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On-road testing with Portable Emissions Measurement Systems (PEMS)

Guidance note
for light-duty vehicles

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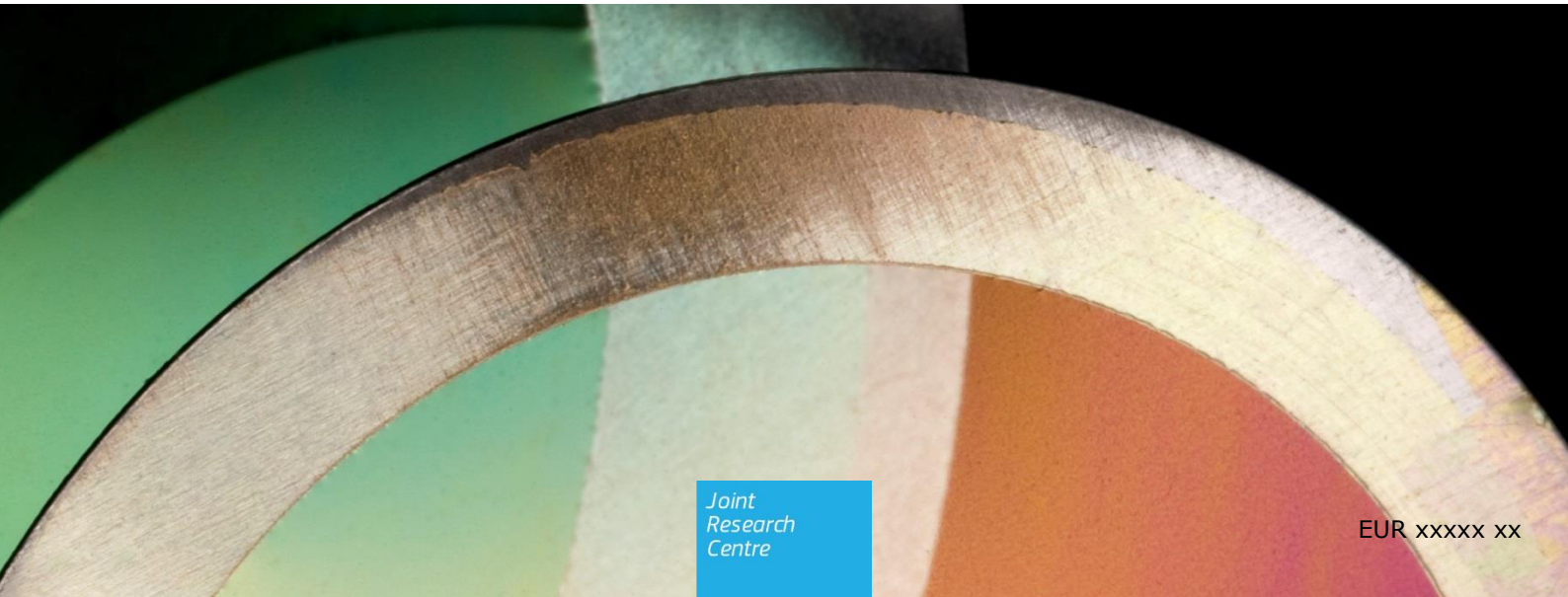

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Contents

Disclaimer

This guidance note describes the best practice for the preparation, the execution, and the follow-up of emissions tests that are conducted with PEMS on board of light-duty vehicles (LDV) equipped with conventional combustion engines (gasoline, diesel, CNG, LPG), in particular for testing vehicles according to the RDE legislative requirements laid down in Regulations (EU) 2017/1151, 2016/467, 2016/626, and 2017/1154 (collectively referred to in this document as the **RDE LDV regulations**). The document does not substitute the operation manuals of the instruments, safety rules and recommendations, and official regulatory texts regarding in-use emissions tests with PEMS.

It is intended to facilitate the implementation of Regulation (EC) No 715/2007. It is itself not legally binding. Any authoritative reading of the law should only be derived from Regulation (EC) 715/2007 itself and other applicable legal texts or principles, for example the regulations mentioned above. While this note seeks to assist authorities and operators by presenting good practices for an effective implementation of the applicable law, only the Court of Justice of the European Union is competent to authoritatively interpret Union legislation

 The sections containing this icon are related to documentation and data exchange requirements.

 The sections containing this icon are recommendations for a safe installation and use of the PEMS instruments.

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1. Introduction

This document provides practical recommendations for the execution of real-driving emissions (RDE) tests with Portable Emissions Measurement Systems (PEMS) on board of light-duty vehicles (LDV). The best practices contained in this guidance note aim at obtaining valid PEMS tests and to prevent wrongdoings in the preparation, execution, and follow up of emissions testing with PEMS. Three main types of PEMS tests can be envisaged and different sets of requirements and recommendations apply for each of them:

- An "official" RDE test conducted during new vehicle type approvals (RDE-TA);
- An "official" RDE test conducted on in-service vehicles with a certain mileage for in-service conformity compliance testing (RDE-ISC);
- Other type of PEMS testing, not according to the RDE LDV regulations, and conducted for other than the two purposes mentioned above (e.g. vehicle development, assessment of vehicle emissions outside the RDE boundary conditions, emission factor development, defeat device screening, etc.).

Table 1 summarises the applicable set of requirements for each type of test and the major differences between them.

Table 1. Types of PEMS tests on light-duty vehicles and requirements

Requirements	RDE TA	RDE ISC	Other PEMS testing
Parameters to be measured	Mandatory	Mandatory	RDE Recommended (Table 2, Table 3)
Instrumentation performance	Mandatory EFM mandatory No use of vehicle ECU for exhaust flow measurement	Mandatory Possible use of vehicle ECU	RDE Recommended (Table 4)
Testing conditions	Mandatory	Mandatory	To address specific needs
Test execution	Mandatory	Mandatory	To address specific needs
Data evaluation	Mandatory	Mandatory	To address specific needs

2. In-use emissions test with PEMS [What to measure and how to do it]?

The list of mandatory test parameters to be measured for RDE tests is according to Regulation 2016/427, Appendix 1, Section 3.2., and the list of parameters that shall be checked on a case-by-case basis, depending on the vehicle technology and the purpose of the test (type approval, in-service conformity, other PEMS testing) are shown Table 2 and Table 3. The mandatory parameters are indicated with the letter M. Optional parameters to be used on a case-by-case basis are indicated with the letter O. It is recommended to measure and record test parameters at a constant frequency of 1 Hz for RDE-TA and RDE-ISC testing and at least 1 Hz for other PEMS testing.

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

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

When performing PEMS tests in the context of RDE LDV regulations, the measurement of THC is not mandatory at this point in time and all statements concerning THC measurement in the guidelines are intended to provide basic requirements on instrument handling for research purposes. Currently, the THC on-road measurement is performed using the FID measurement principle, which is based on the usage of a hydrogen (40%) / Helium (60%) gas. As this gas is categorized as extremely flammable and asphyxiant, it produces a high safety and health risk, as the gas cylinder is not only transported but used with a pressure reduction valve installed and opened in the passenger cabin. In some countries this is not legal.

From a technical perspective, the use of THC measurement instruments increases the weight of the equipment by approximate 25% and it limits the flexibility and autonomy in the use of a PEMS due to its larger size. In addition, as the sampling system must be heated to 190 °C the energy demand will approximately double. Therefore, larger and heavier batteries must be installed.

Table 2. Test parameters for all vehicles

Parameter	Unit	RDE TA	RDE ISC	Other PEMS testing	Technique[8]
CO_2 concentration[1]	ppm	M	M	O	Analyser
CO concentration[1]	ppm	M	M	O	Analyser
NO_X concentration[1, 11]	ppm	M	M	O	Analyser[7]
PN concentration[4]	#/m^3	M	M	O	Analyser
Exhaust mass flow rate	kg/s	M	O	O	EFM[10]
Ambient humidity	%	M	M	O	Sensor

Table 2. Test parameters for all vehicles (continue)

Parameter	Unit	RDE TA	RDE ISC	Other PEMS testing	Technique[8]
Ambient temperature	K	M	M	O	Sensor
Ambient pressure	kPa	M	M	O	Sensor
Vehicle speed	km/h	M	M	O	Sensor, GPS, or ECU[3]
Vehicle latitude	deg:min:s	M	M	O	GPS
Vehicle longitude	deg:min:s	M	M	O	GPS
Vehicle altitude[9]	m	M	M	O	GPS or sensor
Engine fuel flow[2]	g/s	O	O	O	Sensor or ECU
Engine intake air flow[2]	g/s	O	O	O	Sensor or ECU
Intake air flow temperature[2]	K	O	O	O	Sensor or ECU
THC concentration[1,4]	ppm C_1	O	O	O	Analyser
CH_4 concentration[1,4]	ppm C_1	O	O	O	Analyser
NMHC concentration[1,4]	ppm C_1	O	O	O	Analyser[6]
Exhaust gas temperature[5]	K	O	O	O	Sensor
Engine coolant temperature[5]	K	O	O	O	Sensor or ECU
Engine speed[5]	rpm	O	O	O	Sensor or ECU

[1] To be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4 of Regulation 2016/427.
[2] To be determined only if indirect methods are used to calculate exhaust mass flow rate as described in paragraphs 10.2 and 10.3 of Appendix 4 of Regulation 2016/427.
[3] The method to determine vehicle speed shall be chosen according to Appendix 1, point 4.7, of Regulation 2016/427.
[4] Parameter only mandatory if measurement required by Annex IIIA, Section 2.1. of Regulation 2016/427.
[5] To be determined only if necessary to verify the vehicle status and operating conditions.
[6] May be calculated from THC and CH_4 concentrations according to point 9.2 of Appendix 4 of Regulation 2016/427.
[7] May be calculated from measured NO and NO_2 concentrations.
[8] Multiple parameter sources may be used.
[9] The preferable source is the ambient pressure sensor. GPS is not recommended since loss of positional signal can lead to inaccurate altitude measurement.
[10] For RDE-TA, the exhaust mass flow has to be determined by measurement equipment functioning independently from the vehicle and no vehicle ECU data shall be used in this respect. For RDE-ISC or other PEMS tests, alternative methods to determine the exhaust mass flow can be used according to Appendix 2, Section 7.2 of Regulation 2016/427.
[11] NO_x (nitric oxide: NO and nitrogen dioxide: NO_2), expressed in NO_2 equivalent

Table 3. Test parameters specific to hybrid vehicles

Parameter	Unit	RDE TA	RDE ISC	Other PEMS testing	Technique
Engine torque[(5)]	Nm	O	O	O	Sensor or ECU
Torque at driven axle[(5)]	Nm	O	O	O	Rim torque meter
Pedal position[(5)]	%	O	O	O	Sensor or ECU
Fault status[(5)]	-	O	O	O	ECU
Regeneration status[(5)]	-	O	O	O	ECU
Engine oil temperature[(5)]	K	O	O	O	Sensor or ECU
Actual gear[(5)]	#	O	O	O	ECU
Desired gear (e.g. gear shift indicator)[(5)]	#	O	O	O	ECU
State of charge of the battery	%	O	O	O	ECU
Hybrid battery current	A	O	O	O	ECU or power analyser
Hybrid battery voltage	V	O	O	O	ECU or power analyser

Remark:

For any test, the duplication of measurements (i.e. having the same parameter measured by two different instruments or families of instruments) is recommended whenever possible to prevent voiding of tests due to the failure of an instrument. In addition, when more than 2 instruments are used to record the same parameter (e.g. vehicle speed, altitude) it is possible to verify if the instruments are properly calibrated or worked properly throughout a test by comparing the measurements.

In particular for vehicle speed, Regulation 2016/467, Point 4.7, states that vehicle speed shall be determined by at least one of the following methods: GPS, specific sensor (e.g. optical or micro-wave sensor), or ECU. The total trip distance calculated from the vehicle speed measurements cannot deviate between instruments, or between a single instrument and the distance as calculated with a topographic map, by more than 4 %. The recorded vehicle speed is subjected to a consistency check according to Regulation 2016/467, Appendix 4, point 7. When using a GPS, it is possible to correct data gaps in the vehicle speed signal with a secondary signal as long as it does not exceed an uninterrupted time period of 120 seconds or a total of 300 seconds. When using a sensor to calculate the vehicle speed, an accuracy of ± 1.0 km/h is required to the measurements (as stated in Regulation 2016/467, Appendix 2, point 8).

3. Instrumentation performance requirements [Which instruments to use?]

3.1. Introduction

This section describes the equipment characteristics and their performance requirements. The PEMS systems to be used for the RDE-TA and RDE-ISC testing have to comply with the general requirements described in the RDE LDV regulations, and have the following characteristics:

- To be small, lightweight and easy to install;
- To work with a low power consumption so that tests of at least 2.5-3 hours can be run with one set of batteries;
- To measure and record the concentrations of NO_x (or NO and NO_2), CO, CO_2 gases and Particulate Number (PN) in the vehicle exhaust;
- In case of other PEMS tests, to measure and/or record the relevant parameters (engine data from the ECU, vehicle position from the GPS, weather data, etc.).

3.2. Emissions measurements

For RDE-TA and RDE-ISC tests, the performance of the PEMS equipment to be used for measuring gaseous emissions and particle number on light-duty vehicles shall fulfil the requirements stated in the RDE LDV regulations (Table 4).

For other types of PEMS testing, it is recommended to use commercially available equipment fulfilling at least the same requirements. In case the equipment does not fulfil the requirements settled in Table 4, it is highly recommended to describe the equipment characteristics in the results report.

Table 4. Gas and PN analysers RDE specifications and verification

Item	Reference(s)
Analysers Specifications	Regulations 2016/427, 2016/646, 2017/1151, 2017/1154 and their amendments. In particular, Regulation 2016/427, Appendix 2 settles the specifications for PEMS components: - Section 4 (Requirements for analysers measuring gas components) - Section 6 (Requirements for analysers measuring particle emissions) - Section 7 (Specifications for instruments, sensors and signals for measuring exhaust mass flow) - Section 8 (Requirements for sensors measuring non-exhaust parameters) and other requirements, when applicable
Analysers verification	Regulations 2016/427, 2016/646, 2017/1151, 2017/1154 and their amendments. In particular, Regulation 2016/427, Appendix 2 settles limits for PEMS components verification: - Section 3 (Linearity verification) - Section 4 (Requirements for analysers measuring gas components) - Section 5 (Characteristics of calibration and span gases) - Section 6 (Requirements for analysers measuring particle emissions) and other requirements, when applicable

For RDE-TA and RDE-ISC tests, the Regulation 2016/427, Appendix 3 describes the procedure for validating the PEMS equipment (including the gas and PN analysers, and the EFM) installed on a vehicle under transient conditions, preferably with the worldwide harmonised light vehicles test cycle (WLTC) on a chassis dynamometer. The validation is the process of evaluating the correct installation and functionality of a PEMS and the correctness of exhaust mass flow rate measurements as obtained from one or multiple Exhaust mass Flow Meters (EFM) or as calculated from sensors or ECU signals.

It is recommended to validate the performance of the PEMS equipment at every installation on a vehicle, either before or after a set of PEMS tests. It is suggested to follow the best practices for the validation exercise suggested in the ad-hoc report of the Joint Research Centre[1]. For other types of PEMS testing, it is also recommended to undergo the process of PEMS validation as described for RDE tests.

3.3. PEMS data reporting

For RDE-TA and RDE-ISC tests, there is a set of parameters of the instrumentation used (specified by Regulation 2016/427, Appendix 8) that has to be verified and reported. The list of mandatory parameters is indicated with an M in Table 5. For other types of PEMS testing, a set of equipment parameters is also recommended to be recorded for traceability matters. Those parameters are indicated with the letter O. In case multiple analysers are used, the data from each of them shall be recorded.

Table 5. Equipment information to be reported

Code [2]	RDE TA	RDE ISC	Other PEMS testing	Parameter	Description/Unit
33	M	M	O	PEMS manufacturer	[name]
34	M	M	O	PEMS type	[PEMS name]
35	M	M	O	PEMS serial number	[number]
36	M	M	O	PEMS power supply	[e.g. % battery type]
37	M	M	O	Gas analyser manufacturer	[name]
38	M	M	O	Gas analyser type	[type]
39	M	M	O	Gas analyser serial number	[number]
51	M	O	O	EFM manufacturer	[name]
52	M	O	O	EFM sensor type	[functional principle]

[1] Recomendations for the validation of PEMS in the laboratory. EUR XXXXX EN, Publications Office of the European Union, Ispra, 2017, ISBN XXX-XX-XX-XXXX-X, doi: 10.2760/XXXXXX, JRCXXXXXX

[2] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.

Table 5. Equipment information to be reported (continue

Code (1)	RDE TA	RDE ISC	Other PEMS testing	Parameter	Description/Unit
53	M	O	O	EFM serial number	[number]
54	M	M	O	Source of exhaust mass flow rate	[EFM/ECU/sensor]
55	M	O	O	Air pressure sensor	[type, manufacturer]

[1] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.

4. Test preparation [How to select and prepare the vehicle for the test?]

4.1. Basic test set-up

For RDE-TA, RDE-ISC, and other types of PEMS testing, the installation of the equipment shall be conducted according to the applicable health, safety and road regulations. The main components of the PEMS should in most cases be installed in the following manner:

- The main unit containing the analysers to measure gaseous emissions and/or PN, as well as the PEMS control unit, can be installed either inside or outside the vehicle according to the specifications of the instruments supplier. The installation of the PEMS equipment in the vehicle (Figure 1, left) has to be compatible with the safety regulations in place, particularly in relation to the protection of the driver (the installation has to be made in such a way that no exhaust can enter the cabin of the vehicle). The PEMS in the exterior of the vehicle can be placed on a tow bar or a hook using a platform (Figure 1, right) and should include an appropriate warning sign for other drivers. Either inside or outside the vehicle, the PEMS equipment should be installed in such a way to minimise excessive vibrations, heating, electromagnetic interferences, shocks and exposure to dust.
- In case of direct exhaust flow measurement as required in RDE-TA, the exhaust flow meters are best attached to the vehicle's tailpipe or tailpipe adapters in case of multiple exhaust configurations. The installation of the EFM shall be done according to the recommendations of the manufacturer, and any exhaust pipe adaptors or junctions shall not adversely affect the operation of the engine or exhaust after-treatment systems. An incorrect diameter size of the EFM may result in DPF/ GPF malfunction and a risk in engine damage (e.g. turbocharger overspeed, exhaust valves keeping open, etc.).
- In case the PEMS test allows the use of the ECU, the interface modules might be connected to the appropriate vehicle interfaces, typically a CAN bus. It is forbidden to connect the ECU during an official RDE test.
- The GPS antenna should be installed at the highest point of the vehicle. The weather station should be installed on the body of the vehicle, not exposed to the direct wind flow, and where it cannot be affected by exhaust gas. Preferably install the equipment close to a vehicle opening (window, boot, etc.) to minimise the cable distance exposed to the outside conditions.

Further recommendations for the installation of the PEMS components are detailed in chapter 6.

Figure 1. Installation of PEMS main units left) inside the vehicle right) outside the vehicle

4.2. Vehicle selection and inspection

A general verification of the correct technical functioning of the test vehicle shall be carried out before any kind of PEMS testing. The performance/maintenance inspections of the test vehicle have to be performed prior to the installation of the PEMS equipment. Any identified problem must be documented and solved before testing.

In addition, a safety inspection of the vehicle must be conducted prior to any test. Some safety related issues to be checked are for instance:

- The equipment mounted outside of vehicles, e.g. the EFM on the vehicle tailpipe or the whole PEMS unit, which might require appropriate warning signs.
- Adequate routing of tubes, cables, and the heated exhaust line.
- Check for the presence of hot surfaces and sharp edges and signal if needed.
- When applicable, make sure that the installation of pressurised gas cylinders (e.g. for the FID fuel inside the vehicles) or power analysers on hybrid vehicles are properly secured.

More specifically for RDE-TA and RDE-ISC tests, the following vehicle selection criteria shall apply as described in the RDE LDV Regulations:

- For RDE-TA tests the vehicle should be run-in for 3 000 to 15 000 km.
- For RDE-ISC testing the vehicle shall have been in service for at least 15 000 km or 6 months, and for no more than 100 000 km or 5 years, whichever is the sooner.
- The vehicle maintenance and operational records shall be available (i.e. all maintenance has to be performed by authorised dealerships)
- A visual inspection shall check for the presence of obstructed air paths (intake system), potentially damaged exhaust system, damaged components and tampering systems.
- Any kind of tuning or traces of tuning (body of the vehicle, electrical or electronics) by the vehicle owner would make the vehicle not eligible for official RDE testing.
- Roof boxes or objects on top of the vehicle that may impact its frontal area and which may have an impact on the aerodynamic characteristics of the vehicle are not allowed (other than measuring equipment, i.e. GPS antenna).
- Using a trailer hook for installing the PEMS is permitted but its power supply shall not be used for the PEMS equipment. It is permitted however, to power any safety-related illumination of fixtures (like licence plate lights and safety indicators) by the vehicle's battery, as stated in point 3.4.6 of Appendix I of Regulation 2016/646.
- Towing a trailer is possible as long as the trip requirements in the RDE Regulation can be fulfilled (speed, acceleration, payload, etc.) and it remains within the manufacturers recommendations for the use of trailers. For instance towing a wheel rotational speed sensor to measure vehicle speed is allowed.
- The tyre types and pressure shall be according to the vehicle manufacturer's recommendations. The tyres shall have tread depth as recommended by customer safety associations (i.e. at least 3mm of tread depth for summer tyres and 4 mm for winter tyres).
- The vehicle physical configuration as described under the points above should not be modified during a test (i.e. changing the tyre pressure during an on-going PEMS test is not allowed).

- A vehicle whose operating fluids (i.e. lubricant, coolant, urea, and fuel) do not follow the vehicle manufacturer's recommendations is not eligible for official RDE tests.
- Lubricating oil, fuel, and reagents must be collected before the start of the test and a sample, in quantity enough to allow future chemical analysis of their composition and they should be properly kept for at least 1 year only if the results of the tests are above the Not-to-exceed emission limits (NTE).
- For diesel vehicles: if the urea tank level does not guarantee the completion of the RDE testing, the reagent must be refilled prior to testing. Warnings/reagent level in the dashboard shall be checked prior the test.
- For RDE tests, the vehicle On-Board Diagnostics (OBD) shall be checked and documented at the selection stage. Any issue, as listed in Table 6, makes the vehicle not eligible for RDE testing.

Table 6. List of OBD issues making the vehicle non-eligible for RDE-TA and RDE-ISC tests

Fault memory (Mode 7, Mode 3)
MIL-Status
Visual check of the MIL
If any red or orange alarm lights are present on the dashboard, the vehicle may not be eligible; Check against tuning
The test shall not to be performed when the SCR system is under driver warning system.

4.3. Vehicle information reporting


To ensure a complete traceability of the PEMS tests it is advised to register and report a set of data of the vehicle, the equipment used as well as the trip. For RDE-TA and RDE-ISC tests there is a fixed set of mandatory parameters of the vehicle to be recorded (specified by Regulation 2017/1151 and RDE LDV regulations) indicated with an M in Table 7. Additional recommended parameters to be recorded on a case-by-case basis for RDE tests, and other types of PEMS tests, are indicated with the letter O. The equipment and trip parameters to be recorded are specified in Table 5 and Table 9, respectively.

Table 7. Vehicle information to be reported

Code [1]	RDE TA	RDE ISC	Other PEMS testing	Parameter	Description/Unit
7	M	M	O	Vehicle type	[Vehicle name]
8	M	M	O	Vehicle manufacturer	[name]
9	M	M	O	Vehicle model year	[year]
10	M	M	O	Vehicle ID	[VIN code]
11	M	M	O	Odometer value at test start	[km]

[1] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.

Table 7. Vehicle information to be reported (continue)

Code [1]	RDE TA	RDE ISC	Other PEMS testing	Parameter	Description/Unit
13	M	M	O	Vehicle category	[category]
14	M	M	O	Type approval emissions norm	[Euro X]
15	M	M	O	Engine type	[e.g., spark ignition, compression ignition]
16	M	M	O	Engine rated power	[kW]
17	M	M	O	Peak torque	[Nm]
18	M	M	O	Engine displacement	[ccm]
19	M	M	O	Transmission	[e.g., manual, automatic, CVT]
20	M	M	O	Number of forward gears	[#]
21	M	M	O	Fuel type	[e.g., gasoline, diesel]
22	M	M	O	Lubricant	[product label]
23	M	M	O	Tyre size	[width/height/rim diameter]
24	M	M	O	Front and rear axle tyre pressure	[bar; bar]
25	M	M	O	Road load parameters	[F_0, F_1, F_2]
26	M	M	O	Type-approval test cycle	[NEDC, WLTC]
27	M	M	O	Type-approval CO_2 emissions	[g/km]
28	M	M	O	CO_2 emissions in WLTC mode Low	[g/km]
29	M	M	O	CO_2 emissions in WLTC mode Mid	[g/km]
30	M	M	O	CO_2 emissions in WLTC mode High	[g/km]
31	M	M	O	CO_2 emissions in WLTC mode Extra High	[g/km]
32	M	M	O	Vehicle test mass[2]	[kg]
-	O	O	O	Wheel drive mode	[2-wheel driving, 4-wheel driving]

[1] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.
[2] Mass of the vehicle as tested on the road, including the mass of the driver and all PEMS components.

Table 7. Vehicle information to be reported (continue)

Code [1]	RDE TA	RDE ISC	Other PEMS testing	Parameter	Description/Unit
-	O	O	O	Is the vehicle equipped with start-stop technology?	[Yes, No]
-	O	O	O	Is the vehicle equipped with a particle filter?	[Yes, No]
-	O	O	O	Is the vehicle equipped with SCR technology?	[Yes, No]
-	O	O	O	Is the vehicle equipped with EGR technology?	[Yes, No]
-	O	O	O	Is the vehicle equipped with LNT technology?	[Yes, No]

Figure 2. Vehicles equipped with a roof box (left) or loaders that modify the aerodynamic characteristics of a vehicle (right) are not eligible for RDE-TA and RDE-ISC testing.

[1] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.
[2] Mass of the vehicle as tested on the road, including the mass of the driver and all PEMS components.

5. Test conditions [Under which conditions to test the vehicle?]

5.1. Test conditions

Emissions performance shall be demonstrated by testing vehicles on the road operated over their normal driving patterns, conditions and payloads. For RDE-TA, and RDE-ISC testing, the test conditions must fulfil the requirements of the RDE-LDV regulations. The main requirements are shown in Table 8. For other types of PEMS testing, anything is in principle possible, provided that the testing conditions do not compromise safety and the instrumentation functioning.

Table 8. Overview of testing conditions

Condition	RDE-TA & RDE-ISC requirements	Recommendations and suggestions for other PEMS tests
Test duration	90 to 120 minutes	When the duration is greater than 120 minutes, attention shall be paid to the risk of instrumentation drift and automated zero-checks of the measurement equipment are recommended
Engine start	In order to assess the emissions during trips in hot start, a certain number of vehicles per PEMS test family shall be tested with a warm engine. An engine can be considered as warm when the vehicle has been driving with the internal combustion engine before the hot RDE test at least for 5 minutes (preferably 10 minutes). It is recommended to check in addition, the engine temperature dashboard indication.	Any temperature (coolant, oil) may be used for checking the conditioning of the combustion engine. When the ECU signals are being monitored, it is possible to consider the engine as warm when the engine coolant temperature reaches 70 ºC.

Table 8. Overview of testing conditions (continue)

Condition	RDE-TA & RDE-ISC requirements	Recommendations and suggestions for other PEMS tests
Test route requirements - Urban, rural and motorway definitions and shares	- Urban, rural and motorway driving defined by speed: City: ≤ 60 km/h Rural: >60 km/h and ≤ 90 km/h Highway: >90 km/h For N2 vehicles with a device limiting speed to 90 km/h: Rural: >60 km/h and ≤ 80 km/h Highway: >80 km/h - Urban, rural and motorway driving minimum distance: 16 km - Distance shares: City: ≥29% and ≤ 44 % Rural: ≥23% and ≤ 43 % Highway: ≥23% and ≤ 43 % The vehicle velocity shall normally not exceed 145 km/h. This maximum speed may be exceeded by a tolerance of 15 km/h for not more than 3 % of the time duration of the motorway driving. Local speed limits remain in force at a PEMS test, notwithstanding other legal consequences.	A trip with any combination containing varying percentages of urban, rural and motorway driving is permitted. The vehicle velocity may exceed 145 km/h in roads where this is permitted (e.g. motorways with no speed limit).
Test route requirements - Average speed and stop times	- Urban average speed: ≥15 km/h and ≤ 40 km/h - Cold start average speed including stops: ≥15 km/h and ≤ 40 km/h - Cold start maximum speed ≤ 60 km/h - Stop periods (when vehicle speed < 1km/h) shall account for 6 – 30% of time duration of urban phase. No stop shall exceed 300 seconds or the trip will be voided. - Stop period during cold start ≤ 90 seconds	No requirements
Ambient conditions - Temperature	- Moderate: ≥ 0°C and ≤ 30°C - Extended: (≥ -7°C and < 0°C) or (> 30°C and ≤ 35°C) Derogation limits(1): - Moderate: 3°C to 30°C - Extended: -2°C to <3°C and >30°C to 35°C	No requirements

[1]Derogation limits apply until

	Vehicles of categories M1 and M2	Vehicles of category N1 (class II and III) and category N2
New types of vehicle	01 January 2020	01 January 2021
New vehicles	01 January 2021	01 January 2022

Vehicle categories defined in Annex II to Directive 70/156/EEC

Table 8. Overview of testing conditions (continue)

Condition	RDE-TA & RDE-ISC requirements	Recommendations and suggestions for other PEMS tests
Ambient conditions - Altitude	- Moderate: ≤ 700 m above sea level - Extended: >700 m and ≤ 1300m above sea level - Maximum altitude difference between start and end point: 100 m - Maximum cumulative altitude gain: 1200 m per 100km. Valid for both the urban and total trip.	No requirements. Attention shall be paid to potential and automated altitude corrections in the instruments, which might not be applicable outside the RDE ranges.
Road condition	RDE-TA and RDE-ISC cannot be performed on unpaved roads. In addition, even though the RDE LDV regulations do not specify this point, common sense and safety recommend avoiding extreme weather conditions (mud, icy roads, fresh snow).	Same as for RDE are recommended.
Fuel, lubricating oil, reagent	Vehicles must use market fuel, oil, and reagent, always following the recommendations of the vehicle's manufacturer. It is required to collect a sample of the test fuel(s), oil and reagent(s) for RDE tests whenever the emissions are above the NTE.	Vehicles should follow the recommendations of the vehicle's manufacturer.
Driving Time	PEMS emissions tests should be conducted during normal working days (Monday to Friday). Recommended hours range from 7am to 8pm.	No requirements.
Vehicle payload	The vehicle's basic payload shall comprise the driver, a witness of the test (if applicable) and the test equipment, including the mounting and the power supply devices. The total shall not exceed 90% of the vehicle's permissible payload.	The total shall not exceed 100% of the vehicle's permissible payload.

Table 8. Overview of testing conditions (continue)

Condition	RDE-TA & RDE-ISC requirements	Recommendations and suggestions for other PEMS tests
Vehicle pre-conditioning	Before an RDE-TA or RDE-ISC test, the vehicle has to be driven for at least 30 minutes in normal roads, parked with doors and bonnet closed and kept in engine-off status between 6 and 56 hours within moderate or extended altitude and temperatures conditions. It is recommended to drive at least 20 to 25 minutes on the motorway to limit the risk of regeneration of the DPF during the actual test. In general terms, the recommendations regarding the use of vehicle air-conditioning, auxiliary devices, payload, road condition, gear shifting, tyre conditions and the driver behaviour apply to the pre-conditioning drive. When several RDE tests are conducted in consecutive days, the previous day RDE test can be used as pre-conditioning drive for the current day test. Problems identified during the pre-conditioning and the total soaking time should be reported. It is not necessary to make use of the PEMS instruments during the pre-conditioning drive. However, its use is encouraged to identify potential problems with the instrumentation performance or in the recording that may prevent/delay the actual RDE test. During the parking in low temperatures it might be wise to heat the PEMS equipment using an external source in order to avoid issues of condensation. For a hot RDE test, no preconditioning is required and it may follow a cold RDE test with or without turning off the engine. It may be then required to change/charge batteries for the PEMS systems.	Same as for RDE recommended
Vehicle air-conditioning and auxiliary devices	The air conditioning system or other auxiliary devices can be operated in a way which corresponds to their possible use by a consumer at real driving on the road. Any misuse of the air-conditioning system should be avoided, such as for instance using it with open windows, if not needed for the measuring equipment. The recommended temperature for the comfort of the passenger(s) is in the range of 20 to 24°C. - All original auxiliary devices available to the user are allowed (i.e. only original devices from the Original Equipment Manufacturer and not retrofitted equipment). Electrical auxiliaries that are automatically shut-down when their goal is achieved (i.e. rear window heating, mirror heating, etc.) should only be re-started again if actually needed for a safe driving.	

Table 8. Overview of testing conditions (continue)

Condition	RDE-TA & RDE-ISC requirements	Recommendations and suggestions for other PEMS tests
Vehicle gear shift and operating modes	When several gear shift and/or vehicle operating modes are available the vehicle can be tested under any mode: eco, standard, or sport with the exception of the off-road modes (for non-paved roads). It is however recommended to use the predominant mode, including the D (drive) mode for automatic transmissions. In case a vehicle has a "race" mode, to be used only on test tracks, this mode shall not be used for RDE testing, as safety features might be disabled.	Same as for RDE
Vehicle battery	Vehicles should not be tested with an empty battery. In case the vehicle has problems starting, the battery may be replaced following the recommendations of the vehicle's manufacturer. The vehicle shall then be pre-conditioned as indicated above and tested. It is possible to charge the battery prior to the pre-conditioning test but not before an actual RDE-TA or RDE-ISC tests.	Vehicles should not be tested with an empty/faulty battery. In case it is needed, the battery may be charged/replaced prior the vehicle conditioning.
Vehicle tyres	The tyre types and pressure shall be according to the vehicle's manufacturer recommendations. The tyre pressure shall be checked prior to the pre-conditioning and adjusted to the recommended values if needed. The tyre profile depth should be verified according to the recommendations of customer safety associations (e.g. ADAC), but should have at least 3mm of tread depth for summer tyres and 4 mm for winter tyres. The use of chains is not permitted since the RDE trip speed requirements cannot be fulfilled and it is not recommended to drive on snow during RDE tests.	Same as for RDE, except for the chains

5.2. Selection of test routes for RDE testing

Any publicly available trip planner may be used to define a route which is likely to result as compliant according to the RDE trip requirements, in particular with the urban/rural/motorway distance shares, the altitude difference between the start and end point and the cumulative altitude gain. The trip shall always start with the urban part which should be driven on urban roads with a speed limit of 60 km/h or less. In case the urban part of the trip needs to be driven for a limited period of time on roads with speed limit higher than 60 km/h, the vehicle shall be driven with speeds up to 60 km/h. The trip must start with the urban driving followed by the rural and the motorway. Any combination of trips is acceptable (such as URMRMU) as long as the percentages are kept and the trip starts with an urban portion of at least 16 km. The trip may also start and end at the same point. The vehicle's velocity shall be above 100 km/h for at least 5 minutes. For M2 and N2 category

vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 100 km/h and 90 km/h, the speed range of the motorway driving be above 90 km/h and 80 km/h for at least 5 minutes, respectively.

Once the trip or trips are defined, it is recommended to "try" them, using a data logger to record the vehicle speed and altitude. It is recommended to conduct such tests during the times of the day which are intended for the complete RDE test with the PEMS. Depending on the local traffic situation and potential traffic jams, it is also advisable to design alternative routes and/or local detours. It is also recommended to avoid using the same street more than twice in a specific route.

It is suggested not to always select the same route for each RDE test, but to vary them. It is also recommended to perform the hot RDE test on the exact same route as equivalent cold ones. *Geofencing* (i.e. any sensing of the vehicle of its position for the purposes of modifying the emission behaviour) is strictly forbidden.

5.3. Recommendations to drivers

The drivers shall be instructed and trained according to the health, work safety, and road safety regulations in force locally. Local speed limits remain in force during a PEMS test, notwithstanding other legal consequences. Note however, that violations of local speed limits per se do not invalidate the results of an RDE-TA or RDE-ISC test.

For RDE-TA and RDE-ISC tests:

- The driver shall be at least informed about the trip composition requirements, stop requirements, and the recommendations regarding the vehicle systems (i.e. air conditioning, use of auxiliaries). Drivers shall be acquainted with the fact that temporarily exceed the speed boundaries (60 and 90 km/h) of RDE urban/rural/motorway phases is allowed as long as it does not compromise the distance and shares requirements. For instance, attention shall be paid to the section intended for rural driving where the vehicle speed should not exceed 90 km/h, otherwise risking decreasing the rural driving share to the benefit of the motorway driving and eventually making the trip invalid.
- The driver should be aware that the vehicle stop (vehicle speed < 1 km/h) during the entire cold start period shall be kept to the minimum possible and it shall not exceed 90 s. In addition, the idling immediately after the first ignition of the combustion engine shall be kept to the minimum possible and it shall not exceed 15 s. Ensuring a proper GPS connection shall therefore be done prior to the first engine start to fulfill the 2 criteria cited above.
- Any biased driving should be avoided, such as repeatedly pumping with the accelerator pedal, even if it would be needed in order to keep within some of the boundaries.
- For manual transmission vehicles, it is recommended that the driver follows as much as possible the gear shift indicator (GSI). The advice is to be no more than 1 gear up or down from the GSI.
- The driver must know that if the engine stalls during the test, it may be restarted, but the sampling shall not be interrupted. Repeated stalling of the engine (suddenly turned off) should be avoided during an RDE trip.
- The driver should circulate on the road in a way which corresponds to the normal traffic situation. The use of RDE-driver aid software is allowed as long as it does not interfere with safety. For other types of PEMS testing, the use of driver-aid software is left to the discretion of the tester and it is recommended to log the driving attitude of the driver (defensive/following traffic/aggressive).

5.4. Test information reporting

 For RDE-TA and RDE-ISC testing, it is mandatory to check and to record the data listed as M in Table 9. The parameters marked as TS in the *Code* column are the time-series recorded during the PEMS test. The time-series must include all the elements recorded during the operation of the instruments at their sample frequency. For other types of PEMS testing, the recommended information is indicated with the letter O.

Table 9. Testing conditions to be recorded

Code [1]	RDE TA	RDE ISC	Other PEMS testing	Parameter	Description/Unit
1	M	M	O	Test ID	[code]
2	M	M	O	Test date	[day.month.year]
3	M	M	O	Organisation supervising the test	[name of the organisation]
4	M	M	O	Test location	[city, country]
5	M	M	O	Person supervising the test	[name of the principal supervisor]
6	M	M	O	Vehicle driver	[name of the driver]
57	M	M	O	Start time of pre-test procedure	[h:min]
58	M	M	O	Start time of trip	[h:min]
59	M	M	O	Start time of post-test procedure	[h:min]
60	M	M	O	End time of pre-test procedure	[h:min]
61	M	M	O	End time of trip	[h:min]
62	M	M	O	End time of post-test procedure	[h:min]
TS	M	M	O	Test time	[s]
TS	M	M	O	CO_2 mass; CO_2 flow rate (sensor)	[ppm; g/s]
TS	M	M	O	CO mass; CO flow rate (sensor)	[ppm; g/s]

[1] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.

Table 9. Testing conditions to be recorded (continue)

Code [1]	RDE TA	RDE ISC	Other PEMS testing	Parameter	Description/Unit
TS	M	M	O	NO_2 mass flow rate (sensor) [5]	[ppm; g/s]
TS	M	M	O	NO mass flow rate (sensor) [5]	[ppm; g/s]
TS	M	M	O	NO_x mass flow rate (sensor) [5]	[ppm; g/s]
TS	M	M	O	GPS Vehicle speed[2]	[km/h]
TS	-	O	O	ECU Vehicle speed[2]	[km/h]
TS	O	O	O	Sensor Vehicle speed[2]	[km/h]
TS	M	M	O	Latitude (GPS)	[deg:min:s]
TS	M	M	O	Longitude (GPS)	[deg:min:s]
TS	O	O	O	GPS altitude[3]	[m]
TS	O	O	O	Sensor altitude[3]	[m]
TS	M	M	O	Ambient pressure (sensor)	[kPa]
TS	M	M	O	Ambient temperature (sensor)	[K]
TS	M	M	O	Ambient humidity (sensor)	[g/kg; %]
TS	-	O	O	Engine speed (ECU)[4]	[rpm]
TS	-	O	O	Engine coolant temperature (ECU)[4]	[K]
TS	-	O	O	Engine oil temperature (ECU)[4]	[K]
TS	-	O	O	Regeneration status (ECU)[4]	[-]
TS	-	O	O	Pedal position (ECU)[4]	[%]
TS	-	O	O	Vehicle status (ECU)[4]	[error 1; normal 0]
TS	-	O	O	State of charge (ECU)[4]	[%]
TS	-	O	O	Engine torque (ECU)[4]	[Nm]
TS	-	O	O	Fuel rate (ECU)[4]	[g/s]

[1] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.
[2] To be determined by at least one method for RDE-ISC. For RDE-TA, recording the vehicle speed from the ECU is not permitted.
[3] To be determined by at least one method, although pressure sensor is the recommended option for retrieving the altitude.
[4] It is not permitted to record ECU signals during RDE-TA tests.
[5] NO_x may be either measured or calculated from measured NO and NO_2 concentrations.

Table 9. Testing conditions to be recorded (continue)

Code	RDE TA	RDE ISC	Other PEMS testing	Parameter	Description/Unit
TS	-	O	O	Engine fuel flow (ECU)[4]	[g/s]
TS	-	O	O	Engine intake fuel flow (ECU)[4]	[g/s]
TS	O	O	O	O_2 mass flow rate (sensor)	[ppm; g/s]
TS	O	O	O	THC mass flow rate (sensor)	[ppm; g/s]
TS	O	O	O	CH_4 mass flow rate (sensor)	[ppm; g/s]
TS	O	O	O	NMHC mass flow rate (sensor)	[ppm; g/s]
TS	O	O	O	Hybrid battery State of Charge (ECU or power analyser)	[%]
TS	O	O	O	Hybrid battery current(ECU or power analyser)	[A]
TS	O	O	O	Hybrid battery voltage (ECU or power analyser)	[V]

6. Test Protocol [How to conduct the test?]

This section presents a comprehensive overview of the emissions testing protocol with PEMS on-board LDV. The aim is to provide guidance through the whole PEMS testing process including safety tips on the installation and usage of the equipment. The step by step description is the result of the experience of PEMS testing on LDV at the Joint Research Centre.

The test protocol shall be adapted on a case-by-case situation depending on the vehicle to be tested, the available PEMS instruments, and the type of test. It is also a good practice to document the installation of the instruments with pictures for traceability matters.

6.1. Installation of instruments (Detailed by PEMS component)

STEP 1. Installation of the PEMS main unit

The main PEMS main shall be installed according to the specifications of the instruments supplier, in such a way that it minimises electromagnetic interferences, exposition to dust, shocks, vibrations and excessive heating (Figure 3). In addition, the installation and operation of the PEMS shall be leak-tight and minimise heat losses. Access to the test equipment shall not be prevented – in view of the potential checks during or between the tests.

The main unit should be secured with load straps or according to the instrument supplier recommendations (Figure 3).

When the unit is installed inside the vehicle, the PEMS unit should be equipped with gas monitors or warning systems for hazardous gases (e.g. CO).

The mounting location should be chosen so that the unit's cooling fans are unobstructed. Sample stream exhaust lines should be routed outside of the vehicle's cabin in order to prevent contamination of the vehicle cabin environment. These lines should be routed in such a manner as to prevent pinching or rupturing and should be without strains in order to prevent damage due to vibrations.

Figure 3. left) installation of PEMS main units outside the vehicle; right) securing the instruments with straps inside the vehicle

STEP 2. Selection of the exhaust flow meter range

For RDE tests, the exhaust mass flow has to be measured by means of an EFM. The measurement range of the EFM shall match the range of the exhaust mass flow rate expected during the test. Refer to the PEMS user's manual for the selection of the EFM range.

STEP 3. Installation of the exhaust flow meter

Whenever used, the exhaust mass flow meter shall be attached to the vehicle's tailpipe(s) in accordance with the recommendations of the EFM manufacturer. The EFM shall not change the nature of the exhaust gas nor unduly increase the length of the tailpipe or increase the pressure at the exhaust outlet. It is advisable that the additional backpressure does not exceed 20 mbar. Any bend in the exhaust pipe should be smooth and of sufficient radius (sharp 90-degree bends can affect the exhaust flow readings).

 To avoid damage to the engine or negatively affect exhaust-after-treatment systems a minimum of four pipe diameters or 150 mm of straight tubing, whichever is larger, shall be placed at either side of the flow-sensing element.

For the installation of the EFM, different solutions are available, depending on exhaust configuration and expected exhaust temperatures.

- *Solution 1 (recommended): Clamping and fixation point*
  The first solution is to weld two identical flanges on the tailpipe and on one end of the EFM. These two flanges should then be clamped whereas a sealing material must be used to minimise exhaust leakage. This solution is safe, makes easy the installation and possible re-installation of the EFM and also eliminates the risk to see the alignment of the Pitot tubes modified because of vibrations.
- *Solution 2: Specific tailpipe adapters* (Figure 4)

 A fixation point is always needed to secure the EFM (Figure 4).

 To prevent heating and possible damages, the outlet of the EFM should not be directed towards a tyre or other vehicle components.

 In case silicon tubes (secured with collars) are used to attach the EFM to the vehicle's tailpipe, the silicon must never be directly in contact with the exhaust gas since new silicon ducting in contact with the exhaust gas at high temperature may generate large amounts of particles.

Remarks:

- The clamps and the mounting of the EFM should be visually inspected before the initial test cycle and between each subsequent test cycle.
- The Pitot sensor should be placed between two pieces of straight tube whose length should be at least 5 times the Pitot diameter (upstream and downstream).
- The EFM shall be placed after the vehicle silencer (if any), to limit the effect of exhaust gas pulsations upon the measurements.
- It is recommended to insulate the outlet of the Pitot tubes to limit water condensation at low temperatures.
- The EFM, once mounted should not prevent the access to important vehicle functions such as the spare wheel, fuses, etc. since those may be needed on the road. In case a tyre or a fuse has to be changed during an official RDE test that test will be voided.
- For dual exhaust configurations, it is recommended that Y-connection shall be implemented so that the entire exhaust stream is sampled by the exhaust flow meter test section.
- When testing a multi-cylinder engine with a branched exhaust manifold, it is recommended to position the exhaust mass flow meter downstream of where the manifolds combine and to increase the cross section of the piping such as to have an equivalent, or larger, cross sectional area from which to sample. If this is not feasible, exhaust flow measurements with several exhaust mass flow meters may be used.
- The thermocouple to measure the exhaust temperature is part of the EFM.
- According to instrument manufacturers' specifications, EFM can stand exhaust temperatures of at least 600°C in continuous operation.
- It is a good practice to document the EFM set-up using photographs (Figure 5).
-

Figure 4. EFM Installation left) using a tailpipe adaptor; right) tubes and collars on a dual exhaust

Figure 5. left) examples of EFM installation when the PEMS main unit is installed inside the vehicle; right) proper signalling of the EFM

STEP 4. Mounting of the GPS antenna

The antenna should be mounted at the highest possible location, without risking interference with any obstructions encountered during on-road operation. Mounting is accomplished with either a magnetic or fixed mount post (Figure 6).

Figure 6. Installation examples for the GPS antenna and the weather station

STEP 5. Preparation of the ECU communication cables

If desired in other type of PEMS testing, relevant vehicle and engine parameters listed in Table 2 can be recorded by using a data logger connected with the ECU or the vehicle network through standards, such as ISO 15031-5 or SAE J1979, OBD-II, EOBD or WWH-OBD. If applicable, manufacturers shall disclose the labels which would allow the proper identification of required parameters.

STEP 6. Connection and installation of the ECU communication cable

The cable shall be routed in such a manner as to provide minimum interference to vehicle occupants. In addition, the unit should be securely mounted in the cab of the test vehicle in a location that does not permit unnecessary moisture, vibration, or excessive operating temperatures (Figure 7).

Figure 7. left) connection to the vehicle ECU, right) secure mounting of a laptop connected to the OBD reader.

STEP 7. Installation of the power supply

In order to accommodate the power requirements of a complete PEMS system, it is recommended to use a set of rechargeable batteries (AGM, gel, or lithium-ion) as light as possible. These batteries do not offer a great advantage in terms of volume, weight and flexibility. However, they are the only possibility for small vehicles, for which the noise and the exhaust gas from a generator would not be acceptable.

The batteries shall be safely installed on the vehicle. The use of straps to securely attach them to the vehicle chassis is recommended (Figure 8).

Figure 8. left) Charging of the batteries; right) batteries to operate the PEMS, located in the trunk, properly secured with straps

Remark: When measuring THC emissions with PEMS, the heated probe and the heated FID are responsible for a significant part of the power consumption. For some configurations, cold ambient temperatures and highway driving conditions (forced cooling) may significantly affect the behaviour of the heated probe and its temperature control.

STEP 8. Installation of the weather station

Install the weather station on the outside of the cab in a location that is shielded from direct air-flow and contamination from debris. The location should be as close to the intake air flow as possible. The temperature sensor should be shielded from any warm-up effects like sunshine or hot air coming from the vehicle engine or exhaust. The mounting location of the ambient absolute pressure transducer shall be selected such that air motion effects on the sensor are minimised (Figure 6).

STEP 9. Connection of the heated probe (gas analysers)

Connect the inlet of the heated sampling line to the sampling probe port located on the exhaust flow rate measurement tube. Connect the outlet of the heated sampling line to the inlet port on the PEMS exhaust sample conditioning unit.

Any replacement involving a modification of the length of the heated probe should be avoided, due to the associated variations that would be observed in system transport times. If the PEMS main unit is installed in the trunk, it is recommended that the sampling line be routed through side windows or access doors (Figure 9). When installed outside, the heated probe shall be routed in a way to secure visibility for the driver and minimise aerodynamic resistance (Figure 9).

Make sure that the heated probe is properly insulated, especially at the connection points: EFM and back of the analysers, to avoid cold spots potentially causing errors in emissions measurements (e.g. condensation and evaporation of gases).

Figure 9. Routing heated probe left) from the inside of the vehicle; right) outside of the vehicle

STEP 10. Connection of other tubes and cables

Connect the different cables and tubes as described in the manuals of the instruments.

The wiring should be routed in such a manner as to prevent pinching and should be free of strains in order to prevent damage due to vibrations and relative movement between vehicle chassis/body components.

6.2. Pre-Test Procedures

STEP 11. Check connections and wirings

To be made every > 3 to 5 Tests

Prior to supplying power to the instruments, visually inspect and touch all connections to check if they are loose, possibly due to vibrations.

STEP 12. Verify the PEMS power supply batteries charge level

To be made every > Single Test

STEP 13. Power-up the main software

To be made every > Single Test

It is recommended to follow the PEMS manufacturer initialisation procedure of the software to guarantee the operability of all the instruments.

STEP 14. Starting and stabilizing the main unit.

To be made every > Day (Better is to keep equipment in stand-by once installed)

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

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

STEP 15. Check of zero level of the analysers

To be made every > Single Test

Zero and span calibration adjustments of the analysers shall be performed using calibration gases that meet the requirements of point 5 of Appendix 2 of Regulation 2016/427. The zero response drift, defined as the mean response to zero flow during a time interval of at least 30 seconds, has to be less than ±2 per cent of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated over a period of 4 hours (pre-test vs post-test are compared to calculate zero level drift).

For RDE tests, it is required to use HEPA filtered air for the PN analyser to perform the zero level test, according to the requirements laid down in Regulations 2016/427 Appendix 1, point 4.6. The signal shall be recorded at a constant frequency of 1 Hz averaged over a period of 2 minutes; the final concentration shall be within the manufacturer's specifications, but shall not exceed 5 000 particles per cubic centimetre

For non-official RDE tests, when ambient air is used to zero the analysers, make sure that the air is not sampled near a contamination source (e.g. other engine).

STEP 16. Span calibration of the analysers

To be made every > Single Test

The calibration gases shall be chosen to match the range of pollutant concentrations expected during the emissions test. The calibration span of the emissions analysers shall be performed using the span-gas concentrations recommended by the instruments manufacturer.

For RDE tests, the calibration gases shall fulfill the requirements laid down in Regulations 2016/427, Appendix 2, Section 5. In particular, the span response drift, defined as the mean response to a span flow during a time interval of at least 30 seconds, shall be less than ± 2 per cent of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated over a period of 4 hours (pre-test vs post-test are compared to calculate zero level drift).

For a test scenario in which the vehicle is tested on a long trip, the span gas bottles can be stored in the workshop or near the vehicle parking spot.

STEP 17. Archiving zero level and span calibration data

To be made every > Single Test

 Zero and calibration span records must be archived, including the results before and after the PEMS testing, and the details of the gases used.

For RDE tests, the zero and span calibration shall be conducted according to the requirements laid down in the Regulation 2016/427 and the data listed in Table 10 shall be recorded (M and O stand for mandatory and optional requirements, respectively).

Table 10. Pre-test analysers' verification records

Code[1]	RDE TA	RDE ISC	Other PEMS testing	Item	Unit
81	O	O	O	Span reference value THC	[ppm]
82	O	O	O	Span reference value CH_4	[ppm]
84	O	O	O	Span reference value O_2	[%]
85	M	M	O	Span reference value PN	[#]
86	M	M	O	Span reference value CO	[ppm]
87	M	M	O	Span reference value CO_2	[%]
88	M	M	O	Span reference value NO	[ppm]
89	M	M	O	Span Reference Value NO_2	[ppm]
96	O	O	O	Pre-test zero response THC	[ppm]
97	O	O	O	Pre-test zero response CH_4	[ppm]

[1] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.

Table 10. Pre-test analysers' verification records (continue)

Code[1]	RDE TA	RDE ISC	Other PEMS testing	Item	Unit
99	O	O	O	Pre-test zero response O_2	[%]
100	M	M	O	Pre-test zero response PN	[#]
101	M	M	O	Pre-test zero response CO	[ppm]
102	M	M	O	Pre-test zero response CO_2	[%]
103	M	M	O	Pre-test zero response NO	[ppm]
104	M	M	O	Pre-test zero response NO_2	[ppm]
105	O	O	O	Pre-test span response THC	[ppm]
106	O	O	O	Pre-test span response CH_4	[ppm]
108	O	O	O	Pre-test span response O_2	[%]
109	M	M	O	Pre-test span response PN	[#]
110	M	M	O	Pre-test span response CO	[ppm]
111	M	M	O	Pre-test span response CO_2	[%]
112	M	M	O	Pre-test span response NO	[ppm]
113	M	M	O	Pre-test span response NO_2	[ppm]

STEP 18. Exhaust flow meter cleaning

To be made every > Single Test

For RDE tests, when the EFM is used to measure the exhaust mass flow, it shall be purged and prepared for operation in accordance with the specifications of the EFM manufacturer. This procedure shall, if applicable, remove condensation and deposits from the lines and the associated measurement ports.

It is recommended to clean the EFM by purging the pressure transducer connections with pressurised clean air or nitrogen. This back-flush procedure is used to remove condensation and diesel particulate matter from the pressure lines and associated flow tube pressure measurement ports.

[1] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.

STEP 19. Analyser System Leak Check

To be made every > Every new PEMS installation

This procedure should be conducted according to the recommendations provided by the instrument manufacturer or as follows (Text from Regulations 2016/427, 2016/646, 2017/1151, 2017/1154 and amendments, Appendix 1, Section 4.1).

The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilization period all flow meters shall read approximately zero in the absence of a leak. Else, the sampling lines shall be checked and the fault corrected. The leakage rate on the vacuum side shall not exceed 0.5 per cent of the in-use flow rate for the portion of the system being checked. The analyser flows and bypass flows may be used to estimate the in-use flow rates.

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

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

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

STEP 20. Calibration of the flow meter

To be made every > Single Test

Before every PEMS test, the EFM has to be calibrated in accordance with the specifications of the EFM manufacturer. It is recommended to visually check the EFM zero flow and verify it from the PEMS data logged before the combustion engine starts.

STEP 21. Switch to batteries power.

This can be done shortly before the test starts. Otherwise, standard 230V electrical power should be used from a building, in particular to warm up the instruments.

STEP 22. Check that data acquisition storage media and backup have sufficient space.

To be made every > Single Test

STEP 23. Check GPS

To be made every > Single Test

Check GPS signals and GPS status.

The GPS signal shall be logged from the first sec.

Care has to be taken to avoid prolonged idling of the vehicle while waiting for GPS signal since this may void the test for exceeding the maximum stop time from RDE requirements.

STEP 24. Start the engine

To be made every > Single Test

Start the engine for cold-start test. For warm engine condition tests, the engine may be kept on after the heating up driving, or in between PEMS tests.

STEP 25. When applicable, Check ECU communication

To be made every > Every new PEMS installation

When applicable, check that the system is correctly displaying and recording ECU data.

STEP 26. When applicable, Qualification of ECU signals

To be made every > Every new PEMS installation

 ECU engine data broadcasts should be qualified with a secondary measurement device during each PEMS installation. After the secondary measurement device is installed the engine should be operated throughout the data ranges. Data should be logged using the ECU verification procedure of the PEMS data acquisition program. Any observed inconsistencies between the ECU broadcast data and the measurements made with the secondary technique should be recorded in the pre-test data sheet(s).

STEP 27. Qualification of ambient temperature and humidity sensors

To be made every > Every new PEMS installation

Ambient temperature and pressure measurements must be made with independent devices (non ECU) and compared to pre-test values measured with the weather station of the PEMS.

STEP 28. Verify that all temperature controllers are set at the correct operating values

To be made every > Single Test

STEP 29. Spot check

To be made every > Every new PEMS installation

Log onto the data acquisition computer and start the PEMS data acquisition program. Verify that all pertinent data is being recorded (spot check).

STEP 30. Pre-test (Optional)

To be made every > Every new PEMS installation

 To check the correct installation and functioning of the PEMS instruments before an on-road test, the test vehicle may be operated during a few minutes. All the data shall be recorded during this procedure and checked.

For RDE-TA and RDE-ISC tests, it is highly recommended to conduct a validation test according to Appendix 3 of Regulation 2016/427, before or after the actual PEMS test. Such a test will evaluate the correct installation and functionality of the PEMS 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. For the validation of the PEMS installation it is recommended to follow the best practices contained in the Joint Research Centre guidance note[1].

As a pre-test inspection, the exhaust flow rate measurement pressure transducers signal and emissions measurement system integrity shall be verified by acquiring data for 30 seconds with the vehicle engine idling in warm conditions. This data should be examined for any anomalies, and corrective measures should be initiated if any were identified.

Note that the validation test should be considered as a separate test (and hence have its own zero and span calibrations before and after the test). Such tests must be exercised with care: Installation of EFMs (equipped with sensitive pressure transducers), the selection and the design of the sampling points are of great importance and shall be conducted using the best available engineering practice.

Once verified and correctly set in the PEMS, the time alignment settings shall not be changed during the following tests.

STEP 31. Verification of pre-test data

To be made every > Single Test or Every new PEMS installation

The following data screening is recommended:

- Analysers concentrations: check for the measured ranges, eventual range saturation and negative values;
- Vehicle ground speed, comparing the values from the ECU (when applicable) and from the GPS;
- Exhaust mass flow, comparing the direct measurement of the EFM to a 'backup' value (e.g. the exhaust mass flow recalculated from ECU fuel mass flow and A/F ratio);
- Ambient conditions, comparing the values from the weather station to the ones given by the vehicle ECU.

STEPS 26 to 31 are recommended for series of tests conducted on the same vehicle and shall be repeated for new installations.

[1] Recommendations for the validation of PEMS in the laboratory. EUR XXXXX EN, Publications Office of the European Union, Ispra, 2017, ISBN XXX-XX-XX-XXXX-X, doi: 10.2760/XXXXXX, JRCXXXXXX

6.3. Test runs

STEP 32. Normal test run

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

Data logging and sampling shall be initiated at least 60 seconds prior to the start of the engine or the trip. Sampling, measurement and recording of parameters shall continue throughout the on-road test of the vehicle. The engine may be stopped and started, but emissions sampling and parameter recording shall continue. All measurement data shall be logged for a period of 60 seconds after the test route has been completed. Any warning signals, suggesting malfunctioning of the PEMS, shall be documented and verified. If any error signal(s) of the PEMS instrumentation appear during the test, the test shall be voided.

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

6.4. Post-test

STEP 33. Conclusion of a test run

The end of the test is reached when the vehicle has completed the trip and the ignition is turned off. Excessive idling of the engine after the completion of the trip shall be avoided. The data recording shall continue until the response time of the sampling systems has elapsed.

STEP 34. Zero and span check of gas analysers

To be made every > Single Test

 Zero and span procedure should be performed on the emissions measurement sensors/analysers according to the pre-test procedures section.

For RDE tests, the zero and span check shall be conducted according to the requirements laid down in the Regulations 2016/427, 2016/646, 2017/1151, 2017/1154 regulations and their amendments and the data listed in Table 11 shall be recorded (M and O stand for mandatory and optional requirements, respectively).

Table 11. Post-test analysers verification records

Code[1]	RDE TA	RDE ISC	Other PEMS testing	Item	Unit
114	O	O	O	Post-test zero response THC	[ppm]
115	O	O	O	Post-test zero response CH_4	[ppm]
116	O	O	O	Post-test zero response NMHC	[ppm]
117	O	O	O	Post-test zero response O_2	[%]
118	M	M	O	Post-test zero response PN	[#]
119	M	M	O	Post-test zero response CO	[ppm]
120	M	M	O	Post-test zero response CO_2	[%]
121	M	M	O	Post-test zero response NO	[ppm]
122	M	M	O	Post-test zero response NO_2	[ppm]
123	O	O	O	Post-test span response THC	[ppm]
124	O	O	O	Post-test span response CH_4	[ppm]
125	O	O	O	Post-test span response NMHC	[ppm]
126	O	O	O	Post-test span response O_2	[%]
127	M	M	O	Post-test span response PN	[#]
128	M	M	O	Post-test span response CO	[ppm]
129	M	M	O	Post-test span response CO_2	[%]
130	M	M	O	Post-test span response NO	[ppm]
131	M	M	O	Post-test span response NO_2	[ppm]

STEP 35. Zero of exhaust flow-meter

To be made every > Single Test

The values displayed by the exhaust flow meter shall be referenced against pre-test values and recorded.

STEP 36. Back up test data

It is recommended to perform a backup of the test data as soon as possible after the end of the test.

[1] Code for RDE reporting according to Regulation 2016/427, Appendix 8, Table 1.

STEP 37. Verification of test data

To be made every > Single Test

Same recommendations as for STEP 31.

STEP 38. Turn off the emissions sampling system and all measurement devices

It is recommended to follow the shutdown sequence described in the manufacturer's instructions.

STEP 39. Remove power from the instruments

6.5. Conclusion of Test Series (PEMS installation)

STEP 40. Dismount PEMS equipment and restore vehicle/machine to the original configuration

To be made every > Every new PEMS installation

Disconnect the heated sampling line from the exhaust sampling port, all data cables and transducer lines, remove instruments and restore the vehicle exhaust system to its pre-test configuration.

STEP 41. Weight of the installed PEMS equipment (including batteries)

To be made every > Every new PEMS installation

The total weight of the installed equipment shall be measured and recorded.

7. Data screening [How to evaluate the quality of the measurements?]

7.1. Introduction

This section only regards the data screening recommendations, i.e. the steps which must be taken to ensure that the quality of the data is sufficient to proceed with the ex-post evaluation.

For RDE-TA and RDE-ISC tests, the mandatory ex-post evaluation is comprised of several steps:

- The actual distance shares of urban, rural and motorway.
- The potential excess of driving dynamics according to the principles laid down in Regulations 2016/427, 2016/646, 2017/1151, and 2017/1154, Appendix 7a.
- The trip overall dynamics and the cumulative altitude gain according to the principles laid down in Regulations 2016/427, 2016/646, 2017/1151, and 2017/1154, following Appendix 5 or Appendix 6.

For other types of PEMS testing, the ex-post evaluation is conducted on a case-by-case basis.

In both cases it is recommended to check the time alignment of the data according to the best available practices, and to undergo the data screening step presented in the following section.

7.2. Test data screening

At the end of each test or a series of tests, the following items may be checked prior to any data processing:

- Presence of mandatory parameters for RDE tests (0);
- Quality screening of mandatory parameters. Check for the measured ranges, possible empty ranges of data, saturation of measurement range and/or negative values (Table 12).
- Presence of zero drift and span drift results for THC, CO, NO_x (or NO/NO_2) and CO_2.
- Zero drift of the exhaust flow meter.
- Correctness of test conditions not requiring any data processing (Table 8).
- Presence of regeneration events (see 7.5).
- Signal noise level, considering that noise means two times the root mean square of ten standard deviations, each calculated from the zero responses measured at a constant recording frequency of at least 1.0 Hz during a period of 30 seconds, shall not exceed 2 % of full scale.

Should one of these items reveal problems in the quality of the data and/or the non-compliance of the testing conditions, it is not necessary to proceed to the ex-post evaluation, i.e. the emissions calculations.

Table 12. Data ranges for screening

Parameter	Recommended range for screening
Wet CO_2 [ppm]	0; 200 000
Wet O_2 [ppm]	0; 500 000
Wet CO [ppm]	0; 800 000
Wet THC [ppm]	0; 10 000
Wet NO_x [ppm]	0; 2 500
Wet NO_2 [ppm]	0; 2 500
Wet NO [ppm]	0; 2 500
PN [#/m^3]	0; 2 000 000
Exhaust mass flow []	0; 5 000
Exhaust temperature [K]	0; 1 000
Relative humidity [%]	0; 100
Atmospheric pressure [kPa]	0; 150
Ambient temperature [K]	250; 323
ECU Engine Torque [Nm]	-5 000; 5 000
ECU Engine Speed [rpm]	0; 10 000
ECU Vehicle speed [km/h]	0; 200
ECU Fuel Rate [g/s]	0; 100
ECU Coolant Temperature [K]	0; 600
GPS Latitude [degrees]	0; 180
GPS Longitude [degrees]	-80; 80
Altitude [m]	0; 5 000
GPS Vehicle speed [km/h]	0; 200

7.3. Time alignment and emissions calculation formulae

For all the emissions calculations the test parameters have to be recorded and stored with 1 Hz (RDE-TA, RDE-ISC), or at least 1 Hz (other types of PEMS testing) on a computer system. The data may be processed using the PEMS post-processors.

To minimise time lags between the various measurements and signals, the parameters relevant for emissions calculation shall be time aligned. For the time alignment, as the sampling and the measurement and recording of parameters shall

begin prior to the start of the engine, time alignment is facilitated and can be checked using the starting point of the combustion engine. "Best practice approaches" must be considered, e.g. using the relevant tools provided with each PEMS to adjust the delay times (Table 13).

Table 13. Time alignment and emissions calculations

Item	Recommendations
Time alignment of data	Regulations 2016/427, 2016/646, 2017/1151, and 2017/1154 regulations and amendments , Appendix 1
Calculation of the emissions - Calculation of the instantaneous gaseous emissions	Regulations 2016/427, 2016/646, 2017/1151, and 2017/1154 regulations and amendments , Appendix 4

7.4. Concrete example #1: Time alignment verification

The time alignment may be verified using the best practice approach, such as for instance, verifying the gaseous concentrations rising after engine start or the alignment of correlated signals (Figure 10).

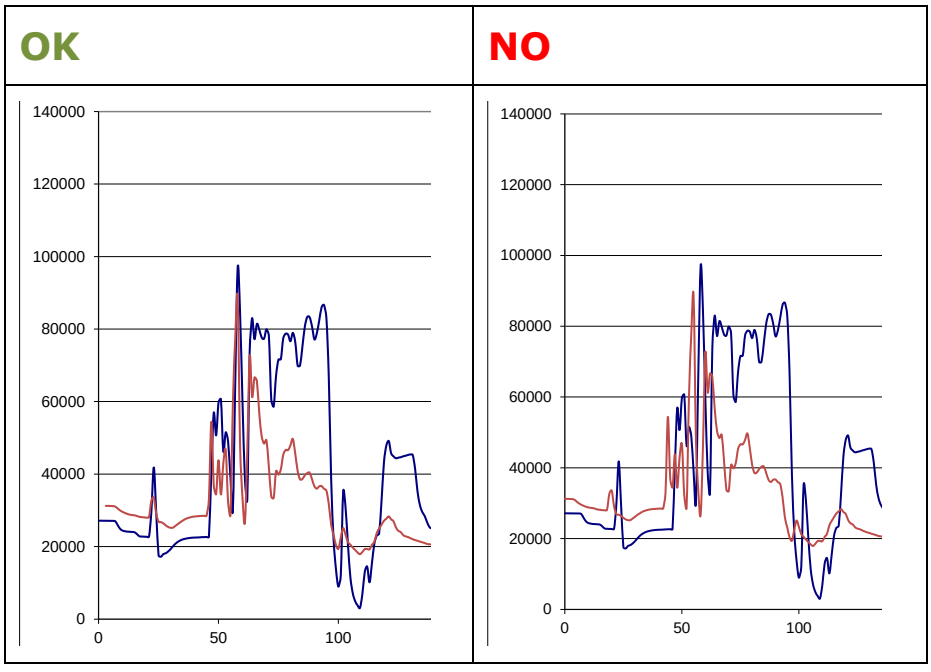

Figure 10. CO_2 [ppm] and NO_x [ppm] analysers

In addition, it is recommended that the gas and PN analysers shall be shifted to maximise the correlation factor with the exhaust mass flow time-series. When ECU signals have been recorded (not in RDE tests), it is suggested to time align the ECU vehicle speed with the GPS vehicle speed by maximising their correlation factor.

7.5. Concrete example #2: Presence of (DPF) regeneration event

There is no systematic and absolute evidence to determine the presence of regeneration events during a test. When an ECU connection is available, the information might be found within the recorded engine and after-treatment parameters. Otherwise, qualitative elements might help, as illustrated in Figure 11 with the increase of CO_2 emissions and exhaust temperature, which are typical for most of the regeneration of Diesel Particulate Filters (DPFs).

The verification of a regeneration event may be based on expert judgement through cross-correlation of several of the following signals, which may include exhaust temperature, PN, CO_2, O_2 measurements in combination with vehicle speed and acceleration. If periodic regeneration occurred during the test, the result without the application of either the K_i -factor of the K_i offset shall be checked against the requirements of point 3.1.0. If the resulting emissions do not fulfil the requirements, then the test shall be voided and repeated once at the request of the manufacturer. The manufacturer may ensure the completion of the regeneration before the PEMS test. The second test is considered valid even if regeneration occurs during it.

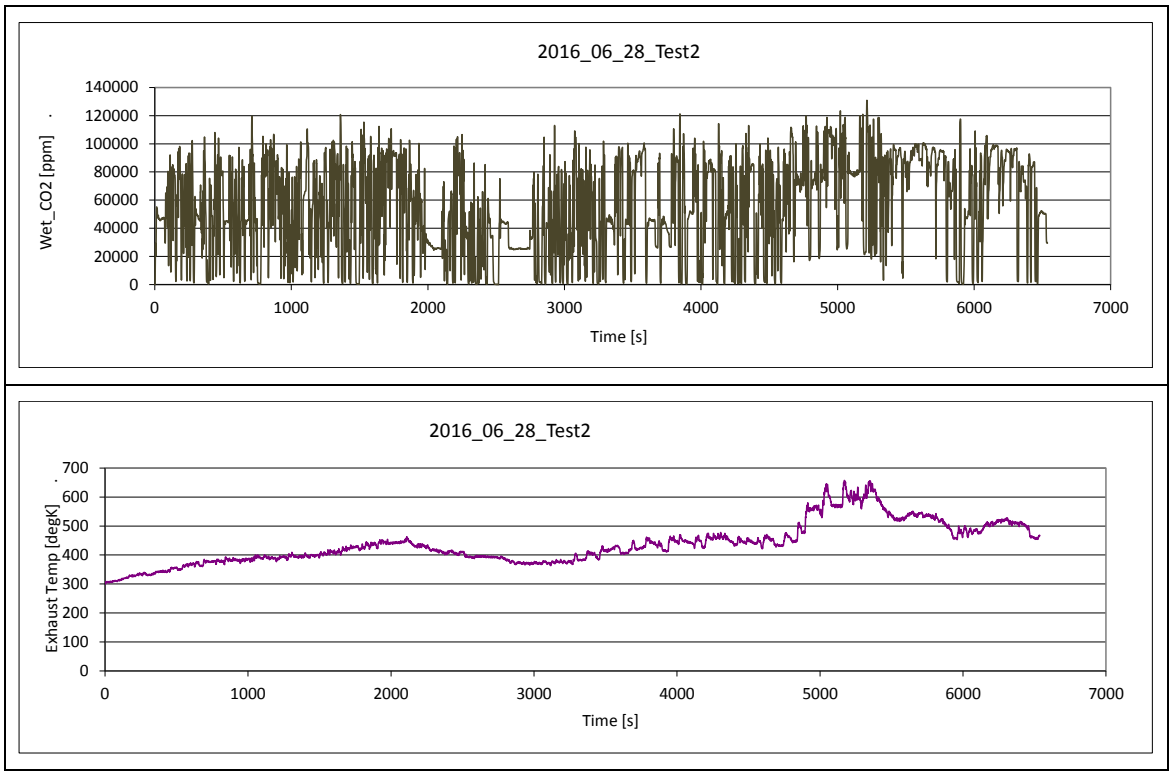

Figure 11. CO_2 and exhaust temperature increase during DPF regeneration (after 5000 seconds)

List of acronyms

#/m^3: number per cubic metre

A: Ampere

AGM: Absorbent glass mat battery

CH_4: Methane

CNG: Compressed natural gas

CO: Carbon Monoxide

CO_2: Carbon Dioxide

deg:min:s: Degrees (°), minutes ('), seconds ('')

DPF: Diesel Particulate Filter

EC: European Commission

ECU: Engine Control Unit

EFM: Exhaust mass Flow Meter

EGR: Exhaust Gas Recirculation System

FID: Flame Ionization Detector

g/kg: for relative humidity, mass (grams) of water vapour divided by mass (kg) of dry air

g/s: gram per second

GPF: Gasoline Particulate Filter

GPS: Global Positioning System

GSI: gear shift indicator

Hz: hertz

K: kelvin

kg/s: kilogramme per second

km/h: kilometre per hour

kPa: kilopascal

LDV: Light-duty vehicle

LNT: lean NO_x trap

LPG: Liquid Petroleum Gas

m: meter

MIL: Malfunctioning Indicator Lamp

Nm: Newton metre

NMHC: non-methane hydrocarbons

NO: Nitrogen Oxide

NO_2: Nitrogen Dioxide

NO_x: Nitrogen Oxides

NTE: Not-to-exceed emission limits

OBD: On-Board Diagnostics

PEMS: Portable Emissions Measurement System

PN: Particle Number

ppm C_1: parts per million carbon equivalent

ppm: parts per million

RDE: Real Driving Emissions

RDE-ISC: Real Driving Emissions testing for In-service conformity

RDE-TA: Real Driving Emissions testing for Type-approval

rpm: revolutions per minute

SCR: Selective Catalytic Reduction

THC: Total Hydrocarbons

V: Volt

WWH-OBD: Worldwide Harmonised On-Board Diagnostics

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