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

*Guidance note for
light-duty vehicles*

Valverde Morales, V., Bonnel, P.

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Contact information

Name: Pierre Bonnel

Address: European Commission, Joint Research Centre, Via E. Fermi 2749, I-21027, Ispra (VA) - Italy

Email: pierre.bonnel@ec.europa.eu

Tel.: +39 0332 785301

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Disclaimer

This guidance note provides best practices 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 European RDE legislative requirements laid down in Regulations (EU) [2017/1151](#), [2016/427](#), [2016/646](#), [2017/1154](#) and the last "RDE4" package approved at TCMV on May 3rd 2018 ([Main ACT](#), [Annex](#)), collectively referred to in this document as the **EU-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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Authors

Víctor Valverde Morales

Pierre Bonnel

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) in the European context. 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. Different sets of requirements and recommendations apply to each of them:

- "Official" EU-RDE tests conducted during new vehicle type approvals (EU-RDE-TA);
- "Official" EU-RDE tests conducted on in-service vehicles with a certain mileage for in-service conformity testing (EU-RDE-ISC);
- Other types of PEMS tests, not according to the EU-RDE LDV regulations, and conducted for other than the two purposes mentioned above (e.g. vehicle development, 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	EU-RDE TA	EU-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 On-road emissions test with PEMS [What to measure and how to do it]?

The list of mandatory test parameters to be measured during the RDE tests is according to the EU-RDE Regulation, 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 in Table 2 and Table 3 (for hybrid electric vehicles). The mandatory parameters are indicated with the letter M. Optional parameters which may be used on a case-by-case basis are indicated with the letter O. For EU-RDE-TA and EU-RDE-ISC testing, test parameters shall be measured at a constant frequency of 1 Hz or higher and recorded at a 1Hz frequency. For other types of PEMS testing it is recommended to measure and record test parameters at least at 1 Hz.

In line with the definitions from the EU-RDE regulation:

- '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 EU-RDE LDV regulations, the measurement of THC is not required. All the information regarding THC measurement is intended to provide basic requirements on instrument handling for research purposes. Currently, the on-road measurement of THC is performed using the FID measurement principle, which is based on the usage of a gas mixture of Hydrogen (40%) and Helium (60%). 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. The possibility to use such pressurized gas cylinders in the cabin of the vehicle depends on the applicable health, safety and road regulations.

From a technical perspective, the use of THC measurement instruments increases the weight of the equipment by approximately 25% and it limits the flexibility in the use of a PEMS due to its larger size. In addition, as the sampling system (including connectors, lines, etc.) must be heated to at least 191 C the energy demand will approximately double. Therefore, larger and heavier batteries must be installed.

Table 2. Test parameters for all vehicles

Parameter	Unit	EU-RDE TA	EU-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	#/m ³	M	M	O	Analyser
Exhaust mass flow rate	kg/s	M	O	O	EFM ⁽¹⁰⁾

Test parameters for all vehicles (*continued*)

Parameter	Unit	EU-RDE TA	EU-RDE ISC	Other PEMS testing	Technique ⁽⁸⁾
Ambient humidity	%	M	M	O	Sensor
Ambient temperature	K	M	M	O	Sensor
Ambient pressure	kPa	M	M	O	Sensor
Vehicle speed	km/h	M	M	O	Sensor, GNSS, or ECU ⁽³⁾
Vehicle latitude	deg:min:s	M	M	O	GNSS
Vehicle longitude	deg:min:s	M	M	O	GNSS
Vehicle altitude ⁽⁹⁾	m	M	M	O	GNSS 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	K	O	O	O	Sensor or ECU
THC concentration ^(1,4)	ppm C ₁	-	-	O	Analyser
CH ₄ concentration ^(1,4)	ppm C ₁	-	-	O	Analyser
NMHC concentration ^(1,4)	ppm C ₁	-	-	O	Calculated ⁽⁶⁾
Exhaust gas temperature ⁽⁵⁾	K	M	M	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 Calculated from THC and CH₄ concentrations according to point 9.2 of Appendix 4 of Regulation 2016/427.

⁷ May be calculated from measured NO and NO₂ concentrations.

⁸ Multiple parameter sources may be used.

⁹ The preferable source is the ambient pressure sensor. GNSS is not recommended since loss of positional signal can lead to inaccurate altitude measurement.

¹⁰ For EU-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 EU-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: NO₂), expressed in NO₂ equivalent

Test parameters for all vehicles (*continued*)

Parameter	Unit	EU-RDE TA	EU-RDE ISC	Other PEMS testing	Technique ⁽⁸⁾
Engine torque ⁽⁵⁾	Nm	0	0	0	Sensor or ECU
Torque at driven axle ⁽⁵⁾	Nm	0	0	0	Rim torque meter
Pedal position ⁽⁵⁾	%	0	0	0	Sensor or ECU
Fault status ⁽⁵⁾	-	0	0	0	ECU
Regeneration status ⁽⁵⁾	-	0	0	0	ECU
Engine oil temperature ⁽⁵⁾	K	0	0	0	Sensor or ECU
Actual gear ⁽⁵⁾	#	0	0	0	ECU
Desired gear (e.g. gear shift indicator) ⁽⁵⁾	#	0	0	0	ECU

Table 3. Test parameters specific to hybrid vehicles

Parameter	Unit	EU-RDE TA	EU-RDE ISC	Other PEMS testing	Technique
State of charge of the battery	%	0	0	0	ECU
Hybrid battery current	A	0	0	0	ECU or power analyser
Hybrid battery voltage	V	0	0	0	ECU or power analyser

Remark:

Considering that an incorrect acquisition of GNSS data can lead to an invalidation of a trip (wrong calculation of trip composition, trip dynamics, elevation gain, etc.) it is recommended to duplicate the variables captured by the GNSS using other sensors (ECU speed, ambient pressure sensor to derive altitude, optical velocity measurement systems, etc.).

In particular for vehicle speed, Regulation 2016/427, Point 4.7, states that vehicle speed shall be determined by at least one of the following methods: GNSS, 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 2016/427, Appendix 4, point 7. When using a GNSS, 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 acceleration, an accuracy of 0,1 % for all speed values above 3 km/h and a sampling frequency of 1 Hz is required.

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 EU-RDE-TA and EU-RDE-ISC testing have to comply with the general requirements described in the EU-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 NO₂), CO, CO₂ gases and Particulate Number (PN) in the vehicle exhaust;
- To measure Exhaust mass flow rate of the vehicle exhaust (compulsory on EU-RDE-TA, optional on EU-RDE-ISC);
- In case of other PEMS tests, to measure and/or record the relevant parameters (engine data from the ECU, vehicle position from the GNSS, weather data, etc.).

3.2 Emissions measurements

For EU-RDE-TA and EU-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 EU-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 and a proof of technical suitability of the equipment in the results report.

Table 4. Gas and PN analysers. RDE specifications and verification

Item	Reference(s)
Analysers Specifications	<p>EU-RDE Regulations 2016/427, 2016/646, 2017/1151, 2017/1154 and their amendments. In particular, Regulation 2016/427, Appendix 2 sets the specifications for PEMS instrumentation:</p> <ul style="list-style-type: none"> - 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) <p>and other requirements, when applicable</p>
Analysers verification	<p>EU-RDE Regulations 2016/427, 2016/646, 2017/1151, 2017/1154 and their amendments. In particular, Regulation 2016/427, Appendix 2 sets limits for PEMS instrumentation verification:</p> <ul style="list-style-type: none"> - 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) <p>and other requirements, when applicable</p>

For EU-RDE-TA and EU-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 highly recommended to validate the performance of the PEMS equipment after each new PEMS installation on a vehicle and either before and/or after each set of tests. It is suggested to follow the best practices for the validation exercise suggested in the ad-hoc report of the Joint Research Centre¹. For other types of PEMS testing, it is also recommended to undergo the process of PEMS validation as described for EU-RDE tests.

3.3 PEMS data reporting



For EU-RDE-TA and EU-RDE-ISC tests, the parameters to be recorded and reported are specified by the EU-RDE Regulation, Appendix 8 (e.g. PEMS manufacturer, PEMS type, PEMS serial number, Gas analyser type, EFM type, etc.). The list of mandatory and optional parameters is indicated in Appendix 8 together with the compulsory format for data exchange. The last section of the present document provides a short overview of the formatting requirements and potential issues.

¹ Recommendations for the validation of PEMS in the laboratory (under development)

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

4.1 Basic PEMS set-up

For EU-RDE-TA, EU-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 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 inside the vehicle (**Figure 1, left**) has to be conducted according to the applicable safety regulations, particularly in relation to the protection of the driver (the installation has to be made in such a way that the exhaust gas does not leave the analyser and sampling lines due to leakages, and the components of the PEMS must be safely attached). 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 (caused road condition/driving style, etc.), heating, electromagnetic interferences, shocks and exposure to dust.
- For direct exhaust flow measurements the exhaust flow meters must be attached to the vehicle's tailpipe according to the recommendations of the PEMS manufacturer and at least one additional fixation point. Exhaust pipe adaptors or junctions shall not adversely affect the operation of the engine or exhaust after-treatment systems. A simple rule to select the EFM diameter is to have it at least as the tailpipe diameter to avoid backpressure. An incorrect diameter size of the EFM may result in DPF/ GPF malfunction and a risk in engine damage (e.g. turbocharger over speed, exhaust valves keeping open, etc.). Avoid abrupt diameter changes and leave enough straight tube before the flow sensing elements.
- In case the PEMS test allows the use of the ECU, the interface of the ECU data acquisition modules might be connected to the appropriate vehicle interfaces, typically a CAN bus. It is forbidden to connect the ECU during an official EU-RDE-TA test to measure the exhaust flow.
- The GNSS antenna should be installed at the highest point of the vehicle. In case this is not possible (e.g., convertibles with fabric top) it is recommended to clamp it to the side window. The weather station should be installed on the body of the vehicle in a location where it minimises its aerodynamic drag, and where it cannot be affected by exhaust gas. Preferably install the equipment close to a vehicle opening (window, boot, etc.).

Further details and 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



Source: left) JRC VELA lab right) Sensors, Inc.

4.2 Vehicle selection and inspection

A general verification of the correct technical functioning of the test vehicle shall be carried out before any PEMS test. 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.
-  For safety reasons, the equipment inside the vehicle shall be properly secured (e.g. holding straps to secure the batteries and load).
- Adequate routing of tubes, cables, and the heated exhaust line.
- Check for the presence of hot surfaces and sharp edges, take appropriate action to avoid injuries, 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 sensors on hybrid vehicles are properly secured. The use of burnable substances on a PEMS test (like the FID-gas) has to be checked by the responsible safety services in every case.

More specifically for EU-RDE-TA and EU-RDE-ISC tests¹, the following vehicle selection criteria shall apply (non-exhaustive):

- For RDE-TA tests, the vehicle shall be in good mechanical condition and shall have been run in and driven at least 3 000 km before the test. The running-in of the vehicle shall use all available components of the vehicle.
- For RDE-ISC testing the vehicle shall have been in service for at least 15 000 km and for no more than 100 000 km. In addition, and since the date of its first registration, the vehicle must be between 6 months and 5 years old.
- The vehicle must be registered in the EU.
- The vehicle maintenance and operational records shall be available (i.e. all maintenance has to be performed by authorised dealerships).

¹ Details available in RDE regulation, Annex II - Part B (New In-Service Conformity Methodology), Appendix 1 (Criteria for vehicle selection and failed vehicles decision)

- 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. GNSS antenna that should have the minimum possible cross-section surface) (**Figure 2**).
- Using a trailer hook for installing the PEMS is permitted but the vehicle's power supply must not be connected or 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 not possible since it will have an important impact on the test mass. However, light trailers such as a wheel rotational speed sensors to measure vehicle speed is allowed 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. The maximum support load of the rear-suspension must not be exceeded for safety reasons.
- 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.
- In the case of an RDE test with a failed result, samples of fuel, lubricant and reagent (if applicable) shall be taken and kept for at least 1 year under conditions guaranteeing the integrity of the sample. Once analysed, the samples can be discarded.
- 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 5, makes the vehicle not eligible for RDE testing.
- For RDE-ISC testing, vehicles used for racing/motor sport are not eligible.

For EU-RDE-ISC, the complete list of criteria for vehicle selection and failed vehicles decision can be found in the Annex.

Table 5. List of OBD issues making the vehicle non-eligible for RDE-TA and RDE-ISC tests

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

4.3 Vehicle information reporting



For EU-RDE-TA and EU-RDE-ISC tests there is a fixed set of mandatory parameters of the vehicle to be recorded (specified by the EU-RDE LDV regulations) indicated with an M in Table 6. Additional recommended parameters to be recorded on a case-by-case basis for EU-RDE-TA and EU-RDE-ISC tests, and other PEMS testing, are indicated with the letter O. The testing conditions to be recorded are specified in Table 10.

Table 6. Vehicle information to be reported

EU-RDE TA	EU-RDE ISC	Other PEMS testing	Parameter	Description/Unit
M	M	O	Vehicle type	[Vehicle commercial name]
M	M	O	Vehicle manufacturer	[name]
M	M	O	Vehicle model year	[year]
M	M	O	Vehicle ID	[VIN code as defined in ISO 3779:2009]
M	M	O	Odometer value at test start	[km]
M	M	O	Odometer value at test end	[km]
M	M	O	Vehicle category	[category as defined in Annex II to Directive 70/156/EEC]
M	M	O	Type approval emissions norm	[Euro X]
M	M	O	Ignition type	[SI/CI]
M	M	O	Engine rated power	[kW]
M	M	O	Peak torque	[Nm]
M	M	O	Engine displacement	[ccm]
M	M	O	Transmission	[manual/ automatic/ CVT]
M	M	O	Number of forward gears	[#]
M	M	O	Fuel type. If flexifuel indicate fuel used in the test	[gasoline/ diesel/LPG / NG]
M	M	O	Lubricant	[product label]
M	M	O	Front and rear tyre size ⁽³⁾	[width.height.rim.diameter]
M	M	O	Front and rear axle tyre pressure	[bar/bar]
M	M	O	Road load parameters	[F ₀ /F ₁ /F ₂]
M	M	O	Type-approval test cycle	[NEDC/WLTC]
M	M	O	Type-approval CO ₂ emissions	[g/km]
M	M	O	CO ₂ emissions in WLTC mode Low	[g/km]

Vehicle information to be reported (*continued*)

EU-RDE TA	EU-RDE ISC	Other PEMS testing	Parameter	Description/Unit
M	M	O	CO ₂ emissions in WLTC mode Mid	[g/km]
M	M	O	CO ₂ emissions in WLTC mode High	[g/km]
M	M	O	CO ₂ emissions in WLTC mode Extra High	[g/km]
M	M	O	Vehicle test mass ⁽²⁾	[kg]
M	M	O	Propulsion Type	[ICE/NOVC-HEV/ OVC-HEV]
M	M	O	Wheel drive mode	[2WD/4WD]
M	M	O	Electric motor power	[kW. 0 if vehicle with ICE only]
M	M	O	Engine condition at test start	[cold/warm]
M	M	O	Artificial payload	[% deviation from the payload]
M	M	O	Fuel used	[reference/market/EN228]
M	M	O	Tyre tread depth	[mm]
M	M	O	Vehicle age	[months]
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.



Source: left) FREE PLAST srl.; right) Enganches y Remolques Aragón s.l.

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

5.1 Test conditions

For EU-RDE-TA, and EU-RDE-ISC testing, the test conditions must fulfil the requirements of the RDE-LDV regulations. The main requirements are shown in Table 7. For EU-RDE-ISC testing it is recommended to select the boundary conditions of the different RDE trips within a given sample in a way as to cover the distribution of driving situations under real life operation in a representative way. For other types of PEMS testing, anything is in principle possible, provided that the testing conditions do not compromise safety and the PEMS instrumentation functioning.

Table 7. Overview of testing conditions

Condition	EU-RDE-TA & EU-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. The power supply must be set accordingly to the trip duration.
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 without conditioning but with a warm engine. An engine can be considered as warm when the engine coolant temperature and/or engine oil temperature is above 70 °C.	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 is above 70 °C.
Test route requirements - Urban, rural and motorway definitions and shares	<ul style="list-style-type: none"> - Urban, rural and motorway driving defined by speed: <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> Rural: >60 km/h and ≤ 80 km/h Highway: >80 km/h - Urban, rural and motorway driving minimum distance: 16 km - Distance shares: <ul style="list-style-type: none"> City: ≥29% and ≤ 44 % Rural: ≥23% and ≤ 43 % Highway: ≥23% and ≤ 43 % <p>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.</p>	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) according with other legal limits.

Overview of testing conditions (*continued*)

Condition	EU-RDE-TA & EU-RDE-ISC requirements	Recommendations and suggestions for other PEMS tests
Test route requirements - Average speed and stop times	<ul style="list-style-type: none"> - 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 < 1 km/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	<ul style="list-style-type: none"> - Moderate: $\geq 0^{\circ}\text{C}$ and $\leq 30^{\circ}\text{C}$ - Extended: ($\geq -7^{\circ}\text{C}$ and $< 0^{\circ}\text{C}$) or ($> 30^{\circ}\text{C}$ and $\leq 35^{\circ}\text{C}$) Derogation limits⁽¹⁾: <ul style="list-style-type: none"> - Moderate: 3°C to 30°C - Extended: -2°C to $< 3^{\circ}\text{C}$ and $> 30^{\circ}\text{C}$ to 35°C 	The manufacturers recommended temperatures of use for analysers and sensors must not be exceeded.
Ambient conditions – Altitude	<ul style="list-style-type: none"> - Moderate: ≤ 700 m above sea level - Extended: > 700 m and ≤ 1300 m 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. 	Attention shall be paid to potential and automated altitude corrections in the instruments, which might not be applicable outside the RDE ranges. The manufacturers recommended pressures of use for analysers and sensors must not be exceeded.
Road condition	<p>EU-RDE-TA and EU-RDE-ISC cannot be performed on unpaved roads.</p> <p>In addition, even though the EU-RDE LDV regulations do not specify this point, common sense and safety recommend avoiding extreme weather conditions (mud, icy roads, and fresh snow).</p>	Same as for EU-RDE recommended.
Fuel, lubricating oil, reagent	<p>Vehicles must be run using market fuel, oil, and reagent, always following the recommendations of the vehicle's manufacturer.</p> <p>It is required to collect a sample of the test fuel(s), oil and reagent(s) for EU-RDE tests whenever the emissions are above the NTE limit.</p>	Follow the recommendations of the vehicle's manufacturer.
Driving Time	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 payload shall not exceed 100% of the vehicle's permissible payload. The maximum load per axle should not be exceeded.

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 2007/46/EC

Overview of testing conditions (*continued*)

Condition	EU-RDE-TA & EU-RDE-ISC requirements	Recommendations and suggestions for other PEMS tests
Vehicle pre-conditioning	<p>Before an EU-RDE-TA or EU-RDE-ISC test, the vehicle has to be driven for at least 30 minutes, 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. Soaking temperature 3 hours prior to the test must be recorded.</p> <p>It is recommended to drive in normal roads and at least 20 to 25 minutes on the motorway to limit the risk of regeneration of the DPF during the actual test.</p> <p>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.</p> <p>When several EU-RDE tests are conducted in consecutive days, the previous day EU-RDE test can be used as pre-conditioning drive for the current day test.</p> <p>Problems identified during the pre-conditioning and the total soaking time should be reported.</p> <p>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 EU-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.</p> <p>For a hot EU-RDE test, the vehicle shall be driven to reach an engine oil or engine coolant temperature above 70C. Then the engine shall be stopped, and the pre-test shall be performed (calibration of PEMS system).</p>	Same as for EU-RDE recommended.
Vehicle air-conditioning and auxiliary devices	<p>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.</p> <p>All original auxiliary devices available to the user are allowed (i.e. only original devices from the Manufacturer). Any use shall be documented. 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.</p>	Same as for EU-RDE.
Vehicle gear shift and operating modes	<p>When several gear shift and/or vehicle operating modes are available the vehicle can be tested under any mode: eco, standard, sport, etc. 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. OVC-HEVs vehicles may be tested in any selectable mode (charge depleting, charge sustaining), including battery charge mode.</p> <p>In case a vehicle has a "race" mode, to be used only on test tracks, this mode shall not be used for EU-RDE testing, as safety features might be disabled.</p> <p>It is strongly recommended not to disable safety related vehicle modes (e.g. ABS, DSC, ADM, ESP, etc.) in case the test is carried by non-professional drivers.</p>	Same as for EU-RDE.

Overview of testing conditions (*continued*)

Condition	EU-RDE-TA & EU-RDE-ISC requirements	Recommendations and suggestions for other PEMS tests
Vehicle battery	<p>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.</p> <p>It is possible to charge the battery prior to the pre-conditioning but not before the start of an EU-RDE-TA or EU-RDE-ISC tests.</p>	<p>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.</p>
Vehicle tyres	<p>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.</p> <p>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.</p> <p>The use of chains is not permitted since the EU-RDE trip speed requirements cannot be fulfilled and it is not recommended to drive on snow during EU-RDE tests and it is not recommended to drive under extreme weather conditions during EU-RDE tests.</p>	<p>Same as for EU-RDE.</p>

5.2 Selection of test routes for EU-RDE testing

Any trip planner may be used to define a route which is likely to result as compliant according to the EU-RDE trip requirements, in particular with the required urban/rural/motorway distance shares, the altitude difference between the start and end point and the cumulative altitude gain.

For EU-RDE-TA and EU-RDE-ISC tests:

- 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;
- The trip must be driven in urban-rural-motorway order, however, rural operation may be interrupted by urban operation, and motorway operation can be interrupted by urban and/or rural operation;
- The trip may 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 trials during the times of the day which are intended for the complete EU-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 EU-RDE test, but to vary them. It is also recommended to perform the hot EU-RDE test on the exact same route as equivalent cold ones.

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 may not invalidate the results of test.

For EU-RDE-TA and EU-RDE-ISC tests:

- The driver shall be 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 EU-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, for conventional vehicles or for OVC-HEVs, and NOVC-HEVs starting the test with the internal combustion engine on, the idling immediately after test start shall be kept to the minimum possible and it shall not exceed 15 s. Ensuring a proper GNSS connection shall therefore be done prior to the first engine start to fulfil 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 EU-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 (only verbal instructions are allowed to prevent distractions to the driver). The use of RDE-driver aid software or verbal instructions during the trip shall not be used to bias the emission result or to trim tests towards to the limits of the valid range. For non-EU-RDE PEMS testing, the same safety recommendations apply. However, 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).

6 Test Protocol [How to conduct the test?]

This section presents a comprehensive overview of the emissions testing protocol with PEMS on passenger cars and light-commercial vehicles. 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 at various European testing laboratories, including the Joint Research Centre.

The test protocol may be adapted on a case-by-case situation depending on the vehicle to be tested, the available PEMS instruments, and the type of test. For RDE-TA tests, the Type Approval Authority may verify if the test setup and the equipment used fulfils the requirements of Appendices 1 and 2, through a direct inspection or an analysis of the supporting evidence (e.g. photographs, records). In general, it is a good practice to document the installation of the instruments with pictures for traceability matters.

6.1 Checks before the installation of the instruments in the vehicle

This section presents an overview of the elements that shall be verified on a vehicle before proceeding to the installation of the measurement equipment. Checking the elements listed in Table 8 is a way for the testing party to find out whether a test can be performed according to the EU-RDE regulation or not even before proceeding with the PEMS installation. The complete list of elements to be checked and report for EU-RDE ISC tests can be checked in the Annex of this guidance document.

Table 8. Elements to be checked before the installation of the instruments

Element	Description/Unit
Tyre pressure	According to the vehicle manufacturer's recommendations
Tyre tread depth	According to the vehicle manufacturer's recommendations (at least 3mm of tread depth for summer tyres and 4 mm for winter tyres)
OBD check	EU-RDE-TA & EU-RDE-ISC: the vehicle is not eligible in case faulty checks (Table 5). Print error log
Are there any warning light activated on the instrument panel?	EU-RDE-TA & EU-RDE-ISC: any Malfunction Indication Light (MIL) makes the vehicle not eligible
Vehicle fluids	Check that the fluid levels (engine oil, cooling liquid, etc.) are within the min/max recommendations and top up if needed.
Aerodynamic modifications	EU-RDE-TA & EU-RDE-ISC: Verify no aftermarket aerodynamics modification was made (roof boxes, load racking, spoilers, etc.) and no standard aerodynamics components are missing (front deflectors, diffusers, splitters, etc.). Otherwise the vehicle is not eligible for testing.
Mileage	EU-RDE-TA: 3 000 – 15 000 EU-RDE-ISC: 15 000 – 100 000 km
Vehicle age	EU-RDE-ISC: 6 months – 5 years
Country of registration and use	EU-RDE-TA & EU-RDE-ISC: EU country, registered and used in the European Union for at least 90% of the time
Is the vehicle involved in a recall or service campaign?	EU-RDE-ISC: vehicle not eligible if the repair was not done

Elements to be checked before the installation of the instruments (*continued*)

Element	Description/Unit
Was the vehicle used for racing/motor sport?	EU-RDE-ISC: if yes, vehicle not eligible
Has the vehicle carried heavy loads over the specifications of the manufacturer?	EU-RDE-ISC: if yes, vehicle not eligible
Check for traces of tuning	EU-RDE-ISC: if yes, vehicle not eligible
Was any part of the emissions after-treatment system replaced	EU-RDE-ISC: if not original parts were used as replacement, the vehicle is not eligible
Service and repair history	EU-RDE-ISC: if the full documentation supporting that the vehicle has been maintained according to the manufacturer's recommendations cannot be provided, the vehicle is not eligible

6.2 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. After the installation of PEMS is completed, a leak check shall be performed at least once for each PEMS-vehicle installation as prescribed by the PEMS manufacturer or as follows. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilisation 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 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.



PN analyser, especially those with working fluids should be installed horizontally.



Warnings of the vehicle or PEMS before, during or after the test shall be documented and actions taken according to the vehicle -or instrument-manufacturer's recommendations.

Figure 3.

left) installation of PEMS main units outside the vehicle;
centre) installation outside on small cars without hook;
right) securing the instruments with straps inside the vehicle



Source: left) HORIBA; centre) MAHA-AIP GmbH & Co.; right) JRC VELA lab

STEP 2. Selection of the exhaust flow meter range

For EU-RDE-TA, the exhaust mass flow has to be measured by means of an Exhaust Flow Meter (EFM). It is recommended to select the EFM in order to have the maximum expected flow rate during the test covering at least 75% of the EFM full range. For EU-RDE ISC tests, the exhaust flow can be calculated (using ECU signals or appropriate sensors) or measured by means of an EFM. In the latter case, the selection of the EFM shall follow the same recommendations as for EU-RDE-TA tests.

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 and calibration 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). The installation of the EFM and any exhaust pipe adaptors or junctions shall not adversely affect the operation of the engine or exhaust after-treatment system. A small downwards inclination is recommended to reduce any condensation sink in the EFM. The EFM shall be purged and prepared for operation in accordance with the specifications of the EFM manufacturer. This procedure shall, if applicable, remove condensation and deposits from the lines and the associated measurement ports. When testing a multi-cylinder engine with a branched exhaust manifold, it is recommended to position the exhaust mass flow meter downstream of where the manifolds combine and to increase the cross section of the piping such as to have an equivalent, or larger, cross sectional area from which to sample. If this is not feasible, exhaust flow measurements with several exhaust mass flow meters may be used. The wide variety of exhaust pipe configurations, dimensions and exhaust mass flow rates may require compromises, guided by good engineering judgement, when selecting and installing the EFM(s). It is permissible to install an EFM with a diameter smaller than that of the exhaust outlet or the total cross-sectional area of multiple outlets, providing it improves measurement accuracy and does not adversely affect the operation or the exhaust after-treatment as specified in point 3.4.2. The accuracy of the EFM, defined as the deviation of the EFM reading from the reference flow value, shall not exceed ± 3 percent of the reading, 0,5 % of full scale or $\pm 1,0$ per cent of the maximum flow at which the EFM has been calibrated, whichever is larger.

The installation of the EFM shall be documented using photographs.



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. In addition, abrupt changes of diameters shall be avoided.

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 (**Figure 4**). 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.

Figure 4. Installation of the EFM: elements for clamping



Source: ACEA

- *Solution 2 (to be used if solution 1 cannot be achieved with reasonable effort.): Specific tailpipe adapters (Figure 5)*



A fixation point is always needed to secure the EFM (**Figure 5**).



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 and between each subsequent test. It is recommended to secure clamps by appropriate measures (cable strips or splint pins).
- The Pitot sensor should be placed between two pieces of straight tube of the same diameter whose length should be at least 4 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.
- All electronics (PEMS and EFM) shall be mounted in such a way that the cooling air-flow is sufficient but they are not exposed to too excessive conditions (rain, splash water).
- The PN and gas sampling should be done from the centerline of the EFM. If particles are sampled, then the probe should be placed upstream of the other sampling probes (for gases).
- It shall be ensured that the sampling system is clean and free of moisture condensation.
- 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 EU-RDE test that test should 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.
- 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 if cooling of electronics is adequate.
- For EU-RDE-TA it is necessary to document the EFM set-up using photographs (**Figure 6**).

Figure 5. EFM Installation
left) using a tailpipe adaptor;
right) tubes and collars on a dual exhaust



Source: JRC VELA lab

Figure 6.

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



Source: JRC VELA lab

STEP 4. Mounting of the GNSS 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 7**).

Figure 7. Installation examples for the GNSS antenna and the weather station



Source: JRC VELA lab

STEP 5. Preparation of the ECU communication cables

If desired for non-EU-RDE types 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 ECU parameters are obtained, these may be obtained at a substantially higher frequency but the recording rate shall be 1.0 Hz. When applicable, manufacturers shall disclose the labels which allow the correct identification of available 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. The ECU communication cable shall be shorter than 5 meters in order to minimize the effect of radio waves to the measurements. 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 8**).

Figure 8.

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



Source: JRC VELA lab

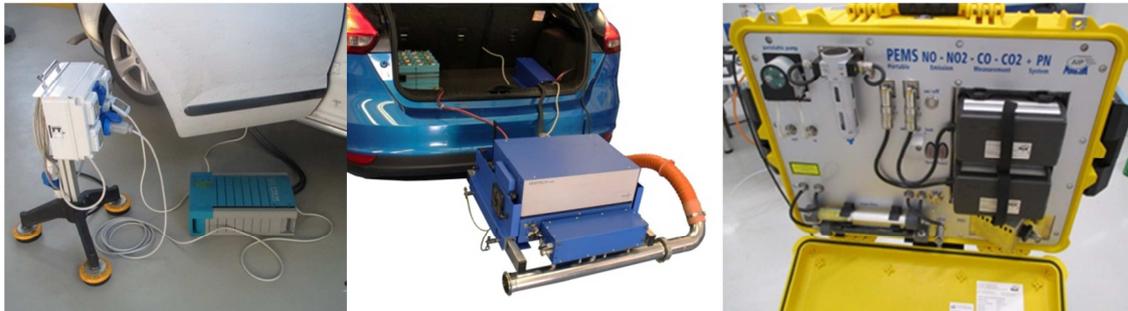
STEP 7. Installation of the power supply

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.



The batteries shall be safely installed and secured on the vehicle or in the PEMS. The use of straps to securely attach them to the vehicle is essential (**Figure 9**).

Figure 9. left) Charging of the batteries;
centre) batteries to operate the PEMS, located in the trunk, properly secured with straps;
right) example of PEMS main unit with portable batteries.



Source: left) JRC VELA lab; centre) Sensors, Inc.; right) MAHA-AIP GmbH & Co.

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 temperature sensor should be shielded from any warm-up effects like 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 7**).

STEP 9. Connection of the heated probe(s)

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. If particles are measured, the exhaust shall be sampled from the centre of the exhaust stream. If several probes are used for emissions sampling, the particle sampling probe should be placed upstream of the other sampling probes. The particle sampling probe should not interfere with the sampling of gaseous pollutants.

Any replacement involving a modification of the length of the heated probe must be done in consultation with the instrument manufacturer, as it directly alters the time-alignment within the PEMS. 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 10**). When installed outside, the heated probe shall be routed in a way to secure visibility for the driver and minimise aerodynamic resistance (**Figure 10**).

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



Source: left) JRC VELA lab; right) AVL LIST GmbH

STEP 10. Connection of other tubes and cables

Connect the different cables and tubes as described in the manuals of the instruments. Avoid sharp bends, loose cable loops or dangling parts. They could get damage during testing. No parts, cables or tubes shall touch the ground or moving parts of the vehicle.



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.

6.3 Pre-Test Procedures

STEP 11. Check connections and wirings

To be made every > Single Test



Prior to supplying power to the instruments, visually inspect all connections to check if they are loose, possibly due to vibrations. Safety rules should be followed, in particular because there can be electrical power even with switched-off equipment.

STEP 12. Verify the PEMS power supply batteries charge level

To be made every > Single Test

The batteries shall be charged prior the PEMS test. It is recommended to perform the pre-test with the batteries connected to the power supply to prevent its depletion before the actual 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. All available signals shall be checked for consistency, in particular, the main software may warn of incorrect electrical connections/cable breaks. The PEMS shall function free of errors and critical warnings.

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.

If possible the warming up mode, pause mode and standby mode of the instrument should be powered from the power socket while keeping the instrument battery charged.

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. If hydrocarbons are measured, the sampling line shall be heated to 464 ± 10 K (191 ± 10 °C). For the measurement of other gaseous components with or without cooler, the sampling line shall be kept at a minimum of 333 K (60 °C) to avoid condensation and to ensure appropriate penetration efficiencies of the various gases. If particles are sampled and not diluted at the tailpipe, the sampling line from the raw exhaust sample point to the point of dilution or particle detector shall be heated to a minimum of 373 K (100 °C). The residence time of the sample in the particle sampling line shall be less than 3 s until reaching first dilution or the particle detector.

For EU-RDE-TA and EU-RDE-ISC tests the ambient temperature sensor shall be checked to verify if the ambient temperature boundary conditions are fulfilled. This is also recommended for other types of tests.

STEP 15. Check of zero level of the analysers

To be made every > Single Test

Zero verifications of the analysers shall be performed using gases which fulfil the specifications of Regulation 2017/1151 Appendix 2, point 5. The shelf life of calibration and span gases shall be respected. 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). The zero response drift must be within the permissible response defined in point 6 Appendix 1 (Table 2) of RDE Regulation.

For EU-RDE-TA and EU-RDE-ISC tests, it is required that the zero level of the particles analyser shall be recorded by sampling HEPA filtered ambient air at an appropriate sampling point, usually at the inlet of the sampling line. The signal shall be recorded at a constant frequency which is a multiple of 1.0 Hz averaged over a period of 2 minutes; the final concentration shall be within the manufacturer's specifications, but shall not exceed 5 000 particles per cubic-centimetre.

For non EU-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). Preferably use HEPA filtered air.

STEP 16. Span calibration of the analysers

To be made every > Single Test

The calibration gases shall cover at least 90% of the concentration values obtained from 99 % of the measurement of the valid parts of the emissions test. It is permissible that 1 % of the total number of measurements used for evaluation exceeds the used span gas by up to a factor of two. If these requirements are not met, the test shall be voided. For the first test, the calibration span of the emissions analysers shall be performed using the span-gas concentrations recommended by the instruments manufacturer. To minimize analyser drift, one should conduct the zero and span calibration of analysers at an ambient temperature that resembles, as closely as possible, the temperature experienced by the test equipment during the trip.

For EU-RDE tests, the gases shall fulfil the requirements laid down in EU-RDE Regulation, Appendix 2. 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). The span response drift must be within the permissible response defined in point 6 Appendix 1 (Table 2) of the EU-RDE Regulation. PN span drift check is not currently feasible. Pure as well as mixed calibration and span gases shall fulfil the specifications of Regulation 2017/1151.

NO₂ calibration gas is permissible. The concentration of the NO₂ calibration gas shall be within two per cent of the declared concentration value. The amount of NO contained in the NO₂ calibration gas shall not exceed 5 per cent of the NO₂ content.

STEP 17. Archiving zero level and span calibration data

To be made every > Single Test



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

STEP 18. Exhaust flow meter cleaning

To be made every > Single Test

For EU-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.

STEP 19. Gas 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 EU-RDE Regulation, 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:

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



CPC based PN-analysers can be severely damaged by vacuum.

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. Verification of the flow meter

To be made every > Single Test

Before every PEMS test, the EFM has to be verified 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. Only the zero value can be validated.

STEP 21. Check that data acquisition storage media and backup have sufficient space

To be made every > Single Test

The memory of the system shall allow sufficient storage capacity for at least 120 minutes test.

STEP 22. Spot check

To be made every > Single Test

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

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

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

STEP 23. Check GNSS

To be made every > Single Test

Check GNSS signals and GNSS status.

The GNSS signal shall be logged from the first sec.

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

STEP 24. Check weather station

To be made every > Single Test

Check that ambient temperature, humidity, and pressure are properly registering and the monitored values are displayed in the data acquisition computer.

STEP 25. Verify that all temperature controllers are set at the correct operating values

To be made every > Single Test

When the vehicle is soaked inside it is important to check during the first minutes of the test that the temperature measured by the weather station gets properly aligned to the ambient temperature provided by the vehicle.

STEP 26. 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 27. Start the engine

To be made every > Single Test

Start the engine for cold-start test. For warm engine condition tests it is possible to drive a hot test just after a cold one. However, since the test end is defined as "when the vehicle has completed the trip and the combustion engine is switched off" (Point 5.3 of Appendix 1), it is not possible to keep the engine on in between PEMS tests. In between PEMS tests, the PEMS shall be reconnected to the power supply of the building.

STEP 28. 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.

6.4 Test runs

Pre-test including validation test (Recommended)

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 EU-RDE-TA and EU-RDE-ISC tests, it is highly recommended to conduct a validation test according to Appendix 3 of the EU-RDE Regulation, preferably before 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 under laboratory conditions. For the validation of the PEMS installation it is recommended to follow the best practices contained in the Joint Research Centre guidance note¹.

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 engine 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.

Verification of pre-test or validation test data

To be made every > Every new PEMS installation

The following data screening is recommended:

- Analysers concentrations: check for the measured ranges, eventual range saturation and anomalous values;
- Vehicle ground speed, comparing the values from the ECU (when applicable) and from the GNSS (when applicable);
- 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);
- Comparing integral values of different phases of total of an appropriate driving cycle and a CVS.
- Ambient conditions, comparing the values from the weather station to the ones given by specific sensors.

STEP 29. Normal test run

Sampling, measurement and recording of parameters shall begin prior to the test start (**Figure 11**). For EU-RDE, the test start shall be defined by either:

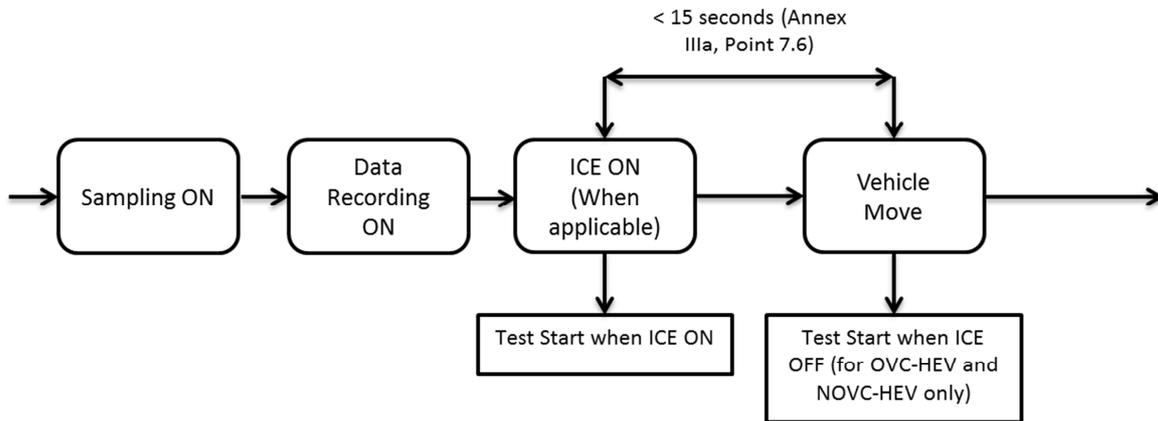
- the first ignition of the internal combustion engine;

¹ Recommendations for the validation of PEMS in the laboratory (under development).

- or the first movement of the vehicle with speed greater than 1 km/h for OVC-HEVs and NOVC-HEVs starting with the internal combustion engine off.

For non-EU-RDE tests, it is recommended to use the same definition for the test start.

Figure 11. Test start sequence.



Source: EU-RDE LDV regulations

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. The data recording shall continue until the response time of the sampling systems has elapsed. An OBD-check shall be performed and documented directly after test end (**Figure 12**).

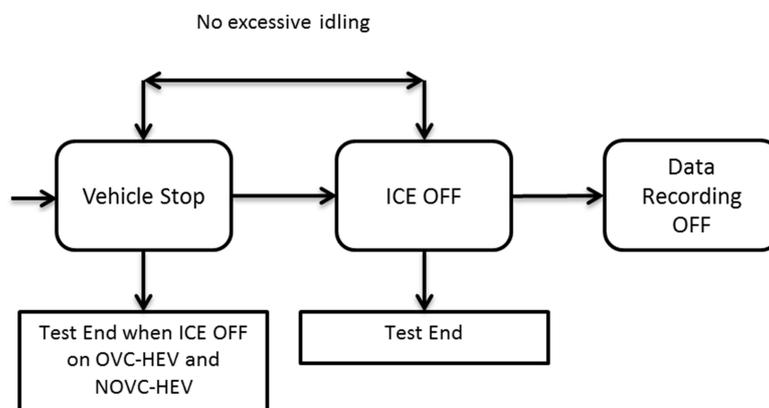
6.5 Post-test

STEP 30. Conclusion of a test run

The end of the test is reached when the vehicle has completed the trip and either when:

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

Figure 12. Test end sequence.



Source: EU-RDE LDV regulations

Any warning signals, suggesting malfunctioning of the PEMS and the vehicle, 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 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. It is recommended to follow the PEMS manufacturer recommendations on how to deal with auto-zeroing equipment. It is strongly recommended to initiate PEMS system verifications during periods of zero vehicle speed.

Excessive idling of the engine after the completion of the trip shall be avoided. The data recording shall continue until the response time of the sampling systems has elapsed. For vehicles with a signal detecting regeneration (see line 42 in the Transparency List 1 in Appendix 5 of Annex II), the OBD-check shall be performed and documented directly after data recording and before any further driven distance is driven.

STEP 31. 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 EU-RDE-TA & EU-RDE-ISC tests, the zero and span check shall be conducted according to the requirements laid down in the EU-RDE Regulation and the post-test zero and span data listed in Table 1 of Appendix 8 shall be recorded.

STEP 32. 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 33. Post-test OBD check

It is recommended to check the vehicle for OBD messages after test end to find out if the vehicle registered failures or malfunctions during the test as indicated in **Table 5**.

STEP 34. 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.

STEP 35. Verification of test data

To be made every > Single Test

The same recommendations as for the verification of the pre-test data shall apply.

STEP 36. 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 37. Remove power from the instruments

6.6 Conclusion of Test Series (PEMS dismounting)

STEP 38. Dismount PEMS equipment and restore vehicle/machine to the original configuration

To be made every > Every new PEMS installation

After a reasonable time of cooling down, 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 39. 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?]

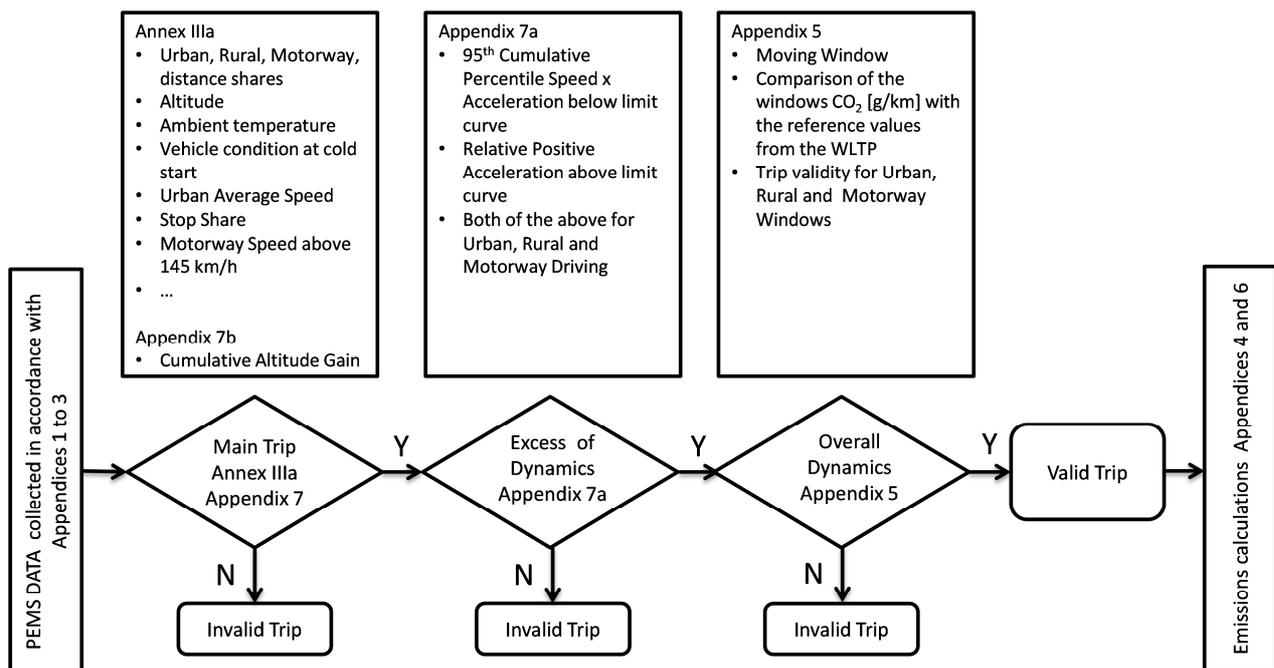
7.1 Introduction

This section only regards the data screening, 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 EU-RDE-TA and EU-RDE-ISC tests, the mandatory ex-post evaluation is comprised of several steps illustrated in for steps B to D, which address the trip compliance (**Figure 13**):

- STEP A: To ensure that parameter recording reaches a data completeness higher than 99 %
- STEP B: The trip complies with the general requirements, boundary conditions, trip and operational requirements, and the specifications for lubricating oil, fuel and reagents defined in points 4 to 8 of Annex IIIa and Appendix 7b of the EU-RDE Regulation;
- STEP C: The trip complies with the requirements defined in Appendices 7a of the EU-RDE Regulation;
- STEP D: The trip complies with the requirements defined in Appendix 5 of the EU-RDE Regulation.

Figure 13. Verification of trip validity according to EU-RDE



Source: EU-RDE LDV regulations

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

The emissions calculations shall be made between test start (**Figure 11**) and test end (**Figure 12**). Compliance of the software tool used to verify the trip validity and calculate emissions in accordance with the provisions laid down in Appendices 4, 5, 6, 7a, and 7b shall be validated by the tool provider or a type approval authority. Where such software tool is incorporated in the PEMS instrument, proof of the validation shall be provided along with the instrument.

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

7.2 Test data screening

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

- Presence of mandatory parameters for EU-RDE tests (Table 2);
- Quality screening of mandatory parameters. Check for the measured ranges, possible empty ranges of data, saturation of measurement range and/or negative values (Table 9).
- Presence of zero drift and span drift results for THC, CO, NO_x (or NO/NO₂), CO₂, and PN.
- Zero drift of the exhaust flow meter.
- Correctness of test conditions not requiring any data processing (Table 7).
- Presence of regeneration events (Recommended practice in 7.3).
- 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 frequency which is a multiple of 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, proceeding to the ex-post evaluation (i.e. the emissions calculations) should be avoided.

Table 9. Recommended ranges for data quality screening

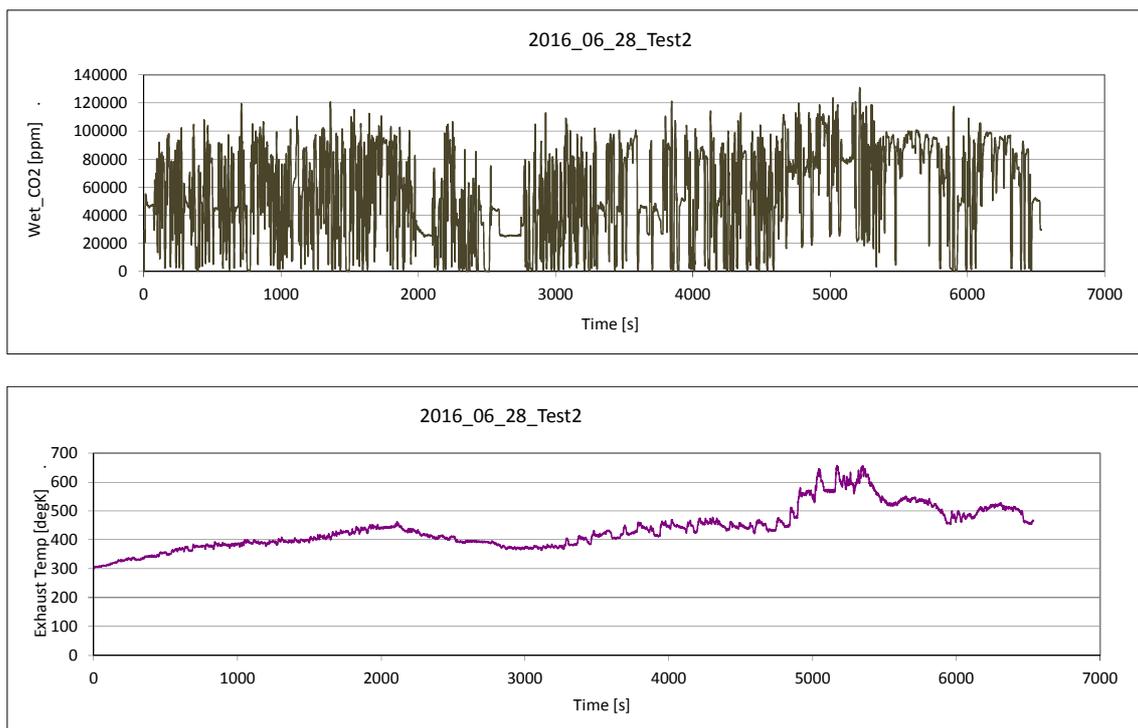
Parameter	Recommended range for screening
Wet CO ₂ [ppm]	0; 200 000
Wet O ₂ [ppm]	0; 500 000
Wet CO [ppm]	0; 800 000
Wet THC [ppm]	0; 10 000
Wet NO _x [ppm]	0; 2 500
Wet NO ₂ [ppm]	0; 2 500
Wet NO [ppm]	0; 2 500
PN [# /m ³]	0; 2 000 000
Exhaust mass flow [kg/s]	0; 0.25
Exhaust temperature [K]	0; 1 000
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
GNSS Latitude [degrees]	0; 180
GNSS Longitude [degrees]	-80; 80
Altitude [m]	0; 5 000
GNSS Vehicle speed [km/h]	0; 200

7.3 Verification 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 14** with the increase of CO₂ emissions and exhaust temperature, which are typical for most of the regeneration of Diesel Particulate Filters (DPFs).

The verification of regeneration may be based on expert judgement through cross-correlation of several of the following signals, which may include exhaust temperature, PN, CO₂, O₂ measurements in combination with vehicle speed and acceleration. If the vehicle has a regeneration recognition feature declared in Transparency List 1 set out in Table 1 of Appendix 5 to Annex II of WLTP 2nd Act regulation, it shall be used to determine the occurrence of regeneration. The manufacturer shall also declare in Transparency List 1 the procedure needed in order to complete the regeneration. The manufacturer may advise how to recognise whether regeneration has taken place in case such a signal is not available. If regeneration occurred during the test, the result without the application of either the K_i -factor or the K_i offset shall be checked against the requirements of point 3.1.0. If the resulting emissions do not fulfil the requirements, then the test shall be voided and repeated once. The completion of the regeneration and stabilisation through at least 1 hour of driving shall be ensured prior to the start of the second test. The second test is considered valid even if regeneration occurs during it.

Figure 14. CO₂ and exhaust temperature increase during DPF regeneration (after 5000 seconds).



Source: JRC own development

8 Data exchange files [How to report the test data?]



According to the EU-RDE Regulation, Appendix 8 and its amendments regarding the data exchange and reporting requirements, the PEMS data files shall be structured using standardized contents and formats. RDE4 introduces an update on the format and contents of the data exchange files to enhance harmonization on the PEMS reporting.

For EU-RDE-TA and EU-RDE-ISC tests, the contents and the formats are strict and mandatory. For other types of PEMS testing, it is highly recommended to use the formatting requirements from the EU-RDE Regulation to ensure the highest compatibility with the data processing tools which are on the market.

It is strongly recommended to use the .csv Sample files for Data Exchange file, Reporting file #1, and Reporting file #2 that have been made available publicly in [CIRCABC: EUROPA > European Commission > CIRCABC > GROW > wltip > New light duty test procedures > RDE-LDV > rde-ldv_reference](#) Empty lines shall be used in case some parameters are not reported.

For EU-RDE-TA and EU-RDE-ISC testing, it is mandatory to verify and to record the data listed as M in Table 10. The time-series (**Table 11**) must include all the elements recorded during the operation of the instruments, at least between test-start and test-end, at their sample frequency. For other types of PEMS testing, the recommended information is indicated with the letter O. It is recommended that the equipment used for testing provides data in a way that complies to the legislation with respect to data file generation and reporting.

Table 10. Testing conditions to be recorded

EU-RDE TA	EU-RDE ISC	Other PEMS testing	Parameter	Description/Unit
M	M	O	Test ID	[code]
M	M	O	Test date	[dd.mm.yyyy]
M	M	O	Organisation supervising the test	[name of the organisation]
M	M	O	Test location	[city (Country)]
M	M	O	Organisation commissioning the test	[name of the organization]
M	M	O	Vehicle driver	[TS/Lab/OEM]

Table 11. Time series to be recorded

EU-RDE TA	EU-RDE ISC	Other PEMS testing	Parameter	Description/Unit
M	M	O	Start time of pre-test procedure	[h:min]
M	M	O	Start time of trip	[h:min]
M	M	O	Start time of post-test procedure	[h:min]
M	M	O	End time of pre-test procedure	[h:min]
M	M	O	End time of trip	[h:min]

Time series to be recorded (*continued*)

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

¹ To be determined by at least one method for EU-RDE-ISC. For EU-RDE-TA, recording the vehicle speed from the ECU is not permitted.

² To be determined by at least one method, although pressure sensor is the recommended option for retrieving the altitude.

³ It is not permitted to record ECU signals to calculate exhaust mass flow during EU-RDE-TA tests.

⁵ NO_x may be either measured or calculated from measured NO and NO₂ concentrations.

Time series to be recorded (*continued*)

EU-RDE TA	EU-RDE ISC	Other PEMS testing	Parameter	Description/Unit
-	0	0	Fuel rate (ECU) ⁽⁴⁾	[g/s]
-	0	0	Engine fuel flow (ECU) ⁽⁴⁾	[g/s]
-	0	0	Engine intake fuel flow (ECU) ⁽⁴⁾	[g/s]
0	0	0	O ₂ mass flow rate (sensor)	[ppm; g/s]
0	0	0	THC mass flow rate (sensor)	[ppm; g/s]
0	0	0	CH ₄ mass flow rate (sensor)	[ppm; g/s]
0	0	0	Hybrid battery State of Charge (ECU or power analyser)	[%]
0	0	0	Hybrid battery current (ECU or power analyser)	[A]
0	0	0	Hybrid battery voltage (ECU or power analyser)	[V]

List of abbreviations and definitions

#/m³	number per cubic metre
A	Ampere
AGM	Absorbent glass mat battery
CH₄	Methane
CNG	Compressed natural gas
CO	Carbon Monoxide
CO₂	Carbon Dioxide
CPC	Condensation Particle Counter
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
GNSS	Global Navigation Satellite System (GNSS)
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
NO₂	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 C₁	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
VELA	Vehicle Emissions Laboratory
WWH-OBD	Worldwide Harmonised On-Board Diagnostics

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Annex: Criteria for vehicle selection and failed vehicles decision

Selection of vehicles for European In-Service Conformity emissions testing

	x = Exclusion Criteria	X = Checked and reported	Confidential
Date:			x
Name of investigator:			x
Location of test:			x
Country of registration (in EU only):		x	

Vehicle Characteristics

Registration plate number:		x	x
Mileage: <i>The vehicle must have between 15 000 km and 100 000 km</i>	x		
Date of first registration: <i>The vehicle must be between 6 months (or 12 months for testing evaporative emissions) and 5 years old</i>	x		

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

Vehicle owner interview

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

	x = Exclusion Criteria	X = Checked and reported	Confidential
Name of the owner (only available to the accredited inspection body or lab/technical service)			x
Contact (address / telephone) (only available to the accredited inspection body or lab/technical service)			x
How many owners did the vehicle have?		x	
Did the odometer not work? <i>If yes, the vehicle cannot be selected.</i>	x		
Was the vehicle used for one of the following?			
As presentation car?		x	
As a taxi?		x	
As delivery vehicle?		x	
For racing / motor sports?	x		
As a rental car?		x	
Has the vehicle carried heavy loads over the specifications of the manufacturer? <i>If yes, the vehicle cannot be selected.</i>	x		
Have there been major engine or vehicle repairs?		x	
Have there been unauthorised major engine or vehicle repairs? <i>If yes, the vehicle cannot be selected.</i>	x		
Has there been a power increase/tuning? <i>If yes, the vehicle cannot be selected.</i>	x		
Was any part of the emissions after-treatment and/or the fuel system replaced? Were original parts used? <i>If original parts were not used, the vehicle cannot be selected.</i>	x	x	
Was any part of the emissions after-treatment system removed? <i>If yes, the vehicle cannot be selected</i>	x		
Were there any unauthorised devices installed (Urea killer, emulator, etc.)? <i>If yes, the vehicle cannot be selected</i>	x		

	x = Exclusion Criteria	X = Checked and reported	Confidential
Was the vehicle involved in a serious accident? Provide a list of damage and repairs done afterwards		x	
Have the car been used with a wrong fuel type (i.e. gasoline instead of diesel) in the past? Have the car been used with non-commercially available EU-quality fuel (black market, or blended fuel?) <i>If yes, the vehicle cannot be selected.</i>	x		
Did you use air-fresher, cockpit-spray, brake cleaner or other high hydrocarbon emission source around the vehicle during the last month? <i>If yes, the vehicle cannot be selected for evaporative testing.</i>	x		
Was there a gasoline spill in the inside or outside of the vehicle during the last 3 months? <i>If yes, the vehicle cannot be selected for evaporative testing.</i>	x		
Did anyone smoke in the car during the last 12 months? <i>If yes, the vehicle cannot be selected for evaporative testing</i>	x		
Did you apply corrosion protection, stickers, under seal protection, on any other potential sources of volatile compounds to the car? <i>If yes, the vehicle cannot be selected for evaporative testing</i>	x		
Was the car repainted? <i>If yes, the vehicle cannot be selected for evaporative testing</i>	x		
Where do you use your vehicle more often?			
% motorway		x	
% rural		x	
% urban		x	
Did you drive the vehicle in a non EU Member State for more than 10% of driving time? <i>If yes, the vehicle cannot be selected</i>	*	-	
In which country was the vehicle refuelled during the last two times? <i>If the vehicle was refuelled the last two times outside a state applying the EU Fuel Standards, the vehicle cannot be selected.</i>	x		

	x = Exclusion Criteria	X = Checked and reported	Confidential
Has a fuel additive, not approved by the manufacturer used? <i>If yes then the vehicle cannot be selected.</i>	x		
Has the vehicle been maintained and used according to the manufacturer's recommendations? <i>If not, the vehicle cannot be selected.</i>	x		
Full service and repair history including any re-works <i>If the full documentation cannot be provided, the vehicle cannot be selected.</i>	x		

Vehicle examination and maintenance

X= Exclusion
Criteria /
F= Faulty
Vehicle

X=checked and
reported

<p>Fuel tank level (full / empty) Is the fuel reserve light ON? <i>If yes, refuel before test.</i></p>		x
<p>Are there any warning lights on the instrument panel activated indicating a vehicle or exhaust after-treatment system malfunctioning that cannot be resolve by normal maintenance? (Malfunction Indication Light, Engine Service Light, etc.?) <i>If yes, the vehicle cannot be selected</i></p>	x	
<p>Is the SCR light on after engine-on? <i>If yes, the Ad Blue should be filled in, or the repair executed before the vehicle is used for testing.</i></p>	x	
<p>Visual inspection exhaust system Check leaks between exhaust manifold and end of tailpipe. Check and document (with photos) <i>If there is damage or leaks, the vehicle is declared faulty.</i></p>	F	
<p>Exhaust gas relevant components Check and document (with photos) all emissions relevant components for damage. <i>If there is damage, the vehicle is declared faulty.</i></p>	F	
<p>Evaporative system Pressurize fuel-system (from canister side), testing for leaks in a constant ambient temperature environment, FID sniff test around and in the vehicle <i>If the FID sniff test is not passed, the vehicle is declared faulty.</i></p>	F	
<p>Fuel sample Collect fuel sample from the fuel tank.</p>		x
<p>Air filter and oil filter Check for contamination and damage and change if damaged or heavily contaminated or less than 800 km before the next recommended change.</p>		x
<p>Window washer fluid (only for evaporative testing) Remove window washer fluid and fill tank with hot water.</p>		x
<p>Wheels (front & rear) Check whether the wheels are freely moveable or blocked by the brake. <i>If not, the vehicle cannot be selected.</i></p>	x	
<p>Tyres (only for evaporative testing) Remove spare tyre, change to stabilised tyres if the tyres were changes less than 15.000 km ago. Use summer and all season tyres only.</p>		x

	X= Exclusion Criteria / F= Faulty Vehicle	X=checked and reported
Drive belts & cooler cover <i>In case of damage, the vehicle is declared faulty. Document with photos</i>	F	
Check fluid levels Check the max. and min. levels (engine oil, cooling liquid) / top up if below minimum		x
Filler flap (only for evaporative testing) Check overfill line within filler flap is completely free of residues or flush the hose with hot water.		x
Vacuum hoses and electrical wiring Check all for integrity. <i>In case of damage, the vehicle is declared faulty. Document with photos</i>	F	
Injection valves / cabling Check all cables and fuel lines. <i>In case of damage, the vehicle is declared faulty. Document with photos</i>	F	
Ignition cable (gasoline) Check spark plugs, cables, etc. In case of damage, replace them.		x
EGR & Catalyst, Particle Filter Check all cables, wires and sensors. <i>In case of tampering, the vehicle cannot be selected. In case of damage the vehicle is declared Faulty, Document with photos</i>	x/F	
Safety condition Check tires, vehicle's body, electrical and braking system status are in safe conditions for the test and respect road traffic rules. <i>If not, the vehicle cannot be selected.</i>	x	
Semi-trailer Are there electric cables for semi-trailer connection, where required?		x
Aerodynamic modifications Verify no aftermarket aerodynamics modification that cannot be removed before testing was made (roof boxes, load racking, spoilers, etc.) and no standard aerodynamics components are missing (front deflectors, diffusers, splitters, etc.). <i>If yes, the vehicle cannot be selected. Document with photos.</i>	x	
Check if less than 800 km away from next scheduled service, if yes, then perform the service.		x
All checks requiring OBD connections to be performed before and/or after the end of testing		
Powertrain Control Module calibration part number and checksum		x

**X= Exclusion
Criteria /
F= Faulty
Vehicle**

**X=checked and
reported**

OBD diagnosis (before or after the emissions test) Read Diagnostic Trouble Codes & Print error log		x
OBD Service Mode 09 Query (before or after the emissions test) Read Service Mode 09. Record the information.		x
OBD mode 7 (before or after the emissions test) Read Service Mode 07. Record the information		
Remarks for: Repair / replacement of components / part numbers		

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