Submitted by the expert from European Commission

Informal document **GRPE-80-31**
80th GRPE,14-17 January 2020
Agenda item 3.(c)

DRAFT UNR RDE

Section 1: Scope and application

Commented [DP1]: Please note that the text has been restructured in this document to make it compatible with a UN Regulation structure.

This Regulation aims at providing a worldwide harmonised method to determine the levels of Real Driving Emissions (RDE) of gaseous compounds and particles from light-duty vehicles.

This Regulation applies to the type approval of vehicles of categories M1 with a reference mass not exceeding 2,610 kg and vehicles of categories M2 and N1 with a reference mass not exceeding 2,610 kg and a technical permissible maximum laden mass not exceeding 3,500 kg with regard to their Real Driving Emissions.

Section 2: Definitions and Abbreviations

For the purposes of this Regulation, the following definitions shall apply:

'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 family" as defined in point xxxx;

Test equipment

"Accuracy" means the difference between a measured value and a reference value, traceable to a national standard and describes the correctness of a result.

"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.

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

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

"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 (t_{10}) with the sampling probe being defined as the reference point.

"Full scale" means the full range of an analyser, flow-measuring instrument or sensor as specified by the equipment manufacturer. If a sub-range of the analyser, flow-measuring instrument or sensor is used for measurements, full scale shall be understood as the maximum reading of the sub-range.

"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 ppmC1.

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

"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.

"Non-methane hydrocarbons" (NMHC) means the Total Hydrocarbons (THC) minus the methane (CH4) contribution.

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

"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.

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

"Response time" (t_{90}) 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 (t_{90}) 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

"Rise time" means the difference in time between the 10 per cent and 90 per cent response of the final reading (t_{10} to t_{90} ~~— t_{10}~~)

"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.

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

Commented [JRC-ISPRA3]: Generic definition
Application to EFM in Appendix 2; *The precision, defined as 2,5 times the standard deviation of 10 repetitive responses*
and gas analysers, also in Appendix 2

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"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.

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

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

Commented [JRC-ISPRA4]: Generic definition
Application to EFM and analysers in Appendix 2
The span response drift is defined as the mean response to a span flow during a time interval of at least 30 seconds.

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

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

"Transformation time" means the time difference between a change of concentration or flow (t_0) at the reference point and a system response of 50 per cent of the final reading (t_{50}).

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Important because the time alignment is based on t0

"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.

"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.

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

Commented [JRC-ISPRA6]: Term also used for trip verification, adjust?

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

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

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

"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.

Commented [JRC-ISPRA7]: Application to EFM and analysers in Appendix 2
(EFM) The zero response drift is defined as the mean response to zero flow during a time interval of at least 30 seconds.

Figure 1 - Definition of accuracy, precision and reference value

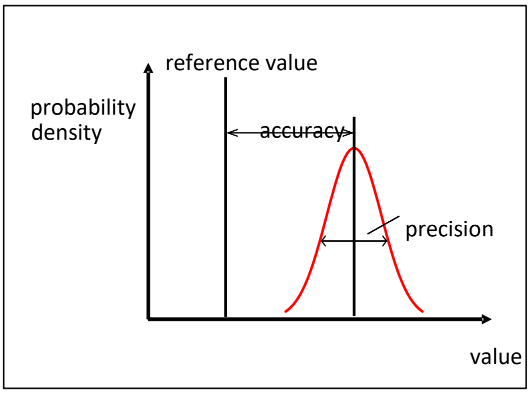
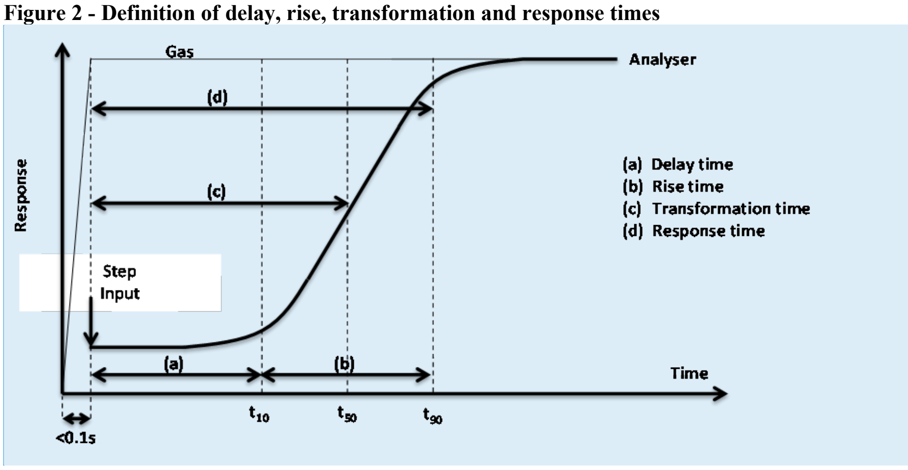


Figure 2 - Definition of delay, rise, transformation and response times



Commented [DP8]: Add T10 to T90 in figure

Vehicle characteristics and driver

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

"Allowable Test Mass of the vehicle" can be between the actual mass of the vehicle and the maximum allowable test mass of the vehicle.

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"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.

"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.

"Maximum Allowable Test mass of the vehicle" means the sum of:
- the actual mass of the vehicle;
- 90% of the difference between the technically permissible maximum laden mass and the actual mass of the vehicle (Figure 3).

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

"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.

"RDE Power-to-test mass-ratio" corresponds to the ratio of the rated engine power and of the test mass.

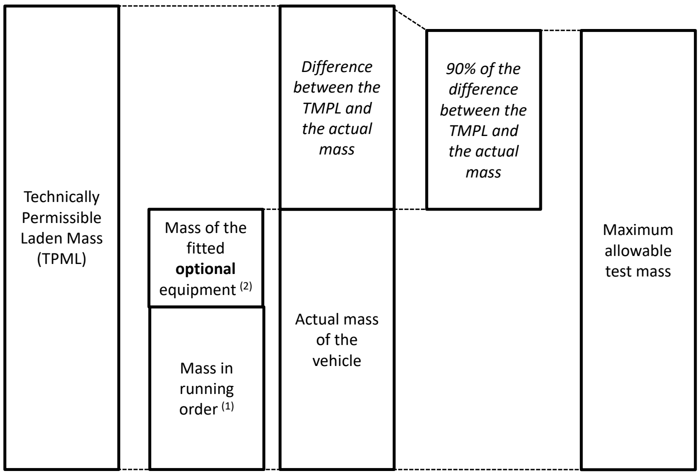
Commented [JRC-ISPRA10]: General definition is Prated divided by a Mass
More specific in appendix 7a: use the test mass to calculate the PMR
When using the test mass to calculate PMR, the RDE PMR won't match exactly the WLTC PMR (which is calculated using MIRO-75kg)

"Rated engine power (P_{rated})" means maximum net power of the engine or motor in kW as per the certification procedure based on current regional regulation. In the absence of a definition, the rated engine power shall be declared by the manufacturer according to Regulation No. 85.

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

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

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.

Pure electric, pure ICE, hybrid electric, fuel cell and alternatively-fuelled vehicles

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

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

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

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

Calculations

"Axis intercept" of a linear regression (a_0) means:

$$a_0 = \overline{y} - (a_1 \times \overline{x})$$

where:
a_1 is the slope of the regression line
$\overline{x}$ is the mean value of the reference parameter
$\overline{y}$ is the mean value of the parameter to be verified

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"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

"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

"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

"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:
$\overline{x}$ is the mean value of the reference parameter
$\overline{y}$ is the mean value of the parameter to be verified
x_i is the actual value of the reference parameter
y_i is the actual value of the parameter to be verified
n is the number of values

"Standard error of estimate" (SEE) means:

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

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
x_{max} is the maximum actual value of the reference parameter
n is the number of values

General

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

"Criteria emissions" means those emission compounds for which limits are set in regional legislation

"Deactivated internal combustion engine" means an internal combustion engine for which two of the following criteria apply:
- the recorded engine speed is < 50 rpm;
- the exhaust mass flow rate is measured at < 3 kg/h;
- the measured exhaust mass flow rate drops to < 15 % of the typical steady-state exhaust mass flow rate at idling.

"Engine capacity" means either of the following:
- for reciprocating piston engines, the nominal engine swept volume;
- for rotary piston (Wankel) engines, double the nominal engine swept volume.

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

"Exhaust emissions" means the emission of gaseous, solid and liquid compounds from the tailpipe.

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

PM/PN

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.

"Particle number emissions" (PN) means the total number of solid particles emitted from the vehicle exhaust quantified according to the dilution, sampling and measurement methods as specified in this UN GTR.

"Particulate matter emissions" (PM) means the mass of any particulate material from the vehicle exhaust quantified according to the dilution, sampling and measurement methods as specified in this UN GTR.

Procedure

"Cold start PEMS trip" means a trip with conditioning of the vehicle prior to the test (as described in point 5.3 in the present Regulation).

Commented [JRC-ISPRA11]: Always double-check the reference or keep the definition generic and details of the conditioning procedure in the appropriate section(s)

"Hot start PEMS trip" means a trip without conditioning of the vehicle prior to the test (as described in point 5.3 in the present Regulation), but with a warm engine with engine coolant temperature and/or engine oil temperature above 70 °C.

Commented [JRC-ISPRA12]: Same as previous comment

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

"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.

"Test end " means (Figure 4) that the vehicle has completed the trip and either when:
- the internal combustion engine is switched off;
or:
- for OVC-HEVs and NOVC-HEVS finishing the test with the internal combustion engine off, the vehicle stops and the speed is lower than or equal to 1 km/h.

"Test start" means (Figure 5) whichever occurs first from:
- the first ignition of the internal combustion engine;
- the first movement of the vehicle with speed greater than 1 km/h for OVC-HEVs and NOVC-HEVS.

"Validation of PEMS" means the process of evaluating the correct installation and functionality of a Portable Emissions Measurement System and the correctness of 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.

Figure 4 - Test start definition

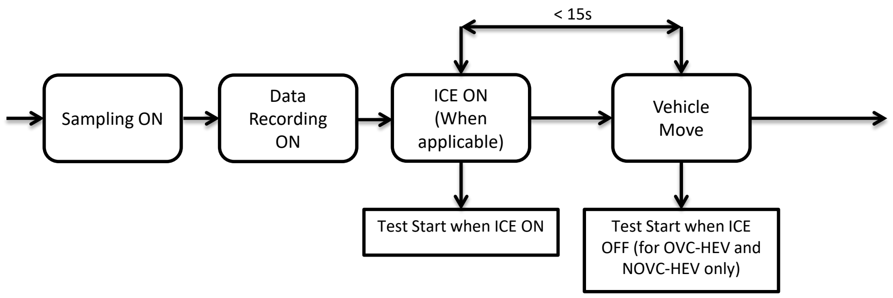
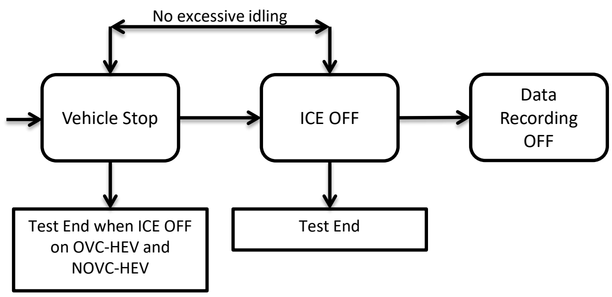


Figure 5 - Test end definition



Abbreviations

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

CH_4	—	Methane
CLD	—	ChemiLuminescence Detector
CO	—	Carbon Monoxide
CO_2	—	Carbon Dioxide
CVS	—	Constant Volume Sampler
DCT	—	Dual Clutch Transmission
ECU	—	Engine Control Unit
EFM	—	Exhaust mass Flow Meter
FID	—	Flame Ionisation Detector

FS	—	full scale
GPS	—	Global Positioning System
H_2O	—	Water
HC	—	HydroCarbons
HCLD	—	Heated ChemiLuminescence Detector
HEV	—	Hybrid Electric Vehicle
ICE	—	Internal Combustion Engine
ID	—	identification number or code
LPG	—	Liquid Petroleum Gas
MAW	—	Moving Average Window
max	—	maximum value
N_2	—	Nitrogen
NDIR	—	Non-Dispersive InfraRead analyser
NDUV	—	Non-Dispersive UltraViolet analyser
NEDC	—	New European Driving Cycle
NG	—	Natural Gas
NMC	—	Non-Methane Cutter
NMC-FID	—	Non-Methane Cutter in combination with a Flame-Ionisation Detector
NMHC	—	Non-Methane HydroCarbons
NO	—	Nitrogen Monoxide
No.	—	Number
NO_2	—	Nitrogen Dioxide
NO_X	—	Nitrogen Oxides
NTE	—	Not-to-exceed
O_2	—	Oxygen
OBD	—	On-Board Diagnostics

PEMS	—	Portable Emissions Measurement System
PHEV	—	Plug-in Hybrid Electric Vehicle
PN	—	particle number
RDE	—	Real Driving Emissions
RPA	—	Relative Positive Acceleration
SCR	—	Selective Catalytic Reduction
SEE	—	Standard Error of Estimate
THC	—	Total HydroCarbons
UN/ECE	—	United Nations Economic Commission for Europe
VIN	—	Vehicle Identification Number
WLTC	—	Worldwide harmonised Light vehicles Test Cycle
WWH-OBD	—	WorldWide Harmonised On-Board Diagnostics

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Section 3: Application for Approval

3.1. The application for approval of a vehicle type with regard to the requirements of this Regulation shall be submitted by the vehicle manufacturer or by their authorized representative to the Type Approval Authority.

3.1.1. The application referred to in paragraph 3.1. shall be drawn up in accordance with the model of the information document set out in Annex A1 to this Regulation.

Commented [RG 24111914]: Need to update to refer to the paperwork which will accompany the application

3.2. A vehicle representative of the vehicle type to be approved shall be submitted to the Technical Service responsible for the approval tests.

3.3. The manufacturer shall demonstrate that all vehicles within the PEMS family comply with UNR WLTP, including conformity of production requirements.

The manufacturer shall confirm compliance with this Regulation by completing the certificate set out in Appendix 9.

Section 4: Approval

4.1. If the vehicle type submitted for approval meets all the relevant requirements of paragraphs 5., 6., 7., 8. and 9. of this Regulation, approval of that vehicle type shall be granted.

4.2. An approval number shall be assigned to each type approved.

4.2.1. The type approval number shall consist of four sections. Each section shall be separated by the '*' character.

Section 1: The capital letter 'E' followed by the distinguishing number of the Contracting Party which has granted the type approval.

Section 2: The number [of this UN Regulation,] followed by the letter 'R', successively followed by:

(a) Two digits (with leading zeros as applicable) indicating the series of amendments incorporating the technical provisions of the UN Regulation applied to the approval (00 for the UN Regulation in its original form);

(b) A slash (/) and two digits (with leading zeros as applicable) indicating the number of supplement to the series of amendments applied to the approval (00 for the series of amendments in its original form);

Section 3: A four-digit sequential number (with leading zeros as applicable). The sequence shall start from 0001.

Section 4: A two-digit sequential number (with leading zeros if applicable) to denote the extension. The sequence shall start from 00.

All digits shall be Arabic digits.

4.2.2. Example of an Approval Number to this Regulation:

E11*[XXX]R01/00~~/02~~*0123*01

The first extension of the Approval numbered 0123, issued by the United Kingdom to Series of Amendments 01 ~~which is a Level 2 Approval~~.

4.2.3. The same Contracting Party shall not assign the same number to another vehicle type.

4.3. Notice of approval or of extension or refusal of approval of a vehicle type pursuant to this Regulation shall be communicated to the Contracting Parties to the 1958 Agreement which apply this Regulation by means of a form conforming to the model in Annex 1 to this Regulation.

4.3.1. In the event of amendment to the present text, for example, if new limit values are prescribed, the Contracting Parties to the 1958 Agreement shall be informed which vehicle types already approved comply with the new provisions.

4.4. There shall be affixed, conspicuously and in a readily accessible place specified on the approval form, to every vehicle conforming to a vehicle type approved under this Regulation, an international approval mark consisting of:

4.4.1. A circle surrounding the letter "E" followed by the distinguishing number of the country that has granted approval[1].

4.4.2. The number of this Regulation, followed by the letter "R", a dash and the approval number to the right of the circle described in paragraph 5.4.1.

4.5. If the vehicle conforms to a vehicle type approved, under one or more other Regulations annexed to the 1958 Agreement, in the country which has granted approval under this Regulation, the symbol prescribed in paragraph 5.4.1. need not be repeated; in such a case, the Regulation, approval numbers and the additional symbols of all the Regulations under which approval has been granted in the country which has granted approval under this Regulation shall be placed in vertical columns to the right of the symbol prescribed in paragraph 5.4.1.

4.6. The approval mark shall be clearly legible and be indelible.

4.7. The approval mark shall be placed close to or on the vehicle data plate.

4.7.1. Annex 2 to this Regulation gives examples of arrangements of the approval mark.

[1] The distinguishing numbers of the Contracting Parties to the 1958 Agreement are reproduced in Annex 3 to the Consolidated Resolution on the Construction of Vehicles (R.E.3), document ECE/TRANS/WP.29/78/Rev.3 – Annex 3, www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html.

Section 5: General Requirements

5.1 Compliance requirements

Throughout the normal life of a vehicle type approved according to this Regulation, its emissions at any possible RDE test performed in accordance with the requirements of this Regulation, divided by the relevant conformity factor specified in point 5.1.1, shall not be higher than all the relevant emission limits found in UNR WLTP (specify where).

The requirements of emission limits regulated by each Contracting Party shall be fulfilled for the urban part and the complete PEMS trip.

The RDE tests required by this Regulation provide a presumption of conformity with the requirement set out in point 2.1. The presumed conformity may be reassessed by additional RDE tests.

The RDE performance shall be demonstrated by testing vehicles on the road (or track) operated over their normal driving patterns, conditions and payloads. The RDE test shall be representative for vehicles operated on their real driving routes, with their normal load.

5.1.1. Conformity Factors

The Conformity factor for each pollutant is defined as 1+margin $_{pollutant}$., where margin of pollutant is a measure of the uncertainty of the PEMS measurements compared to the ones performed in the laboratory.

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

Pollutant	Mass of oxides of nitrogen (NO_x)	Number of particles (PN)	Mass of carbon monoxide (CO)[2]	Mass of total hydrocarbons (THC)	Combined mass of total hydrocarbons and oxides of nitrogen ($THC + NO_x$)
$margin_{pollutant}$	0,43	0,5	*unspecified*	*unspecified*	*unspecified*

5.2 Facilitation of PEMS testing

Contracting Party 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, e.g. by constructing the exhaust pipes in order to facilitate sampling of the exhaust, making available suitable adapters for exhaust pipes, providing guidance available online without the need of registration or login on how to attach a PEMS system to the exhaust pipe of vehicles approved under this Regulation, granting access to ECU signals [relevant to this Regulation] and making the necessary administrative arrangements. The measures taken by manufacturers shall be agreed upon with the Approval Authority.

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[For testing by independent parties the manufacturer shall also make available 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 publically accessible website.]

A contracting Party may choose, in case of difficulty to conduct RDE testing on public roads due to regional law, to use a test track following a driving situation recorded during a typical valid RDE test on the road. The validity of a test conducted in a test track will be judged on the actual test driven on the test track.

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5.3 *Selection of vehicles for PEMS testing*

Due to their particular characteristics, PEMS tests shall not be required for each '*vehicle type with regard to emissions*', hereinafter *'vehicle emission type'*. Several vehicle emission types may be put together by the vehicle manufacturer to form a '*PEMS test family*' in accordance with the requirements of point 3, which shall be validated in accordance with the requirements of point 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

5.3.1 PEMS TEST FAMILY BUILDING

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

Administrative criteria

- The approval authority issuing the emission type approval in accordance with …. ('authority')
- The manufacturer having received the emission type approval in accordance with…. ('manufacturer').

Technical criteria

- Propulsion type (e.g. ICE, HEV, PHEV)
- 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.
- Combustion process (e.g. two stroke, four stroke)
- Number of cylinders
- Configuration of the cylinder block (e.g. in-line, V, radial, horizontally opposed)

- 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.
- Method of engine fuelling (e.g. indirect or direct or combined injection)
- Type of cooling system (e.g. air, water, oil)
- Method of aspiration such as naturally aspirated, pressure charged, type of pressure charger (e.g. externally driven, single or multiple turbo, variable geometries …)
- Types and sequence of exhaust after-treatment components (e.g. three-way catalyst, oxidation catalyst, lean NOx trap, SCR, lean NOx catalyst, particulate trap).
- Exhaust gas recirculation (with or without, internal/external, cooled/non-cooled, low/high pressure)

4. VALIDATION OF A PEMS TEST FAMILY

4.1. General requirements for validating a PEMS test family

4.1.1. The vehicle manufacturer presents 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 Regulation.

4.1.2. The authority selects additional vehicles according to the requirements of point 4.2 of this Appendix for PEMS testing carried out by a Technical Service to demonstrate compliance of the selected vehicles with the requirements of this Regulation. The technical criteria for selection of an additional vehicle according to point 4.2. shall be recorded with the test results.

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 points 4.2.2 and 4.2.6 of this Appendix and in total at least 50 % of the PEMS tests required by this Appendix 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.

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

By selecting vehicles from a PEMS test family it should be ensured that the following technical characteristics relevant for pollutant emissions are covered by a PEMS test. One 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:

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

4.2.2. The manufacturer shall specify a value PMR_H (= highest power-to-reference mass-ratio of all vehicles in the PEMS test family) and a value PMR_L (= lowest power-to-reference 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. If the power-to-reference mass ratio of a vehicle deviates by not more than 5 % from the specified value for PMR_H, or PMR_L, the vehicle should be considered as representative for this value.

4.2.3. 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.

4.2.4. At least one four-wheel drive vehicle (4x4 vehicle) shall be selected for testing if such vehicles are part of the PEMS test family.

4.2.5. For each engine volume occurring on a vehicle in the PEMS family at least one representative vehicle shall be tested.

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

4.2.8. Notwithstanding the provisions in points 4.2.1 to 4.2.6, at least the following number of vehicle emission types of a given PEMS test family shall be selected for testing:

Number N of vehicle emission types in a PEMS test family	Minimum number NT of vehicle emission types selected for PEMS cold start testing	Minimum number NT of vehicle emission types selected for PEMS hot start testing
1	1	1[3]
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 x N[4]	2
more than 49	NT = 0,15 x N[5]	3

5. REPORTING

5.1. The vehicle manufacturer provides a full description of the PEMS test family, which includes in particular the technical criteria described in point 3.2 and submits it to the authority.

5.2. The manufacturer attributes a unique identification number of the format *AP-OEM-X-Y* to the PEMS test family and communicates it to the authority. Here *CP* is the distinguishing number of the Contracting Party issuing the EC type-approval[6], 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).

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.

Commented [DP19]: Rob to double check with family definition in WLTP….and move to section 4.

Commented [RG 24111920]: This is different to the Approval Number and so should not be ,moved to Section 4.

We should not include the CP number here.

As a comparator, UNR WLTP has :

Each of the vehicle families specified below shall be attributed a unique identifier of the following format:
FT-nnnnnnnnnnnnnnn-WMI
Where:
FT is an identifier of the family type:
- IP = Interpolation family as defined in paragraph 6.3.2. with or without using the interpolation method
- RL = Road load family as defined in paragraph 6.3.3.
- RM = Road load matrix family as defined in paragraph 6.3.4.
- PR = Periodically regenerating systems (K_i) family as defined in paragraph 6.3.5.
- AT = ATCT family as defined in paragraph 2. of Annex B6a.
- EV = Evaporative emissions family, as defined in paragraph 6.6.3.
- DF = Durability family, as defined in paragraph 6.7.5.
- OB = OBD family identifier, as defined paragraph 6.8.1.
- SR = SCR family identifier, as defined in paragraph 6.9.2.
- GV = GFV family identifier, as defined in paragraph 6.3.6.3.
- [OF = OBFCM family identifier, as defined in paragraph 6.3.7.]

nnnnnnnnnnnnnnn is a string with a maximum of fifteen characters, restricted to using the characters 0-9, A-Z and the underscore character '_'.
WMI (world manufacturer identifier) is a code that identifies the manufacturer in a unique manner defined in ISO 3780:2009.
It is the responsibility of the owner of the WMI to ensure that the combination of the string nnnnnnnnnnnnnnn and the WMI is unique to the family and that the string nnnnnnnnnnnnnnn is unique within that WMI to the approval tests performed to obtain the approval.

For each emission type all corresponding combinations of vehicle type approval numbers, types, variants and versions shall be provided as well.

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 4, which also provides the necessary information on how the selection criteria of point 4.2 are covered. This list shall also indicate whether the provisions of point 4.1.3 were applied for a particular PEMS test.

A PEMS test results 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 Regulation 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;

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.

Section 6: Performance Requirements for instrumentation

The instrumentation used for RDE tests shall comply with the requirements found in Annex 4.

Section 7: Test Conditions

Only an RDE test performed according to the conditions specified in this Section shall be accepted as valid. Tests performed outside the test conditions specified in this Section shall be considered as invalid.

7.1. Ambient conditions

The test shall be conducted under ambient conditions laid down in this section. The ambient conditions become 'extended' when at least one of the temperature and altitude conditions is extended. The correction factor for extended conditions for temperature and altitude shall only be applied once. If a part of the test or the entire test is performed outside of normal or extended conditions, the test shall be invalid only when emissions do not fulfil the applicable regional requirement. The conditions are as follows;

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).

7.2. 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 verification of the normality of dynamic conditions shall be done after the test is completed, using the recorded PEMS data. This verification shall be conducted in 2 steps:

- The excess or insufficiency of driving dynamics during the trip shall be checked using the methods described in Annex 9.
- If the trip results are valid following the verifications in accordance with the previous point, the methods for verifying the normality of the test conditions as laid down in Annexes 7, 8 and 10 shall be applied.

Commented [DP21]: JRC, please double check the Annex numbers

7.3. Vehicle condition and operation

7.3.1 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. In case a vehicle has a "race" mode, to be used only on test tracks, this mode shall not be used, as safety features might be disabled.

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. [The tyre profile depth should be verified according to the recommendations of customer safety associations (e.g. ADAC), but should have at least 3mm of tread depth for summer tyres and 4 mm for winter tyres.] Driving the vehicle with snow chains is not permitted.
Vehicles should not be tested with an empty battery. In case the vehicle has problems starting, the battery shall be replaced following the recommendations of the vehicle's manufacturer.

Commented [o22]: For Reg 83

Commented [o23]: Define that it is not the traction battery

The vehicle's test mass comprising 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 shall be between the actual mass of the vehicle and the maximum allowable test mass of the vehicle at the beginning of 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. In case of need, 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 GPS data and potentially further vehicle data parameters like engine speed, gear, accelerator pedal position etc.

Commented [DP24]: JRC to check guidance & Q-A doc if there is something to be copied.

7.3.2 Vehicle conditioning for cold engine-start testing

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

The vehicle shall be driven, 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). The vehicle shall then be parked with doors and bonnet closed and kept in engine-off status within moderate or extended altitude and temperatures in accordance with points 5.2.2 to 5.2.6 between 6 and 56 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 absence of warning signals, suggesting malfunctioning. In the case of a malfunction the source of the malfunctioning shall be identified and corrected or the vehicle shall be rejected.

Commented [PG25]: Add comma to ensure no confusion about 'rural motorway'

7.3.3. 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.

7.3.4. Vehicles equipped with periodically regenerating systems

All results shall be corrected with the K_i factors or with the K_i offsets developed by the procedures in Appendix 1 to sub-annex 6 of Annex XXI 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 6.

If the emissions do not fulfil the regional requirements, 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 applicable, if the vehicle has a regeneration recognition feature declared in Transparency List 1 set out in Table 1 of Appendix 5 to Annex II, it shall be used to determine the occurrence of regeneration. The manufacturer shall also declare in Transparency List 1 of set out in Table 1 of Appendix 5 to Annex II the procedure needed in order to complete the regeneration. The manufacturer may advise how to recognise whether regeneration has taken place in case such a signal is not available.

If regeneration occurred during the test, the result without the application of either the K_i -factor or the K_i offset shall be checked against the regional requirements. If the resulting emissions do not fulfil the requirements, then the test shall be voided and repeated once. The completion of the regeneration and stabilisation through ~~aproximately~~approximately 1 hour of driving shall be ensured prior to the start of the second test. The second test is considered valid even if regeneration occurs during it.

Even if the vehicle fulfils the requirements of point 3.1.0, the occurrence of regeneration may be verified as in point 5.5.2.3 above. 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.

7.3.5. Other

RDE tests shall be conducted on paved roads (e.g. off road operation is not permitted).

7.4 OPERATIONAL REQUIREMENTS of PEMS

The trip shall be selected in such a way that the testing is uninterrupted and the data continuously recorded to reach the minimum test duration defined in point 6.10.

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 influence the vehicle emissions or performance or both to the minimum extent possible. Care should be exercised to minimis~~z~~e the mass of the installed equipment and potential aerodynamic modifications of the test vehicle. The vehicle payload shall be in accordance with point 5.1.

Commented [M26]: Please change the reference to GTR 15 or UNR.

Commented [o27]: Change reference to WLTP UNR

Commented [M28]: Manufacturers may be able to take signals such as OBD and Raw CAN, but it may be difficult for some third parties.

During type approval, a validation test in the laboratory shall be performed before running an RDE test according to point xxxx.

Commented [DP29]: JRC to double check whether we have text that covers this, or we should copy something from the Guidance.

7.5 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 UNR WLTP, or otherwise within the specifications recommended by the manufacturer for vehicle operation by the customer. The reagent and lubricant used shall be within the specifications recommended or issued by the manufacturer.

In case where reference fuel, lubricant and reagent was not used, and the RDE test has failed, 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 but the analysis shall be retained in the test report.

At the option of the Contracting Party, the motor vehicle manufacturer, etc. shall submit to the testing institute a document describing the property of fuel, lubricating oil and reagent (limited only to cases where they are used).

Section 8: Test Procedure

8.1 TYPES OF OPERATION BASED ON SPEED

Urban operation is characterised by vehicle speeds lower than or equal to 60 km/h. The average speed (including stops) of the urban driving part of the trip should be between 15 and 40 km/h.

Rural operation 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 operation is characterised by vehicle speed higher than 60 km/h and lower than or equal to 80 km/h.

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

Commented [DP30]: In EU we need to deal with vehicles that cannot drive more than 100 km/h.

For M2 category vehicles that are equipped with a device permanently limiting vehicle speed to 100 km/h, the speed range of the motorway driving 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.

[In the case that for the specific vehicle being tested, the local speed limits prevent compliance with the requirements of this paragraph, the requirements of paragraph 6.9.1. shall apply:

Commented [o31]: To rephrase in order to limit for specific cases

6.9.1. 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.]

Medium operation is characterised by speeds above 60 km/h and up to 100 km/h.

8.2 Shares of trip operations

The following composition of the trip operation broadly reflects the operation in contracting parties applying WLTC 4 and 3 phases:

The Contracting Party applying WLTC 4 phases	The Contracting Party applying WLTC 3 phases
The trip shall consist of approximately 34 % per cent urban, 33 % per cent rural and 33 % per cent motorway operation. 'Approximately' shall mean the interval of ±10 per cent points around the stated percentages. The urban operation shall however never be less than 29% of the total trip distance.	The trip shall consist of approximately 55 % per cent urban and 45 % per cent medium operation. 'Approximately' shall mean the interval of ±10 per cent points around the stated percentages. The urban operation however can be lower than 45% but never be less than 40% of the total trip distance.

8.3 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.

An RDE trip shall be driven in order to prove compliance with the emission requirements for Contracting Parties applying the WLTC4 and WLTC3 phases. The design of the trip shall be such as to comprise driving that would in principle cover all of the requirements. In case, that a single trip is not capable of complying with all requirements described in Section 7, paragraph 8.2. and 8.3. to Section 8, paragraph 4.5.1. and 4.5.2. to Annex 7 and paragraph 4 to Annex 9 simultaneously, then a second RDE trip shall be done. During the second RDE trip, the phase requirements which were not satisfied in the first RDE trip shall be satisfied. During the second trip, it is not necessary to re-evaluate the requirements which were satisfied during the first trip.

The shares of urban, rural and motorway operation shall be expressed as a percentage of the total trip distance for Contracting Parties applying the WLTC4 phases. The shares of urban and medium operation shall be expressed as a percentage of the trip distance with velocity not exceeding 100km/h for Contracting Parties applying the WLTC3 phases.

The trip shall always start with urban driving followed by rural, motorway and medium operation in accordance with the required shares in point 8.2. 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 operation when driving through urban areas. Motorway operation may be interrupted by short periods of urban or rural operation, e.g., when passing toll stations or sections of road work.

The vehicle velocity 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 % of the time duration of the motorway driving. 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 % of the time duration of urban operation. Urban operation may contain several stop periods of 10 s or longer. However, individual stop periods shall not exceed 300 consecutive seconds; else the trip shall be voided. If stop periods in urban driving part are over 30% 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 point 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 part of the trip as determined in accordance with point 4.3 shall be less than 1200 m/100 km and be determined in accordance with Annex 10.

The minimum distance of each, the urban, rural and motorway operation shall be 16 km.

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 as defined in point 5.1. of Appendix 1, the vehicle shall move within 15 seconds. The vehicle stop during the entire cold start period, as defined in point 4 of Appendix 4, shall be kept to the minimum possible and it shall not exceed in total 90 s. If the engine stalls during the test, it may be restarted, but the sampling shall not be interrupted. If the engine stops during the test, the sampling shall not be interrupted.

Commented [DP32]: Add clear instructions later at which point the data higher than 100 km/h are taken out.

Commented [M33]: For WLTP 3-phases, use only 100km/h or less data.

Commented [M34]: Delete.
Because, these requirements are same for WLTC4 and WLTC3 phases.

8.4 Hot start trip

In order to also assess emissions during trips in hot start, a certain number of vehicles per PEMS test family, shall be tested without conditioning the vehicle as described in point 5.3, but with a warm engine with engine coolant temperature and/or engine oil temperature above 70 °C.

8.4 Other trip requirements

The exhaust mass flow shall be determined by measurement equipment functioning independently from the vehicle and no vehicle ECU data shall be used in this respect.

If the approval authority is not satisfied with the data quality check and validation results of a PEMS test conducted in accordance with Appendices 1 and 4, the approval authority may consider the test to be void. In such case, the test data and the reasons for voiding 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 payload and ambient conditions requirements, as specified in points 5.1 and 5.2, 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 environments meeting the requirements of point 8.2. 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 1 and 2, through a direct inspection or an analysis of the supporting evidence (e.g. photographs, records).

8.5 Compliance of software tools

For the software tool used to verify the trip validity and calculate emissions compliance with the provisions laid down in Appendices 4, 5, 6, 7a, and 7b shall be validated by an entity defined by the Contracting Party. Where such software tool is incorporated in the PEMS instrument, proof of the validation shall be provided along with the instrument.

Section 9: Test Data Analysis

9.1 EMISSIONS AND TRIP EVALUATION

9.1. The test shall be conducted in accordance with Annex 3.

9.2. The trip validity shall be verified in a three-step procedure as follows:

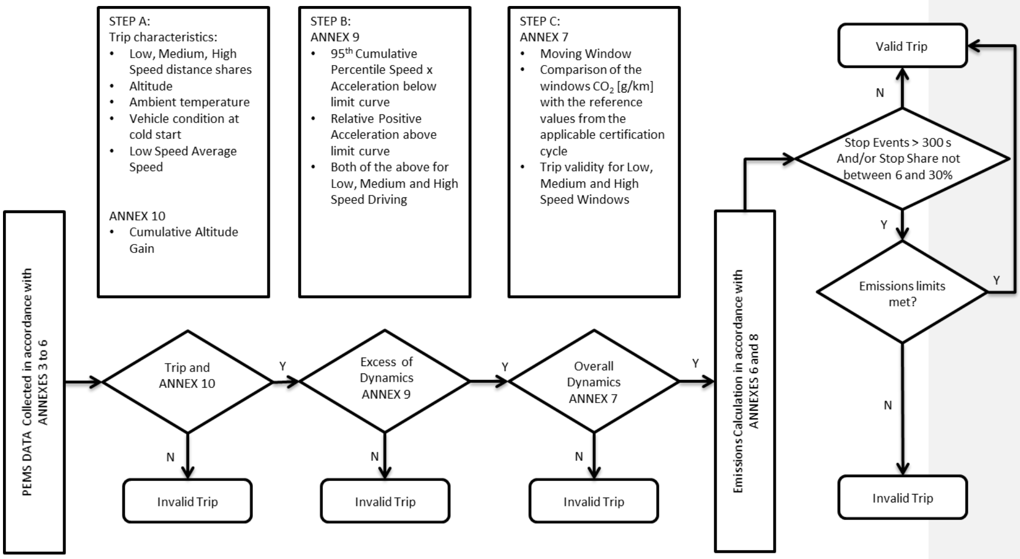
STEP A: The trip complies with the general requirements, boundary conditions, trip and operational requirements, and the specifications for lubricating oil, fuel and reagents set out in Section 7 and 8;

STEP B: The trip complies with the requirements set out in Annexes 9 and 10.

STEP C: The trip complies with the requirements set out in Annex 7.

The steps of the procedure are detailed in Figure 1.

Figure 1. Verification of trip validity



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

The final test results shall be 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. Intermediate steps in the calculations shall not be rounded.

9.3. It shall not be permitted to combine data of different trips or to modify or remove data from a trip.

9.4. After establishing the validity of a trip in accordance with point 9.2, emission results shall be calculated using the methods laid down in ANNEX 6 and ANNEX 8. The emissions calculations shall be made between test start and test end, as defined in ANNEX 3, points 5.1. and 5.3. respectively.

9.5. If during a particular time interval the ambient conditions are extended in accordance with point 5.2, the pollutant emissions during this particular time interval, calculated according to Annex 6, shall be divided by a value of 1,6 before being evaluated for compliance with the requirements of this Regulation. This provision does not apply to carbon dioxide emissions.

9.6. Gaseous pollutant and particle number emissions during cold start, as defined in point 4 of ANNEX 6, shall be included in the normal evaluation in accordance with ANNEXES 6,7 and 8.

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 point 5.2, then the provisions of point 9.5 apply to the data collected during the cold start period, even if the running conditions are not within the extended temperature range.

Section 10: Modifications and extensions to Type Approval

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 points 3 and 4. This may in particular require the PEMS testing of additional vehicles to validate the extended PEMS test family according to point 4.

Rob: Is text needed for modification of TA?

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Section 11: Conformity of Production

The conformity of production of emissions is already covered by the rules specified in Regulation UNR WLTP. Therefore, there is no specific need to repeat conformity of production for vehicles covered by both UNR WLTP and UNR RDE.

Commented [DP35]: OICA to propose rewording

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Section 12: Penalties for non-conformity of production

12.1. The approval granted in respect of a vehicle type pursuant to this Regulation, may be withdrawn if the requirements laid down in paragraph 11. are not complied with.

Commented [RG 24111936]: May need a different form of wording given that there is no RDE CoP

12.2. If a Contracting Party to the 1958 Agreement which applies this Regulation withdraws an approval it has previously granted, it shall forthwith so notify the other Contracting Parties applying this Regulation, by means of a communication form conforming to the model in Annex 1 to this Regulation.

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Section 13: Production definitively discontinued

If the holder of the approval completely ceases to manufacture a type of vehicle approved in accordance with this Regulation, they shall so inform the Type Approval Authority which granted the approval. Upon receiving the relevant communication, that authority shall inform thereof the other Contracting Parties to the 1958 Agreement applying this Regulation by means of copies of the communication form conforming to the model in Annex A2 to this Regulation.

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Section 14: Names and Addresses of Technical Services

The Contracting Parties to the 1958 Agreement which apply this Regulation shall communicate to the United Nations Secretariat the names and addresses of the Technical Services responsible for conducting approval tests and of the Type Approval Authorities which grant approval and to which forms certifying approval or extension or refusal or withdrawal of approval, issued in other countries, are to be sent.

Submitted by the expert from European Commission

Informal document **GRPE-80-31**
80th GRPE,14-17 January 2020
Agenda item 3.(c)

ANNEX 1: Communication

(maximum format: A4 (210 x 297 mm))

issued by: Name of administration:

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....
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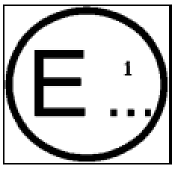
....



Concerning:[2] Approval granted
Approval extended
Approval refused
Approval withdrawn
Production definitively discontinued

of a vehicle type with regard to the emission of gaseous pollutants by the engine pursuant to UN Regulation No. RDE

Approval No. ……….................................

Reason for extension :……………………

Section I

0.1. Make (trade name of manufacturer): ....

0.2. Type: ....

0.2.1. Commercial name(s) (if available): ....

0.3. Means of identification of type if marked on the vehicle[3]

0.3.1. Location of that marking: ....

0.4. Category of vehicle:[4] ....

0.5. Name and address of manufacturer: ....

0.8. Name(s) and address(es) of assembly plant(s): ....

0.9. If applicable, name and address of manufacturer's representative: ....

1.0. Remarks: …

Section II

[1] Distinguishing number of the country which has granted/extended/refused/withdrawn approval (see approval provisions in the Regulation).

[2] Strike out what does not apply.

[3] If the means of identification of type contains characters not relevant to describe the vehicle, component or separate technical unit types covered by this information document, such characters shall be represented in the documentation by the symbol '?' (e.g. ABC??123??).

[4] As defined in the Consolidated Resolution on the Construction of Vehicles (R.E.3.), document ECE/TRANS/WP.29/78/Rev.3, para. 2. - www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html.

Field Code Changed

1. Additional information (where applicable): (see addendum)
2. Technical Service responsible for carrying out the tests: ....
3. ~~Date of Type 1 test report~~: ....
4. ~~Number of Type 1 test report~~: ....
5. Remarks (if any): (see addendum)
6. Place:...
7. Date:..
8. Signature: ....

Attachments: 1. Information package.

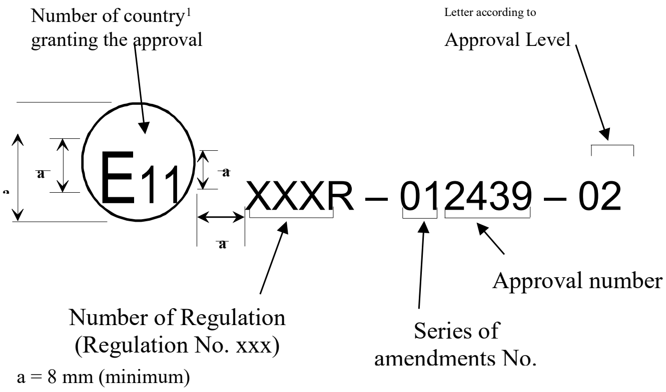
2. Test reports.

ANNEX 2: Arrangement of the Approval Mark

In the approval mark issued and affixed to a vehicle in conformity with paragraph 4. of this Regulation, the type approval number shall be accompanied by an alphanumeric character reflecting the level that the approval is limited to.

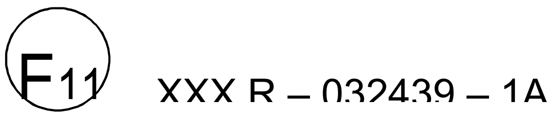
This annex outlines the appearance of this mark and gives an example how it shall be composed.

The following schematic graphic presents the general lay-out, proportions and contents of the marking. The meaning of numbers and alphabetical character are identified, and sources to determine the corresponding alternatives for each approval case are also referred.



a = 8 mm (minimum)

The following graphic is a practical example of how the marking should be composed.



[1] Number of country according to footnote in paragraph 5.4.1. of this Regulation.

ANNEX 3

TEST PROCEDURE FOR VEHICLE EMISSIONS TESTING WITH A PORTABLE EMISSIONS MEASUREMENT SYSTEM (PEMS)

1. INTRODUCTION

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

2. SYMBOLS, PARAMETERS AND UNITS

Commented [DP37]: Transfer all at beginning

≤	—	smaller or equal
#	—	number
#/m³	—	number per cubic metre
%	—	per cent
°C	—	degree centigrade
g	—	gramme
g/s	—	gramme per second
h	—	hour
Hz	—	hertz
K	—	kelvin
kg	—	kilogramme
kg/s	—	kilogramme per second
km	—	kilometre
km/h	—	kilometre per hour
kPa	—	kilopascal
kPa/min	—	kilopascal per minute
l	—	litre
l/min	—	litre per minute
m	—	metre
m³	—	cubic-metre

mg	—	milligram
min	—	minute
p_e	—	evacuated pressure [kPa]
q_{vs}	—	volume flow rate of the system [l/min]
ppm	—	parts per million
ppmC$_1$	—	parts per million carbon equivalent
rpm	—	revolutions per minute
s	—	second
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 points 3.1.1 to 3.1.5. If applicable, a connection with the vehicle ECU may be established to determine relevant engine and vehicle parameters as specified in point 3.2.

3.1.1. Analysers to determine the concentration of pollutants in the exhaust gas.

3.1.2. One or multiple instruments or sensors to measure or determine the exhaust mass flow.

3.1.3. A Global Positioning System to determine the position, altitude and, speed of the vehicle.

3.1.4. If applicable, sensors and other appliances being not part of the vehicle, e.g., to measure ambient temperature, relative humidity, air pressure, and vehicle speed.

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

3.2. Test parameters

Test parameters as specified in Table 1 of this Appendix shall be measured at a constant frequency of 1,0 Hz or higher and recorded and reported in accordance with the requirements of Appendix 8 at a frequency of 1,0 Hz. If ECU parameters are 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 2 and 3.

Table 1		
Test parameters		
Parameter	Recommended unit	Source[7]

7 Multiple parameter sources may be used.

THC concentration[8],[9] (if applicable)	ppm C_1	Analyser
CH_4 concentration[10],[11] (if applicable)	ppm C_1	Analyser
NMHC concentration[12],[13] (if applicable)	ppm C_1	Analyser[14]
CO concentration[15],[16]	Ppm	Analyser
CO_2 concentration[17]	Ppm	Analyser
NO_X concentration[18],[19]	Ppm	Analyser[20]
PN concentration[21]	$\#/m^3$	Analyser
Exhaust mass flow rate	kg/s	EFM, any methods described in point 7 of Appendix 2
Ambient humidity	%	Sensor
Ambient temperature	K	Sensor
Ambient pressure	kPa	Sensor
Vehicle speed	km/h	Sensor, GPS, or ECU[22]
Vehicle latitude	Degree	GPS
Vehicle longitude	Degree	GPS
Vehicle altitude[23],[24]	M	GPS or Sensor
Exhaust gas temperature[25]	K	Sensor

8 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
9 parameter only mandatory if measurement required by Annex IIIA, section 2.1
10 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
11 parameter only mandatory if measurement required by Annex IIIA, section 2.1
12 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
13 parameter only mandatory if measurement required by Annex IIIA, section 2.1
14 may be calculated from THC and CH_4 concentrations according to point 9.2 of Appendix 4
15 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
16 parameter only mandatory if measurement required by Annex IIIA, section 2.1
17 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
18 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
19 parameter only mandatory if measurement required by Annex IIIA, section 2.1
20 may be calculated from measured NO and NO_2 concentrations
21 parameter only mandatory if measurement required by Annex IIIA, section 2.1
22 method to be chosen according to point 4.7
23 to be determined only if necessary to verify the vehicle status and operating conditions
24 The preferable source is the ambient pressure sensor.
25 to be determined only if necessary to verify the vehicle status and operating conditions

Engine coolant temperature[26]	K	Sensor or ECU
Engine speed[27]	Rpm	Sensor or ECU
Engine torque[28]	Nm	Sensor or ECU
Torque at driven axle[29] (if applicable)	Nm	Rim torque meter
Pedal position[30]	%	Sensor or ECU
Engine fuel flow[31] (if applicable)	g/s	Sensor or ECU
Engine intake air flow[32] (if applicable)	g/s	Sensor or ECU
Fault status[33]	—	ECU
Intake air flow temperature	K	Sensor or ECU
Regeneration status[34] (if applicable)	—	ECU
Engine oil temperature[35]	K	Sensor or ECU
Actual gear[36]	#	ECU
Desired gear (e.g. gear shift indicator)[37]	#	ECU
Other vehicle data[38]	unspecified	ECU

[26] to be determined only if necessary to verify the vehicle status and operating conditions
[27] to be determined only if necessary to verify the vehicle status and operating conditions
[28] to be determined only if necessary to verify the vehicle status and operating conditions
[29] to be determined only if necessary to verify the vehicle status and operating conditions
[30] to be determined only if necessary to verify the vehicle status and operating conditions
[31] to be determined only if indirect methods are used to calculate exhaust mass flow rate as described in paragraphs 10.2 and 10.3 of Appendix 4
[32] to be determined only if indirect methods are used to calculate exhaust mass flow rate as described in paragraphs 10.2 and 10.3 of Appendix 4
[33] to be determined only if necessary to verify the vehicle status and operating conditions
[34] to be determined only if necessary to verify the vehicle status and operating conditions
[35] to be determined only if necessary to verify the vehicle status and operating conditions
[36] to be determined only if necessary to verify the vehicle status and operating conditions
[37] to be determined only if necessary to verify the vehicle status and operating conditions
[38] to be determined only if necessary to verify the vehicle status and operating conditions

3.3. Preparation of the vehicle

The preparation of the vehicle shall include a general verification of the correct technical functioning of the test vehicle. As a minimum the following checks shall be performed:

Checks for selection of Vehicles for PEMS Emissions Testing

			Confidential
Date:			x
Name of investigator:			x
Location of test:			x
Country of registration:		x	

Vehicle Characteristics	x = Exclusion Criteria	X = Checked and reported	
Registration plate number:		x	x
Mileage: *The vehicle must have more than 3 000 km*	x		
Date of first registration:		x	

VIN:		x	
Emission class and character or Model Year		x	
Country of registration: *The vehicle must be registered in a CP*	x	x	
Model:		x	
Engine code:		x	
Engine volume (l):		x	
Engine power (kW):		x	
Gearbox type (auto/manual):		x	
Drive axle (FWD/AWD/RWD):		x	
Tyre size (front and rear if different):		x	
Is the vehicle involved in a recall or service campaign? If yes: Which one? Has the campaign repairs already been done? *The repairs must have been done*	x	x	

Vehicle Owner Interview

(the owner will only be asked the main questions and shall have no knowledge of the implications of the replies)

Name of the owner (only available to the accredited inspection body or laboratory/technical service)			x
Contact (address / telephone) (only available to the accredited inspection body or laboratory/technical service)			x

How many owners did the vehicle have?		**x**	
Did the odometer not work? *If yes, the vehicle cannot be selected.*	**x**		
Was the vehicle used for one of the following?			
As car used in show-rooms?		**x**	
As a taxi?		**x**	
As delivery vehicle?		**x**	
For racing / motor sports?	**x**		
As a rental car?		**x**	
Has the vehicle carried heavy loads over the specifications of the manufacturer? *If yes, the vehicle cannot be selected.*	**x**		
Have there been major engine or vehicle repairs?		**x**	
Have there been unauthorised major engine or vehicle repairs? *If yes, the vehicle cannot be selected.*	**x**		
Has there been a power increase/tuning? *If yes, the vehicle cannot be selected.*	**x**		
Was any part of the emissions after-treatment replaced? Were original parts used? *If original parts were not used, the vehicle cannot be selected.*	**x**	**x**	
Was any part of the emissions after-treatment system removed or disabled? *If yes, the vehicle cannot be selected*	**x**		
Were there any unauthorised devices installed (Urea killer, emulator, etc)? *If yes, the vehicle cannot be selected*	**x**		
Was the vehicle involved in a serious accident? Provide a list of damage and repairs done afterwards		**x**	

Has the car been used with a fuel type not specified by the manufacturer (i.e. gasoline instead of diesel) in the past? Has the car been used with non-commercially available fuel (black market, or blended fuel?) *If yes, the vehicle cannot be selected.*	**x**		
Where do you use your vehicle more often?	-	-	-
% motorway	-	**x**	-
% rural	-	**x**	-
% urban	-	**x**	-
Did you drive the vehicle in a non CP for more than 10% of driving time? *If yes, the vehicle cannot be selected*	**x**	**-**	-
In which country was the vehicle refuelled during the last two times? *If the vehicle was refuelled the last two times outside a state applying the relevant Fuel Standards, the vehicle cannot be selected.*	**x**		
Has a fuel additive, not approved by the manufacturer been used? *If yes then the vehicle cannot be selected.*	**x**		
Has the vehicle been maintained and used in accordance with the manufacturer's instructions? *If not, the vehicle cannot be selected.*	**x**		
Full service and repair history including any re-works *If the full documentation cannot be provided, the vehicle cannot be selected.*	**x**		

	Vehicle Examination and Maintenance	**X= Exclusion Criteria / F= Faulty Vehicle**	**X=checked and reported**
1	**Fuel tank level (full / empty)** Is the fuel reserve light ON? *If yes, refuel before test.*		**x**
2	**Are there any warning lights on the instrument panel activated indicating a vehicle or exhaust after-treatment system malfunctioning that cannot be resolved by normal maintenance? (Malfunction Indication Light, Engine Service Light, etc?)** *If yes, the vehicle cannot be selected*	**x**	
3	**Is the SCR light on after engine-on?** *If yes, the reagent should be filled, or the repair executed before the vehicle is used for testing.*	**x**	

4	**Visual inspection exhaust system** Check leaks between exhaust manifold and end of tailpipe. Check and document (with photos) *If there is damage or leaks, the vehicle cannot be tested*	x	
5	**Exhaust gas relevant components** Check and document (with photos) all emissions relevant components for damage. *If there is damage, the vehicle cannot be tested*	x	
7	**Fuel sample** Collect fuel sample from non-pressurised fuel tanks		x
8	**Air filter and oil filter** Check for contamination and damage. Change if damaged or heavily contaminated or less than 800 km before the next recommended change.		x
10	**Wheels (front & rear)** Check whether the wheels are freely moveable or blocked or impeded by the brake. *If not freely moveable, the vehicle cannot be selected.*	x	
12	**Drive belts & cooler cover** *In case of damage, the vehicle cannot be tested.*	x	
13	**Check fluid levels** Check the max. and min. levels (engine oil, cooling liquid) / top up if below minimum		x
15	**Vacuum hoses and electrical wiring** Check all for integrity. *In case of damage, the vehicle cannot be tested.*	x	
16	**Injection valves / cabling** Check all cables and fuel lines. *In case of damage, the vehicle cannot be tested.*	x	
17	**Ignition cable (gasoline)** Check spark plugs, cables, etc. In case of damage, replace them.		x
18	**EGR & Catalyst, Particle Filter** Check all cables, wires and sensors. *In case of tampering or damage, the vehicle cannot be selected.*	x	
19	**Safety condition** Check tyres, vehicle's body, electrical and braking system status are in safe conditions for the test and respect road traffic rules. *If not, the vehicle cannot be selected.*	x	
20	**Semi-trailer** Are there electric cables for semi-trailer connection, where required?		x
21	**Aerodynamic modifications** Verify no aftermarket aerodynamic modifications that cannot be removed before testing were made (roof boxes, load racking, spoilers, etc.) and no standard aerodynamics components are missing (front deflectors, diffusers, splitters, etc.).	x	

Commented [G[38]: We added "liquid" to address natural gas. Any special consideration for propane, which is in liquid state under pressure in the tank?

	The vehicle cannot be selected if it is not in stock aerodynamic configuration and cannot be returned to that configuration before testing. Document with photos.		
22	**Check if less than 800 km away from next scheduled service, if yes, then perform the service.**		x
23	**All checks requiring OBD connections to be performed before and/or after the end of testing**		
24	**Powertrain Control Module calibration part number and checksum**		x
25	**OBD diagnosis (before or after the emissions test)** Read Diagnostic Trouble Codes & Print error log		x
26	**OBD Service Mode 09 Query (before or after the emissions test)** Read Service Mode 09. Record the information.		x
27	**OBD mode 7 (before or after the emissions test)** Read Service Mode 07. Record the information		

Remarks for: Repair / replacement of components / part numbers

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 during the test electromagnetic interferences as well as exposure to shocks, vibration, dust and variability in temperature. The installation and operation of the PEMS shall be leak-tight and minimise heat loss. The installation and operation of PEMS shall not change the nature of the exhaust gas nor unduly increase the length of the tailpipe. To avoid the generation of particles, connectors shall be thermally stable at the exhaust gas temperatures expected during the test. It is recommended 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 at high engine load.

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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*

Commented [o39]: Review whether extra clauses are needed from OICA guidance points

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

3.4.4. *Global Positioning System (GPS)*

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

3.4.5. *Connection with the Engine Control Unit (ECU)*

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

3.4.6. *Sensors and auxiliary equipment*

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

3.5. Emissions sampling

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

If the engine is equipped with an exhaust after-treatment system, the exhaust sample shall be taken downstream of the exhaust after-treatment system. When testing a vehicle with a branched exhaust manifold, the inlet of the sampling probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions of all cylinders. In multi-cylinder engines, having distinct groups of manifolds, such as in a ‘V’ engine configuration, the sampling probe shall be positioned downstream of where the manifolds combine. If this is technically not feasible, multi-point sampling at locations of well-mixed exhaust may be used. 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, the exhaust 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.

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 corresponding to the pressure decrease provided that the sampling system ensures a penetration efficiency of 95 % for all regulated gaseous pollutants. If particles are sampled and not diluted at the tailpipe, the sampling line from the raw exhaust sample point to the point of dilution or particle detector shall be heated to a minimum of 373 K (100 °C). The residence time of the sample in the particle sampling line shall be less than 3 s until reaching first dilution or the particle detector.

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

4. PRE-TEST PROCEDURES

4.1. PEMS leak check

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

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

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

$(\Delta p)(p_e V_s\ q_{vs}\ 0.005)$Alternatively, a concentration step change at the beginning of the sampling line shall be introduced by switching from zero to span gas while maintaining the same pressure conditions as under 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 point 5 of Appendix 2. The calibration gases shall be chosen to match the range of pollutant concentrations expected during the RDE test. To minimize analyser drift, one should conduct the zero and span calibration of analysers at an ambient temperature that resembles, as closely as possible, the temperature experienced by the test equipment during the trip.

4.6. Checking the analyser for measuring particle emissions

The zero level of the analyser shall be recorded by sampling HEPA filtered ambient air at an appropriate sampling point, usually at the inlet of the sampling line. The signal shall be recorded at a constant frequency which is a multiple of 1,0 Hz averaged over a period of 2 minutes; the final concentration shall be within the manufacturer’s specifications, but shall not exceed 5000 particles per cubic-centimetre.

4.7. Determining vehicle speed

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

(a) a GPS; if vehicle speed is determined by a GPS, the total trip distance shall be checked against the measurements of another method according to point 7 of Appendix 4.

(b) a sensor (e.g., optical or micro-wave sensor); if vehicle speed is determined by a sensor, the speed measurements shall comply with the requirements of point 8 of Appendix 2, or alternatively, the total trip distance determined by the sensor shall be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the sensor shall deviate by no more than 4 % from the reference distance.

(c) the ECU; if vehicle speed is determined by the ECU, the total trip distance shall be validated according to point 3 of Appendix 3 and the ECU speed signal adjusted, if necessary to fulfil the requirements of point 3.3 of Appendix 3. Alternatively, the total trip distance as determined by the ECU can be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the ECU shall deviate by no more than 4 % from the reference.

4.8. Check of PEMS set up

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

5. EMISSIONS TEST

5.1. Test start

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

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

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 that indicates mechanical problems) 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 voided. Parameter recording shall reach a data completeness of higher than 99 %. Measurement and data recording may be interrupted for less than 1 % of the total trip duration but for no more than a consecutive period of 30 s solely in the case of unintended signal loss or for the purpose of PEMS system maintenance. Interruptions may be recorded directly by the PEMS 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 until the response time of the sampling systems has elapsed. For vehicles with a signal detecting regeneration (see line 42 in the Transparency List 1 in Appendix 5 of Annex II), 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 point 4.5 to evaluate the analyser's zero and response drift compared to the pre-test calibration. It is permissible to zero the analyser prior to verifying the span drift, if the zero drift was determined to be within the permissible range. The post-test drift check shall be completed as soon as possible after the test and before the PEMS, or individual analysers or sensors, are turned off or have switched into a non-operating mode. The difference between the pre-test and post-test results shall comply with the requirements specified in Table 2.

Table 2

Permissible analyser drift over a PEMS test

Pollutant	Absolute Zero response drift	Absolute Span response drift[39]
CO_2	≤ 2000 ppm per test	≤ 2 % of reading or ≤ 2000 ppm per test, whichever is larger
CO	≤ 75 ppm per test	≤ 2 % of reading or ≤ 75 ppm per test, whichever is larger
NO_X	≤ 5 ppm per test	≤ 2 % of reading or ≤ 5 ppm per test, whichever is larger
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 voided and the test repeated.

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

6.2. Checking the analyser for measuring particle emissions

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

6.3. Checking the on-road emission measurements

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

Submitted by the expert from European Commission

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80th GRPE,14-17 January 2020
Agenda item 3.(c)

ANNEX 4

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

Commented [DP40]: Move at beginning of text

>	—	larger than
≥	—	larger than or equal to
%	—	per cent
≤	—	smaller than or equal to
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
$c_{FS,b}$	—	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) [$ppmC_1$]
°C	—	degree centigrade
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]
G	—	gram
gH_2O/kg	—	gramme water per kilogram
H	—	hour
H	—	water vapour concentration [%]
H_m	—	maximum water vapour concentration [%]
Hz	—	hertz
K	—	kelvin
Kg	—	kilogramme
km/h	—	kilometre per hour
kPa	—	kilopascal
Max	—	maximum value
$NO_{X,dry}$	—	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
Ppm	—	parts per million
$ppmC_1$	—	parts per million carbon equivalents
r^2	—	coefficient of determination
S	—	second

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
χ_{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 1. If air flow, fuel flow, the air-to-fuel ratio or the exhaust mass flow rate is obtained from the ECU, the calculated exhaust mass flow rate shall meet the linearity requirements specified in Table 1.

Table 1

Linearity requirements of measurement parameters and systems

Measurement parameter/instrument	(χ_{min}(a_1 1) a_0)	Slope a_1	Standard error SEE	Coefficient of determination r^2
Fuel flow rate[40]	≤ 1 % max	0,98 – 1,02	≤ 2 %	≥ 0,990
Air flow rate[41]	≤ 1 % max	0,98 – 1,02	≤ 2 %	≥ 0,990
Exhaust mass flow rate	≤ 2 % max	0,97 – 1,03	≤ 3 %	≥ 0,990

[40] optional to determine exhaust mass flow
[41] optional to determine exhaust mass flow

Gas analysers	≤ 0,5 % max	0,99 – 1,01	≤ 1 %	≥ 0,998
Torque[42]	≤ 1 % max	0,98 – 1,02	≤ 2 %	≥ 0,990
PN analysers[43]	≤ 5 % max	0,85 – 1,15[44]	≤ 10 %	≥ 0,950

3.3. Frequency of linearity verification

The linearity requirements pursuant to point 3.2 shall be verified:

(a) for each gas analyser at least every 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 point 3.2 for sensors or ECU signals that are not directly traceable shall be performed with a traceably calibrated measurement device on the chassis dynamometer once for each PEMS-vehicle setup.

3.4. Procedure of linearity verification

3.4.1. *General requirements*

The relevant analysers, instruments and sensors shall be brought to their 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 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

42 optional parameter

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

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

relevant parameter shall be chosen to match the range of values expected during the emissions test. For measurements of exhaust mass flow, reference points below 5 % of the maximum calibration value can be excluded from the linearity verification.

(e) For gas analysers, known gas concentrations in accordance with point 5 shall be introduced to the analyser port. Sufficient time for signal stabilisation shall be given.

(f) The values under evaluation and, if needed, the reference values shall be recorded at a constant frequency which is a multiple of 1.0 Hz over a period of 30 seconds.

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

$(y)(a_1x\ a_0)$

where:

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

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

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

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

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

Commented [M41]: Please change the reference to GTR15. We prefer GTR15 to UNR83 for the reference in this GTR.

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

4. ANALYSERS FOR MEASURING GASEOUS COMPONENTS

4.1. Permissible types of analysers

4.1.1. *Standard analysers*

The gaseous components shall be measured with analysers specified in points 1.3.1 to 1.3.5 of Appendix 3, Annex 4A to UN/ECE Regulation No 83, 07 series of amendments. If an NDUV analyser measures both NO and NO_2, a NO_2/NO converter is not required.

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4.1.2. *Alternative analysers*

Any analyser not meeting the design specifications of point 4.1.1 is permissible provided that it fulfils the requirements of point 4.2. The 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 points 5, 6 and 7 of this Annex. Upon request, the manufacturer of the analyser shall submit in writing supplemental information, demonstrating that the measurement performance of the alternative analyser is consistently and reliably in line with the measurement performance of standard analysers. Supplemental information shall contain:

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

(b) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 over the expected range of pollutant concentrations and ambient conditions of the type-approval test defined in Annex XXI to this Regulation as well as a validation test as described in point 3 of Appendix 3 for a vehicle equipped with a spark-ignition and compression-ignition engine; the manufacturer of the analyser shall demonstrate the significance of equivalency within the permissible tolerances given in point 3.3 of Appendix 3.

(c) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 with respect to the influence of atmospheric pressure on the measurement performance of the analyser; the demonstration test shall determine the response to span gas having a concentration within the analyser range to check the influence of atmospheric pressure under moderate and extended altitude conditions defined in point 5.2 of this Annex. Such a test can be performed in an altitude environmental test chamber.

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

(e) a demonstration that the influence of vibrations, accelerations and ambient temperature on the analyser reading does not exceed the noise requirements for analysers set out in point 4.2.4.

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

4.2. Analyser specifications

4.2.1. *General*

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

4.2.2. *Accuracy*

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

4.2.3. *Precision*

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than 1 % of the full scale concentration for a measurement range equal or above 155 ppm (or $ppmC_1$) and 2 % 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 % of full scale. Each of the 10 measurement periods shall be interspersed with an interval of 30 seconds in which the analyser is exposed to an appropriate span gas. Before each sampling period and before each span period, sufficient time shall be given to purge the analyser and the sampling lines.

4.2.5. *Zero response drift*

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

4.2.6. *Span response drift*

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

Table 2

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

Pollutant	Absolute Zero response drift	Absolute Span response drift
CO_2	≤ 1000 ppm over 4 h	≤ 2 % of reading or ≤ 1000 ppm over 4 h, whichever is larger
CO	≤ 50 ppm over 4 h	≤ 2 % of reading or ≤ 50 ppm over 4 h, whichever is larger
PN	5000 particles per cubic centimetre over 4 h	According to manufacturer specifications

NO_X	≤ 5 ppm over 4 h	≤ 2 % of reading or 5 ppm 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 ($t_{90} – t_{10}$; see point 4.4), shall not exceed 3 seconds.

4.2.8. *Gas drying*

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

4.3. Additional requirements

4.3.1. *General*

The provisions in points 4.3.2 to 4.3.5 define additional performance requirements for specific analyser types and apply only to cases, in which the analyser under consideration is used for 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 of point 2.4 of Appendix 3 of Annex 4a to UN/ECE Regulation No 83, 07 series of amendments. The efficiency of the NO_X converter shall be verified no longer than one month before the emissions test.

Commented [M43]: Please change the reference to GTR15. We prefer GTR15 to UNR83 for the reference in this GTR.

4.3.3. *Adjustment of the Flame Ionisation Detector (FID)*

(a) Optimization of the detector response

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

(b) Hydrocarbon response factors

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

(c) Oxygen interference check

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

The following procedure applies:

(i) The analyser shall be set at zero;

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

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

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

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

(vi) The oxygen interference E_{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:

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

where:

$c_{ref,b}$		is the reference HC concentration in step (ii) [ppmC1]
$c_{ref,d}$		is the reference HC concentration in step (iv) [ppmC1]
$c_{FS,b}$		is the full scale HC concentration in step (ii) [ppmC1]
$c_{FS,d}$		is the full scale HC concentration in step (iv) [ppmC1]
$c_{m,b}$		is the measured HC concentration in step (ii) [ppmC1]
$c_{m,d}$		is the measured HC concentration in step (iv) [ppmC1]

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

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Commented [AZ44]: Is this correct ? in this form (L133 of Reg.1151) C_m,b can be simplified and not needed… In fact there is no c_md in the equation but appears below in the table, I guess it is c_m,d in the second fraction. Maybe some Errata I've missed for Reg.1151?

(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 point 9.2 of Appendix 4). It is not necessary to determine the methane conversion efficiency in case the NMC-FID is calibrated according to method (b) in point 9.2 of Appendix 4 by passing the methane/air calibration gas through the NMC.

(a) Methane conversion efficiency

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

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

where:

$c_{HC(w/NMC)}$		is the HC concentration with CH_4 flowing through the NMC [ppmC1]
$c_{HC(w/o\ NMC)}$		is the HC concentration with CH_4 bypassing the NMC [ppmC1]

(b) Ethane conversion efficiency

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

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

where:

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

4.3.5. *Interference effects*

(a) General

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

(b) CO analyser interference check

Water and 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 full scale of the maximum operating range of the CO analyser used during the test shall be bubbled through water at room temperature and the analyser response recorded. The analyser response shall not be more than 2 per cent of the mean CO concentration expected during 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 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*. 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:

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

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:

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

where:

D_e		is the expected diluted NO concentration [ppm]

C		is the measured diluted NO concentration [ppm]
H_m		is the maximum water vapour concentration [%]
H		is the actual water vapour concentration [%]

(iii) Maximum allowable quench

The combined 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 (iv), 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 Sub-Annex 5 of Annex XXI to this Regulation.

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

5.2. Gas dividers

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

Table 3

Oxygen interference check gases

	Engine type	
	Compression ignition	Positive ignition
O_2 concentration	21 ± 1 %	10 ± 1 %
	10 ± 1 %	5 ± 1 %
	5 ± 1 %	0,5 ± 0,5 %

6. ANALYSERS FOR MEASURING (SOLID) PARTICLE EMISSIONS

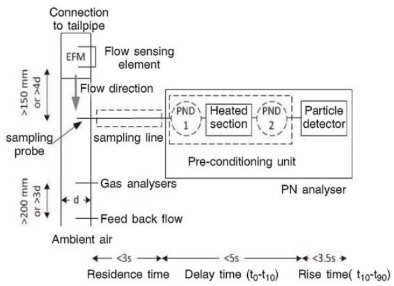
This sections will define future requirement for analysers for measuring particle number emissions, once their measurement becomes mandatory.

6.1. General

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

Figure 1

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



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

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

The PN analyser shall include a heated section at wall temperature ≥ 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 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 the UNECE Regulations 83 or 49 or GTR 15 automatically comply with the calibration requirements of this Annex.

6.2. Efficiency requirements

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

Table 3a							
PN analyser (including the sampling line) system efficiency requirements							
d_p [nm]	Sub-23	23	30	50	70	100	200

$E(d_p)$ PN analyser	To be determined	0,2 – 0,6	0,3 – 1,2	0,6 – 1,3	0,7 – 1,3	0,7 – 1,3	0,5 – 2,0

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

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

6.3. Linearity requirements

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

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

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

6.4. Volatile removal efficiency

The system shall achieve > 99 % removal of ≥ 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 polydisperse alcane (decane or higher) or emery oil with count median diameter > 50 nm and mass > 1 mg/m^3.

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

7. INSTRUMENTS FOR MEASURING EXHAUST MASS FLOW

7.1. General

Instruments 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 minimize additional errors.

7.2. Instrument specifications

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

(a) Pitot-based flow devices;

(b) Pressure differential devices like flow nozzle (details see ISO 5167);

(c) Ultrasonic flow meter;

(d) Vortex flow meter.

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

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

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

7.2.1. *Calibration and verification standards*

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

7.2.2. *Frequency of verification*

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

7.2.3. *Accuracy*

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

7.2.4. *Precision*

The precision, defined as 2,5 times the standard deviation of 10 repetitive responses to a given nominal flow, approximately in the middle of the calibration range, shall not exceed 1 per cent of the maximum flow at which the EFM has been calibrated.

7.2.5. *Noise*

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

7.2.6. *Zero response drift*

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

7.2.7. *Span response drift*

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

7.2.8. *Rise time*

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

7.2.9. *Response time check*

The response time of exhaust mass flow meters shall be determined by applying similar parameters as those applied for the emissions test (i.e., pressure, flow rates, filter settings and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the exhaust mass flow meter. The gas flow switching shall be done as fast as possible, but highly recommended in less than 0,1 second. The gas flow rate used for the test shall cause a flow rate change of at least 60 per cent full scale of the exhaust mass flow meter. The gas flow shall be recorded. The delay time is defined as the time from the gas flow switching (t_0) until the response is 10 per cent (t_{10}) of the final reading. The rise time is defined as the time between 10 per cent and 90 per cent response ($t_{90} – t_{10}$) of the final reading. The response time (t_{90}) is defined as the sum of the delay time and the rise time. The exhaust mass flow meter response time (t_{90}) shall be ≤ 3 seconds with a rise time ($t_{90} – t_{10}$) of ≤ 1 second in accordance with point 7.2.8.

8. SENSORS AND AUXILIARY EQUIPMENT

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

Table 4

Accuracy requirements for measurement parameters

Measurement parameter	Accuracy
Fuel flow[45]	± 1 % of reading[46]
Air flow[47]	± 2 % of reading
Vehicle speed[48]	± 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

[45] optional to determine exhaust mass flow

[46] The accuracy shall be 0,02 per cent of reading if used to calculate the air and exhaust mass flow rate from the fuel flow according to point 10 of Appendix 4.

[47] optional to determine exhaust mass flow

[48] 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 the signal of a wheel rotational speed sensor.

ANNEX 5

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

%	—	per cent
#/km	—	number per kilometre
a_0	—	*y* intercept of the regression line
a_1	—	slope of the regression line
g/km	—	gramme per kilometre
Hz	—	hertz
km	—	kilometre
m	—	metre
mg/km	—	milligramme per kilometre
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.

3.2. PEMS validation procedure

3.2.1. *PEMS installation*

The PEMS shall be installed and prepared according to the requirements of Appendix 1. The PEMS installation shall be kept unchanged in the time period between the validation and the 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 Annex XXI to this Regulation. It is

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

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3.3. Permissible tolerances for PEMS validation

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

Table 1

Permissible tolerances

Parameter [Unit]	Permissible absolute tolerance
Distance [km][49]	250 m of the laboratory reference
THC[50] [mg/km]	15 mg/km or 15 % of the laboratory reference, whichever is larger
CH_4[51] [mg/km]	15 mg/km or 15 % of the laboratory reference, whichever is larger
NMHC[52] [mg/km]	20 mg/km or 20 % of the laboratory reference, whichever is larger
PN[53] [#/km]	$1 \cdot 10^{11}$ p/km or 50 % of the laboratory reference[54] whichever is larger
CO[55] [mg/km]	150 mg/km or 15 % of the laboratory reference, whichever is larger
CO_2 [g/km]	10 g/km or 10 % of the laboratory reference, whichever is larger

49 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
50 parameter only mandatory if measurement required by point 2.1 of this Annex.
51 parameter only mandatory if measurement required by point 2.1 of this Annex.
52 parameter only mandatory if measurement required by point 2.1 of this Annex.
53 parameter only mandatory if measurement required by point 2.1 of this Annex.
54 PMP system.
55 parameter only mandatory if measurement required by point 2.1 of this Annex.

NO_x[56] [mg/km]	15 mg/km or 15 % 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 point 3 of Appendix 2 under steady-state conditions, the linearity of non-traceable exhaust mass flow meters or the exhaust mass flow rate calculated from non-traceable sensors or ECU signals shall be validated under transient conditions for each test vehicle against a calibrated exhaust mass flow meter or the CVS.

4.2. Validation procedure

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

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 point 3 of Appendix 4.

(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 2.

4.3. Requirements

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

Table 2

56 parameter only mandatory if measurement required by point 2.1 of this Annex.

Linearity requirements of calculated and measured exhaust mass flow				
Measurement parameter/system	a_0	Slope a_1	Standard error SEE	Coefficient of determination r^2
Exhaust mass flow	0,0 ± 3,0 kg/h	1,00 ± 0,075	≤10 % max	≥ 0,90

Submitted by the expert from European Commission

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Agenda item 3.(c)

ANNEX 6

DETERMINATION OF INSTANTANEOUS EMISSIONS

1. INTRODUCTION

This appendix describes the procedure to determine the instantaneous mass and particle number emissions [g/s; #/s] that shall be used for the subsequent evaluation of a RDE trip and the calculation of the final emission result as described in Appendix 6.

2. SYMBOLS, PARAMETERS AND UNITS

%	—	per cent
$<$	—	smaller than
#/s	—	number per second
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	—	degrees centigrade
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]

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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]
$c_{HC(w/oNMC)}$	—	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
g	—	gramme
g/s	—	gramme per second
H_a	—	intake air humidity [g water per kg dry air]
i	—	number of the measurement
kg	—	kilogramme
kg/h	—	kilogramme per hour
kg/s	—	kilogramme per second
k_w	—	dry-wet correction factor
m	—	metre
$m_{gas,i}$	—	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
rpm	—	revolutions per minute
s	—	second
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 point 5.1 of Appendix 1. The time correction and alignment of parameters shall be carried out by following the sequence described in points 3.1 to 3.3.

3.1. Time correction of component concentrations

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

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

where:

$c_{i,c}$		is the time-corrected concentration of component i as function of time *t*
$c_{i,r}$		is the raw concentration of component i as function of time *t*
$\Delta t_{t,i}$		is the transformation time t of the analyser measuring component i

3.2. Time correction of exhaust mass flow rate

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

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

where:

$q_{m,c}$		is the time-corrected exhaust mass flow rate as function of time *t*
$q_{m,r}$		is the raw exhaust mass flow rate as function of time *t*
$\Delta t_{t,m}$		is the transformation time t of the exhaust mass flow meter

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

3.3. Time alignment of vehicle data

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

3.3.1. *Vehicle speed from different sources*

To time align vehicle speed with the exhaust mass flow rate, it is first necessary to establish one valid speed trace. In case vehicle speed is obtained from multiple sources (e.g., the GPS, 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. COLD START

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

5. EMISSION MEASUREMENTS DURING STOP OF THE COMBUSTION ENGINE

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

Add consistency check for Temperature

6. CONSISTENCY CHECK OF VEHICLE ALTITUDE

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

7. CONSISTENCY CHECK OF GPS VEHICLE SPEED

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

8. CORRECTION OF Measured Values

8.1. Dry-wet correction

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

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:

$$\boldsymbol{k}_{\mathbf{w}} = \left(\frac{\mathbf{1}}{\mathbf{1} + \boldsymbol{\alpha} \times \mathbf{0.005} \times \left(\boldsymbol{c}_{\mathbf{CO_2}} + \boldsymbol{c}_{\mathbf{CO}}\right)} - \boldsymbol{k}_{\mathbf{w1}}\right) \times \mathbf{1.008}$$

where:

$$\boldsymbol{k}_{\mathbf{w1}} = \frac{\mathbf{1{,}608} \times \boldsymbol{H}_{\mathbf{a}}}{\mathbf{1\,000} + (\mathbf{1.608} \times \boldsymbol{H}_{\mathbf{a}})}$$

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

8.2. Correction of NO_x for ambient humidity and temperature

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

8.3. Correction of negative emission results

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

8.4. Correction for extended conditions

The second-by second emissions calculated in accordance with this Appendix shall be divided by a value of 1,6 solely for the cases laid down in points 9.5 and 9.6.

The corrective factor of 1,6 shall be applied only once. The corrective factor of 1,6 applies to pollutant emissions but not to CO_2.

9. DETERMINATION OF THE INSTANTANEOUS GASEOUS EXHAUST COMPONENTS

9.1. Introduction

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

9.2. 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 point 4.3.3.(b) of Appendix 2
E_M		is the methane efficiency as determined in point 4.3.4.(a) of Appendix 2
E_E		is the ethane efficiency as determined in point 4.3.4(b) of Appendix 2

If the methane FID is calibrated through the cutter (method b), then the methane conversion efficiency as determined in point 4.3.4.(a) of Appendix 2 is zero. The density used for calculating the NMHC mass shall be equal to that of total hydrocarbons at 273,15 K and 101,325 kPa and is fuel-dependent.

10. DETERMINATION OF EXHAUST MASS FLOW RATE

10.1. Introduction

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

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

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

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

where:

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

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

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

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

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

where:

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

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

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_β H_α O_ε N_δ S_γ with $\beta = 1$ for carbon based fuels. The concentration of HC emissions is typically low and may be omitted when calculating λ_i.

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

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

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

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

Commented [AZ49]: Pierre, is this correct? If wrong, then also wrong in Reg.1151.

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

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

11. CALCULATING THE INSTANTANEOUS MASS EMISSIONS OF GASEOUS COMPONENTS

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

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

where:

$m_{gas,i}$		is the mass of the exhaust component 'gas' [g/s]
u_{gas}		is the ratio of the density of the exhaust component 'gas' and the overall density of the exhaust as listed in Table 1
$c_{gas,i}$		is the measured concentration of the exhaust component 'gas' in the exhaust [ppm]
$q_{mew,i}$		is the measured exhaust mass flow rate [kg/s]
gas		is the respective component

i		number of the measurement

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]					
		2.053	1.250	(1)	1.9636	1.4277	0.716
		u_{gas} (2,6)					
Diesel (B0)							
Diesel (B5)							
Diesel (B7)	1.2943	0.001586	0.000966	0.000482	0.001517	0.001103	0.000553
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)							
Petrol (E5)							
Petrol (E10)	1.2931	0.001587	0.000966	0.000499	0.001518	0.001104	0.000553
Ethanol (E75)							
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

Commented [DP50]: JRC and ROB:
Table to be finished after the January meeting.
US to propose updates based on GTR11 on chemical balance. JRC to review.
Korean fuels to be found in GTR15.
Update the EU ones.

Commented [J51]: Table re-formatted, coefficients being verified for added fuels

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As an alternative to the above method, emission rates might also be calculated with the method described in Annex 7 of GTR 11.

12. CALCULATING THE INSTANTANEOUS PARTICLE NUMBER EMISSIONS

The instantaneous particle number emissions [particles/s] shall be determined by multiplying the instantaneous concentration of the pollutant under consideration [particles/cm^3] with the instantaneous exhaust mass flow rate [kg/s], both corrected and aligned for the transformation time. If applicable, negative instantaneous emission values shall enter all subsequent data evaluations. All significant digits of intermediate results shall enter the calculation of the instantaneous emissions. The following equation shall apply:

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

where:

PN,i		is the particle number flux [particles/s]
$c_{PN,i}$		is the measured particle number concentration [#/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 1)

13. DATA EXCHANGE

The data shall be exchanged between the measurement systems and the data evaluation software by a standardised data exchange file found in XXXX. Any pre-processing of data (e.g. time correction according to point 3 or the correction of the GPS vehicle speed signal according to point 7) shall be done with the control software of the measurement systems and shall be completed before the data exchange file is generated. Rounding of intermediate values and data in the exchange file is not permitted.

14. Data reporting

For contracting parties applying the WLTP xxxx, all data required for reporting of the data of an RDE test shall be formatted and reported according to the data reporting file found in XXX.

Submitted by the expert from European Commission

Informal document **GRPE-80-31**
80th GRPE,14-17 January 2020
Agenda item 3.(c)

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ANNEX 7

ASSESSMENT OF OVERALL TRIP DYNAMICS USING THE MOVING AVERAGING WINDOW METHOD

1. INTRODUCTION

The Moving Averaging Window method is 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 is 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 applicable WLTC test. For compliance with this Regulation, the method shall be applied using the 4-phase and the 3-phase WLTC procedures.

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)

Δ	-	difference
$\geq$	-	larger or equal
#	-	number
%	-	per cent
$\leq$	-	smaller or equal
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]
$\overline{v}_j$	-	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

Commented [DP52]: JRC to check if reference should be made to 4-3 phases or ATCT corrections are needed…

3.1. Definition of averaging windows

The instantaneous CO_2 emissions calculated according to Appendix 4 shall be integrated using a moving averaging window method, based on a reference CO_2 mass.

The usage of the reference CO2 mass is defined in Figure 2 of this Annex. 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 WLTC cycle. The moving window calculations are conducted with a time increment Δt corresponding to the data sampling frequency. These sub-sets used to calculate the vehicle on-road CO_2 emissions and its average speed are referred to as 'averaging windows' in the following sections. The calculation described in the present point shall be run from the first data point (forward).

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

Commented [M53]: Why did you delete 'emission' and add 'vechicle average speed' in RDE4 ?

Commented [JRC-ISPRA54]: Because the windows are no longer used to calculate criteria emissions, only distance-specific CO2, which is a result of the CO2 mass divided by the distance in the 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 Annex 6 to this Regulation.

Commented [JRC-ISPRA55]: References to be corrected in UNR (should now be ANNEX 6 for that case)

Figure 1

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

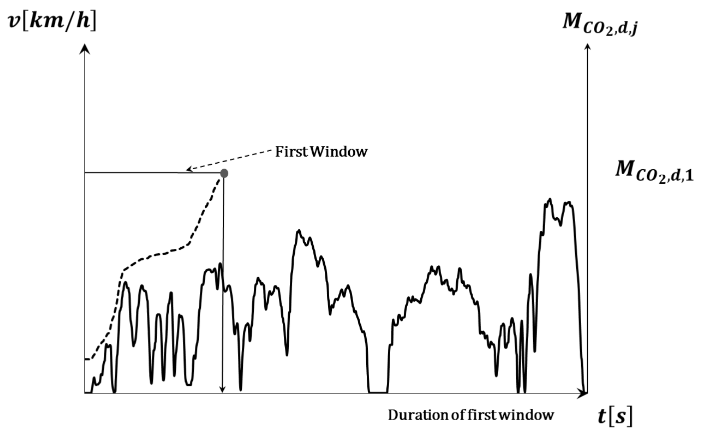
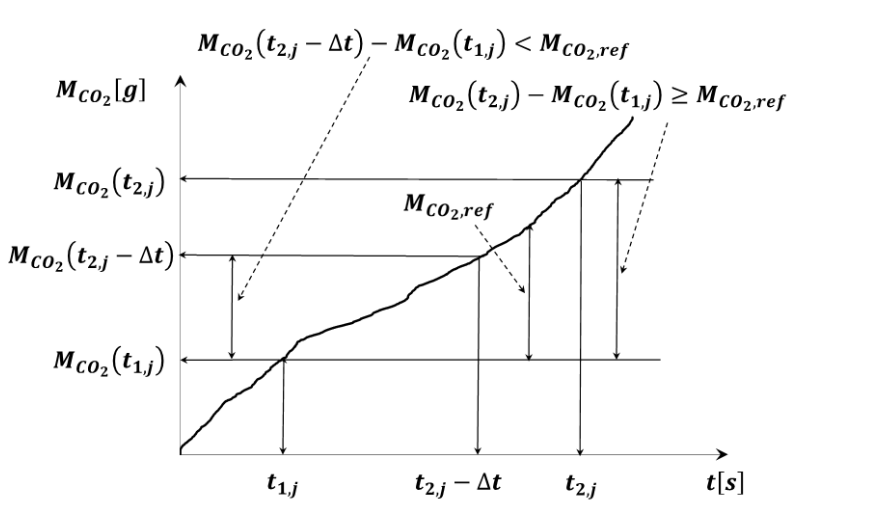


Figure 2

Definition of CO2 mass based on averaging windows



The duration $(t_{2,j}-t_{1,j})$ of the jth 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 half of the CO_2 mass emitted by the vehicle over the applicable WLTC test.

During type approval the CO_2 reference value shall be taken from the WLTP performed during type approval testing of the individual vehicle.

For ISC testing purposes, the reference CO_2 mass shall be obtained from point 12 of the Transparency list 1 of Appendix 5 of Annex II with interpolation between vehicle H and vehicle L (if relevant) as defined in Sub-Annex 7 of Annex XXI, using Test mass and Road load coefficients (f0, f1 & f2) obtained from the Certificate of Conformity for the individual vehicle as defined in Annex IX. The value for OVC-HEV vehicles is to be obtained from the applicable WLTP test conducted using the Charge Sustaining mode.

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

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

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 4 to this Annex.

Commented [DP56]: JRC to correct equations and figures missing at the end

Commented [DP57]: Rob to move to Reg. 83

3.2. Calculation of window parameters

The following shall be calculated for each window determined in accordance with point 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'. To obtain the distance specific CO_2 emissions, the vehicle shall be tested on the WLTP cycle in accordance with Regulation WLPT.

4.2. CO_2 characteristic curve reference points

The distance-specific CO_2 emissions to be considered in this paragraph for the definition of the reference curve shall be obtained from point 12 of the Transparency list 1 of Appendix 5 of Annex II with interpolation between vehicle H and vehicle L (if relevant) as defined in Sub-Annex 7 of Annex XXI, using Test mass and Road load coefficients (f0, f1 & f2) obtained from the Certificate of Conformity for the individual vehicle as defined in Annex IX. The value for OVC-HEV vehicles is to be that obtained from the applicable WLTP test conducted using the Charge Sustaining mode.

Commented [M58]: Please change the reference to GTR 15 or UNR.

During type approval, the values shall be taken from the WLTP performed during type approval testing of 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 cycle [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 cycle [g/km]

4.2.3. *Point P_3* (The Contracting Party applying WLTC 4 phases)

Commented [M59]: This paragraph is for the CP applying WLTC 4 phases.
(Extra High is not included in WLTC 3 phases.)

$\overline{v_{P3}} = 91.997\ km/h$ (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 cycle [g/km]

4.3.1 CO_2 characteristic curve definition (The Contracting Party applying WLTC 4 phases)

Using the reference points defined in section 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 3

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

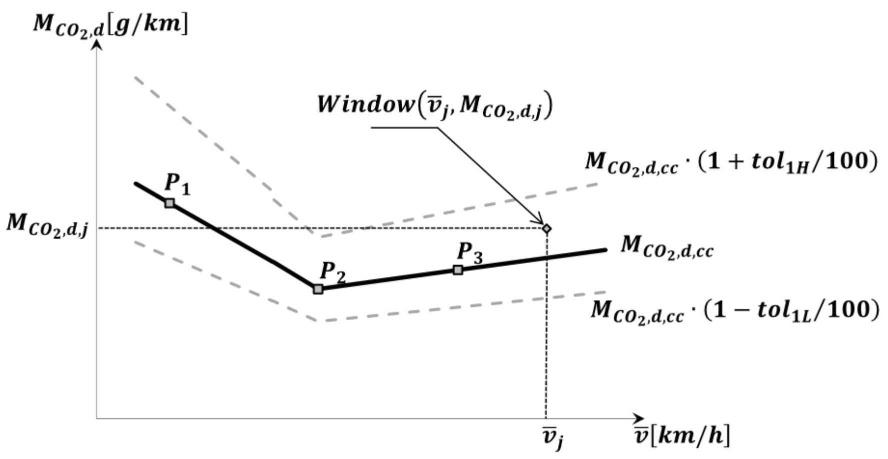
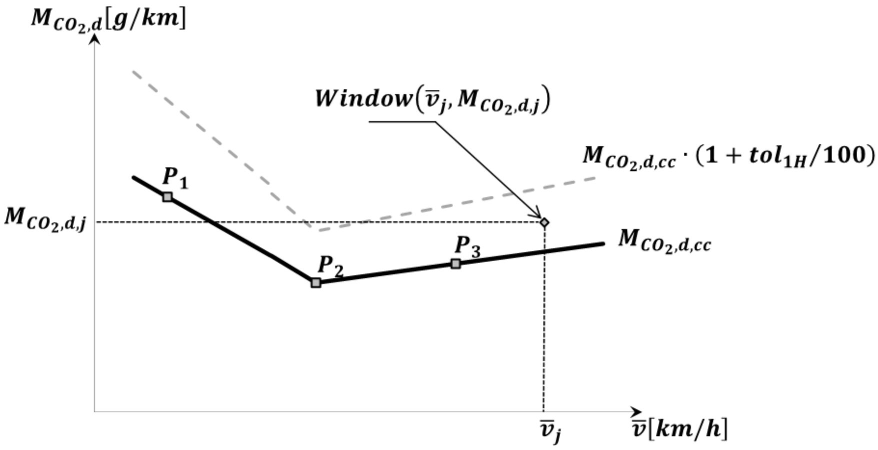


Figure 4:

Vehicle CO_2 characteristic curve and tolerances for OVC-HEV vehicles



4.3.2 CO_2 characteristic curve definition (The Contracting Party applying WLTC 3 phases)

Commented [M60]: Excluding P3 for the CP applying WLTC 3 phases.

Using the reference points defined in section 4.2, the characteristic curve CO_2 emissions are calculated as a function of the average speed using a linear section (P_1, P_2). The characteristic curve is defined by equations as follows:

For the section (P_1, P_2):

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

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

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

Figure 3-2

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

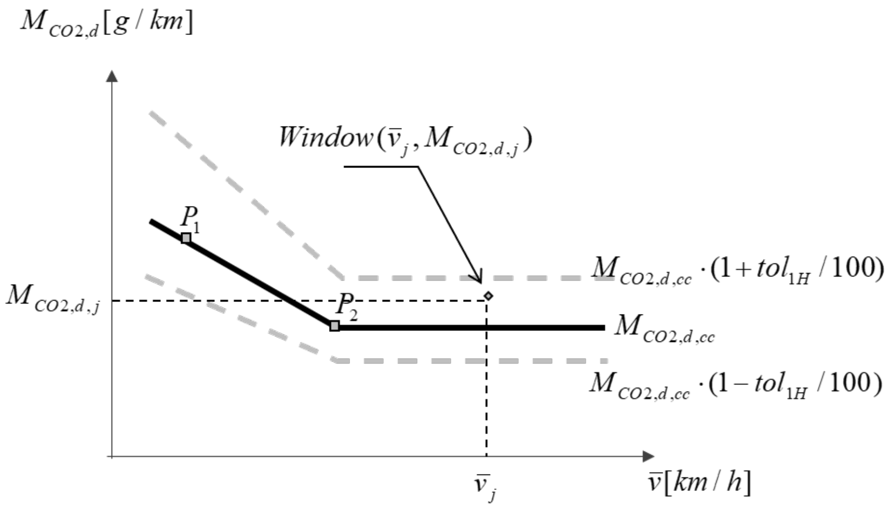
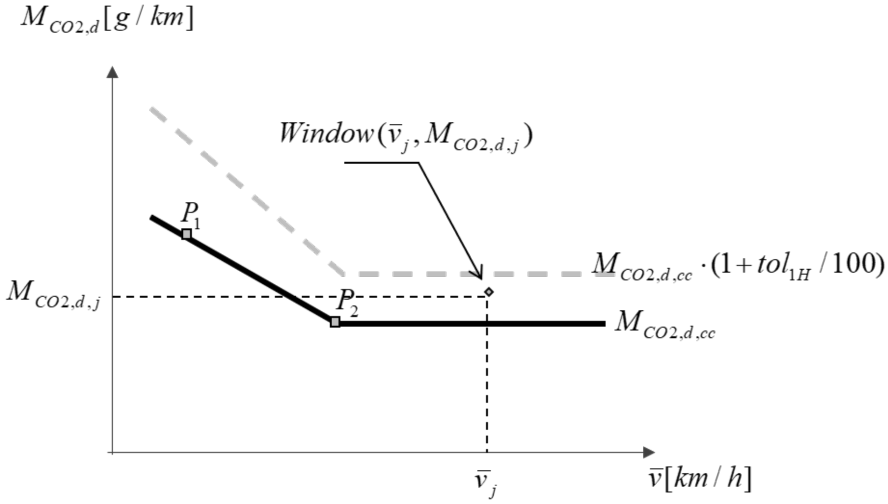


Figure 4-2:

Vehicle CO_2 characteristic curve and tolerances for OVC-HEV vehicles



4.4.1. Low, medium and high speed windows (The Contracting Party applying WLTC 4 phases)

4.4.1.1. Low speed windows

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

4.4.1.2. Medium speed windows

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

For N2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h, rural windows are characterized by average vehicle speeds $\overline{v}_j$ lower than 70 km/h.

4.4.1.3. High speed windows

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

For N2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h, high speed windows are characterized by average vehicle speeds $\overline{v}_j$ greater than or equal to 70 km/h and lower than 90 km/h.

Figure 5

Vehicle CO_2 characteristic curve: low, medium and high speed driving definitions (Illustrated for ICE and NOVC-HEV vehicles) except N2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h)

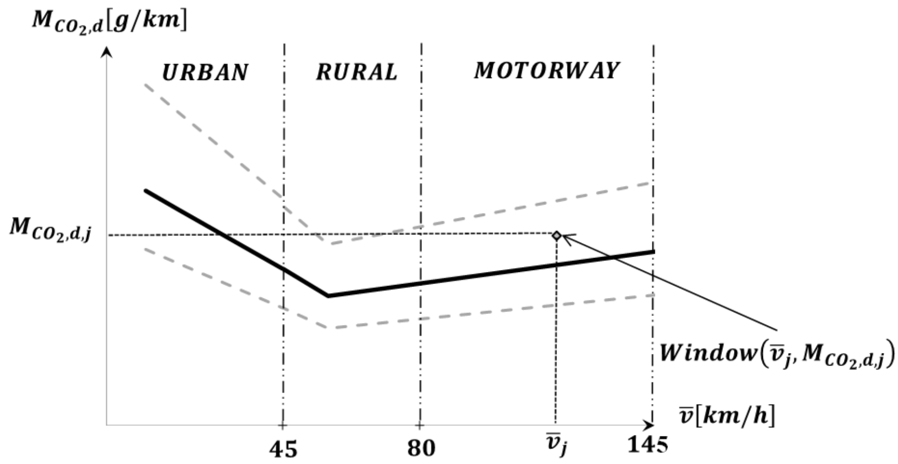
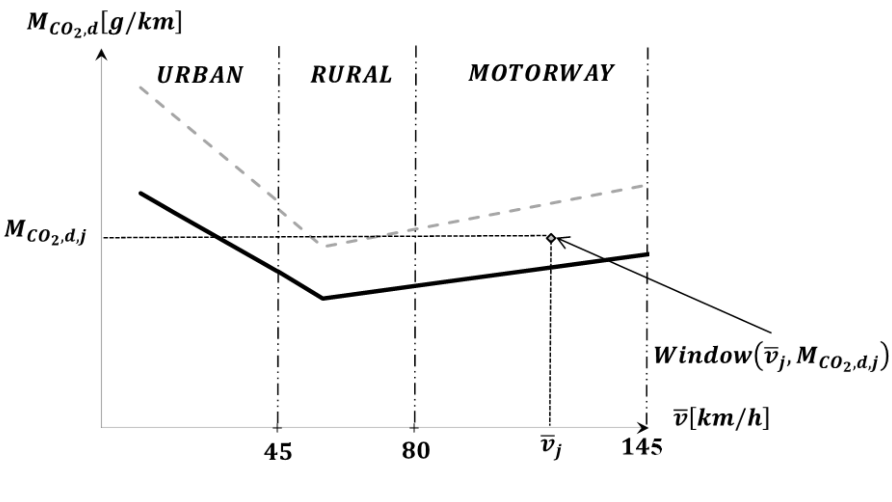


Figure 6.

Vehicle CO_2 characteristic curve: low, medium and high speed~~urban, rural and motorway~~ driving definitions (Illustrated for OVC-HEV vehicles) except N2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h)



4.4.2. Low, medium and high speed windows (The Contracting Party applying WLTC 3 phases)

Commented [M61]: Since the average speed is differet between WLTC 4 phases and WLTC 3 phases, a paragraph for 3pahses is establised.

4.4.2.1. Low/Medium speed windows

Low/Medium speed windows are characterized by average vehicle ground speeds $\overline{v}_j$ lower than 50 km/h.

4.4.2.2. High speed windows

High speed windows are characterized by average vehicle ground speeds $\overline{v}_j$ greater than or equal to 50 km/h.

Figure 5-2

Vehicle CO_2 characteristic curve: low, medium and high speed driving definitions (Illustrated for ICE and NOVC-HEV vehicles)

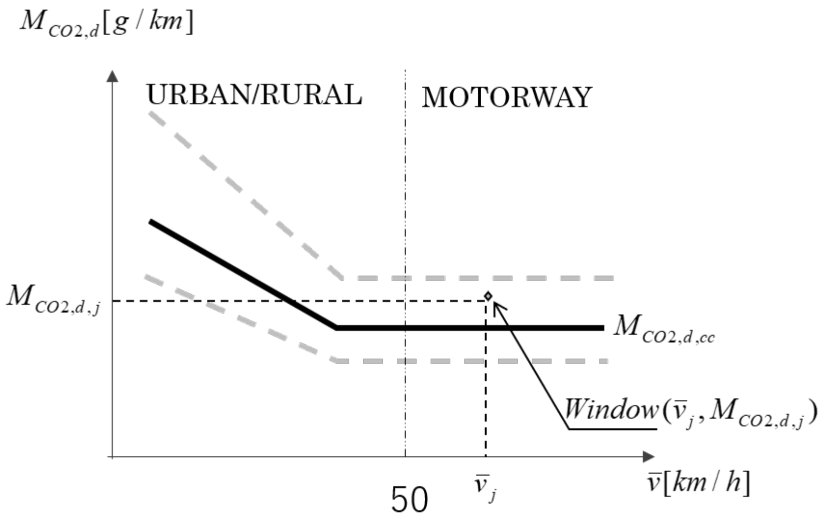
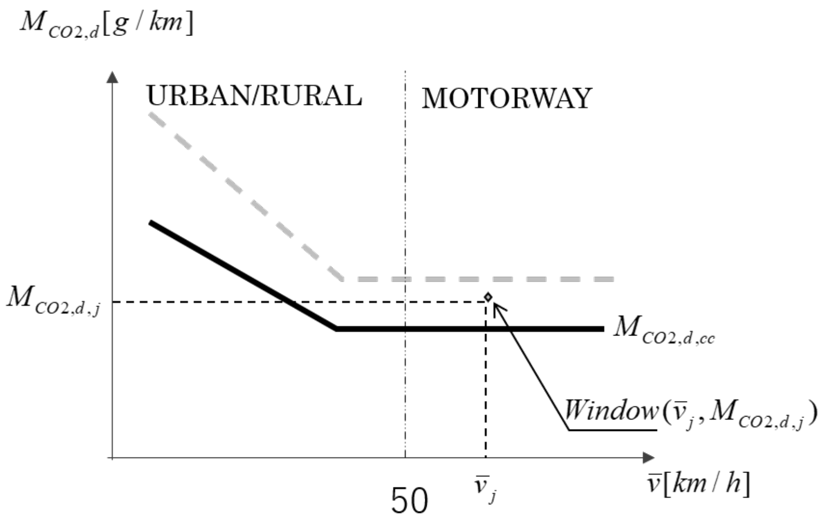


Figure 6-2.

Vehicle CO_2 characteristic curve: low, medium and high speed driving definitions (Illustrated for OVC-HEV vehicles)



4.5.1. Assessment of trip validity *(The Contracting Party applying WLTC 4 phases)*

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% 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 by steps of 1 % until the 50 % target is reached. When using this mechanism, the value of tol_{1H} shall never exceed 50 %.

4.5.2. Assessment of trip validity *(The Contracting Party applying WLTC 3 phases)*

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

4.5.2.2. Assessment of test validity
The test is valid when it comprises at least 50% 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 by steps of 1 % until the 50 % target is reached. When using this mechanism, the value of tol_{1H} shall never exceed 50 %.

ANNEX 8

Commented [PG62]: If taking the opportunity to restructure… perhaps put this after Dynamics & CPAG annexes – so that structure aligns to the flow diagram?

CALCULATION OF THE FINAL RDE EMISSIONS RESULTS

1. Symbols, Parameters and Units

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

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 on its charge sustaining mode

r_k 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

2. Calculation of the Final RDE emissions results

The trip validity shall be verified in accordance with point 9.2. of this Regulation. For the valid trips, the final RDE results are calculated as follows for vehicles with ICE, NOVC-HEV and OVC-HEV.

For the complete RDE trip and for the low speed part of the RDE trip (k=t=total, k=ls=low speed):

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

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=ls=low speed) shall be obtained using the functions laid down in point 2.2. for vehicles with ICE and NOVC-HEV, and in point 2.3. for OVC-HEV. These evaluation factors shall be subject to review by the Commission and shall be revised as a result of technical progress. A graphical illustration of the method is provided in Figure App 6.1 below, while the mathematical formulas are found in Table App 6.1:

Figure App 6.1: Function to calculate the result evaluation factor

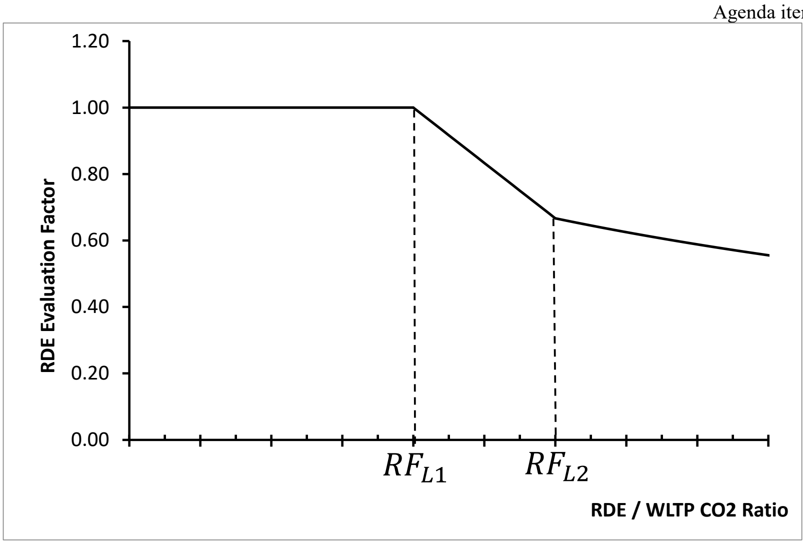


Table App 6.1 Result evaluation factors calculation

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. 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 applicable WLTC test conducted in accordance with Sub-Annex 6 to Annex XXI of this Regulation, obtained from point 12 of the Transparency list 1 of Appendix 5 of Annex II with interpolation between vehicle H and vehicle L (if relevant) as defined in Sub-Annex 7 of Annex XXI, using Test mass and Road load coefficients (F0, F1 & F2) obtained from the Certificate of Conformity for the individual vehicle as defined in Annex IX. For the low speed emissions, the relevant phases of the WLTP driving cycle shall be:

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

b) for NOVC-HEVs the whole applicable WLTP driving cycle.

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

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4. 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 CO2 emitted by the vehicle over the applicable WLTC test conducted using the Charge Sustaining mode in accordance with Sub-Annex 6 to Annex XXI of this Regulation, obtained from point 12 of the Transparency list 1 of Appendix 5 of Annex II with interpolation between vehicle H and vehicle L (if relevant) as defined in Sub-Annex 7 of Annex XXI, using Test mass and Road load coefficients (F0, F1 & F2) obtained from the Certificate of Conformity for the individual vehicle as defined in Annex IX. 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 using the charge sustaining mode. The formula below shall be subject to review by the Commission and shall be revised as a result of technical progress.

Commented [M64]: Please change the reference to GTR 15 or UNR.

For either the low speed 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 low speed or total trip with the combustion engine on divided by the total low speed 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 Appendix 4 Paragraph 5.

Commented [JRC-ISPRA65]: To be corrected

Submitted by the expert from European Commission

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80th GRPE,14-17 January 2020
Agenda item 3.(c)

ANNEX 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

RPA *Relative Positive Acceleration*

Δ	—	difference
>	—	larger
≥	—	larger or equal
%	—	per cent
<	—	smaller
≤	—	smaller or equal
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

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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]
T4253H	—	compound data smoother
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]
$((v\ a)_i)$	—	actual vehicle speed per acceleration in time step i [m^2/s^3 or W/kg]
$((v\ a_{pos})_{j,k})$	—	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].
$((v\ a_{pos})_k[95])$	—	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]
(v_k)	—	average vehicle speed for urban, rural and motorway shares [km/h]

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3. TRIP INDICATORS

3.1. Calculations

3.1.1. *Data pre-processing*

Dynamic parameters like acceleration, $(v\ a_{pos})$ 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. This accuracy requirement is generally fulfilled by distance calibrated signals obtained from a wheel (rotational) speed sensor. Otherwise, acceleration shall be determined with an accuracy of 0,01 m/s^2 and a sampling frequency of 1 Hz. In this case the separate speed signal, in $v\ a_{pos}$, shall have an accuracy of at least 0,1 km/h. The correct speed trace builds the basis for further calculations and binning as described in paragraph 3.1.2 and 3.1.3.

3.1.2. *Calculation of distance, acceleration and (v a)*

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

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

$$d_i = \frac{v}{i},6,i \quad i = 1\ to\ N_t$$

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/s²]. For i = 1: (v_{i-1} 0), for (i N_t): ($v_{i\,1}$ 0).

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

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

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].

3.1.3.1. *Binning of the results (The Contracting Party applying WLTC 4 phases)*

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

All datasets with (v_i 60 kmh) belong to the 'urban' speed bin, all datasets with (60 kmh v_i 90 kmh) belong to the 'rural' speed bin and all datasets with (v_i 90 kmh) 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 $v_i \leq$ 60km/h belong to the "urban" speed bin, all datasets with 60km/h < $v_i \leq$ 80 km/h belong to the "rural" speed bin and all datasets with v_i >80km/h belong to the "motorway" speed bin.

The number of datasets with acceleration values (a_i > 0,1 ms2) shall be greater or equal to 100 in each speed bin.

For each speed bin the average vehicle speed (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.

3.1.3.2. *Binning of the results (The Contracting Party applying WLTC 3 phases)*

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

All datasets with (v_i 60 kmh) belong to the 'urban/rural' speed bin and all datasets with (v_i 60 kmh) belong to the 'motorway' speed bin.

The number of datasets with acceleration values ($a_i > 0{,}1$ ms2) shall be greater or equal to 100in each speed bin.

For each speed bin the average vehicle speed (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.

3.1.4.1. *Calculation of (v a_{pos}[95]) per speed bin (The Contracting Party applying WLTC 4 phases)*

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

The ((v a)$_{i,k}$) values in each speed bin shall be ranked in ascending order for all datasets with ($a_{i,k}$ 0,1 ms2)($a_{i,k}$ 0,1 ms2) and the total number of these samples M_k shall be determined.

Percentile values are then assigned to the ((v a_{pos})$_{i,k}$) values with ($a_{i,k}$ 0,1 ms2) as follows:

The lowest (v 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 a_{pos})$_k$[95]) is the ((v a_{pos})$_{j,k}$) value, with (jM_k 95 %.) If (jM_k 95 %.) cannot be met, ((v a_{pos})$_k$[95]) shall be calculated by linear interpolation between consecutive samples j and j+1 with (jM_k 95 %) and ((j 1)M_k 95 %).

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

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

where:

RPA_k		is the relative positive acceleration for urban, rural and motorway shares in [m/s^2 or kWs/(kg*km)]
Δ_t		is a time difference equal to 1 second
M_k		is the sample number for urban, rural and motorway shares with positive acceleration
N_k		is the total sample number for urban, rural and motorway shares

Commented [PG71]: Low speed ?

Commented [PG72]: Medium speed ?

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3.1.4.2. *Calculation of (v a_{pos}[95]) per speed bin (The Contracting Party applying WLTC 3 phases)*

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

The ((v a)$_{i,k}$) values in each speed bin shall be ranked in ascending order for all datasets with ($a_{i,k}$ 0,1 ms2)($a_{i,k}$ 0,1 ms2) and the total number of these samples M_k shall be determined.

Percentile values are then assigned to the ((v a_{pos})$_{i,k}$) values with ($a_{i,k}$ 0,1 ms2) as follows:

The lowest (v 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 a_{pos})$_k$[95]) is the ((v a_{pos})$_{j,k}$) value, with (jM_k 95 %.) If (jM_k 95 %.) cannot be met, ((v a_{pos})$_k$[95]) shall be calculated by linear interpolation between consecutive samples j and j+1 with (jM_k 95 %) and ((j 1)M_k 95 %).

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

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

where:

RPA_k		is the relative positive acceleration for urban/rural and motorway shares in [m/s^2 or kWs/(kg*km)]
Δ_t		is a time difference equal to 1 second
M_k		is the sample number for urban/rural and motorway shares with positive acceleration
N_k		is the total sample number for urban/rural and motorway shares

4. ASSESSMENT OF TRIP VALIDITY

4.1.1. Assessment of (v a_{pos}[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:

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

$$(v \times a_{pos})_{k\text{-}}[95] > (0{,}136 \times \overline{v}_k + 14{,}44)$$

is fulfilled, the trip is invalid.

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

$$\left(v \times a_{pos}\right)_{k\text{-}}[95] > (-0{,}097 \times \overline{v}_k + 31{,}635)$$

is fulfilled, the trip is invalid.

To calculate the power-to-test mass ratio, the following values shall be used:

- the mass which corresponds to the actual test mass of the vehicle including the drivers and the PEMS equipment (kg);

- the maximum rated engine power as declared by the manufacturer (W).

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 $\overline{v}_k > 94{,}05 km/h$ and $RPA_k < 0{,}025$ is fulfilled, the trip is invalid.

ANNEX 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]

$h_{GPS,i}$	—	instantaneous vehicle altitude measured with GPS [m above sea level]
$h_{GPS}(t)$	—	vehicle altitude measured with GPS at data point t [m above sea level]
$h_{int}(d)$	—	interpolated altitude at the discrete way point under consideration *d* [m above sea level]
$h_{int,sm,1}(d)$	—	smoothed and interpolated altitude, after the first smoothing run at the discrete way point under consideration *d* [m above sea level]
$h_{map}(t)$	—	vehicle altitude based on topographic map at data point t [m above sea level]
Hz	—	hertz
km/h	—	kilometer per hour
m	—	meter
$road_{grade,1}(d)$	—	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 $h_{GPS,i}$ [m above sea level] as measured with the GPS, the instantaneous vehicle speed v_i [km/h] recorded at a frequency of 1 Hz and the corresponding time *t* [s] that has passed since test start.

4. CALCULATION OF CUMULATIVE POSITIVE ELEVATION GAIN

4.1. General

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

4.2. Screening and principle check of data quality

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

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

The altitude correction shall be applied so that:

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

where:

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

4.3. Correction of instantaneous vehicle altitude data

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

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

The altitude correction shall be applied so that:

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

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 Point 13.4.

4.4. Final calculation of the cumulative positive elevation gain

4.4.1. *Establishment of a uniform spatial resolution*

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

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

Where:

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

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

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

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

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 traveled atuntil 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]

Commented [M76]: Align with point 2. of this Appendix.

4.4.2. *Additional data smoothing*

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

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

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

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

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

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

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]

Commented [M77]: Align with point 2. of this Appendix.

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:

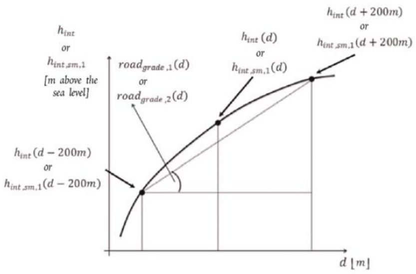
$road_{grade,2}(d)$	—	smoothed road grade at the discrete way point under consideration after the second smoothing run [m/m]
$h_{int,sm,1}(d)$	—	smoothed interpolated altitude, after the first smoothing run at the discrete way point under consideration *d* [m above sea level]
d	—	cumulative distance travelled at the discrete way point under consideration [m]
d_a	—	reference way point at *d(0)* [m]

Commented [M78]: Align with point 2. of this Appendix.

d_e	—	cumulative distance travelled until the last discrete way point [m]

Figure 1

Illustration of the procedure to smooth the interpolated altitude signals



4.4.3. *Calculation of the final result*

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

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

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

Commented [AZ79]: Pierre please check if correct (also in the Act Annex)

Where:

v_w - waypoint vehicle speed [km/h]

All datasets with v_w =< 60 km/h belong to the urban part of the trip.

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

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

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

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

Submitted by the expert from European Commission

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80th GRPE,14-17 January 2020
Agenda item 3.(c)

ANNEX 11: Manufacturer's 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 this Regulation for all possible valid RDE tests.

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

....
(Stamp and signature of the manufacturer's representative)

Annex:
— List of vehicle types to which this certificate applies