Attachment 119 to the Announcement that Prescribes Details of Safety Regulations for Road Vehicles (Ministry of Land, Infrastructure, Transport and Tourism Announcement No. 619 of July 15, 2002)

TECHNICAL STANDARD FOR ON-ROAD EXHAUST EMISSIONS OF DIESEL-POWERED LIGHT- AND MEDIUM-DUTY MOTOR VEHICLES

1. Scope

This Technical Standard shall apply to measurements of emission amount and verifications of the said emission generated at the time when diesel-powered ordinary-sized motor vehicles and small-sized motor vehicles with a gross vehicle weight of 3.5 tons or less or used exclusively for carriage of passengers with a passenger capacity of 9 persons or less are driven on road or on test road and emitted from the exhaust pipe to the atmosphere (hereinafter referred to as the "emission").

2. Definitions and Abbreviations

2–1 Definition

The definitions of terms used in this Technical Standard shall be as the following.

2–1–1 "Accuracy" means the deviation between a measured or calculated value and the traceable reference value.

2–1–2 "Axis intercept" of a linear regression line (a_0) shall be calculated by the following equation:

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

where:

a_1: Slope of linear regression line

$\bar{x}$: Mean value of reference parameter

$\bar{y}$: Mean value of parameter to be verified

2–1–3 "Coefficient of determination" (r^2) shall be calculated by the following equation:

$$r^2 = 1 - \frac{\sum_{i=1}^{n}[y_i - a_0 - (a_1 \times x_i)]^2}{\sum_{i=1}^{n}(y_1 - y)^2}$$

where:

a_0: Axis intercept of linear regression line

a_1: Slope of linear regression line

x_i: Measured reference value

y_i: Measured value of parameter to be verified

$\bar{y}$: Mean value of parameter to be verified

n: Number of values

2–1–4 "Cross correlation coefficient" (r) shall be calculated by the following equation:

$$\mathrm{r} = \frac{\sum_{i=1}^{n-1}(x_i - \bar{x}) \times (y_1 - \bar{y})}{\sqrt{\sum_{i=1}^{n-1}(x_i - \bar{x})^2 \times \sqrt{\sum_{i=1}^{n-1}(y_1 - \bar{y})^2}}}$$

where:

x_i: Measured reference value

y_i: Measured value of parameter to be verified

$\bar{x}$: Mean value of reference parameter

$\bar{y}$: Mean value of parameter to be verified

n: Number of values

2–1–5 "Delay time" means the time from the gas flow switching (t_0) until the response reaches 10% (t_{10}) of the final reading.

2–1–6 "ECU signal" or "ECU data" means any signal or information recorded from the on-board network using protocol specified in Paragraph 3–4–5 of Attached Sheet 1.

2–1–7 "ECU" means the electronic unit that controls various actuators to ensure the optimal performance of the power train.

2–1–8 "Major maintenance" means the adjustment, repair or replacement of an analyzer, flow-measuring instrument or sensor that could affect the accuracy of measurements.

2–1–9 "Noise" means two times the effective value of 10 standard deviations, each calculated from the zero response measured at a constant recording frequency of at least 1.0 Hz dover a period of 30 seconds.

2–1–10 "Precision" means 2.5 times the standard deviation of 10 repetitive responses to a given traceable standard value.

2–1–11 "Response time" (t_{90}) means the sum of the delay time and the rise time.

2–1–12 "Rise time" means the time between 10% and 90% response ($t_{90} – t_{10}$) of the final reading.

2–1–13 "Effective value" (x_{rms}) means the square root of arithmetic mean of the squares of values and calculated by the following equation.

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

where:

x: Measured value or calculation value

n: Number of values

2–1–14 "Sensor" means any measurement device that is not part of the motor vehicle and installed to determine parameters other than the concentration of emissions and exhaust mass flow.

2–1–15 "Span calibration" means the calibration of an instrument so that it gives a proper response to a calibration standard that represents between 75% and 100% of the maximum value in the instrument range or expected range of use.

2–1–16 "Span response" means the mean response to a span signal over a period of at least 30 seconds.

2–1–17 “Span response drift” means the difference between the mean response to a span signal and the actual span signal that is measured at a defined period after an analyzer, flow-measuring instrument or sensor was accurately spanned.

2–1–18 “Slope of linear regression line” (a_1) shall be calculated by the following equation:

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

where:

$\bar{x}$: Mean value of reference parameter

$\bar{y}$: Mean value of parameter to be verified

x_i: Measured reference value

y_i: Measured value of parameter to be verified

n: Number of values

2–1–19 “Standard error of estimate” (SEE) shall be calculated by the following equation:

$$SEE - \frac{1}{x_{max}} = \sqrt{\frac{\sum_{i=1}^{n}(y_1-\acute{y})^2}{(n-2)}}$$

where:

$\acute{y}$: Estimated value of parameter to be verified

y_i: Measured value of parameter to be verified

x_{max}: Maximum measured value of reference parameter

n: Number of values

2–1–20 “Traceable” means a characteristic to relate a measurement or reading through an unbroken chain of comparisons to a known and commonly agreed standard,.

2–1–21 “Transformation time” means the time between the start of a change of concentration or flow (t_0) at the reference point and a system response of 50% of the final reading (t_{50}).

2–1–22 “Type of analyzer” means a group of analyzers produced by the same manufacturer that apply an identical principle to determine the concentration of one specific gaseous component.

2–1–23 “Type of exhaust mass flow meter” means a group of exhaust mass flow meters produced by the same manufacturer that share a similar tube inner diameter and function based on an identical principle to determine the mass flow rate of the exhaust gas.

2–1–24 “Validation” means the process of evaluating the correct installation and functionality of a Portable Emission Measurement System and the correctness of exhaust mass flow rate measurements as obtained from one or multiple non-traceable exhaust mass flow meters or as calculated from sensors or ECU signals.

2–1–25 “Verification” means the process of evaluating whether the results of measurement or calculation of an analyzer, flow-measuring instrument, sensor or signal agree with a reference signal within one or more predetermined thresholds for pass/fail evaluation.

2–1–26 “Zero calibration” means the calibration of an analyzer, flow-measuring instrument and sensor so that it gives an accurate response to a zero signal.

2–1–27 “Zero response” means the mean response to a zero signal over a period of at least 30 seconds.

2–1–28 “Zero response drift” means the difference between the mean response to a zero signal and the actual zero signal that is measured over a defined time period after an analyzer, flow-measuring instrument or sensor has been accurately zero calibrated.

2–1–29 “Hybrid electric vehicle” means a motor vehicle equipped with an internal combustion engine and an electric motor as prime movers as well as with a function to convert the kinetic energy of the motor vehicle concerned into the electric energy and to charge the electric storage device for driving the electric motor.

2–1–30 “Off-vehicle chargeable hybrid electric vehicle” means a hybrid electric vehicle that can be charged from an external source.

2–1–31 “Not off-vehicle chargeable hybrid electric vehicle” means a hybrid electric vehicle that cannot be charged from an external source.

2–1–32 “Unladen mass” means the mass of a motor vehicle in the unladen state with no passenger riding, including the mass of the fuel, coolant, lubricants, tools, coupling and the spare wheel(s) (limited to cases where they are fitted in accordance with the specifications of the motor vehicle manufacturer, etc. as the standard equipment) in accordance with the specifications of the motor vehicle manufacturer, etc. In this case, all fuel tanks shall be filled with fuel to at least 90% of their capacities.

2–1–33 “Optional equipment” means devices other than standard equipment which are fitted by the motor vehicle manufacturer, etc.

2–1–34 “Technically permissible maximum laden mass” means the maximum mass which is fully permissible on the basis of the construction, devices and performance of the motor vehicle, in terms of ensuring safety, preventing pollution and preserving the environment.

2–1–35 “Periodically regenerating system” means an exhaust emission control device that requires a periodical regeneration process to return the after-treatment devices, such as catalyst converter and DPF, to the initial state in less than 4,000 km of vehicle operation.

2–1–36 “General roads” mean those other than expressways, etc. among roads.

2–1–37 “Powertrain” means a mechanism comprising the engine, fuel system, peripheral devices, transmission and other devices necessary for the purpose of vehicle propulsion.

2–1–38 “Testing institute” means the National Agency for Automobile and Land Transport Technology.

2–2 Abbreviations

The abbreviations used in this Technical Standard shall be as prescribed in Attached Sheet 1 to Attached Sheet 8, in addition to those defined as follows.

CLD	Chemiluminescence Detector
CO	Carbon monoxide
CO_2	Carbon dioxide

CVS	Constant Volume Sampler
ECU	Engine Control Unit
EFM	Emission mass Flow Meter
GPS	Global Positioning System
H_2O	Water
HCLD	Heated Chemiluminescence Detector
MAW	Moving Average Window
N_2	Nitrogen
NDIR	Non-Dispersive Infrared analyzer
NDUV	Non-Dispersive Ultraviolet analyzer
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides
NTE	Not-to-exceed
O_2	Oxygen
OBD	On-Board Diagnosis system
PEMS	Portable Emissions Measurement System
RPA	Relative Positive Acceleration
SCR	Selective Catalytic Reduction
SEE	Standard Error of Estimate

3. General Requirements

3–1 Not-to-exceed emission limit values

Throughout the normal life, the results of any possible on-road test performed in accordance with the requirements prescribed in this Technical Standard shall not be higher than the following not-to-exceed (NTE) emission limit values.

NTE emission limit value = CF $\times$ EL

where:

CF: Conformity factor

EL: Value applied to the motor vehicle concerned among the values relating to NOx enumerated in Paragraph 1 of Article 41 of the Details Announcement

3–1–1 Conformity factor

The value of CF in Paragraph 3–1 shall be 2.0.

3–2　The test conducted pursuant to this Technical Standard shall provide a presumption of conformity to the requirements prescribed in Paragraph 3–1.

3–3　The motor vehicle manufacturers, etc. shall, as requested by the testing institute, provide information for accessing ECU signals and shall also take necessary measures for conducting on-road tests, for example, by making available suitable adapters for exhaust pipes.

3–4　The integrated NOx emission in urban areas and rural areas determined pursuant to Attached Sheet 5 or the integrated NOx emission in low-speed and medium-speed running determined pursuant to Attached Sheet 8 as well as NOx emission in the entire running shall comply with the requirements in Paragraph 3–1.

3–5　For judgment of type designation, etc., the emission mass flow shall be determined by measurement equipment functioning independently from the test vehicle and no ECU data shall be used in this respect.

3–6　When the data quality check and validation results of an on-road test conducted according to Attached Sheets 1 and 4 are insufficient, the testing institute shall consider the said test to be void.

3–7　The emission reduction performance shall be demonstrated by on-road tests under normal running patterns, conditions and loading capacity. The said test shall be representative for actual operation on the running routes under their normal load.

3–8　The test shall be conducted on road or test road. If the test is conducted on the road, the running of the said test shall include running on general roads and expressways, etc.

Furthermore, the test vehicle may be adjusted in a location other than the road or test road. However, the running from this location to the road or test road shall be kept to minimum. The said running shall be included in the running of the test.

3–9　The collection of ECU data shall not affect the emission amount or performance of the motor vehicle concerned.

4.　Special Requirements

4–1　Test on the test road

4–1–1　Conducting the test on the test road

The test conducted on the test road may be selected instead of conducting the test on the road. In this case, testing on the test road means that all the running for emission measurements is to be conducted on the test road.

4–1–2 Driving method on the test road

The driving of the test vehicle on the test road shall be conducted, using the running pattern of time and speed based on the actual running on the road as the target. The deviation from the target running pattern shall be avoided. In cases where the deviated condition is deemed to have continued for a long time, the test may be voided by the testing institute.

5. Test Conditions

5–1 Weight at the time of test

5–1–1 A driver and a witness of the test (limited only to cases where the testing institute has deemed necessary) shall be riding the test vehicle and test equipment (including the mounting and the power supply system) shall be installed.

5–1–2 Some artificial weight may be added to the test vehicle in addition to those provided for in Paragraph 5–1–1. However, the final weight of the test vehicle including the weight of the driver, the witness of the test and test equipment as well as the artificially added weight shall not exceed the maximum weight at the time of test in the following equation.

$$W_{max} = W_{vehicle} + 75 + (W_M - W_{vehicle} - 75) \times 0.9$$

where:

W_{max}: Maximum weight at the time of test

$W_{vehicle}$: The weight where the weight of optional equipment was added to the weight under the unloaded state. (It shall be equal to the weight where tools, coupling device and spare tyres prescribed as standard equipment by the manufacturer, etc. are loaded on the unloaded state and where the fuel is reduced to 90% of the fuel tank full capacity.)

W_M: Weight equivalent to technically permissible maximum laden mass

5–2 Ambient conditions

5–2–1 The test shall be conducted under the ambient conditions enumerated below. The ambient conditions become extended when at least one of temperature and altitude conditions is extended.

In cases where part or the entire test was conducted outside the general conditions and extended conditions and had not satisfied the requirements prescribed in Paragraph 3–1, the test shall be voided. In cases where part or the entire test was conducted outside the general conditions and extended conditions and had satisfied the requirements prescribed in Paragraph 3–1, the test may be valid, but it also may be voided at the request of the motor vehicle manufacturer, etc. In this case, with regard to the temperature condition, the test shall be regarded as having been conducted outside the general conditions and extended conditions if the moving average of the ambient temperature of the test vehicle at every minute that is measured during the test is outside the range of the general conditions and extended conditions.

5–2–2 General altitude condition: lower than or equal to 700 above sea level

5–2–3 Extended altitude condition: higher than 700 m above sea level, but lower than or equal to 1000 m above sea level

5–2–4 General temperature condition: above or equal to 273.15K (0℃), but lower than or equal to 308.15K (35℃)

5–2–5 Extended temperature condition: above or equal to 271.15K (-2℃), but lower than 273.15K (0℃) or above 308.15K (35℃), but lower than or equal to 311.15K (38℃)

5–3 Preconditioning and soaking the test vehicle

The test vehicle shall be driven at least for 30 minutes before the test, be parked with the doors and bonnet closed and be soaked with the engine in a stopped condition for 6 to 56 hours at the altitude and temperature of the general or expanded conditions pursuant to Paragraphs 5–2–2 and 5–2–5. In this case, exposure to extreme atmospheric environment such as heavy snow, storm, hail, etc. or excess dust shall be avoided. The damage on the test vehicle and equipment shall be verified before the start of the test and it shall be confirmed that no warning signal indicating malfunction exists.

5–4 Dynamic conditions

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

5–4–1 The overall excess and deficiency of the dynamic condition during running shall be verified in accordance with the method prescribed in Attached Sheet 6.

5–4–2 If the running was valid in the verification of the preceding Paragraph, the methods for verifying the normality of the dynamic conditions prescribed in Attached Sheets 5, 6 and 7 shall be applied. However, the validity of the run and normality of testing condition for off-vehicle chargeable hybrid electric vehicles shall be verified according to Attached Sheet 8, in place of Attached Sheet 5.

5–5 Test vehicle condition and operation

5–5–1 Auxiliary systems

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

5–5–2 Motor vehicles equipped with periodically regenerating system

5–5–2–1 The test results of motor vehicles equipped with periodically regenerating system shall be corrected using Ki factor or Ki offset determined in Attached Sheet 6 Appendix to Part II of Attachment 42 “Measurement Procedure for Exhaust Emissions of Light- and Medium-Duty Motor Vehicles” (hereinafter simply referred to as “Attachment 42”).

5–5–2–2 If the emission does not satisfy the requirement of Paragraph 3–1, the occurrence of regeneration shall be verified by cross correlation between the measurement of emission temperature, carbon dioxide (CO_2), oxygen (O_2) and the speed and acceleration of the test vehicle.

If regeneration had occurred during the test, it shall be confirmed whether the result which does not apply Ki factor or Ki offset satisfy the requirement of Paragraph 3–1. In cases where the emission result does not satisfy the requirement, the test shall be voided and be repeated one more time, at the request of the motor vehicle manufacturer, etc. In this case, the motor vehicle manufacturer, etc. may complete regeneration. The test will be regarded as valid, even if regeneration occurs in the second test.

5–5–2–3 At the request of the motor vehicle manufacturer, etc., the confirmation of occurrence of regeneration prescribed in Paragraph 5–5–2–2 may be conducted even when the requirement in Paragraph 3–1 was satisfied. In cases where whether regeneration had occurred is confirmed and it is agreed by the testing institute, the final result may be shown without applying Ki factor or Ki offset.

5–5–2–4 The motor vehicle manufacturer, etc. shall without fail complete regeneration and appropriately precondition the test vehicle prior to the second test.

5–5–2–5 If regeneration occurs during the retest, the emission mass during the retest shall be included in the emission evaluation.

6. Running requirement

6–1 The instantaneous speed of the run shall be classified into low-speed, medium-speed and high-speed pursuant to the provisions of Paragraphs 6–3 to 6–5 and their shares shall be expressed as a percentage of the total running distance, respectively.

6–2 When the test is conducted on the road, the sequence of the run shall consist of the general road followed by the expressways, etc. However, it is permitted to drive on the general road after the run on expressways, etc. in order to move to a place where the vehicle can be parked,

6–3 The run at a speed of 40 km/h or less shall be classified as low-speed.

6–4 The run at a speed exceeding 40 km/h, but 60 km/h or less shall be classified as medium-speed.

6–5 The run at a speed exceeding 60 km/h shall be classified as high-speed.

6–6 The run shall consist of, proportionate to the distance, approximately 25% of low-speed running, approximately 30% of medium-speed running and approximately 45% of high-speed running. In this case “approximately” shall mean a range of ±10. However, the low-speed run shall not be less than 20%.

6–7 The run at a speed of 20 km/h or less shall not continue uninterruptedly for more than 20 minutes. If this is exceeded, the test shall be voided.

6–8 Stop periods, defined as a speed of less than 1 km/h, shall account for 7% to 36% of the duration of low-speed running. The low-speed running shall contain several stop periods of 10 seconds or longer. However, each stop period shall not exceed 300 seconds without interruption. If it is exceeded, the test shall be voided.

6–9 The high-speed running shall include 20 % or more, proportionate to the time, of operation at 80 km/h or more. If this is not satisfied, the test shall be voided.

6–10 The running duration time shall be between 90 minutes to 120 minutes.

6–11 The start point and end point shall not differ in their elevation above sea level by more than 100 m.

Also, the proportionally positive cumulative difference in altitude shall be less than 1200 m/100 km in the entire run as well as low-speed and medium-speed running, which shall be calculated according to Attached Sheet 7. However, this provision shall not apply when the test is conducted on the test road and the positive cumulative difference in altitude is known.

6–12 The average speed (including stops) during cold start defined in Paragraph 4. of Attached Sheet 4 shall be between 15 km/h and 40 km/h. The maximum speed during cold start shall not exceed 60 km/h.

7. Driving requirement

7–1 Running route shall be selected and the test shall be run in such a way that the test is uninterrupted and the data is continuously recorded from the beginning of the test until the minimum running duration time defined in Paragraph 6–10 is reached.

7–2 Electric power shall not be supplied to the PEMS directly or indirectly from the engine of the test vehicle.

7–3 The installation of the PEMS equipment shall be done in such a way to influence the emissions mass and running performance to the minimum extent possible, while exercising care to minimize the possible change in aerodynamics to the test vehicle.

7–4 The test shall be conducted on a paved road.

7–5 The idling time of the engine (except electric motors) after the first ignition at the start of the test shall be kept to a minimum, and it shall not exceed 15 seconds. The stop time during cold start prescribed in Paragraph 4. of Attached Sheet 4 shall be kept to a minimum, and the cumulative time shall not exceed 90 seconds. If the engine stalls during the test, the engine may be restarted, but the sampling shall not be interrupted.

8. Lubricating oil, fuel and reagent

8–1 The fuel used in the test shall meet the standard prescribed in Article 3 of the Details Announcement. Also, the lubricating oil and reagent (limited only to cases where they are used) specified by the motor vehicle manufacturer, etc. shall be used.

8–2 The motor vehicle manufacturer, etc. shall submit to the testing institute a document describing the property of fuel, lubricating oil and reagent (limited only to cases where they are used).

9. Emission amount of exhaust emission and evaluation of running

9–1 The test shall be conducted in accordance with Attached Sheet 1.

9–2 The running shall fulfill the requirements prescribed in Paragraphs 3–7 to 8.

9–3 It shall not be permitted to combine data of different running or to modify or remove data based on the running.

9–4 After establishing the validity of the test according to Paragraph 9–2, the emission amount of the exhaust emission shall be calculated using the methods prescribed in Attached Sheet 5 (Attached Sheet 8 for off-vehicle chargeable hybrid electric vehicles).

9–5 If during a particular time interval the ambient conditions are extended according to Paragraph 5–2, the NOx emission during this particular time interval calculated according to Attached Sheet 4 shall be divided by the correction coefficient 1.6, then the compliance with the requirements in this Attachment shall be evaluated. Even when multiple ambient conditions were extended, the correction coefficient shall be applied only once.

9–6 If the test vehicle was soaked under a condition where the average ambient temperature during at least 3 hours before the test start is within the range of the extended conditions prescribed in Paragraph 5–2, the NOx emission during a period where the ambient conditions are not extended shall be divided by 1.6 for cold start period prescribed in Paragraph 4. of Attached Sheet 4. Even when multiple ambient conditions were extended, the correction coefficient shall be applied only once.

Attached Sheet 1

TEST PROCEDURE FOR EXHAUST EMISSION WITH PEMS

1. This Attached Sheet prescribes the procedure for measuring exhaust emission of a test vehicle using PEMS.

2. Symbols

#	Number
p_e	Vacuum pressure [kPa]
q_{VS}	Volume flow rate of system [1/min]
ppm	Parts per million
rpm	Revolutions per minute
V_s	System volume [l]

3. General Requirements

3–1 PEMS

The test shall be conducted with a PEMS composed of devices prescribed in Paragraphs 3–1–1 to 3–1–5. In this case, the PEMS and the ECU may be connected in order to determine engine and vehicle parameters shown in Paragraph 3–2.

3–1–1 Analyzers for measuring NOx and CO_2 concentration in exhaust gas.

3–1–2 One or multiple instruments or sensors to measure or determine the exhaust mass flow.

3–1–3 GPS to determine the position, altitude and speed of the test vehicle.

3–1–4 Sensors and other appliances being not part of the vehicle, to measure ambient temperature, relative humidity, atmospheric pressure and speed.

3–1–5 Power unit independent of the test vehicle to supply power to the PEMS.

3–2 Measurement parameters

The parameters enumerated in Table 1 shall be measured and recorded at a constant frequency of 1.0 Hz or higher. If ECU parameters are obtained, these shall be made available at a substantially higher frequency than the parameters recorded by PEMS to ensure accurate sampling. The PEMS analyzers, flow-measuring instruments and sensors shall comply with the requirements prescribed in Attached Sheet 2 and Attached Sheet 3.

The testing institute may designate additional parameters for measurement, as required, in addition to the parameters enumerated in Table 1.

Table 1 Measurement parameters

Parameter	Units	Measuring equipment, etc. (7)
CO_2 concentration (1)	ppm	Analyzer
CO concentration (1) (2)	ppm	Analyzer
NOx concentration (1) (3)	ppm	Analyzer
Exhaust mass flow rate	kg/s	EFM or any method explained in Paragraph 6. of Attached Sheet 2
Ambient humidity	%	Hygrometer
Ambient temperature	K or ℃	Thermometer
Ambient pressure	kPa	Barometer
Speed	km/h	Speedometer, GPS or ECU
Latitude	degrees	GPS
Longitude	degrees	GPS
Altitude (4)	m	GPS
Engine coolant temperature (6)	K or ℃	Measuring equipment or ECU
Engine speed	rpm	Measuring equipment or ECU
Fault status	-	ECU
DPF regeneration status	-	ECU
Actual gear (5)	#	ECU
Desired gear (5)	#	ECU
Exhaust gas temperature (6)	K or ℃	Sensor
Engine torque (6)	Nm	Sensor or ECU
Pedal position (6)	%	Sensor or ECU
Engine intake air temperature (6)	K or ℃	Sensor or ECU
Engine oil temperature (6)	K or ℃	Sensor or ECU

(1) This shall either be measured on wet basis or be corrected by the method prescribed in Paragraph 8–1 of Attached Sheet 4.

(2) Limited only to cases where it is necessary for exhaust mass flow calculation.

(3) This may be calculated from the measured values of NO and NO_2 concentration.

(4) Measured values from barometer may be used for correction only when the method is deemed appropriate by the testing institute.

(5) For motor vehicles with a manual transmission or a device to indicate to the driver the recommended gear, limited only to cases where the test is conducted using these devices.

(6) This shall be measured only when it is necessary for verification of the test vehicle status and operating conditions.

(7) Multiple measuring equipment, etc. may be used.

3–3 Preparation of test vehicle

The inspection enumerated in Attached Table 2 of the Motor Vehicle Checking Standards (Ministry of Transport Ordinance No. 70 of 1951) and necessary maintenance shall be conducted on the test vehicle.

3–4 Installation of PEMS

3–4–1 General requirements

The installation of the PEMS shall follow the method prescribed by the PEMS manufacturer, and the PEMS shall be installed as to minimize the effect of electromagnetic waves 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 tail pipe. To avoid the generation of particles, connectors shall be thermally stable at the exhaust gas temperature expected during the test. It is recommended not to use elastomer connectors to connect the vehicle exhaust pipe and the connecting tube. If an elastomer connector must be used, it shall not be in direct contact with the exhaust gas.

3–4–2 Permissible back-pressure

The installation and operation of the PEMS sampling probe shall not unduly increase the static pressure at the exhaust outlet by such method that would affect the representability of the measurement. Therefore, it is desirable to install only one sampling probe on the same plane. If technically feasible, any extension to facilitate the sampling or the connection with the EFM shall have an equivalent, or larger, cross-section area than the exhaust pipe. In cases where the sampling probe blocks a significant area of the cross-section area of the exhaust pipe, the testing institute may request back-pressure measurements.

3–4–3 EFM

When EFM is used, it shall be installed on the exhaust pipe of the test vehicle 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 the installation of any exhaust pipe adapter or junction shall not adversely affect the operation of the engine or exhaust after-treatment system, and a minimum of four pipe diameters or 150 mm of straight tubing, whichever is larger, shall be placed in front and behind the flow-sensing element. When testing motor vehicles equipped with a multi-cylinder engine with a branched exhaust manifold, the EFM shall be located downstream of the manifold joint and the cross-section of the piping shall be increased to have the same or greater cross-section area than the sampling section to the extent possible. If this is not feasible, exhaust flow measurements may be done with several EFM, with the approval of the testing institute. An EFM with a diameter smaller than that of the exhaust outlet or smaller than the total cross-sectional area of multiple outlets may be installed as long as the installation improves the measurement accuracy and does not adversely affect the operation or after-treatment system prescribed in Paragraph 3–4–2. In this case, the testing institute may request the motor vehicle manufacturer, etc. to submit a document including a photograph showing the installation condition of the EFM.

3–4–4 Global positioning system (GPS)

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

3–4–5 Connection with ECU

The parameters of the test vehicle and engine prescribed in Paragraph 3–2 may be recorded by using a data logger, as required. The data logger used shall be connected with the ECU or the on-board network in accordance with ISO 15031-5 or SAE J1979 or other standards. In this case, the motor vehicle manufacturer, etc. shall disclose to the testing institute parameter labels to allow the identification of required parameters.

3–4–6 Sensors and auxiliary devices

Speed sensors, temperature sensors, thermocouples for measuring coolant temperature and other optional measurement devices not part of the test vehicle shall be installed to measure the applicable parameters in a representative, reliable and accurate manner without unduly interfering with the operation of the test vehicle as well as the functioning of other analyzers, flow-measuring instruments, sensors and signals. In this case, the sensors and auxiliary devices shall be powered independently of the test vehicle.

However, power may be supplied from the battery of the test vehicle to the safety lamps equipped in cases where various devices of the PEMS are installed outside the test vehicle compartment.

3–5 Emission sampling

Emission sampling shall be representative and conducted at locations where exhaust gas is well mixed and the influence of the downstream ambient air is minimal. In this case, emissions shall be sampled downstream of the EFM and at a distance of at least 150 mm away from the flow sensing element. The sampling probes shall be fitted at least 200 mm or 3 times the diameter of the exhaust pipe, whichever is larger, upstream of the point where the exhaust exits the PEMS sampling system and discharged to the atmosphere. In cases where emission is returned from the PEMS to the exhaust 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. If the length of sample line is changed, the system transport time shall be verified and if necessary corrected.

If the engine is equipped with an exhaust after-treatment system, the exhaust sample shall be taken downstream of the said exhaust after-treatment system. At When testing a motor vehicle equipped with a multi-cylinder engine and branched exhaust manifold, the inlet of the sampling probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "V" engine configuration, the sampling probe shall be placed downstream of the manifold joint. If this is not technically feasible, multipoint sampling may be conducted at multiple locations where exhaust is well mixed, with the approval of the testing institute. In this case, the number and location of sampling probes shall match as far as possible the number and location of the EFM. In case of unequal exhaust flows, proportional sampling or sampling with multiple analyzers shall be considered and the most appropriate method shall be selected.

4. Pre-test procedures

4–1 PEMS leak check

After the completion of PEMS installation, a leak check shall be performed at least once for each PEMS installation as prescribed by the PEMS manufacturer or by the following procedure. The probe shall be disconnected from the exhaust system and the end plugged. Then, the analyzer pump shall be switched on. If all flowmeter readings are approximately zero after activation of the pump and after a sufficient period to stabilize the operation, it shall be judged that there is no leak. If the reading clearly does not indicate approximately zero, the sampling lines shall be checked and the leak repaired.

The leakage amount on the vacuum side shall not exceed 0.5% of the flow rate used for leak check. In this case, the analyzer flows and by-pass flows may be used to estimate the in-use flor rates.

As an alternative method to leak check, the system may be vacuumed to a pressure of at least 20 kPa vacuum (absolute pressure of 80 kPa) and confirm that the pressure increase Δp (kPa/min) in the system does not exceed the value in the following formula after the initial stabilization period:

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

Alternatively, there is a method to introduce a concentration step change at the beginning of the sampling line by switching from zero gas to span gas while maintaining the same pressure conditions as under normal system operation. The leak shall be repaired if the reading by an accurately calibrated analyzer after an adequate period of time is 99% or below the introduced concentration.

4–2 Start-up and stabilization of PEMS

The PEMS shall be switched on and warmed up before the start of the test and be stabilized according to the specifications of the PEMS manufacturer until main parameters (for example, pressure, temperature and flow) reach their respective operating set points. In order to guarantee accuracy, the PEMS may be left switched on while preconditioning the test vehicle or be warmed up to stabilize. The system shall not exhibit any error or serious warning.

4–3 Preparation of sampling system

The sampling system consisting of the sampling probe and sampling lines shall be prepared for the test according to the method prescribed by the PEMS manufacturer. It shall be ensured that the sampling system is clean and free of moisture condensation.

4–4 Preparation of 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. In this case, this procedure shall remove condensation and deposits from the applicable lines and associated measurement ports.

4–5 Check and calibration of analyzer for measuring emissions

The zero and span calibration of the analyzers shall be performed using calibration gases that meet the requirements in Paragraph 5. of Attached Sheet 2. The calibration gases shall be chosen to match the range of emission concentrations expected during the test.

In order to minimize analyzer drift, the zero and span calibration of the analyzer shall be performed at an ambient temperature that is as close as possible to the temperature that the measurement instrument will be exposed during the test.

4–6 Measurement of test vehicle speed

The test vehicle speed shall be determined by at least one of the following methods:

(a) GPS: If the speed is determined by a GPS, the total running distance shall be checked against the measured value by another method according to Paragraph 7. of Attached Sheet 4.

(b) Sensor (optical sensor, microwave sensor, etc.): If the speed is determined by a sensor, the measured speed shall comply with the requirements in Paragraph 7. of Attached Sheet 2. Alternatively, the total running distance determined by the sensor shall be compared with a reference distance obtained from a digital road network or topographic map. The total running distance determined by the sensor shall deviate by no more than 4% from the reference distance.

(c) ECU: If the speed is determined by the ECU, the total running distance shall be validated according to Paragraph 3. of Attached Sheet 3 and the ECU speed signal shall be adjusted, if necessary to fulfill the requirements in Paragraph 3–3 of Attached Sheet 3. Alternatively, the total running distance determined by the ECU shall be compared with a reference distance obtained from a digital road network or topographic map. The total running distance determined by the ECU shall deviate no more than 4% from the reference distance.

4–7 Check of PEMS set-up

The correctness of connections with all sensors, including connections with the ECU of the test vehicle, shall be verified. If engine parameters are retrieved, it shall be ensured that the ECU outputs values correctly. The PEMS shall function free of errors and serious warnings.

5. Emissions Test

5–1 Test start

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

5–2 Test

Sampling, measurement and recording of parameters shall continue throughout the emissions test. The engine may be stopped and started during the test, but emissions sampling and parameter recording shall continue. Any warning signals, suggesting malfunctioning of the PEMS, shall be documented and verified. If any error signal(s) appear during the test, the test shall be voided.

Parameter recording shall reach a data completeness of higher than 99%. Measurement and data recording may be interrupted for less than 1% of the total trip duration but for no more than a consecutive period of 30 seconds solely in the case of unintended signal loss or for the purpose of PEMS system maintenance. Interruptions may be recorded directly by the PEMS but it is not permissible to introduce interruptions in the recorded parameter via the pre-processing, exchange or post-processing of data. If conducted, auto zeroing shall be performed against a traceable zero standard similar to the one used to zero the analyzer. It is strongly recommended to initiate PEMS system maintenance during periods when the test vehicle is stopped.

5–3 Test end

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

6. Post-Test Procedure

6–1 Checking analyzers for measuring emissions

The zero and span of the analyzers of gaseous components shall be checked by using calibration gases identical to the ones used in Paragraph 4–5 to evaluate the analyzer response drift compared to the pre-test calibration. It is permissible to zero the analyzer prior to verifying the span drift, if the zero drift was determined to be within the permissible range. The post-test drift check shall be completed as soon as possible after the test and before the PEMS, or individual analyzers or sensors, are turned off or have switched into a non-operating mode. The difference between the pre-test and post-test results in the zero drift and span drift shall comply with the requirements specified in Table 2.

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

Table 2 Permissible analyzer drift range after PEMS test (per test)

Emission components	Absolute zero response drift	Absolute span response drift (1)
CO_2	≤ 2000 ppm	≤ 2% of reading or ≤ 2000 ppm, whichever is larger
CO (2)	≤ 75 ppm	≤ 2% of reading or ≤ 75 ppm, whichever is larger
NOx	≤ 5 ppm	≤ 2% of reading or ≤ 5 ppm, whichever is larger

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

(2) Limited only to cases where it is necessary for the calculation of the emission mass flowrate.

6–2 Checking emission measurements

The calibrated range of the analyzers 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 exceeds the calibrated range of the analyzers by up to a factor of two. If these requirements are not met, the test shall be voided.

Attached Sheet 2

SPECIFICATIONS AND CALIBRATION OF PEMS AND SIGNALS

1. This Attached Sheet sets out the specifications and calibration of PEMS and signals.

2. Symbols

A	Undiluted CO_2 concentration [%]
a_0	y-axis intercept of the linear regression line
a_1	Slope of the linear regression line
B	Diluted CO_2 concentration [%]
C	Diluted NO concentration [ppm]
D	Undiluted NO concentration [ppm]
D_e	Expected diluted NO concentration [ppm]
E	Absolute operating pressure [kPa]
E_{CO2}	Percent CO_2 quench
E_{H2O}	Percent water quench
F	Water temperature [K]
G	Saturation vapour pressure [kPa]
gH_2O/kg	Gram water per kilogram [g]
H	Water vapour concentration [%]
H_m	Maximum water vapour concentration [%]
$NOx_{,dry}$	Moisture-corrected mean concentration of the stabilized NOx recordings
$NOx_{,m}$	Mean concentration of the stabilized NOx recordings
$NOx_{,ref}$	Reference mean concentration of the stabilized NOx recordings
ppm	Parts per million
r^2	Coefficient of determination
t_0	Time point of gas flow switching [s]
t_{10}	Time point of 10% response of the final reading
t_{50}	Time point of 50% response of the final reading
t_{90}	Time point of 90% response of the final reading
x	Independent variable or reference value
X_{min}	Minimum value
y	Dependent variable or measured value

3. Linearity Verification

3–1 General Requirements

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

3–2 Linearity requirements

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

Table 1: Linearity requirements of measurement parameters and systems

Measurement parameters / instrument	$\lvert X_{min} \times (a_1 - 1) + a_0 \rvert$	Slope a_1	Standard error of estimate SEE	Coefficient of determination r^2
Fuel flow rate (1)	max ≤ 1%	0.98 – 1.02	max ≤ 2%	≥ 0.990
Air flow rate (1)	max ≤ 1%	0.98 – 1.02	max ≤ 2%	≥ 0.990
Exhaust mass flow rate	max ≤ 2%	0.97 – 1.03	max ≤ 3%	≥ 0.990
Gas analyzers	max ≤ 0.5%	0.99 – 1.01	max ≤ 1%	≥ 0.998
Torque (2)	max ≤ 1%	0.98 – 1.02	max ≤ 2%	≥ 0.990

(1) Optional parameter to determine exhaust mass flow

(2) Optional parameter

3–3 Frequency of linearity verification

The linearity requirements shall be verified according to Paragraph 3–2:

The verification for sensors or ECU signals that are not directly traceable shall be performed once for each PEMS set-up on the test vehicle with a traceably calibrated measurement device on the chassis dynamometer.

(a) For each analyzer, it shall be conducted at least once every 12 months or whenever a system repair or replacement of parts is made that could influence the calibration;

(b) For other relevant instruments, such as the EFM and calibrated sensors, the linearity shall be verified whenever damage is observed and repairs are performed, as required by internal audit procedures or by the instrument manufacturer. However, if no verification has been conducted for the linearity for one year before the test, it shall be conducted before the test.

3–4 Procedure of linearity verification

3–4–1 General requirements

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

3–4–2 General procedure

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

(a) The analyzer, flow-measuring instrument or sensor shall be set at zero by introducing a zero signal. For gas analyzers, purified synthetic air or nitrogen shall be introduced to the analyzer port via a gas path that is as direct and short as possible.

(b) The analyzer, flow-measuring instrument or sensor shall be spanned by introducing a span signal. For gas analyzers, an appropriate span gas shall be introduced to the analyzer 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 analyzers, known gas concentrations in accordance with Paragraph 5. shall be introduced to the analyzer port. Sufficient time for signal stabilization 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-second period shall be used to calculate the least squares linear regression parameters, using the following equation:

$$y = a_1 x + a_0$$

where:

y: Actual value of measurement system

a_1: Slope of regression line

x: Reference value

a_0: y intercept of regression line

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

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

3–4–3 Requirements for linearity verification on 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 Attached Sheet 6 of Part II of Attachment 42. If necessary, the instrument or sensor to be calibrated shall be installed on the test vehicle and operated according to the requirements of Attached Sheet 1. The calibration procedure shall follow whenever possible the requirements of Paragraph 3–4–2. At least 10 appropriate reference values shall be selected as to ensure that at least 90% 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 EFM or the CVS shall be attached to the exhaust pipe of the test vehicle.

Accurate measurement by the EFM according to Paragraph 3–4–3 of Attached Sheet 1 shall be ensured. The test vehicle shall be operated by applying constant throttle at a constant gear selection and chassis dynamometer load.

4. Analyzers for Measuring Gaseous Components

4–1 Permissible types of analyzers

The gaseous components shall be measured with analyzers specified in Paragraph 5–1–4 of Attached Sheet 5 of Part II of Attachment 42.

4–2 Analyzer specifications

4–2–1 General requirements

In addition to the linearity requirements defined for each analyzer in Paragraph 3., the compliance of analyzer types with the specifications laid down in Paragraphs 4–2–2 to 4–2–8 shall be demonstrated by the analyzer manufacturer. Analyzers shall have a measuring range and response time appropriate to measure with adequate accuracy the concentrations of the exhaust gas components under transient and steady state conditions. The sensitivity of the analyzers to shocks, vibration, aging, variability in temperature and air pressure as well as electromagnetic interferences and other impacts related to the vehicle and analyzer operation shall be limited as far as possible.

4–2–2 Accuracy

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

4–2–3 Precision

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

4–2–4 Noise

The noise, defined as two times the effective value 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 the full scale. Each of the 10 measurement periods shall be interspersed with an interval of 30 seconds in which the analyzer is exposed to an appropriate span gas. Before each sampling period and before each span period, sufficient time shall be given to purge the analyzer and the sampling lines.

4–2–5 Zero response drift

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

4–2–6 Span response drift

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

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

Emission components	Absolute zero response drift	Absolute span response drift
CO_2	≤ 1000 ppm over 4 hours	≤ 2% of reading or ≤ 1000 ppm over 4 hours, whichever is larger
CO	≤ 50 ppm over 4 hours	≤ 2% of reading or ≤ 50 ppm over 4 hours, whichever is larger
NOx	≤ 5 ppm over 4 hours	≤ 2% of reading or ≤ 5 ppm over 4 hours, whichever is larger

4–2–7 Rise time

Rise time is defined as the time between the 10% and 90% response of the final reading ($t_{90} – t_{10}$; see Paragraph 4–4.). The rise time of PEMS analyzers shall not exceed 3 seconds.

4–2–8 Gas drying

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

4–3 Additional requirements

4–3–1 General requirements

The provisions in Paragraphs 4–3–2 to 4–3–5 define additional performance requirements for specific analyzer types and apply only to cases in which the analyzer under consideration is used for PEMS emission measurements.

4–3–2 Efficiency test for NOx converters

If a NOx converter is applied to convert NO_2 into NO for analysis with a CLD, its efficiency shall comply with the provision of Paragraph 5–5 of Attached Sheet 5 of Part II of Attachment 42. The efficiency of the NOX converter shall be verified no longer than one month before the emissions test.

4–3–3 Interference effects

(a) General requirements

Analyzers shall be subjected to a check as to whether or not gases other than the ones being analyzed affect the analyzer reading and a check for the correct functionality of analyzers by the analyzer manufacturer at least once for each type of analyzer or device described in Items (b) to (f).

(b) CO analyzer interference check

A CO_2 span gas having a concentration of 80 to 100% of the full scale of the maximum operating range of the CO analyzer used during the test shall be bubbled through water at room temperature and the analyzer response recorded. The analyzer response shall not be more than 2% of the mean CO concentration expected during normal emission test or ±50 ppm, whichever is larger. The interference check for H_2O and CO_2 may be run as separate procedures. If the H_2O and CO_2 levels used for the interference check are higher than the maximum levels expected during the test, each observed interference value shall be scaled down by multiplying the observed interference with the ratio of the maximum expected concentration value during the test and the actual concentration value used during this check. Separate interference checks with concentrations of H_2O that are lower than the maximum concentration expected during the test may be run. At this time, the observed H_2O interference value shall be scaled up by multiplying the observed interference with the ratio of the maximum H_2O concentration value expected during the test and the actual concentration value used during this check. The sum of the two scaled interference values shall meet the tolerance specified in this Paragraph.

(c) NOx analyzer quench check

The quench at the highest concentrations expected during the test shall be determined as follows:

If the CLD and HCLD analyzers use quench compensation algorithms that utilize H_2O or CO_2 measurement analyzers or both, quench shall be evaluated with these analyzers active and with the compensation algorithms applied.

(i) CO_2 quench check

A CO_2 span gas having a concentration of 80 to 100% of the full scale of the maximum operating range shall be passed through the NDIR analyzer; the CO_2 value shall be recorded as A. The CO_2 span gas shall then be diluted by approximately 50% with NO span gas and passed through the NDIR and CLD or HCLD; the CO_2 and NO values shall be recorded as B and C, respectively. The CO_2 gas flow shall then be shut off and only the NO span gas shall be passed through the CLD or HCLD; the NO value shall be recorded as D. The quench shall be calculated as:

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

where:

A: Undiluted CO_2 concentration measured with NDIR [%]

B: Diluted CO_2 concentration measured with NDIR [%]

C: Diluted NO concentration measured with CLD or HCLD [ppm]

D: Undiluted NO concentration measured with CLD or HCLD [ppm]

Alternative methods of diluting and quantifying of CO_2 and NO span gas values, such as dynamic mixing and blending, are permitted upon approval of the testing institute.

(ii) Water quench check

The water quench check applies to measurements of wet gas concentrations only. The calculation of water quench shall consider dilution of the NO span gas with water vapour and the scaling of the water vapour concentration in the gas mixture to concentration levels that are expected to occur during an emissions test. A NO span gas having a concentration of 80% to 100% of the full scale of the normal operating range shall be passed through the CLD or HCLD; the NO value shall be recorded as D. The NO span gas shall then be bubbled through water at room temperature and passed through the CLD or HCLD; the NO value shall be recorded as C. The analyzer'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:

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

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

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

The maximum concentration of water vapour in the exhaust gas (%) expected during the test shall be recorded as H_m after being estimated, under the assumption of a fuel H/C ratio of 1.8/1, from the maximum CO_2 concentration in the exhaust gas A as follows:

$$H_m = 0.9 \times A$$

The per cent water quench shall be calculated as:

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

where:

D_e: Expected diluted NO concentration [ppm]

C: Measured diluted NO concentration [ppm]

H_m: Maximum water vapour concentration [%]

H: Actual water vapour concentration [%]

(iii) Maximum allowable quench

The combined CO_2 and water quench shall not exceed 2% of the full scale.

(d) Quench check for NDUV analyzers

The manufacturer of the NDUV analyzer shall use the following procedure to verify that quench effects are limited:

(i) The analyzer and chiller shall be set up by following the operating instructions of the manufacturer; adjustments should be made as to optimize the analyzer and chiller performance.

(ii) A zero calibration and span calibration at concentration values expected during the emissions test shall be performed for the analyzer.

(iii) A NO_2 calibration gas shall be selected that matches as far as possible the maximum NO_2 concentration expected during the emissions test.

(iv) The NO_2 calibration gas shall overflow at the gas sampling system's probe until the NOx response of the analyzer has stabilized.

(v) The mean concentration of the stabilized NOx recordings over a period of 30 seconds shall be calculated and recorded as $NOx_{,ref}$.

(vi) The flow of the NO_2 calibration gas shall be stopped and the sampling system saturated by overflowing with a dew point generator's output, set at a dew point of 50 °C. The dew point generator's output shall be sampled through the sampling system and chiller for at least 10 minutes until the chiller is expected to be removing a constant rate of water.

(vii) Upon completion of (iv), the sampling system shall again be overflown by the NO_2 calibration gas used to establish $NOx_{,ref}$ until the total NOx response has stabilized.

(viii) The mean concentration of the stabilized NOx recordings over a period of 30 seconds shall be calculated and recorded as $NOx_{,m}$.

(ix) $NOx_{,m}$ shall be corrected to $NOx_{,dry}$ based upon the residual water vapour that passed through the chiller at the chiller's outlet temperature and pressure.

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

(e) Sample dryer

For dry CLD analyzers, it shall be demonstrated that at the highest expected water vapour concentration H_m the sample dryer maintains the CLD absolute humidity at ≤ 5 g [water]/kg [air] (or about 0.8% H_2O). The highest water vapour concentration is 100% relative humidity at 3.9 °C and 101.3 kPa or about 25% relative humidity at 25 °C and 101.3 kPa. Compliance may be demonstrated by measuring the temperature at the outlet of a thermal sample dryer or by measuring the humidity at a point just upstream of the CLD. Compliance may be demonstrated by measuring the humidity of the CLD exhaust might as long as the only flow into the CLD is the flow from the sample dryer.

(f) Sample dryer NO_2 penetration

If a sample dryer is used in combination with an NDUV without an NO_2/NO converter upstream, the sample dryer shall allow for measuring at least 95% of the NO_2 contained in a gas that is saturated with water vapour and consists of the maximum NO_2 concentration expected to occur during a emissions test.

4–4 Response time check of analytical system

For the response time check, the settings shall be the same as during the emissions test, i.e. pressure, flow rates, filter settings of the analytical system and all other parameters influencing the response time. The gases used for the response time check shall cause a concentration change of at least 60% of the full scale of the analyzer. The response time shall be determined with gas switching directly in less than 0.1 second at the inlet of the sample probe. 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% of the final reading (t_{10}). The rise time is defined as the time between 10% and 90% 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 analyzer and exhaust flow signals, the transformation time is defined as the time from the change start point (t_0) until the response is 50% of the final reading (t50).

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

5. Gases

5–1 General requirements

The shelf life of calibration gas and span gas shall be respected. Calibration gas and span gas shall fulfil the specifications of Paragraph 6. of Attached Sheet 5 of Part II of Attachment 42. In addition, NO_2 calibration gas is permissible. The concentration of the NO_2 calibration gas shall be within 2% of the declared concentration value. The amount of NO contained in NO_2 calibration gas shall not exceed 5% of the NO_2 content.

5–2 Gas dividers

Gas dividers, i.e. precision blending devices that dilute with purified N_2 or synthetic air, can be used to obtain calibration gas and span gas. The accuracy of the gas divider shall be such that the concentration of the blended calibration gases is accurate to within ±2%. The verification shall be performed at between 15% and 50% of the 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% of the nominal concentration value.

6. Instruments for Measuring Exhaust Mass Flow Rate

6–1 General requirements

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.

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 (See ISO 5167.);

(c) Ultrasonic flow meter; and

(d) Vortex flow meter.

Each individual EFM shall fulfil the linearity requirements set out in Paragraph 3. Furthermore, the instrument manufacturer shall demonstrate the compliance of each type of EFM with the specifications in Paragraphs 6–2–3 to 6–2–9.

In addition to the direct measurement method above, 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 3. and the accuracy requirements of Paragraph 7. However, the resulting exhaust mass flow rate shall be validated according to Paragraph 4 of Attached Sheet 3.

In addition, the exhaust mass flow rate may be determined, based on directly traceable EFM and other instruments and signals. However, the resulting exhaust mass flow rate must fulfil the linearity requirements of Paragraph 3. and must be validated according to Paragraph 4. of Attached Sheet 3.

6–2–1 Calibration and verification standards

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

6–2–2 Frequency of verification

The compliance with the specifications prescribed in Paragraphs 6–2–3 and 6–2–9 shall be verified at least once no longer than one year before the actual test.

6–2–3 Accuracy

The accuracy, defined as the deviation of the EFM reading from the reference flow value, shall not exceed ±2% of the reading, 0.5% of the full scale or ±1.0% of the maximum flow at which the EFM has been calibrated, whichever is larger.

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% of the maximum flow at which the EFM has been calibrated.

6–2–5 Noise

The noise, defined as two times the effective value of 10 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 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.

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 primary signals, e.g. pressure. The drift of the primary signals over a period of 4 hours shall be less than ±2% of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

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 primary signals, e.g. pressure. The drift of the primary signals over a period of 4 hours shall be less than ±2% of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

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 analyzers as specified in Paragraph 4–2–7. However, the rise time shall not exceed 1 second.

6–2–9 Response time check

The response time of EFM shall be determined by applying parameters 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 EFM. The gas flow switching shall be done as fast as possible. The gas flow rate used for the test shall cause a flow rate change of at least 60% of the full scale of the EFM. 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% (t_{10}) of the final reading. The rise time is defined as the time between 10% and 90% 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 EFM response time (t_{90}) shall be ≤ 3 seconds with a rise time ($t_{90} - t_{10}$) of ≤ 1 second in accordance with Paragraph 6–2–8.

7. Sensors and Auxiliary Equipment

Any sensor and auxiliary equipment used to determine the temperature, atmospheric pressure, ambient humidity, speed, fuel flow or intake air flow and other parameters 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 3. Compliance with the requirements of Table 3 shall be demonstrated at intervals specified by the instrument manufacturer or at a point required by internal audit procedures or in accordance with ISO 9000.

Table 3 Accuracy requirements for measurement parameters

Measurement parameter	Accuracy
Fuel flow (1)	±1% of reading (3)
Air flow (1)	±2% of reading
Speed (2)	±1.0 km/h (absolute value)
Temperature ≤ 600K	±2K (absolute value)
Temperature > 600K	±0.4% of reading (K)
Ambient pressure	±0.2 kPa (absolute value)
Relative humidity	±5% (absolute value)
Absolute humidity reading	±10% or 1 gH_2O/kg dry air, whichever is larger

(1) Optional parameter to determine exhaust mass flow

(2) This general requirement applies to the speed sensor only. If the speed is used to determine parameters like acceleration, the product of speed and positive acceleration, or RPA, the speed signal shall have an accuracy of 0.1% above 3 km/h and a sampling frequency of 1 Hz. This accuracy requirement can be met by using the signal of a wheel rotational speed sensor.

(3) The accuracy shall be 0.02% of reading if used to calculate the air and exhaust mass flow rate from the fuel flow according to Paragraph 10. of Attached Sheet 4.

Attached Sheet 3

VALIDATION OF PEMS AND NON-TRACEABLE EXHAUST MASS FLOW RATE

1. This Attached Sheet describes the requirements to validate under transient conditions the functionality of the PEMS installed on the test vehicle as well as the correctness of the exhaust mass flow rate. For the purpose of this Attached Sheet, the exhaust mass flow rate refers to values obtained from non-traceable EFM or calculated from ECU signals.

2. Symbols

a_0	y intercept of the regression line
a_1	Slope of the regression line
r^2	Coefficient of determination
x	Actual value of the reference signal
y	Actual value of the signal under validation

3. Validation Procedure for PEMS

3–1 Frequency of PEMS validation

The installed PEMS shall be validated every time the PEMS is installed on the test vehicle either before or after the test. The PEMS installation shall be kept unchanged in the time period between the test and the validation.

3–2 PEMS validation procedure

3–2–1 PEMS installation

The PEMS shall be installed and prepared according to the requirements of Attached Sheet 1.

3–2–2 Conditions at time of validation

The validation test shall be conducted on a chassis dynamometer according to the provisions of Part II of Attachment 42. The ambient temperature shall be within the range specified in Paragraph 5–2 of this Attached Sheet.

The exhaust flow extracted by the PEMS during the validation test shall be fed back to the CVS. If the testing institute judges that feeding to the CVS is not feasible, the CVS results shall be corrected for the extracted exhaust mass. If the exhaust mass flow rate is validated with an EFM, it is recommended to cross-check the mass flow rate measurements with data obtained from a sensor or the ECU.

3–2–3 Data analysis

The distance-specific emissions [g/km] measured with laboratory equipment shall be calculated, following the provisions of Part II of Attachment 42. The emissions as measured with the PEMS shall be calculated according to Paragraph 9. of Attached Sheet 4, summed to give the total mass of each emission component [g] and then divided by the test distance [km] as obtained from the chassis dynamometer. It shall be confirmed that the total distance-specific mass of emission components [g/km], as determined by the PEMS and traceably calibrated stationary type analyzers or other test equipment, be within the permissible tolerances specified in Paragraph 3–3. For the validation of NOx emission measurements, humidity correction factor prescribed in Paragraph 3–2–1–2 of Attached Sheet 7 of Part II of Attachment 42. shall be applied.

3–3 Permissible tolerances for PEMS validation

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

Table 1 Permissible tolerances

Parameter [Unit]	Permissible tolerances
Distance [km] (1)	±250 m of the laboratory reference
CO [mg/km] (2)	± 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
NOx [mg/km]	± 15 mg/km or 15% of the laboratory reference, whichever is larger

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

(2) Limited only to cases where it is necessary for exhaust mass flow calculation.

4. Validation Procedure for Exhaust Mass Flow Rate Measured by Non-Traceable Instruments and Sensors

4–1 Frequency of validation

In addition to fulfilling the linearity requirements of Paragraph 3. of Attached Sheet 2 under steady-state conditions, the linearity of non-traceable EFM or the exhaust mass flow rate calculated from non-traceable sensors or ECU signals shall be validated and the validation shall be done under transient conditions for each test vehicle against a calibrated EFM or the CVS.

The validation can be executed without the installation of the PEMS, but shall generally follow the requirements defined in Part II of Attachment 42. and the requirements pertinent to EFM defined in Attached Sheet 1, in addition to this Attached Sheet.

4–2 Validation procedure

The validation test shall be conducted on a chassis dynamometer by following the provisions of Part II of Attachment 42. 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 this Attachment. The installation of the EFM and the execution of the validation test shall fulfil the requirement of Paragraph 3–4–3 of Attached Sheet 1.

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

(a) The signal under validation and the reference signal shall be time corrected by following the requirements of Paragraph 3. of Attached Sheet 4.

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

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

$$y = a_1 x + a_0$$

where:

y: Actual value of signal under validation

a_1: Slope of regression line

x: Actual value of reference signal

a_0: y intercept of regression line

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

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

4–3 Requirements

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

Table 2 Linearity requirements of calculated and measured values of exhaust mass flow

Measurement parameter / system	a_0	Slope a_1	Standard error of estimate SEE	Coefficient of determination r^2
Exhaust mass flow	0.0 ± 3.0 kg/h	1.00 ± 0.075	max ≤ 10%	≥ 0D.90

Attached Sheet 4

DETERMINATION OF EMISSIONS

1. This Attached Sheet describes the procedure to determine the instantaneous mass that shall be used for the subsequent evaluation of a test trip and the calculation of the final emission result as described in Attached Sheet 5.

2. Symbols

α	Molar hydrogen ratio (H/C)
β	Molar carbon ratio (C/C)
γ	Molar sulphur ratio (S/C)
δ	Molar nitrogen ratio (N/C)
$\Delta t_{t,i}$	Transformation time t of the analyzer [s]
$\Delta t_{t,m}$	Transformation time t of the EFM [s]
ε	Molar oxygen ratio (O/C)
ρ_e	Density of the exhaust
ρ_{gas}	Density of the exhaust component “gas”
λ	Excess air ratio
λ_i	Instantaneous excess air ratio
A/F_{st}	Stoichiometric air-to-fuel ratio [kg/kg]
c_{CH4}	Concentration of methane
c_{CO}	Dry CO concentration [%]
c_{CO2}	Dry CO2 concentration [%]
c_{dry}	Dry concentration of a pollutant in ppm or per cent volume
$c_{gas,i}$	Instantaneous concentration of the exhaust component “gas” [ppm]
$c_{i,c}$	Time-corrected concentration of component *i* [ppm]
$c_{i,r}$	Concentration of component *i* [ppm] in the exhaust
c_{wet}	Wet concentration of a pollutant in ppm or per cent volume
H_a	Intake air humidity [g water per kg dry air]
i	Number of the measurement
k_w	Dry-wet correction factor
$m_{gas,i}$	Mass of the exhaust component “gas” [g/s]
$q_{maw,i}$	Instantaneous intake air mass flow rate [kg/s]
$q_{m,c}$	Time-corrected exhaust mass flow rate [kg/s]
$q_{mew,i}$	Instantaneous exhaust mass flow rate [kg/s]
$q_{mf,i}$	Instantaneous fuel mass flow rate [kg/s]
$q_{m,r}$	Raw exhaust mass flow rate [kg/s]

r	Cross-correlation coefficient
r^2	Coefficient of determination
r_h	Hydrocarbon response factor
rpm	Revolutions per minute
u_{gas}	u value of the exhaust component “gas”

3. Time Correction of Parameters

For the correct calculation of distance-specific emissions, the recorded traces of component concentrations, exhaust mass flow rate, vehicle speed, and other vehicle data shall be time corrected. The time correction and alignment of parameters shall be carried out by following the sequence described in Paragraphs 3–1 to 3–3.

3–1 Time correction of component concentrations

The recorded traces of all component concentrations shall be time corrected by reverse shifting according to the transformation times of the respective analyzers. The transformation time of analyzers shall be determined according to Paragraph 4–4 of Attached Sheet 2:

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

Where:

$c_{i,c}$: Time-corrected concentration of component i as function of time t

$c_{i,r}$: Raw concentration of component i as function of time t

$\Delta t_{t,i}$: Transformation time t of the analyzer measuring component i.

3–2 Time correction of exhaust mass flow rate

The exhaust mass flow rate measured with an exhaust flow meter shall be time corrected by reverse shifting according to the transformation time of the EFM. The transformation time of the EFM shall be determined according to Paragraph 4–4 of Attached Sheet 2:

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

Where:

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

$q_{m,r}$: Raw exhaust mass flow rate as function of time t

$\Delta t_{t,m}$: Transformation time t of the exhaust mass flow meter.

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

3–3 Time alignment of other data

Other data obtained from a sensor or the ECU shall be time-aligned by cross-correlation with component concentrations and other suitable emission data.

3–3–1 Vehicle speed from different sources

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

3–3–2 Vehicle speed with exhaust mass flow rate

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

3–3–3 Further signals

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

4. Cold Start

The cold start period covers the first 5 minutes after initial start of the combustion engine (except electric motors). If the coolant temperature can be reliably determined, the cold start period ends once the coolant has reached 343 K (70℃) for the first time but no later than 5 minutes after initial engine start. Cold start emissions shall be recorded.

5. Emission Measurement During Engine Stop

Any instantaneous emissions or exhaust flow measurements obtained while the combustion engine (except electric motors) is deactivated shall be recorded. 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:

(1) The recorded engine speed is < 50 rpm;

(2) The exhaust mass flow rate is measured at < 3 kg/h; and

(3) The measured exhaust mass flow rate drops to < 15 % of the steady-state exhaust mass flow rate at idling.

6. Consistency Check of Vehicle Altitude

In case well-reasoned doubts exist that a trip has been conducted above of the permissible altitude as specified in Paragraph 5–2 of this Attachment 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.

7. Consistency Check of 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, prior to the consistency check. The original and uncorrected data file shall be retained and any corrected data shall be marked. The corrected data shall not exceed an uninterrupted time period of 120 s or a total of 300 s. The total trip distance as calculated from the corrected GPS data shall deviate by no more than 4 % from the reference. If the GPS data do not meet these requirements and no other reliable speed source is available, the test results shall be voided.

8. Correction of Emissions

8–1 Dry-wet correction

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

$c_{wet} = k_w \times c_{dry}$

Where:

c_{wet}: Wet concentration of a pollutant in ppm or per cent volume

c_{dry}: Dry concentration of a pollutant in ppm or per cent volume

k_w: Dry-wet correction factor

The following equation shall be used to calculate k_w:

$$\mathrm{k_w} = \frac{1}{1 + a \times 0.005 \times (c_{CO2} + c_{CO})} - k_{w1} \times 1.008$$

Where:

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

Where:

H_a: Intake air humidity [g water per kg dry air]

c_{CO2}: Dry CO2 concentration [%]

c_{CO}: Dry CO concentration [%]

a: Molar hydrogen ratio

8–2 Correction of NOx for ambient humidity and temperature

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

9. Measurement of Instantaneous Emissions

The components in the raw exhaust gas shall be measured with the measurement and sampling analyzers described in Attached Sheet 2. The raw concentrations of relevant components shall be measured in accordance with Attached Sheet 1. The data shall be time corrected and aligned in accordance with Paragraph 3.

10. Determination of Exhaust Mass Flow

10–1 The exhaust mass flow rate shall be determined by one of the direct measurement methods specified in Paragraph 6–2 of Attached Sheet 2. Alternatively, it is permissible to calculate the exhaust mass flow rate as described in Paragraphs 10–2 to 10–4.

10–2 Calculation method using air mass flow rate and fuel mass flow rate

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

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

Where:

$q_{mew,i}$: Instantaneous exhaust mass flow rate [kg/s]

$q_{maw,i}$: Instantaneous intake air mass flow rate [kg/s]

$q_{mf,i}$: Instantaneous fuel mass flow rate [kg/s].

If the air mass flow rate and the fuel mass flow rate or the exhaust mass flow rate are determined from ECU recording, the calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust mass flow rate in Paragraph 3 of Attached Sheet 2 and the validation requirements specified in Paragraph 4–3 of Attached Sheet 3.

10–3 Calculation method using air mass flow and air-to-fuel ratio

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

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

Where:

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

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

Where:

$q_{maw,i}$: Instantaneous intake air mass flow rate [kg/s]

A/F_{ST}: Stoichiometric air-to-fuel ratio [kg/kg]

λ_i: Instantaneous excess air ratio

c_{CO2}: Dry CO2 concentration [%]

c_{CO}: Dry CO concentration [ppm]

c_{HCw}: Wet HC concentration [ppm]

a: 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).

Coefficients refer to a fuel $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$ with β=1 for carbon-based fuels.

The concentration of HC emissions is typically low and may be omitted when calculating λ_i.

If the air mass flow rate and air-to-fuel ratio are determined from ECU recording, the calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust mass flow rate in Paragraph 3 of Attached Sheet 2 and the validation requirements specified in Paragraph 4–3 of Attached Sheet 3.

10–4 Calculation method using fuel mass flow and air-to-fuel ratio

The instantaneous exhaust mass flow rate can be calculated from the fuel flow and the air-to-fuel ratio (calculated with A/Fst and *l*i according to point 10.3) as follows:

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

The calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust gas mass flow rate in Paragraph 3 of Attached Sheet 2 and the validation requirements specified in Paragraph 4–3 of Attached Sheet 3.

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 corrected and aligned for the transformation time), and the respective *u* value of Table 1. If measured on a dry basis, the dry-wet correction according to Paragraph 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:

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

Where:

$m_{gas,i}$: Mass of the exhaust component “gas” [g/s]

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

$c_{gas,i}$: Measured concentration of the exhaust component “gas” in the exhaust [ppm]

$q_{mew,i}$: Measured exhaust mass flow rate [kg/s]

gas: Respective component

i: Number of the measurement.

Table 1 Raw exhaust gas *u* values depicting the ratio between the densities of exhaust component or pollutant [kg/m^3] and the density of the exhaust gas [kg/m^3]

<table>
<tr><td rowspan="5">Fuel</td><td rowspan="5">ρ_e [kg/m^3]</td><td colspan="3">Component or pollutant i</td></tr>
<tr><td>NOx</td><td>CO</td><td>CO_2</td></tr>
<tr><td colspan="3">ρ_{gas} [kg/m^3]</td></tr>
<tr><td>2.053</td><td>1.250</td><td>1.9636</td></tr>
<tr><td colspan="3">u_{gas} (Atλ= 2, dry air, 273 K, 101,3 kPa)</td></tr>
<tr><td>Diesel</td><td>1.2943</td><td>0.001586</td><td>0.000966</td><td>0.001517</td></tr>
</table>

12. Data Reporting and Exchange

The data shall be exchanged between the measurement systems and the data evaluation software by a reporting file defined by the testing institute. Any pre-processing of data, e.g. time correction according to Paragraph 3 or the correction of the GPS vehicle speed signal according to Paragraph 7, shall be done with the control software of the measurement systems and shall be completed before the data reporting file is generated. If data are corrected or processed prior to entering the data reporting file, the original raw data shall be saved. Rounding of intermediate values is not permitted. Instead, intermediate values shall enter the calculation of instantaneous emissions [g/s] as reported by the analyzer, flow- measuring instrument, sensor or the ECU.

Attached Sheet 5

VERIFICATION OF TRIP DYNAMIC CONDITIONS BY MOVING AVERAGE WINDOW

1. This attached sheet prescribes the statistic processing procedure for performance evaluation of real driving emissions by Moving Average Window method.

Step 1. Segmentation of the data

Step 2. Calculation of emissions by windows (3–1)

Step 3. Identification of normal Windows (4.)

Step 4. Verification of test completeness and normality (5.)

Step 5. Calculation of emissions using the normal window

2. Symbols, Parameters and Units

Additional character (i)	Time step
Additional character (j)	Window
Additional character (k)	Classification (t=total, u=urban area, r=rural area, m=motorways) or CO_2 characteristic curve (cc)
Additional character “gas”	Exhaust emission component
a_1, b_1	Coefficient of CO_2 the characteristic curve
a_2, b_2	Coefficient of CO_2 the characteristic curve
d_j	Distance covered by window *j* [km]
f_k	Weighing factors for urban, rural and motorway shares
h	Distance of windows to the CO2 characteristic curve [%]
h_j	Distance of window j to the CO2 characteristic curve [%]
$\bar{h}_k$	Severity index for urban, rural and motorway shares and the complete trip
k_{11}, k_{12}	Coefficients of the weighing function
k_{21}, k_{22}	Coefficients of the weighing function
$M_{CO2,ref}$	Reference CO_2 mass [g]
M_{gas}	Mass or particle number of the exhaust component “gas” [g]
$M_{gas,j}$	Mass or particle number of the exhaust component “gas” in window j [g]
$M_{gas,d}$	Distance-specific emission for the exhaust component “gas” [g/km]

$M_{gas,d,j}$	Distance-specific emission for the exhaust component “gas” in window j [g/km]
N_k	Number of windows for urban, rural, and motorway shares
P1,P2	Reference points
t	Time [s]
$t_{1,j}$	First second of the j[th] averaging window
$t_{2,j}$	Last second of the j[th] averaging window
t_j	Total time of step i [s]
t_j	Total time of step i whose window j will be considered [s]
tol_1	Primary tolerance of the CO_2 characteristic curve [%]
tol_2	Secondary tolerance of the CO_2 characteristic curve [%]
t_t	Duration of a test [s]
v	Vehicle speed [km/h]
$\bar{v}$	Average speed of windows [km/h]
v_i	Actual vehicle speed in time step I [km/h]
$\bar{v}_j$	Average vehicle speed in window j [km/h]
$\overline{v_{P1}}$=19.0 km/h	Average speed of the Low Speed phase of the WLTC cycle
$\overline{v_{P2}}$=56.6 km/h	Average speed of High Speed phase of the WLTC cycle
w	Weighing factor for windows
w_j	Weighing factor of window j.

3. Moving Averaging Windows

3–1 Definition of averaging windows

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

The “averaging window” is the data sub-sets used to average the emissions data.

One averaging window includes data during the period until half of the CO_2 mass emitted from the test vehicle over the WLTC complete trip of Part II of Attachment 42 on chassis dynamometer is emitted. For these data, the moving average calculations shall be conducted in sequence from the first point of time corresponding to the data sampling frequency. This calculation shall be conducted from the first point by forward calculation.

Data during the periodic verification of the instruments and/or after the zero drift verifications as well as data when the vehicle ground speed is less than 1 km/h, shall not be considered for the calculation of the CO_2 mass, the emissions and the distance of the averaging windows.

The mass emissions $M_{gas,j}$ shall be determined by integrating the instantaneous emissions in g/s calculated as specified in Attached Sheet 4.

Figure 1: Vehicle speed versus time Vehicle averaged emissions verses time, starting from the first averaging window

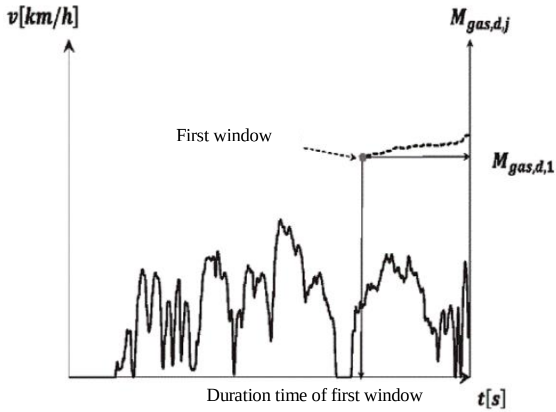
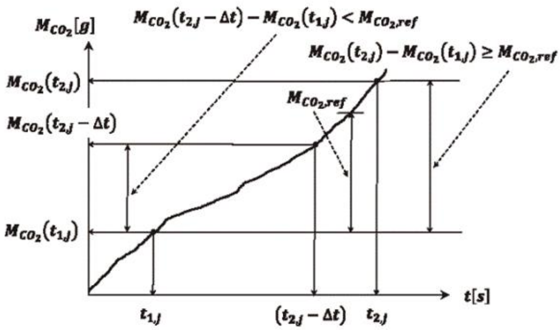


Figure 2: Definition of CO_2 mass based averaged windows



The duration (t2,*j*– t1,*j*) of the jth averaging window is determined by:

$$M_{CO2}(t_{2,j}) - M_{CO2}(t_{1,j}) \geqq M_{CO2,ref}$$

Where:

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

$M_{CO2,ref}$: Half of the CO_2 mass [g] emitted by the test vehicle over the WLTC cycle of Part II of Attachment 42

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

$$M_{CO2}(t_{2,j} - \Delta t) - M_{CO2}(t_{1,j}) < M_{CO2,ref} \leqq M_{CO2}(t_{2,j}) - M_{CO2}(t_{1,j})$$

Where:

Δt: Data sampling period

The CO_2 masses are calculated in the windows by integrating the instantaneous emissions calculated as specified in Attached Sheet 4.

3–2 Calculation of window emissions and averages

The following shall be calculated for each window determined in accordance with Paragraph 3–1:

— the distance-specific emissions $M_{gas,d,j}$ for all the pollutants specified in this annex

— the distance-specific CO_2 emissions $M_{CO2,d,j}$

— the average vehicle speed $\overline{v}_j$

For tests of off-board charging hybrid electric motor vehicle, the calculation of the window shall start from the start of the power train and include driving with no CO_2 emissions.

4. Evaluation of Windows

4–1 Introduction

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

To obtain the distance-specific CO2 emissions, the vehicle shall be tested using the road load settings prescribed in the Attached Sheet 4 of Part II of

Attachment 42.

4–2 CO_2 characteristic curve reference points

The reference points $P1$ and $P2$ required to define the curve shall be established as follows:

4–2–1 Reference Point $P1$

$\bar{v}_{p1}$=19.0 km/h (average speed of the Low Speed phase of the WLTC cycle)

$M_{CO2,d,P1}$=Vehicle CO_2 emissions over the Low Speed phase of the WLTC cycle×1.1 [g/km]

4–2–2 Reference Point $P2$

$\bar{v}_{p2}$=56.6 km/h (average speed of the High Speed phase of the WLTC cycle)

$M_{CO2,d,P2}$=Vehicle CO_2 emissions over the High Speed phase of the WLTC cycle×1.1 [g/km]

4–3 CO_2 characteristic curve definition

Using the reference points defined in Paragraph 4–2, the characteristic curve CO_2 shall be defined by equations as follows as a function CO_2 emissions M_{CO2} for average vehicle speed at two linear sections with $\bar{v}_{p2}$=56.6 km/h as the boarder:

4–3–1 When $\bar{v} \leqq \bar{v}_{p2}$=56.6 km/h,

$M_{CO2,d,CC}(\bar{v})=a_1\bar{v}+b_1$

Where:

$a_1=(M_{CO2,d,P2}-M_{CO2,d,P1})/(\bar{v}_{p2}-\bar{v}_{p1});$

$b_1=M_{CO2,d,P1} - a_1\bar{v}_{P1}$

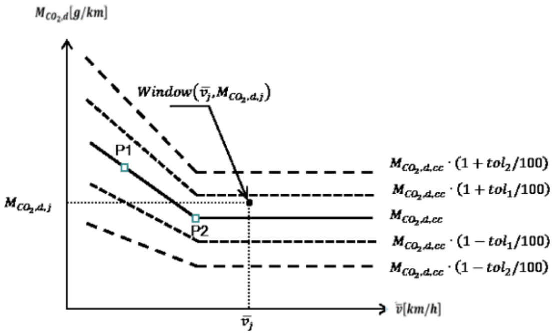
4–3–2 When $\bar{v}>\bar{v}_{p2}$=56.6 km/h,

$M_{CO2,d,CC}(\bar{v})=b_2$

Where:

$b_2 = M_{CO2,d,P2}$

Figure 3: Vehicle CO_2 characteristic curve



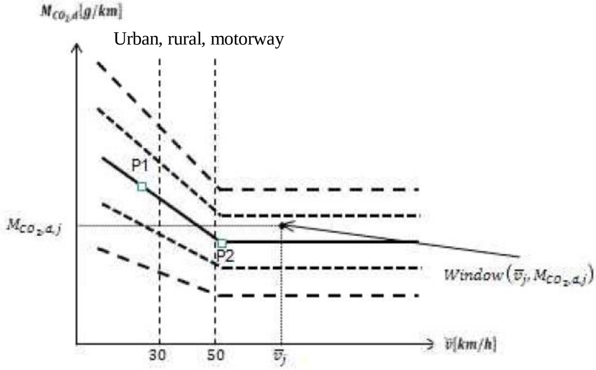
4–4 Urban, rural and motorway windows

4–4–1 Windows with a window average speed of less than 30 km/h shall be classified as urban windows.

4–4–2 Windows with a window average speed of 30 km/h or more but less than 50 km/h shall be classified as rural windows.

4–4–3 Windows with a window average speed of more than 50 km/h shall be classified as urban windows.

Figure 4: Vehicle CO2 characteristic curve: urban, rural and motorway driving definition



5. Verification of Trip Completeness and Normality

5–1 Tolerances around the vehicle CO_2 characteristic curve

The primary tolerance and the secondary tolerance of the vehicle CO_2 characteristic curve are respectively *tol*1= 25 % and *tol2* = 50 %.

5–2 Verification of test completeness

The test shall be complete when it comprises at least 10 % of urban, rural and motorway windows, out of the total number of windows.

5–3 Verification of test normality

The test shall be normal when at least 50 % of the urban, rural and motorway windows are within the primary tolerance defined for the characteristic curve.

If the specified minimum 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, tol_1 shall never exceed 30 % (50% in the case of off-board charging hybrid electric motor vehicles).

6. Calculation of Emissions

6–1 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.

$$M_{gas,d,k} = \frac{\sum(w_j M_{gas,d,j})}{\sum w_j}$$

$$k = u, r, m$$

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

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

Then $w_j = 1$

If $M_{CO2,d,cc(\bar{v}j)} \cdot (1 + tol_1/100) < M_{CO2,d,j} \leqq M_{CO2,d,cc(\bar{v}j)} \cdot (1 + tol_2/100)$

Then $w_j = k_{11} h_j + k_{12}$

However, with $k_{11} = 1/(tol_1 - tol_2)$ and $k_{12} = tol_2/(tol_2 - tol_1)$

If $M_{CO2,d,cc(\bar{v}j)} \cdot (1 - tol_2/100) \leqq M_{CO2,d,j} < M_{CO2,d,cc(\bar{v}j)} \cdot (1 - tol_1/100)$

Then $w_j = k_{21} h_j + k_{22}$

However, with $k_{21} = 1/(tol_2 - tol_1)$ and $k_{22} = k_{12} = tol_2/(tol_2 - tol_1)$

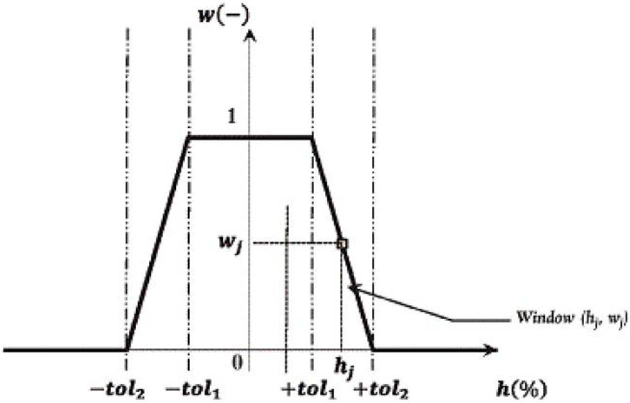
If $M_{CO2,d,j} < M_{CO2,d,cc(\bar{v}j)} \cdot (1 - tol_2/100)$ or $M_{CO2,d,j} > M_{CO2,d,cc(\bar{v}j)} \cdot (1 + tol_2/100)$

Then $w_j = 0$

Where:

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

Figure 5: Averaging window weighing function



6–2 Calculation of severity indices

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

$$\bar{h}_k = \frac{1}{N_k}\sum h_j$$

$k = u,r,m$

and complete trip:

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

Where *fu*, *fr fm* are equal to 0.25, 0.30 and 0.45 respectively.

6–3 Calculation of emissions for the total trip

Using the weighted distance-specific emissions calculated under Paragraph 6–1, the distance-specific emissions in [mg/km] shall be calculated for the complete trip each gaseous pollutant in the following way:

$$M_{gas,d,u+r} = 1000 \cdot \frac{f_u \cdot M_{gas,d,u} + f_r M_{gas,d,r}}{(f_u + f_r)}$$

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

Where:

$M_{gas,d,u+r}$: Emissions for urban and rural trips

$M_{gas,d,t}$: Emissions for the complete trip

and *fu, fr fm* are equal to 0.25, 0.30 and 0.45 respectively.

Attached Sheet 6

VERIFICATION OF OVERALL TRIP DYNAMIC STATE

1. This Attached Sheet prescribes the calculation procedure to verify the overall trip dynamic state during the test and to determine excess or deficiency of the positive acceleration.

2. Symbols

RPA	Relative positive acceleration
a	Acceleration [m/s^2]
a_i	Acceleration in time step i [m/s^2]
a_{pos}	Positive acceleration greater than 0.1 m/s^2 [m/s^2]
$a_{pos,i,k}$	Positive acceleration greater than 0.1 m/s^2 in time step i taking into consideration classification to the mid-, low-speed or high-speed [m/s^2]
a_{res}	Acceleration resolution [m/s^2]
d_i	Distance within the range of time step i [m]
$d_{i,k}$	Distance within the range of time step i taking into consideration classification to the mid-, low-speed or high-speed [m]
Additional character (i)	Time step
Additional character (j)	Time step of positive acceleration data set
Additional character (k)	Classification (t=total, 1=mid-, low-speed, h=high speed)
M_k	Number of samples of mid-, low-speed or high-speed running with a positive acceleration greater than 0.1m/s^2
N_k	Total number of samples at the time of mid-, low-speed, high-speed or complete distance trip
RPA_k	Relative positive acceleration at the time of mid-, low-speed or high-speed running [m/s^2 or kWs/(kg×km)]
t_k	Duration time at the time of middle-, low-speed or high-speed running or complete distance trip [s]
v	Speed [km/h]
v_i	Actual speed in time step i [km/h]
$v_{i,k}$	Actual speed in time step i taking into consideration classification to the mid-, low-speed or high-speed [km/h]

$(v{\cdot}a)_{\mathrm{i}}$	Product of actual speed in time step i and acceleration [m^2/s^3 or W/kg]
$(v{\cdot}a_{pos})_{\mathrm{j,k}}$	Product of actual speed in time step j taking into consideration classification to the mid-, low-speed or high-speed and acceleration greater than 0.1 m/s2 [m^2/s^3 or W/kg]
$(v{\cdot}a_{pos})_{\mathrm{k}}$– [95]	95th percentile of the product of speed at the time of mid-, low-speed or high-speed running and acceleration greater than 0.1 m/s^2 [m^2/s^3 or W/kg]
$\bar{v}_k$	Average speed at the time of mid-, low-speed or high-speed running [km/h]

3. Trip Indicator

3–1 Calculation

3–1–1 Data pre-processing

Dynamic parameters like acceleration, $v{\cdot}a_{pos}$ or RPA shall be determined with a speed signal of an accuracy of 0.1% above 3 km/h and a sampling frequency of 1 Hz.

First, confirm whether there are any data faulty section characterized by steps or terraced speed traces, jumps or missing speed data. Short data faulty sections shall be corrected, for example, by data interpolation or benchmarking against a secondary speed signal. Certain trips containing faulty sections may be excluded from data analysis.

Next, the acceleration values shall be ranked in ascending order in order to determine the acceleration resolution a_{res} (minimum acceleration value > 0).

When $a_{res} \leqq 0.01\ m/s^2$, the speed measurement shall be deemed accurate enough.

When $0.01\ m/s^2 < a_{res}$, the data shall be smoothed using a T4253 Hanning filter.

The T4253 Hanning filter performs the following calculation:

The smoother starts with a running median value of 4. Its center is a running median value of 2. It then re-smoothes these values by applying a running median value of 5, running median value of 3, and Hanning (running weighted averages). Residuals shall be computed by subtracting the smoothed series from the original series. Furthermore, this whole process shall then be repeated on the computed residuals. Finally, the smoothed residuals shall be computed by subtracting the smoothed values obtained the first time through the process.

The correct speed trace builds the basis for further calculations and binning as described in Paragraph 3–1–2.

3–1–2 Calculation of distance, acceleration and $v{\cdot}a$

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

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

$$d_i = \frac{v_1}{3.6}$$

$i = 1$ to N_t

Where:

d_i : Distance covered in time step i [m]

v_i : Actual speed in time step i [km/h]

N_i : Total number of samples

The acceleration shall be calculated as follows:

$a_i=(v_{i+1} - v_{i-1})/(2{\cdot}3.6)$

$i = 1$ to N_t

Where:

a_i : Acceleration in time step i [m/s^2]

when $i = 1$, $v_{i-1}=0$, when $i = N_t$, $v_{i+1}=0$

The product of speed and acceleration shall be calculated as follows:

$(v{\cdot}a)_i=v_i{\cdot}a_i/3.6$

i=1 to N_t

Where:

$(v{\cdot}a)_i$: Product of the actual speed and acceleration in time step i [m^2/s^3 or W/kg]

3–1–3 Binning of results

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

The data sets with $v_i \leqq 60$ km/h shall be classified as “mid-, low-speed,” and the data sets with $v_i > 60$ km/h as “high-speed.”

The number of data sets with acceleration $a_i > 0.1$ [m/s^2] shall be bigger or equal to 150 in each classification, respectively.

For each speed classification, the average speed $\bar{v}_k$ shall be calculated as follows:

$$\overline{v_k} = \left(\sum_{i=1}^{N_t} v_{i,k}\right)/N_k, k = l, h$$

Where:

N_k : Total number of samples at mid-, low-speed and high-speed, respectively.

3–1–4 Calculation of $v{\cdot}a_{POS\,-}[95]$

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

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

Next, percentile values shall be assigned to the $(v{\cdot}a_{POS})_{i,k}$ values with $a_{i,k} \geqq 0.1$ m/s^2 as follows.

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

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

The relative positive acceleration shall be calculated as follows:

$$\mathrm{RPA_k} = \left(\sum_{\mathrm{i=1}}^{\mathrm{M_k}}(\Delta t \cdot (v \cdot a_{pos})_{\mathrm{j,k}})\right) / \sum_{\mathrm{i=1}}^{\mathrm{N_k}} d_{\mathrm{j,k}}\,, k = l, h$$

Where:

RPA_k : Relative positive acceleration for each speed classification [m/s^2 or kWs/(kg×km)]

Δt_i : Time difference equal to 1 second

M_k : Number of samples for each speed classification with positive acceleration

N_k : Total number of samples for each speed classification

4. Verification of Trip Validity

4–1 Verification of $v{\cdot}a_{POS-}[95]$

When $\bar{v}_k \leqq 74.6$ km/h and $(v{\cdot}a_{POS})_{k-}[95] > (0.136{\cdot}\bar{v}_k + 14.44)$ are fulfilled, the trip is invalid.

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

4–2 Verification of RPA

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

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

Attached Sheet 7

PROCEDURES TO DETERMINE CUMULATIVE POSITIVE ELEVATION GAIN OF TRIP

1. This Attached Sheet prescribes the procedure to determine the cumulative positive elevation gain of a trip.

2. Symbols

$d(0)$	Distance at the start of a trip [m]
d	Cumulative running distance at discrete way point under consideration [m]
d_0	Cumulative running distance until the measurement directly before the respective way point *d* [m]
d_1	Cumulative running distance until the measurement directly after the respective way point *d* [m]
d_a	Reference way point at $d(0)$ [m]
d_e	Cumulative running distance until the last discrete way point [m]
d_i	Instantaneous distance [m]
d_{tot}	Total test distance [m]
$h(0)$	Altitude after the screening and principle verification of data quality at the start of a trip [m above sea level]
$h(t)$	Altitude after the screening and principle verification of data quality at point *t* [m above sea level]
$h(d)$	Altitude at the way point *d* [m above sea level]
$h(t\text{-}1)$	Altitude after the screening and principle verification of data quality at point *t-1* [m above sea level]
$h_{corr}(0)$	Corrected altitude directly before the respective way point *d* [m above sea level]
$h_{corr}(1)$	Corrected altitude directly after the respective way point *d* [m above sea level]
$h_{corr}(t)$	Corrected instantaneous altitude at data point *t* [m above sea level]
$h_{corr}(t\text{-}1)$	Corrected instantaneous altitude at data point *t-1* [m above sea level]
$h_{GPS,i}$	Instantaneous altitude measured with GPS [m above sea level]
$h_{GPS}(t)$	Altitude measured with GPS at data point *t* [m above sea level]

$h_{int}(d)$	Interpolated altitude at the discrete way point under consideration d [m above sea level]
$h_{int,sm,1}(d)$	Smoothed interpolated altitude, after the first smoothing at the discrete way point under consideration d [m above sea level]
$h_{map}(t)$	Altitude based on topographic map at data point t [m above sea level]
$road_{grade,1}(d)$	Smoothed road grade at the discrete way point under consideration d after the first smoothing [m/m]
$road_{grade,2}(d)$	Smoothed road grade at the discrete way point under consideration d after the second smoothing [m/m]
t	Time passed since test start [s]
t_0	Time passed at the measurement directly located before the respective way point d [s]
v_i	Instantaneous speed [km/h]
$v(t)$	Speed at data point t [km/h]

3. General Requirements

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

4. Calculation of Cumulative Positive Elevation Gain

4–1 General

The cumulative positive elevation gain of a trip shall be calculated by the following 3-step procedure.

(i) Screening and principle verification of data quality;

(ii) Correction of instantaneous altitude data; and

(iii) Calculation of cumulative positive elevation gain.

4–2 Screening and principle verification of data quality

Correcting missing data is permitted if gaps of instantaneous speed data satisfy the requirements prescribed in Paragraph 7. of Attached Sheet 4.

For the gaps of instantaneous speed data, the data gaps shall be completed by linear interpolation based on the data before and after the gaps and the correctness of interpolated data shall be verified by the topographic map.

Interpolated data shall be corrected if the following condition applies:

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

Correction shall be performed so that the following formula is satisfied.

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

Where:

$h(t)$: Altitude after the screening and principle verification of data quality at point t [m above sea level]

$h_{GPS}(t)$: Altitude measured by GPS at data point t [m above sea level]

$h_{map}(t)$: Altitude based on topographic map at data point t [m above sea level]

4–3 Correction of instantaneous altitude data

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

$$\left| h(t) - h(t-1) \right| > (v(t)) / 3.6 \times \sin 45°)$$

The altitude correction shall be applied so that the following formula is satisfied.

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

Where:

$h(t)$: Altitude after the screening and principle verification of data quality at point t [m above sea level]

$h(t-1)$: Altitude after the screening and principle verification of data quality at point $t-1$ [m above sea level]

$v(t)$: Speed at data point t [km/h]

$h_{corr}(t)$: Corrected instantaneous altitude at data point t [m above sea level]

$h_{corr}(t-1)$: Corrected instantaneous altitude at data point $t-1$ [m above sea level]

Upon the completion of the correction procedure, a valid set of altitude data is established. This data shall be used for the final calculation of the cumulative positive elevation gain as prescribed in Paragraph 4–4.

4–4 Final calculation of cumulative positive elevation gain

4–4–1 Establishment of uniform spatial resolution

The total running distance d_{tot} [m] shall be determined as the sum of the instantaneous distances d_i.

The instantaneous distance d_i shall be determined by the following formula:

$$\mathrm{d_i} = \frac{\mathrm{v_1}}{3.6}$$

Where:

d_i : Instantaneous distance [m]

v_i : Instantaneous speed [km/h]

The cumulative elevation gain shall be calculated from the altitude data per 1 m, starting with the distance $d(0)$ at the start of a trip as the base point. The discrete data points per 1 m are referred to as way points, and the altitude $h(d)$ of each way point d shall be calculated through interpolation of the corrected instantaneous altitude $h_{corr}(0)$ by the following formula:

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

Where:

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

$h_{corr}(0)$: Corrected altitude directly before the respective way point d [m above sea level]

$h_{corr}(1)$: Corrected altitude directly after the respective way point d [m above sea level]

d : Cumulative running distance at the discrete way point under consideration [m]

d_0 : Cumulative running distance until the measurement located directly before the respective way point d [m]

d_1 : Cumulative running distance until the measurement located directly after the respective way point d [m]

4–4–2 Smoothing of interpolation altitude data per 1 m

The altitude data obtained for each discrete way point shall be smoothed by a two-step procedure (Diagram 1).

d_a and d_e denote the first and last data point, respectively.

The first smoothing shall be applied as follows:

When $d \leqq 200$

$$\mathrm{road}_{\mathrm{grade},1}(d) = \frac{\mathrm{h_{int}(d+200m)} - \mathrm{h_{int}}(d_\mathrm{a})}{\mathrm{d+200m}}$$

When $200\ m < d < (d_e - 200m)$

$$\mathrm{road}_{\mathrm{grade},1}(d) = \frac{\mathrm{h_{int}(d+200m)} - \mathrm{h_{int}}(d-200m)}{\mathrm{(d+200m)-(d-200m)}}$$

When $d \geqq (d_e - 200m)$

$$\mathrm{road}_{\mathrm{grade},1}(d) = \frac{\mathrm{h_{int}(d_e)} - \mathrm{h_{int}}(d-200m)}{\mathrm{d_e-(d-200m)}}$$

$$h_{int,sm,1}(d) = h_{int,sm,1}(d - 1m) + road_{grade,1}(d)$$

$$d = d_a + 1 \text{ to } d_e$$

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

Where:

$road_{grade,1}(d)$: Smoothed road grade at the discrete way point d under consideration after the first smoothing [m/m]

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

$h_{int,sm,1}(d)$: Smoothed interpolated altitude after the first smoothing at the discrete way point d [m above sea level]

d : Cumulative running distance at the discrete way point under consideration [m]

d_a : Reference way point at d(0) [m]

d_e : Cumulative running distance until the last discrete way point [m]

The second smoothing shall be applied as follows:

When $d \leqq 200$

$$\mathrm{road}_{\mathrm{grade},2}(d) = \frac{\mathrm{h}_{\mathrm{int,sm,1}}(\mathrm{d+200m}) - \mathrm{h}_{\mathrm{int,sm,1}}(d_{\mathrm{a}})}{(\mathrm{d+200m})}$$

When $200\,m < d < (d_e - 200m)$

$$\mathrm{road}_{\mathrm{grade},2}(d) = \frac{\mathrm{h}_{\mathrm{int,sm,1}}(\mathrm{d+200m}) - \mathrm{h}_{\mathrm{int,sm,1}}(d-200m)}{(\mathrm{d+200m}) - (\mathrm{d-200m})}$$

When $d \geqq (d_e - 200m)$

$$\mathrm{road}_{\mathrm{grade},2}(d) = \frac{\mathrm{h}_{\mathrm{int,sm,1}}(\mathrm{d_e}) - \mathrm{h}_{\mathrm{int,sm,1}}(d-200m)}{\mathrm{d_e} - (\mathrm{d-200m})}$$

Where:

$road_{grade,2}(d)$: Smoothed road grade at the discrete way point d under consideration after the second smoothing [m/m]

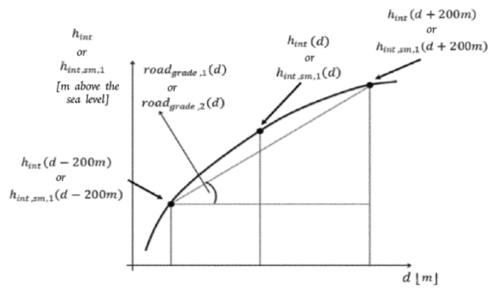
$h_{int,sm,1}(d)$: Smoothed interpolated altitude after the first smoothing at the discrete way point d [m above sea level]

d : Cumulative running distance at the discrete way point under consideration [m]

d_a : Reference way point at d(0) [m]

d_e : Cumulative running distance until the last discrete way point [m]

Diagram 1: Illustration of procedure to smooth the interpolated altitude



4–4–3 Calculation of final results

The positive cumulative elevation gain of a trip shall be calculated by integrating all positive smoothed road grades, i.e. $road_{grade,2}(d)$. The result shall be normalized by the total test distance d_{tot} and expressed in meters of cumulative elevation gain per 100 km of distance.

Attached Sheet 8

VERIFICATION OF TRIP CONDITIONS OF OFF-VEHICLE CHARGING HYBRID ELECTRIC VEHICLES AND CALCULATION OF FINAL ON-ROAD EMISSIONS

1. This Attached Sheet prescribes the verification of trip conditions of off-vehicle charging hybrid electric vehicles and the calculation of the final on-road emissions.

2. Symbols, Parameters and Units

M_t	Weighted mass per distance of exhaust emission emitted throughout trip [mg/km]
m_t	Mass of exhaust emission emitted throughout trip [g]
$m_{t,CO2}$	Mass of CO_2 emitted throughout trip [g]
M_{l+m}	Weighted mass per distance of exhaust emission emitted at low-speed and medium-speed running [mg/km]
m_{l+m}	Mass of exhaust emission emitted at low-speed and medium-speed running [g]
$m_{l+m,CO2}$	Mass of CO_2 emitted during low-speed and medium-speed running [g]
$M_{WLTC,CO}$	Mass of CO_2 per distance in tests of charge-sustaining condition against WLTC [g/km]

3. General Requirements

The amount of exhaust emission of off-vehicle charging hybrid electric vehicles shall be evaluated in two stages. First, the trip conditions shall be evaluated according to Paragraph 4. Next, the final on-road trip exhaust results shall be calculated according to Paragraph 5. To satisfy the requirements in Paragraph 4, it is desirable to start the trip in charge-sustaining condition. The battery shall not be charged externally while running.

4. Verification of Trip Conditions

The engine (except electric motors) shall be operated for a total of 12 km or more in the low-speed and medium-speed range. The test shall be void when this requirement is not met.

5. Calculation of Final On-Road Emissions

For a valid run, the final on-road emissions shall be calculated by the following procedure.

(1) The emission amount throughout the trip shall be m_t, and the emission amount during the low-speed and medium-speed running shall be m_{l+m};

(2) The CO_2 emission amount throughout the trip shall be $m_{t,CO2}$, and the CO_2 emission amount during the low-speed and medium-speed running shall be $m_{l+m,CO2}$; and

(3) The CO_2 emission amount per distance [g/km] during the charge-sustaining test prescribed in Attached Sheet 8 of Part II of Attachment 42 shall be $M_{WLTC,CO2}$;

(4) The final emission amount shall be calculated as follows:

Throughout trip

$$M_t = \frac{m_t}{m_{t,CO2}} \cdot M_{WLTC,CO2}$$

For low-speed and medium-speed running

$$M_{l+m} = \frac{m_{l+m}}{m_{l+m,CO2}} \cdot M_{WLTC,CO2}$$