

[REDACTED] (GROW)

From: [REDACTED] <[REDACTED]@acea.be>
Sent: 17 December 2014 12:50
To: [REDACTED] (ENV); [REDACTED] (GROW); [REDACTED] (GROW)
Cc: [REDACTED] (ENV); [REDACTED] (GROW)
Subject: Re: RDE proposal
Attachments: 2014_12_16_RDE_Body_AnnexIIIa_v11 revised by ACEA (final)v4_clean.docx; 2014_12_16_Appendices_1_9_Final revised by ACEA v2.docx

Importance: High

Dearest [REDACTED] & [REDACTED]

I found an important mistake in the draft of Annex IIIA I sent you last Friday. It is in the references to the dates of the RDE phases just above the 2 tables on page 6 - see attached updated Annex IIIA.

Please replace the previous version of Annex IIIA with the attached.

In addition, I also now attach the complete Appendices 1-9.

best regards,

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From: [REDACTED]
Sent: 12 December 2014 16:22
To: [REDACTED] (European Commission); [REDACTED] (European Commission); [REDACTED] (European Commission)
Cc: [REDACTED] (European Commission); [REDACTED] (European Commission)
Subject: RDE proposal

Dear [REDACTED]

I'm sorry we are delayed but it took much longer than first thought to go through the v11 of Annex IIIA and the Appendices.

I am sending you a note explaining our concept for a complete RDE Regulation with the important parts identified in Annex IIIA. However, we still require a few more days checking Appendices 5, 6 and 8. We will deliver those Appendices next week.

We believe this 2-phase RDE approach will achieve two key objectives:

- to give the member states a complete and suitable RDE proposal for a timely TCMV vote and,
- an RDE tool that industry can now start working on and deliver RDE compliant new diesel vehicle types from 2017 that includes still challenging measures that we believe can be achieved by that date and further more stringent measures applied to vehicles with the accepted principles of lead-time - being from 5 years after this RDE regulation proposal would be voted by TCMV and published in the OJ.

Due to the speed of this work we reserve the right to come back with any changes for items that may have been overlooked or due to editorial errors.

We will meet you on 16 December from 10:15h where we will present this RDE package and the benefits that we expect it to realise based on the air quality modelling studies we briefly presented in a previous meeting. We will be joined at that meeting by experts from the independent consultancy Aviso.

If you have any questions before that meeting please come back to me.

best regards,



COMMISSION REGULATION (EU) No ...

of...

amending Regulation (EC) No 715/2007 of the European Parliament and of the Council and Commission Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6) THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information¹, and in particular Article 5(3),

Having regard to Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (Framework Directive)², in particular Article 39(2) thereof,

Whereas:

- 1) Regulation (EC) No 715/2007 requires the Commission to keep under review the procedures, tests and requirements for type approval that are set out in Regulation (EC) No 692/2008 of 18 July 2008 implementing and amending Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information³ and to adjust them so that they adequately reflect the emissions generated by real driving on the road, if necessary.
- 2) The Commission has performed a detailed analysis in this respect on the basis of own research and external information and found that emissions generated by real driving on the road of Euro 5/6 vehicles substantially exceed the emissions measured on the regulatory New European Driving Cycle (NEDC), in particular with respect to NOx emissions of diesel vehicles.
- 3) Type-approval emission requirements for motor vehicles have been tightened significantly through the introduction and subsequent revision of Euro standards. As noted in the Commission Communication on A Clean Air Program for the EU⁴ (see point 2.2.1), “... successive generations of Euro standards and fuel quality standards have been agreed so as to control vehicle emissions in the EU. The required reductions have been delivered, with one exception: NOx emissions from light-duty diesel engines”. Sustained high levels of NO₂ concentrations in ambient air are particularly related to these emissions and are a major concern regarding human health and for compliance with the NO₂ limits laid down in Directive 2005/80/EC. Actions for helping correct this situation are urgently needed.

¹ OJ L 171, 29.6.2007, p. 1.

² OJ L 263, 9.10.2007, p. 1.

³ OJ L 199, 28.7.2008, p. 1.

⁴ 18 December 2013, COM(2013)918 final – see point 2.2.1.

- 4) As a consequence the Commission has established in January 2011 a working group involving all interested stakeholders for developing a real driving emission (RDE) test procedure better reflecting emissions measured on the road. For this purpose the technical option suggested in Regulation (EC) 715/2007, i.e. the use of portable emission measurement systems and not-to-exceed (RDE) regulatory concepts has been followed.
- 5) In order to allow manufacturers to properly adapt to the RDE requirements, the respective test procedures should be introduced in two phases according to the principles agreed with stakeholders in the CARS21 final report. This will allow industry to demonstrate diesel NO_x controls in a first phase but also aim for a more significant step in a second phase that requires the appropriate lead-time for industry to undertake significant redesign of vehicle platforms and emission control hardware. A first phase should apply for new diesel vehicle types only and commence 3 years after the Euro 6 dates laid down in Regulation (EC) 715/2007. A second phase should commence for new vehicle types from 1 September 2020 with the understanding that this date should be no earlier than 5 years after the publication in the Official Journal of this RDE Regulation including also the necessary NO_x conformity factors (if the conformity factors are published in a subsequent Regulation). The second phase should commence 1 year later for all new vehicles.
- 6) In order for technical services, certification laboratories, type-approval authorities and vehicle manufacturers to all gain experience using the RDE Regulation and its new tools and processes, a monitoring phase should commence from a suitable date after the RDE procedures and NO_x conformity factors are published in the Official Journal.
- 7) This Regulation addresses the better control of diesel NO_x real driving emissions. However, as foreseen in Regulation (EC) No 459/2012, the Commission will propose a type approval test method ensuring the effective limitation of the number of particles emitted by vehicles equipped with positive-ignition direct injection engines under real driving conditions and, based on further experience of the use of the method, the appropriate CFs that should be justified by environmental and cost impact assessment. Accordingly, industry shall be given sufficient lead-time to comply with any new requirements.
- 8) An individual RDE test at the initial type approval cannot cover the full range of relevant traffic and ambient conditions. Therefore in-service-conformity testing is of utmost importance for ensuring that a wide range of such conditions is at least potentially covered by a regulatory RDE test, thereby providing for compliance with the regulatory requirements to adequately reflect the emissions generated by real driving on the road.
- 9) Periodical regeneration processes of pollution control devices may have a significant influence on emissions, which should be included in the overall assessment of a vehicle's RDE performance according to the frequency of the occurrence of such processes under real driving conditions. The Commission should prepare and propose provisions for that purpose as soon as possible and at least until 31 December 2015, also investigating possibilities for a better and unambiguous identification of periodic regeneration processes.
- 10) The operational and trip conditions at PEMS trips for regulatory purposes should reflect the real driving on the road and should not be biased in order to achieve an intended result. It may therefore be necessary to review the requirements and develop further dynamical trip indicators invalidating PEMS trips that are driven unduly, e.g. either too "gently" or "harshly" with respect to the pollutants emitted at real driving on

the road. If necessary, the Commission will review such operational and trip conditions by 30 June 2015.

- 11) While the algorithms, the minimum and maximum shares and tolerances to verify trip completeness, sufficient class coverage and normality of the two normalisation tools have been developed based on a limited data base, it is essential to prove the general applicability of the tools for all powertrain concepts. The Commission should validate the tool performance by defining clear criteria to allow a robust verification of the trip completeness and normality and sufficient coverage. The Commission should prepare a decision for the future use of one single normalisation tool by 31 December 2015.
- 12) For small volume manufacturers the execution of PEMS tests according to the procedural requirements of this regulation may constitute a significant burden that is not in balance with the expected environmental benefit. The Commission will therefore investigate to what extent the provisions for such manufacturers can be facilitated, taking into account special procedural needs of small volume manufacturers and the potential environmental hazards created by their specific vehicle portfolios. Attention has to be given to the use of such facilitated conditions outside the regulatory intention and only on the basis of formal criteria.
- 13) The Commission should keep under review the real driving emissions test procedure and update and improve elements if necessary to reflect, e.g. changes in vehicle technology. To assist the review of the procedure, the use of vehicle and emissions data obtained during the transitional period should be considered.

Article 1

Regulation (EC) 692/2008 is amended as follows:

- 1) In Article 2, the following points 41, 42, 43 and 44 should be added:

“41. 'Real driving emissions' (RDE) means the emissions of a vehicle under its normal conditions of use;

42. 'Portable emissions measurement system' (PEMS) means a portable emissions measurement system meeting the requirements specified in Appendix 1 to Annex IIIA of this Regulation;

43. 'Normal conditions of use' means conditions of vehicle use that describe ambient, trip and operational conditions that are statistically usual and ordinary. Moderate conditions cover approximately 70% of the relevant parameter statistically occurring in Europe. Extended conditions are applicable between 70% and approximately 95%, respectively;

44. 'Real driving indicator' (RDI) ensures that passenger car and light duty emission are controlled over a range of speed and load combinations commonly experienced under normal conditions of use. Emissions are monitored during operation and averaged over the complete test. The distance specific emissions must not exceed a specified value for any of the regulated pollutants. The test procedure does not involve a specific driving cycle of any specific length (mileage or time). Rather it involves driving of any type that could occur within the limits of given parameter sets of boundary conditions, including operation under steady-state or transient conditions and under varying ambient conditions;”

- 2) The following section 10 should be added to Article 3:

"10 . Provisions for the application of the requirements of Annex IIIA.

10.1. Excepting paragraph 2.2.2, the provisions laid down in Annex IIIA are applicable to new types of vehicles of category M and N1 class 1 from 3 years after the dates given in paragraph 4 of Article 10 of Regulation (EC) 715/2007.

10.2. The provisions laid down in Annex IIIA are applicable to new types of vehicle of category M and N1 class 1 from *[publications office to add the date which should be 1 September 2020, but no earlier than 5 years after the date of publication of this Regulation including also the necessary NOx conformity factors in case the conformity factors are included in a subsequent Regulation]*.

10.3. The provisions laid down in Annex IIIA are applicable to new types of vehicle of category N1 classes 2 and 3 and N2 from *[publications office to add the date which should be 1 September 2021, but no earlier than 6 years after the date of publication of this Regulation including also the necessary NOx conformity factors in case the conformity factors are included in a subsequent Regulation]*.

10.4. The provisions laid down in Annex IIIA are applicable to new vehicles of category M and N1 class 1 from *[publications office to add the date which should be 1 September 2021, but no earlier than 6 years after the date of publication of this Regulation including also the necessary NOx conformity factors in case the conformity factors are included in a subsequent Regulation]*.

10.5. The provisions laid down in Annex IIIA are applicable to new vehicles of category N1 classes 2 and 3 and N2 from *[publications office to add the date which should be 1 September 2022, but no earlier than 7 years after the date of publication of this Regulation including also the necessary NOx conformity factors in case the conformity factors are included in a subsequent Regulation]*.

10.6. During a transitional period that will commence from 1 September 2015, but no earlier than 2 months after the date of publication of this Regulation, until the dates given in paragraph 10.1, excepting the provisions of paragraphs 2.2.1 and 2.2.2, the provisions laid down in Annex IIIA are applicable to new types of vehicles that are type approved according to Regulation (EC) No 715/2007 during this transitional period.

10.7. By way of exception to point 10.6, the requirements of Annex IIIA do not apply to type approvals granted to small volume manufacturers as defined in Article 2(32) of Regulation (EC) No 715/2007.

10.8. It is sufficient that the minimum coverage requirements as defined in Appendices 5, section 5.4 and 6, section 6.2.5, table 4 of Annex IIIA are satisfied for only one of the two data evaluation methods defined in those Appendices. In this case the analysis of the completeness and normality shall be recorded for both methods and the calculation required by paragraph 9.3 of Annex IIIA and reporting required by Appendix 8 may be limited to the method for which the completeness and normality requirements are satisfied. The manufacturer shall provide one additional test in order to provide additional data for examining the difference in the results of the two data evaluation methods."

- 3) In the list of annexes, the following text is inserted after the line starting with "Annex III":

"ANNEX IIIA Verifying real driving emissions (RDE) under normal conditions of use (type 1A test)"

- 4) In Annex I, in point 2.4.1., Figure I.2.4 is amended as follows:

- 5) (a) The following rows are inserted after the row starting with "Particulate mass and particulate number (Type 1 test)":

<i>Gaseous pollutants, RDE (Type IA test)</i>	-	-	-	-	-	-	-	-	-	<i>Yes (both fuels)</i>	<i>Yes</i>	-	-
<i>Particulate number, RDE (Type IA test) ⁽⁵⁾</i>	<i>Yes</i>	-	-	-	<i>Yes (both fuels)</i>	<i>Yes (both fuels)</i>	<i>Yes (both fuels)</i>	<i>Yes (both fuels)</i>	-	-	-	-	-

- (b) The following footnote is added:

"⁽⁵⁾ The particulate number RDE test only applies to PI direct injection vehicles for which Euro 6 emission limits are defined in Table 2 of Annex I to Regulation (EC) 715/2007."

- 6) The following Annex IIIA is inserted:

ANNEX IIIA

VERIFYING REAL DRIVING EXHAUST EMISSIONS

1. INTRODUCTION

This Annex describes the procedure for the test verifying the Real Driving Emissions (RDE) performance of the vehicle.

2. GENERAL REQUIREMENTS

2.1 Throughout its normal life, the emissions of a vehicle type approved according to Regulation (EC) 715/2007 as determined according to the requirements of this Annex and emitted at a RDE test performed in accordance to the requirements in this Annex, shall not be higher than the following RDI values:

$$RDE_{pollutant} = CF_{pollutant} \times EURO-6,$$

where Euro-6 is the applicable Euro 6 emission limit in Table 2 of Annex I to Regulation (EC) 715/2007.

2.1.1 In time period defined in points 10.1 of Article 3 of Regulation (EC) No 692/2008, the conformity factors $CF_{pollutant}$ are the following:

	Boundary condition ¹	Nitrogen oxides (NOx) ⁵	Carbon monoxide (CO) ²
$CF_{pollutant}$ ⁴	moderate	3,5	-
$CF_{pollutant}$ ⁴	extended	5	-

¹ Moderate and extended boundary conditions are defined in paragraph 5 of this Annex.

² CO emissions shall be measured and recorded during RDE tests only to validate the exhaust aftertreatment system performance.

⁴ Hybrids will be exempted from RDE-testing until robust testing and evaluation procedures are defined by the Commission.

⁵ Applies only to vehicles with compression-ignition engines.

2.1.2 In time period defined in points 10.2, 10.3, 10.4 and 10.5 of Article 3 of Regulation (EC) No 692/2008, the conformity factors $CF_{pollutant}$ are the following:

	Boundary condition ¹	Nitrogen oxides (NOx) ⁵	Particle numbers (PN) ²	Carbon monoxide (CO) ³
$CF_{pollutant}$ ⁴	moderate	2	tbd.	-
$CF_{pollutant}$ ⁴	extended	3	tbd.	-

¹ Moderate and extended boundary conditions are defined in paragraph 5 of this Annex.

² A Commission proposal should be made for the RDE method for positive-ignition direct injection engine PN and, based on further experience of the use of the method, the appropriate CFs justified by environmental and cost impact assessment, should be introduced into this table. The PN method and CFs shall apply to new types of vehicles no earlier than 5 years, and to all vehicles no earlier than 6 years after the publication of the method and PN CFs in the Official Journal of the European Union.

³ CO emissions shall be measured and recorded during RDE-tests only to validate the exhaust aftertreatment system performance.

⁴ Hybrids will be exempted from RDE-testing until robust testing and evaluation procedures are defined by the Commission.

⁵ Applies only to vehicles with compression-ignition engines.

2.2 The manufacturer shall confirm compliance with point 2.1 by completing the certificate set out in Appendix 9.

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

2.4 Manufacturers shall ensure that vehicles, to which the requirements of this Annex apply, can be tested with PEMS [...] by granting access to ECU signals [laid down in Appendix 1 table 1]. If the ECU data cannot be provided, suitable adapters for the widely different exhaust pipe configurations shall be made available by the respective vehicle manufacturer for a proportional and reasonable fee.

3. RDE TEST TO BE PERFORMED

3.1. Type approval according to Regulation (EC) 715/2007 can only be issued if the vehicle is part of a validated PEMS test family according to the requirements of this point and Appendix 7.

The following special requirements apply to PEMS tests:

3.1.1. Reporting and dissemination of RDE test information

Information document prepared by the vehicle manufacturer in accordance with Appendix 8 shall be made available to the type approval authority.

3.1.1.1. The vehicle manufacturer shall ensure that the following information is made available on a publicly accessible website without costs:

3.1.1.1.1. The unique identification number of a PEMS test family to which a given vehicle emission type belongs, as defined in point 3.2 of Appendix 7, by entering the vehicle emission type approval number;

3.1.1.1.2. By entering the unique identification number of a PEMS test family:

- the full information as required by point 3.1 of Appendix 7,
- the lists described in points 3.3 and 3.4 of Appendix 7;
- the results of the PEMS tests as set out in points 5.5.3 of Appendix 5 and 6.4.8 of Appendix 6 for all vehicle emission types in the list described in point 3.4 of Appendix 7.

3.1.1.1. Upon request of a different type approval authority, the type approval authority that issued the system type approval shall make available the information listed under points 3.1.3.1 and 3.1.3.2 within 30 days of receiving the request. The type approval authority may charge a reasonable and proportionate fee, which does not discourage an inquirer with a justified interest from requesting the respective information or exceed the internal costs of the authority for making the requested information available.

4. GENERAL REQUIREMENTS FOR PEMS TESTING

- 4.1. The RDE performance of vehicles shall be demonstrated by testing vehicles on the road 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.
- 4.2. The manufacturer shall demonstrate to the Type Approval Authority that the chosen vehicle, driving patterns, conditions and payloads are representative for the vehicle family. The payload and altitude requirements, as specified in paragraphs 5.1 and 5.2, shall be used ex-ante to determine whether the conditions are acceptable for RDE testing. In case another test is justified for practical reasons and, after the agreement of the type-approval authority, another procedure may be used but the manufacturer has to demonstrate equal stringency to the type-approval authority.
- 4.3. The Type Approval Authority confirms for an OEM the selected PEMS route that has to meet the requirements of paragraph 6. For the purpose of the trip selection, the definition of urban rural, and motorway operation shall be based on map data.
- 4.4. Vehicles where the collection of ECU data influences the vehicle emissions or performance shall be considered as non-compliant.

5. BOUNDARY CONDITIONS FOR PEMS TESTING

- 5.1. The PEMS tests may be conducted under boundary conditions laid down in this section. The boundary conditions become 'extended', when at least [one] of the conditions are extended. An extreme combination of "extended" conditions of vehicle test mass (paragraph 5.2.3), road grade (paragraph 6.13.2), and driving behaviour (paragraph 6.14.2) shall be avoided in agreement with the type approval authority.

5.2. Vehicle payload and test mass

- 5.2.1. The vehicle's test mass shall be comprised of the vehicle reference weight, as defined in [...], a witness of the test (if applicable) and the test equipment, including the mounting and the power supply devices.

5.2.2. Moderate vehicle test mass:

M1: maximum of unladen vehicle mass excluding driver + 200 kg.

N1, N2, M2: maximum of unladen vehicle mass excluding driver + 200 kg

5.2.3. Extended vehicle test mass:

M1: The vehicle test mass shall not exceed the lower of 90% of the Gross Vehicle Weight or 2840 kg.

N1, N2, M2: The vehicle test mass shall not exceed the minimum of unladen vehicle weight (without driver) plus 50% of the payload and 2840kg.

5.3. Ambient conditions

- 5.3.1. Moderate altitude conditions: Atmospheric pressure lower than or equal to 93kPa (700 meters above sea level).

- 5.3.2. Extended altitude conditions: Atmospheric pressure greater than 93 kPa (700 meters above sea level) and lower than 87 kPa (1300 meters above sea level).

5.3.3. Moderate temperature conditions: greater than or equal to 282K (9°C) and lower than or equal to 303K (30°C).

5.3.4. Extended temperature conditions: greater than or equal to 276 K (3°C) and lower than or equal to 303 K (30°C).

5.4. Dynamic conditions: The dynamic boundary conditions encompass the effect of road grade, head wind and driving dynamics (accelerations, decelerations) and auxiliary systems upon the vehicle energy consumption and emissions. The verification of the test normality of dynamic conditions shall be done after the test is completed, using the recorded PEMS data. The methods for this verification, assessing the normality of the dynamic conditions, are laid down in Appendices 5 and 6. Each method includes a reference for dynamic conditions, ranges around the reference and the minimum coverage requirements to achieve a valid test.

5.4.1. Auxiliary systems

The air conditioning system or other auxiliary devices shall be operated in a way which is compatible with their possible use by a consumer at real driving on the road.

5.4.2. Vehicles equipped with periodically regenerating systems

5.4.2.1. ‘Periodically regenerating systems’ shall be understood according to the definition in Article 2(6) of Regulation 692/2008.

5.4.2.2. If periodic regeneration occurred during a test, the test may be voided and repeated once at the request of the vehicle manufacturer.

5.4.2.3. The manufacturer may ensure the completion of the regeneration and precondition the vehicle appropriately prior to the second test.

5.4.2.4. If regeneration occurs during the repetition of the RDE test, pollutants emitted during the repeated test shall be included in the emissions evaluation of the test vehicle.

6. TRIP REQUIREMENTS FOR PEMS TESTING

6.1. The shares of operation for urban rural and motorway driving shall be expressed as a percentage of the total trip distance.

6.2. The trip sequence shall consist of urban driving followed by rural and motorway driving according to the shares specified in paragraphs 6.5. The urban, rural and motorway operation shall be run continuously to the maximum extent possible. If another testing order is justified for practical reasons, another order of urban, rural and motorway operation may be used, after agreement of the Type Approval Authority. Rural operation may include short periods of urban driving when driving through urban areas. Characterization of urban, rural and motorway operation by map and allocation to the measured data according to distance driven with a minimum special resolution of 5 m with linear interpolation between defined points to fit to the measured emission data also at low speed at least in 1Hz resolution.

Roads in urban areas, which are inside a “City Limit” sign where appropriate and where the speed limit is below 60 km/h are considered urban. Urban operation is characterised by vehicle speeds up to 60 km/h.

6.3. Roads with at least 2 structurally separated lanes in the direction of driving and where the speed limit is above 80 km/h are considered to be motorways.

- 6.4. All roads which are not considered urban or motorway are rural roads. Villages or parts of small towns with speed limit less than 60 km/h should be categorized as urban, when they are passed during the rural section. Motorway operation is characterised by speeds above 90 km/h.
- 6.5. For the purpose of this paragraph, "approximately" shall mean the target value ± 5 per cent. The trip shall consist of approximately 26% per cent urban, 44% per cent rural and 30% per cent motorway operation.
- 6.6. The vehicle velocity shall normally not exceed 130. If the maximum speed exceeds 130 km/h, the boundary conditions become 'extended'. This maximum speed may be exceeded by a tolerance of 15 km/h for not more than 3% of the distance of the motorway driving.
- 6.7. 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.
- 6.8. The average speed (including stops) of the urban driving part of the trip should be between 20 and 40 km/h.

To avoid unusual traffic situations and driving situations the stationary share of the trip can be indicated by the absolute duration of an idling event and the idling share of the trip. An idling event should include standstill and idling cruise with $v < [2]$ km/h. Each single idling event shall not exceed 90s. The idling duration shall be greater than or equal to 3% and lower than 15% of the time of the complete PEMS trip.

- 6.9. 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. The average speed (including stops) of the motorway driving part of the trip should be between 90 and 120 km/h.
- 6.10. The trip duration shall be between 90 and 120 minutes.
- 6.11. The minimum distance of each, the urban, rural and motorway operation shall be at least 16 km.
- 6.12. Beginning and ending of tour should be approximately the same position in terms of GPS coordinates. In the case the tour cannot be circular for practical reasons and after the agreement of the approval authority and the manufacturer another tour operation may be used, where the altitude difference should not exceed [50] m.
- 6.13. Unusual road grade should be avoided.
 - 6.13.1. Moderate road grade: the [95]% distance share of the PEMS trip doesn't exceed an incline of [20] m/km and the cumulative positive altitude gain is below [650m/100km].
 - 6.13.2. Extended road grade: if the [95]% distance share of the PEMS trip exceeds an incline of [35] m/km and the cumulative positive altitude gain exceeds [1000m/100km], an alternative route should be considered
- 6.14. Deliberate misuse or driving in a gross negligent manner or on the other hand, driving purposely excessively slowly and smoothly (e.g. by applying cruise control very often) should be avoided. The driving behaviour is described by the following equation: $v \times a_{pos\ 95\ \%ile} = A_i + 0,288 \times V_{mean}$. V_{mean} is the average of all velocity signals during the valid test time in urban, road and motorway conditions

including idling phases and engine stop phases. The positive acceleration means values $> 0,1 \text{ m/s}^2$.

- 6.14.1. Moderate driving behaviour: the 95th percentile of the frequency distribution of the product of all positive accelerations and the vehicle velocity lower than or equal $11 + 0,288 \times V_{\text{mean}}$ and greater than $2 + 0,288 \times V_{\text{mean}}$ during the valid test time in urban, road and motorway conditions.
- 6.14.2. Extended driving behaviour: the 95th percentile of the frequency distribution of the product of all positive accelerations and the vehicle velocity lower than or equal $14 + 0,288 \times V_{\text{mean}}$ and greater than $2 + 0,288 \times V_{\text{mean}}$ during the valid test time in urban, road and motorway conditions.

7. OPERATIONAL REQUIREMENTS FOR PEMS TESTING

- 7.1. The trip shall be selected in such a way that the testing is uninterrupted and the data continuously recorded to reach the minimum test duration defined in paragraph 6.10.
- 7.2. It shall not be permitted to combine data of different trips or to modify or remove data from a trip.
- 7.3. If the engine stalls, it may be restarted, but the sampling shall not be interrupted.
- 7.4. The electrical power to the PEMS system shall be supplied by an external power supply unit, and not from a source that draws its energy either directly or indirectly from the engine of the vehicle under test.
- 7.5. The installation of the PEMS equipment shall be done in a way to influence the vehicle emissions and/or performance to the minimum extent possible. Care should be exercised to minimize the mass of the installed equipment and potential aerodynamic modifications caused by the PEMS installation. In any case, the vehicle payload shall be in accordance with section 5.2.
- 7.6. Vehicles shall be operated on normal working days between 06:00 - 20:00 local time.
- 7.7. The tests shall be conducted on paved roads and streets (e.g. no off-road operation).
- 7.8. "Pumping" or the closing of the throttle shall be avoided when passing from acceleration to steady speed. It is recommended to perform accelerations and decelerations as anticipatory as possible throughout the operation
- 7.9. Vehicles with a manual transmission shall be driven according to the indication of the GSI if fitted, in this case. The GSI indication should be followed in at least 90% of the time duration of the complete trip. Alternatively, very unusual shifting behavior in speed phases can be indicated by relative engine speed n_{rel} . The relative engine speed shall normally not exceed 0,5. This maximum relative engines speed may be exceeded for not more than 3% of the time duration of the complete PEMS trip. The evaluation should exclude standstill and very low velocities $v < 10 \text{ km/h}$, to exclude e.g. open clutch or idling operation. n_{rel} is defined as:

$$n_{\text{rel}}(t_i) = \frac{n_{\text{act}}(t_i) - n_{\text{idle}}}{n_{\text{rated}} - n_{\text{idle}}}$$

8. LUBRICATING OIL, FUEL AND REAGENT DURING PEMS TESTING

8.1. The fuel, lubricating oil and reagent (if applicable) shall be within the specifications that are recommended by the vehicle manufacturer for the correct operation of the vehicle by the customer.

8.1.1. The test fuel shall be market fuel. Diesel shall comply with standard EN590:2013. Petrol shall comply with standard EN228:2012 (E5 or E10).

8.2. In the case of tests conducted in accordance with this Annex by a technical service or an independent party, samples of the fuel, lubricating oil and reagent (if applicable) shall be taken and kept under the appropriate storage conditions for subsequent analysis. Such samples shall be made available to the respective vehicle manufacturer on request.

8.2.1. If a sample provided to the manufacturer according to paragraph 8.2 does not meet the specifications recommended by the manufacturer (as verified by independent analysis), any RDE test results for vehicles where those samples were used shall be void.

9. EMISSIONS AND TRIP EVALUATION OF PEMS TESTING

9.1. The test shall be conducted in accordance with the provisions of Appendix 1 to this Annex.

9.2. The trip shall fulfil the requirements set out in sections 4, 5, 6, 7 and 8 of this Annex.

9.3. Emission results shall be calculated using the two methods laid down in Appendix 5 and Appendix 6.

9.4. If the lower bounds are not met, the trip is invalid, i.e. classified as having insufficient kinematic driving conditions.

9.5. If the upper bounds are exceeded, the trip is invalid if the vehicle exceeds the emission limit values, set out in section [2.1], for the PEMS test i.e. classified as having too severe driving conditions. Under this condition the test has to be repeated. If the emission limits are met also under the severe conditions or during the Monitoring Phase, the trip can be defined as valid PEMS test in agreement with the type approval authority and the manufacturer.

9.6. The cold start is defined in accordance with paragraph 4.4 of Appendix 4 and shall not be included in the emission evaluation.

List of Appendices

- 1) Test procedure for vehicle emissions testing with a Portable Emissions Measurement System (PEMS)
- 2) Specifications and calibration of PEMS components and signals
- 3) Validation of PEMS and non-traceable exhaust mass flow rate
- 4) Determination of emissions
- 5) Verification of trip dynamic conditions with method 1 (Moving Averaging Window)
- 6) Evaluation by normalization to a standardized power frequency distribution
- 7) Selection of vehicles for PEMS testing at initial type approval
- 8) Reporting and data dissemination
- 9) Manufacturer's certificate of compliance

Colour codes:

Cross-references to other paragraphs; always to be checked

Definitions used in the Appendices

“*Accuracy*” is defined as the deviation between a measured or calculated value and a traceable reference value.

“*Analyser*” is defined as any measurement device that is not part of the vehicle itself but installed to determine the concentration or the amount of gaseous pollutants.

“*Axis intercept*” of a linear regression (a_0) is defined as:

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

where:

a_1 is the slope of the regression line

\bar{x} is the mean value of the reference parameter

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

“*Calibration*” is defined as the process of setting the response of an analyser, flow-measuring instrument, sensor, or signal so that its output agrees with one or multiple reference signals.

“*Coefficient of determination*” (r^2) is defined as:

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

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
\bar{y}	is the mean value of the parameter to be verified
n	is the number of values

“Cross-correlation coefficient” (r) is defined as:

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

where:

x_i	is the measured reference value
y_i	is the measured value of the parameter to be verified
\bar{x}	is the mean reference value
\bar{y}	is the mean value of the parameter to be verified
n	is the number of values

“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.

“Engine control unit” is defined as the electronic unit that controls various actuators to ensure the optimal performance of the powertrain.

“Exhaust”, also referred to as exhaust gas, is defined here as the total of all gaseous and particulate components emitted at the exhaust outlet or tailpipe as the result of the combustion of fuel within a vehicle’s internal combustion engine.

“Exhaust emissions” is defined as the gaseous components at the tailpipe of a vehicle.

“Full scale” is defined as 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.

“Major maintenance” is defined as the adjustment, repair or replacement of an analyser, flow-measuring instrument, or sensor that could affect the accuracy of measurements.

“Noise” is defined as two times the root mean square of ten standard deviations, each calculated from the zero responses measured at a constant recording frequency of at least 1.0 Hz during a period of 30 seconds.

“Precision” is defined as 2.5 times the standard deviation of 10 repetitive responses to a given traceable standard value.

“Reading” is defined as the numerical value displayed by an analyser, flow-measuring instrument, sensor, or any other measurement device applied in the context of vehicle emission measurements.

“Response time” (t_{90}) is defined as the sum of the delay time and the rise time.

“*Rise time*” is defined as the time between the 10 per cent and 90 per cent response ($t_{90} - t_{10}$) of the final reading.

“*Root mean square*” (x_{rms}) is the square root of the arithmetic mean of the squares of values and defined as:

$$x_{\text{rms}} = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + \dots + x_n^2)}$$

where:

x is the measured or calculated value
 n is the number of values

“*Sensor*” is defined as any measurement device that is not part of the vehicle itself but installed to determine parameters other than the concentration of gaseous pollutants and the exhaust mass flow.

“*Span*” is defined as the calibration of an analyser, flow-measuring instrument, or sensor so that it gives an accurate response to a standard that matches as closely as possible the maximum value expected to occur during the actual emissions test.

“*Span response*” is defined as the mean response to a span signal during a time interval of at least 30 seconds.

“*Span response drift*” is defined as 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 has been accurately spanned.

“*Slope*” of a linear regression (a_1) is defined as:

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

where:

\bar{x} is the mean value of the reference parameter
 \bar{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) is defined as:

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

where:

\hat{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

“*Transformation time*” is defined as 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}).

“*Type of analyser*”, also referred to as “*analyser type*” is defined as all analysers produced by one manufacturer that function on an identical principle to determine the concentration or the amount of the same gaseous pollutant.

“*Type of exhaust mass flow meter*” is defined as all exhaust mass flow meters produced by one manufacturer that share a similar tube inner diameter and function on an identical principle to determine the mass flow rate of the exhaust gas.

“*Validation*” is defined here as the process of evaluating the principle functionality of a Portable Emissions Measurement System connected to a vehicle and the correctness of exhaust mass flow rate as measured by non-traceable exhaust mass flow meters or as calculated from sensors or ECU signals.

“*Verification*” is defined as the process of evaluating whether measured or calculated output of an analyser, flow-measuring instrument, sensor, or signal agrees with applied reference signals within one or more predetermined thresholds for acceptance.

“*Zero*” is defined as the calibration of an analyser, flow-measuring instrument or sensor so that it gives an accurate response to a zero signal.

“*Zero response*” is defined as the mean response to a zero signal during a time interval of at least 30 seconds.

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

Abbreviations used in the Appendices

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

CLD	- ChemiLuminescence Detector
CO	- Carbon Monoxide
CO ₂	- Carbon Dioxide
CVS	- Constant Volume Sampler
ECU	- Engine Control Unit
EFM	- Exhaust mass Flow Meter
e.g.	- for example
FS	- full scale
GPS	- Global Positioning System

HCLD	- Heated ChemiLuminescence Detector
H ₂ O	- Water
ID	- identification number or code
i.e.	- that is
max	- maximum value
N ₂	- Nitrogen
NDIR	- Non-Dispersive InfraRead
NDUV	- Non-Dispersive UltraViolet
NO	- Nitrogen Monoxide
No.	- number
NO ₂	- Nitrogen Dioxide
NO _x	- Nitrogen Oxides
OBD	- On-Board Diagnostics
PEMS	- Portable Emissions Measurement System
SEE	- Standard Error of Estimate
UN/ECE	- United Nations Economic Commission for Europe
WLTC	- Worldwide harmonized Light vehicles Test Cycle
WWHOB	- Worldwide Harmonized On-Board-Diagnostics

Symbols, parameters and units used in the Appendices

Δ	- difference
\geq	- larger or equal
#	- number
%	- per cent
\leq	- smaller or equal
α	- molar hydrogen ratio (H/C)
β	- molar carbon ratio (C/C)
γ	- molar sulphur ratio (S/C)
δ	- molar nitrogen ratio (N/C)
ϵ	- molar oxygen ratio (O/C)
a_0	- y-axis intercept of a linear regression line
a_1	- slope of a linear regression line
ρ_e	- Density of exhaust [kg/m ³]
ρ_{gas}	- Density of a specific component or pollutant
Hz	- hertz
°C	- degrees centigrade
cm ³	- cubic centimetre
c_{dry}	- dry concentration of a pollutant in ppm or per cent volume
c_{CO_2}	- dry CO ₂ concentration [%]
c_{CO}	- dry CO concentration [%]
c_{wet}	- wet concentration of a pollutant in ppm or per cent volume
g	- gramme
h	- hour
H_a	- intake air humidity [g water per kg dry air]
K	- kelvin
kg	- kilogramme
km	- kilometre
km/h	- kilometres per hour

kPa	- kilopascal
k_w	- dry-wet correction factor
l	- litre
m	- metre
m^3	- cubic metre
mg	- milligramme
min	- minute
q_{vs}	- volume flow rate of the system
p_e	- evacuated pressure
ppm	- parts per million
r	- cross-correlation coefficient
r^2	- coefficient of determination
rpm	- revolutions per minute
s	- second
t_0	- time of gas flow switching
t_{10}	- delay time
t_{90}	- response time
V_s	- system volume
x	- value of the reference signal in a linear regression analysis
χ_{min}	- minimum value
y	- value of the signal under validation in a linear regression analysis

Appendix 1. Test procedure for vehicle emissions testing with a Portable Emissions Measurement System (PEMS)

1.1 Introduction

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

1.2 Symbols

#	-	number
%	-	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/h	-	kilometre per hour
kPa	-	kilopascal
kPa/min	-	kilopascal per minute
l	-	litre
l/min	-	litre per minute
m	-	metre
m ³	-	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
rpm	-	revolutions per minute
s	-	second
V_s	-	system volume [l]

1.3 General requirements

1.3.1 PEMS

The test shall be carried out with a PEMS, comprised of components specified in paragraphs 1.3.1.1 to 1.3.1.5. If applicable, a connection with the vehicle ECU may be established to determine relevant engine and vehicle parameters as specified in paragraph 1.3.2.

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

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

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

1.3.1.4 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.

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

1.3.2 Test parameters

Test parameters as specified in **Table 1** shall be measured and recorded at a constant frequency of 1.0 Hz or higher. If ECU parameters are obtained, these should be available at a substantially higher frequency than the parameters recorded by PEMS to ensure correct sampling. The PEMS analysers, flow-measuring instruments, and sensors shall comply with the requirements laid down in **Appendix 2 and 3**.

Table 1: Test parameters

Parameter	Recommended unit	Source ⁽¹¹⁾
CO concentration ⁽¹⁾	ppm	Analyser ⁽³⁾
CO ₂ concentration ⁽¹⁾	ppm	Analyser ⁽³⁾
NO _x concentration ⁽¹⁾	ppm	Analyser ^(3,10)
Exhaust mass flow rate	kg/s	EFM, any methods described in paragraph 2.7
Ambient humidity	%	Sensor ⁽⁴⁾
Ambient temperature	K	Sensor ⁽⁴⁾
Ambient pressure	kPa	Sensor ⁽⁴⁾
Vehicle speed	km/h	Sensor ⁽⁴⁾ , GPS, or ECU ^(5,6)
Vehicle latitude	degree	GPS
Vehicle longitude	degree	GPS
Vehicle altitude ^(8,12)	m	GPS or Sensor ⁽⁴⁾
Exhaust gas temperature ⁽⁸⁾	K	Sensor ⁽⁴⁾
Engine coolant temperature ⁽⁸⁾	K	Sensor ⁽⁴⁾ or ECU ⁽⁵⁾
Engine speed ⁽⁸⁾	rpm	Sensor ⁽⁴⁾ or ECU ⁽⁵⁾
Engine torque ⁽⁸⁾	Nm	Sensor ⁽⁴⁾ or ECU ⁽⁵⁾
Pedal position ⁽⁸⁾	%	Sensor ⁽⁴⁾ or ECU ⁽⁵⁾
Engine fuel flow ⁽²⁾	g/s	Sensor ⁽⁴⁾ or ECU ⁽⁵⁾
Engine intake air flow ⁽²⁾	g/s	Sensor ⁽⁴⁾ or ECU ⁽⁵⁾
Fault status ⁽⁸⁾	-	ECU ⁽⁵⁾
Intake air flow temperature	K	Sensor ⁽⁴⁾ or ECU ⁽⁵⁾
Regeneration status ⁽⁸⁾	-	ECU ⁽⁵⁾
Engine oil temperature ⁽⁸⁾	K	Sensor ⁽⁴⁾ or ECU ⁽⁵⁾
Actual gear ⁽⁸⁾	#	ECU ⁽⁵⁾
Desired gear (e.g. GSI) ⁽⁸⁾	#	ECU ⁽⁵⁾
Other vehicle data ⁽⁸⁾	unspecified	ECU ⁽⁵⁾

Notes:

- (1) to be measured on a wet basis or to be corrected as described in **paragraph 4.8.1**
- (2) to be determined only if indirect methods are used to calculate exhaust mass flow rate as described in **paragraphs 4.10.2 and 4.10.3**
- (3) Analyser means any measurement device that is not part of the vehicle itself but installed to determine the concentration of gaseous pollutants.
- (4) Sensor means any measurement device that is installed but not part of the vehicle itself to determine parameters other than the concentration of gaseous pollutants and exhaust mass flow.

- (5) ECU means any vehicle information and signal recorded from the vehicle network using the protocols specified in paragraph 1.3.4.5.
- (6) the method to determine vehicle speed shall be chosen according to paragraph 1.4.7
- (8) to be determined only if necessary to verify the vehicle status and operating conditions
- (10) may be calculated from measured NO and NO₂ concentrations
- (11) Multiple parameter sources may be used.
- (12) The preferable source is the ambient pressure sensor.

1.3.3 Preparation of the vehicle

The preparation of the vehicle shall include a general technical and operational check. The test vehicle, fuel, lubricant, and other liquids shall meet the technical requirements for Type I type approval testing, unless specified otherwise in Annex IIIA.

1.3.4 Installation of PEMS

1.3.4.1 General

The installation of the PEMS shall follow the instructions of the PEMS manufacturer and the local health and safety regulations. The PEMS should be installed as to minimize 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 minimize 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. It is recommended not to use elastomer connectors to bridge the connection between the vehicle exhaust outlet and the connecting tube. Elastomer connectors, if used, shall have a minimum exposure to the exhaust gas to avoid artefacts at high engine load.

1.3.4.2 Permissible backpressure

The installation and operation of the PEMS shall not unduly increase the static pressure at the exhaust outlet. 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 as the exhaust pipe.

1.3.4.3 Exhaust mass flow meter

Whenever used, the exhaust mass flow meter shall be attached to the vehicle's tailpipe(s) according to 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. 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 five pipe diameters of straight tubing shall be placed either side of the flow-sensing element. When testing a multi-cylinder engine with a branched exhaust manifold, it is recommended to combine the manifolds upstream of the exhaust mass flow meter and to increase the cross section of the piping appropriately as to minimize backpressure in the exhaust. If this is not feasible, exhaust flow measurements with several exhaust mass flow meters shall be considered. The wide variety of exhaust pipe configurations, dimensions and expected exhaust mass flow rates may require compromises driven by good engineering judgement for the selection and installation of the EFM(s). If measurement accuracy requires, 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 does not adversely affect the operation or the exhaust after-treatment as specified above.

1.3.4.4 Global Positioning System

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.

1.3.4.5 Connection with the Engine Control Unit

If desired, relevant vehicle and engine parameters listed in Table 1 can be recorded by using a data logger connected with the ECU following the worldwide harmonized standards for on-board diagnostics, e.g., OBD-II and WWHOBd. If applicable, vehicle manufacturers shall disclose parameter labels to allow the identification of required parameters.

1.3.4.6 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.

1.3.5 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 300 mm to the flow sensing element. The sampling probes shall be fitted at least 0.2 m or three times the diameter of the exhaust pipe, whichever is larger, upstream of the exit of the exhaust outlet. 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 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 multi-cylinder engine and branched exhaust manifold, the inlet of the sampling probe shall be located sufficiently far downstream as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines, having distinct groups of manifolds such as in a "Vee" engine configuration, the manifolds shall be combined upstream of the sampling probe. If this is technically not feasible, multi-point sampling at locations of well-mixed exhaust free of ambient air shall be considered. In this case, the number and location of sampling probes shall match as far as possible that of the exhaust mass flow meters. In case of unequal exhaust flows, proportional sampling or sampling with multiple analysers shall be considered.

The sampling line shall be heated to a minimum of 333 K (60°C) for the measurement of gaseous components with or without cooler as 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.

1.4 Pre-test procedures

1.4.1 PEMS leak check

After the installation of 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 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 rates.

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

$$\Delta p = \frac{p_e}{V_s} \times q_{vs} \times 0.005 \quad (\text{Equation 1})$$

where:

p_e is the evacuated pressure [kPa]
 V_s is the system volume [l]
 q_{vs} is the volume flow rate of the system [l/min]

Alternatively, a concentration step change at the beginning of the sampling line shall be introduced by switching from zero to span gas while maintaining the same pressure conditions than 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.

1.4.2 Starting and stabilizing the PEMS

The PEMS shall be switched on, warmed up and stabilized according to the specifications of the PEMS manufacturer until, e.g., pressures, temperatures and flows have reached their operating set points.

1.4.3 Preparing the sampling system

The sampling system, consisting of the sampling probe, sampling lines, and the analysers, 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.

1.4.4 Preparing the 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.

1.4.5 Checking and calibrating the analysers for measuring gaseous emissions

Zero and span calibration adjustments of the analysers shall be performed using calibration gases that meet the requirements of [paragraph 2.5](#). The calibration gases shall be chosen to

match the range of pollutant concentrations expected during the emissions test as described in 1.6.3.

1.4.6 Measuring 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 paragraph 4.7;
- 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 paragraph 2.8, 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 paragraph 3.3 and the ECU speed signal adjusted, if necessary to fulfil the requirements of paragraph 3.3.3. Alternatively, the total trip distance as determined by the ECU shall 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.

1.4.7 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 deactivated). The PEMS shall function free of warning signals and error indication.

1.5 Emissions test run

1.5.1 Test start

Sampling, measurement, and recording of parameters shall begin prior to the start of the engine. To facilitate time alignment, it is recommended to record the data which is subject to time alignment either in a single data recording device or with a synchronised timestamp. Before as well as directly after engine start, it shall be confirmed that all necessary parameters are recorded by the data logger.

1.5.2 Test run

Sampling, measurement, and recording of parameters shall continue throughout the on-road test of the vehicle. The engine may be stopped and started, but emissions sampling and parameter recording shall continue. Any warning signals, suggesting malfunctioning of the PEMS, shall be documented and verified. Parameter recording shall reach a data completeness of 99%. Measurement and data recording may be interrupted for 1% of the total trip duration but for no more than a consecutive period of 30 s in the case of signal loss or for the purpose of PEMS system maintenance (e.g., back purging or auto-zeroing of analysers). 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.

1.5.3 Test end

The end of the test is reached when the vehicle has completed the trip and the combustion engine is switched off. The data recording shall continue until the response time of the sampling systems has elapsed.

1.6 Post-test procedure

1.6.1 Checking the analysers for measuring gaseous emissions

The zero and span of the gaseous analysers shall be checked by using calibration gases identical to the ones applied under paragraph 1.4.5 to evaluate the analyser 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 but before the PEMS or individual sensors are turned off or switched to 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	Zero response drift	Span response drift ⁽¹⁾
CO ₂	≤2000 ppm per test	≤2% of reading or ≤2000 ppm per test, whichever is larger
CO	≤75 ppm per test	≤2% of reading or ≤75 ppm, per test, whichever is larger
NO ₂	≤5 ppm per test	≤2% of reading or ≤5 ppm per test, whichever is larger
NO/NO _x	≤5 ppm per test	≤2% or reading or ≤5 ppm per test, whichever is larger

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

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

1.6.2 Checking the on-road emission measurements

The calibrated range of the analysers shall account at least for 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 exceed the calibrated range of the analysers by up to a factor of two. If these requirements are not met, the test shall be voided.

Appendix 2. Specifications and calibration of PEMS components and signals

2.1 Introduction

This appendix describes the requirements to calibrate and verify under stationary conditions analysers, flow-measuring instruments, sensors, and signals.

2.2 Symbols

$>$	- larger than
\geq	- larger than or equal to
$\%$	- per cent
\leq	- smaller than or equal to
a_0	- y-axis intercept of the linear regression line
a_1	- slope of the linear regression line
C	- measured diluted NO concentration [ppm]
c	- analyser response in the oxygen interference test
$^{\circ}\text{C}$	- degree centigrade
D_e	- expected diluted NO concentration [ppm]
E_E	- ethane efficiency
E_{O_2}	- oxygen interference
g	- gram
$g\text{H}_2\text{O}/\text{kg}$	- gramme water per kilogram
h	- hour
H	- actual water vapour concentration [%]
H_m	- maximum water vapour concentration [%]
Hz	- hertz
K	- kelvin
kg	- kilogram
km/h	- kilometre per hour
kPa	- kilopascal
max	- maximum value
$\text{NO}_{X,\text{dry}}$	- moisture-corrected mean concentration of the stabilized NO_X recordings
$\text{NO}_{X,\text{m}}$	- mean concentration of the stabilized NO_X recordings
$\text{NO}_{X,\text{ref}}$	- reference mean concentration of the stabilized NO_X recordings
ppm	- parts per million
r^2	- coefficient of determination
s	- second
t_0	- time point as 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
x	- independent variable or reference value
χ_{\min}	- minimum value
y	- dependent variable or measured value

2.3 Linearity verification

2.3.1 General

The 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.

2.3.2 Linearity requirements

All analysers, flow-measuring instruments, sensors and signals shall comply with the linearity requirements given in Table 3. 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 3.

Table 3: Linearity requirements of measurement parameters and systems

Measurement parameter/instrument	$[\chi_{min} \times (a_1 - 1) + a_0]$	Slope a_1	Standard error SEE	Coefficient of determination r^2
Fuel flow rate ⁽¹⁾	$\leq 1 \% \text{ max}$	0.98 - 1.02	$\leq 2 \% \text{ max}$	≥ 0.990
Air flow rate ⁽¹⁾	$\leq 1 \% \text{ max}$	0.98 - 1.02	$\leq 2 \% \text{ max}$	≥ 0.990
Exhaust mass flow rate	$\leq 2 \% \text{ max}$	0.97 - 1.03	$\leq 2 \% \text{ max}$	≥ 0.990
Gas analysers	$\leq 0.5 \% \text{ max}$	0.99 - 1.01	$\leq 1 \% \text{ max}$	≥ 0.998

⁽¹⁾ optional to determine exhaust mass flow

2.3.3 Frequency of linearity verification

The linearity requirements according to paragraph 2.3.2 shall be verified:

- (i) for each analyser at least every three months or whenever a system repair or change is made that could influence the calibration;
- (ii) for other relevant instruments, such as exhaust mass flow meters and traceably calibrated sensors, whenever damage is observed, as required by internal audit procedures, by the instrument manufacturer, or by ISO 9000 but no longer than one year before the actual test.

The linearity requirements according to paragraph 2.3.2 for sensors or ECU signals that are not directly traceable shall be performed once for each PEMS setup with a traceably calibrated measurement device on the chassis dynamometer.

2.3.4 Procedure of linearity verification

2.3.4.1 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.

2.3.4.2 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 at 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 verification shall be established by introducing at least 10, approximately equally spaced and valid, reference values (including zero). The reference values with respect to the concentration of components, the exhaust mass flow rate or any other relevant parameter shall be chosen to match the range of values expected during the emissions

test. For measurements of exhaust mass flow, reference points below 5% of the maximum calibration value can be excluded from the linearity verification.

- e) For gas analysers, known gas concentrations in accordance with paragraph 2.5 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 of at least 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 according to Equation 2, with the best-fit equation having the form:

$$y = a_1x + a_0 \quad \text{(Equation 2)}$$

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 3.

2.3.4.3 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 the chassis dynamometer. The procedure shall follow as far as applicable, the requirements of Annex 4a to Revision 4 of UN/ECE Regulation 83. If necessary, the to-be-calibrated instrument or sensor 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 paragraph 2.3.4.2; 10 appropriate reference values shall be selected as to ensure that at least 90% of the maximum value expected to occur during the emissions test is covered.

If a not directly traceable flow-measuring instrument, sensor or ECU signal for determining exhaust flow is to be calibrated, a traceably calibrated reference exhaust mass flow meter or the CVS shall be attached to the vehicle's tailpipe. It shall be ensured that the vehicle exhaust is accurately sampled by the exhaust mass flow meter according to paragraph 1.3.4.3. The vehicle shall be operated by applying constant throttle at a constant gear selection and chassis dynamometer load.

2.4 Analysers for measuring gaseous components

2.4.1 Permissible types of analysers

2.4.1.1 Standard analysers

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

2.4.1.2 Alternative analysers

Any analyser not meeting the design specifications of paragraph 2.4.1.1 is permissible provided that it fulfils the requirements of paragraph 2.4.2. 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 on-road testing as specified in paragraphs 5 to 7 of Annex IIIA. 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 should contain:

- (i) a description of the theoretical basis and the technical components of the alternative analyser;
- (ii) a demonstration of equivalency with the respective standard analyser specified in paragraph 2.4.1.1 over the expected range of pollutant concentrations and ambient conditions of the type-approval test defined in Annex 4a to Revision 4 of UN/ECE Regulation 83 as well as a validation test as described in paragraph 3.3.2 for a vehicle equipped with a spark-ignition and compression-ignition engine; the manufacturer of the analyser shall demonstrate the significance of equivalency within the permissible tolerances given in paragraph 3.3.3.
- (iii) a demonstration of equivalency with the respective standard analyser specified in paragraph 2.4.1.1 respect to the influence of atmospheric pressure on the measurement performance of the analyser; the demonstration test shall determine the response to span gas having a concentration within the analyser range to check the influence of atmospheric pressure under moderate and extended altitude conditions defined in paragraph 5.2 of Annex IIIA. Such a test can be performed in an altitude environmental test chamber.
- (iv) a demonstration of equivalency with the respective standard analyser specified in paragraph 2.4.1.1 over at least three on-road tests that fulfil the requirements of Annex IIIA.
- (v) a demonstration that the influence of vibrations, accelerations and ambient temperature on the analyser reading does not exceed the noise requirements for analysers defined in paragraph 2.4.2.4.

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

2.4.2 Analyser specifications

2.4.2.1 General

In addition to the linearity requirements defined for each analyser in paragraph 2.3, the compliance of analyser types with the specifications laid down in paragraphs 2.4.2.2 to 2.4.2.8 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.

2.4.2.2 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.

2.4.2.3 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 and 2% of the full scale concentration for a measurement range of below 155 ppm.

2.4.2.4 Noise

The noise, defined as two times the root mean square of ten standard deviations, each calculated from the zero responses measured at a constant recording frequency of at least 1.0 Hz during a period of 30 seconds, 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.

2.4.2.5 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 4.

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 4.

Table 4: Permissible zero and span response drift of analysers for measuring gaseous components under laboratory conditions

Pollutant	Zero response drift	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
NO ₂	≤5 ppm over 4 h	≤2% of reading or ≤ 5 ppm over 4 h, whichever is larger
NO/NO _x	≤5 ppm over 4 h	≤2% or reading or 5 ppm over 4h, whichever is larger

2.4.2.7 Rise time

Rise time is defined as the time between the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$; see paragraph 2.4.4). The rise time of PEMS analysers shall not exceed 3 seconds.

2.4.2.8 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.

2.4.3 Additional requirements

2.4.3.1 General

The provisions in paragraphs 2.4.3.2 to 2.4.3.5 define additional performance requirements for specific analyser types and apply only to cases, in which the analyser under consideration is used for PEMS emission measurements.

2.4.3.2 Efficiency test for NO_x converters

If a NO_x converter is applied, for example to convert NO₂ into NO for analysis with a chemiluminescence analyser, its efficiency shall be tested by following the requirements of paragraph 2.4 of Appendix 3 of Annex 4a to Revision 4 of UN/ECE Regulation 83. The efficiency of the NO_x converter shall be verified no longer than one month before the emissions test.

2.4.3.3 Interference effects

2.4.3.3.1 General

Other gases than the ones being analysed can affect the analyser reading. A check for interference effects and the correct functionality of analysers shall be performed by the analyser manufacturer prior to market introduction at least once for each type of analyser or device addressed in paragraphs 2.4.3.5.2 to 2.4.3.5.6.

2.4.3.3.2 CO analyser interference check

Water and CO₂ can interfere with the measurements of the CO analyser. Therefore, a CO₂ span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range 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 H₂O and CO₂ may be run as separate procedures. If the H₂O and CO₂ levels used for the interference check are higher than the maximum levels expected during the test, each observed interference value shall be scaled down by multiplying the observed interference with the ratio of the maximum expected concentration value and the actual concentration value used during this procedure. Separate interference procedures with concentrations of H₂O that are lower than the maximum concentration expected during the test may be run, but the observed H₂O interference shall be scaled up by multiplying the observed interference with the ratio of the maximum expected H₂O concentration value and the actual concentration value used during this procedure. The sum of the two scaled interference values shall meet the tolerance specified in this paragraph.

2.4.3.3.3 NO_x analyser quench check

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

2.4.3.3.3.1 CO₂ quench check

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

$$E_{CO_2} = \left[1 - \left(\frac{C \times A}{(D \times A) - (D \times B)} \right) \right] \times 100 \quad (\text{Equation 7})$$

where:

- A* is the undiluted CO₂ concentration measured with NDIR [%]
- B* is the diluted CO₂ concentration measured with NDIR [%]
- C* is the diluted NO concentration measured with (H)CLD [ppm]
- D* is the undiluted NO concentration measured with (H)CLD [ppm]

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

2.4.3.3.3.2 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 during the 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 (H)CLD; 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 (H)CLD; the NO value shall be recorded as *C*. The analyser's absolute operating pressure and the water temperature shall be determined and recorded as *E* and *F*, respectively. The mixture's saturation vapour pressure that corresponds to the water temperature of the bubbler *F* shall be determined and recorded as *G*. The water vapour concentration *H* [%] of the gas mixture shall be calculated as:

$$H = \frac{G}{E} \times 100 \quad (\text{Equation 8})$$

The expected concentration of the diluted NO-water vapour span gas shall be calculated as:

$$D_e = D \times \left(1 - \frac{H}{100}\right) \quad (\text{Equation 9})$$

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

$$H_m = 0.9 \times A \quad (\text{Equation 10})$$

and recorded as *H_m*. The per cent water quench shall be calculated as:

$$E_{H_2O} = \left(\left(\frac{D_e - C}{D_e} \right) \times \left(\frac{H_m}{H} \right) \right) \times 100 \quad (\text{Equation 11})$$

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 [%]

2.4.3.3.3.3 Maximum allowable quench

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

2.4.3.3.4 Quench check for NDUV analysers

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

- (a) 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.
- (b) A zero calibration and span calibration at concentration values expected during emissions testing shall be performed for the analyser.
- (c) A NO₂ calibration gas shall be selected that matches as far as possible the maximum NO₂ concentration expected during emissions testing.
- (d) The NO₂ calibration gas shall overflow at the gas sampling system's probe until the NO_x response of the analyser has stabilised.
- (e) The mean concentration of the stabilized NO_x recordings over a period of 30 s shall be calculated and recorded as NO_{x,ref}.
- (f) The flow of the NO₂ calibration gas shall be stopped and the sampling system saturated by overflowing with a dew point generator's output, set at a dew point of 50 °C. The dew point generator's output shall be sampled through the sampling system and chiller for at least 10 minutes until the chiller is expected to be removing a constant rate of water.
- (g) Upon completion of (f), the sampling system shall again be overflowed by the NO₂ calibration gas used to establish NO_{x,ref} until the total NO_x response has stabilized.
- (h) The mean concentration of the stabilized NO_x recordings over a period of 30 s shall be calculated and recorded as NO_{x,m}.
- (i) 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}.

2.4.3.3.5 Sample dryer

A sample dryer removes water, which can otherwise interfere with a NO_x measurement. For dry CLD analysers, it shall be demonstrated that at the highest expected water vapour concentration H_m (see paragraph 2.4.3.5.3.2), the sample dryer maintains the CLD humidity at ≤ 5 g water/kg dry air (or about 0.008 per cent H₂O), which is 100 per cent relative humidity at 3.9 °C and 101.3 kPa or about 25 per cent relative humidity at 25 °C and 101.3 kPa. Compliance may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, 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 dehumidifier.

2.4.3.3.6 Sample dryer NO₂ penetration

Liquid water remaining in an improperly designed sample dryer can remove NO₂ from the sample. If a sample dryer is used in combination with a NDUV analyser without an NO₂/NO converter upstream, water could therefore remove NO₂ from the sample prior to the NO_x measurement. The sample dryer shall allow for measuring at least 95 per cent of the NO₂ contained in a gas that is saturated with water vapour and consists of the maximum NO₂ concentration expected to occur during a vehicle test.

2.4.4 Response time check of the analytical system

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

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

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

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

2.5 Gases

2.5.1 General

The shelf life of any calibration gases shall be respected. Pure and mixed calibration and span gases shall fulfil the specifications of paragraphs 3.1 and 3.2 of Appendix 3 of Annex 4A to Revision 4 of UN/ECE Regulation No 83. In addition, NO₂ calibration gas is permissible. The concentration of the NO₂ calibration gas shall be within ± 2 per cent of the declared concentration value. The amount of NO contained in NO₂ calibration gas shall not exceed 5 per cent of the NO₂ content.

2.5.2 Gas dividers

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

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

2.6 Instruments for measuring exhaust mass flow

2.6.1 General

Instruments, sensors or signals for measuring the exhaust mass flow rate shall have a measuring range and response time appropriate for the accuracy required to measure the exhaust mass flow rate under transient and steady state conditions. The sensitivity of

instruments, sensors, and signals to shocks, vibration, aging, variability in temperature, ambient air pressure, electromagnetic interferences and other impacts related to vehicle and instrument operation shall be on a level as to minimize additional errors.

2.6.2 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 defined in paragraph 2.3. Furthermore, the instrument manufacturer shall demonstrate the compliance of each type of exhaust mass flow meter with the specifications laid down in paragraphs 2.7.2.3 to 2.7.2.9.

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 paragraph 2.3, the accuracy requirements of paragraph 2.8 and if the resulting exhaust mass flow rate is validated according to paragraph 3.4.

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 paragraph 2.3 and is validated according to paragraph 3.4.

2.6.2.1 Calibration and verification standards

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

2.6.2.2 Frequency of verification

The compliance of exhaust mass flow meters with paragraphs 2.7.2.3 and 2.7.2.9 shall be verified no longer than one year before the actual test.

2.6.2.3 Accuracy

The accuracy, defined as the deviation of the EFM reading from the reference flow value, shall not exceed ± 2 per cent 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.

2.6.2.4 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 be no greater than ± 1 per cent of the maximum flow at which the EFM has been calibrated.

2.6.2.5 Noise

The noise, defined as two times the root mean square of ten standard deviations, each calculated from the zero responses measured at a constant recording frequency of at least 1.0 Hz during a period of 30 seconds, 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.

2.6.2.6 Zero response drift

Zero response 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.

2.6.2.7 Span response drift

Span response 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.

2.6.2.8 Rise time

The rise time of the exhaust flow instruments and methods should match as far as possible the rise time of the gas analysers as specified in [paragraph 2.4.2.7](#) but shall not exceed 1 second.

2.6.2.9 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 (FS) 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 [paragraph 2.7.2.8](#).

2.7 Sensors and auxiliary equipment

Any sensor and auxiliary equipment used to determine, e.g., temperature, atmospheric pressure, ambient humidity, vehicle speed, fuel flow, or intake air flow shall not alter or unduly affect the performance of the vehicle's engine and exhaust after-treatment system. The accuracy of sensors and auxiliary equipment shall fulfil the requirements of [Table 6](#). Compliance with the requirements of [Table 6](#) shall be demonstrated at intervals specified by the instrument manufacturer, as required by internal audit procedures, or in accordance with ISO 9000.

Table 6: Accuracy requirements for measurement parameters

Measurement parameter	Accuracy
Fuel flow ⁽¹⁾	$\pm 1\%$ of reading ⁽³⁾
Air flow ⁽¹⁾	$\pm 2\%$ of reading
Vehicle ground speed ⁽²⁾	± 1.0 km/h absolute
Temperatures ≤ 600 K	± 2 K absolute

Temperatures > 600 K	± 0.4% of reading in Kelvin
Ambient pressure	± 0.2 kPa absolute
Relative humidity	± 5% absolute
Absolute humidity	± 10% of reading or, 1 gH ₂ O/kg dry air, whichever is larger

⁽¹⁾ optional to determine exhaust mass flow

⁽²⁾ The requirement applies to the speed sensor only.

⁽³⁾ The accuracy shall be 0.02 per cent of reading if used to calculate the air and exhaust mass flow rate with Equation 26 from the fuel flow.

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

3.1 Introduction

This appendix describes the requirements to validate under transient conditions the principle 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.

3.2 Symbols

%	-	per cent
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

3.3 Validation procedure for PEMS

3.3.1 Frequency of PEMS validation

It is recommended to validate the installed PEMS once for each PEMS-vehicle combination either before the test or, alternatively, after the completion of an on-road test. The PEMS installation shall be kept unchanged in the time period between the on-road test and the validation.

3.3.2 PEMS validation procedure

3.3.2.1 PEMS installation

The PEMS shall be installed and prepared according to the requirements of **Appendix 1**. After the completion of the validation test until the start of the on-road test, the PEMS installation shall not be changed.

3.3.2.2 Test conditions

The validation test shall be conducted on a chassis dynamometer, as far as applicable, under type approval conditions by following the requirements of **Annex 4a to Revision 4 of UN/ECE Regulation 83** or any other adequate measurement method. It is recommended to conduct the validation test with the Worldwide harmonized Light vehicles Test Cycle (WLTC) as specified in Annex 1 to UNECE Global Technical Regulation No. 15 (ECE/TRNAS/180/Add/15). The ambient temperature shall be within the range specified in **paragraph 5.2 of Annex IIIA**.

It is recommended to feed the exhaust flow extracted by the PEMS during the validation test back to the CVS. If this is not feasible, the CVS results could 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.

3.3.2.3 Data analysis

The total distance-specific emissions [g/km] measured with laboratory equipment shall be calculated following Annex 4a to Revision 4 of UN/ECE Regulation 83. The emissions as measured with the PEMS shall be calculated according to paragraph 4.9, summed to give the total mass of pollutant emissions [g] and then divided by the test distance [km] as obtained from the chassis dynamometer or the ECU. The total distance specific mass of pollutants [g/km], as determined by the PEMS and the reference laboratory system, shall be compared and evaluated against the requirements specified in paragraph 3.3.3. For the validation of NO_x emission measurements, humidity correction shall be applied following paragraph 6.6.5 of Annex 4a to Revision 4 of UN/ECE Regulation 83.

3.3.3 Permissible tolerances for PEMS validation

The PEMS validation results shall fulfil the requirements given in Table 7. If any permissible tolerance is not met, corrective action shall be taken and the PEMS validation shall be repeated.

Table 7: Permissible tolerances

Parameter [Unit]	Permissible tolerance
Distance [km] ⁽¹⁾	± 250 m of the laboratory reference
CO [mg/km]	± 150 mg/km or 15% of the laboratory reference, whichever is larger
CO ₂ [g/km]	± 10 g/km or 10% of the laboratory reference, whichever is larger
NO _x [mg/km]	± 15 mg/km or 15% of the laboratory reference, whichever is larger

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

3.4 Validation procedure for the exhaust mass flow rate determined by non-traceable instruments and sensors

3.4.1 Frequency of validation

In addition to fulfilling the linearity requirements of paragraphs 2.3 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. The validation test procedure can be executed without the installation of the PEMS but shall generally follow the requirements defined in Annex 4a to Revision 4 of UN/ECE Regulation 83 and the requirements pertinent to exhaust mass flow meters defined in Appendix 1.

3.4.2 Validation procedure

The validation test shall be conducted on a chassis dynamometer under type approval conditions, as far as applicable, by following the requirements of Annex 4a to Revision 4 of UN/ECE Regulation 83. By contrast to Annex 4a to Revision 4 of UN/ECE Regulation 83, the test cycle shall be the Worldwide harmonized Light vehicles Test Cycle (WLTC) as specified in Annex 1 to UNECE Global Technical Regulation No. 15 (ECE/TRNAS/180/Add/15. As reference, a traceably calibrated flow meter shall be used. The ambient temperature can be any within the range specified in paragraph 5.2 of Annex IIIA. The installation of the exhaust mass flow meter and the execution of the test shall fulfil the requirement of paragraph 1.3.4.3.

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

- a) The signal under validation and the reference signal shall be time aligned by following, as far as applicable, the requirements of paragraph 4.3.

- 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:

$$y = a_1 x + a_0 \quad (\text{Equation 12})$$

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 8.

3.4.3 Requirements

The linearity requirements given in Table 8 shall be fulfilled. If any permissible tolerance is not met, corrective action shall be taken and the validation shall be repeated.

Table 8: Linearity requirements of calculated and measured exhaust mass flow

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

Appendix 4. Determination of emissions

4.1 Introduction

This appendix describes the procedure to determine the instantaneous mass emissions [g/s] that shall be used for the subsequent evaluation of trip dynamics and the calculation of the final emission result as described in [Appendices 5 and 6](#).

4.2 Symbols

%	-	per cent
<	-	smaller than
α	-	molar hydrogen ratio (H/C)
β	-	molar carbon ratio (C/C)
γ	-	molar sulphur ratio (S/C)
δ	-	molar nitrogen ratio (N/C)
ε	-	molar oxygen ratio (O/C)
ρ_e	-	density of the exhaust
ρ_{gas}	-	density of the exhaust component “gas”
λ_i	-	instantaneous excess air ratio
A/F_{st}	-	stoichiometric air-to-fuel ratio [kg/kg]
$^{\circ}\text{C}$	-	degrees centigrade
c_{CO}	-	dry CO concentration [%]
c_{CO_2}	-	dry CO ₂ concentration [%]
c_{dry}	-	dry concentration of a pollutant in ppm or per cent volume
$c_{\text{gas},i}$	-	instantaneous concentration of the exhaust component “gas” [ppm]
c_{wet}	-	wet concentration of a pollutant in ppm or per cent volume
g	-	gramme
g/s	-	gramme per second
H_a	-	intake air humidity [g water per kg dry air]
kg	-	kilogram
kg/h	-	kilogramme per hour
kg/s	-	kilogramme per second
k_w	-	dry-wet correction factor
m	-	meter
m_{gas}	-	mass of the exhaust component “gas” [g/s]
$q_{\text{maw},i}$	-	instantaneous intake air mass flow rate [kg/s]
$q_{\text{mew},i}$	-	instantaneous exhaust mass flow rate [kg/s]
$q_{\text{mf},i}$	-	instantaneous fuel mass flow rate [kg/s]
r	-	cross-correlation coefficient
r^2	-	coefficient of determination
rpm	-	revolutions per minute
s	-	second
u_{gas}	-	u value of the exhaust component “gas”
\bar{x}	-	mean reference value
x_i	-	measured reference value
\bar{y}	-	mean value of the parameter to be verified
y_i	-	measured value of the parameter to be verified

4.3 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, it is recommended to record the data which is subject to time alignment either in a single data recording device or with a synchronised timestamp, following paragraph 1.5.1. The time correction and alignment of parameters shall be carried out by following the sequence described in paragraphs 4.3.1 to 4.3.3.

4.3.1 Time correction of component concentrations

The recorded traces of all component concentrations shall be time corrected by reverse shifting according to the transformation times of the respective analysers. The transformation time of analysers shall be determined according to paragraph 2.4.4:

$$c_{i,c}(t-\Delta t_{t,i})=c_{i,r}(t) \quad (\text{Equation 13})$$

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

Samples with a resulting $t_c=t-\Delta t_{t,i}<0$ should be omitted.

4.3.2 Time correction of exhaust mass flow rate

The exhaust mass flow rate measured with an exhaust flow meter shall be time corrected by reverse shifting according to the transformation time of the exhaust mass flow meter. The transformation time of the mass flow meter shall be determined according to paragraph 2.4.4.9:

$$q_{m,c}(t-\Delta t_{t,m})=q_{m,r}(t) \quad (\text{Equation 14})$$

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

Samples with a resulting $t_c=t-\Delta t_{t,m}<0$ should be omitted.

In case the exhaust mass flow rate is determined by ECU data or a sensor, an additional transformation time shall be considered and obtained by cross-correlation between the calculated exhaust mass flow rate and the exhaust mass flow rate measured following paragraph 3.4.

4.3.3 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 (either concentration or mass flow).

4.3.3.1 Vehicle speed with exhaust mass flow rate

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

4.3.3.2 Further signals

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

4.4 Cold start

The cold start period covers the first 5 minutes after initial combustion engine start. If the coolant temperature can be reliably determined, the cold start period ends once the coolant has reached 343 K (70 °C) for the first time but no later than 5 min after initial engine start. Cold start emissions shall be analysed as specified in [paragraph 9.6 of Annex IIIA](#).

4.5 Emission measurements during engine stop

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 steady-state exhaust mass flow rate at idling.

4.6 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 paragraph 5.2 of Annex IIIA 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 altitude depicted in the topographic map shall be manually corrected and marked.

4.7 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, all test results shall be voided.

4.8 Correction of emissions

4.8.1 Dry-wet correction

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

$$c_{\text{wet}} = k_w * c_{\text{dry}} \quad (\text{Equation 15})$$

where:

c_{wet} is the wet concentration of a pollutant in ppm or per cent volume
 c_{dry} is the dry concentration of a pollutant in ppm or per cent volume
 k_w is the dry-wet correction factor

The following equation shall be used to calculate k_w :

$$k_w = \left(\frac{1}{1 + \alpha \times 0.005 \times (c_{\text{CO}_2} + c_{\text{CO}})} - k_{w1} \right) \times 1.008 \quad (\text{Equation 16})$$

where:

$$k_{w1} = \frac{1.608 \times H_a}{1000 + (1.608 \times H_a)} \quad (\text{Equation 17})$$

where:

H_a is the intake air humidity [g water per kg dry air]
 c_{CO_2} is the dry CO₂ concentration [%]
 c_{CO} is the dry CO concentration [%]
 α is the molar hydrogen ratio

4.8.2 Correction of NO_x for ambient humidity and temperature

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

4.9 Determination of the instantaneous gaseous exhaust components

4.9.1 Introduction

The components in the raw exhaust gas 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 aligned in accordance with paragraph 4.3.

4.10 Determination of exhaust mass flow

4.10.1 Introduction

The calculation of instantaneous mass emissions according to paragraphs 4.11 and 4.12 requires determining the exhaust mass flow rate. The exhaust mass flow rate shall be determined by one of the direct measurement methods specified in paragraph 2.7.2. Alternatively, it is permissible to calculate the exhaust mass flow rate as described in paragraphs 4.10.2-4.10.4.

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:

$$q_{\text{mew},i} = q_{\text{maw},i} + q_{\text{mf},i} \quad (\text{Equation 22})$$

where:

$q_{\text{mew},i}$ is the instantaneous exhaust mass flow rate [kg/s]
 $q_{\text{maw},i}$ 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 paragraph 2.3 and the validation requirements specified in paragraph 3.4.3.

4.10.3 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:

$$q_{mew,i} = q_{maw,i} \times \left(1 + \frac{1}{A/F_{st} \times \lambda_i}\right) \quad (\text{Equation 23})$$

where:

$$A/F_{st} = \frac{138.0 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right)}{12.011 + 1.008 \times \alpha + 15.9994 \times \varepsilon + 14.0067 \times \delta + 32.0675 \times \gamma} \quad (\text{Equation 24})$$

$$\lambda_i = \frac{\left(100 - \frac{c_{CO} \times 10^{-4}}{2} - c_{HCW} \times 10^{-4}\right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{CO} \times 10^{-4}}{3.5 \times c_{CO_2}} - \frac{\varepsilon}{2} - \frac{\delta}{2}}{1 + \frac{c_{CO} \times 10^{-4}}{3.5 \times c_{CO_2}}}\right) \times (c_{CO_2} + c_{CO} \times 10^{-4})}{4.764 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \times (c_{CO_2} + c_{CO} \times 10^{-4} + c_{HCW} \times 10^{-4})} \quad (\text{Equation 25})$$

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

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

c_{HCW} is the wet HC concentration [ppm]

α is the molar hydrogen ratio (H/C)

β is the molar carbon ratio (C/C)

γ is the molar sulphur ratio (S/C)

δ is the molar nitrogen ratio (N/C)

ε is the molar oxygen ratio (O/C)

Coefficients refer to a fuel $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$ with $\beta = 1$ for carbon based fuels and $\beta = 0$ for hydrogen fuel. The concentration of HC emissions is typically low and may be omitted when calculating λ_i .

If the air mass flow rate and air-to-fuel ratio are determined from ECU recording, the calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust mass flow rate in paragraph 2.3 and the validation requirements specified in paragraph 3.4.3.

4.10.4 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 as follows:

$$q_{mew,i} = q_{mf,i} \times (1 + A/F_{st} \times \lambda_i) \quad (\text{Equation 26})$$

The calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust gas mass flow rate in paragraph 2.3 and the validation requirements specified in paragraph 3.4.3.

4.11 Calculating the instantaneous mass emissions

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 aligned for the transformation time, and the respective u value of Table 9. If measured on a dry basis, the dry-wet correction according to paragraph 4.8.1 shall be applied to the instantaneous component concentrations before executing any further calculations. 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 be applied:

$$m_{gas,i} = u_{gas} \cdot c_{gas,i} \cdot q_{mew,i} \quad (\text{Equation 27})$$

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 9
- $c_{gas,i}$ 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

Table 9: Raw exhaust gas u values depicting the ratio between the densities of exhaust component or pollutant i [kg/m³] and the density of the exhaust gas [kg/m³]⁽⁶⁾

Fuel	ρ_e [kg/m ³]	Component or pollutant <i>i</i>			
		<i>NO_x</i>	<i>CO</i>	<i>CO₂</i>	<i>O₂</i>
		ρ_{gas} [kg/m ³]			
		2.053	1.250	1.9636	1.4277
		$u_{gas}^{(2,6)}$			
Diesel (B7)	1.2943	0.001586	0.000966	0.001517	0.001103
Ethanol (ED95)	1.2768	0.001609	0.000980	0.001539	0.001119
CNG ⁽³⁾	1.2661	0.001621	0.000987	0.001551	0.001128
Propane	1.2805	0.001603	0.000976	0.001533	0.001115
Butane	1.2832	0.001600	0.000974	0.001530	0.001113
LPG ⁽⁵⁾	1.2811	0.001602	0.000976	0.001533	0.001115
Petrol (E10)	1.2931	0.001587	0.000966	0.001518	0.001104
Ethanol (E85)	1.2797	0.001604	0.000977	0.001534	0.001116

- (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%
- (5) u accurate within 0.2% for mass composition of: C₃=70-90%; C₄=10-30%
- (6) u_{gas} is, per convention, a unitless parameter; the u_{gas} values presented here include unit conversions to ensure that Equation 23 yields instantaneous emissions in the specified physical unit, i.e., g/s

4.12 Data reporting and exchange

The data shall be exchanged between the measurement systems and the data evaluation software by a standardized reporting file as specified in paragraph 2 of Appendix 8. Any pre-processing of data (e.g. time correction according to paragraph 4.3 or GPS-speed or the consistency check of GPS vehicle speed according to paragraph 4.7) shall be completed before the data reporting file is generated. If data are processed prior to entering the data reporting file, the original raw data shall be kept for quality assurance and monitoring. Rounding of intermediate values is not permitted. Instead, intermediate values shall enter the calculation of instantaneous emissions [g/s] as reported by the analyser, flow-measuring instrument, sensor, or the ECU.

Appendix 5. – Verification of trip dynamic conditions with method 1 (Moving Averaging Window)

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, u=urban, r=rural, m= motorway) or to the CO₂ characteristic curve (cc)

Index 'gas' refers to the regulated exhaust gas components (e.g. NO_x, CO, PN...)

Δ	- difference
\geq	- larger or equal
#	- number
%	- per cent
\leq	- smaller or equal
f_k	- weighing factors for urban, rural and motorway shares
M_{gas}	- mass/ particle number of the exhaust component "gas", [g]/[#]
$M_{gas,j}$	- mass/ particle number of the exhaust component "gas" in window j, [g]/[#]
$M_{gas,d}$	- emission for the exhaust component "gas", [g/km] or [# /km]
$M_{gas,d,j}$	- emission for the exhaust component "gas" in window j [g/km] or [# /km]
t_i	- total time in step i, [s]
t_t	- duration of a test, [s]
v_i	- actual vehicle speed in time step i, [km/h]
\bar{v}_j	- average vehicle speed in window j, [km/h]
h_j	- distance of window j to the CO ₂ characteristic curve, [%]
w_j	- weighing factor of window j
tol_1	- primary tolerance for the vehicle CO ₂ characteristic curve, [%]
tol_2	- secondary tolerance for the vehicle CO ₂ characteristic curve, [%]

5.1 Introduction

The Moving Averaging Window analysis provides an insight on the real-driving emissions (RDE) occurring during the test at a given scale. The test is divided in sub-sections (windows) and the subsequent statistical treatment aims at identifying which windows are suitable to assess the vehicle RDE performance.

The 'normality' of the windows is conducted by comparing their CO₂ distance-specific emissions¹ with a reference curve. The test is complete when the test includes a sufficient number of normal windows, covering different speed areas (urban, rural, motorway).

Further details of their application to different steps are given in the following sections.

¹ For hybrids, the total energy consumption shall be converted to CO₂. The rules for this conversion will be introduced in a second step.

Step 1. Segmentation of the data and exclusion of cold start emissions;
Step 2. Calculation of emissions by sub-sets or “windows” (section 5.2);
Step 3. Identification of normal windows; (section 5.3)
Step 4. Verification of test completeness and normality (section 5.4);
Step 5. Calculation of emissions using the normal windows (section 5.5).

5.2 Moving Averaging Windows

5.2.1 Definition of averaging windows

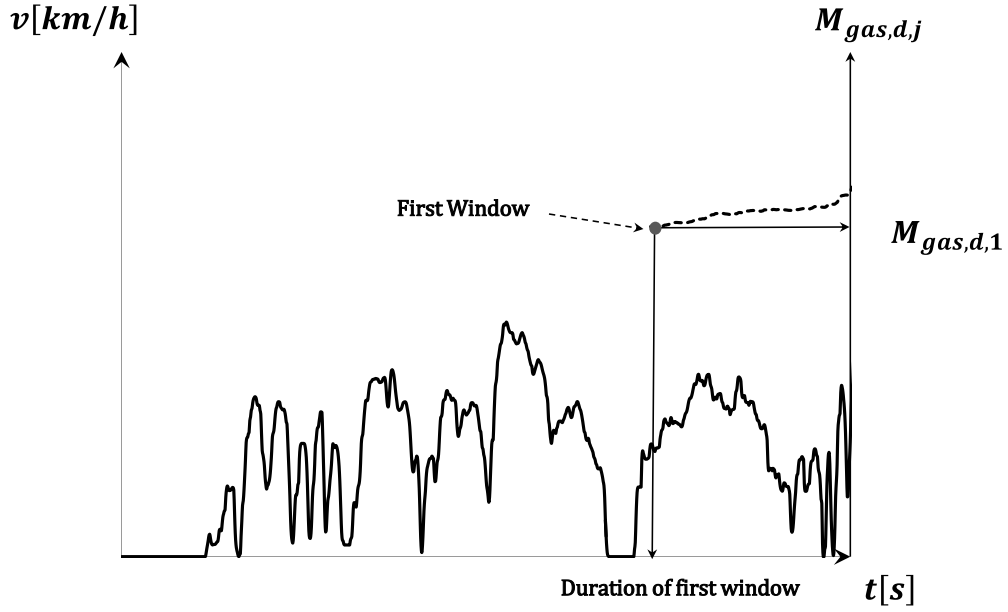
The instantaneous emissions calculated according to Appendix 4 shall be integrated using a moving averaging window method, based on the reference CO₂ mass. The principle of the calculation is as follows: The mass emissions are not calculated for the complete data set, but for sub-sets of the complete data set, the length of these sub-sets being determined so as to match the CO₂ mass emitted by the vehicle over the reference laboratory cycle. The moving average calculations are conducted with a time increment Δt equal to the data sampling frequency. These sub-sets used to average the emissions data are referred to as “averaging windows” in the following sections. The calculation described in the present section may be run from the last point (backwards) or from the first point (forward).

Any section of invalidated data for:

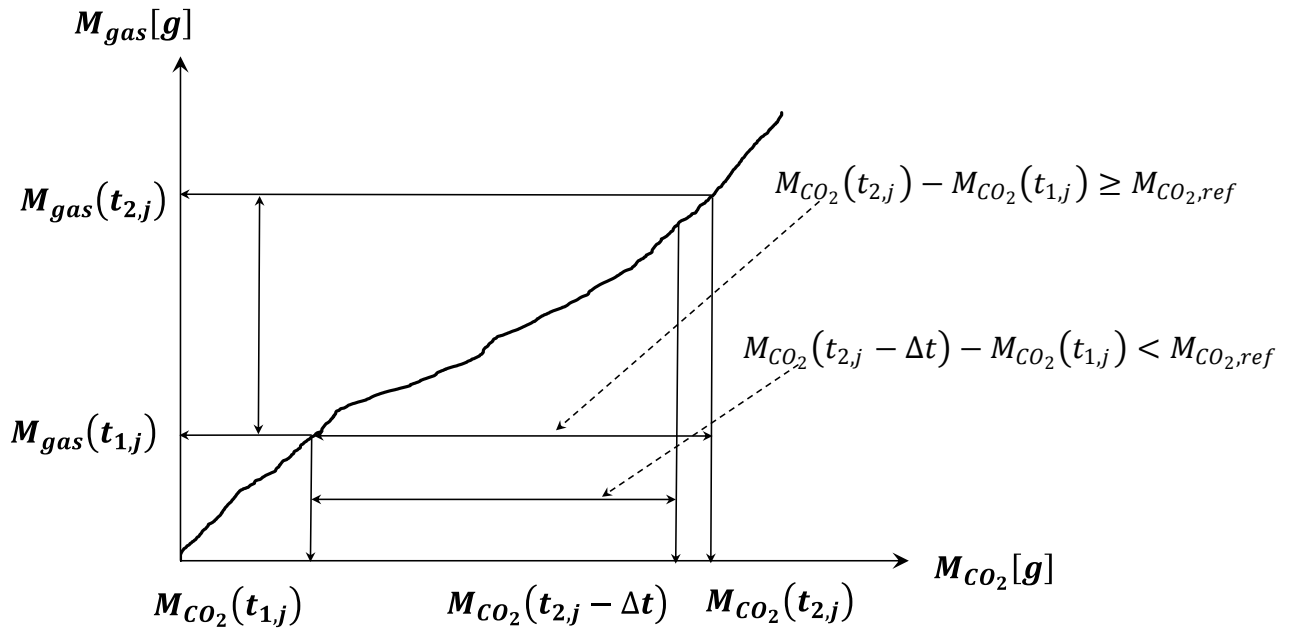
- The periodic verification of the instruments and/or after the zero drift verifications;
- The cold start emissions, defined according to Appendix 4, paragraph 4.4 to this Annex;
- The zero vehicle ground speed;
- Any section of the test during which the combustion engine is switched off;

Shall not be considered for the calculation of the CO₂ mass, the emissions and the distance of the averaging windows.

The mass (or particle number) emissions $M_{gas,j}$ shall be determined by integrating the instantaneous emissions in g/s (or #/s) calculated as specified in Appendix 4 to this Annex.



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



- Definition of CO₂ mass based averaging windows

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

$$(E1). \quad M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j}) \geq M_{CO_2,ref}$$

Where:

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

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

$$(E2). \quad M_{CO_2}(t_{2,j} - \Delta t) - M_{CO_2}(t_{1,j}) < M_{CO_2,ref} \leq M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j})$$

Where Δt is the data sampling period,.

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

5.2.2 Calculation of window emissions and averages

From the windows defined according to the principles laid down in section 5.2.1:

- The distance-specific emissions $M_{gas,d,j}$ for all the pollutants specified in this annex;
- The distance-specific CO₂ emissions $M_{CO_2,d,j}$;
- The average vehicle speed \bar{v}_j .

shall be calculated for each window.

5.3 Evaluation of windows

5.3.1 Introduction

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

5.3.2 CO₂ Characteristic curve reference points

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

5.3.2.1 Point P_1

$\bar{v}_{P1} = 19 \text{ km/h}$ (Average Speed of the Low Speed phase of the WLTC)
 $M_{CO_2,d,P1}$ = Vehicle CO₂ emissions over the Low Speed phase of the WLTC [g/km]

5.3.2.2 Point P_2

$\bar{v}_{P2} = 56.6 \text{ km/h}$ (Average Speed of the High Speed phase of the WLTC)
 $M_{CO_2,d,P2}$ = Vehicle CO₂ emissions over the High Speed phase of the WLTC [g/km]

5.3.2.3 Point P_3

$\bar{v}_{P3} = 92.3 \text{ km/h}$ (Average Speed of the Extra High Speed phase of the WLTC)
 $M_{CO_2,d,P3}$ = Vehicle CO₂ emissions over the Extra High Speed phase of the WLTC [g/km]

5.3.2.4 CO₂ Characteristic curve definition

Using the reference points defined in section 5.3, the characteristic curve CO₂ 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):

$$(E3). \quad M_{CO_2,d,CC}(\bar{v}) = a_1 \bar{v} + b_1$$

$$(E4). \quad \text{with: } a_1 = (M_{CO_2,d,P_2} - M_{CO_2,d,P_1}) / (\bar{v}_{P_2} - \bar{v}_{P_1})$$

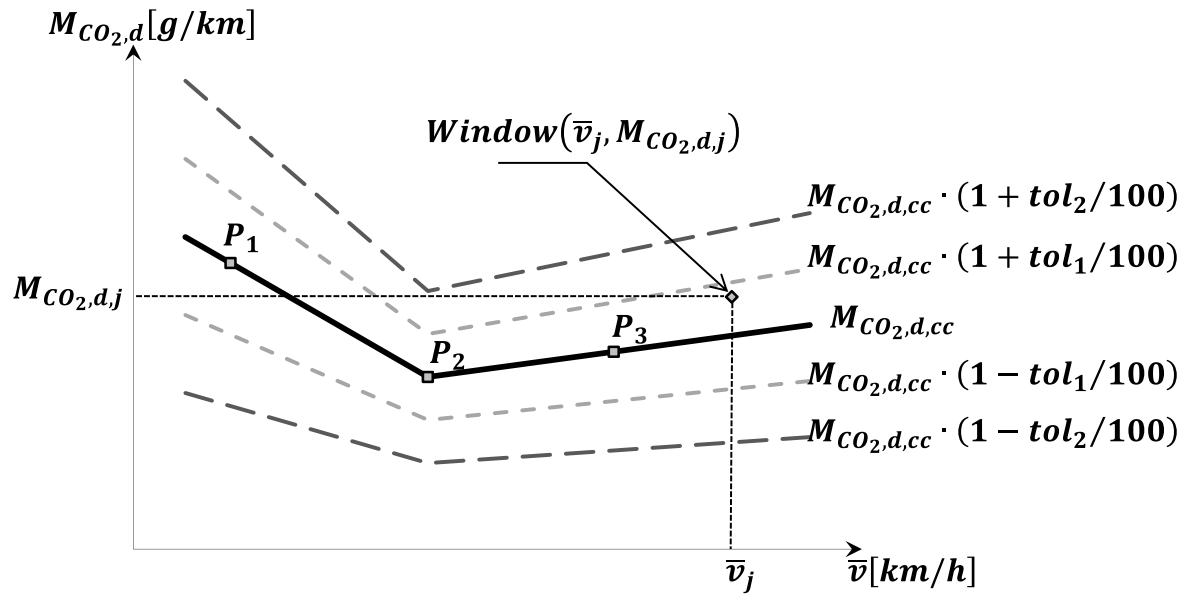
$$(E5). \quad \text{and: } b_1 = M_{CO_2,d,P_1} - a_1 \bar{v}_{P_1}$$

For the section (P_2, P_3):

$$(E6). \quad M_{CO_2,d,CC}(\bar{v}) = a_2 \bar{v} + b_2$$

$$(E7). \quad \text{with: } a_2 = (M_{CO_2,d,P_3} - M_{CO_2,d,P_2}) / (\bar{v}_{P_3} - \bar{v}_{P_2})$$

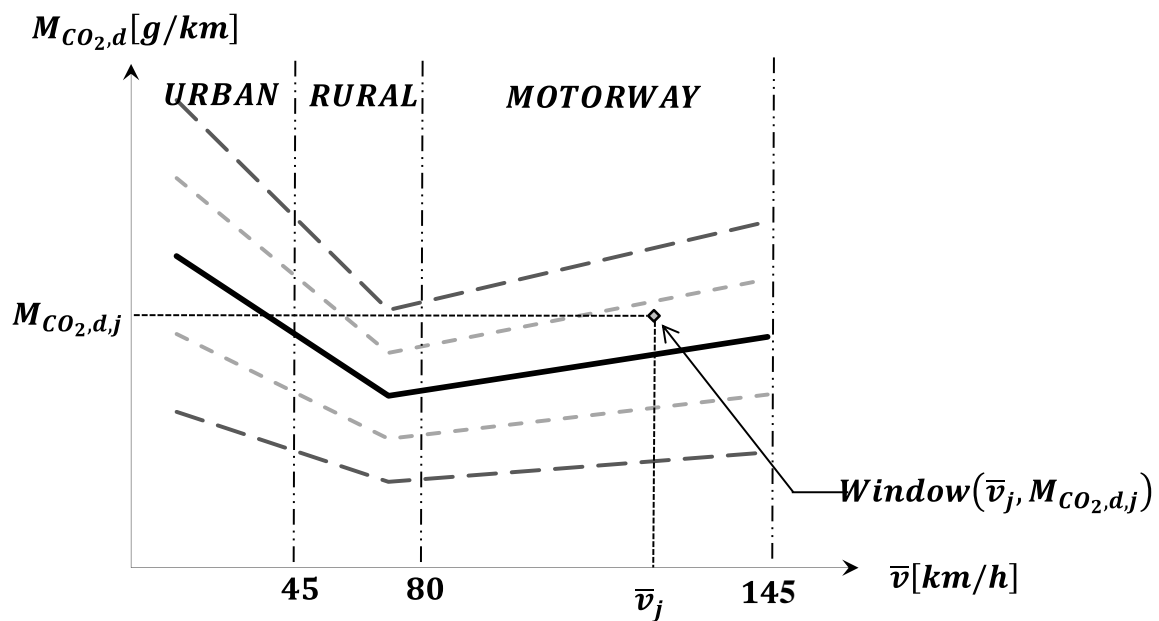
$$(E8). \quad \text{and: } b_2 = M_{CO_2,d,P_2} - a_2 \bar{v}_{P_2}$$



- Vehicle CO₂ characteristic curve

5.3.3 Urban, rural and motorway windows

- 5.3.3.1 Urban windows are characterized by average vehicle ground speeds \bar{v}_j smaller than 45 km/h,
- 5.3.3.2 Rural windows are characterized by average vehicle ground speeds \bar{v}_j greater than or equal to 45 km/h and smaller than 80 km/h,
- 5.3.3.3 Motorway windows are characterized by average vehicle ground speeds \bar{v}_j greater than or equal to 80 km/h and smaller than 145 km/h



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

5.4 Verification of trip completeness and normality

5.4.1 Tolerances around the vehicle CO₂ characteristic curve

The primary tolerance and the secondary tolerance of the vehicle CO₂ characteristic curve are respectively $tol_1 = 25\%$ $tol_2 = 50\%$.

5.4.2 Verification of test completeness

The test is complete when it comprises at least 15% of urban, rural and motorway windows, out of the total number of windows.

5.4.3 Verification of test normality

The test is complete when it comprises at least 50% of the urban, rural and motorway windows are within the primary tolerances defined for the characteristic curve.

If a test results as incomplete because the requirement of 50% is not met, the upper positive tolerance tol_1 may be increased by steps of 1% until the 50% of normal windows target is reached. When using this mechanism, the value of tol_1 shall never exceed 30%.

5.5 Calculation of emissions

5.5.1 Calculation of weighted distance-specific emissions

The emissions shall be calculated as a weighted average of the windows distance-specific emissions separately for the urban, rural and motorway categories and the complete trip.

$$(E9). \quad M_{gas,d,k} = \frac{\sum w_i M_{gas,d,i,j}}{\sum w_i} \quad k = u, r, m$$

The weighing factor w_j for each window shall be determined as such:

If $M_{CO2,d,CC}(\bar{v}_j) \cdot (1 - tol_1/100) \leq M_{CO2,d,j} \leq M_{CO2,d,CC}(\bar{v}_j) \cdot (1 + tol_1/100)$

(E10). Then $w_j = 1$

If $M_{CO2,d,CC}(\bar{v}_j) \cdot (1 + tol_1/100) \leq M_{CO2,d,j} \leq M_{CO2,d,CC}(\bar{v}_j) \cdot (1 + tol_2/100)$

(E11). Then $w_j = k_{11}h_j + k_{12}$

(E12). with $k_{11} = 1/(tol_1 - tol_2)$

(E13). and $k_{12} = tol_2/(tol_2 - tol_1)$

If $M_{CO2,d,CC}(\bar{v}_j) \cdot (1 - tol_2/100) \leq M_{CO2,d,j} \leq M_{CO2,d,CC}(\bar{v}_j) \cdot (1 - tol_1/100)$

(E14). Then $w_j = k_{21}h_j + k_{22}$

(E15). with $k_{21} = 1/(tol_2 - tol_1)$

(E16). and $k_{22} = k_{21} = tol_2/(tol_2 - tol_1)$

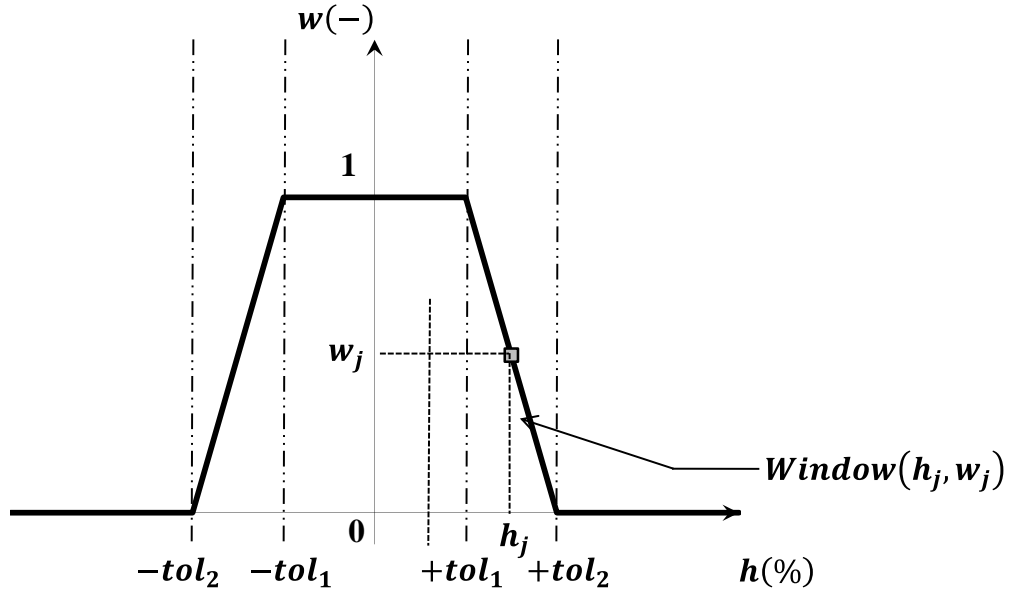
If $M_{CO2,d,j} \geq M_{CO2,d,CC}(\bar{v}_j) \cdot (1 - tol_2/100)$

or $M_{CO2,d,j} \leq M_{CO2,d,CC}(\bar{v}_j) \cdot (1 + tol_2/100)$

(E17). Then $w_j = 0$

Where:

$$(E18). \quad h_j = 100 \cdot \frac{M_{CO2,d,j} - M_{CO2,d,CC}(\bar{v}_j)}{M_{CO2,d,CC}(\bar{v}_j)}$$



- Averaging window weighing function

5.5.2 Calculation of severity indices

The severity indices shall be calculated separately for the urban, rural and motorway categories.

$$(E19). \bar{h}_k = \frac{1}{N} \sum_j h_j \quad k = u, r, m$$

and the complete trip:

$$(E20). \bar{h}_t = \frac{f_u \bar{h}_u + f_r \bar{h}_r + f_m \bar{h}_m}{f_u + f_r + f_m}$$

Where f_u, f_r, f_m are respectively equal to 0.26, 0.44 and 0.30.

5.5.3 Calculation of emissions for the total trip

Using the weighted distance-specific emissions calculated under section 5.5.1, the distance-specific emissions in [mg/km] shall be calculated for the complete trip each gaseous pollutant in the following way:

$$(E21). M_{gas,d,t} = 1000. \frac{f_u \cdot M_{gas,d,u} + f_r \cdot M_{gas,d,r} + f_m \cdot M_{gas,d,m}}{(f_u + f_r + f_m)}$$

And for particle number:

$$(E22). M_{PN,d,t} = \frac{f_u \cdot M_{PN,d,u} + f_r \cdot M_{PN,d,r} + f_m \cdot M_{PN,d,m}}{(f_u + f_r + f_m)}$$

Where f_u, f_r, f_m are respectively equal to 0.26, 0.44 and 0.30.

5.6 Numerical examples

5.6.1 Averaging window calculations (paragraph 5.3.1)

$M_{CO2,ref}$ [g]	610
Direction for averaging window calculation	Forward
Acquisition Frequency [Hz]	1

Table 1. Main calculation settings

Figure 6 shows how averaging windows are defined on the basis of data recorded during an on-road test performed with PEMS. For sake of clarity, only the first 1200 seconds of the trip are showed hereafter.

Seconds 0 up to 43 as well as seconds 81 to 86 are excluded due to operation under zero vehicle speed.

The first averaging window starts at $t_{1,1} = 0s$ and ends at second $t_{2,1} = 524s$ (Table 3). The window average vehicle speed, integrated CO and NO_x masses [g] emitted and corresponding to the valid data over the first averaging window are listed in Table 4.

$$M_{CO2,d,1} = \frac{M_{CO2,1}}{d_1} = \frac{610.217}{4.977} = 122.61 \text{ g/km}$$

$$M_{CO,d,1} = \frac{M_{CO,1}}{d_1} = \frac{2.25}{4.98} = 0.45 \text{ g/km}$$

$$M_{NOx,d,1} = \frac{M_{NOx,1}}{d_1} = \frac{3.51}{4.98} = 0.71 \text{ g/km}$$

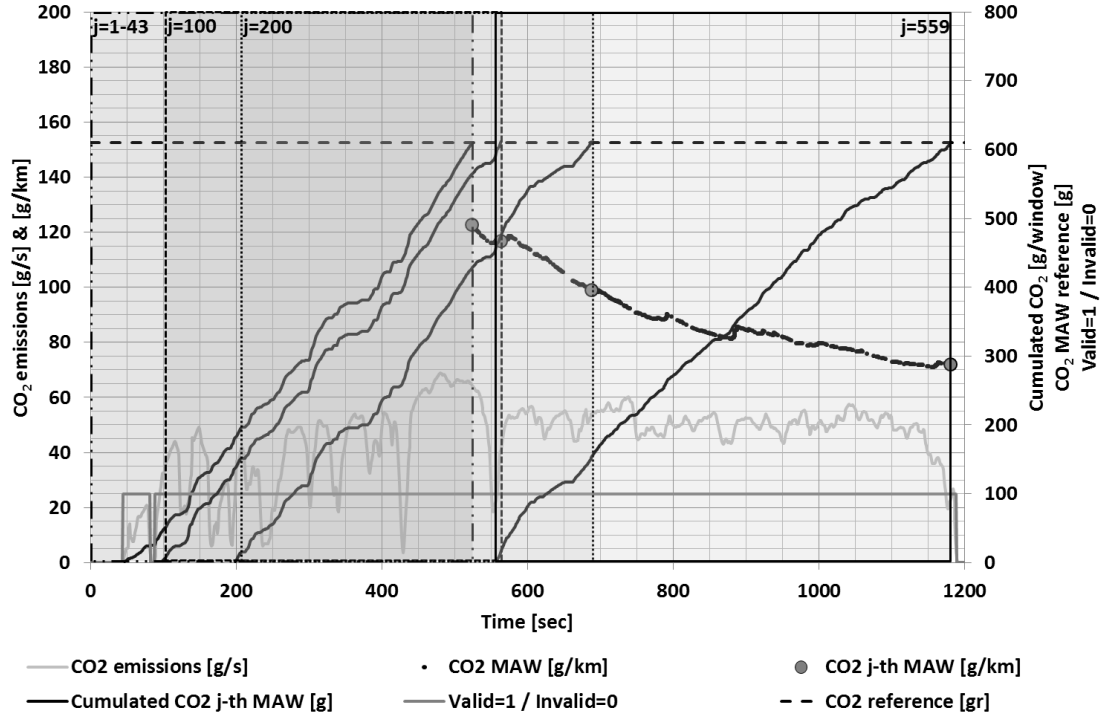


Figure 6: Instantaneous CO₂ emissions recorded during on-road test with PEMS as a function of time. Rectangular frames indicate the duration of the j^{th} window. Data series named “Invalid=0 / Valid=1” shows second by second data to be excluded from analysis.

5.6.2 Evaluation of windows (paragraph 5.3)

CO ₂ Low Speed WLTC (P ₁) [g/km]	154
CO ₂ High Speed WLTC (P ₂) [g/km]	96
CO ₂ Extra-High Speed WLTC (P ₃) [g/km]	120

Reference Point		
P_1	$\bar{v}_{P_1} = 19.0 \text{ km/h}$	$M_{CO_2,d,P_1} = 154 \text{ g/km}$
P_2	$\bar{v}_{P_2} = 56.6 \text{ km/h}$	$M_{CO_2,d,P_2} = 96 \text{ g/km}$
P_3	$\bar{v}_{P_3} = 92.3 \text{ km/h}$	$M_{CO_2,d,P_3} = 120 \text{ g/km}$

Table 2. Calculation settings for the CO₂ characteristic curve definition

The definition of the CO₂ characteristic curve is as follows:

For the section (P_1, P_2):

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

$$\text{with: } a_1 = (96 - 154) / (56.6 - 19.0) = -\frac{58}{37.6} = -1.543$$

$$\text{and: } b_1 = 154 + (-1.543) \times 19.0 = 154 + 29.317 = 183.317$$

For the section (P_2, P_3):

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

$$\text{with: } a_2 = (120 - 96)/(92.3 - 56.6) = \frac{24}{35.7} = 0.672$$

$$\text{and: } b_2 = 96 - 0.672 \times 56.6 = 96 - 38.035 = 57.965$$

Examples of calculation for the weighing factors and the window categorisation as urban, rural or motorway are:

For window #45:

$$M_{CO_2,d,45} = 122.62 \text{ g/km}$$

$$\bar{v}_{45} = 38.12 \text{ km/h}$$

For the characteristic curve:

$$M_{CO_2,d,CC}(\bar{v}_{45}) = a_1 \bar{v}_{45} + b_1 = -1.543 \times 38.12 + 183.317 = 124.498 \text{ g/km}$$

Verification of:

$$M_{CO_2,d,CC}(\bar{v}_j) \cdot (1 - tol_1/100) \leq M_{CO_2,d,j} \leq M_{CO_2,d,CC}(\bar{v}_j) \cdot (1 + tol_1/100)$$

$$M_{CO_2,d,CC}(\bar{v}_{45}) \cdot (1 - tol_1/100) \leq M_{CO_2,d,45} \leq M_{CO_2,d,CC}(\bar{v}_{45}) \cdot (1 + tol_1/100)$$

$$124.498 \times (1 - 25/100) \leq 122.62 \leq 124.498 \times (1 + 25/100)$$

$$93.373 \leq 122.62 \leq 155.622$$

Leads to : $w_{45} = 1$

For window #556:

$$M_{CO_2,d,556} = 72.15 \text{ g/km}$$

$$\bar{v}_{556} = 50.12 \text{ km/h}$$

For the characteristic curve:

$$M_{CO_2,d,CC}(\bar{v}_{556}) = a_1 \bar{v}_{556} + b_1 = -1.543 \times 50.12 + 183.317 = 105.982 \text{ g/km}$$

Verification of:

$$M_{CO_2,d,CC}(\bar{v}_j) \cdot (1 - tol_2/100) \leq M_{CO_2,d,j} \leq M_{CO_2,d,CC}(\bar{v}_j) \cdot (1 + tol_2/100)$$

$$M_{CO_2,d,CC}(\bar{v}_{556}) \cdot (1 - tol_2/100) \leq M_{CO_2,d,556} \leq M_{CO_2,d,CC}(\bar{v}_{556}) \cdot (1 + tol_2/100)$$

$$105.982 \times (1 - 50/100) \leq 72.15 \leq 105.982 \times (1 + 50/100)$$

$$52.991 \leq 72.15 \leq 158.973$$

Leads to:

$$h_{556} = 100 \cdot \frac{M_{CO_2,d,556} - M_{CO_2,d,CC}(\bar{v}_{556})}{M_{CO_2,d,CC}(\bar{v}_{556})} = 100 \cdot \frac{72.15 - 105.982}{105.982} = -31.922$$

$$w_{556} = k_{21} h_{556} + k_{22} = -0.04 \times 31.922 + 2 = 0.723$$

with $k_{21} = 1/(tol_2 - tol_1) = 1/(50 - 25) = 0.04$

and $k_{22} = k_{21} \cdot tol_2/(tol_2 - tol_1) = 50/(50 - 25) = 2$

Window [#]	$t_{1,j}$ [s]	$t_{2,j} - \Delta t$ [s]	$t_{2,j}$ [s]	$M_{CO_2}(t_{2,j} - \Delta t) - M_{CO_2}(t_{1,j}) < M_{CO_2,ref}$ [g]	$M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j}) \geq M_{CO_2,ref}$ [g]
1	0	523	524	609.06	610.22
2	1	523	524	609.06	610.22
...
43	42	523	524	609.06	610.22
44	43	523	524	609.06	610.22
45	44	523	524	609.06	610.22
46	45	524	525	609.68	610.86
47	46	524	525	609.17	610.34
...
100	99	563	564	609.69	612.74
...
200	199	686	687	608.44	610.01
...
474	473	1024	1025	609.84	610.60
475	474	1029	1030	609.80	610.49

556	555	1173	1174	609.96	610.59
557	556	1174	1175	609.09	610.08
558	557	1176	1177	609.09	610.59
559	558	1180	1181	609.79	611.23

Table 3. Emissions numerical data

Window [#]	$t_{1,i}$ [s]	$t_{2,i}$ [s]	d_i [km]	\bar{v}_j [km/h]	$M_{CO_2,i}$ [g]	$M_{CO,i}$ [g]	$M_{NOx,i}$ [g]	$M_{CO_2,d,i}$ [g/km]	$M_{CO,d,i}$ [g/km]	$M_{NOx,d,i}$ [g/km]	$M_{CO_2,d,cc}(\bar{v}_j)$ [g/km]	Window (U/R/M)	h_i [%]	w_i [%]
1	0	524	4.98	38.12	610.22	2.25	3.51	122.61	0.45	0.71	124.51	URBAN	-1.53	1.00
2	1	524	4.98	38.12	610.22	2.25	3.51	122.61	0.45	0.71	124.51	URBAN	-1.53	1.00
...
43	42	524	4.98	38.12	610.22	2.25	3.51	122.61	0.45	0.71	124.51	URBAN	-1.53	1.00
44	43	524	4.98	38.12	610.22	2.25	3.51	122.61	0.45	0.71	124.51	URBAN	-1.53	1.00
45	44	524	4.98	38.12	610.22	2.25	3.51	122.62	0.45	0.71	124.51	URBAN	-1.51	1.00
46	45	525	4.99	38.25	610.86	2.25	3.52	122.36	0.45	0.71	124.30	URBAN	-1.57	1.00
...
100	99	564	5.25	41.23	612.74	2.00	3.68	116.77	0.38	0.70	119.70	URBAN	-2.45	1.00
...
200	199	687	6.17	46.32	610.01	2.07	4.32	98.93	0.34	0.70	111.85	RURAL	-11.55	1.00
...
474	473	1025	7.82	52.00	610.60	2.05	4.82	78.11	0.26	0.62	103.10	RURAL	-24.24	1.00
475	474	1030	7.87	51.98	610.49	2.06	4.82	77.57	0.26	0.61	103.13	RURAL	-24.79	1.00

556	555	1174	8.46	50.12	610.59	2.23	4.98	72.15	0.26	0.59	105.99	RURAL	-31.93	0.72
557	556	1175	8.46	50.12	610.08	2.23	4.98	72.10	0.26	0.59	106.00	RURAL	-31.98	0.72
558	557	1177	8.46	50.07	610.59	2.23	4.98	72.13	0.26	0.59	106.08	RURAL	-32.00	0.72
559	558	1181	8.48	49.93	611.23	2.23	5.00	72.06	0.26	0.59	106.28	RURAL	-32.20	0.71

Table 4. Window numerical data

5.6.3 Urban, rural and motorway windows - Trip completeness (paragraphs 5.3.3, 5.4)

In this numerical example, the trip consists of 7036 averaging windows. Table 5 lists the number of windows classified in urban, rural and motorway according to their average vehicle speed (see section 5.3.3) and divided in regions respect to their distance to the CO₂ characteristic curve. The trip is complete since comprises at least 15% of urban, rural and motorway windows out of the total number of windows (section 5.4.2) as depicted in Table 5. In addition trip is characterized as normal since at least 50% of the urban, rural and motorway windows are within the primary tolerances defined for the characteristic curve (section 5.4.3).

Driving Conditions	Numbers	Percentage of windows
All Windows		
Urban	1909	$1909/7036=27.1 >15$
Rural	2011	$2011/7036=28.6 >15$
Motorway	3116	$3116/7036=44.3 >15$
Total	$1909+2011+3116=7036$	
Normal Windows		
Urban	1514	$1514/1909=79.3 >50$
Rural	1395	$1395/2011=69.4 >50$
Motorway	2708	$2708/3116=86.9 >50$
Total	$1514+1395+2708=5617$	

Table 5. Verification of trip completeness and normality

Appendix 6. Evaluation by normalization to a standardized power frequency distribution

Symbols, parameters and units

a_i	Actual acceleration in time step i , if not other defined in an equation: $a_i = \frac{(v_{i+1}-v_i)}{3.6 \times (t_{i+1}-t_i)}, [\text{m/s}^2]$
a_{ref}	Reference acceleration for P_{drive} , [0.45 m/s ²]
D_{WLTC}	intercept of the Veline from WLTC
f_0, f_1, f_2	Driving resistance coefficients as defined of Annex 4 in [N], [N/(km/h)], and [N/(km/h) ²] respectively
i	Time step for instantaneous measurements, minimum resolution 1Hz
j	Wheel power class, $j=1$ to 9
k_{WLTC}	Slope of the Veline from WLTC
$m_{\text{gas}, i}$	Instantaneous mass of the exhaust component ‘gas’ at time step i , [g/s]
$m_{\text{gas}, 3s, k}$	3 second moving average mass flow of the exhaust gas component “gas” in time step k given in 1 Hz resolution [g/s]
$\bar{m}_{\text{gas}, j}$	Average emission value of an exhaust gas component in the wheel power class j , g/s
$M_{\text{gas}, d}$	Distance-specific emissions for the exhaust gas component “gas” [g/km]
p	phase of WLTC (low, medium, high and extra-high), $p=1-4$
P_{drag}	Engine drag power in the Veline approach where fuel injection is zero, [kW]
P_{rated}	Maximum rated engine power as declared by the manufacturer, [kW]
$P_{\text{required}, i}$	Power to overcome road load and inertia of a vehicle at time step i , [kW]
$P_{r, i}$	Same as $P_{\text{required}, i}$ defined above used in longer equations
$P_{\text{wot}}(n_{\text{norm}})$	Full load power curve, [kW]
$P_{c, j}$	Wheel power class limits for class number j , [kW] ($P_{c, j}$, lower bound represents the lower limit $P_{c, j}$, upper bound the upper limit)
$P_{c, \text{norm}, j}$	Wheel power class limits for class j as normalised power value, [-]
$P_{r, i}$	Power demand at the vehicles wheel to overcome driving resistances in time step i [kW]
$P_{w, 3s, k}$	3 second moving average power demand at the vehicles wheel to overcome driving resistances in in time step k in 1 Hz resolution [kW]
P_{drive}	Power demand at the wheel hub for a vehicle at reference speed and acceleration [kW]
P_{norm}	Normalised power demand at the wheel hub [-]
t_i	Total time in step i , [s]
$t_{c, j}$	Time share of the wheel power class j , [%]
t_s	Start time of the WLTC phase p , [s]
t_e	end time of the WLTC phase p , [s]
TM	Test mass of the vehicle, [kg]; to be specified per section: real test weight in PEMS test, NEDC inertia class weight or WLTP masses (TM_L , TM_H or TM_{ind})
SPF	Standardised Power Frequency distribution
v_i	Actual vehicle speed in time step i , [km/h]
\bar{v}_j	Average vehicle speed in the wheel power class j , km/h
v_{ref}	Reference velocity for P_{drive} , [70 km/h]

$v_{3s,k}$ 3 seconds moving average of the vehicle velocity in time step k, [km/h]

6.1 Introduction

Appendix 6 describes the data evaluation according to the power binning method, named in this appendix “evaluation by normalization to a standardized power frequency (SPF) distribution”.

6.2 Evaluation of the measured emissions using a standardized wheel power frequency distribution

The SPF² evaluation method applies the instantaneous and time aligned mass flow values of the pollutants, $m_{gas,i}$ (g/s) calculated according to chapter 2.1.4.4.

The $m_{gas,i}$ shall be classified according to the corresponding power at the wheels and the classified average emissions per power class shall be weighted to obtain the emission values for a test with a normal power distribution according to the following steps.

The time alignment of the mass flow values shall be sufficiently accurate with less than +/-1 second misalignment as defined in Annex 3.

6.2.1 Sources for the actual wheel power

The actual wheel power $P_{r,i}$ shall be the total power to overcome air resistance, rolling resistance, longitudinal acceleration of the vehicle and rotational acceleration of the wheels.

The wheel power signal shall be gained from the validated ECU signal (chapter xxx) or from the instantaneous CO₂ mass flow (chapter 6.5) or from a calibrated wheel hub torque meter (chapter xx). In case of doubts, the calibrated wheel hub torque meter signal shall be seen as reference instrument to provide the $P_{r,i}$ signal during a PEMS trip.

If the ECU signal is used, a generic transmission efficiency of 95% shall be applied. On demand the manufacturer can use a lower efficiency.

6.2.2 Calculation of the moving averages of the instantaneous test data

Three second moving averages shall be calculated from all relevant instantaneous test data to reduce influences of possibly imperfect time alignment between emission mass flow and wheel power. The moving average values shall be computed in a 1 Hz frequency:

$$E\ 1: \quad m_{gas,3s,k} = \frac{\sum_{i=k}^{k+3} m_{gas,i}}{3} \quad \text{in [g/s]}$$

$$E\ 2: \quad P_{w,3s,k} = \frac{\sum_{i=k}^{k+3} P_{w,i}}{3} \quad \text{in [kW]}$$

$$E\ 3: \quad v_{3s,k} = \frac{\sum_{i=k}^{k+3} v_i}{3} \quad \text{in [km/h]}$$

With k time step for moving average values in 1 Hz

i time step from time aligned instantaneous test data in 1 Hz

6.2.3 Set up the wheel power classes for emission classification

The power classes and the corresponding time shares of the power classes in normal driving are defined for normalized power values to be representative for any LDV (Table 1).

² Formerly called CLEAR (Classification of Emissions from Automobiles in Real driving) but this name may be misleading in legislation → we suggest SPF

Table 1: Normalized standard power frequencies for urban driving and for a weighted average for a total trip consisting of 26% urban, 44% road, 30% motorway mileage

Power class No.	$P_{c,norm,j}$ [-]		Urban	Total trip
	From >	to \leq	Time share, $t_{c,i}$	
1		-0.1	21.97%	18.07%
2	-0.1	0.1	28.79%	20.50%
3	0.1	1	44.00%	44.06%
4	1	1.9	4.74%	14.30%
5	1.9	2.8	0.45%	2.559%
6	2.8	3.7	0.045%	0.455%
7	3.7	4.6	0.004%	0.055%
8	4.6	5.5	0.0004%	0.0028%
9	5.5		0.00025%	0.00030%

The $P_{c,norm}$ columns in Table 1 shall be de-normalized by multiplication with P_{drive} , where P_{drive} is the actual wheel power of the tested car in the type approval settings at the chassis dynamometer at v_{ref} and a_{ref} .

E 4: $P_{c,j} \text{ [kW]} = P_{c,norm,j} * P_{drive}$

E 5: $P_{drive} = \frac{v_{ref}}{3.6} \times (f_0 + f_1 \times v_{ref} + f_2 \times v_{ref}^2 + TM_{NEDC} \times a_{ref}) \times 0.001$

With j..... power class index according to Table 1

TM_{NEDC} inertia class of the vehicle in type approval test, [kg]

Correction of the wheel power classes for lower powered cars:

The maximum wheel power class to be considered is the highest class in Table 1 which includes $(P_{rated} \times 0.9)$. The time shares of all excluded classes shall be added to the highest remaining class.

From each $P_{c,norm,j}$ the corresponding $P_{c,i}$ shall be calculated to define the upper and lower bounds in kW per wheel power class for the tested vehicle as shown in Figure 1.

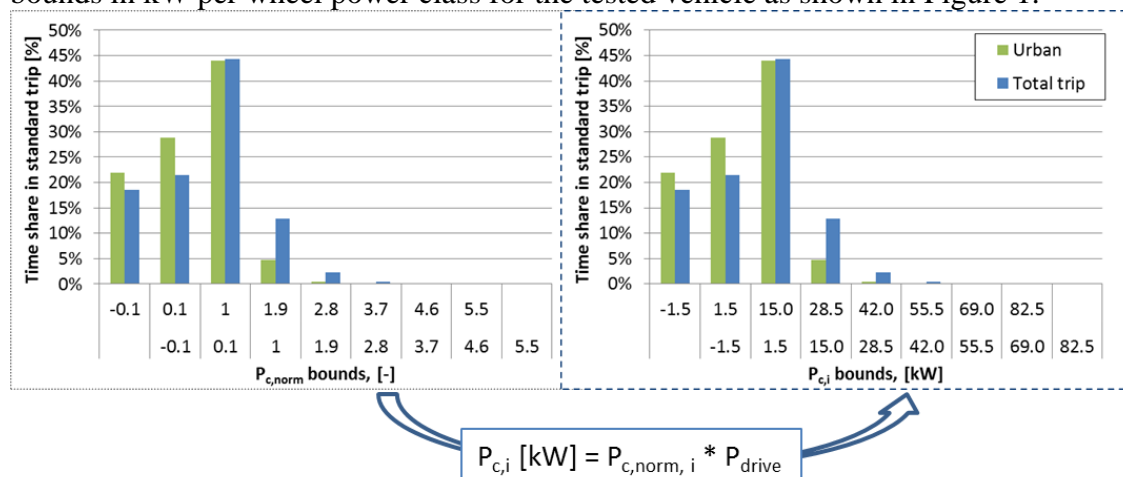


Figure 1: Schematic picture for converting the normalized standardized power frequency into a vehicle specific power frequency

An example for this de-normalisation is given below.

Example for input data:

Parameter	Value
f_0 [N]	79.19
f_1 [N/(km/h)]	0.73
f_2 [N/(km/h) ²]	0.03
TM [kg]	1470
P_{rated} [kW]	120 in Example 1
P_{rated} [kW]	75 in Example 2

Corresponding results:

$P_{drive} =$

$$70[km/h]/3.6*(79.19+0.73[N/(km/h)]*70[km/h]+0.03[N/(km/h)^2]*(70[km/h])^2+1470[kg]*0.45[m/s^2])*0.001$$

$P_{drive} = 18.25 \text{ kW}$

Table 2: De-normalised standard power frequency values from Table 1 for Example 1.

Power class No.	$P_{c,j}$ [kW]		Urban	Total trip
	From >	to \leq	Time share, $t_{C,j}$ [%]	
1	All < -1.825	-1.825	21.97%	18.07%
2	-1.825	1.825	28.79%	20.50%
3	1.825	18.25	44.00%	44.06%
4	18.25	34.675	4.74%	14.30%
5	34.675	51.1	0.45%	2.559%
6	51.1	67.525	0.045%	0.455%
7	67.525	83.95	0.004%	0.055%
8	83.95	100.375	0.0004%	0.0028%
9 ⁽¹⁾	100.375	All > 100.375	0.00025%	0.00030%

(1) The highest class wheel power class to be considered is the one containing $0.9 \times P_{rated}$. Here $0.9 \times 120 = 108$.

Table 3: De-normalised standard power frequency values from Table 1 for Example 2.

Power class No.	$P_{c,j}$ [kW]		Urban	Total trip
	From >	to \leq	Time share, $t_{C,j}$ [%]	
1	All < -1.825	-1.825	21.97%	18.07%
2	-1.825	1.825	28.79%	20.50%
3	1.825	18.25	44.00%	44.06%
4	18.25	34.675	4.74%	14.30%
5	34.675	51.1	0.45%	2.559%
6 ⁽¹⁾	51.1	All > 51.1	0.045%	0.5131%
7	67.525	83.95	-	-
8	83.95	100.375	-	-
9	100.375	All > 100.375	-	-

(1) The highest class wheel power class to be considered is the one containing $0.9 \times P_{rated}$. Here $0.9 \times 75 = 67.5$.

6.2.4 Classification of the moving average values

Each moving average value from chapter 6.4.2 shall be sorted into the de-normalized wheel power class into which the actual 3 second moving average wheel power $P_{w,3s,k}$ fits. The de-normalized wheel power class limits have to be calculated according to chapter 6.4.3.

The classification shall be done for all three second moving averages of the entire valid trip data as well as for the all urban trip parts. All moving averages classified to urban shall be classified into one set of urban power classes independently of the time when the moving average appears in the trip.

Then the average of all three second moving average values within a wheel power class shall be calculated for each wheel power class per parameter. The equations are described below and shall be applied once for the urban data set and once for the total data set.

Classification of the 3-second moving average values into power class j ($j = 1$ to 9):

E 6: *if* $P_{C,j \text{ lower bound}} < P_{w,3s,k} \leq P_{C,j \text{ upper bound}}$
 then: class index for emissions and velocity = j

The number of 3-second moving average values shall be counted for each power class:

E 7: *if* $P_{C,j \text{ lower bound}} < P_{w,3s,k} \leq P_{C,j \text{ upper bound}}$
 then: $\text{counts}_j = n + 1$ (counts_j is counting the number of 3 second moving average emission value in a power class to check later the minimum coverage demands)

6.2.5 Check of power class coverage and of normality of power distribution

For a valid test the time shares of the single wheel power classes shall be in the ranges listed in Table 4.

The lower bound and upper bound of the shares per power class for a valid test cannot be completed now. Additional work has to be done, to validate the normality check of the power binning method.

Table 4: Minimum and maximum shares per power class for a valid test

Power class No.	$P_{c,norm,j}$ [-]		Total trip		Urban trip parts	
	From >	to \leq	lower bound	upper bound	lower bound	upper bound
Sum 1+2 ⁽¹⁾		0.1	15%	60%	5% ⁽¹⁾	60%
3	0.1	1	35%	50%	28%	50%
4	1	1.9	7%	25%	7%	25%
5	1.9	2.8	1.0%	10%	>5 counts	5%
6	2.8	3.7	>5 counts	2.5%	0%	2%
7	3.7	4.6	0%	1.0%	0%	1%
8	4.6	5.5	0%	0.5%	0%	0.5%
9	5.5		0%	0.25%	0%	0.25%

In addition to the requirements in Table 4 a minimum coverage of 5 counts is demanded for the total trip in each wheel power class up to the class containing 90% of the rated power to provide a sufficient sample size.

A minimum coverage of 5 counts is demanded for the urban part of the trip in each wheel power class up to class No. 5. If the counts in the urban part of the trip in a wheel power class above number 5 are less than **5**, the average class emission value shall be set to zero.

6.2.6 Averaging of the measured values per wheel power class

The moving averages sorted in each wheel power class shall be averaged as follows:

$$\text{E 8: } \bar{m}_{gas,j} = \frac{\sum_{all\ k\ in\ class\ j} m_{gas,3s,k}}{counts_j} \quad \text{in [g/s]}$$

$$\text{E 9: } \bar{v}_j = \frac{\sum_{all\ k\ in\ class\ j} v_{3s,k}}{counts_j} \quad \text{in [km/h]}$$

With j..... wheel power class 1 to 9 according to Table 1
 $\bar{m}_{gas,j}$ average emission value of an exhaust gas component in a wheel power class (separate value for total trip data and for the urban parts of the trip), g/s
 \bar{v}_j average velocity in a wheel power class (separate value for total trip data and for the urban parts of the trip), km/h
k.....time step for moving average values in 1 Hz

6.2.7 Weighting of the average values per wheel power class

The average values of each wheel power class shall be multiplied with the time share, $t_{c,j}$ per class according to Table 1 and then summed up to produce the weighted average value for each parameter. This value represents the weighted result for trip with the standardised power frequencies. The weighted averages shall be computed for the urban part of the test data using the time shares for urban power distribution as well as for the total trip using the time shares for total.

The equations are described below and shall be applied once for the urban data set and once for the total data set.

$$\text{E 10: } \bar{m}_{gas} = \sum_{j=1}^9 \bar{m}_{gas,j} \times t_{c,j} \quad \text{in [g/s]}$$

$$\text{E 11: } \bar{v} = \sum_{j=1}^9 \bar{v}_j \times t_{c,j} \quad \text{in [km/h]}$$

6.2.8 Calculation of the weighted distance specific emission value

The time based weighted averages of the emissions in the test shall be converted into distance based emission values as follows:

$$\text{E 12: } M_{w,gas,d} = 1000 \cdot \frac{\bar{m}_{gas} \times 3600}{\bar{v}} \quad \text{in [mg/km]}$$

Following values shall be calculated according to the method described before

$M_{w,NOx,d}$ weighted NOx test result in [mg/km]

$M_{w,CO,d}$ weighted CO test result in [mg/km]

6.3 Assessment of the wheel power from the instantaneous CO₂ mass flow

The power at the wheels ($P_{w,i}$) can be computed from the measured CO₂ mass flow in 1 Hz basis. For this calculation the vehicle specific CO₂ lines (“Veline”) shall be used. The Veline shall be calculated from the vehicle type approval test in the WLTC according to the test procedure described in the in the UNECE Global Technical Regulation No. 15 - Worldwide harmonized Light vehicles Test Procedure (ECE/TRANS/180/Add.15).

Calculate the average wheel power per WLTC phase in 1 Hz from the driven velocity and from the chassis dynamometer settings. Wheel power values below the drag power shall be set to the drag power value.

$$E\ 13 \quad P_{w,i} = \frac{v_i}{3.6} \times \left(f_0 + f_1 \times v_i + f_2 \times v_i^2 + TM \times a_i \right) \times 0.001$$

With f_0, f_1, f_2 road load coefficients used in the WLTP test performed with the vehicle
 TM test mass of the vehicle in the WLTP test performed with the vehicle in [kg]

$$E\ 14 \quad P_{drag} = -0.04 \times P_{rated}$$

$$E\ 15 \quad \text{if } P_{w,i} < P_{drag} \text{ then } P_{w,i} = P_{drag}$$

The average power per WLTC phase is calculated from the 1 Hz wheel power according to E 16:

$$E\ 16 \quad \overline{P_{w,p}} = \frac{\sum_{j=ts}^{te} P_{w,i}}{te-ts}$$

With p phase of WLTC (low, medium, high and extra-high)
 ts Start time of the WLTC phase p , [s]
 te end time of the WLTC phase p , [s]

Then a linear regression shall be made with the CO₂ mass flow from the bag values of the WLTC on the y-axis and from the average wheel power P_w per phase on the x-axis as illustrated in Figure 2.

The resulting Veline equation defines the CO₂ mass flow as function of the wheel power:

$$E\ 17 \quad CO_{2,i} = k_{WLTC} \times P_{w,i} + D_{WLTC} \quad CO_2 \text{ in [g/h]}$$

With k_{WLTC} slope of the Veline from WLTC, [g/kWh]
 D_{WLTC} intercept of the Veline from WLTC, [g/h]

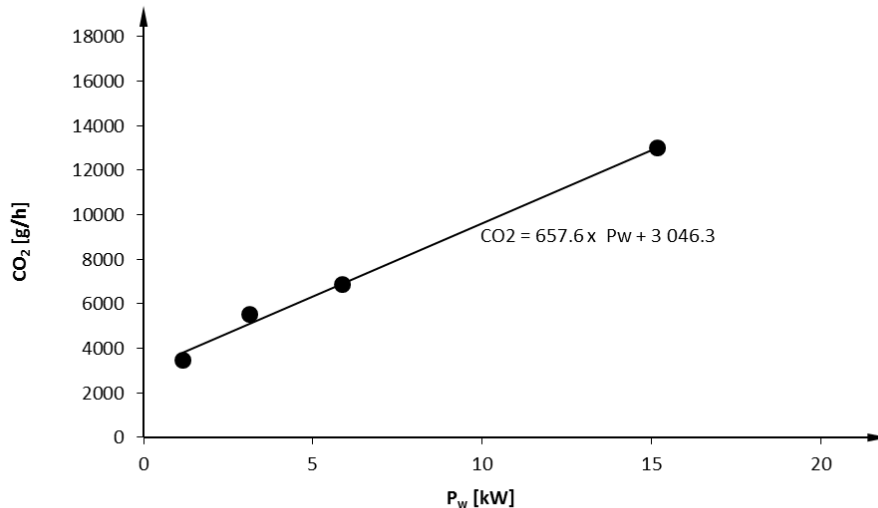


Figure 2: Schematic picture of setting up the vehicle specific Veline from the CO₂ test results in the 4 phases of the WLTC

E 17 shall be transformed to calculate the actual wheel power from the measured CO₂ mass flow:

E 18 $P_{w,i} = \frac{CO2_i - D_{WLTC}}{k_{WLTC}}$ CO₂ in [g/h] and P_{w,j} in [kW]

E 18 can be used to provide P_{w,i} for the classification of the measured emissions as described in chapter 6.4.4 with following additional conditions in the calculation

E 19 *if $v_i < 0.5$ and if $a_i < 0$ then $P_{w,i} = 0$* v in [m/s]

E 20 *if $CO2_i < 0.5 \times D_{WLTC}$ then $P_{w,i} = P_{drag}$* v in [m/s]

Appendix 7 – Selection of vehicles for PEMS testing at initial type approval

1 Introduction

Due to their particular characteristics PEMS tests are not required to be performed for each *'vehicle type with regard to emissions and vehicle repair and maintenance information'* as defined in Article 2(1) of this Regulation, which is called in the following *'vehicle emission type'*. Several vehicle emission types may be put together by the vehicle manufacturer to form a *"PEMS test family"* according to the requirements of point 2, which has to be validated according to the requirements of point 3.

2 PEMS test family building

A PEMS test family shall comprise vehicles with similar emission characteristics. Upon the choice of the manufacturer vehicle emission types may be included in a PEMS test family only if they are identical with respect to the characteristics in sections 2.1. and 2.2..

2.1 Administrative criteria

2.1.1 The approval authority issuing the emission type approval according to Regulation (EC) 715/2007.

2.1.2 A single vehicle manufacturer.

2.2 Technical criteria

2.2.1 Propulsion type (e.g. ICE, HEV, PHEV)

2.2.2 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.

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

2.2.4 Number of cylinders

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

2.2.6 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 $V_{eng_max} \geq 1500$ ccm and -32% from V_{eng_max} if $V_{eng_max} < 1500$ ccm.

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

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

2.2.9 Method of aspiration such as naturally aspirated or pressure charged

2.2.10 Types and sequence of exhaust aftertreatment components (e.g. three-way catalyst, oxidation catalyst, lean NO_x trap, SCR, lean NO_x catalyst, particulate trap).

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

2.3 Extension of a PEMS test family

An existing PEMS test family may be extended by adding new vehicle emission types to it. The extended PEMS test family and its validation must also fulfill the requirements of points 2 and 3. This may in particular require the PEMS testing of additional vehicles to validate the extended PEMS test family according to point 3.

2.4 Alternative PEMS test family

As an alternative to the provisions of point 2.1 to 2.2 the vehicle manufacturer may define a PEMS test family, which is identical to a single vehicle emission type. In this the requirement of point 3.1.2 for validating the PEMS test family is not applicable.

3. Validation of a PEMS test family

3.1 General requirements for validating a PEMS test family

- 3.1.1 The vehicle manufacturer presents a representative vehicle of the PEMS test family to the type approval authority. The vehicle shall be subject to a PEMS test carried out by a Technical Service to demonstrate compliance of the representative vehicle with the requirements of this Annex.
- 3.1.2 The authority responsible for issuing the emission type approval of Regulation (EC) 715/2007 selects additional vehicles according to the requirements of point 3.2 of this Appendix for PEMS testing carried out by a Technical Service to demonstrate compliance of the selected vehicles with the requirements of this Annex.
- 3.1.3 With agreement of the type approval 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 3.2.2 and 3.2.5 and in total at least approximately 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.
- 3.1.4 PEMS test results of a specific vehicle emission type may be used for validating different PEMS test families according to the requirements of this Appendix under the following conditions:
 - the vehicles included in all PEMS test families to be validated are approved by a authority according to the requirements of Regulation (EC) 715/2007;
 - If a new type is added to a RDE- family, according to the technical family criteria, a PEMS test validated for the family can be re-used by another Type Approval Authority, or a new PEMS test if required can be performed by another Type Approval Authority.
 - the specific vehicle emission type is included in all PEMS test families to be validated;
 - for each validation the applicable responsibilities are considered to be borne by the manufacturer of the vehicles in the respective family, regardless of whether this manufacturer was involved in the PEMS test of the specific vehicle emission type.

3.2 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:

- 3.2.1 For each combination of fuels (e.g. petrol-LPG, petrol-NG, petrol only), on which some vehicle of the PEMS test family can operate, one vehicle that can operate on this combination of fuels shall be selected for PEMS testing.
- 3.2.2 The manufacturer shall specify a value PMR_H (= highest power-to-mass-ratio of all vehicles in the PEMS test family) and a value PMR_L (= lowest power-to-mass-ratio of all vehicles in the PEMS test family). Here the "power-to-mass-ratio" corresponds to the ratio of the maximum net power of the internal combustion engine as indicated in point 3.2.1.8 of Appendix 3 to Annex I of this Regulation and of the reference mass as defined in Article 3(3) of Regulation (EC) 715/2007. 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-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.
- 3.2.3 At least one vehicle for each transmission type (manual, automatic, DCT,...) installed in vehicles of the PEMS test family shall be selected for testing.
- 3.2.4 At least one vehicle representative for the highest and one vehicle representative for the lowest engine volume shall be selected for testing.
- 3.2.5 At least one vehicle for each number of installed exhaust aftertreatment components shall be selected for testing.
- 3.2.6 Notwithstanding the provisions above, 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 testing
1	1
from 2 to 4	2
from 5 to 7	3
from 8 to 10	4
from 11 to 49	$NT = 3 + 0,1 \times N (*)$
more than 49	$NT = 0,15 \times N (*)$

(*) NT shall be rounded to the next higher integer number

- 3.2.7 In case an incomplete vehicle belongs to a PEMS test family which includes at least one complete vehicle, a PEMS test is not required for that incomplete vehicle.

- 3.2.8 In case the emission type(s) entirely consists of incomplete vehicle(s), it shall not be included into Number N as defined in 3.2.6 of this appendix providing the PEMS test family still contains at least one complete vehicle

4 Reporting and access to information

- 4.1 The vehicle manufacturer provides a full description of the PEMS test family, which includes in particular the technical criteria described in point 2.2 and submits it to the responsible type approval authority.
- 4.2 The manufacturer attributes a unique identification number of the format *OEM-X-Y* to the PEMS test family and communicates it to the type approval authority. 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).
- 4.3 The type approval authority and the vehicle manufacturer shall maintain a list of vehicle emission types being part of a given PEMS test family.
- 4.4 The type approval authority and the vehicle manufacturer shall maintain a list of vehicle emission types selected for PEMS testing in order to validate a PEMS test family in accordance with point 3 of this Appendix, which also provides the necessary information on how the selection criteria of point 3.2 are covered. This list shall also indicate whether the respective vehicle whether the provisions of point 3.1.3 were applied for a particular PEMS test.

Appendix 8: Reporting and data dissemination

8.1 Introduction

This Appendix describes the requirements for the data exchange between the measurement systems and the data evaluation software. It also describes the requirements for formatting the calculated results and the reporting of the data evaluation.

The exchange and reporting of mandatory and optional parameters shall follow the requirements of Appendix 1 paragraph 1.3.2.

8.2 Data exchange file format

8.2.1 General

The instantaneous emissions as well as any other relevant parameters shall be saved and exchanged as csv-formatted data files. The files shall be formatted as comma separated value. This means that:

- (i) Parameter values shall be separated by comma, ASCII-Code #h2C.
- (ii) The decimal marker of numerical values shall be a point, ASCII-Code #h2E.
- (iii) Lines shall be terminated by carriage return, ASCII-Code #h0D. No thousands separators shall be used.

8.2.2 Test specific data

The data shall be exchanged between the measurement systems and the data evaluation software by a standardized reporting file that contains a minimum set of all mandatory and optional parameters. The first 197 lines shall be reserved for a header that provides specific information about the test, e.g., the conditions, the identity and calibration of the PEMS equipment (Table 1) and the vehicle. Lines 198-200 shall contain the labels and units of parameters. Lines 201 and all consecutive data lines shall comprise the body of the data exchange file and report parameter values (Table 2). The body of the data exchange file shall contain at least as many data lines as the test duration in seconds multiplied by the recording frequency in Hertz.

Table 1: Header of the data exchange file #1

Line	Parameter	Description/unit
1	TEST ID	[code]
2	Test date	[day.month.year]
3	Organisation supervising the test	[name of the organization]
4	Test location	[city, country]
5	Person supervising the test	[name of the principal supervisor]
6	Vehicle driver	[name of the driver]
7	Vehicle type	[vehicle name]
8	Vehicle manufacturer	[name]
9	Vehicle model year	[year]
10	Vehicle ID	[VIN code]
11	Vehicle ID additional info	[info]
12	Odometer value at test start	[km]
13	Odometer value at test end	[km]
14	Vehicle category	[category]
15	Type approval emissions limit	[Euro X]
16	Engine type	[e.g., spark ignition, compression ignition]

17	Engine type additional info	[info]
18	Engine rated power	[kW]
19	Rated engine speed	[rpm]
20	Idle engine speed	[rpm]
21	Peak torque	[Nm]
22	Engine displacement	[ccm]
23	Transmission	[e.g., manual, automatic]
24	Number of forward gears	[#]
25	Fuel	[e.g., gasoline, diesel]
26	Lubricant	[product label]
27	Tire sizes (front/rear)	[width/height/rim diameter]
28	Front and rear tire pressure (left, right)	FL,FR,RL,RR,[bar]
29	Vehicle test mass ⁽³⁾	[kg]
30	Gross vehicle mass	[kg]
31	Vehicle unladen mass	[kg]
32	PEMS manufacturer	[name]
33	Reference CO ₂ mass (M _{CO₂,ref} App 5 5.2.1)	[g]
34	Road load parameters f0	[N]
35	Road load parameters f1	[N/(km/h)]
36	Road load parameters f2	[N/(km/h) ²]
37	Type approval test mass	[kg]
38	Type-approval test cycle	[NEDC, WLTC]
39	Type-approval CO ₂ emissions	[g/km]
40	CO ₂ emissions in WLTC mode Low	[g/km]
41	CO ₂ emissions in WLTC mode Mid	[g/km]
42	CO ₂ emissions in WLTC mode High	[g/km]
43	CO ₂ emissions in WLTC mode Extra High	[g/km]
44	Transmission Efficiency	[%]
45	PEMS type	[PEMS name]
46	PEMS serial number	[number]
47	PEMS power supply	[e.g., battery type]
48	Gas analyser manufacturer	[name]
49	Gas analyser type	[type]
50	Gas analyser serial number	[number]
51-60 ⁽⁴⁾
61	EFM manufacturer ⁽¹⁾ [if applicable]	[name]
62	EFM sensor type ⁽¹⁾ [if applicable]	[functional principle]
63	EFM serial number ⁽¹⁾ [if applicable]	[number]
64	EFM date of last calibration [if applicable]	[date YYYY-MM-DD]
65-70 ⁽⁴⁾
71	Source of exhaust mass flow rate	[EFM/ECU/sensor]
72	Air pressure sensor	[type, manufacturer]
73	Start time of pre-test procedure	[h:min]
74	Start time of trip	[h:min]
75	Start time of post-test procedure	[h:min]
76	End time of pre-test procedure	[h:min]
77	End time of trip	[h:min]
78	End time of post-test procedure	[h:min]
79-90 ⁽²⁾
91	Time correction: Shift CO	[s]
92	Time correction: Shift CO ₂	[s]
93	Time correction: Shift NO	[s]
94	Time correction: Shift NO ₂	[s]
95	Time correction: Shift exhaust mass flow rate	[s]

96-100 ⁽⁴⁾	...	
101	Span reference value CO	[ppm]
102	Span reference value CO ₂	[%]
103	Span reference value NO	[ppm]
104	Span Reference Value NO ₂	[ppm]
105-110 ⁽⁴⁾
111	Pre-test zero response CO	[ppm]
112	Pre-test zero response CO ₂	[%]
113	Pre-test zero response NO	[ppm]
114	Pre-test zero response NO ₂	[ppm]
115-120 ⁽⁴⁾
121	Pre-test span response CO	[ppm]
122	Pre-test span response CO ₂	[%]
123	Pre-test span response NO	[ppm]
124	Pre-test span response NO ₂	[ppm]
125-130 ⁽⁴⁾
131	Post-test zero response CO	[ppm]
132	Post-test zero response CO ₂	[%]
133	Post-test zero response NO	[ppm]
134	Post-test zero response NO ₂	[ppm]
135-140 ⁽⁴⁾
141	Post-test span response CO	[ppm]
142	Post-test span response CO ₂	[%]
143	Post-test span response NO	[ppm]
144	Post-test span response NO ₂	[ppm]
145-150 ⁽⁴⁾
151	PEMS validation – results CO [if applicable]	[mg/km;%] ⁽⁵⁾
152	PEMS validation – results CO ₂ [if applicable]	[g/km;%] ⁽⁵⁾
153	PEMS validation – results NO _x [if applicable]	[mg/km;%] ⁽⁵⁾
... ⁽⁶⁾	... ⁽⁶⁾	... ⁽⁶⁾

⁽¹⁾ Mandatory if the exhaust mass flow rate is determined by an EFM.

⁽²⁾ If required, additional information can be added here.

⁽³⁾ Mass of the vehicle as tested on the road, including the mass of the driver and all PEMS components.

⁽⁴⁾ Placeholder for additional information about analyser manufacturer and serial number in case multiple analysers are used. Number of reserved rows is indicative only; no empty rows shall occur in the completed data reporting file.

⁽⁵⁾ PEMS validation is optional; distance-specific emissions as measured with the PEMS; Percentage shall indicate the deviation from the laboratory reference.

⁽⁶⁾ Optional parameters and units can be added until line 195 to characterise and label the test.

Table 2: Body of the data exchange file #1; the rows and columns of this table shall be transposed in the body of the data exchange file #1

Line	198	199	200	201
	Time	Trip	[s]	(1)
	Vehicle speed ⁽²⁾	Sensor	[km/h]	(1)
	Vehicle speed ⁽²⁾	GPS	[km/h]	(1)
	Vehicle speed ⁽²⁾	ECU	[km/h]	(1)
	Latitude	GPS	[deg:min:s]	(1)
	Longitude	GPS	[deg:min:s]	(1)
	Altitude ⁽²⁾	GPS	[m]	(1)
	Altitude ⁽²⁾	Sensor	[m]	(1)
	Ambient pressure	Sensor	[kPa]	(1)
	Ambient temperature	Sensor	[K]	(1)
	Ambient humidity	Sensor	[g/kg; %]	(1)

	CO mass	Analyser	[g/s]	(1)
	CO ₂ mass	Analyser	[g/s]	(1)
	NO _x mass	Analyser	[g/s]	(1)
	NO mass	Analyser	[g/s]	(1)
	NO ₂ mass	Analyser	[g/s]	(1)
	Gas measurement active	PEMS	[active (1); inactive (0); error (>1)]	(1)
	Engine speed	ECU	[rpm]	(1)
	Engine torque	ECU	[Nm]	(1)
	Coolant temperature	ECU	[K]	(1)
	Oil temperature	ECU	[K]	(1)
	Regeneration status	ECU	[periodical regen (≥ 1); normal (0)]	(1)
	Vehicle status	ECU	[error (≥ 1); normal (0)]	(1)
	GSI recommended gear	ECU	[-]	
	Actual gear	ECU	[-]	
	(3)	(3)	(3)	(1,3)
	

(1) Actual values to be included from line 201 onward until the end of data

(2) To be determined by at least one method

(3) If necessary, optional parameters and units can be added to characterise vehicle and test conditions.

(4) Mass flow calculated from sensor(s) as reported in row 71 of table 1.

Table 3: Body of the data exchange file #2; the rows and columns of this table shall be transposed. The recording frequency shall be greater than or equal to 10 Hz. The body of the data file shall contain at least as many data lines as the test duration in seconds multiplied by the recording frequency in Hertz.

Line	1	2	3	4
	Time	Trip	[s]	(1)
	Pedal position	ECU	[%]	(1)

(1) Actual values to be included from line 4 onward until the end of data

8.2.3 Trip data

The information concerning the PEMS-trip shall be contained in one data exchange file #3. This file combines the information derived from a digital map (Table 4), the evaluation based on Appendix 5 (Table 5) and the evaluation based on Appendix 6 (Table 6).

Table 4: digital map information of file #2

Line	Parameter	Unit / Equation
1	Total trip distance	[km]
2	Total trip duration	[min:s]
3	Total stop time	[s]
4	Trip average speed	[km/h]
5	Trip maximum speed	[km/h]
6	Distance urban part	[km]
7	Duration urban part	[min:s]
8	Stop time urban part	[s]
9	Average speed urban part	[km/h]
10	Urban [$v \cdot a$] _{apos>0.1} 95% tile time based	[m ² /s ³]
11	Maximum speed urban part	[km/h]
12	Distance rural part	[km]
13	Duration rural part	[min:s]
14	Stop time rural part	[s]
15	Average speed rural part	[km/h]
16	Rural [$v \cdot a$] _{apos>0.1} 95% tile time based	[m ² /s ³]

17	Maximum speed rural part	[km/h]
18	Distance motorway part	[km]
19	Duration motorway part	[min:s]
20	Stop time motorway part	[s]
21	Average speed motorway part	[km/h]
22	Maximum speed motorway part	[km/h]
23	Motorway $[v \cdot a]_{a_{pos} > 0.1}$ 95% tile time based	$[m^2/s^3]$
24	Maximum speed motorway part 97% tile dist. based	[km/h]
25	Duration of the longest single stop	[s]
26	Road grade: incline 95% tile dist. based	[m/km]
27	Road grade: altitude gain	[m/100km]
28	Time share with gear \leftrightarrow GSI recommended gear	[%]
29	Relative engine speed 97%tile, time based	[-]
30-50 ⁽¹⁾

(1) If necessary, optional parameters and units can be added

Table 5: trip information based on Appendix 5 file #3

Line	Parameter	Unit / Equation
51	Total trip distance	[km]
52	Total trip duration	[min:s]
53	Total stop time	[s]
54	Trip average speed	[km/h]
55	Trip maximum speed	[km/h]
56	Distance urban part	[km]
57	Duration urban part	[min:s]
58	Stop time urban part	[s]
59	Average speed urban part	[km/h]
60	Maximum speed urban part	[km/h]
61	Distance rural part	[km]
62	Duration rural part	[min:s]
63	Stop time rural part	[s]
64	Average speed rural part	[km/h]
65	Maximum speed rural part	[km/h]
66	Distance motorway part	[km]
67	Duration motorway part	[min:s]
68	Stop time motorway part	[s]
69	Average speed motorway part	[km/h]
70	Maximum speed motorway part	[km/h]
71	Share of urban windows	[%]
72	Share of rural windows	[%]
73	Share of motorway windows	[%]
74	Share of urban windows within $\pm tol_1$	[%]
75	Share of rural windows within $\pm tol_1$	[%]
76	Share of motorway windows within $\pm tol_1$	[%]
77	Average severity index of all windows	[%] / Appendix5-E20
78	Average severity index of urban windows	[%] / Appendix5-E19
79	Average severity index of rural windows	[%] / Appendix5-E19
80	Average severity index of motorway windows	[%] / Appendix5-E19
81	Calculation software and version	(e.g. EMROAD 5.8)
82-100 ⁽¹⁾

(1) If necessary, optional parameters and units can be added

Table 6: trip information based on Appendix 6 file #3

Line	Parameter	Unit / Equation
101	Slope of the Veline	[g/kWh] / Appendix 6-E17
102	Intercept of the Veline	[g/h] / Appendix 6-E17
103	Calculation software and version	(e.g. CLEAR 1.8)
104-150 ⁽¹⁾

(1) If necessary, optional parameters and units can be added

Table 7: Body of the data reporting file #3 - Detailed results - Data evaluation method according to Appendix 6; the rows and columns of this table shall be transposed in the body of the data reporting file

Line	151	152	153 ⁽²⁾
	Total trip - Power class number ⁽¹⁾	-	⁽²⁾
	Total trip - Lower power class limit ⁽¹⁾	[kW]	⁽²⁾
	Total trip - Upper power class limit ⁽¹⁾	[kW]	⁽²⁾
	Total trip - Goal pattern used (distribution) ⁽¹⁾	[% , #]	⁽²⁾
	Total trip - Power class occurrence ⁽¹⁾	[%]	⁽²⁾ Appendix6-E7
	Urban trip - Power class number ⁽¹⁾	-	⁽²⁾
	Urban trip - Lower power class limit ⁽¹⁾	[kW]	⁽²⁾
	Urban trip - Upper power class limit ⁽¹⁾	[kW]	⁽²⁾
	Urban trip - Goal pattern used (distribution) ⁽¹⁾	[%]	⁽²⁾
	Urban trip - Power class occurrence ⁽¹⁾	[%]	⁽²⁾ Appendix6-E7
	... ⁽³⁾	... ⁽³⁾	... ^(2, 3)

⁽¹⁾ Results reported for each power class starting from power class #1 up to power class which includes 90% of P_{rated}

⁽²⁾ Actual values to be included from line 151 to line 153 to onward until the end of data

⁽³⁾ If necessary, optional parameters and units can be added

8.2.4 Calculated data based on evaluation method of Appendix 5

Table 8: Emission data from evaluation as provided by Appendix 5

Parameter	Unit / Equation
Total trip - CO Emissions EMROAD	[mg/km] / Appendix5-E21
Total trip - NO _x Emissions EMROAD	[mg/km] / Appendix5-E21

8.2.5 Calculated data based on evaluation method of Appendix 6

Table 9: Emission data from evaluation as provided by Appendix 6

Parameter	Unit / Equation
Total trip - CO Emissions SPF	[mg/km] / Appendix 6-E12
Total trip - NO _x Emissions SPF	[mg/km] / Appendix 6-E12

8.3 Reporting

The manufacturer shall present to the type approval authority an information document containing the elements of tables 8 and 9 as applicable. The emissions values shall not exceed the $RDE_{pollutant}$ set out in chapter 2 of this Annex.

8.4 Special provisions during the monitoring phase

During the monitoring phase as defined in Article 2 10.3 of Regulation (EC) 692/2008 special provisions shall apply.

8.4.1 Development of test equipment, - procedure and evaluation tools

An expert team shall be appointed for the purpose of further development of equipment, test procedure and the evaluation tools. based on the data collected during the monitoring period.

Additional data may be added by agreement of the expert team. Any other usage and publication of this data shall not be allowed.

8.4.2 Reporting

Manufacturers provide the requested PEMS test values to an independent expert as the sole recipient of RDE monitoring data for communicating them onwards in a manner which fits to the desires of Member States to learn from this data but also the desires of OEMs to avoid misinformed analysis of the results.

8.4.2.1 Vehicle data

- 8.4.2.1.1 Vehicle type, (A-segment mini, B-segment small, C-segment medium, D-segment large, E-segment executive, F-segment luxury, S-segment sports, M-segment multi-purpose, J-segment sports utility, M2, N1 or N2).
- 8.4.2.1.2 Test mass [kg]
- 8.4.2.1.3 Fuel (petrol, diesel, LPG, NG, ...)
- 8.4.2.1.4 Engine capacity bracket ($v < 600 \text{ cm}^3$, $600 \leq v < 900 \text{ cm}^3$, $900 \leq v < 1200 \text{ cm}^3$, $1200 \leq v < 1600 \text{ cm}^3$, $1600 \leq v < 2000 \text{ cm}^3$, $2000 \leq v < 2500 \text{ cm}^3$, $2500 \leq v < 3000 \text{ cm}^3$, $3500 \leq v < 4000 \text{ cm}^3$, $\geq 4000 \text{ cm}^3$)
- 8.4.2.1.5 Exhaust aftertreatment technology (three-way catalyst, oxidation catalyst, lean NOx trap, SCR, lean NOx catalyst, particulate trap)

8.4.2.2 Test data

Aggregate data evaluated for the complete trip.

- 8.4.2.2.1 Average emission, NO_x [mg/km]
- 8.4.2.2.2 Average emission, CO [mg/km]
- 8.4.2.2.3 Evaluation result, NO_x (EMROAD) [mg/km]
- 8.4.2.2.4 Evaluation result, CO (EMROAD) [mg/km]
- 8.4.2.2.5 Evaluation result, NO_x (SPF) [mg/km]
- 8.4.2.2.6 Evaluation result, CO (SPF) [mg/km]
- 8.4.2.2.7 Average vehicle speed, v_{mean} [km/h] including standstill
- 8.4.2.2.8 Relative positive acceleration, RPA [m^2/s^2]
- 8.4.2.2.9 P95% ($v \times a_{\text{pos}}$) [m^2/s^3], time based
- 8.4.2.2.10 P50% ($v \times a_{\text{pos}}$) [m^2/s^3], time based
- 8.4.2.2.11 Average power (P3s) [kW]
- 8.4.2.2.12 P97% (nrel) [1], time based
- 8.4.2.2.13 P95% vehicle speed, v [km/h], distance based
- 8.4.2.2.14 P95% Road incline [%], distance based
- 8.4.2.2.15 Positive altitude gain [m/100km]
- 8.4.2.2.16 Average ambient temperature [K]
- 8.4.2.2.17 Average ambient pressure [kPa]

Appendix 9: 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 attachment to this Certificate are in compliance with the provisions of section 2.1 of Annex IIIA or Regulation (EC) 692/2008 relating to real driving emissions.

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

On [.....(Date)]

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

Annex:

- List of vehicle types to which this certificate applies