.

4. PERFORMANCE REQUIREMENTS FOR INSTRUMENTATION

The instrumentation used for RDE tests shall comply with the requirements in Appendix 5. If requested by the authorities, the tester shall provide proof that the instrumentation used complies with the requirements in Appendix 5.

5. TEST CONDITIONS

Only an RDE test fulfilling the requirements of this Section shall be accepted as valid. Tests performed outside the test conditions specified in this Section shall be considered as invalid, unless specified otherwise.

5.1. Ambient conditions

The test shall be conducted under the ambient conditions laid down in this section. The ambient conditions become ‘extended’ when at least one of the temperature or altitude conditions is extended. The factor for extended conditions as defined in paragraph 7.5. shall only be applied once even if both conditions are extended in the same time period. Notwithstanding the opening paragraph of this section, if a part of the test or the entire test is performed outside of extended conditions, the test shall be invalid only when final emissions as calculated in Appendix 11, are greater than the applicable emission limits. The conditions are as follows:

[3] 1 for Germany; 2 for France; 3 for Italy; 4 for the Netherlands; 5 for Sweden; 6 for Belgium; 7 for Hungary; 8 for the Czech Republic; 9 for Spain; 12 for Austria; 13 for Luxembourg; 17 for Finland; 18 for Denmark; 19 for Romania; 20 for Poland; 21 for Portugal; 23 for Greece; 24 for Ireland. 25 for Croatia; 26 for Slovenia; 27 for Slovakia; 29 for Estonia; 32 for Latvia; 34 for Bulgaria; 36 for Lithuania; 49 for Cyprus; 50 for Malta

For type approvals with character EA as in Table 1, Appendix 6 of Annex I:

Moderate altitude conditions:	Altitude lower or equal to 700 meters above sea level.
Extended altitude conditions:	Altitude higher than 700 meters above sea level and lower or equal to 1300 meters above sea level.
Moderate temperature conditions:	Greater than or equal to 273.15 K (0 °C) and lower than or equal to 303.15 K (30 °C).
Extended temperature conditions:	Greater than or equal to 266.15 K (– 7 °C) and lower than 273.15 K (0 °C) or greater than 303.15 K (30 °C) and lower than or equal to 308.15 K (35 °C).

For type approvals with character EB and EC as in Table 1, Appendix 6 of Annex I:

Moderate altitude conditions:	Altitude lower or equal to 700 meters above sea level.
Extended altitude conditions:	Altitude higher than 700 meters above sea level and lower or equal to 1300 meters above sea level.
Moderate temperature conditions:	Greater than or equal to 273.15 K (0 °C) and lower than or equal to 308.15 K (35 °C).
Extended temperature conditions:	Greater than or equal to 266.15 K (– 7 °C) and lower than 273.15 K (0 °C) or greater than 308.15 K (35 °C) and lower than or equal to 311.15 K (38 °C).

5.2. Dynamic conditions of trip

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 validity of the trip for the dynamic conditions shall be checked after the test is completed, using the recorded data. This verification shall be conducted in 2 steps:

STEP i: The excess or insufficiency of driving dynamics during the trip shall be checked using the methods described in Appendix 9.

STEP ii: If the trip is valid following the verifications in accordance with STEP i, the methods for verifying the validity of the trip as laid down in Appendices 8 and 10 shall be applied.

5.3. Vehicle condition and operation

5.3.1. Vehicle condition

The vehicle, including the emission related components, shall be in good mechanical condition and shall have been run in and driven at least 3,000 km before the test. The mileage and the age of the vehicle used for RDE testing shall be recorded.

All vehicles, and in particular OVC-HEVs vehicles may be tested in any selectable mode, including battery charge mode. On the basis of technical evidence provided by the manufacturer and with the agreement of the responsible authority, the dedicated driver-selectable modes for very special limited purposes shall not be considered (e.g. maintenance mode, race driving, crawler mode). All remaining modes used for driving may be considered and the pollutant emissions limits shall be fulfilled in all these modes.

Modifications that affect the vehicle aerodynamics are not permitted, with the exception of the PEMS installation. The tyre types and pressure shall be according to the vehicle's manufacturer recommendations. The tyre pressure shall be checked prior to the pre-conditioning and adjusted to the recommended values if needed. Driving the vehicle with snow chains is not permitted.

Vehicles should not be tested with an empty starter battery. In case the vehicle has problems starting, the battery shall be replaced following the recommendations of the vehicle's manufacturer.

The vehicle's test mass comprises of the driver, a witness of the test (if applicable), the test equipment, including the mounting and the power supply devices and any artificial payload. It shall be between the actual mass of the vehicle and the maximum permissible test mass of the vehicle at the beginning of the test and shall not increase during the test.

The test vehicles shall not be driven with the intention to generate a passed or failed test due to extreme driving that do not represent normal conditions of use. If necessary, verification of normal driving may be based on expert judgement made by or on behalf of the granting type approval authority through cross-correlation on several signals, which may include exhaust flow rate, exhaust temperature, CO_2, O_2 etc. in combination with vehicle speed, acceleration and GNSS data and potentially further vehicle data parameters like engine speed, gear, accelerator pedal position etc.

5.3.2. Vehicle conditioning for cold start PEMS trip

Before RDE testing, the vehicle shall be preconditioned in the following way:

The vehicle shall be driven on public roads, preferably on the same route as the planned RDE testing or for at least 10 min per type of operation (e.g. urban, rural, motorway) or 30 minutes with a minimum average velocity of 30 km/h. The validation test in the laboratory, as in Appendix 6 of this Annex, also counts as preconditioning. The vehicle shall subsequently be parked with doors and bonnet closed and kept in engine-off status within moderate or extended altitude and temperatures, in accordance with paragraph 5.1., for between 6 and 72 hours. Exposure to extreme atmospheric conditions (such as heavy snowfall, storm, hail) and excessive amounts of dust or smoke should be avoided.

Before the test start, the vehicle and equipment shall be checked for damages and the presence of warning signals that may suggest malfunctioning. In the case of a malfunction the source of the malfunctioning shall be identified and corrected or the vehicle shall be rejected.

5.3.3. Auxiliary devices

The air conditioning system or other auxiliary devices shall be operated in a way which corresponds to their typically intended use during real driving on the road. Any use shall be documented. The vehicle windows shall be closed when the air conditioning or heating are used.

5.3.4. Vehicles equipped with periodically regenerating systems

5.3.4.1. All results shall be corrected with the K_i factors or with the K_i offsets developed by the procedures in Appendix 1 to Annex B6 of the UN Regulation No. 154[4] for type-approval of a vehicle type with a periodically regenerating system. The K_i factor or the K_i offset shall be applied to the final results after evaluation in accordance with Appendix 11.

[4] UN Regulation No. 154 – Uniform provisions concerning the approval of light duty passenger and commercial vehicles with regards to criteria emissions, emissions of carbon dioxide and fuel consumption and/or the measurement of electric energy consumption and electric range (WLTP) ([OJ L xxx, xx.xx.2022, p. xx. [to be completed by the Publications Office before adoption, as soon as OJ publication of the 02 series of amendment to UN Regulation 154 has taken place]).

5.3.4.2. If the final emissions as calculated in Appendix 11 are above the applicable emission limits, then the occurrence of regeneration shall be verified. The verification of a regeneration may be based on expert judgement through cross-correlation of several of the following signals, which may include exhaust temperature, PN, CO_2, O_2 measurements in combination with vehicle speed and acceleration. If the vehicle has a regeneration recognition feature, it shall be used to determine the occurrence of regeneration. The manufacturer may advise how to recognise whether regeneration has taken place in case such a signal is not available.

5.3.4.3. If regeneration occurred during the test, the final emission result without the application of either the K_i factor or the K_i offset shall be checked against applicable emission limits. If the final emissions are above the emission limits, then the test shall be invalid and repeated once. The completion of the regeneration and stabilisation, through approximately 1 hour of driving, shall be done prior to the start of the second test. The second test is considered valid even if regeneration occurs during it.

Even if the final emission results fall below the applicable emission limits, the occurrence of regeneration may be verified as in paragraph 5.3.4.2. If the presence of regeneration can be proved and with the agreement of the Type Approval Authority, the final results shall be calculated without the application of either the K_i factor or the Ki offset.

5.4. PEMS operational requirements

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 paragraph 6.3.

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.

The installation of the PEMS equipment shall be done in a way to minimise the influence on the vehicle's emissions or performance or both to the greatest extent possible. Care should be exercised to minimise the mass of the installed equipment and potential aerodynamic modifications of the test vehicle.

During type approval, a validation test in the laboratory shall be performed before running an RDE test according to Appendix 6. For OVC-HEV the test shall be conducted in Charge Sustaining vehicle operation.

5.5. Lubricating oil, fuel and reagent

For the test performed during type approval, the fuel used for RDE testing shall be either the reference fuel defined in Annex B3 of the UN Regulation No. 154 or within the specifications issued by the manufacturer for vehicle operation by the customer. The reagent (where applicable) and lubricant used shall be within the specifications recommended or issued by the manufacturer.

For tests performed during ISC, or Market Surveillance the fuel used for RDE testing may be any fuel legally available in the market[5] and within the specifications issued by the manufacturer for vehicle operation by the customer.

[5] See Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC, OJ L 140, 5.6.2009, p. 88.

In the case of an RDE test with a failed result, samples of fuel, lubricant and reagent (if applicable) shall be taken and kept for at least 1 year under conditions guaranteeing the integrity of the sample. Once analysed, the samples can be discarded.

6. TEST PROCEDURE

6.1. Types of speed bins

Urban speed bin is characterised by vehicle speeds lower than or equal to 60 km/h.

Rural speed bin is characterised by vehicle speeds higher than 60 km/h and lower than or equal to 90 km/h. For those vehicles that are equipped with a device permanently limiting vehicle speed to 90 km/h, rural speed bin is characterised by vehicle speed higher than 60 km/h and lower than or equal to 80 km/h.

Motorway speed bin is characterised by speeds above 90 km/h.

For those vehicles that are equipped with a device permanently limiting vehicle speed to 100 km/h, motorway speed bin is characterised by speed higher than 90 km/h.

For those vehicles that are equipped with a device permanently limiting vehicle speed to 90 km/h, motorway speed bin is characterised by speed higher than 80 km/h.

6.1.1. Other requirements

The average speed (including stops) of the urban speed bin shall be between 15 and 40 km/h.

The speed range of the motorway driving shall properly cover a range between 90 and at least 110 km/h. The vehicle's velocity shall be above 100 km/h for at least 5 minutes.

For those vehicles that are equipped with a device permanently limiting vehicle speed to 100 km/h, the speed range of the motorway speed bin shall properly cover a range between 90 and 100 km/h. The vehicle's velocity shall be above 90 km/h for at least 5 minutes.

For those vehicles that are equipped with a device limiting vehicle speed to 90 km/h, the speed range of the motorway speed bin of shall properly cover a range between 80 and 90 km/h. The vehicle's velocity shall be above 80 km/h for at least 5 minutes.

In the case that the local speed limits for the specific vehicle being tested prevent compliance with the requirements of this paragraph, the requirements of the following paragraph shall apply:

The speed range of the motorway driving shall properly cover a range between X – 10 and X km/h. The vehicle's velocity shall be above x - 10 km/h for at least 5 minutes. Where X = the local speed limit for the tested vehicle.

6.2. Required distance shares of trip speed bins

The following is the distribution of the speed bins in an RDE trip that are required for respecting the needs of evaluation: The trip shall consist of approximately 34 % per cent urban, 33 % per cent rural and 33 % per cent motorway speed bins. 'Approximately' shall mean the interval of ±10 per cent points around the stated percentages. The urban speed bin shall however never be less than 29% of the total trip distance.

The shares of urban, rural and motorway speed bins shall be expressed as a percentage of the total trip distance.

The minimum distance of each, urban, rural and motorway speed bins shall be 16 km.

6.3. RDE test to be performed

The RDE performance shall be demonstrated by testing vehicles on the road, operated over their normal driving patterns, conditions and payloads. RDE tests shall be conducted on paved roads (e.g. off-road operation is not permitted). An RDE trip shall be driven in order to prove compliance with the emission requirements.

6.3.1. The design of the trip shall be such as to comprise driving that would in principle cover all of the required shares of speed bins in paragraph 6.2 and comply with all other requirements described in paragraph 6.1.1. and 6.3, paragraph 4.5.1. of Appendix 8 and section 4. of Appendix 9.

6.3.2. The planned RDE trip shall always start with urban operation followed by rural, then motorway operation, in accordance with the required shares for speed bins in paragraph 6.2. The urban, rural and motorway operation shall be run consecutively, but may also include a trip which starts and ends at the same point. Rural operation may be interrupted by short periods of urban speed bin when driving through urban areas. Motorway operation may be interrupted by short periods of urban or rural speed bins, e.g., when passing toll stations or sections of road work.

6.3.3. The vehicle speed shall normally not exceed 145 km/h. This maximum speed may be exceeded by a tolerance of 15 km/h for not more than 3 per cent of the time duration of the motorway operation. Local speed limits remain in force during a PEMS test, notwithstanding other legal consequences. Violations of local speed limits per se do not invalidate the results of a PEMS test.

Stop periods, defined by vehicle speed of less than 1 km/h, shall account for 6-30 per cent of the time duration of urban operation. Urban operation may contain several stop periods of 10 s or longer. If stop periods in urban driving part are over 30 per cent or there are individual stop periods exceeding 300 consecutive seconds, the test shall be invalid only if the emission limits are not met.

The trip duration shall be between 90 and 120 minutes.

The start and the end points of a trip shall not differ in their elevation above sea level by more than 100 m. In addition, the proportional cumulative positive altitude gain over the entire trip and over the urban operation shall be less than 1,200 m/100 km and be determined in accordance with Appendix 10.

6.3.4. The average speed (including stops) during cold start period shall be between 15 and 40 km/h. The maximum speed during the cold start period shall not exceed 60 km/h.

At the test start, the vehicle shall move within 15 seconds. The vehicle stop periods during the entire cold start period, as defined in paragraph 2.5.1., shall be kept to the minimum possible and it shall not exceed 90 s in total.

6.4. Other trip requirements

If the engine stalls during the test, it may be restarted, but the sampling and data recording shall not be interrupted. If the engine stops during the test, the sampling and data recording shall not be interrupted.

In general, the exhaust mass flow shall be determined by measurement equipment functioning independently from the vehicle. With agreement of the authority vehicle ECU data may be used in this respect during initial type approval.

If the approval authority is not satisfied with the data quality check and validation results of a PEMS test conducted in accordance with Appendix 4, the approval authority may consider the test to be invalid. In such case, the test data and the reasons for invalidating the test shall be recorded by the approval authority.

The manufacturer shall demonstrate to the approval authority that the chosen vehicle, driving patterns, conditions and payloads are representative of the PEMS test family. The ambient conditions and payload requirements, as specified in paragraph 5.1. and paragraph 5.3.1. respectively, shall be used ex-ante to determine whether the conditions are acceptable for RDE testing.

The approval authority shall propose a test trip in urban, rural and motorway operation meeting the requirements of paragraph 6.2. If applicable, for the purpose of trip design, the urban, rural and motorway parts shall be selected based on a topographic map. If for a vehicle the collection of ECU data influences the vehicle's emissions or performance, the entire PEMS test family to which the vehicle belongs shall be considered as non-compliant.

For RDE tests performed during type approval, the type approval authority may verify if the test setup and the equipment used fulfil the requirements of Appendices 4 and 5 through a direct inspection or an analysis of the supporting evidence (e.g. photographs, records).

6.5. Compliance of software tools

Any software tool used to verify the trip validity and calculate emissions compliance with the provisions laid down in paragraphs 5 and 6 and Appendices 7, 8, 9, 10 and 11 shall be validated by an entity defined by the Member State. Where such software tool is incorporated in the PEMS instrument, proof of the validation shall be provided along with the instrument.

7. TEST DATA ANALYSIS

7.1. Emissions and trip evaluation

The test shall be conducted in accordance with Appendix 4.

7.2. The trip validity shall be assessed 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 Sections 5 and 6 and Appendix 10;

STEP B: The trip complies with the requirements set out in Appendix 9.

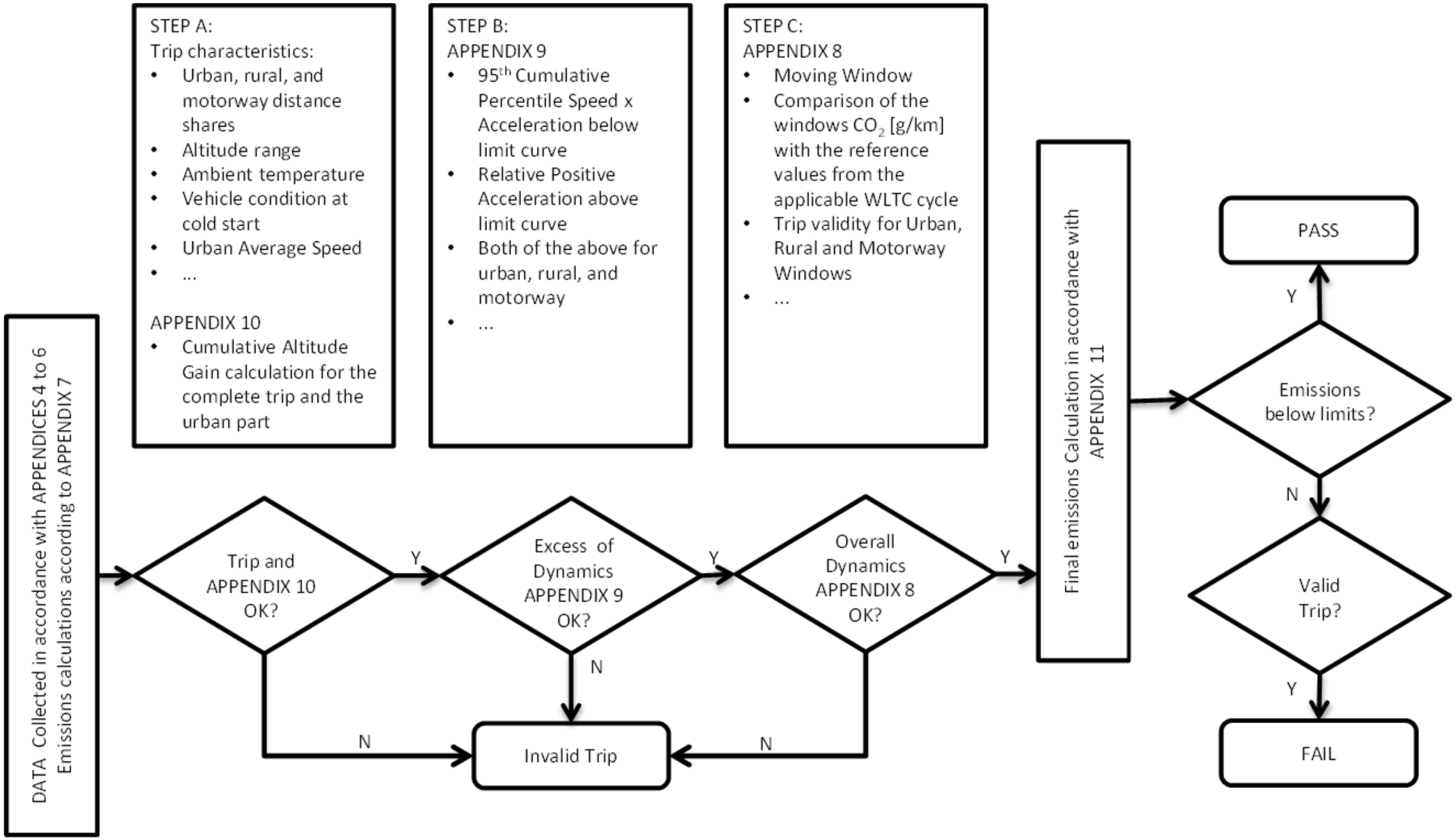
STEP C: The trip complies with the requirements set out in Appendix 8.

The steps of the procedure are detailed in Figure 6.

If at least one of the requirements is not fulfilled, the trip shall be declared invalid.

Figure 6

Assessment of trip validity – schematic (i.e. not all details are included in the steps included in the figure, see the relevant Appendices for such details)



7.3. In order to preserve data integrity, it shall not be permitted to combine data of different RDE trips in a single data set or to modify or remove data from an RDE trip, except for cases mentioned explicitly in this Annex.

7.4. Emission results shall be calculated using the methods laid down in Appendix 7 and Appendix 11. The emissions calculations shall be made between test start and test end.

7.5. The extended factor for this Annex is set at 1.6. If during a particular time interval the ambient conditions are extended, in accordance with paragraph 5.1., then the pollutant emissions calculated according to Appendix 7, during that particular time interval, shall be divided by the extended factor. This provision does not apply to carbon dioxide emissions.

7.6. Gaseous pollutant and particle number emissions during the cold start period, as defined in paragraph 2.6.1., shall be included in the normal evaluation in accordance with Appendices 7 and 11.

If the vehicle was conditioned for the last three hours prior to the test at an average temperature that falls within the extended range in accordance with paragraph 5.1., then the provisions of paragraph 7.5. apply to the data collected during the cold start period, even if the test ambient conditions are not within the extended temperature range.

7.7. Data Reporting

7.7.1. General

All data of a single RDE test shall be recorded according to the data exchange and data reporting files provided by the Commission[6].

7.7.2. Reporting and dissemination of RDE type approval test information

7.7.2.1. A technical report prepared by the manufacturer shall be made available to the approval authority. The technical report is composed of 4 items:

(i) the Data Exchange file

(ii) the Reporting file

(iii) the Vehicle and engine description as described in Appendix 4 of Annex I of Regulation 2017/1151;

(iv) visual supporting material (photographs and/or videos) of the PEMS installation in the tested vehicle of adequate quality and quantity to identify the vehicle and to assess if the installation of the PEMS main unit, the EFM, the GNSS antenna, and the weather station follow the instrument manufacturers recommendations and the general good practices of PEMS testing.

7.7.2.2. The manufacturer shall ensure that the information listed in point 7.7.2.2.1. is made available on a publicly accessible website without costs and without the need for the user to reveal his identity or sign up. The manufacturer shall keep the Commission and Type Approval Authorities informed on the location of the website.

7.7.2.2.1. The website shall allow a wildcard search of the underlying database based on one or more of the following:

6 To be found in CIRCABC link…..xxxxx

Make, Type, Variant, Version, Commercial name, or Type Approval Number as referred to in the certificate of conformity, pursuant to Annex IX to Directive 2007/46/EC or Annex VIII to Commission Implementing Regulation (EU) 2020/683.

The information described below shall be made available for each vehicle in a search:

– The PEMS family ID to which that vehicle belongs, in accordance with the Transparency List 2 set out in Table 1 of Appendix 5 to Annex II;

– The Declared Maximum RDE Values as reported in point 48.2 of the Certificate of Conformity, as described in Annex VIII to Commission Implementing Regulation (EU) 2020/683 .

7.7.2.3. Upon request, without costs and within 10 days, the manufacturer shall make available the technical report referred to in point 7.7.2.1 to any third party and the Commission. The manufacturer shall also make available the technical report referred to in point 7.7.2.1 upon request and with a reasonable and proportionate fee to others, which does not discourage an inquirer with a justified interest from requesting the respective information or exceed the internal costs of the manufacturer for making the requested information available.

Upon request, the type approval authority shall make available the information listed under points 7.7.2.1 and 7.7.2.2 without costs and within 10 days of receiving the request to any third party or the Commission. The type approval authority shall also make available to others upon request the information listed under points 7.7.2.1 and 7.7.2.2 with a reasonable and proportionate fee, which does not discourage an inquirer with a justified interest from requesting the respective information or exceed the internal costs of the authority for making the requested information available.

Appendix 1 - Reserved

Appendix 2 - Reserved

Appendix 3 - Reserved

Appendix 4 - Test procedure for vehicle emissions testing with a portable emissions measurement system (PEMS)

Test procedure for vehicle emissions testing with a portable emissions measurement system (PEMS)

1. Introduction

This appendix describes the test procedure to determine pollutant emissions from passenger and light commercial vehicles using a Portable Emissions Measurement System.

2. Symbols, Parameters and Units

p_e	—	evacuated pressure [kPa]
q_{vs}	—	volume flow rate of the system [l/min]
$ppmC_1$	—	parts per million carbon equivalent
V_s	—	system volume [l]

3. General requirements

3.1. PEMS

The test shall be carried out with a PEMS, composed of components specified in paragraphs 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 paragraph 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 GNSS receiver to determine the position, altitude and, 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 and air pressure.

3.1.5. An energy source independent of the vehicle to power the PEMS.

3.2. Test parameters

Test parameters, as specified in Table A4/1, shall be measured at a constant frequency of 1.0 Hz or higher and recorded and reported in accordance with the requirements of paragraph 10. of Appendix 7 at a sampling frequency of 1.0 Hz. If ECU parameters are obtained, 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 5 and 6.

Table A4/1

Test parameters

Parameter	*Recommended unit*	*Source*[7]
THC concentration[8,9] (if applicable)	ppm C_1	Analyser
CH_4 concentration[7,8,9] (if applicable)	ppm C_1	Analyser
NMHC concentration[7,8,9] (if applicable)	ppm C_1	Analyser[10]
CO concentration[7,8,9]	ppm	Analyser
CO_2 concentration[8]	ppm	Analyser
NO_X concentration[8,9]	ppm	Analyser[11]
PN concentration[9]	#/m^3	Analyser
Exhaust mass flow rate	kg/s	EFM, any methods described in paragraph 7. of Appendix 5.
Ambient humidity	%	Sensor
Ambient temperature	K	Sensor
Ambient pressure	kPa	Sensor
Vehicle speed	km/h	Sensor, GNSS, or ECU[12]
Vehicle latitude	Degree	GNSS
Vehicle longitude	Degree	GNSS
Vehicle altitude[13,14]	m	GNSS or Sensor

7 Multiple parameter sources may be used.
8 to be measured on a wet basis or to be corrected as described in paragraph 5.1. of Appendix 7
9 parameter only mandatory if measurement required for compliance with the limits
10 may be calculated from THC and CH_4 concentrations according to paragraph 6.2. to Appendix 7.
11 may be calculated from measured NO and NO_2 concentrations.
12 method to be chosen according to paragraph 4.7. of this Appendix.
13 to be determined only if necessary to verify the vehicle status and operating conditions.
14 The preferable source is the ambient pressure sensor.

Parameter	*Recommended unit*	*Source*[7]
Exhaust gas temperature[13]	K	Sensor
Engine coolant temperature[13]	K	Sensor or ECU
Engine speed[13]	RPM	Sensor or ECU
Engine torque[13]	Nm	Sensor or ECU
Torque at driven axle[13] (if applicable)	Nm	Rim torque meter
Pedal position[13]	%	Sensor or ECU
Engine fuel flow[15] (if applicable)	g/s	Sensor or ECU
Engine intake air flow[15] (if applicable)	g/s	Sensor or ECU
Fault status[13]	—	ECU
Intake air flow temperature	K	Sensor or ECU
Regeneration status[13] (if applicable)	—	ECU
Engine oil temperature[13]	K	Sensor or ECU
Actual gear[13]	#	ECU
Desired gear (e.g. gear shift indicator) [13]	#	ECU
Other vehicle data[13]	unspecified	ECU

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. When the PEMS is installed inside the vehicle, the vehicle should be equipped with gas monitors or warning systems for hazardous gases (e.g. CO). The PEMS should be installed as to minimise electromagnetic interferences during the test as well as exposure to shocks, vibration, dust and variability in temperature. The installation and operation of the PEMS shall be such that it avoids leakage and minimise heat loss. The installation and operation of PEMS shall not change the nature of the

[15] to be determined only if indirect methods are used to calculate exhaust mass flow rate as described in paragraphs 7.2. and 7.4. of Appendix 7.

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 to avoid the 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. If the test performed with the use of elastomer connectors fails, the test shall be repeated without the use of elastomer connectors.

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 so that the maximum expected flow rate during the test reaches at least 75 per cent of the EFM full range but does not exceed 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 cross-sectional area of multiple outlets, providing it improves measurement accuracy and does not adversely affect the operation or the exhaust after-treatment as specified in paragraph 3.4.2. It is recommended to document the EFM set-up using photographs.

3.4.4. Global Positioning System (GNSS)

The GNSS antenna shall be mounted as near as possible to the highest location on the vehicle, so as to ensure good reception of the satellite signal. The mounted GNSS 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 A4/1 can be recorded by using a data logger connected with the ECU or the vehicle network through national or international 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 devices

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 gas exits the PEMS sampling installation into the environment.

If the PEMS feeds part of the sample back to the exhaust flow, this shall occur downstream of the sampling probe in a manner that does not affect 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 vehicle is equipped with more than one tailpipe then all functioning tailpipes shall be connected before sampling and measuring exhaust flow.

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 pollutant 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. 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 particles are measured, they shall be sampled from the centre of the exhaust stream. If several probes are used for emissions sampling, the particle sampling probe should be placed upstream of the other sampling probes. The particle sampling probe should not interfere with the sampling of gaseous pollutants. The type and specifications of the probe and its mounting shall be documented in detail (e.g. L type or 45° cut, internal diameter, with or without hat, etc).

If hydrocarbons are measured, the sampling line shall be heated to 463 ± 10 K (190 ± 10 °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 °C) to avoid condensation and to ensure appropriate penetration efficiencies of the various gases. For low pressure sampling systems, the temperature can be lowered correspondingly to the pressure decrease provided that the sampling system ensures a penetration efficiency of 95 per cent 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 °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 tailpipe 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. If this is not the case the sampling lines shall be checked and the fault shall 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:

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

where:

p_e is the evacuated pressure [Pa],

V_s is the system volume [l],

q_{vs} is the volume flow rate of the system [l/min].

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 normal 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 in accordance with 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 paragraph 5. of Appendix 5. The calibration gases shall be chosen to match the range of pollutant concentrations expected during the RDE test. To minimise analyser drift, it is recommended to 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, ideally 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 sensor (e.g., optical or micro-wave sensor); if vehicle speed is determined by a sensor, the speed measurements shall comply with the requirements of paragraph 8. of Appendix 5, 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 per cent from the reference distance.

(b) the ECU; if vehicle speed is determined by the ECU, the total trip distance shall be validated according to paragraph 3. of Appendix 6 and the ECU speed signal adjusted, if necessary, to fulfil the requirements of paragraph 3. of Appendix 6. 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 per cent from the reference distance.

(c) a GNSS; if vehicle speed is determined by a GNSS, the total trip distance shall be checked against the measurements of another method according to paragraph 6.5. of Appendix 4.

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. Emissions test

5.1. Test start

Sampling, measurement and recording of parameters shall begin prior to the test start (as defined in point 2.6.5. of this Annex). 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.

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. Repeated stalling of the engine (i.e. unintentional stopping of the engine) should be avoided during an RDE trip. Any warning signals, suggesting malfunctioning of the PEMS, shall be documented and verified. If any error signal(s) appear during the test, the test shall be invalid. Parameter recording shall reach a data completeness of higher than 99 per cent. Measurement and data recording may be interrupted for less than 1 per cent 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 but 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. It is strongly recommended to initiate PEMS system maintenance during periods of zero vehicle speed.

5.3. Test end

Excessive idling of the engine after the completion of the trip shall be avoided. The data recording shall continue after the test end (as defined in paragraph 2.6.6. of this Annex) and until the response time of the sampling systems has elapsed. For vehicles with a signal detecting regeneration, the OBD-check shall be performed and documented directly after data recording and before any further driven distance is driven.

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 paragraph 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 A4/2.

Table A4/2

Permissible analyser drift over a PEMS test

Pollutant	*Absolute Zero response drift*	*Absolute Span response drift*[16]
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	⩽ 3 ppm per test	⩽ 2 % of reading or ⩽ 3 ppm per test, whichever is larger
CH_4	⩽ 10 ppm C_1 per test	⩽ 2 % of reading or ⩽ 10 ppm C_1 per test, whichever is larger
THC	≤ 10 ppm C_1 per test	≤ 2 % of reading or ≤ 10 ppm C_1 per test, whichever is larger

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 invalid 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 paragraph 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 per cent of the concentration values obtained from 99 per cent of the measurements of the valid parts of the emissions test. It is permissible that 1 per cent of the total number of measurements used for evaluation exceeds the concentration of the span gas used by up to a factor of two. If these requirements are not met, the test shall be invalid.

6.4. Consistency check of vehicle altitude

In case altitude has only been measured with a GNSS, the GNSS 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 GNSS 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

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

manually corrected. The original and uncorrected data shall be retained and any corrected data shall be marked.

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:

$$\left|h_{GNSS}(t) - h_{map}(t)\right| > 40\ m$$

The altitude correction shall be applied so that:

$$\left|h(t) - h_{map}(t)\right| < 40\ m$$

where:

h(t)	—	vehicle altitude after the screening and principle check of data quality at data point t [m above sea level]
$h_{GNSS}(t)$	—	vehicle altitude measured with GNSS 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]

6.5. Consistency check of GNSS vehicle speed

The vehicle speed as determined by the GNSS 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 GNSS data for obvious errors, e.g., by applying a dead reckoning sensor, prior to the consistency check. The original and uncorrected data 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 GNSS data shall deviate by no more than 4 per cent from the reference. If the GNSS data do not meet these requirements and no other reliable speed source is available, the test shall be invalid.

6.6. Consistency check of the ambient temperature

The ambient temperature data shall be checked for consistency and inconsistent values corrected by substituting outliers with the average of the neighbouring values. The original and uncorrected data shall be retained and any corrected data shall be marked.

Appendix 5 - **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

A	—	undiluted CO_2 concentration [%]
a_0	—	y-axis intercept of the linear regression line
a_1	—	slope of the linear regression line
B	—	diluted CO_2 concentration [%]
C	—	diluted NO concentration [ppm]
c	—	analyser response in the oxygen interference test
C_b		Measured diluted NO concentration through bubbler
$c_{FS,b}$	—	full scale HC concentration in step (b) [$ppmC_1$]
$c_{FS,d}$	—	full scale HC concentration in step (d) [$ppmC_1$]
$c_{HC(w/NMC)}$	—	HC concentration with CH_4 or C_2H_6 flowing through the NMC [$ppmC_1$]
$c_{HC(w/o NMC)}$	—	HC concentration with CH_4 or C_2H_6 bypassing the NMC [$ppmC_1$]
$c_{m,b}$	—	measured HC concentration in step (b) [$ppmC_1$]
$c_{m,d}$	—	measured HC concentration in step (d) [$ppmC_1$]
$c_{ref,b}$	—	reference HC concentration in step (b) [$ppmC_1$]
$c_{ref,d}$	—	reference HC concentration in step (d) [$ppmC_1$]
D	—	undiluted NO concentration [ppm]
D_e	—	expected diluted NO concentration [ppm]
E	—	absolute operating pressure [kPa]
E_{CO2}	—	per cent CO_2 quench
$E(d_p)$	—	PEMS-PN analyser efficiency
E_E	—	ethane efficiency
E_{H2O}	—	per cent water quench
E_M	—	methane efficiency
E_{O2}	—	oxygen interference
F	—	water temperature [K]
G	—	saturation vapour pressure [kPa]
H	—	water vapour concentration [%]
H_m	—	maximum water vapour concentration [%]
$NO_{X,dry}$	—	moisture-corrected mean concentration of the stabilized NO_X recordings

$NO_{X,m}$	—	mean concentration of the stabilized NO_X recordings
$NO_{X,ref}$	—	reference mean concentration of the stabilized NO_X recordings
r^2	—	coefficient of determination
t_0	—	time point of gas flow switching [s]
t_{10}	—	time point of 10 % response of the final reading
t_{50}	—	time point of 50 % response of the final reading
t_{90}	—	time point of 90 % response of the final reading
Tbd	—	to be determined
X	—	independent variable or reference value
x_{min}	—	minimum value
Y	—	dependent variable or measured value

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 A5/1. 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 A5/1.

Table A5/1

Linearity requirements of measurement parameters and systems

Measurement parameter/instrument	$\lvert x_{min} \times (a_1 - 1) + a_0 \rvert$	Slope a_1	Standard error of the estimate *SEE*	Coefficient of determination r^2
Fuel flow rate[17]	≤ 1 % x_{max}	0.98 – 1.02	≤ 2 % of x_{max}	≥ 0.990
Air flow rate[15]	≤ 1 % x_{max}	0.98 – 1.02	≤ 2 % of x_{max}	≥ 0.990

[17] optional to determine exhaust mass flow.

Exhaust mass flow rate	⩽ 2 % x_{max}	0.97 – 1.03	⩽ 3 % of x_{max}	⩾ 0.990
Gas analysers	⩽ 0.5 % max	0.99 – 1.01	⩽ 1 % of x_{max}	⩾ 0.998
Torque[18]	≤ 1 % x_{max}	0.98 – 1.02	≤ 2 % of x_{max}	≥ 0.990
PN analysers[19]	≤ 5 % x_{max}	0.85 – 1.15[20]	≤ 10 % of x_{max}	≥ 0.950

3.3. Frequency of linearity verification

The linearity requirements pursuant to paragraph 3.2. shall be verified:

(a) for each gas analyser at least every 12 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 PN analysers, exhaust mass flow meters and traceably calibrated sensors, whenever damage is observed, as required by internal audit procedures or by the instrument manufacturer but no longer than one year before the actual test.

The linearity requirements pursuant to paragraph 3.2. for sensors or ECU signals that are not directly traceable shall be performed using a measurement device with a traceable calibration 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 normal 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 normal 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

18 optional parameter.

19 The linearity check shall be verified with soot-like particles, as these are defined in paragraph 6.2. of this appendix.

20 To be updated based on error propagation and traceability charts.

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 per cent of the maximum calibration value can be excluded from the linearity verification.

(e) For gas analysers, known gas concentrations in accordance with paragraph 5. shall be introduced to the analyser port. Sufficient time for signal stabilisation shall be given. For particle number analysers, the particle number concentrations shall be at least two times the limit of detection (defined in point 6.2).

(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 (60 s for particle number analysers).

(g) The arithmetic mean values over the 30 (or 60 s) seconds period shall be used to calculate the least squares linear regression parameters, with the best-fit equation having the form:

$$y = a_1 x + a_0$$

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 A5/1.

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 UN Regulation No. 154. If necessary, the instrument or sensor to be calibrated shall be installed on the test vehicle and operated according to the requirements of Appendix 4. The calibration procedure shall follow whenever possible the requirements of paragraph 3.4.2.. At least 10 appropriate reference values shall be selected as to ensure that at least 90 per cent of the maximum value expected to occur during the RDE test is covered.

If a non-traceable flow-measuring instrument, sensor or ECU signal for determining exhaust flow is to be calibrated, a reference exhaust mass flow meter with traceable calibration 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 paragraph 3.4.3. of Appendix 4. 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 paragraph 4.1.4., Annex B5 to UN Regulation No. 154. If an NDUV analyser measures both NO and NO_2, a NO_2/NO converter is not required.

4.1.2. *Alternative analysers*

Any analyser not meeting the design specifications of paragraph 4.1.1. is permissible provided that it fulfils the requirements of paragraph 4.2. The manufacturer 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 RDE testing as specified in paragraphs 5., 6. and 7. of this Appendix. 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 paragraph 4.1.1. over the expected range of pollutant concentrations and ambient conditions of the type-approval test defined in UN Regulation No. 154 as well as a validation test as described in paragraph 3. of Appendix 6 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 paragraph 3.3. of Appendix 6.

(c) a demonstration of equivalency with the respective standard analyser specified in paragraph 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 paragraph 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 paragraph 4.1.1. over at least three on-road tests that fulfil the requirements of this Appendix.

(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 paragraph 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 paragraph 3., the compliance of analyser types with the specifications laid down in paragraphs 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 per cent of reading or 0.3 per cent 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 per cent of the full scale concentration for a measurement range equal or above 155 ppm (or $ppmC_1$) and 2 per cent of the full scale concentration for a measurement range of below 155 ppm (or $ppmC_1$).

4.2.4. Noise

The noise shall not exceed 2 per cent 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 A5/2.

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 A5/2.

Table A5/2

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	$\leqslant$ 1000 ppm over 4 h	$\leqslant$ 2 % of reading or $\leqslant$ 1000 ppm over 4 h, whichever is larger

Pollutant	*Absolute Zero response drift*	*Absolute Span response drift*
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 4 h	According to manufacturer specifications
NO_X	⩽ 3 ppm over 4 h	⩽ 2 % of reading or 3ppm over 4 h, whichever is larger
CH_4	⩽ 10 ppm C_1	⩽ 2 % of reading or ⩽ 10 ppm C_1 over 4 h, whichever is larger
THC	⩽ 10 ppm C_1	⩽ 2 % of reading or ⩽ 10 ppm C_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_{10} to t_{90}; see paragraph 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 paragraphs 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 RDE emission measurements.

4.3.2. Efficiency test for NO_X converters

If a NO_X converter is applied, for example to convert NO_2 into NO for analysis with a chemiluminescence analyser, its efficiency shall be tested by following the requirements in paragraph 5.5. of Annex B5 to UN Regulation No. 154. The efficiency of the NO_X converter shall be verified no longer than one month before the emissions 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 as specified by the instrument manufacturer. 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 paragraph 5.4.3. of Annex B5 to UN Regulation No. 154, 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 paragraph 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_{O2} [%] shall be calculated for each oxygen interference check gas in step (iv) as follows:

$$E_{O2} = \frac{(c_{ref,d} - c)}{c_{ref,d}} \times 100$$

where the analyser response is:

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

where:

$c_{ref,b}$		is the reference HC concentration in

		step (ii) [ppmC$_1$]
$c_{\text{ref,d}}$		is the reference HC concentration in step (iv) [ppmC$_1$]
$c_{\text{FS,b}}$		is the full scale HC concentration in step (ii) [ppmC$_1$]
$c_{\text{FS,d}}$		is the full scale HC concentration in step (iv) [ppmC$_1$]
$c_{\text{m,b}}$		is the measured HC concentration in step (ii) [ppmC$_1$]
$c_{\text{m,d}}$		is the measured HC concentration in step (iv) [ppmC$_1$]

(vii) The oxygen interference E_{O2} shall be less than ±1.5 per cent for all required oxygen interference check gases.

(viii) If the oxygen interference E_{O2} 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 paragraph 6.2. of Appendix 7). It is not necessary to determine the methane conversion efficiency in the case where the NMC-FID is calibrated according to method (b) in paragraph 6.2. of Appendix 7 by passing the methane/air calibration gas through the NMC.

(a) Methane conversion efficiency

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

$$E_M = 1 - \frac{c_{HC(w/NMC)}}{c_{HC(w/o\ NMC)}}$$

where:

$c_{HC(w/NMC)}$		is the HC concentration with CH_4 flowing through the NMC [$ppmC_1$]
$c_{HC(w/o\ NMC)}$		is the HC concentration with CH_4 bypassing the NMC [$ppmC_1$]

(b) Ethane conversion efficiency

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

$$E_E = 1 - \frac{c_{HC(w/NMC)}}{c_{HC(w/o\ NMC)}}$$

where:

$c_{HC(w/NMC)}$		is the HC concentration with C_2H_6 flowing through the NMC [$ppmC_1$]
$c_{HC(w/o\ NMC)}$		is the HC concentration with C_2H_6 bypassing the NMC [$ppmC_1$]

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 paragraphs 4.3.5. (b) to (f).

(b) CO analyser interference check

Water and CO_2 can interfere with the measurements of the CO analyser. Therefore, a CO_2 span gas, having a concentration of 80 to 100 per cent of the full scale of the maximum operating range of the CO_2 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 normal on-road testing or ± 50 ppm, whichever is larger. The interference check for H_2O and CO_2 may be run as separate procedures. If the H_2O and CO_2 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 H_2O that are lower than the maximum concentration expected during the test may be run and the observed H_2O interference shall be scaled up by multiplying the observed interference with the ratio of the maximum H_2O 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 CO_2 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 H_2O or CO_2 measurement analysers or both, quench shall be evaluated with these analysers active and with the compensation algorithms applied.

(i) CO_2 quench check

A CO_2 span gas having a concentration of 80 to 100 per cent of the maximum operating range shall be passed through the NDIR analyser; the CO_2 value shall be recorded as A. The CO_2 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 CO_2 and NO values shall be recorded as B and C, respectively. The CO_2 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:

$$E_{CO2} = \left[1 - \left(\frac{C \times A}{(D \times A) - (D \times B)}\right)\right] \times 100$$

where:

A		is the undiluted CO_2 concentration measured with the NDIR [%]
B		is the diluted CO_2 concentration measured with

EN EN

		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 CO_2 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 normal 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_b. 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 CO_2 concentration in the exhaust gas A as follows:

$$H_m = 0.9 \times A$$

The per cent water quench shall be calculated as:

$$E_{H2O} = \left(\frac{D_e - C_b}{D_e}\right) \times \left(\frac{H_m}{H}\right) \times 100$$

where:

D_e		is the expected diluted NO concentration [ppm]
C_b		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 CO_2 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 NO_2 calibration gas shall be selected that matches as far as possible the maximum NO_2 concentration expected during emissions testing.

(iv) The NO_2 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 NO_2 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 (vi), the sampling system shall again be overflown by the NO_2 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 H_2O), 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 NO_2 penetration

Liquid water remaining in an improperly designed sample dryer can remove NO_2 from the sample. If a sample dryer is used in combination with a NDUV analyser without an NO_2/NO converter upstream, water could therefore remove NO_2 from the sample prior to the NO_X measurement. The sample dryer shall allow for measuring at least 95 per cent of the

NO_2 contained in a gas that is saturated with water vapour and consists of the maximum NO_2 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.

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 RDE tests

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 Annex B5 of UN Regulation No. 154.

5.1.2. NO_2 calibration gas

In addition, NO_2 calibration gas is permissible. The concentration of the NO_2 calibration gas shall be within two per cent of the declared concentration value. The amount of NO contained in the NO_2 calibration gas shall not exceed 5 per cent of the NO_2 content.

5.1.3. Multicomponent mixtures

Only multicomponent mixtures which fulfil the requirements of paragraph 5.1.1. shall be used. These mixtures may contain two or more of the components. Multicomponent mixtures containing both NO and NO_2 are exempted of the NO_2 impurity requirement set out in paragraphs 5.1.1. and 5.1.2.

5.2. Gas dividers

Gas dividers (i.e., precision blending devices that dilute with purified N_2 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 $ppmC_1$. 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 A5/3; the remainder of the oxygen interference check gas shall consist of purified nitrogen.

Table A5/3

Oxygen interference check gases

	Engine type	
	Compression ignition	*Positive ignition*
O_2 concentration	21 ± 1 %	10 ± 1 %
	10 ± 1 %	5 ± 1 %
	5 ± 1 %	0.5 ± 0.5 %

6. Analysers for measuring (solid) particle emissions

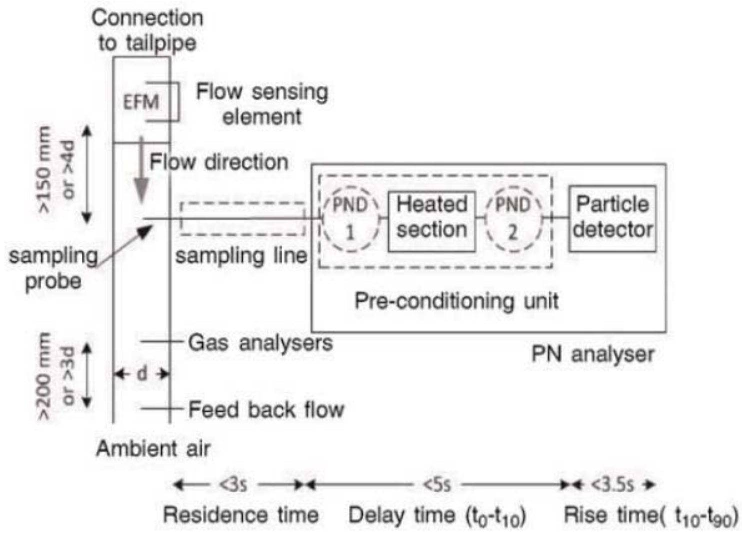
This section will define future requirement for analysers for measuring particle number emissions, once their measurement becomes mandatory.

6.1. General

The PN analyser shall consist of a pre-conditioning unit and a particle detector that counts with 50 per cent 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. An example of a PN analyser setup is provided in Figure A5/1.

Figure A5/1

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 paragraph 3.5. of Appendix 4, 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 for example 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 ≥ 573 K. The unit shall control the heated stages to constant nominal operating temperatures, within a tolerance of ± 10 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 paragraph 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 ≤ 5 s.

The PN analyser (and/or particle detector) shall have a rise time of ≤ 3.5 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 UN Regulation No. 154 automatically comply with the calibration requirements of this appendix.

6.2. Efficiency requirements

The complete PN analyser system including the sampling line shall fulfil the efficiency requirements of Table A5/3a.

Table A5/3a

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 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 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 shall 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 shall 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 the PN analyser and the sampling line together fulfil the requirements of Table A5/3a. 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 paragraph 3.2. of Appendix 5 using monodisperse or polydisperse soot-like particles. The particle size (mobility diameter or count median diameter) shall be larger than 45 nm. The reference instrument shall be an Electrometer or a Condensation Particle Counter (CPC) with d_{50} = 10 nm or lower, verified for linearity. Alternatively, a particle number system compliant with UN Regulation No. 154.

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 >90% of the PN analyser nominal measurement range.

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 shall be considered in the slope calculation.

6.4. Volatile removal efficiency

The system shall achieve > 99 % removal of ≥ 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles with an inlet concentration of ≥ 10000 particles per cubic-centimetre at the minimum dilution.

The system shall also achieve a > 99 % removal efficiency of tetracontane with count median diameter > 50 nm and mass > 1 mg/m^3.

The volatile removal efficiency with tetracontane shall be proven only once for the instrument family. The instrument manufacturer though shall 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 shall be checked yearly for each instrument.

7. Instruments for measuring exhaust mass flow

7.1. General

Instruments 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 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 eliminate 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 paragraph 3. Furthermore, the instrument manufacturer shall demonstrate the compliance of each type of exhaust mass flow meter with the specifications in paragraphs 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 sensors with traceable calibration if these fulfil the linearity requirements of paragraph 3., the accuracy requirements of paragraph 8. and if the resulting exhaust mass flow rate is validated according to paragraph 4. of Appendix 6.

In addition, other methods that determine the exhaust mass flow rate based on non-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 paragraph 3. and is validated according to paragraph 4. of Appendix 6.

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 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 paragraphs 7.2.3. to 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, or 0.3 % of full scale, 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 paragraph 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 in less than 0.1 second is highly recommended. 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_{10} to t_{90}) 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 $\leq$ 3 seconds with a rise time (t_{10} to t_{90}) of $\leq$ 1 second in accordance with paragraph 7.2.8.

8. Sensors and auxiliary equipment

Any sensor or auxiliary equipment used to determine temperature, atmospheric pressure, ambient humidity, vehicle speed, fuel flow or intake air flow, for example, 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 A5/4. Compliance with the requirements of Table A5/4 shall be demonstrated at intervals specified by the instrument manufacturer, as required by internal audit procedures or in accordance with ISO 9000.

Table A5/4

Accuracy requirements for measurement parameters

Measurement parameter	Accuracy
Fuel flow[21]	± 1 % of reading[22]
Air flow[23]	± 2 % of reading
Vehicle speed[24]	± 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_2O/kg dry air, whichever is larger

21 optional to determine exhaust mass flow

22 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 paragraph 7 of Appendix 7.

23 optional to determine exhaust mass flow.

24 This requirement applies to the speed sensor only; if vehicle speed is used to determine parameters like acceleration, the product of speed and positive acceleration, or RPA, the 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 a wheel rotational speed signal.

Appendix 6 - 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

a_0	—	y intercept of the regression line
a_1	—	slope of the regression line
r^2	—	coefficient of determination
x	—	actual value of the reference signal
y	—	actual value of the signal under validation

3. Validation procedure for PEMS

3.1. Frequency of PEMS validation

It is recommended to validate the correct installation of a PEMS on a vehicle via comparison with laboratory installed equipment on a test performed on a chassis dynamometer either before the RDE test or, alternatively, after the completion of the test. For tests performed during type approval, the validation test is required.

3.2. PEMS validation procedure

3.2.1. PEMS installation

The PEMS shall be installed and prepared according to the requirements of Appendix 4. The PEMS installation shall be kept unchanged in the time period between the validation and the RDE test.

3.2.2. Test conditions

The validation test shall be conducted on a chassis dynamometer, as far as possible, under type approval conditions by following the requirements of UN Regulation No. 154. It is recommended to feed the exhaust flow extracted by the PEMS during the validation test back to the CVS. If this is not feasible, 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 with UN Regulation No. 154. The emissions as measured with the PEMS shall be calculated according to Appendix 7, summed to give the total mass of pollutants [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 paragraph 3.3. For the validation of NO_X emission measurements, humidity correction shall be applied in accordance with UN Regulation No. 154.

3.3. Permissible tolerances for PEMS validation

The PEMS validation results shall fulfil the requirements given in Table A6/1. If any permissible tolerance is not met, corrective action shall be taken and the PEMS validation shall be repeated.

Table A6/1

Permissible tolerances

Parameter [Unit]	Permissible absolute tolerance
Distance [km][25]	250 m of the laboratory reference
THC[26] [mg/km]	15 mg/km or 15 % of the laboratory reference, whichever is larger
CH_4[26] [mg/km]	15 mg/km or 15 % of the laboratory reference, whichever is larger
NMHC[26] [mg/km]	20 mg/km or 20 % of the laboratory reference, whichever is larger
PN[26] [#/km]	$8 \cdot 10^{10}$ p/km or 42 % of the laboratory reference[27] whichever is larger
CO[26] [mg/km]	100 mg/km or 15 % of the laboratory reference, whichever is larger
CO_2 [g/km]	10 g/km or 7.5 % of the laboratory reference,

25 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.

26 parameter only mandatory if measurement required for compliance with the limits.

27 PMP system.

	whichever is larger
NO_x[26] [mg/km]	10 mg/km or 12.5 % of the laboratory reference, whichever is larger

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 paragraph 3. of Appendix 5 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 on the same vehicle used for the RDE test. As reference, a flow meter with traceable calibration shall be used. The ambient temperature can be any within the range specified in paragraph 5.1. of this Annex. The installation of the exhaust mass flow meter and the execution of the test shall fulfil the requirement of paragraph 3.4.3. of Appendix 4.

The following calculation steps shall be taken to validate the linearity:

(a) The signal under validation and the reference signal shall be time corrected by following, as far as applicable, the requirements of paragraph 3. of Appendix 7.

(b) Points below 10 % of the maximum flow value shall be excluded from the further analysis.

(c) At a constant frequency of at least 1.0 Hz, the signal under validation and the reference signal shall be correlated using the best-fit equation having the form:

$$y = a_1 x + a_0$$

where:

y		is the actual value of the signal under validation
a_1		is the slope of the regression line

x		is the actual value of the reference signal
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.

(d) The linear regression parameters shall meet the requirements specified in Table A6/2.

4.3. Requirements

The linearity requirements given in Table A6/2 shall be fulfilled. If any permissible tolerance is not met, corrective action shall be taken and the validation shall be repeated.

Table A6/2

Linearity requirements of calculated and measured exhaust mass flow

Measurement parameter/system	a_0	Slope a_1	Standard error of the estimate SEE	Coefficient of determination r^2
Exhaust mass flow	0.0 ± 3.0 kg/h	1.00 ± 0.075	⩽10 % max	⩾ 0.90

Appendix 7 - Determination of instantaneous emissions

1. Introduction

This appendix describes the procedure to determine the instantaneous mass and particle number emissions [g/s; #/s], following application of the data consistency rules of Appendix 4. The instantaneous mass and particle number emissions shall then be used for the subsequent evaluation of a RDE trip and the calculation of the intermediate and final emission result as described in Appendix 11.

2. Symbols, Parameters and Units

α	—	molar hydrogen ratio (H/C)
β	—	molar carbon ratio (C/C)
γ	—	molar sulphur ratio (S/C)
δ	—	molar nitrogen ratio (N/C)
$\Delta t_{t,i}$	—	transformation time t of the analyser [s]
$\Delta t_{t,m}$	—	transformation time t of the exhaust mass flow meter [s]
ε	—	molar oxygen ratio (O/C)
ρ_e	—	density of the exhaust
ρ_{gas}	—	density of the exhaust component 'gas'
λ	—	excess air ratio
λ_i	—	instantaneous excess air ratio
A/F_{st}	—	stoichiometric air-to-fuel ratio [kg/kg]
c_{CH4}	—	concentration of methane
c_{CO}	—	dry CO concentration [%]
c_{CO2}	—	dry CO_2 concentration [%]
c_{dry}	—	dry concentration of a pollutant in ppm or per cent volume
$c_{gas,i}$	—	instantaneous concentration of the exhaust component 'gas' [ppm]
c_{HCw}	—	wet HC concentration [ppm]
$c_{HC(w/NMC)}$	—	HC concentration with CH_4 or C_2H_6 flowing through the NMC [ppmC$_1$]

$c_{HC(w/o NMC)}$	—	HC concentration with CH_4 or C_2H_6 bypassing the NMC [$ppmC_1$]
$c_{i,c}$	—	time-corrected concentration of component *i* [ppm]
$c_{i,r}$	—	concentration of component *i* [ppm] in the exhaust
c_{NMHC}	—	concentration of non-methane hydrocarbons
c_{wet}	—	wet concentration of a pollutant in ppm or per cent volume
E_E	—	ethane efficiency
E_M	—	methane efficiency
H_a	—	intake air humidity [g water per kg dry air]
i	—	number of the measurement
$m_{gas,i}$	—	mass of the exhaust component 'gas' [g/s]
$q_{maw,i}$	—	instantaneous intake air mass flow rate [kg/s]
$q_{m,c}$	—	time-corrected exhaust mass flow rate [kg/s]
$q_{mew,i}$	—	instantaneous exhaust mass flow rate [kg/s]
$q_{mf,i}$	—	instantaneous fuel mass flow rate [kg/s]
$q_{m,r}$	—	raw exhaust mass flow rate [kg/s]
r	—	cross-correlation coefficient
r^2	—	coefficient of determination
r_h	—	hydrocarbon response factor
u_{gas}	—	*u* value of the exhaust component 'gas'

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 paragraph 5.1. of Appendix 4. The time correction and alignment of parameters shall be carried out by following the sequence described in paragraphs 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 paragraph 4.4. of Appendix 5.:

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

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 paragraph 4.4. of Appendix 5.:

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

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 paragraph 4. of Appendix 6.

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 speed trace. In case vehicle speed is obtained from multiple sources (e.g., the GNSS, a sensor or the ECU), the 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. 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 the data exchange file.

5. Correction of measured values

5.0 Drift correction

$$c_{\mathrm{cor}} = c_{\mathrm{ref,z}} + (c_{\mathrm{ref,s}} - c_{\mathrm{ref,z}})\left(\frac{2c_{\mathrm{gas}} - (c_{\mathrm{pre,z}} + c_{\mathrm{post,z}})}{(c_{\mathrm{pre,s}} + c_{\mathrm{post,s}}) - (c_{\mathrm{pre,z}} + c_{\mathrm{post,z}})}\right)$$

$c_{ref,z}$		is the reference concentration of the zero gas (usually zero) [ppm]
$c_{ref,s}$		is the reference concentration of the span gas [ppm]
$c_{pre,z}$		is the pre-test analyser concentration of the zero gas [ppm]
$c_{pre,s}$		is the pre-test analyser concentration of the span gas [ppm]
$c_{post,z}$		is the post-test analyser concentration of the zero gas [ppm]
$c_{post,s}$		is the post-test analyser concentration of the span gas [ppm]
c_{gas}		is the sample gas concentration [ppm]

5.1. Dry-wet correction

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

where:

$$c_{\mathrm{wet}} = k_{\mathrm{w}} \times c_{\mathrm{dry}}$$

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:

$$\boldsymbol{k_w} = \left(\frac{\mathbf{1}}{\mathbf{1} + \boldsymbol{\alpha} \times \mathbf{0.005} \times (\boldsymbol{c_{CO_2}} + \boldsymbol{c_{CO}})} - \boldsymbol{k_{w1}}\right) \times \mathbf{1.008}$$

where:

$$\boldsymbol{k_{w1}} = \frac{\mathbf{1.608} \times \boldsymbol{H_a}}{\mathbf{1\,000} + (\mathbf{1.608} \times \boldsymbol{H_a})}$$

where:

H_a		is the intake air humidity [g water per kg dry air]
c_{CO2}		is the dry CO_2 concentration [%]
c_{CO}		is the dry CO concentration [%]
α		is the molar hydrogen ratio of the fuel (H/C)

5.2. Correction of NO_x for ambient humidity and temperature

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

5.3. Correction of negative emission results

Negative instantaneous results shall not be corrected.

6. Determination of the instantaneous gaseous exhaust components

6.1. Introduction

The components in the raw exhaust shall be measured with the measurement and sampling analysers described in Appendix 5. The raw concentrations of relevant components shall be measured in accordance with Appendix 4. The data shall be time corrected and aligned in accordance with paragraph 3.

6.2. Calculating NMHC and CH_4 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/N_2 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 CH_4 and NMHC shall be calculated as follows:

$$c_{CH4} = \frac{c_{HC(w/o\ NMC)} \times (1 - E_M) - c_{HC(w/NMC)}}{E_E - E_M}$$

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

In method (b), the concentration of CH_4 and NMHC shall be calculated as follows:

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

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

where:

$c_{HC(w/oNMC)}$		is the HC concentration with CH_4 or C_2H_6 bypassing the NMC [ppmC_1]
$c_{HC(w/NMC)}$		is the HC concentration with CH_4 or C_2H_6 flowing through the NMC [ppmC_1]
r_h		is the hydrocarbon response factor as determined in paragraph 4.3.3.(b) of Appendix 5
E_M		is the methane efficiency as determined in paragraph 4.3.4.(a) of Appendix 5
E_E		is the ethane efficiency as determined in paragraph 4.3.4.(b) of Appendix 5

If the methane FID is calibrated through the cutter (method b), then the methane conversion efficiency as determined in paragraph 4.3.4.(a) of Appendix 5 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.

7. Determination of exhaust mass flow rate

7.1. Introduction

The calculation of instantaneous mass emissions according to paragraphs 8. and 9. requires determining the exhaust mass flow rate. The exhaust mass flow rate shall be determined by one of the direct measurement methods specified in paragraph 7.2. of Appendix 5. Alternatively, it is permissible to calculate the exhaust mass flow rate as described in paragraphs 7.2. to 7.4 of this Appendix.

7.2. 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:

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

where:

$q_{m\mathrm{ew,i}}$		is the instantaneous exhaust mass flow rate [kg/s]
$q_{m\mathrm{aw,i}}$		is the instantaneous intake air mass flow rate [kg/s]
$q_{m\mathrm{f,i}}$		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 paragraph 3. of Appendix 5 and the validation requirements specified in paragraph 4.3. of Appendix 6.

7.3. 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:

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

where:

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

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

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 paragraph 3. of Appendix 5 and the validation requirements specified in paragraph 4.3. of Appendix 6.

7.4. 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 paragraph 7.3.) as follows:

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

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

The calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust gas mass flow rate in paragraph 3. of Appendix 5 and the validation requirements specified in paragraph 4.3. of Appendix 6.

8. 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 in Table A7/1. If measured on a dry basis, the dry-wet correction according to paragraph 5.1. 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:

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

where:

$m_{\mathrm{gas,i}}$		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 A7/1
$c_{\mathrm{gas,i}}$		is the measured concentration of the exhaust component 'gas' in the exhaust [ppm]
$q_{m\mathrm{ew,i}}$		is the measured exhaust mass flow rate [kg/s]
gas		is the respective component
i		number of the measurement

Table A7/1

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]

Fuel	ρ_e [kg/m^3]	Component or pollutant i					
		NO_x	CO	HC	CO_2	O_2	CH_4
		ρ_{gas} [kg/m^3]					
		2.052	1.249	(1)	1.9630	1.4276	0.715
		u_{gas} $^{(2,6)}$					
Diesel (B0)	1.2893	0.001593	0.000969	0.000480	0.001523	0.001108	0.000555
Diesel (B5)	1.2893	0.001593	0.000969	0.000480	0.001523	0.001108	0.000555
Diesel (B7)	1.2894	0.001593	0.000969	0.000480	0.001523	0.001108	0.000555
Ethanol (ED95)	1.2768	0.001609	0.000980	0.000780	0.001539	0.001119	0.000561
CNG(3)	1.2661	0.001621	0.000987	0.000528(4)	0.001551	0.001128	0.000565
Propane	1.2805	0.001603	0.000976	0.000512	0.001533	0.001115	0.000559
Butane	1.2832	0.001600	0.000974	0.000505	0.001530	0.001113	0.000558
LPG(5)	1.2811	0.001602	0.000976	0.000510	0.001533	0.001115	0.000559
Petrol (E0)	1.2910	0.001591	0.000968	0.000480	0.001521	0.001106	0.000554
Petrol (E5)							

	1.2897	0.001592	0.000969	0.000480	0.001523	0.001108	0.000555
Petrol (E10)	1.2883	0.001594	0.000970	0.000481	0.001524	0.001109	0.000555
Ethanol (E85)	1.2797	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 CH_4 shall be used)

(5) u accurate within 0.2% for mass composition of: C_3=70-90%; C_4=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

9. 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/cm^3] with the instantaneous exhaust mass flow rate [kg/s], both corrected and aligned for the transformation time and by dividing with the density [kg/m^3] according to Table A7/1. If applicable, negative instantaneous emission values shall enter all subsequent data evaluations. All significant digits of preceding 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 [#/m^3] 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/m^3] at 0 °C (Table A7/1)

10. Data exchange

Data Exchange: The data shall be exchanged between the measurement systems and the data evaluation software by a standardised data exchange file provided by the Commission[6].

Any pre-processing of data (e.g. time correction according to paragraph 3, vehicle speed correction according to paragraph 4.7 of Appendix 4 or the correction of the GNSS vehicle speed signal according to paragraph 6.5. of Appendix 4) shall be done with the control software of the measurement systems and shall be completed before the data exchange file is generated.

Appendix 8 Assessment of overall trip validity using the moving averaging window method

1. Introduction

The Moving Averaging Window method shall be used to assess 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 RDE purposes. The 'normality' of the windows shall be assessed by comparing their CO_2 distance-specific emissions with a reference curve obtained from the vehicle CO_2 emissions measured in accordance with the WLTP test.

2. Symbols, Parameters and Units

Index (i) refers to the time step

Index (j) refers to the window

Index (k) refers to the category (t=total, ls=low speed, ms=medium speed, hs=high speed) or to the CO_2 characteristic curve (cc)

a_1, b_1 - coefficients of the CO_2 characteristic curve

a_2, b_2 - coefficients of the CO_2 characteristic curve

M_{CO_2} - CO_2 mass, [g]

$M_{CO_2,j}$ - CO_2 mass in window j, [g]

t_i - total time in step i, [s]

t_t - duration of a test, [s]

v_i - actual vehicle speed in time step i, [km/h]

$\bar{v}_j$ - average vehicle speed in window j, [km/h]

tol_{1H} - upper tolerance for the vehicle CO_2 characteristic curve, [%]

tol_{1L} - lower tolerance for the vehicle CO_2 characteristic curve, [%]

3. Moving averaging windows

3.1. Definition of averaging windows

The instantaneous CO_2 emissions calculated according to Appendix 7 shall be integrated using a moving averaging window method, based on a reference CO_2 mass.

The usage of the reference CO_2 mass is illustrated in Figure A8/2. The principle of the calculation is as follows: The RDE distance-specific CO_2 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 CO_2 mass emitted by the vehicle over the applicable WLTP test (after all appropriate corrections e.g. ATCT are applied, where relevant). 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 CO_2 emissions and its average speed are referred to as 'averaging windows' in the following sections. The calculation described in this point shall be run from the first data point (forward), as shown in Figure A8/1.

The following data shall not be considered for the calculation of the CO_2 mass, the distance and the vehicle average speed in each averaging window:

The periodic verification of the instruments and/or after the zero drift verifications;

Vehicle ground speed < 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 CO_2 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 7.

Figure A8/1

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

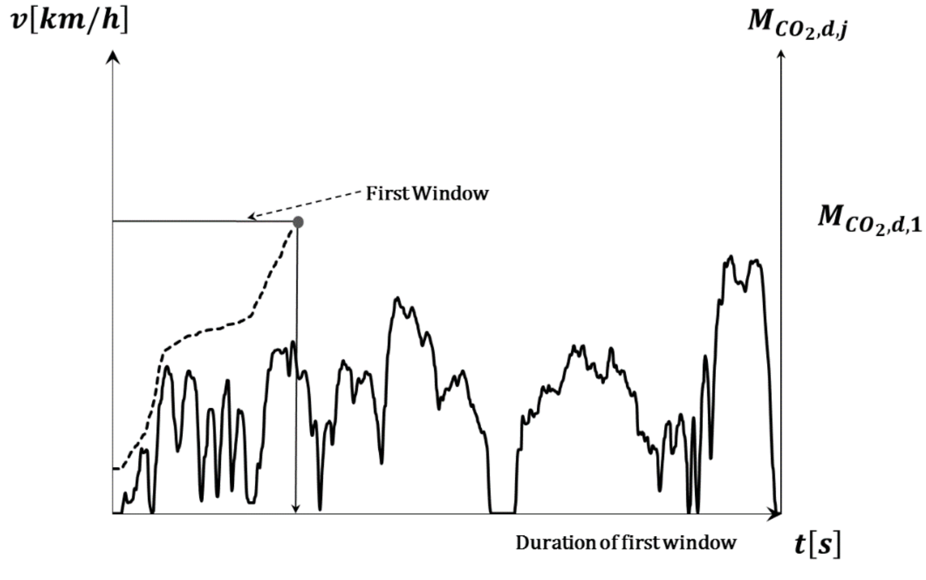
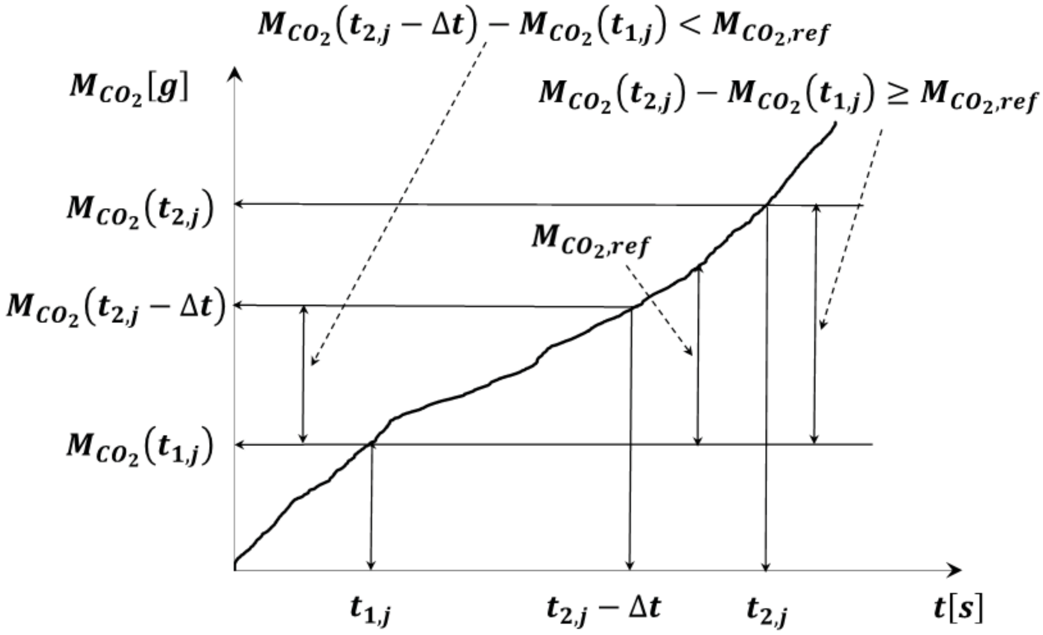


Figure A8/2

Definition of CO_2 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 CO_2 mass measured between the test start and time $t_{i,j}$, [g];

$M_{CO_2,ref}$ is the reference CO_2 mass (half of the CO_2 mass emitted by the vehicle over the applicable WLTP test).

During type approval, the CO_2 reference value shall be taken from the WLTP test CO_2 values of the individual vehicle, obtained in accordance with UN Regulation 154, including all appropriate corrections.

For ISC or market surveillance testing purposes, the reference CO_2 mass shall be obtained from the Certificate of Conformity[28] for the individual vehicle. The value for OVC-HEV vehicles shall be obtained from the WLTP test conducted using the Charge Sustaining mode.

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

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

---

[28] As found in Annex VIII of Regulation (EU) 2020/638.

Where Δt is the data sampling period.

The CO_2 masses $M_{CO_2,j}$ in the windows are calculated by integrating the instantaneous emissions calculated as specified in Appendix 7.

3.2. Calculation of window parameters

– The following shall be calculated for each window determined in accordance with paragraph 3.1. The distance-specific CO_2 emissions $M_{CO2,d,j}$;

– 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 CO_2 emissions versus average speed measured at type approval on the WLTP test and referred to as 'vehicle CO_2 characteristic curve'.

4.2. CO_2 characteristic curve reference points.

During type approval, the values shall be taken from the WLTP CO2 values of the individual vehicle, obtained in accordance with UN Regulation 154, including all appropriate corrections.

For ISC or market surveillance testing purposes, the distance-specific CO_2 emissions to be considered, in this paragraph for the definition of the reference curve shall be obtained from the Certificate of Conformity for the individual vehicle.

The reference points P_1, P_2 and P_3 required to define the vehicle CO_2 characteristic curve shall be established as follows:

4.2.1. Point P_1

$\overline{v_{P1}} = 18.882\ km/h$ (Average Speed of the Low Speed phase of the WLTP cycle)

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

4.2.2. *Point P_2*

$\overline{v_{P2}} = 56.664\ km/h$ (Average Speed of the High Speed phase of the WLTP cycle)

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

4.2.3. *Point P_3*

$\overline{v_{P3}} = 91.997\ km/h$ (Average Speed of the Extra High Speed phase of the WLTP cycle)

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

4.3. CO_2 characteristic curve definition

Using the reference points defined in paragraph 4.2., the characteristic curve CO_2 emissions are calculated as a function of the average 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):

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

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

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

For the section (P_2, P_3):

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

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

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

Figure A8/3

Vehicle CO_2 characteristic curve and tolerances for ICE and NOVC-HEV vehicles

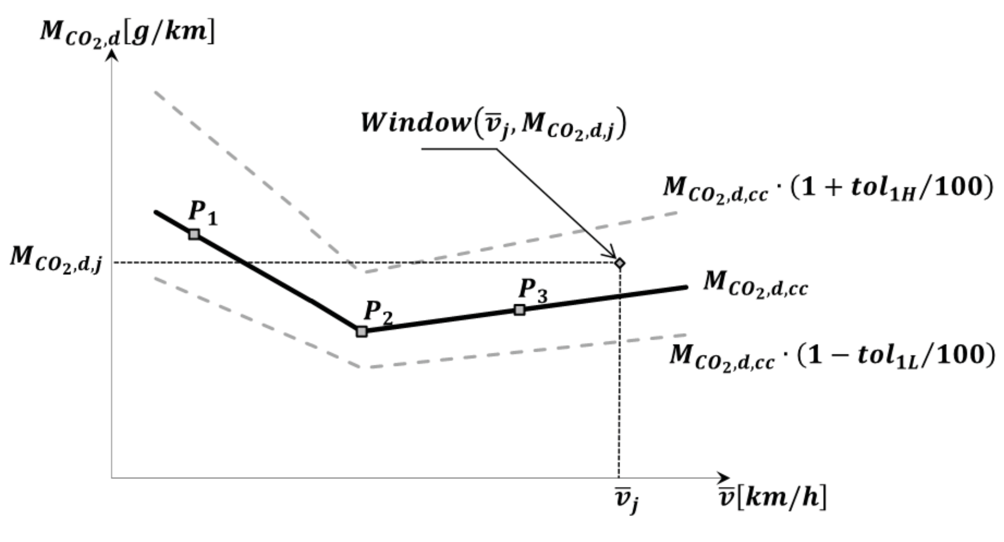
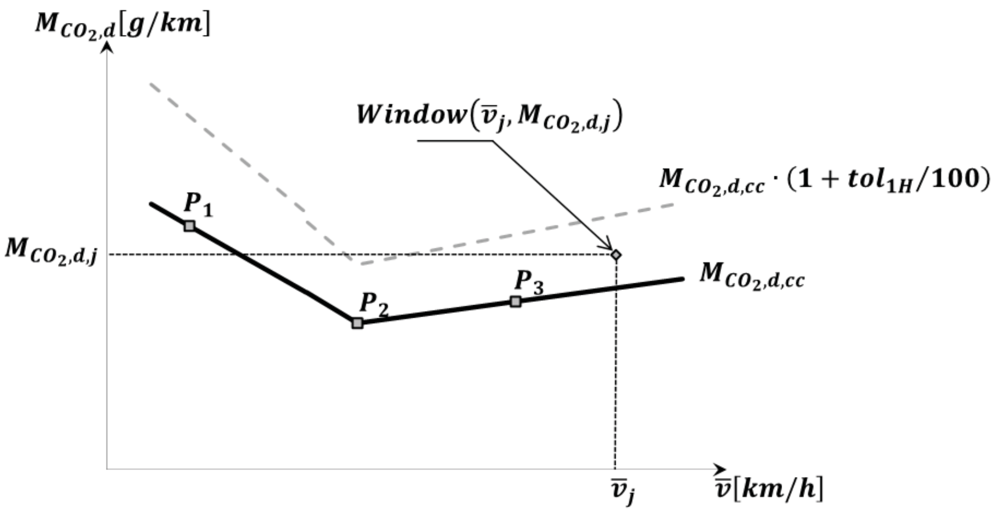


Figure A8/4:

Vehicle CO_2 characteristic curve and tolerances for OVC-HEV vehicles



4.4. Low, medium and high-speed windows

4.4.1. The windows shall be categorised into low, medium, and high speed bins according to their average speed.

4.4.1.1. Low-speed windows

Low-speed windows are characterized by average vehicle ground speeds $\bar{v}_j$ lower than 45 km/h.

4.4.1.2. Medium-speed windows

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

For those vehicles that are equipped with a device limiting vehicle speed to 90 km/h, medium-speed windows are characterized by average vehicle speeds $\bar{v}_j$ lower than 70 km/h.

4.4.1.3. High-speed windows

High-speed windows are characterized by average vehicle ground speeds $\bar{v}_j$ greater than or equal to 80 km/h and lower than 145 km/h

For those vehicles that are equipped with a device limiting vehicle speed to 90 km/h, high-speed windows are characterized by average vehicle speeds $\bar{v}_j$ greater than or equal to 70 km/h and lower than 90 km/h.

Figure A8/5

Vehicle CO_2 characteristic curve: low, medium and high speed definitions (Illustrated for ICE and NOVC-HEV vehicles) except N2 category vehicles that are equipped with a device limiting vehicle speed to 90 km/h

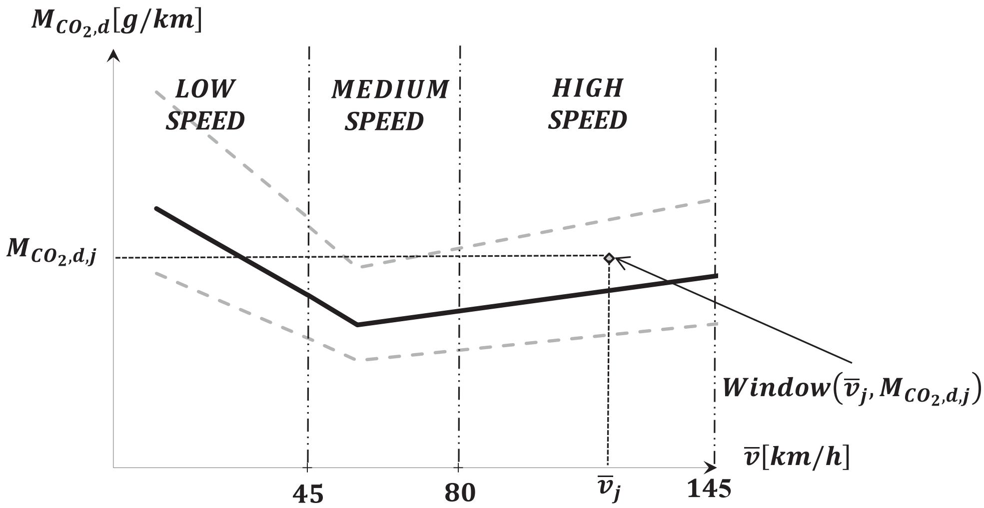
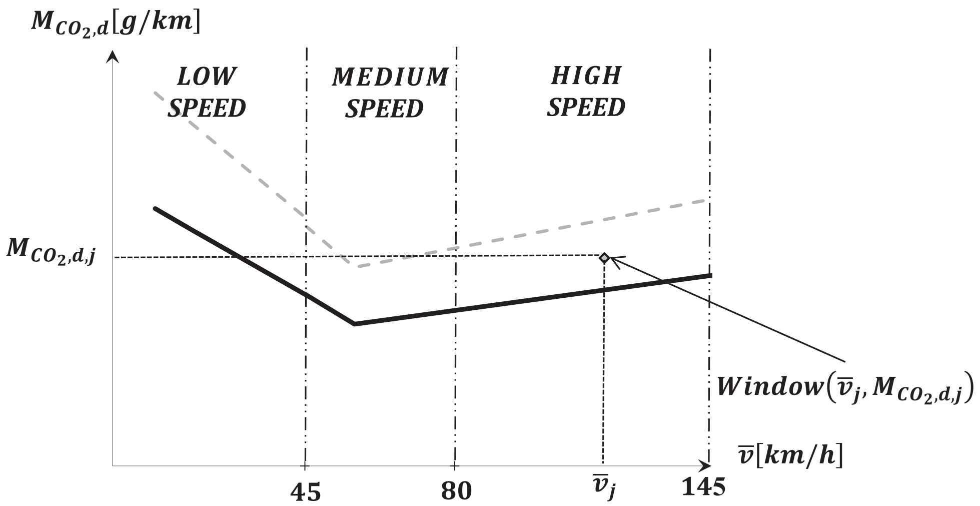


Figure A8/6.

Vehicle CO_2 characteristic curve: low, medium and high speed driving definitions (Illustrated for OVC-HEV vehicles) except those vehicles that are equipped with a device limiting vehicle speed to 90 km/h



4.5.1. Assessment of trip validity

4.5.1.1. Tolerances around the vehicle CO_2 characteristic curve

The upper tolerance of the vehicle CO_2 characteristic curve is $tol_{1H} = 45\%$ for low speed driving and $tol_{1H} = 40\%$ for medium and high speed driving.

The lower tolerance of the vehicle CO_2 characteristic curve is $tol_{1L} = 25\%$ for ICE and NOVC-HEV vehicles and $tol_{1L} = 100\%$ for OVC-HEV vehicles.

4.5.1.2. Assessment of test validity

The test is valid when it comprises at least 50 per cent of the low, medium and high speed windows that are within the tolerances defined for the CO_2 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 until the value of tol_{1H} reaches 50 per cent.

For OVC-HEVs when no MAWs are calculated as result of the ICE not turning on, the test is still valid.

Appendix 9 - Assessment of excess or absence 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 an RDE trip.

2. Symbols, Parameters and Units

a	—	acceleration [m/s^2]
a_i	—	Acceleration in time step i [m/s^2]
a_{pos}	—	positive acceleration greater than 0.1 m/s^2 [m/s^2]
$a_{pos,i,k}$	—	positive acceleration greater than 0.1 m/s^2 in time step i considering the urban, rural and motorway shares [m/s^2]
a_{res}	—	acceleration resolution [m/s^2]
d_i	—	distance covered in time step i [m]
$d_{i,k}$	—	distance covered in time step i considering the urban, rural and motorway shares [m]
Index (i)	—	discrete time step
Index (j)	—	discrete time step of positive acceleration datasets
Index (k)	—	refers to the respective category (t=total, u=urban, r=rural, m=motorway)
M_k	—	number of samples for urban, rural and motorway shares with positive acceleration greater than 0.1 m/s^2
N_k	—	total number of samples for the urban, rural and motorway shares and the complete trip
RPA_k	—	relative positive acceleration for urban, rural and motorway shares [m/s^2 or kWs/(kg*km)]
t_k	—	duration of the urban, rural and motorway shares and the complete trip [s]
v	—	vehicle speed [km/h]
v_i	—	actual vehicle speed in time step i [km/h]
$v_{i,k}$	—	actual vehicle speed in time step i considering the urban, rural and motorway shares [km/h]
$(v \times a)_i$	—	actual vehicle speed per acceleration in time step i [m^2/s^3 or W/kg]
$(v \times a)_{j,k}$	—	actual vehicle speed per positive acceleration greater than 0.1 m/s^2 in time step j considering the urban, rural and motorway shares [m^2/s^3 or W/kg].
$(v \times a_{pos})_{k-}[95]$	—	95th percentile of the product of vehicle speed per positive acceleration greater than 0.1 m/s^2 for urban, rural and motorway shares [m^2/s^3 or

		W/kg]
$\overline{v}_k$	—	average vehicle speed for urban, rural and motorway shares [km/h]

3 Trip indicators

3.1. Calculations

3.1.1. Data pre-processing

Dynamic parameters, such as acceleration, $(v \times a_{pos})$ or RPA, shall be determined with a speed signal of an accuracy of 0.1 % for all speed values above 3 km/h and a sampling frequency of 1 Hz. Otherwise, acceleration shall be determined with an accuracy of 0.01 m/s^2 and a sampling frequency of 1 Hz. In this case, a separate speed signal is required for $(v \times a_{pos})$ and shall have an accuracy of at least 0.1 km/h. The speed trace shall form the basis for further calculations and binning as described in paragraphs 3.1.2. and 3.1.3.

3.1.2. Calculation of distance, acceleration and $(v \times a)$

The following calculations shall be performed over the whole time based speed trace from the beginning to the end of the test data.

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

$$d_i = \frac{v_i}{3.6} \quad i = 1 \; to \; N_t$$

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:

$$a_i = \frac{v_{i+1} - v_{i-1}}{2 \times 3.6} \quad i = 1 \; to \; N_t$$

where:

a_i		is the acceleration in time step i [m/s^2]. 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:

$$(v \times a)_i = v_i \times a_i / 3.6$$

where:

$(v \times a)_i$		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

3.1.3.1.

Binning of the results

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

All datasets with ($v_i \leq$ 60 km/h) belong to the ‘urban’ speed bin, all datasets with (60 km/h < v_i ≤ 90 km/h) belong to the ‘rural’ speed bin and all datasets with (v_i > 90 km/h) belong to the ‘motorway’ speed bin.

For N2 category vehicles that are equipped with a device limiting vehicle speed to 90 km/h, all datasets with $v_i \leq 60$ km/h belong to the “urban” speed bin, all datasets with 60 km/h < v_i ≤ 80 km/h belong to the “rural” speed bin and all datasets with v_i > 80 km/h belong to the “motorway” speed bin.

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

For each speed bin the average vehicle speed ($\overline{v}_k$) shall be calculated as follows:

$$\overline{v}_k = \frac{1}{N_k} \sum_i v_{i,k} \quad i = 1\ to\ N_k, k = u, r, m$$

where:

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

3.1.4. Calculation of $(v \times a_{pos})_{k-}[95]$ per speed bin

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

The $(v \times a_{pos})_{i,k}$ values in each 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 $(v \times a_{pos})_{i,k}$ values with $a_{i,k} > 0.1$ m/s^2 as follows:

The lowest $(v \times a_{pos})$ 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 %.)

$(v \times a_{pos})_{k-}[95]$ is the $(v \times a_{pos})_{j,k}$ value, with j/M_k = 95 %. If j/M_k = 95 % cannot be met, $(v \times a_{pos})_{k-}[95]$ 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 speed bin shall be calculated as follows:

$$RPA_k = \frac{\sum_j (v \times a_{pos})_{j,k}}{\sum_i d_{i,k}},$$
$$j = 1 \; to \; M_k, i = 1 \; to \; N_k, k = u, r, m$$

where:

RPA_k		is the relative positive acceleration for urban, rural and motorway shares in [m/s^2 or kWs/(kg*km)]
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. Assessment of trip validity

4.1.1. Assessment of $(v \times a_{pos})_{k-}[95]$ per speed bin (with v in [km/h])

If $\overline{v}_k \leq 74.6 \; km/h$ and

$$(v \times a_{pos})_{k-}[95] > (0.136 \times \overline{v}_k + 14.44)$$

is fulfilled, the trip is invalid.

If $\overline{v}_k > 74.6 \; km/h$ and

$$(v \times a_{pos})_{k-}[95] > (0.0742 \times \overline{v}_k + 18.966)$$

is fulfilled, the trip is invalid.

Upon the request of the manufacturer, and only for those N1 or N2 vehicles where the vehicle power-to-test mass ratio is less than or equal to 44 W/kg then:

If $\overline{v}_k \leq 74.6 km/h$ and

$(\mathrm{v} \times \mathrm{a_{pos}})_{\mathrm{k-}}[95] > (0.136 \times \overline{\mathrm{v}}_{\mathrm{k}} + 14{,}44)$

is fulfilled, the trip is invalid.

If $\overline{v}_k > 74.6\ km/h$ and

$$\left(v \times a_{pos}\right)_{k-}[95] > (-0.097 \times \overline{v}_k + 31.635)$$

is fulfilled, the trip is invalid.

4.1.2. Assessment of RPA per speed bin

If $\overline{v}_k \leq 94.05\ km/h$ and

$RPA_k < (-0.0016 \cdot \overline{v}_k + 0.1755)$

is fulfilled, the trip is invalid.

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

Appendix 10 - 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

$d(0)$	—	distance at the start of a trip [m]
d	—	cumulative distance travelled at the discrete way point under consideration [m]
d_0	—	cumulative distance travelled until the measurement directly before the respective way point d [m]
d_1	—	cumulative distance travelled until the measurement directly after the respective way point d [m]
d_a	—	reference way point at $d(0)$ [m]
d_e	—	cumulative distance travelled until the last discrete way point [m]
d_i	—	instantaneous distance [m]
d_{tot}	—	total test distance [m]
$h(0)$	—	vehicle altitude after the screening and principle verification of data quality at the start of a trip [m above sea level]
$h(t)$	—	vehicle altitude after the screening and principle verification of data quality at point t [m above sea level]
$h(d)$	—	vehicle altitude at the way point d [m above sea level]
$h(t-1)$	—	vehicle altitude after the screening and principle verification of data quality at point t-1 [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]
$h_{corr}(t)$	—	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]

$h_{GNSS,i}$	—	instantaneous vehicle altitude measured with GNSS [m above sea level]
$h_{GNSS}(t)$	—	vehicle altitude measured with GNSS at data point t [m above sea level]
$h_{\text{int}}(d)$	—	interpolated altitude at the discrete way point under consideration *d* [m above sea level]
$h_{\text{int,sm,1}}(d)$	—	smoothed and interpolated altitude, after the first smoothing run at the discrete way point under consideration *d* [m above sea level]
$h_{\text{map}}(t)$	—	vehicle altitude based on topographic map at data point t [m above sea level]
$road_{grade,1}(d)$	—	smoothed road grade at the discrete way point under consideration *d* after the first smoothing run [m/m]
$road_{grade,2}(d)$	—	smoothed road grade at the discrete way point under consideration *d* after the second smoothing run [m/m]
sin	—	trigonometric sine function
t	—	time passed since test start [s]
t_0	—	time passed at the measurement directly located before the respective way point *d* [s]
v_i	—	instantaneous vehicle speed [km/h]
$v(t)$	—	vehicle speed at a data point t [km/h]

3. General requirements

The cumulative positive elevation gain of a RDE trip shall be determined based on three parameters: the instantaneous vehicle altitude $h_{GNSS,i}$ [m above sea level] as measured with the GNSS, 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 RDE trip shall be calculated as a two-step procedure, consisting of (i) the correction of instantaneous vehicle altitude data, and (ii) the calculation of the cumulative positive elevation gain.

4.2. Correction of instantaneous vehicle altitude data

The altitude *h(0)* at the start of a trip at *d(0)* shall be obtained by GNSS 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:

$$|h(t) - h(t-1)| > v(t)/3.6 \ \times sin45°$$

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 check of data quality at data point t [m above sea level]
h(t-1)	—	vehicle altitude after the screening and principle check 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 the following.

4.3. Final calculation of the cumulative positive elevation gain

4.3.1. Establishment of a uniform spatial resolution

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:

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

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 travelled at 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]

4.3.2. 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 A10/1). The first smoothing run shall be applied as follows:

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

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

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

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

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

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 *d(0)* [m]
d_e	—	cumulative distance travelled until the last discrete way point [m]

The second smoothing run shall be applied as follows:

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

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

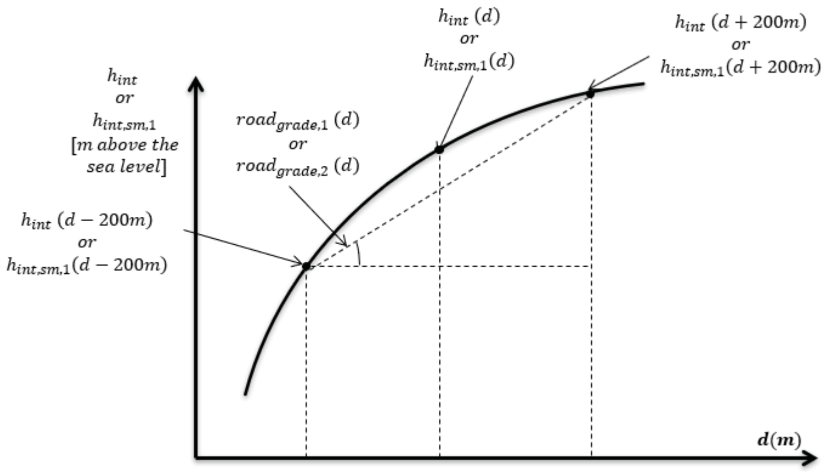
$$road_{grade,2}(d) = \frac{h_{int,sm,1}(d_e) - h_{int,sm,1}(d - 200\,m)}{d_e - (d - 200\,m)} \quad for\ d \geq (d_e - 200\,m)$$

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 *d(0)* [m]
d_e	—	cumulative distance travelled until the last discrete way point [m]

Figure A10/1

Illustration of the procedure to smooth the interpolated altitude signals



4.3.3. 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 meters of cumulative elevation gain per one hundred kilometres of distance.

The waypoint vehicle speed v_w shall then be calculated over each discrete way point of 1m:

$$v_w = \frac{1}{(t_{w,i} - t_{w,i-1})}$$

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. All datasets with $v_w \leq 60$ km/h belong to the urban part of the trip. All of the positive interpolated and smoothed road grades that correspond to urban datasets shall be integrated.

The number of 1m waypoints which correspond to urban datasets shall be integrated and converted to km to define the urban test distance d_{urban} [km].

The positive cumulative elevation gain of the urban part of the 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.

Appendix 11 - Calculation of the final RDE emission results

1. This appendix describes the procedure to calculate the final pollutant emissions for the complete and urban part of an RDE trip

2. Symbols, Parameters and Units

Index (k) refers to the category (t=total, u=urban, 1-2=first two phases of the WLTP test)

IC_k	is the distance share of usage of the internal combustion engine for an OVC-HEV over the RDE trip
$d_{ICE,k}$	is the distance driven [km], with the internal combustion engine on for an OVC-HEV over the RDE trip
$d_{EV,k}$	is the distance driven [km], with the internal combustion engine off for an OVC-HEV over the RDE trip
$M_{RDE,k}$	is the final RDE distance-specific mass of gaseous pollutants [mg/km] or particle number [#/km]
$m_{RDE,k}$	is the distance-specific mass of gaseous pollutant [mg/km] or particle number [#/km] emissions, emitted over the complete RDE trip and prior to any correction in accordance with this appendix
$M_{CO_2,RDE,k}$	is the distance-specific mass of CO_2 [g/km], emitted over the RDE trip
$M_{CO_2,WLTC,k}$	is the distance-specific mass of CO_2 [g/km], emitted over the WLTC cycle
$M_{CO_2,WLTC\_CS,k}$	is the distance-specific mass of CO_2 [g/km], emitted over the WLTC cycle for an OVC-HEV vehicle tested in charge sustaining vehicle operation
r_k	is the ratio between the CO_2 emissions measured during the RDE test and the WLTP test
RF_k	is the result evaluation factor calculated for the RDE trip
RF_{L1}	is the first parameter of the function used to calculate the result evaluation factor

RF_{L2} is the second parameter of the function used to calculate the result evaluation factor

3. Calculation of the Intermediate RDE emissions results

For the valid trips, the intermediate RDE results are calculated as follows for vehicles with ICE, NOVC-HEV and OVC-HEV.

Any instantaneous emissions or exhaust flow measurements obtained while the combustion engine is deactivated, as defined in paragraph 2.5.2. of this Annex, shall be set to zero.

Any correction of the instantaneous pollutant emissions for Extended conditions according to paragraph 5.1., 7.5. and 7.6. of this Annex shall be applied.

For the complete RDE trip and for the urban part of the RDE trip (k=t=total, k=u=urban):

$$M_{RDE,k} = m_{RDE,k} \times RF_k$$

The values of the parameter RF_{L1} and RF_{L2} of the function used to calculate the result evaluation factor are as follows:

$RF_{L1} = 1.30$ and $RF_{L2} = 1.50$;

The RDE result evaluation factors RF_k (k=t=total, k=u=urban) shall be obtained using the functions laid down in paragraph 3.1. for vehicles with ICE and NOVC-HEV, and in paragraph 3.2. for OVC-HEV. A graphical illustration of the method is provided in Figure A11/1 below, while the mathematical formulas are found in Table A11/1:

Figure A11/1

Function to calculate the result evaluation factor

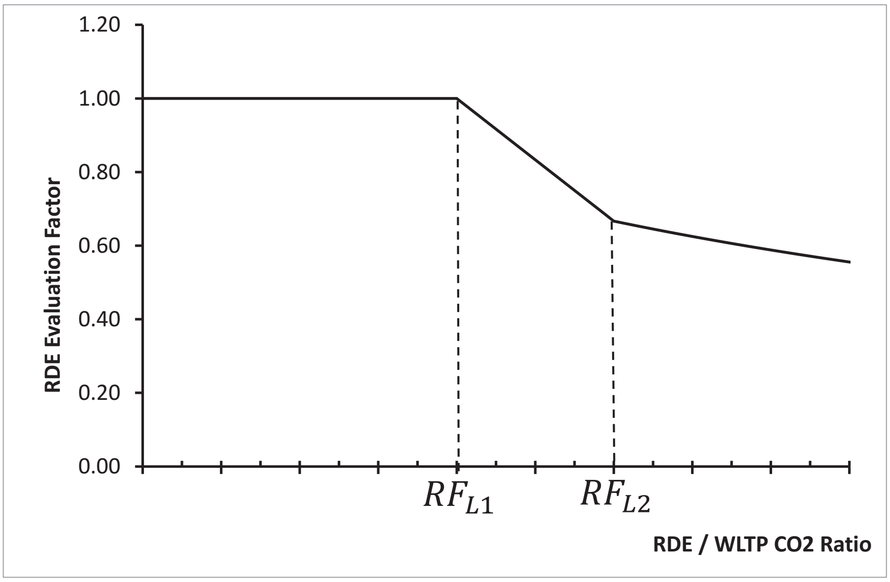


Table A11/1

Result evaluation factors calculation

When:	*Then the Result evaluation factor RF_k is:*	*Where:*
$r_k \leq RF_{L1}$	$RF_k = 1$	
$RF_{L1} < r_k \leq RF_{L2}$	$RF_k = a_1 r_k + b_1$	$a_1 = \frac{RF_{L2} - 1}{[RF_{L2} \times (RF_{L1} - RF_{L2})]}$ $b_1 = 1 - a_1 RF_{L1}$
$r_k > RF_{L2}$	$RF_k = \frac{1}{r_k}$	

3.1. RDE result evaluation factor for vehicles with ICE and NOVC-HEV

The value of the RDE result evaluation factor depends on the ratio r_k between the distance specific CO_2 emissions measured during the RDE test and the distance-specific CO_2 emitted by the vehicle over the validation WLTP test conducted on this vehicle including all appropriate corrections.

For the urban emissions, the relevant phases of the WLTP test shall be:

(a) for ICE vehicles, the first two WLTC phases, i.e. the Low and the Medium speed phases,

$$r_k = \frac{M_{CO_2,RDE,k}}{M_{CO_2,WLTP,k}}$$

(b) for NOVC-HEVs, all the phases of the WLTC driving cycle.

$$r_k = \frac{M_{CO_2,RDE,k}}{M_{CO_2,WLTP,t}}$$

3.2. RDE result evaluation factor for OVC-HEV

The value of the RDE result evaluation factor depends on the ratio r_k between the distance-specific CO_2 emissions measured during the RDE test and the distance-specific CO_2 emitted by the vehicle over the applicable WLTP test conducted in Charge Sustaining vehicle operation including all appropriate corrections. The ratio r_k is corrected by a ratio reflecting the respective usage of the internal combustion engine during the RDE trip and on the WLTP test, to be conducted in charge sustaining vehicle operation.

For either the urban or the total driving:

$$r_k = \frac{M_{CO_2,RDE,k}}{M_{CO_2,WLTP\_CS,t}} \times \frac{0.85}{IC_k}$$

where IC_k is the ratio of the distance driven either in urban or total trip with the combustion engine activated, divided by the total urban or total trip distance:

$$IC_k = \frac{d_{ICE,k}}{d_{ICE,k} + d_{EV,k}}$$

With determination of combustion engine operation in accordance with paragraph 2.5.2. of this Annex.

4. Final RDE emission results taking into account the PEMS margin

In order to take into account the uncertainty of the PEMS measurements compared to the ones performed in the laboratory with the applicable WLTP test, the intermediate calculated emission values $M_{RDE,k}$ shall be divided by 1+margin$_{pollutant.}$, where margin$_{pollutant}$ is defined in the Table A11/2:

The PEMS *margin* for each pollutant is specified as follows:

Table A11/2

Pollutant	*Mass of oxides of nitrogen (NO_x)*	*Number of particles (PN)*	*Mass of carbon monoxide (CO)*	*Mass of total hydrocarbons (THC)*	*Combined mass of total hydrocarbons and oxides of nitrogen (THC + NO_x)*
Margin$_{pollutant}$	0.10	0.34	*Not yet specified*	*Not yet specified*	*Not yet specified*

Any negative final results shall be set to zero.

Any Ki factors which are applicable, according to point 5.3.4. of this Annex, shall be applied.

These values shall be considered the Final RDE Emission Results for NOx and PN.

Appendix 12 - Manufacturer's RDE certificate of compliance

Manufacturer’s certificate of compliance with the Real Driving Emissions requirements

(Manufacturer): ……………………………………………………………………..

(Address of the Manufacturer): …………………………………………………………..

Certifies that:

The vehicle types listed in the attachment to this Certificate comply with the requirements laid down in point 3.1 of Annex IIIA to Regulation (EU) 2017/1151 for all valid RDE tests which are performed in accordance with the requirements of the above Annex.

Done at [......................... (Place)]

On [........................ (Date)]

....

(Stamp and signature of the manufacturer's representative)

Annex:

— List of vehicle types to which this certificate applies

– List of the Declared Maximum RDE values for each vehicle type expressed as mg/km or particle numbers/km as appropriate.

’.