DRAFT

CHAPTERS 7 – 9

OF

GLOBAL TECHNICAL REGULATION

UNIFORM PROVISIONS CONCERNING THE APPROVAL OF COMPRESSION-
IGNITION (C.I.) ENGINES TO BE INSTALLED IN AGRICULTURAL AND
FORESTRY TRACTORS AND IN **NON-ROAD MOBILE MACHINER**Y WITH
REGARD TO THE EMISSIONS OF POLLUTANTS BY THE ENGINE

10. ANNEXES

ANNEX A.1. – DUTY CYCLES
A.1.1. ISO C1 steady-state cycle – Discrete and ramped
A.1.2. ISO D2 steady-state cycle – Discrete and ramped
A.1.3. Steady-state discrete mode test cycle G2
A.1.4. Full transient (variable speed & variable load) engine dynamometer schedule (NRTC)

ANNEX A.2. – GENERALITY
A.2.1. Data requirements
A.2.2. Statistics
A.2.3. Drift correction
A.2.4. 1980 international gravity formula

ANNEX A.3. – PROCEDURES FOR CONDUCTING THE TEST FOR DURABILITY [RESERVED]
A.3.1. Introduction
A.3.2. Selection of engines for establishing deterioration factors
A.3.3. Establishing useful life deterioration factors
A.3.4. Maintenance
A.3.5. Demonstration

ANNEX A.4. – CARBON FLOW CHECK

ANNEX A.5. – EQUIPMENT AND AUXILIARIES TO BE INSTALLED FOR THE TEST TO DETERMINE ENGINE POWER

ANNEX A.6. – REFERENCE FUELS FOR COMPRESSION IGNITION ENGINES

ANNEX A.7. – MEASUREMENT EQUIPMENT

ANNEX A.8. – MASS BASED CALCULATIONS

ANNEX A.9. – MOLAR BASED CALCULATIONS

TEST PROCEDURES

7.1. Introduction

Paragraph §7. describes the determination of brake specific emissions of gaseous and particulate pollutants on engines to be tested.

A laboratory emission test consists of measuring emissions and other parameters for the duty cycles specified in this gtr. The following aspects are treated:
(a) the laboratory configurations for measuring the brake specific emissions (§7.2.);
(b) the pre-test and post-test verification procedures (§7.3.);
(c) the duty cycles (§7.4.);
(d) the general test sequence (§7.5.);
(e) the specific characteristics of the two types (steady-state and transient) of duty cycles (§7.6.).

7.2. Principle of emission measurement

To measure the brake-specific emissions the engine shall be operated over the test duty cycles defined in §7.4. The measurement of brake-specific emissions requires the determination of the mass of pollutants in the exhaust (i.e. HC, CO, NOx and PM) and the corresponding engine work.

7.2.1. Total mass

The total mass of each constituent shall be determined over the applicable duty cycle by selecting the following methods:
(a) Continuous sampling. In continuous sampling, the constituent's concentration shall be measured continuously from raw or dilute exhaust. This concentration is multiplied by the continuous (raw or dilute) flow rate at the emission sampling location to determine the constituent's flow rate. The constituent's emission is continuously summed over the test. This sum is the total mass of the emitted constituent. Another way of continuous sampling is the measurement of the exhaust component over a certain time and the calculation of its mean value.
 (b) Batch sampling. In batch sampling, a sample of raw or dilute exhaust is continuously extracted and stored for later measurement. The extracted sample shall be proportional to the raw or dilute exhaust flow rate. Examples of batch sampling are collecting diluted gaseous emissions in a bag and collecting PM on a filter. In principal the method of emission calculation is done as follows: the batch sampled concentrations are multiplied by the total mass or mass flow (raw or dilute) from which it was extracted during the duty cycle. This product is the total mass or mass flow of the emitted constituent. To calculate the PM concentration, the PM deposited onto a filter from proportionally extracted exhaust shall be divided by the amount of filtered exhaust.
(c) Combined sampling: any combination of continuous and batch sampling is permitted (e.g. PM with batch sampling and gaseous emissions with continuous sampling).

7.2.2. Work determination

The work shall be determined over the duty cycle by synchronously multiplying speed and brake torque to calculate instantaneous values for engine brake power. Engine brake power shall be summed up over the duty cycle to determine total work.

The following figure 1 illustrates the two aspects of the test procedures for measuring brake specific emissions: the equipments with the sampling lines in raw and diluted exhaust gas (figure 1A) and the operations requested to calculate the pollutant emissions in steady-state and transient tests (figure 1B).

```
                              Exhaust
                  ┌──────────────────────────┐
                 Raw                    Full dilution (3)
            ┌───────────┐                     │
       Continuous   Part dilution            CVS
            │      ┌──────────┐                │
           Gas  Constant   Varying        Varying
                dilution   dilution       dilution
            │      │          │         ┌──────────┐
      Integration(2) Filter  Filter  Continuous   Batch
                     │          │         │      ┌──────────┐
                  PM(1)      PM(3)        Gas    Bag    Filter
                                          │       │       │
                                    Integration  Gas     PM
```
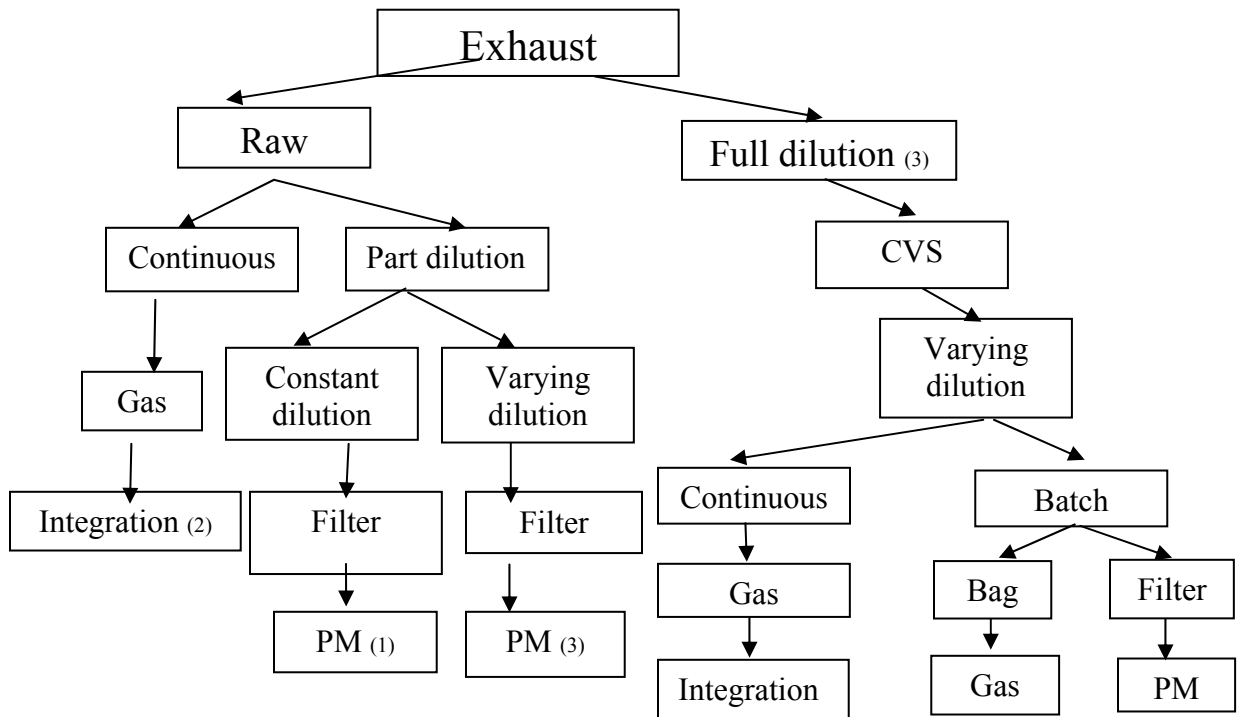
(1) Steady-state test only; (2) Transient test only; (3) Steady-state and transient tests

Figure 1A of paragraph §7.2. – Overview of sampling lines in raw and diluted exhaust gas.

Exhaust

Raw gaseous sampling	+	Partial flow PM sampling	Full flow dilution for gaseous and PM

Transient [1]	Steady-state [2]	Transient [1]	Steady-state [2]	Transient and steady-state [3]
For whole test:	For each mode:	Varying dilution ratio	Constant dilution ratio	Varying dilution ratio
Continuous gas analysis	Average gas analysis gas concentration	Single filter method	Multiple filter method	Continuous gas analysis for NOx and HC / Batch sampling (Bag, Filter)
+ continuous flow measurement	Average flow			Calculation of average concentration / Gaseous emissions CO, CO2 / PM
Calculation of instantaneous emission [g/h]	Calculation of emission [g/h]		Calculation of emission for each mode [g/h]	
Integration of instantaneous emissions	Multiplying modal emissions with weighting factors	Calculation of emission for whole test [g/h]	Multiplying modal emissions with weighting factors	Emission calculation by multiplication of average concentration (from continuous or batch sampling) with average flow

[1] Transient and Ramped Modal Test Cycle; [2] Discrete Mode Steady State Cycle; [3] Transient, ramped modal and discrete mode Steady-State Cycles

Figure 1B of paragraph §7.2. – Requested operations to calculate pollutant emissions in steady-state and transient tests (see annexes §A.8. and §A.9.)

7.3. Verification and calibration

7.3.1. Pre-test procedures

7.3.1.1. Ambient conditions

Ambient conditions shall be verified to be within the following tolerances: ambient temperature and atmospheric pressure shall fulfil the requirements of §6.1.

7.3.1.2. Preconditioning

Upon request of the engine manufacturer, the sampling systems may be preconditioned.

7.3.1.3. Verification of HC contamination

After the last practice or preconditioning cycle before an emission test, the amount of contamination in the HC sampling system shall be verified as follows:
(a) The HC analyzer range for measuring the mean concentration expected at the HC standard shall be selected.
(b) The HC analyzer shall be zeroed at the analyzer zero or sample port.
(c) The HC analyzer shall be spanned using span gas introduced at the analyzer span or sample port.

(d) Zero gas shall be overflowed at the HC probe or into a fitting between the HC probe and its transfer line.

(e) The initial value for HC concentration in the sampling system shall be determined as follows:

(i) For continuous sampling, it is the mean HC concentration as overflow zero air flows.

(ii) For batch sampling, the sample medium shall be filled and its mean HC concentration shall be recorded.

(f) This value shall be recorded as the initial HC concentration, x_{HCinit}, and used to correct measured values as described in §A.8.-A.9.

(g) If x_{HCinit} exceeds 2% of the mean concentration measured during testing or 2 ppmC, whichever is higher, the source of the contamination shall be determined and corrective action shall be taken, such as purging the system during an additional preconditioning cycle or replacing contaminated portions.

7.3.1.4. Preparation of measurement equipment for sampling

The following steps shall be taken before emission sampling begins:

(a) Leak checks shall be performed within 8 hours prior to emission sampling according to section §8.1.8.7.

(b) For batch sampling, clean storage media shall be connected, such as evacuated bags or tare-weighed filters.

(c) All measurement instruments shall be started according to the instrument manufacturer's instructions and good engineering judgment.

(d) Dilution systems, sample pumps, cooling fans, and the data-collection system shall be started.

(e) The sample flow rates shall be adjusted to desired levels, using bypass flow, if desired.

(f) Heat exchangers in the sampling system shall be pre-heated or pre-cooled to within their operating temperature tolerances for a test.

(g) Heated or cooled components such as sample lines, filters, chillers, and pumps shall be allowed to stabilize at their operating temperatures.

(h) Calibration of gas analyzers and zeroing of continuous analyzers shall be carried out according to the procedure of the next paragraph 7.3.1.5.

(i) Any electronic integrating devices shall be zeroed or re-zeroed, before the start of any test interval.

7.3.1.5. Calibration of gas analyzers

Gas analyzer ranges shall be selected. Analyzers may be used that automatically switch ranges during a test only if switching is performed by changing the span over which the digital resolution of the instrument is applied. During a test the gains of an analyzer's analogue operational amplifier(s) may not be switched.

All continuous analyzers shall be zeroed and spanned using internationally-traceable gases that meet the specifications of §9.5.1. FID analyzers shall be spanned on a carbon number basis of one (C_1).

7.3.1.6. PM filter preconditioning and tare weighing

If the engine must comply with a PM standard, the procedures for PM filter preconditioning and tare weighing shall be followed according to §8.2.3.

7.3.2. Post-test procedures

The following steps shall be taken after emission sampling is complete:

7.3.2.1. Verification of proportional sampling

For any proportional batch sample, such as a bag sample or PM sample, it shall be verified that proportional sampling was maintained according to §8.2.1. Any sample that did not maintain proportional sampling according to §8.2.1. shall be voided.

7.3.2.2. Post-test PM conditioning and weighing

Any used PM samples shall be placed into covered or sealed containers and they shall be returned to the PM-stabilization environment. The PM sample post-conditioning and total weighing procedures in §8.2.4. shall be followed.

7.3.2.3. Analysis of gaseous batch sampling

As soon as practical after the duty cycle is complete but no later than 30 minutes after the duty cycle is complete, the following shall be performed:
(a) All batch gas analyzers shall be zeroed and spanned.
(b) Any gaseous batch samples, including background samples shall be analyzed.

7.3.2.4. Drift verification

After quantifying exhaust gases, drift shall be verified as follows:
(a) For batch and continuous gas analyzers, the mean analyzer value shall be recorded after stabilizing a zero gas to the analyzer. Stabilization may include time to purge the analyzer of any sample gas, plus any additional time to account for analyzer response.
(b) The mean analyzer value shall be recorded after stabilizing the span gas to the analyzer. Stabilization may include time to purge the analyzer of any sample gas, plus any additional time to account for analyzer response.
(c) These data shall be used to validate and correct for drift as described in §8.2.2.

7.4. Duty cycles

To the compression ignition (CI) engines considered in this gtr the following duty cycles apply:

(a) for variable-speed engines with a maximum power at or above 19 kW, the C1 cycle and the corresponding ramped modal cycle, and the transient cycle NRTC as specified in annex §A.1.1. and annex §A.1.4. respectively;

(b) for constant-speed engines with a maximum power at or above 19 kW, the D2 cycle and the corresponding ramped modal cycle as specified in annex §A.1.2.;

(c) for variable speed engines below 19 kW, the discrete mode steady-state G2 cycle as specified in annex §A.1.3.

7.4.1. Steady-state duty cycles (C1, D2, G2)

Steady-state duty cycles are specified in annex §A.1. as a list of discrete operating points (modes), where each operating point has one value of speed and one value of torque. Ramped-modal cycles for steady-state testing also list test times for each mode and ramps of speed and torque to follow between modes. A steady-state cycle shall be started as a hot running test, where the emissions shall be measured with a warmed up engine and running according to manufacturer's specification. A steady-state duty cycle may be run as a discrete-mode cycle or a ramped-modal cycle, as explained in the following paragraphs.

7.4.1.1. Steady-state discrete mode test cycle

The steady-state discrete 8-mode test C1 cycle consists of eight speed and load modes which cover the typical operating range of variable speed engines with a maximum power, equal or above 19 kW. The cycle is shown in annex §A.1.1.1., with engine speed, load and weighing factor for each mode.

The steady-state discrete 5-mode test D2 cycle consists of five load modes all at rated speed which cover the typical operating range of constant speed engines with a maximum power equal or above 19 kW. The cycle is shown in annex §A.1.2.1., with engine load and weighing factor for each mode.

The steady-state discrete 6-mode test G2 cycle consists of five load modes at rated speed and one mode at idle which cover the typical operating range of variable speed (non hand-held lawn and garden utility) engines with a maximum power below 19 kW. The cycle is shown in annex §A.1.3., with engine speed, load and weighing factor for each mode.

Before emission sampling, the engine shall be warmed-up and stabilized. The engine is operated for a constant period (10 minutes) for each mode. The sampling time of gaseous emissions measurement is specified in paragraph §7.6.1.3.2. For PM measurement batch sampling with accumulation on one filter represents the standard PM measurement (one filter method). As an alternative PM samples can be taken for each mode individually (multi-filter method). In this case the operation period of 10 minutes can be increased to get enough PM material onto the filter. The validity of the test shall be checked in agreement with paragraph §7.6.1.4. The test emissions are calculated using the weighting factors as laid down in annexes §A.8-A.9.

7.4.1.2. Steady-state ramped test cycles

The engine shall be operated for the prescribed time in each mode. During the transition from one mode to the next mode engine speed and load shall be changed linearly within 20 s.

Over the whole test cycle during each mode and including the ramps between the modes, the concentration of each gaseous pollutant shall be determined and the PM be sampled. The gaseous pollutants may be measured raw or diluted and be recorded continuously; they can also be sampled as diluted into a sampling bag. The particulate sample shall be diluted with conditioned ambient air. One sample over the complete test procedure shall be taken, and collected on a single suitable filter.

For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle.

7.4.1.2.1. Ramped test cycle derived from ISO C1

The ramped-modal testing of variable-speed engines with a maximum power at or above 19 kW is conducted with a cycle derived from the ISO C1 test cycle composed by 8-modes which cover the typical operating range. The cycle is shown in the annex §A.1.1.2. with time, engine speed and load in each mode.

7.4.1.2.2. Ramped test cycle derived from ISO D2

The ramped-modal testing of constant speed engines with a maximum power at or above 19 kW is conducted with a cycle derived from ISO D2 test cycle composed by five load modes at rated speed which cover the typical operation. The cycle is shown in the annex §A.1.2.2. with time, engine speed and load in each mode.

7.4.2. Transient test cycle (NRTC)

The Non-Road Transient Cycle (NRTC) is specified in annex §A.1.4. as a second-by-second sequence of normalized speed and torque values. In order to perform the test on an engine test cell, the normalized values shall be converted to the actual values for the individual engine under test based on the engine-mapping curve. The conversion is referred to as denormalization, and the test cycle so developed as the reference duty cycle of the engine to be tested (see paragraph §7.6.). With those reference speed and torque values, the cycle shall be run on the test cell.

A graphical display of the NRTC dynamometer schedule is shown here below.

Speed [%]

NRTC dynamometer schedule

Torque [%]

time [s]
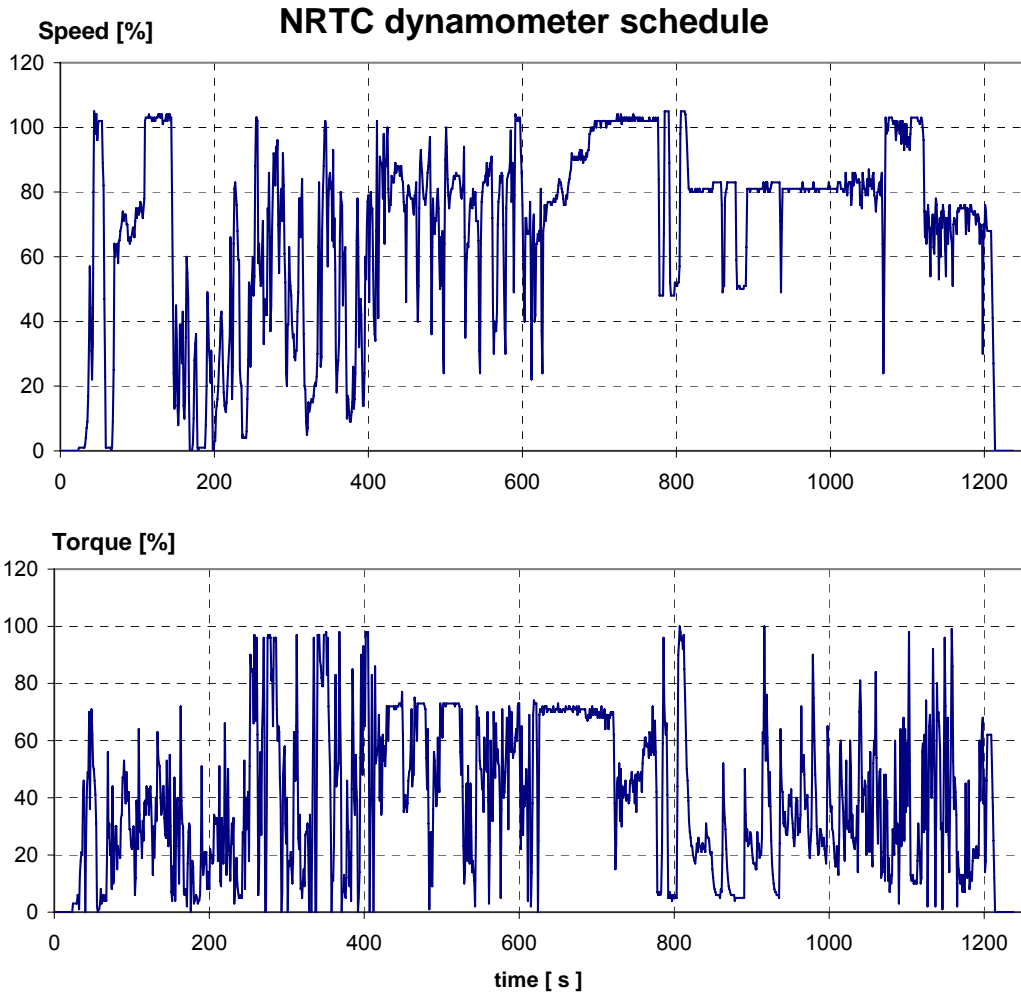
The transient test cycle shall be run twice (see paragraph §7.6.3.3.):
(a) The first time (cold start) after the engine has cooled down to room temperature and the engine coolant and oil temperatures, aftertreatment systems and all auxiliary engine control devices are stabilized between 20 and 30 °C. The measurement of emissions shall be started with the start of the cold engine
(b) The second time (hot start) after a soak period that commences immediately after the completion of the cold start cycle. The measurement of emissions shall be started with the start of this second hot start cycle.

Hot soak period – Immediately upon completion of the cold start test, the engine shall be conditioned for the hot start test by using one of the following options:
(a) 5 ± 1 minutes hot soak period;
(b) 20 ± 1 minutes hot soak period.
The option shall be selected by the Contracting Parties.

Brake specific emissions (g/kWh) shall be determined by using the procedures of this section for both the cold and hot start cycles. Composite weighted emissions shall be

computed by weighting the cold start results X% and the hot start results Y% as detailed in annexes §A.8.-A.9. where X and Y are quantities defined by the Contracting Party.

7.5. General test sequence

To measure engine emissions the following steps have to be performed:
(a) The engine speeds and loads have to be defined for the particular engine by measuring the full load curve.
(b) Normalized duty cycles have to be denormalized with the speeds and load / torques found in the previous paragraph (a).
(c) The engine, equipment, and measurement instruments shall be prepared for the emission test.
(d) Pre-test procedures shall be performed to verify proper operation of certain equipment and analyzers. All analysers have to be calibrated. All pre-test data shall be recorded.
(e) The engine shall be started (NRTC) or kept running (steady-state cycles) at the beginning of the test cycle and the sampling systems shall be started at the same time.
(f) Emissions and other required parameters shall be measured throughout the duty cycle.
(g) Post-test procedures shall be performed to verify proper operation of certain equipment and analyzers.
(h) PM filter(s) shall be conditioned, weighed and then samples shall be evaluated.
(i) Emission test results shall be calculated

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┌─────────────────────────────────────────────────────────────────────────────┐
│  Engine preparation, pre-test measurements, performance checks and           │
│  calibrations                                                                 │
└─────────────────────────────────────────────────────────────────────────────┘

        ┌──────────────────────────┐      ┌──────────────────────────────────┐
        │  Transient NRTC §7.6.3.  │      │ Steady-state discrete §7.6.1. &   │
        │                          │      │ ramp §7.6.2.                      │
        └──────────────────────────┘      └──────────────────────────────────┘
                    │                                    │
                    ▼                                    ▼
   ┌──────────────────────────────────┐   ┌──────────────────────────────────┐
   │ Generation engine map (max       │   │ Full load curve measurement      │
   │ torque curve)                    │···│ Defining steady-state duty cycle  │
   │ Generate reference test cycle    │   │ modes                             │
   └──────────────────────────────────┘   └──────────────────────────────────┘
                    │                                    │
                    ▼                                    ▼
┌─────────────────────────────────────────────────────────────────────────────┐
│ Run one or more practice cycle as necessary to check engine/test             │
│ cell/emissions systems                                                        │
└─────────────────────────────────────────────────────────────────────────────┘
                    │                                    │
                    ▼                                    ▼
   ┌──────────────────────────────────┐   ┌──────────────────────────────────┐
   │ Natural or forced cool down      │   │ Warm-up eng. & particulate system│
   └──────────────────────────────────┘   └──────────────────────────────────┘
                    │                                    │
                    ▼                                    ▼
   ┌──────────────────────────────────┐   ┌──────────────────────────────────┐
   │ Ready all systems for sampling   │   │ Ready all systems for sampling   │
   │ (analyzer calibration included)  │   │ (analyzer calibration included)  │
   │ & data collection                │   │ & data                           │
   └──────────────────────────────────┘   └──────────────────────────────────┘
                    │                                    │
                    ▼                                    ▼
   ┌──────────────────────────────────┐   ┌──────────────────────────────────┐
   │ Cold start exhaust emission test │   │ Exhaust emission test            │
   └──────────────────────────────────┘   └──────────────────────────────────┘
                    │                                    │
                    ▼                                    │
   ┌──────────────────────────────────┐                 │
   │ Hot soak period                  │                 │
   └──────────────────────────────────┘                 │
                    │                                    │
                    ▼                                    │
   ┌──────────────────────────────────┐                 │
   │ Hot start exhaust emission test  │                 │
   └──────────────────────────────────┘                 │
                    │                                    │
                    ▼                                    ▼
   ┌──────────────────────────────────┐   ┌──────────────────────────────────┐
   │ 1) Data collection 2) Post test  │   │ 1) Data collection 2) Post test  │
   │ procedures 3) Evaluations        │   │ procedures 3) Evaluations        │
   └──────────────────────────────────┘   └──────────────────────────────────┘
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│             Emissions calculation §A.8.-A.9.                                  │
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7.6. Specific Duty Cycle Running Procedure

7.6.1. Discrete duty cycles (C1, D2, G2)

7.6.1.1. Engine mapping of discrete-mode duty cycles

7.6.1.1.1. Full load curve

The engine shall be mapped by measuring the full load curve prior to the run of the test cycle to determine the speed vs. torque and speed vs. power curves for determination of the speeds and torques for the steady-state duty cycle run.

7.6.1.1.2. Engine Warm-up

The engine shall be warmed up and towards the end of the warm up it shall be operated for 10 minutes at maximum power or according to the recommendation of the manufacturer and good engineering practice in order to stabilize the engine parameters. When the engine is stabilized, the engine mapping shall be performed according to the following procedure.

7.6.1.1.3. Engine mapping

Engine mapping shall be performed with fully open throttle or governor using discrete speeds in ascending order between idle and the highest speed above maximum power at which power drops down to less than 70% of maximum power. A sufficient number of evenly spaced set-points, but no more than 100 rpm, shall be selected based on good engineering practice or as agreed by the involved contracting parties. If the highest speed is unsafe or unrepresentative (e.g., for ungoverned engines), good engineering judgment shall be used to map up to the maximum safe speed or the maximum representative one. For constant speed engines other methods can be applied to record full load torque and power at the defined operating speed(s) based on good engineering practice or as agreed by the involved contracting parties.

At each set-point, speed shall be stabilized and torque shall be allowed to stabilize. The mean speed and torque shall be recorded at each set-point.

As alternative, also engine mapping from the ramped modal cycle or transient cycle of this engine can be used.

7.6.1.2. Generation of a discrete-mode steady-state duty cycle (denormalization)

7.6.1.2.1. Test speeds

Idle speed: The idle speed is the lowest engine speed with minimum load (greater than or equal to zero load), where an engine governor function controls engine speed. For

engines without a governor function that controls idle speed, idle speed means the manufacturer-declared value for lowest engine speed possible with minimum load.

Rated speed: n = low speed + 0.95 x (high speed – low speed)

Low speed: The lowest engine speed where 50 % of the rated or prime power is delivered.

High speed: The highest engine speed where 70 % of the rated or prime power is delivered.

Intermediate speed: For engines which are designed to operate over a speed range on a full load torque curve, the intermediate speed shall be the declared maximum torque speed if it occurs between 60 % and 75 % of rated speed. If the declared maximum torque speed is less than 60 % of the rated speed, then the intermediate speed shall be 60 % of the rated speed. If the declared maximum torque speed is greater than 75 % of the rated speed then the intermediate speed shall be 75 % of the rated speed.

7.6.1.2.2. Test loads

The per cent load is the fraction of the maximum available torque at the given engine speed of the mode.

The maximum torque values at the specified test speeds shall be derived from the mapping curve (variable speed engines) or be determined by experimentation (constant speed engines) in order to calculate the torque values for the specified test modes. For engines which are not designed to operate over a range on a full load torque curve, the maximum torque at the test speeds shall be declared by the manufacturer.

The engine setting for each test mode shall be calculated using the formula:

$$S = \left(\left(P_{max} + P_{AUX} \right) \times \frac{L}{100} \right) - P_{AUX} \qquad (7\text{-}1)$$

where:
S is the dynamometer setting in kW;
P_{max} is the maximum observed or declared power at the test speed under the test conditions (specified by the manufacturer) in kW;
P_{AUX} is the declared total power absorbed by auxiliaries fitted for the test (see paragraph §6.3) at the test speed in kW;
L is the per cent torque.

In case of cycle D2 the load figures are percentage values of the torque corresponding to the prime power[1] rating defined as the maximum power available during a variable power sequence, which may be run for an unlimited number of hours per year, between stated

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[1] For further understanding of the prime power definition, see figure 2 of ISO 8528-1:1993(E) standard.

maintenance intervals and under the stated ambient conditions, the maintenance being carried out as prescribed by the manufacturer.

The discrete engine mode speeds and loads shall be calculated with reference to the particular steady-state cycle in agreement with the above defined procedure.

7.6.1.3. Emission test sequence

7.6.1.3.1. Engine warming-up for steady state discrete-mode duty cycles

For preconditioning the engine shall be warmed up according to the recommendation of the manufacturer and good engineering practice. At the end of the preconditioning, the engine has to run at least for 10 minutes at rated speed and 50% load to stabilize the engine parameters. When the engine has achieved steady-state condition and the measurement systems for measuring gaseous and particulate emission have been conditioned, the engine has to be brought to mode 1 within 20 seconds to start the cycle.

Pre-test procedure according to paragraph §7.3.1. have to be performed, including analyzer calibration.

7.6.1.3.2. Performing discrete-mode duty cycles

The particulate sampling and the gaseous emission measurement shall not commence before the engine is warmed-up and stabilized according to paragraph §7.6.1.3.1.

(a) The test shall be performed in ascending order of mode numbers as set out for the test cycle (see annexes §A.1.1. and §A.1.2.).
(b) Each mode has a mode length of at least 10 minutes. In each mode the engine shall be stabilized for at least 5 minutes and emissions shall be sampled for 1 − 3 minutes for gaseous emissions at the end of each mode. Extended time of sampling is permitted to improve the accuracy of PM sampling.
The mode length shall be recorded and reported.
(c) The particulate sampling may be done either with the single filter method or with the multiple filter method. Since the results of the methods may differ slightly, the method used must be declared with the results.
For the single filter method the modal weighting factors specified in the test cycle procedure and the actual exhaust flow shall be taken into account during sampling by adjusting sample flow rate and/or sampling time, accordingly. It is required that the effective weighing factor of the PM sampling is within 0.005 of the weighing factor of the given mode.
Sampling must be conducted as late as possible within each mode. For the single filter method, the completion of particulate sampling shall be coincident within ± 5 s with the completion of the gaseous emission measurement. The sampling time per mode must be at least 20 s for the single filter method and at least 60 s for the multi-filter method. For systems without bypass capability, the sampling time per mode must be at least 60 s for single and multiple filter methods.

(d) The engine speed and load, intake air temperature, fuel flow and air or exhaust gas flow shall be measured for each mode at the same time interval which is used for the measurement of the gaseous concentrations.

Any additional data required for calculation shall be recorded.

(e) If the engine stalls at any time after emission sampling begins for a discrete mode in a discrete-mode duty cycle test, the test shall be voided and be repeated from the engine warming up. In case of single mode PM measurement (one sampling filter for each operating mode), the test shall be continued by driving the complete previous mode for engine temperature conditioning and then measurement shall be initiated with the mode where the engine has stalled.

(f) Post-test procedures according to §7.3.2 shall be performed.

7.6.1.4. Quality requirements for a discrete steady state duty cycle

During each mode of the given test cycle (C1 or D2 or G2) after the initial transition period, the measured speed shall deviate from the reference speed not more than $\pm$ 1 % of rated speed or $\pm$ 3 min^{-1} whichever is greater except for low idle which shall be within the tolerances declared by the manufacturer. The measured torque shall deviate from the reference torque not more than $\pm$ 2 % of the maximum torque at the test speed.

7.6.2. Ramped modal steady-state duty cycle (C1, D2)

The ramped modal steady-state cycle (RMC) is a hot running cycle where emissions are started to be measured after the engine is started, warmed up, and running as in the discrete steady-state duty cycle. The engine is controlled by the test bed control unit like in a transient duty cycle. Also the gaseous and particulate emissions are measured continuously and sampled in the same way as in a transient cycle.

The RMC consists of the same modes in the same order as the corresponding discrete steady-state duty cycle. The length of the modes is representing the weighting factors of the corresponding test cycle. The change in engine speed and load from one mode to the next one has to be linear controlled in a time of 20 seconds. The mode change time is part of the new mode (including the first mode).

7.6.2.1. Engine mapping of ramped modal steady-state duty cycles

The procedure is the same as that described in paragraph §7.6.1.1.

7.6.2.2. Generation of a ramped steady-state duty cycle

The procedure is the same as that described in paragraph §7.6.1.2.

7.6.2.3. Emission test sequence

7.6.2.3.1. Engine warming-up for ramped steady-state duty cycles

The procedure is the same as that described in paragraph §7.6.1.3.1.

7.6.2.3.2. Performing a ramped modal steady-state cycle

(a) Execution of the duty cycle, sampling exhaust gases, recording data, and integrating measured values shall be started simultaneously.
(b) Speed and torque shall be controlled to the first mode in the test cycle. The instructions (annex A.1) shall be followed.
(c) If the engine stalls anywhere during the ramped-modal cycle test, the test shall be voided. The engine shall be pre-conditioned and the test repeated.
(c) At the end of the cycle, sampling shall be continued to operate all systems to allow system response time to elapse. Then all sampling and recording shall be stopped , including the recording of background samples. Finally, any integrating devices shall be stopped and the end of the duty cycle shall be indicated in the recorded data.
(d) Post-test procedures according to §7.3.2 shall be performed.

7.6.2.4. Quality requirements for a ramped steady-state duty cycle

The requirements given in §7.6.1.4 shall also be used here.
Taking into account that in the ramp-mode cycle the steady-state test modes are connected with 20 s linear speed and linear torque transitions (paragraph §7.4.1.2.), also during the linear mode change, tolerances for speed and load must be applied. For the ramp, the speed must be held linear within ± 2 % of rated speed or ± 6 min^{-1} whichever is greater. The torque must be held linear within ± 5 % of the maximum torque at rated speed.
As an alternative, cycle validation check as of transient test cycle (paragraph §7.6.3.4.) may be applied.

7.6.3. Transient Duty Cycle (NRTC)

7.6.3.1. Engine Mapping

(a) Determination of the mapping speed range
The minimum and maximum mapping speeds are defined as follows:
Minimum mapping speed = warm idle speed
Maximum mapping speed = n_{hi} x 1.02 or speed where full load torque drops off to zero, whichever is smaller.
Where n_{hi} is the high speed, defined as the highest engine speed where 70% of the rated power is delivered.
(b) Engine mapping curve
The engine shall be warmed up at maximum power in order to stabilize the engine parameters according to the recommendation of the manufacturer and good engineering practice. When the engine is stabilized, the engine mapping shall be performed according to the following procedure.
(i) The engine shall be unloaded and operated at idle speed.
(ii) The engine shall be operated at full load setting of the injection pump at minimum mapping speed.

(iii) The engine speed shall be increased at an average rate of 8 ± 1 min^{-1}/s from minimum to maximum mapping speed. Engine speed and torque points shall be recorded at a sample rate of at least one point per second.

(c) Alternate mapping

As an alternative, engine mapping procedure from steady state duty cycle (paragraph §7.6.1.1.) with linear interpolation in between the engine speed points, can be used.

If a manufacturer believes that the above mapping techniques are unsafe or unrepresentative for any given engine, alternate mapping techniques may be used. These alternate techniques must satisfy the intent of the specified mapping procedures to determine the maximum available torque at all engine speeds achieved during the test cycles. Deviations from the mapping techniques specified in this paragraph for reasons of safety or representativeness shall be approved by the type approval or certification authority along with the justification for their use. In no case, however, the torque curve shall be run by descending engine speeds for governed or turbocharged engines.

(d) Replicate tests

An engine need not be mapped before each and every test cycle. An engine shall be remapped prior to a test cycle if:

(i) an unreasonable amount of time has transpired since the last map, as determined by good engineering judgement, or

(ii) physical changes or recalibrations have been made to the engine which potentially affect engine performance.

7.6.3.2. Generation of a transient duty cycle (denormalization)

7.6.3.2.1. Normalised duty cycle

annex §A.1.4. defines applicable duty cycles in a normalized format. A normalized duty cycle consists of a sequence of paired values for speed and torque.

7.6.3.2.2. Transformation of normalised values

Normalized values of speed, torque, and power shall be transformed using the following conventions:

(a) The normalized speed is transformed into a sequence of reference speeds, n_{ref}, according to §7.6.3.2.4.

(b) The normalized torque shall be expressed as a percentage of the mapped torque at the corresponding reference speed. These normalized values shall be transformed into a sequence of reference torques, T_{ref}, according to §7.6.3.2.6.

7.6.3.2.3. Execution of reference commands

Reference speeds and torques commands shall be sequentially executed to perform the transient cycle. Speed and torque commands shall be issued at a frequency of at least 5 Hz. During an emission test, reference speeds and torques and the feedback speeds and torques shall be recorded with a minimum frequency of 1 Hz, but preferably of 5 Hz or even 10 Hz. These recorded values shall be used to calculate cycle-validation statistics

and total work. With a recorded frequency of only 1 Hz the allowed time shift between measured and reference speed and torque as given in 7.6.3.2. would not be effectively possible.

7.6.3.2.4. Reference speed

The reference speed (n_{ref}) corresponds to the 100 % normalized speed values specified in the engine dynamometer schedule of annex A1.4. The actual engine cycle resulting from denormalization to the reference speed largely depends on selection of the proper reference speed. The reference speed shall be determined by the following definition:
n_{ref} = *low speed + 0.95 * (high speed – low speed)*
(the high speed is the highest engine speed where 70% of the rated power is delivered, while the low speed is the lowest engine speed where 50% of the rated power is delivered).

7.6.3.2.5. Denormalization of engine speed

The engine speed shall be denormalized using the following equation:

$$\text{Actual speed} = \frac{\%\text{speed} \times (\text{reference speed} - \text{idle speed})}{100} + \text{idle speed}$$

7.6.3.2.6. Denormalization of engine torque

The torque values in the engine dynamometer schedule of annex §A.1.4. are normalized to the maximum torque at the respective speed. The torque values of the reference cycle shall be denormalized, using the mapping curve determined according to paragraph §7.6.3.1., as follows:

$$\text{Actual torque} = \frac{\%\text{ torque} \times \text{max. torque}}{100}$$

for the respective actual speed as determined in Section 7.6.3.2.4.

7.6.3.2.7. Example of denormalization procedure

As an example, the following test point shall be denormalized:

% speed = 43 %

% torque = 82 %

Given the following values:

reference speed = 2200 /min

idle speed = 600 /min

results in

$$\text{actual speed} = \frac{43 \times (2200 - 600)}{100} + 600 = 1288 \text{ /min}$$

With the maximum torque of 700 N·m observed from the mapping curve at 1288 /min

$$\text{actual torque} = \frac{82 \times 700}{100} = 574 \text{ N·m}$$

7.6.3.3. Engine starting, restarting, and shutdown

7.6.3.3.1. Engine start

The engine shall be started
(a) as recommended in the owners manual using a production starter motor and adequately charged battery or a suitable power supply; or
(b) by using the dynamometer. The engine shall be motored within ± 25 per cent of its typical in-use cranking speed. Cranking shall be stopped within 1 s of starting the engine. If the engine does not start after 15 s of cranking, cranking shall be stopped and the reason for the failure to start determined, unless the owners manual or the service-repair manual describes a longer cranking time as normal.

7.6.3.3.2. Engine stalling

(a) If the engine stalls anywhere during the cold start test of the NRTC, the test is void.
(b) If the engine stalls anywhere during the hot start test of the NRTC, the test shall be voided. The engine shall be soaked according to paragraph §7.4.2., and the hot start test repeated. In this case, the cold start test need not be repeated.

7.6.3.3.3. Engine shut down

The engine shall be shut down.

7.6.3.4. Emission test sequence (NRTC)

7.6.3.4.1. Engine preconditioning

A natural or forced cool-down procedure may be applied. For forced cool-down, good engineering judgment shall be used to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to remove heat from the coolant through the engine cooling system, and to remove heat from an exhaust after-treatment system. In the case of a forced after-treatment cool down, cooling air shall not be applied until the after-treatment system has cooled below its catalytic activation temperature. Any cooling procedure that results in unrepresentative emissions is not permitted.

Pre-test procedures according to paragraph 7.3.1. have to be performed, including analyzer calibration.

7.6.3.4.2. Performing a transient duty cycle test

Testing shall be started as follows:

Speed and torque shall be controlled to the first mode in the test cycle. The instructions (annex A.1) shall be followed.

For the NRTC, data logging, sampling of exhaust gases, and integrating measured values shall be initiated simultaneously at the start of the engine. The duty cycle shall be initiated when the engine starts and shall be executed according to the schedule of annex §A.1.4.

At the end of the cycle, sampling shall be continued to operate all systems to allow system response time to elapse. Then all sampling and recording shall be stopped , including the recording of background samples. Finally, any integrating devices shall be stopped and the end of the duty cycle shall be indicated in the recorded data.

Post-test procedures according to paragraph §7.3.2. have to be performed.

7.6.3.5. Cycle validation criteria for transient duty cycle

The test shall be checked in order that the test cycle is validated based on the cycle-validation criteria in this chapter.

7.6.3.5.1. Calculation of cycle work

Before calculating the cycle work, any points recorded during engine starting shall be omitted. The actual cycle work W_{act} (kWh) shall be calculated based on engine feedback speed and torque values. The reference cycle work W_{ref} (kWh) shall be calculated based on engine reference speed and torque values. The actual cycle work W_{act} is used for

comparison to the reference cycle work W_{ref} and for calculating the brake specific emissions (see §7.2.)
W_{act} shall be between 85 per cent and 105 per cent of W_{ref}.

7.6.3.5.2. Validation statistics
(see annex A.2.)

Linear regressions of the actual values on the reference values shall be performed for speed, torque and power.

To minimize the biasing effect of the time lag between the actual and reference cycle values, the entire engine speed and torque actual signal sequence may be advanced or delayed in time with respect to the reference speed and torque sequence. If the actual signals are shifted, both speed and torque must be shifted the same amount in the same direction.
The method of least squares shall be used, with the best-fit equation having the form:

$$y = mx + b$$

where:
y = actual value of speed (min^{-1}), torque (N·m), or power (kW)
m = slope of the regression line
x = reference value of speed (min^{-1}), torque (N·m), or power (kW)
b = y intercept of the regression line

The standard error of estimate (SEE) of y on x and the coefficient of determination (r^2) shall be calculated for each regression line (annex A.2.).

It is recommended that this analysis be performed at 1 Hz. For a test to be considered valid, the criteria of table 1 of this section must be met.

	Speed	Torque	Power
Standard error of estimate (SEE) of y on x	max. 100 min^{-1}	max. 13 per cent of maximum engine torque	max. 8 per cent of maximum engine power
Slope of the regression line, m	0.95 to 1.03	0.83 - 1.03	0.89 - 1.03
Coefficient of determination, r^2	min. 0.970	min. 0.850	min. 0.910
y intercept of the regression line, b	± 50 min^{-1}	± 20 N·m or ± 2 per cent of maximum torque whichever is greater	± 4 kW or ± 2 per cent of maximum power whichever is greater

Table 1 of §7.6.3.6.: Regression line tolerances

For regression purposes only, point deletions are permitted where noted in table 2 of this section before doing the regression calculation. However, those points shall not be deleted for the calculation of cycle work and emissions. An idle point is defined as a point having a normalized reference torque of 0 per cent and a normalized reference speed of 0 per cent. Point deletion may be applied to the whole or to any part of the cycle.

Condition	Speed, Torque and/or Power points which may be deleted with reference to the condition listed in the left column
First 6 ± 1 s	Speed, torque, power
Full load demand and actual torque < 95 per cent reference torque	Torque and/or power
Full load demand and actual speed < 95 per cent reference speed	Speed and/or power
No load demand and actual torque > reference torque	Torque and/or power
No load demand and actual torque > ± 2 per cent of maximum torque (idle point)	Speed and/or power

Table 2 of §7.6.3.6.: Permitted point deletions from regression analysis (points to which the point deletion is applied have to be specified).

8. MEASUREMENT PROCEDURES

8.1. Calibration and Performance Checks

8.1.1. Introduction

This Paragraph describes required calibrations and verifications of measurement systems. See paragraph §9.4. for specifications that apply to individual instruments.

Calibrations or verifications shall be generally performed over the complete measurement chain.

If a calibration or verification for a portion of a measurement system is not specified, that portion of the system shall be calibrated and its performance verified at a frequency consistent with any recommendations from the measurement-system manufacturer and consistent with good engineering judgment.

Internationally recognized-traceable standards shall be used to meet the tolerances specified for calibrations and verifications.

8.1.2. Summary of required calibration and verification

The following table 1 summarizes the required and recommended calibrations and verifications described in this subpart and indicates when these have to be performed:

Table 1 of §8.1.2. _Summary of Required Calibration and Verifications

Type of calibration or verification	Minimum frequency[a]
§8.1.3: accuracy, repeatability and noise	Accuracy: Not required, but recommended for initial installation. Repeatability: Not required, but recommended for initial installation. Noise: Not required, but recommended for initial installation.
§8.1.4: linearity	Speed: Upon initial installation, within 370 days before testing and after major maintenance. Torque: Upon initial installation, within 370 days before testing and after major maintenance. Clean gas and diluted exhaust flows: Upon initial installation, within 370 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Raw exhaust flow: Upon initial installation, within 185 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Gas analyzers: Upon initial installation, within 35 days before testing and after major maintenance. PM balance: Upon initial installation, within 370 days before testing and after major maintenance. Stand-alone pressure and temperature: Upon initial installation, within 370 days before testing and after major maintenance.
§8.1.5: Continuous analyzer system response and recording	Upon initial installation, after system reconfiguration, and after major maintenance.

§8.1.6: Continuous analyzer uniform response	Upon initial installation, after system reconfiguration, and after major maintenance.
§8.1.7.1: torque	Upon initial installation and after major maintenance.
§8.1.7.2: pressure, temperature, dewpoint	Upon initial installation and after major maintenance.
§8.1.8.1: fuel flow	Upon initial installation and after major maintenance.
§8.1.8.2: intake flow	Upon initial installation and after major maintenance.
§8.1.8.3: exhaust flow	Upon initial installation and after major maintenance.
§8.1.8.4: diluted exhaust flow (CVS and PFD)	Upon initial installation and after major maintenance.
§8.1.8.5: CVS/PFD and batch sampler verification	Upon initial installation, within 35 days before testing, and after major maintenance. (Propane check)
§8.1.8.8: vacuum leak	Before each laboratory test according to §7.1.
§8.1.9.1: CO_2 NDIR H_2O interference	Upon initial installation and after major maintenance.
§8.1.9.2: CO NDIR CO_2 and H_2O interference	Upon initial installation and after major maintenance.
§8.1.10.1: FID optimization, etc.	Calibrate, optimize, and determine CH_4 response: upon initial installation and after major maintenance. Verify CH_4 response: upon initial installation, within 185 days before testing, and after major maintenance.
§8.1.10.2: raw exhaust FID O_2 interference	Upon initial installation, after FID optimization according to §8.1.10.1., and after major maintenance.
§8.1.10.3: nonmethane cutter penetration	Upon initial installation, within 185 days before testing, and after major maintenance.
§8.1.11.1: CLD CO_2 and H_2O quench	Upon initial installation and after major maintenance.
§8.1.11.3: NDUV HC and H_2O interference	Upon initial installation and after major maintenance.
§8.1.11.4: chiller NO_2 penetration (cooling bath)	Upon initial installation and after major maintenance.
§8.1.11.5: NO_2-to-NO converter conversion	Upon initial installation, within 35 days before testing, and after major maintenance.
§8.1.12.1: PM balance and weighing	Independent verification: upon initial installation, within 370 days before testing, and after major maintenance. Zero, span, and reference sample verifications: within 12 hours of weighing, and after major maintenance.

[a]Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment.

8.1.3. Verifications for accuracy, repeatability, and noise

The performance values for individual instruments specified in table 1 of §9.4.3. are the basis for the determination of the accuracy, repeatability, and noise of an instrument.

It is not required to verify instrument accuracy, repeatability, or noise. However, it may be useful to consider these verifications to define a specification for a new instrument, to verify the performance of a new instrument upon delivery, or to troubleshoot an existing instrument.

8.1.4. Linearity check

8.1.4.1. Scope and frequency

A linearity verification shall be performed on each measurement system listed in table 1 of this section at least as frequently as indicated in the table, consistent with measurement system manufacturer recommendations and good engineering judgment. The intent of a linearity verification is to determine that a measurement system responds proportionally over the measurement range of interest. A linearity verification shall consist of introducing a series of at least 10 reference values to a measurement system. The measurement system quantifies each reference value. The measured values shall be collectively compared to the reference values by using a least squares linear regression and the linearity criteria specified in table 1 of this section.

8.1.4.2. Performance requirements

If a measurement system does not meet the applicable linearity criteria in Table 1 of this section, the deficiency shall be corrected by re-calibrating, servicing, or replacing components as needed.

8.1.4.3. Procedure

The following linearity verification protocol shall be used:
(a) A measurement system shall be operated at its specified temperatures, pressures, and flows.
(b) The instrument shall be zeroed as it would before an emission test by introducing a zero signal. For gas analyzers, a zero gas shall be used that meets the specifications of §9.5.1. and it shall be introduced directly at the analyzer port.
(c) The instrument shall be spanned as it would before an emission test by introducing a span signal. For gas analyzers, a span gas shall be used that meets the specifications of §9.5.1. and it shall be introduced directly at the analyzer port.
(d) After spanning the instrument, zero shall be checked with the same signal which has been used in paragraph (b) of this section. Based on the zero reading, good engineering judgment shall be used to determine whether or not to re-zero and or re-span the instrument before proceeding to the next step.
(e) Instrument manufacturer recommendations and good engineering judgment shall be used to select at least 10 reference values, y_{refi}, that are within the range from zero to the

highest values expected during emission testing. A zero reference signal shall be selected as one of the reference values of the linearity verification.

(f) Instrument manufacturer recommendations and good engineering judgment shall be used to select the order in which the series of reference values will be introduced.

(g) Reference quantities shall be generated and introduced as described in paragraph (d) of this section. For gas analyzers, gas concentrations known to be within the specifications of §7.8.1. shall be used and they shall be introduced directly at the analyzer port.

(h) Time for the instrument to stabilize while it measures the reference value shall be allowed.

(i) At the minimum recording frequency, as specified in table 1 of §9.4.2., the reference value for 30 s shall be measured and the arithmetic mean of the recorded values, $\bar{y}_i$ recorded.

(j) Steps in paragraphs (f) through (h) of this section shall be repeated until all reference quantities are measured.

(k) The arithmetic means $\bar{y}_i$, and reference values, $y_{\mathrm{ref}i}$, shall be used to calculate least-squares linear regression parameters and statistical values to compare to the minimum performance criteria specified in table 1 of this section. The calculations described in §A.2.2. shall be used.

8.1.4.4. Reference signals

This paragraph (§8.1.4.4.) describes recommended methods for generating reference values for the linearity-verification protocol in paragraph (§8.1.4.3.) of this section. Reference values shall be used that simulate actual values, or an actual value shall be introduced and measured with a reference-measurement system. In the latter case, the reference value is the value reported by the reference-measurement system. Reference values and reference-measurement systems must be internationally traceable.

Table 1 of §8.1.4. – Measurement systems that require linearity verifications

Measurement System	Quantity	Minimum verification frequency[a]	Linearity Criteria $|a_0|$[b]	a_1[c]	SEE[b]	r^2
Engine speed	n	Within 370 days before testing	≤0.05 % ·	0.98-1.02	≤2 % ·	≥0.990
Engine torque	T	Within 370 days before testing	≤1 % ·	0.98-1.02	≤2 % ·	≥0.990
Fuel flow rate		Within 370 days before testing[d]	≤1 % ·	0.98-1.02 [e]	≤2 % ·	≥0.990
Intake-air flow rate		Within 370 days before testing [d]	≤1 % ·	0.98-1.02 [e]	≤2 % ·	≥0.990
Dilution air flow rate		Within 370 days before testing [d]	≤1 % ·	0.98-1.02	≤2 % ·	≥0.990
Diluted exhaust flow rate		Within 370 days before testing [d]	≤1 % ·	0.98-1.02	≤2 % ·	≥0.990
Raw exhaust flow rate		Within 185 days before testing [d]	≤1 % ·	0.98-1.02 [e]	≤2 % ·	≥0.990
Batch sampler flow rates		Within 370 days before testing [d]	≤1 % ·	0.98-1.02	≤2 % ·	≥0.990
Gas dividers	X	Within 370 days before testing	≤0.5 % ·	0.98-1.02	≤2 % ·	≥0.990
All gas analyzers	X	Within 35 days before testing	≤0.5 % ·	0.99-1.01	≤1 % ·	≥0.998
PM balance	M	Within 370 days before testing	≤1 % ·	0.99-1.01	≤1 % ·	≥0.998
Stand-alone pressures	p	Within 370 days before testing	≤1 % ·	0.99-1.01	≤1 % ·	≥0.998
Stand-alone temperatures	T	Within 370 days before testing	≤1 % ·	0.99-1.01	≤1 % ·	≥0.998

[a] A linearity verification shall be performed more frequently if the instrument manufacturer recommends it or based on good engineering judgment.

[b] "max" refers to the maximum value expected during a test – the maximum value used for the linearity verification.

[c] The specified ranges are inclusive. For example, a specified range of 0.98-1.02 for a_1 means $0.98 \leq a_1 \leq 1.02$.

[d] These linearity verifications are not required for systems that pass the flow-rate verification for diluted exhaust as described in §7.4.8.6. (propane check) or for systems that agree within ± 2 % based on a chemical balance of carbon or oxygen of the intake air, fuel, and exhaust.

[e] a_0 and a_1 for these quantities are required only if the actual value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value.
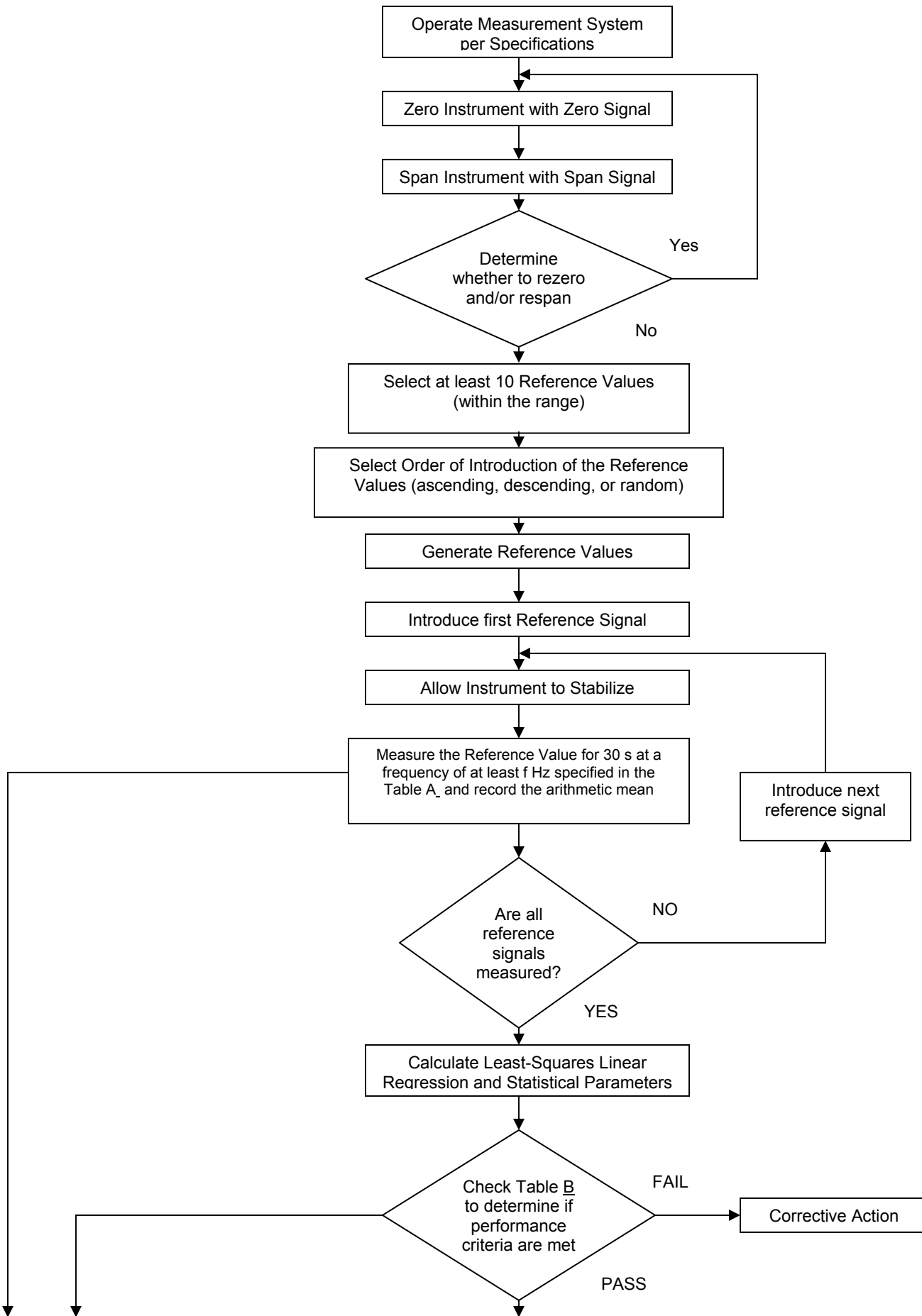
Linearity Verification – Flow chart

```
                    ┌─────────────────────────────┐
                    │  Operate Measurement System  │
                    │       per Specifications      │
                    └─────────────────────────────┘
                                   │
                                   ▼                        ◄──────────┐
                    ┌─────────────────────────────┐                   │
                    │  Zero Instrument with Zero Signal │               │
                    └─────────────────────────────┘                   │
                                   │                                   │
                                   ▼                                   │
                    ┌─────────────────────────────┐                   │
                    │  Span Instrument with Span Signal │               │
                    └─────────────────────────────┘                   │
                                   │                                   │
                                   ▼                          Yes      │
                            ╱────────────╲  ─────────────────────────┘
                           ╱  Determine   ╲
                          ╱ whether to rezero╲
                           ╲  and/or respan  ╱
                            ╲────────────╱
                                   │  No
                                   ▼
                    ┌─────────────────────────────┐
                    │  Select at least 10 Reference Values │
                    │       (within the range)       │
                    └─────────────────────────────┘
                                   │
                                   ▼
                    ┌─────────────────────────────────────┐
                    │ Select Order of Introduction of the Reference │
                    │ Values (ascending, descending, or random) │
                    └─────────────────────────────────────┘
                                   │
                                   ▼
                    ┌─────────────────────────────┐
                    │   Generate Reference Values   │
                    └─────────────────────────────┘
                                   │
                                   ▼
                    ┌─────────────────────────────┐
                    │   Introduce first Reference Signal │
                    └─────────────────────────────┘
                                   │
                                   ▼                            ◄──────────┐
                    ┌─────────────────────────────┐                        │
                    │   Allow Instrument to Stabilize  │                     │
                    └─────────────────────────────┘                        │
                                   │                                        │
                                   ▼                                        │
                    ┌─────────────────────────────┐      ┌──────────────┐
                    │ Measure the Reference Value for 30 s at a │      │  Introduce next  │
                    │ frequency of at least f Hz specified in the │    │ reference signal │
                    │ Table A  and record the arithmetic mean │      └──────────────┘
                    └─────────────────────────────┘              ▲
                                   │                              │
                                   ▼                     NO       │
                            ╱────────────╲  ──────────────────────┘
                           ╱   Are all    ╲
                          ╱  reference     ╲
                          ╲   signals      ╱
                           ╲  measured?   ╱
                            ╲────────────╱
                                   │  YES
                                   ▼
                    ┌─────────────────────────────┐
                    │ Calculate Least-Squares Linear  │
                    │ Regression and Statistical Parameters │
                    └─────────────────────────────┘
                                   │
                                   ▼
                            ╱────────────╲         FAIL
                           ╱ Check Table B ╲ ──────────────►  ┌──────────────────┐
                          ╱ to determine if  ╲                │ Corrective Action │
                          ╲  performance     ╱                └──────────────────┘
                           ╲ criteria are met╱
                            ╲────────────╱
                                   │  PASS
                                   ▼
```

27

Table B

Measurement System	Quantity	Minimum Verification Frequency[a]	Linearity Criteria			
			$\lvert a_o \rvert$ [b]	a_1 [c]	SEE [b]	r^2
Engine Speed	n	Within 370 days before testing	≤ 0.05% n_{max}	0.98-1.02	≤ 2% n_{max}	≥ 0.990
Engine Torque	T	Within 370 days before testing	≤ 1% T_{max}	0.98-1.02	≤ 2% T_{max}	≥ 0.990
Fuel Flow Rate	$\dot{m}$ $\dot{n}$	Within 370 days before testing[d]	≤ 1% $\dot{m}_{max}$	0.98-1.02[e]	≤ 2% $\dot{m}_{max}$	≥ 0.990
Intake-air Flow Rate	$\dot{n}$	Within 370 days before testing[d]	≤ 1% $\dot{n}_{max}$	0.98-1.02[e]	≤ 2% $\dot{n}_{max}$	≥ 0.990
Dilution Air Flow Rate	$\dot{n}$	Within 370 days before testing[d]	≤ 1% $\dot{n}_{max}$	0.98-1.02	≤ 2% $\dot{n}_{max}$	≥ 0.990
Diluted Exhaust Flow Rate	$\dot{n}$	Within 370 days before testing[d]	≤ 1% $\dot{n}_{min}\, x_{max}$	0.98-1.02	≤ 2% $\dot{n}_{min}\, x_{max}$	≥ 0.990
Raw Exhaust Flow Rate	$\dot{n}$	Within 185 days before testing[d]	≤ 1% $\dot{n}_{max}$	0.98-1.02[e]	≤ 2% $\dot{n}_{max}$	≥ 0.990
Batch Sampler Flow Rates	$\dot{n}$	Within 370 days before testing[d]	≤ 1% $\dot{n}_{max}$	0.98-1.02	≤ 2% $\dot{n}_{max}$	≥ 0.990
Gas Dividers	x	Within 370 days before testing	≤ 0.5% x_{max}	0.98-1.02	≤ 2% x_{max}	≥ 0.990
All Gas Analyzers	x	Within 35 days before testing	≤ 0.5% m_{max}	0.99-1.01	≤ 1% m_{max}	≥ 0.998
PM Balance	m	Within 370 days before testing	≤ 1% m_{max}	0.99-1.01	≤ 1% m_{max}	≥ 0.998
Stand-alone Pressures	p	Within 370 days before testing	≤ 1% m_{max}	0.99-1.01	≤ 1% m_{max}	≥ 0.998
Stand-alone Temperatures	T	Within 370 days before testing	≤ 1% m_{max}	0.99-1.01	≤ 1% m_{max}	≥ 0.998

a. Perform a linearity verification more frequently if the instrument manufacturer recommends it or based on good engineering judgment.
b. "max" refers to the maximum value expected during the test-the maximum value used for linearity verification
c. The specified ranges are inclusive.
d. These linearity verifications are not required for systems that pass the flow-rate verification for diluted exhaust as described in §7.4.8.6.%% or for systems that agree within ± 2% based on a chemical balance of carbon or oxygen of intake air, fuel and exhaust
e. a_o and a_1 for these quantities are required only if the actual value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value

Table A

Measurement Instrument	Measured Quantity Symbol	Recording update frequency
Engine Speed Transducer	n	1 Hz means
Engine Torque Transducer	T	1 Hz means
General pressure transducer (not a part of another instrument)	p	1 Hz
Atmospheric pressure meter used for PM-stabilization and balance environments	p_{atmos}	5 times per hour
General purpose atmospheric pressure meter	p_{atmos}	5 times per hour
Temperature sensor for PM-stabilization and balance environments	T	0.1 Hz
Other temperature sensor (not a part of another instrument)	T	0.5 Hz
Dewpoint sensor for PM-stabilization and balance environments	T_{dew}	0.1 Hz
Other dewpoint sensor	T_{dew}	0.1 Hz
Fuel flow meter	$\dot{m}$	1 Hz
Total dilute exhaust meter (CVS)	$\dot{n}$	1 Hz means
Dilution air, inlet air, exhaust, and sample flow meters	$\dot{n}$	1 Hz means of 5 Hz samples
Continuous gas analyzer	x	1 Hz
Inertial PM balance	m_{PM}	1 Hz

8.1.5. Continuous gas analyser system-response and updating-recording verifications

8.1.5.1. Scope and frequency

This verification shall be performed after installing or replacing a gas analyzer that is used for continuous sampling. Also this verification shall be performed if the system is reconfigured in a way that would change system response.

8.1.5.2. Measurement principles and definitions

This test verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. Gas analyzer systems must be optimized such that their overall response to a rapid change in concentration is updated and recorded at an appropriate frequency to prevent loss of information.
Reference is made to figure 1 of paragraph §3.1 showing the definition of the response and transformation time.
The system settings for the response time evaluation shall be exactly the same as during measurement of the test run (i.e. pressure, flow rates, filter settings on the analyzers and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0.1 s. The gases used for the test shall cause a concentration change of at least 60 per cent full scale (FS).
The concentration trace of each single gas component shall be recorded. The response time is defined to be the difference in time between the gas switching and the appropriate change of the recorded concentration. The system response time (t_{90}) consists of the delay time to the measuring detector and the rise time of the detector. The delay time is defined as the time from the change (t_0) until the response is 10 per cent of the final reading (t_{10}). The rise time is defined as the time between 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$).
For time alignment of the analyzer and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 per cent of the final reading (t_{50}).

8.1.5.3. System requirements

(a) General requirements: The system response time shall be ≤ 10 s with a rise time of ≤ 2.5 s for all limited components (CO, NOx, HC or NMHC) and all ranges used.
For the purpose of emissions calculation, the response time of either method described in annexes §A.8-A.9. shall be equal to or less than the analyzer response time of ≤ 10 s. When using a NMC for the measurement of NMHC, the system response time may exceed 10 s.
To demonstrate acceptable updating and recording with respect to the system's overall response, the system must meet one of the following criteria:
(b) The product of the mean rise time and the frequency at which the system records an updated concentration must be at least 5, and the product of the mean fall time and the frequency at which the system records an updated concentration must be at least 5.
(c) The frequency at which the system records an updated concentration must be at least 2 Hz (see also table 1 of paragraph §9.4.2.).

8.1.5.4. Procedure

The following procedure shall be used to verify the response of a continuous gas analyzer system:
(a) Instrument setup. The analyzer system manufacturer's start-up and operating instructions shall be followed. The system shall be adjusted as needed to optimize performance.
(b) Equipment setup. For equipment used to validate system response time, use minimal gas transfer line lengths between all connections, a zero-air source shall be connected to one inlet of a fast-

acting 3-way valve (2 inlets, 1 outlet). Using a gas divider, an NO–CO–CO_2–C_3H_8–CH_4 (balance N_2) span gas shall be equally blended with a span gas of NO_2. The gas divider outlet shall be connected to the other inlet of the 3-way valve. The valve outlet shall be connected to an overflow at the gas analyzer system's probe or to an overflow fitting between the probe and transfer line to all the analyzers being verified. Alternatively the use of gas bottles with single gases and a separate measurement of response times is allowed.

(c) Data collection.

(i) The valve shall be switched to flow zero gas.

(ii) Stabilization shall be allowed for, accounting for transport delays and the slowest instrument's full response.

(iii) Data recording shall be started at the frequency used during emission testing. Each recorded value must be a unique updated concentration measured by the analyzer; interpolation may not be used to increase the number of recorded values.

(iv) The valve shall be switched to flow the blended span gases.

(v) Transport delays and the slowest instrument's full response shall be allowed for.

(vi) The steps in paragraphs (8.1.5.4.)(c)(i) through (v) of this section shall be repeated to record seven full cycles, ending with zero gas flowing to the analyzers.

(vii) Recording shall be stopped.

8.1.5.5. Performance evaluation

The data from paragraph (8.1.5.4.)(c) of this section shall be used to calculate the mean rise time, T_{10-90}, and mean fall time, T_{90-10}, for each of the analyzers.

(a) If it is chosen to demonstrate compliance with paragraph (8.1.5.3.)(b) of this section the following procedure has to be applied: These times (in seconds) shall be multiplied by their respective recording frequencies in Hertz (1/s). The value for each result must be at least 5. If the value is less than 5, the recording frequency shall be increased or the flows adjusted or the design of the sampling system shall be changed to increase the rise time and fall time as needed. Also digital filters may be configured to increase rise and fall times.

(b) If it is chosen to demonstrate compliance with paragraph (8.1.5.3.)(c) of this section, the demonstration of compliance with the requirements of (8.1.5.3.)(c) is sufficient.

8.1.6. Uniform response verification of multiple continuous gas analysers used for single component detection

8.1.6.1. Scope and frequency

If more than one continuous gas analyzer is used to quantify a gaseous constituent, this verification must be performed. This verification shall be performed after initial installation or major maintenance. Also this verification shall be performed if the system is reconfigured in a way that would change system response.

8.1.6.2. Measurement principles

This procedure verifies the time-alignment and uniform response of combined continuous gas measurements.

8.1.6.3. System requirements

It shall be demonstrated that combined continuous concentration measurements have a uniform rise and fall during a simultaneous to a step change in both concentrations. During a system response to a rapid change in multiple gas concentrations, it shall be demonstrated that the t_{50} times of all

combined analyzers all occur at the same recorded second of data or between the same two recorded seconds of data.

8.1.6.4. Procedure

The following procedure shall be used to verify the response of a continuous gas analyzer system:
(a) Instrument setup. The analyzer system manufacturer's start-up and operating instructions shall be followed. The system shall be adjusted as needed to optimize performance.
(b) Equipment setup. Using minimal gas transfer line lengths between all connections, a zero-air source shall be connected to the inlet of a 100 °C heated line. The heated line outlet shall be connected to one inlet of a 100 °C heated fast-acting 3-way valve (2 inlets, 1 outlet). Using a gas divider, an $NO–CO–CO_2–C_3H_8–CH_4$ (balance N_2) span gas shall be equally blended with a span gas of NO_2 (balance N_2). The gas divider outlet shall be connected to the inlet of a 50 °C heated line. Alternatively the use of gas bottles with single gases and a separate measurement of response times is allowed
(i) If the analyser has no correction based on measured water content, the valve outlet shall be connected to an overflow at the gas analyzer system's probe or to an overflow fitting between the probe and transfer line to all the analyzers being verified.
(ii) If the analyser has a correction based on measured water content, the heated line outlet shall be connected to the inlet of a 50 °C gas bubbler filled with distilled water. The bubbler outlet shall be connected to another heated line at 100 °C. The outlet of the 100 °C line shall be connected to the other inlet of the heated 3-way valve. The valve outlet shall be connected to an overflow at the gas analyzer system's probe or to an overflow fitting between the probe and transfer line to all the analyzers being verified.
Also the line at the 3-way valve outlet must be heated at 100 °C or be isolated if very short.
(c) Data collection.
(i) The valve shall be switched to flow zero gas.
(ii) Stabilization shall be allowed for, accounting for transport delays and the slowest instrument's full response.
(iii) Data recording shall be started at the frequency used during emission testing.
(iv) The valve shall be switched to flow span gas.
(v) Transport delays and the slowest instrument's full response shall be allowed for.
(vi) The steps in paragraphs (8.1.6.4.)(c)(i) through (v) of this section shall be repeated to record seven full cycles, ending with zero gas flowing to the analyzers.
(vii) Recording shall be stopped.

8.1.6.5. Performance evaluations

(a) Uniform response evaluation.
(i) The mean rise time, $t_{10–90}$, mean fall time, $t_{90–10}$ shall be calculated for each analyzer.
(ii) The maximum mean rise and fall times shall be determined for the slowest responding analyzer in each combination of continuous analyzer signals that are used to determine a single emission concentration.
(iii) If the maximum rise time or fall time is greater than one second, it shall be verified that all other gas analyzers combined with it have mean rise and fall times of at least 75% of that analyzer's response.
(b) Time alignment evaluation.
(i) After all signals are adjusted to meet the uniform response evaluation, the second at which – or the two seconds between which – each analyzer crossed the midpoint of its response, t_{50} shall be determined.
(ii) It shall be verified that all combined gas analyzer signals are time-aligned such that all of their t_{50} times occurred at the same second or between the same two seconds in the recorded data.

8.1.7. Measurement of engine parameters & ambient conditions

8.1.7.1. Torque calibration

Scope and frequency - All torque-measurement systems including dynamometer torque measurement transducers and systems shall be calibrated upon initial installation and after major maintenance using, among others, reference force or lever-arm length coupled with dead weight. Good engineering judgment shall be used to repeat the calibration. The torque transducer manufacturer's instructions shall be followed for linearizing the torque sensor's output.

8.1.7.2. Pressure, temperature, and dewpoint calibration

Instruments shall be calibrated for measuring pressure, temperature, and dewpoint upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8. Flow-related measurements

8.1.8.1. Fuel flow calibration

Fuel flow meters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8.2. Intake air flow calibration

Intake air flow meters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8.3. Exhaust flow calibration

Exhaust flow meters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8.4. Diluted exhaust flow (CVS) calibration

8.1.8.4.1. Overview

(a) Overview. This section describes how to calibrate flow meters for diluted exhaust constant-volume sampling (CVS) systems.
(b) Scope and frequency. This calibration shall be performed while the flow meter is installed in its permanent position. This calibration shall be performed after any part of the flow configuration upstream or downstream of the flow meter has been changed that may affect the flow-meter calibration. This calibration shall be performed upon initial CVS installation and whenever corrective action does not resolve a failure to meet the diluted exhaust flow verification (*i.e.*, propane check) in §8.1.8.5.
(c) Reference flow meter. A CVS flow meter shall be calibrated using a reference flow meter such as a subsonic venturi flow meter, a long-radius flow nozzle, a smooth approach orifice, a laminar flow element, a set of critical flow venturis, or an ultrasonic flow meter. A reference flow meter shall be used that reports quantities that are internationally-traceable within ±1% uncertainty. This reference flow meter's response to flow shall be used as the reference value for CVS flow-meter calibration.

(d) Configuration. An upstream screen or other restriction that could affect the flow ahead of the reference flow meter may not be used , unless the flow meter has been calibrated with such a restriction.

8.1.8.4.2. PDP calibration

PDP calibration. A positive-displacement pump (PDP) shall be calibrated to determine a flow-versus-PDP speed equation that accounts for flow leakage across sealing surfaces in the PDP as a function of PDP inlet pressure. Unique equation coefficients shall be determined for each speed at which the PDP is operated. A PDP flow meter shall be calibrated as follows:
(a) The system shall be connected as shown in Figure 1 of this section.
(b) Leaks between the calibration flow meter and the PDP must be less than 0.3% of the total flow at the lowest calibrated flow point; for example, at the highest restriction and lowest PDP-speed point.
(c) While the PDP operates, a constant temperature at the PDP inlet shall be maintained within ±2% of the mean absolute inlet temperature, T_{in}.
(d) The PDP speed is set to the first speed point at which it is intended to calibrate.
(e) The variable restrictor is set to its wide-open position.
(f) The PDP is operated for at least 180 s to stabilize the system. Then by continuously operating the PDP, the mean values of at least 30 s of sampled data of each of the following quantities are recorded:
(i) The mean flow rate of the reference flow meter, $\bar{n}_{ref}$.
(ii) The mean temperature at the PDP inlet, T_{in}.
(iii) The mean static absolute pressure at the PDP inlet, p_{in}
(iv) The mean static absolute pressure at the PDP outlet, p_{out}
(v) The mean PDP speed, n_{PDP}.
(g) The restrictor valve shall be incrementally closed to decrease the absolute pressure at the inlet to the PDP, p_{in}.
(h) The steps in paragraphs (8.1.8.4.2.)(f) and (g) of this section shall be repeated to record data at a minimum of six restrictor positions reflecting the full range of possible in-use pressures at the PDP inlet.
(i) The PDP shall be calibrated by using the collected data and the equations in annexes §A.8-A.9.
(j) The steps in paragraphs (f) through (i) of this section shall be repeated for each speed at which the PDP is operated.
(k) The equations in annex §A.8 (mass based approach) or §A.9 (molar based approach) shall be used to determine the PDP flow equation for emission testing.
(l) The calibration shall be verified by performing a CVS verification (*i.e.*, propane check) as described in §8.1.8.5.
(m) The PDP may not be used below the lowest inlet pressure tested during calibration.

8.1.8.4.3. CFV calibration

CFV calibration. A critical-flow venturi (CFV) shall be calibrated to verify its discharge coefficient, C_d, at the lowest expected static differential pressure between the CFV inlet and outlet. A CFV flow meter shall be calibrated as follows:
(a) The system shall be connected as shown in Figure 1 of this section.
(b) The blower shall be started downstream of the CFV.
(c) While the CFV operates, a constant temperature at the CFV inlet shall be maintained within ±2% of the mean absolute inlet temperature, T_{in}.
(d) Leaks between the calibration flow meter and the CFV must be less than 0.3% of the total flow at the highest restriction.

(e) The variable restrictor shall be set to its wide-open position.
(f) The CFV shall be operated for at least 3 min to stabilize the system. The CFV shall continue operating and the mean values of at least 30 seconds of sampled data of each of the following quantities shall be recorded :
(i) The mean flow rate of the reference flow meter, $\bar{\dot{n}}_{\text{ref}}$.

(ii) Optionally, the mean dewpoint of the calibration air, T_{dew}. See annexes §A.8-A.9 for permissible assumptions.
(iii) The mean temperature at the venturi inlet, T_{in}.
(iv) The mean static absolute pressure at the venturi inlet, p_{in}.
(v) The mean static differential pressure between the CFV inlet and the CFV outlet, Δp_{CFV}.
(g) The restrictor valve shall be incrementally closed to decrease the absolute pressure at the inlet to the CFV, p_{in}.
(h) The steps in paragraphs (f) and (g) of this section shall be repeated to record mean data at a minimum of ten restrictor positions, such that the fullest practical range of Δp_{CFV} expected during testing is tested. It is not required to remove calibration components or CVS components to calibrate at the lowest possible restrictions.
(i) C_{d} and the lowest allowable Δp_{CFV} shall be determined as described in annexes §A.8-A.9.
(j) C_{d} shall be used to determine CFV flow during an emission test. the CFV must not be used below the lowest allowed Δp_{CFV}, as determined in annexes §A.8-A.9.
(k) The calibration shall be verified by performing a CVS verification (*i.e.*, propane check) as described in §8.1.8.5.
(l) If the CVS is configured to operate more than one CFV at a time in parallel, the CVS shall be calibrated by one of the following:
(i) Every combination of CFVs shall be calibrated according to this section and annexes §A.8-A.9. See annexes §A.8-A.9 for instructions on calculating flow rates for this option.
(ii) Each CFV shall be calibrated according to this section and annexes §A.8-A.9. See annexes §A.8-A.9 for instructions on calculating flow rates for this option.

8.1.8.4.4. SSV calibration

SSV calibration. A subsonic venturi (SSV) shall be calibrated to determine its calibration coefficient, C_{d} , for the expected range of inlet pressures. An SSV flow meter shall be calibrated as follows:
(a) The system shall be connected as shown in Figure 1 of this section.
(b) The blower shall be started downstream of the SSV.
(c) Leaks between the calibration flow meter and the SSV must be less than 0.3 % of the total flow at the highest restriction.
(d) While the SSV operates, a constant temperature at the SSV inlet shall be maintained within ±2 % of the mean absolute inlet temperature, T_{in}.
(e) The variable restrictor or variable-speed blower shall be set to a flow rate greater than the greatest flow rate expected during testing. Flow rates may not be extrapolated beyond calibrated values, so it is recommended that it is made certain that a Reynolds number, *Re*, at the SSV throat at the greatest calibrated flow rate is greater than the maximum *Re* expected during testing.
(f) The SSV shall be operated for at least 180 s to stabilize the system. The SSV shall continue operating and the mean of at least 30 s of sampled data of each of the following quantities shall be recorded:
(i) The mean flow rate of the reference flow meter, $\bar{\dot{n}}_{\text{ref}}$.

(ii) Optionally, the mean dewpoint of the calibration air, T_{dew}. See annexes §A.8-A.9 for permissible assumptions.
(iii) The mean temperature at the venturi inlet, T_{in}.
(iv) The mean static absolute pressure at the venturi inlet, p_{in}.

(v) Static differential pressure between the static pressure at the venturi inlet and the static pressure at the venturi throat, Δp_{SSV}.

(g) The restrictor valve shall be incrementally closed or the blower speed decreased to decrease the flow rate.

(h) The steps in paragraphs (f) and (g) of this section shall be repeated to record data at a minimum of ten flow rates.

(i) A functional form of C_d versus Re shall be determined by using the collected data and the equations in annexes §A.8-A.9.

(j) The calibration shall be verified by performing a CVS verification (*i.e.*, propane check) as described in §8.1.8.5 using the new C_d versus Re equation.

(k) The SSV shall be used only between the minimum and maximum calibrated flow rates.

(l) The equations in annex §A.8 (mass based approach) or annex §A.9 (molar based approach) shall be used to determine SSV flow during a test.

8.1.8.4.5. Ultrasonic calibration (reserved)
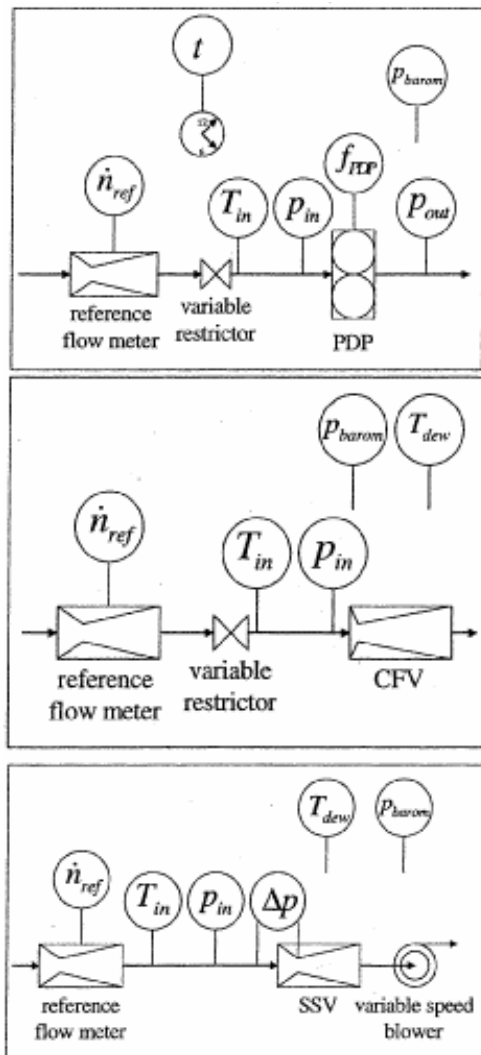
Figure 1 of §8.1.8.4 – Schematic diagrams for diluted exhaust flow CVS calibration

8.1.8.5. CVS and batch sampler verification (propane check)

8.1.8.5.1. Introduction

A propane check serves as a CVS verification to determine if there is a discrepancy in measured values of diluted exhaust flow. A propane check also serves as a batch-sampler verification to determine if there is a discrepancy in a batch sampling system that extracts a sample from a CVS, as described in paragraph (f) of this section. Using good engineering judgment and safe practices, this check may be performed using a gas other than propane, such as CO_2 or CO. A failed propane check might indicate one or more problems that may require corrective action, as follows:

(a) Incorrect analyzer calibration. The FID analyzer shall be re-calibrated, repaired, or replaced.

(b) Leaks. CVS tunnel, connections, fasteners, and HC sampling system shall be inspected, and components repaired or replaced.

(c) Poor mixing. The verification shall be performed in accordance with paragraph §9.2.2.

(d) Hydrocarbon contamination in the sample system. The hydrocarbon-contamination verification shall be performed as described in §7.3.1.3.

(e) Change in CVS calibration. An in-situ calibration of the CVS flow meter shall be performed as described in §8.1.8.4.

(f) Other problems with the CVS or sampling verification hardware or software. The CVS system, CVS verification hardware, and software shall be inspected for discrepancies.

(g) A propane check uses either a reference mass or a reference flow rate of C_3H_8 as a tracer gas in a CVS. If a reference flow rate is used, any non-ideal gas behaviour of C_3H_8 in the reference flow meter shall be accounted for. See annexes §A.8. (mass based approach) or §A.9. (molar based approach), which describe how to calibrate and use certain flow meters. No ideal gas assumption may be used in §8.1.8.5 and §A.8. or §A.9. The propane check compares the calculated mass of injected C_3H_8 using HC measurements and CVS flow rate measurements with the reference value.

8.1.8.5.2. Method of introducing a known amount of Propane into the CVS system

The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of a pollutant gas into the system while it is being operated in the normal manner. The pollutant is analyzed, and the mass calculated according to annexes §A.8-A.9. Either of the following two techniques shall be used.

(a) Metering by means of a gravimetric technique. A mass of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ± 0.01 g. For about 5 to 10 minutes, the CVS system shall be operated as in a normal exhaust emission test, while carbon monoxide or propane is injected into the system. The quantity of pure gas discharged shall be determined by means of differential weighing. A gas sample shall be analyzed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass determined shall be within ± 3.0 per cent of the known mass of the gas injected.

 (b) Metering with a critical flow orifice. A known quantity of pure gas (carbon monoxide or propane) shall be fed into the CVS system through a calibrated critical orifice. If the inlet pressure is high enough, the flow rate, which is adjusted by means of the critical flow orifice, is independent of the orifice outlet pressure (critical flow). The CVS system shall be operated as in a normal exhaust emission test for about 5 to 10 minutes. A gas sample shall be analyzed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass determined shall be within ± 3.0 per cent of the known mass of the gas injected.

8.1.8.5.3. Preparation of the propane check

The propane check shall be prepared for as follows:

(a) If a reference mass of C_3H_8 is used instead of a reference flow rate, a cylinder charged with C_3H_8 shall be obtained. The reference cylinder's mass of C_3H_8 shall be determined within ±0.5% of the amount of C_3H_8 that is expected to be used.
(b) Appropriate flow rates shall be selected for the CVS and C_3H_8.
(c) A C_3H_8 injection port shall be selected in the CVS. The port location shall be selected to be as close as practical to the location where engine exhaust is introduced into the CVS. The C_3H_8 cylinder shall be connected to the injection system.
(d) The CVS shall be operated and stabilized.
(e) Any heat exchangers in the sampling system shall be pre-heated or pre-cooled.
(f) Heated and cooled components such as sample lines, filters, chillers, and pumps shall be allowed to stabilize at operating temperature.
(g) If applicable, a vacuum side leak verification of the HC sampling system shall be performed as described in §8.1.8.7.

8.1.8.5.4. Preparation of the HC sampling system for the propane check

The HC sampling system shall be zeroed, spanned, and verified for contamination, as follows:
(a) The lowest HC analyzer range that can measure the C_3H_8 concentration expected for the CVS and C_3H_8 flow rates shall be selected.
(b) The HC analyzer shall be zeroed using zero air introduced at the analyzer port.
(c) The HC analyzer shall be spanned using C_3H_8 span gas introduced at the analyzer port.
(d) Zero air shall be overflowed at the HC probe or into a fitting between the HC probe and the transfer line.
(e) The stable HC concentration of the HC sampling system shall be measured as overflow zero air flows. For batch HC measurement, the batch container (such as a bag) shall be filled and the HC overflow concentration measured.
(f) If the overflow HC concentration exceeds 2 µmol/mol, it may not be proceeded until contamination is eliminated. The source of the contamination shall be determined and corrective action taken, such as cleaning the system or replacing contaminated portions.
(g) When the overflow HC concentration does not exceed 2 µmol/mol, this value shall be recorded as x_{HCpre} and it shall be used to correct for HC contamination as described in annex §A.8. (mass based approach) or annex §A.9. (molar based approach).

8.1.8.5.5. Description of the propane check performance

The propane check shall be performed as follows:
(a) For batch HC sampling, clean storage media, such as evacuated bags shall be connected.
(b) HC measurement instruments shall be operated according to the instrument manufacturer's instructions.
(c) If correction for dilution air background concentrations of HC is foreseen, background HC in the dilution air shall be measured and recorded.
(d) Any integrating devices shall be zeroed.
(e) Sampling shall begin , and any flow integrators started.
(f) The contents of the C_3H_8 reference cylinder shall be released at the rate selected. If a reference flow rate of C_3H_8 is used, the integration of this flow rate shall be started.
(g) The cylinder's contents shall be continued to be released until at least enough C_3H_8 has been released to ensure accurate quantification of the reference C_3H_8 and the measured C_3H_8.
(h) The C_3H_8 reference cylinder shall be shut off and sampling shall continue until it has been accounted for time delays due to sample transport and analyzer response.
(i) Sampling shall be stopped and any integrators shall be stopped.

8.1.8.5.6. Evaluation of the propane check

Post-test procedure shall be performed as follows:

(a) If batch sampling has been used, batch samples shall be analyzed as soon as practical.

(b) After analyzing HC, contamination and background shall be corrected for.

(c) Total C_3H_8 mass based on the CVS and HC data shall be calculated as described in annexes §A.8.-A.9., using the molar mass of C_3H_8, M_{C3H8}, instead the effective molar mass of HC, M_{HC}.

(d) If a reference mass (gravimetric technique) is used, the cylinder's propane mass shall be determined within ±0.5% and the C_3H_8 reference mass shall be determined by subtracting the empty cylinder propane mass from the full cylinder propane mass. If a critical flow orifice (metering with a critical flow orifice) is used, the propane mass shall be determined as flow rate multiplied by the test time.

(e) the reference C_3H_8 mass shall be subtracted from the calculated mass. If this difference is within ±2.0 % of the reference mass, the CVS passes this verification.

8.1.8.5.7. PM secondary dilution system

PM secondary dilution system verification . The propane check may be repeated to verify a PM secondary dilution system.

(a) The HC sampling system shall be configured to extract a sample near the location of the batch sampler's storage media (such as a PM filter). If the absolute pressure at this location is too low to extract an HC sample, HC may be sampled from the batch sampler pump's exhaust. Caution shall be used when sampling from pump exhaust because an otherwise acceptable pump leak downstream of a batch sampler flow meter will cause a false failure of the propane check.

(b) The propane check shall be repeated as described in this section, but HC shall be sampled from the batch sampler.

(c) C_3H_8 mass shall be calculated, taking into account any secondary dilution from the batch sampler.

(d) The reference C_3H_8 mass shall be subtracted from the calculated mass. If this difference is within ±5% of the reference mass, the batch sampler passes this verification. If not, corrective action shall be taken as described in paragraph (a) of this section.

8.1.8.6. Periodic calibration of the partial flow PM and associated raw exhaust gas measurement systems

8.1.8.6.1. Specifications for differential flow measurement

For partial flow dilution systems, the accuracy of the sample flow q_{mp} is of special concern, if not measured directly, but determined by differential flow measurement:

$$q_{mp} = q_{mdew} - q_{mdw} \qquad (8.1.8.6\text{-}1)$$

where:

q_{mp} = sample mass flow rate of exhaust gas into partial flow dilution system;

q_{mdw} = dilution air mass flow rate (on wet basis);

q_{mdew} = diluted exhaust gas mass flow rate on wet basis.

In this case, the maximum error of the difference shall be such that the accuracy of q_{mp} is within ± 5 per cent when the dilution ratio is less than 15. It can be calculated by taking root-mean-square of the errors of each instrument.

Acceptable accuracies of q_{mp} can be obtained by either of the following methods:

(a) The absolute accuracies of $q_{m\text{dew}}$ and $q_{m\text{dw}}$ are ±0.2 per cent which guarantees an accuracy of q_{mp} of ≤ 5 per cent at a dilution ratio of 15. However, greater errors will occur at higher dilution ratios.
(b) Calibration of $q_{m\text{dw}}$ relative to $q_{m\text{dew}}$ is carried out such that the same accuracies for q_{mp} as in (a) are obtained. For details see paragraph §8.1.8.6.2.
(c) The accuracy of q_{mp} is determined indirectly from the accuracy of the dilution ratio as determined by a tracer gas, e.g. CO_2. Accuracies equivalent to method a) for q_{mp} are required.
(d) The absolute accuracy of $q_{m\text{dew}}$ and $q_{m\text{dw}}$ is within ±2 per cent of full scale, the maximum error of the difference between $q_{m\text{dew}}$ and $q_{m\text{dw}}$ is within 0.2 per cent, and the linearity error is within ±0.2 per cent of the highest $q_{m\text{dew}}$ observed during the test.

8.1.8.6.2. Calibration of differential flow measurement

The partial flow dilution system shall be periodically calibrated with an accurate flow meter traceable to international and/or national standards. The flow meter or the flow measurement instrumentation shall be calibrated in one of the following procedures, such that the probe flow q_{mp} into the tunnel shall fulfil the accuracy requirements of paragraph §8.1.8.6.1.:

a) The flow meter for $q_{m\text{dw}}$ shall be connected in series to the flow meter for $q_{m\text{dew}}$, the difference between the two flow meters shall be calibrated for at least 5 set points with flow values equally spaced between the lowest $q_{m\text{dw}}$ value used during the test and the value of $q_{m\text{dew}}$ used during the test. The dilution tunnel may be bypassed.
b) A calibrated flow device shall be connected in series to the flowmeter for $q_{m\text{dew}}$ and the accuracy shall be checked for the value used for the test. The calibrated flow device shall be connected in series to the flow meter for $q_{m\text{dw}}$, and the accuracy shall be checked for at least 5 settings corresponding to dilution ratio between 3 and 15, relative to $q_{m\text{dew}}$ used during the test.
c) The transfer tube TT (see figure 1 of paragraph §9.2.3.) shall be disconnected from the exhaust, and a calibrated flow measuring device with a suitable range to measure q_{mp} shall be connected to the transfer tube. $q_{m\text{dew}}$ shall be set to the value used during the test, and $q_{m\text{dw}}$ shall be sequentially set to at least 5 values corresponding to dilution ratios between 3 and 15. Alternatively, a special calibration flow path, may be provided, in which the tunnel is bypassed, but the total and dilution air flow through the corresponding meters as in the actual test.
d) A tracer gas, shall be fed into the exhaust transfer tube TT. This tracer gas may be a component of the exhaust gas, like CO_2 or NO_x. After dilution in the tunnel the tracer gas component shall be measured. This shall be carried out for 5 dilution ratios between 3 and 15. The accuracy of the sample flow shall be determined from the dilution ratio r_d:

$$q_{mp} = q_{m\text{dew}} / r_d \qquad (8.1.8.6\text{-}2)$$

The accuracies of the gas analyzers shall be taken into account to guarantee the accuracy of q_{mp}.

8.1.8.6.3. Special requirements for differential flow measurement

8.1.8.6.3.1. Pre-test check

A pre-test check shall be performed within 2 hours before the test run in the following way.
The accuracy of the flow meters shall be checked by the same method as used for calibration (see paragraph §8.1.8.6.2.) for at least two points, including flow values of $q_{m\text{dw}}$ that correspond to dilution ratios between 5 and 15 for the $q_{m\text{dew}}$ value used during the test.
If it can be demonstrated by records of the calibration procedure under paragraph §8.1.8.6.2. that the flow meter calibration is stable over a longer period of time, the pre-test check may be omitted.

8.1.8.6.3.2. Determination of the transformation time

The system settings for the transformation time evaluation shall be exactly the same as during measurement of the test run. The transformation time, defined in figure 1 of paragraph §3.1., shall be determined by the following method.

An independent reference flowmeter with a measurement range appropriate for the probe flow shall be put in series with and closely coupled to the probe. This flowmeter shall have a transformation time of less than 100 ms for the flow step size used in the response time measurement, with flow restriction sufficiently low as to not affect the dynamic performance of the partial flow dilution system, and consistent with good engineering practice. A step change shall be introduced to the exhaust flow (or air flow if exhaust flow is calculated) input of the partial flow dilution system, from a low flow to at least 90% of full scale. The trigger for the step change should be the same one used to start the look-ahead control in actual testing. The exhaust flow step stimulus and the flowmeter response shall be recorded at a sample rate of at least 10 Hz.

From this data, the transformation time shall be determined for the partial flow dilution system, which is the time from the initiation of the step stimulus to the 50% point of the flowmeter response. In a similar manner, the transformation times of the q_{mp} signal (i.e. sample flow of exhaust gas into partial flow dilution system) and of the $q_{mew,i}$ signal (i.e. the exhaust gas mass flow rate on wet basis supplied by the exhaust flow meter) shall be determined. These signals are used in the regression checks performed after each test (see paragraph §8.2.1.2).

The calculation shall be repeated for at least 5 rise and fall stimuli, and the results shall be averaged. The internal transformation time (<100 ms) of the reference flowmeter shall be subtracted from this value. In the case that the system in accordance with paragraph §8.2.1.2 requires the "look-ahead" method, this is the "look-ahead" value of the partial flow dilution system to be applied in accordance with paragraph §8.2.1.2.

8.1.8.7. Vacuum-side leak verification

8.1.8.7.1. Scope and frequency

Upon initial sampling system installation, after major maintenance, and before each test, it shall be verified that there are no significant vacuum-side leaks using one of the leak tests described in this section.

8.1.8.7.2. Measurement principles

A leak may be detected either by measuring a small amount of flow when there should be zero flow, by detecting the dilution of a known concentration of span gas when it flows through the vacuum side of a sampling system or by measuring the pressure increase of an evacuated system.

8.1.8.7.3. Low-flow leak test

A sampling system shall be tested for low-flow leaks as follows:
(a) The probe end of the system shall be sealed by taking one of the following steps:
(i) The end of the sample probe shall be capped or plugged.
(ii) The transfer line shall be disconnected at the probe and the transfer line capped or plugged.
(iii) A leak-tight valve in-line between a probe and transfer line shall be closed.
(b) All vacuum pumps shall be operated. After stabilizing, it shall be verified that the flow through the vacuum-side of the sampling system is less than 0.5% of the system's normal in-use flow rate. Typical analyzer and bypass flows may be estimated as an approximation of the system's normal in-use flow rate.

8.1.8.7.4. Dilution-of-span-gas leak test

Any analyzer, other than a FID, shall be tested for dilution of span gas as follows, noting that this configuration requires an overflow span gas system:
(a) A gas analyzer shall be prepared as it would be for emission testing.
(b) Span gas shall be supplied to the analyzer port and it shall be verified that the span gas concentration is measured within its expected measurement accuracy and repeatability.
(c) Overflow span gas shall be routed to one of the following locations in the sampling system:
(i) The end of the sample probe.
(ii) The transfer line shall be disconnected at the probe connection, and the span gas overflown at the open end of the transfer line.
(iii) A three-way valve installed in-line between a probe and its transfer line.
(d) It shall be verified that the measured overflow span gas concentration is within the measurement accuracy and repeatability of the analyzer. A measured value lower than expected indicates a leak, but a value higher than expected may indicate a problem with the span gas or the analyzer itself. A measured value higher than expected does not indicate a leak.

8.1.9. CO and CO_2 measurements

8.1.9.1. H_2O interference verification for CO_2 NDIR analyzers

8.1.9.1.1. Scope and frequency

If CO_2 is measured using an NDIR analyzer, the amount of H_2O interference shall be verified after initial analyzer installation and after major maintenance.

8.1.9.1.2. Measurement principles

H_2O can interfere with an NDIR analyzer's response to CO_2. If the NDIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously these other measurements shall be conducted to test the compensation algorithms during the analyzer interference verification.

8.1.9.1.3. System requirements

A CO_2 NDIR analyzer must have an H_2O interference that is within ±2% of the expected mean CO_2 concentration.

8.1.9.1.4. Procedure

The interference verification shall be performed as follows:
(a) The CO_2 NDIR analyzer shall be started, operated, zeroed, and spanned as it would be before an emission test.
(b) A water-saturated test gas shall be created by bubbling zero air that meets the specifications in §9.5.1 through distilled water in a sealed vessel at (25 ± 10) °C.
(c) The water-saturated test gas shall be introduced upstream of any sample dryer, if one is used during testing.
(d) Time shall be allowed for the analyzer response to stabilize. Stabilization time shall include time to purge the transfer line and to account for analyzer response.
(e) While the analyzer measures the sample's concentration, 30 s of sampled data shall be recorded. The arithmetic mean of this data shall be calculated. The analyzer meets the interference verification if this value is within ± 2% of the expected mean concentration of CO_2.

8.1.9.2. H_2O and CO_2 interference verification for CO NDIR analyzers

8.1.9.2.1. Scope and frequency

If CO is measured using an NDIR analyzer, the amount of H_2O and CO_2 interference shall be verified after initial analyzer installation and after major maintenance.

8.1.9.2.2. Measurement principles

H_2O and CO_2 can positively interfere with an NDIR analyzer by causing a response similar to CO. If the NDIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously these other measurements shall be conducted to test the compensation algorithms during the analyzer interference verification.

8.1.9.2.3. System requirements

A CO NDIR analyzer must have combined H_2O and CO_2 interference that is within ±2 % of the expected mean concentration of CO.

8.1.9.2.4. Procedure

The interference verification shall be performed as follows:
(a) The CO NDIR analyzer shall be started, operated, zeroed, and spanned as it would be before an emission test.
(b) A water-saturated CO_2 test gas shall be created by bubbling a CO_2 span gas through distilled water in a sealed vessel at (25 ± 10) °C.
(c) The water-saturated CO_2 test gas shall be introduced upstream of any sample dryer, if one is used during testing.
(d) Time shall be allowed for the analyzer response to stabilize.
(e) While the analyzer measures the sample's concentration, its output shall be recorded for 30 s. The arithmetic mean of this data shall be calculated.
(f) This mean value shall be multiplied by the ratio of expected CO_2 to span gas CO_2 concentration. In other words, the mean dry concentration of CO_2 expected during testing shall be estimated, and then this value shall be divided by the concentration of CO_2 in the span gas used for this verification. Then this ratio shall be multiplied by the mean value recorded during this verification.

8.1.10. Hydrocarbon measurements

8.1.10.1. FID optimization and verification

8.1.10.1.1. Scope and frequency

For all FID analyzers the following steps shall be performed:
(a) A FID shall be calibrated upon initial installation. The calibration shall be repeated as needed using good engineering judgment.
(b) A FID's response to various hydrocarbons shall be optimized after initial analyzer installation and after major maintenance. FID response to propylene and toluene shall be between 0.9 and 1.1 relative to propane.
(c) A FID's methane (CH_4) response factor shall be determined after initial analyzer installation and after major maintenance.

(d) Methane (CH_4) response shall be verified within 185 days before testing.

8.1.10.1.2. Calibration

Good engineering judgment shall be used to develop a calibration procedure, such as one based on the FID-analyzer manufacturer's instructions and recommended frequency for calibrating the FID. It shall be calibrated using C_3H_8 calibration gases that meet the specifications of §7.8.1. Regardless of the calibration gas composition, it shall be calibrated on a carbon number basis of one (C_1). For example, if a C_3H_8 span gas of concentration 200 µmol/mol is used, the FID shall be spanned to respond with a value of 600 µmol/mol.

8.1.10.1.3. FID response optimization

Instrument manufacturer requirements and good engineering judgment shall be used for initial instrument start-up and basic operating adjustment using FID fuel and zero air. Heated FIDs must be within their required operating temperature ranges. FID response shall be optimized at the most common analyzer range expected during emission testing. With the fuel and airflow rates set at the manufacturer's recommendations, a 350 ± 75 ppm C span gas shall be introduced to the analyzer. The response at a given fuel flow shall be determined from the difference between the span gas response and the zero gas response. The fuel flow shall be incrementally adjusted above and below the manufacturer's specification. The span and zero response at these fuel flows shall be recorded. The difference between the span and zero response shall be plotted and the fuel flow adjusted to the rich side of the curve. This is the initial flow rate setting which may need further optimization depending on the results of the hydrocarbon response factors and the oxygen interference check according to paragraphs §8.1.10.1.(a)&(d) and §8.1.10.2. If the oxygen interference or the hydrocarbon response factors do not meet the following specifications, the airflow shall be incrementally adjusted above and below the manufacturer's specifications, repeating paragraphs §8.1.10.1.(a) &(d) and §8.1.10.2. for each flow. The optimization may optionally be conducted using the procedures outlined in SAE paper No. 770141. The optimum flow rates for FID fuel and burner air shall be determined, and they shall be sampled and recorded for future reference.

8.1.10.1.4. CH_4 response factor determination

Since FID analyzers generally have a different response to CH_4 versus C_3H_8, each FID analyzer's CH_4 response factor, RF_{CH4} shall be determined, after FID optimization. The most recent RF_{CH4} measured according to this section shall be used in the calculations for HC determination described in annex §A.8. (mass based approach) or annex §A.9. (molar based approach) to compensate for CH_4 response. RF_{CH4} shall be determined as follows, noting that RF_{CH4} is not determined for FIDs that are calibrated and spanned using CH_4 with a nonmethane cutter:
(a) A C_3H_8 span gas that meets the specifications of §9.5.1. shall be selected and the C_3H_8 concentration of the gas shall be recorded.
(b) A CH_4 span gas that meets the specifications of §9.5.1. shall be selected and the CH_4 concentration of the gas shall be recorded.
(c) The FID analyzer shall be operated according to the manufacturer's instructions.
(d) It shall be confirmed that the FID analyzer has been calibrated using C_3H_8 as described in paragraph (b) of this section.
(e) The FID shall be zeroed with a zero gas used for emission testing.
(f) The FID shall be spanned with the selected C_3H_8 span gas.
(g) The selected CH_4 span gas shall be introduced at the sample port of the FID analyzer, the CH_4 span gas that has been selected under paragraph (b) of this section.
(h) The analyzer response shall be stabilized. Stabilization time may include time to purge the analyzer and to account for its response.

(i) While the analyzer measures the CH_4 concentration, 30 s of sampled data shall be recorded and the arithmetic mean of these values shall be calculated.

(j) The mean measured concentration shall be divided by the recorded span concentration of the CH_4 calibration gas. The result is the FID analyzer's response factor for CH_4, RF_{CH4}.

8.1.10.1.5. FID methane (CH_4) response verification

If the value of RF_{CH4} from paragraph (d) of this section is within ± 5.0% of its most recent previously determined value, the FID passes the methane response verification.

8.1.10.2. Raw exhaust FID O_2 interference verification

8.1.10.2.1. Scope and frequency

If FID analyzers are used for raw exhaust measurements, the amount of FID O_2 interference shall be verified upon initial installation and after major maintenance.

8.1.10.2.2. Measurement principles

Changes in O_2 concentration in raw exhaust can affect FID response by changing FID flame temperature. FID fuel, burner air, and sample flow shall be optimized to meet this verification. FID performance shall be verified with the compensation algorithms for FID O_2 interference that is active during an emission test.

8.1.10.2.3. System requirements

Any FID analyzer used during testing must meet the FID O_2 interference verification according to the procedure in this section.

8.1.10.2.4. Procedure

FID O_2 interference shall be determined as follows:

(a) Two span reference gases shall be selected that meet the specifications in §9.5.1. and contain C_3H_8 near 100% of span for HC. The two balance gas concentrations shall be selected such that the concentrations of O_2 and N_2 represent the 5 per cent and 10 per cent oxygen interference check gases.

(b) It shall be confirmed that the FID analyzer meets all the specifications of §8.1.10.1.

(c) The FID analyzer shall be started and operated as it would be before an emission test. Regardless of the FID burner's air source during testing, zero air shall be used as the FID burner's air source for this verification.

(d) The analyzer shall be set at zero.

(e) The analyzer shall be spanned with the 21 per cent oxygen blend.

(f) The zero response shall be rechecked. If it has changed by more than 0.5 per cent of full scale, steps (d) and (e) of this paragraph shall be repeated.

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

(h) The oxygen interference E_{O2} shall be calculated for each mixture in step 7) as follows:

$$E_{O2} = (c_{ref,d} - c) \times 100 / c_{ref,d} \qquad (8.1.10.2\text{-}1)$$

with the analyzer response being

$$c = \frac{c_{ref,b} \times c_{FS,b}}{c_{m,b}} \times \frac{c_{m,d}}{c_{FS,d}} \qquad (8.1.10.2\text{-}2)$$

where:

$c_{ref,b}$ is the reference HC concentration in step (5), ppm C
$c_{ref,d}$ is the reference HC concentration in step (7), ppm C
$c_{FS,b}$ is the full scale HC concentration in step (5), ppm C
$c_{FS,d}$ is the full scale HC concentration in step (7), ppm C
$c_{m,b}$ is the measured HC concentration in step (5), ppm C
$c_{m,d}$ is the measured HC concentration in step (7), ppm C

(i) The oxygen interference E_{O2} shall be less than ± 3.0 per cent for all required oxygen interference check gases prior to testing.

(j) If the oxygen interference E_{O2} is greater than ± 3.0 per cent, corrective action may be taken by incrementally adjusting the airflow above and below the manufacturer's specifications, the fuel flow and the sample flow.

(k) The oxygen interference shall be repeated for each new setting.

8.1.10.3. Nonmethane cutter penetration fractions

8.1.10.3.1. Scope and frequency

If a FID analyzer and a nonmethane cutter (NMC) is used to measure methane (CH_4), the nonmethane cutter's penetration fractions of methane, PF_{CH4}, and ethane, PF_{C2H6} shall be determined. This verification shall be performed after installing the nonmethane cutter. This verification shall be repeated within 185 days of testing to verify that the catalytic activity of the cutter has not deteriorated.

8.1.10.3.2. Measurement principles

A nonmethane cutter is a heated catalyst that removes nonmethane hydrocarbons from the exhaust stream before the FID analyzer measures the remaining hydrocarbon concentration. An ideal nonmethane cutter would have PF_{CH4} of 1.000 (that is, a methane conversion efficiency E_M [-] of 0), and the penetration fraction for all other hydrocarbons would be 0.000, as represented by PF_{C2H6} (that is, an ethane conversion efficiency E_E [-] of 1). The emission calculations in annex §A.8. (mass based approach) or annex §A.9. (molar based approach) use this section's measured values of PF_{CH4} and PF_{C2H6} to account for less than ideal NMC performance.

8.1.10.3.3. System requirements

NMC penetration fractions are not limited to a certain range. However, it is recommended that a nonmethane cutter is optimized by adjusting its temperature to achieve $PF_{CH4} > 0.95$ and $PF_{C2H6} < 0.02$ as determined by paragraphs (d) and (e) of this section, as applicable. If a nonmethane cutter is used for testing, it will meet this recommendation. If adjusting NMC temperature does not result in achieving both of these specifications simultaneously, it is recommended that the catalyst material is replaced. the most recently determined penetration values from this section shall be used to calculate HC emissions according to annexes §A.8.-A.9. as applicable.

8.1.10.3.4. Procedure for measuring CH4 and C2H6 cutter penetration

(a) A CH_4 gas mixture and a C_2H_6 analytical gas mixture shall be selected meeting the specifications of §9.5.1 with the CH_4 concentration typical of its peak concentration expected at the

hydrocarbon standard and the C_2H_6 concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or the THC analyzer span value.

(b) The nonmethane cutter shall be started and operated according to the manufacturer's instructions, including any temperature optimization.

(c) It shall be confirmed that the FID analyzer meets all the specifications of §8.1.10.1.

(d) The FID analyzer shall be operated according to the manufacturer's instructions.

(e) The FID shall be zeroed and spanned as it would be during emission testing. The FID shall be spanned by bypassing the cutter and by using C_3H_8 span gas to span the FID. The FID shall be spanned on a C_1 basis. For example, if the span gas has a propane reference value of 100 μ/mol, the correct FID response to that span gas is 300 μ/mol because there are three carbon atoms per C_3H_8 molecule.

(f) The C_2H_6 analytical gas mixture shall be introduced upstream of the nonmethane cutter.

(g) Time shall be allowed for the analyzer response to stabilize. Stabilization time may include time to purge the nonmethane cutter and to account for the analyzer's response.

(h) While the analyzer measures a stable concentration, 30 s of sampled data shall be recorded and the arithmetic mean of these data points shall be calculated.

(i) The flow path shall be rerouted to bypass the nonmethane cutter, the C_2H_6 analytical gas mixture shall be introduced to the bypass, and the steps in paragraphs (e)(7) through (8) of this section shall be repeated.

(j) The mean C_2H_6 concentration measured through the nonmethane cutter shall be divided by the mean concentration measured after bypassing the nonmethane cutter. The result is the C_2H_6 penetration fraction, PF_{C2H6}, that is equivalent to (1- E_E [-]). This penetration fraction shall be used according to §A.8. or §A.9., as applicable.

(k) The steps in paragraphs (e)(6) through (10) of this section shall be repeated, but with the CH_4 analytical gas mixture instead of C_2H_6. The result will be the CH_4 penetration fraction, PF_{CH4} (equivalent to (1- E_M [-])). This penetration fraction shall be used according to annexes §A.8.-A.9., as applicable.

8.1.11. NOx measurements

8.1.11.1. CLD CO_2 and H_2O quench verification

8.1.11.1.1. Scope and frequency

If a CLD analyzer is used to measure NO_X, the amount of H_2O and CO_2 quench shall be verified after installing the CLD analyzer and after major maintenance.

8.1.11.1.2. Measurement principles

H_2O and CO_2 can negatively interfere with a CLD's NO_X response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD utilizes to detect NO_X. The calculations in §A.2.3. for H_2O quench account for the water vapour in humidified NO span gas. The procedure and the calculations scale the quench results to the water vapour and CO_2 concentrations expected during testing. If the CLD analyzer uses quench compensation algorithms that utilize H_2O and/or CO_2 measurement instruments, these instruments shall be used to measure H_2O and/or CO_2 and quench shall be evaluated with the compensation algorithms applied.

8.1.11.1.3. System requirements

For dilute measurement a CLD analyzer shall not exceed a combined H_2O and CO_2 quench of ±2% or less, for raw measurement a CLD analyzer shall not exceed a H_2O quench of ±3% and CO_2

quench of ±2% or less. Combined quench is the sum of the CO_2 quench determined as described in paragraph (d) of this section, plus the H_2O quench determined in paragraph (e) of this section.

8.1.11.1.4. CO_2 quench verification procedure

The following method shall be used to determine CO_2 quench, or good engineering judgment shall be used to develop a different protocol:
(a) PTFE tubing shall be used to make necessary connections.
(b) A CO_2 span gas shall be connected to one of the inlets of a three-way valve made of stainless steel. A CO_2 span gas shall be used that meets the specifications of §7.8.1 and has a concentration that is approximately twice the maximum CO_2 concentration expected to enter the CLD sample port during testing.
(c) A purified N_2 gas shall be connected to the valve's other inlet. A purified N_2 gas shall be used that meets the specifications of §7.8.1.
(d) The valve's single outlet shall be connected to the balance-gas port of a gas divider that meets the specifications in §9.4.5.6.
(e) A NO span gas shall be connected to the span-port of the gas divider. An NO span gas shall be used that meets the specifications of §9.5.1. It shall be attempted to use an NO concentration that is approximately twice the maximum NO concentration expected during testing.
(f) The gas divider shall be configured such that nearly equal amounts of the span gas and balance gas are blended with each other.
(g) While balance and span gases is flowing through the gas divider, the CO_2 concentration downstream of the gas divider shall be stabilized and the CO_2 concentration shall be measured with an NDIR analyzer that has been prepared for emission testing. This concentration, $x_{CO2meas}$, shall be recorded and it shall be used in the quench verification calculations in §8.1.11.2.
(h) The NO concentration shall be measured downstream of the gas divider. The CLD shall be operated in the NO-only operating mode by bypassing the NO_2 to NO converter. This concentration, $x_{NO,CO2}$, shall be recorded and used in the quench verification calculations in §8.1.11.2.
(i) The three-way valve shall be switched so 100% purified N_2 flows to the gas divider's balance-port inlet. The CO_2 shall be monitored at the gas divider's outlet until its concentration stabilizes at zero.
(j) NO concentration shall be measured at the gas divider's outlet. This value, $x_{NO,N2}$, shall be recorded and used in the quench verification calculations in §8.1.11.2.
(k) The values recorded shall be used according to this paragraph (d) of this section and paragraph (e) of this section to calculate quench as described in §8.1.11.2.

8.1.11.1.5. H_2O quench verification procedure

The following method shall be used to determine H_2O quench
(a) PTFE tubing shall be used to make necessary connections.
(b) If the CLD has an operating mode in which it detects NO-only, as opposed to total NO_X, the CLD shall be operated in the NO-only operating mode.
(c) An NO calibration span gas shall be measured that meets the specifications of §7.8.1 and is near the maximum concentration expected during testing. This concentration, x_{NOdry}, shall be recorded.
(d) The gas shall be humidified by bubbling it through distilled water in a sealed vessel. It is recommended that the gas shall be humidified to the highest sample dewpoint that is estimated during emission sampling. The humidity of the gas shall be measured and recorded and used in the relevant calculations. Regardless of the humidity during this test, the quench verification calculations in §8.1.11.2 scale the recorded quench to the highest dewpoint that is expected entering the CLD sample port during emission sampling.
(e) If no sample dryer is used for NO_X during emissions testing, the vessel water temperature shall be recorded as T_{dew}, and its pressure as p_{total} and these values shall be used according to annexes

§A.8.-A.9. to calculate the amount of water entering the CLD sample port, $x_{H2Omeas}$. If a sample dryer is used for NO_X during emissions testing, the humidity of the sample shall be measured just upstream of the CLD sample port and the measured humidity shall be used according to §A.8.-A.9. to calculate the amount of water entering the CLD sample port, $x_{H2Omeas}$.

(f) To prevent subsequent condensation, it shall be made sure that any humidified sample will not be exposed to temperatures lower than T_{dew} during transport from the sealed vessel's outlet to the CLD. It is recommended using heated transfer lines.

(g) The humidified sample shall be introduced upstream of any sample dryer, if one is used.

(h) The CLD shall be used to measure the NO concentration of the humidified span gas and this value, x_{NOwet}, shall be recorded.

(i) The recorded values from this paragraph (e) shall be used to calculate the quench as described in §8.1.11.2.

(j) The values recorded according to this paragraph (e) of this section and paragraph (d) of this section shall be used to calculate quench as described in §8.1.11.2.

8.1.11.1.6. Corrective action

If the sum of the H_2O quench plus the CO_2 quench is not within ±2% for dilute measurements or, for raw measurements, ±3% H_2O quench and ±2% CO_2 quench , corrective action shall be taken by repairing or replacing the analyzer. Before using a CLD for emission testing, it shall be demonstrated that the corrective action resulted in a value coherent with the values above.

8.1.11.2. CLD quench verification calculations

CLD quench-check calculations shall be performed as follows:

8.1.11.2.1. Amount of water in the span gas

The amount of water in the span gas, $x_{H2Ospan}$, shall be calculated taking into account the measured temperature and humidity of the gas after the humidifier.

8.1.11.2.2. Expected amount of water and CO_2

The expected amount of water and CO_2 in the exhaust sampled, x_{H2Oexp} and $x_{CO2exp,}$ respectively, shall be estimated by considering the maximum expected amounts of water in combustion air, fuel combustion products, and dilution air concentrations (if applicable).

8.1.11.2.3. Water quench

Water quench shall be calculated as follows:

$$quench = \left[\frac{x_{NOwet}/(1-x_{H2Omeas})}{x_{NOdry}} -1 \right] \cdot \frac{x_{H2Oexp}}{x_{H2Omeas}} + \frac{x_{NO,CO2}-x_{NO,N2}}{x_{NO,N2}} \cdot \frac{x_{CO2exp}}{x_{CO2meas}} \qquad (8.1.11.2\text{-}1)$$

Where:
quench = amount of CLD quench.
x_{NOdry} = measured concentration of NO upstream of a bubbler, according to §8.1.11.1.
x_{NOwet} = measured concentration of NO downstream of a bubbler, according to §8.1.11.1.
x_{H2Oexp} = expected maximum amount of water entering the CLD sample port during emission testing.

$x_{H2Omeas}$ = measured amount of water entering the CLD sample port during the quench verification specified in §8.1.11.1.

$x_{NO,CO2}$ = measured concentration of NO when NO span gas is blended with CO_2 span gas, according to §8.1.11.1.

$x_{NO,N2}$ = measured concentration of NO when NO span gas is blended with N2 span gas, according to §8.1.11.1.

x_{CO2exp} = expected maximum amount of CO_2 entering the CLD sample port during emission testing.

$x_{CO2meas}$ = measured amount of CO_2 entering the CLD sample port during the quench verification specified in §8.1.11.1.

8.1.11.3. NDUV analyzer HC and H_2O interference verification

8.1.11.3.1. Scope and frequency

If NO_X is measured using an NDUV analyzer, the amount of H_2O and hydrocarbon interference shall be verified after initial analyzer installation and after major maintenance.

8.1.11.3.2. Measurement principles

Hydrocarbons and H_2O can positively interfere with a NDUV analyzer by causing a response similar to NO_X. If the NDUV analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously such measurements shall be conducted to test the algorithms during the analyzer interference verification.

8.1.11.3.3. System requirements

A NO_X NDUV analyzer must have combined H_2O and HC interference within ± 2% of the mean concentration of NO_X.

8.1.11.3.4. Procedure

The interference verification shall be performed as follows:

(a) The NO_X NDUV analyzer shall be started, operated, zeroed, and spanned according to the instrument manufacturer's instructions.

(b) It is recommended to extract engine exhaust to perform this verification. A CLD shall be used that meets the specifications of paragraph 9.4. to quantify NO_X in the exhaust. The CLD response shall be used as the reference value. Also HC shall be measured in the exhaust with a FID analyzer that meets the specifications of paragraph 9.4. The FID response shall be used as the reference hydrocarbon value.

(c) Upstream of any sample dryer, if one is used during testing, the engine exhaust shall be introduced into the NDUV analyzer.

(d) Time shall be allowed for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(e) While all analyzers measure the sample's concentration, 30 s of sampled data shall be recorded, and the arithmetic means for the three analyzers calculated.

(f) The CLD mean shall be subtracted from the NDUV mean.

(g) This difference shall be multiplied by the ratio of the expected mean HC concentration to the HC concentration measured during the verification. The analyzer meets the interference verification of this section if this result is within ± 2% of the NO_X concentration expected at the standard.

8.1.11.3.5. Cooling bath (chiller) requirements

It shall be demonstrated that for the highest expected water vapour concentration H_m, the water removal technique maintains CLD humidity at ≤ 5 g water/kg dry air (or about 0.8 volume per cent H_2O), which is 100 per cent relative humidity at 3.9 °C and 101.3 kPa. This humidity specification is also equivalent to about 25 per cent relative humidity at 25 °C and 101.3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD.

8.1.11.4. Cooling bath (chiller) NO_2 penetration

8.1.11.4.1. Scope and frequency

If a cooling bath is used to dry a sample upstream of a NO_X measurement instrument, but no NO_2-to-NO converter is used upstream of the cooling bath, this verification shall be performed for cooling bath NO_2 penetration. This verification shall be performed after initial installation and after major maintenance.

8.1.11.4.2. Measurement principles

A cooling bath removes water, which can otherwise interfere with a NO_X measurement. However, liquid water in an improperly designed cooling bath can remove NO_2 from the sample. If a cooling bath is used without an NO_2-to-NO converter upstream, it could therefore remove NO_2 from the sample prior NO_X measurement.

8.1.11.4.3. System requirements

The chiller must allow for measuring at least 95% of the total NO_2 at the maximum expected concentration of NO_2.

8.1.11.4.4. Procedure

The following procedure shall be used to verify chiller performance:
(a) Instrument setup. The analyzer and chiller manufacturers' start-up and operating instructions shall be followed. The analyzer and chiller shall be adjusted as needed to optimize performance.
(b) Equipment setup. An ozonator's inlet shall be connected to a zero-air or oxygen source and its outlet shall be connected to one port of a three-way tee fitting. An NO span gas shall be connected to another port of the tee. A heated line at 100 °C shall be connected to the last port, and a heated three-way tee shall be connected to the other end of the line. A gas humidifier , set at a dewpoint of 50 °C, shall be connected to one end of a heated line at 100 °C. The other end of the line shall be connected to the heated tee and a third 100 °C heated line shall be connected to the chiller inlet. An overflow vent line shall be provided at the chiller inlet.
(c) Adjustments. For the following adjustment steps, the analyzer shall be set to measure only NO (*i.e.*, NO mode), or only the NO channel of the analyzer shall be read:
(i) With the dewpoint generator and the ozonator off, the NO and zero-gas flows shall be adjusted so the NO concentration at the analyzer is at least two times the peak total NO_X concentration expected during testing at the standard. It shall be verified that gas is flowing out of the overflow vent line.
(ii) The dewpoint generator shall be turned on and its flow adjusted so the NO concentration at the analyzer is at least at the peak total NO_X concentration expected during testing at the standard. It shall be verified that gas is flowing out of the overflow vent line.
(iii) The ozonator shall be turned on and the ozonator adjusted so the NO concentration measured by the analyzer decreases by the same amount as the maximum concentration of NO_2 expected

during testing. This ensures that the ozonator is generating NO_2 at the maximum concentration expected during testing.

(d) Data collection. The ozonator adjustment in paragraph (c) of this section shall be maintained, and the NO_X analyzer shall be kept in the NO only mode or only the NO channel of the analyzer shall be read.

(i) Stabilization shall be allowed for, accounting only for transport delays and instrument response.

(ii) The mean of 30 s of sampled data from the analyzer shall be calculated and this value recorded as NO_{ref}.

(iii) The analyzer shall be switched to the total NO_X mode, (that is, sum the NO and NO_2 channels of the analyzer) and stabilization shall be allowed for, accounting only for transport delays and instrument response.

(iv) The mean of 30 s of sampled data from the analyzer shall be calculated and this value recorded as NOx_{meas}.

(v) The ozonator shall be turned off and stabilization allowed for, accounting only for transport delays and instrument response.

(vi) The mean of 30 s of sampled data from the analyzer shall be calculated and this value recorded as NO_{xref}.

(e) Performance evaluation. The quantity of $(NO_{xmeas}-NO_{ref})$ shall be divided by the quantity of $(NO_{xref}-NO_{ref})$. If the result is less than 95%, the chiller shall be repaired or replaced.

8.1.11.5. NO_2-to-NO converter conversion verification

8.1.11.5.1. Scope and frequency

If an analyzer is used that measures only NO to determine NO_X, an NO_2-to-NO converter must be used upstream of the analyzer. This verification shall be performed after installing the converter, after major maintenance and within 35 days before an emission test. This verification must be repeated at this frequency to verify that the catalytic activity of the NO_2-to-NO converter has not deteriorated.

8.1.11.5.2. Measurement principles

An NO_2-to-NO converter allows an analyzer that measures only NO to determine total NO_X by converting the NO_2 in exhaust to NO.

8.1.11.5.3. System requirements

An NO_2-to-NO converter must allow for measuring at least 95% of the total NO_2 at the maximum expected concentration of NO_2.

8.1.11.5.4. Procedure

The following procedure shall be used to verify the performance of a NO_2-to-NO converter:

(a) Instrument setup. The analyzer and NO_2-to-NO converter manufacturers' start-up and operating instructions shall be followed. The analyzer and converter shall be adjusted as needed to optimize performance.

(b) Equipment setup. An ozonator's inlet shall be connected to a zero-air or oxygen source and its outlet shall be connected to one port of a 4-way cross fitting. An NO span gas shall be connected to another port. The NO_2-to-NO converter inlet shall be connected to another port, and an overflow vent line shall be connected to the last port.

(c) Adjustments. The following steps to make adjustments shall be taken:

(i) With the NO_2-to-NO converter in the bypass mode (i.e., NO mode) and the ozonator off, the NO and zero-gas flows shall be adjusted so the NO concentration at the analyzer is at the peak total NO_X concentration expected during testing. It shall be verified that gas is flowing out of the overflow vent.

(ii) With the NO_2-to-NO converter still in the bypass mode, the ozonator shall be turned on and the ozonator adjusted so the NO concentration measured by the analyzer decreases by more than the maximum concentration of NO_2 expected during testing. This ensures that the ozonator is generating NO_2 at or above the maximum concentration expected during testing.

(d) Data collection. The ozonator adjustment in paragraph (c) of this section shall be maintained, and the NO_X analyzer kept in the NO only mode (i.e., bypass the NO_2-to-NO converter).

(i) Stabilization shall be allowed for, accounting only for transport delays and instrument response.

(ii) The mean of 30 s of sampled data from the analyzer shall be calculated and this value recorded as NO_{ref}.

(iii) The analyzer shall be switched to the total NO_X mode (that is, sample with the NO_2-to-NO converter) and stabilization shall be allowed for, accounting only for transport delays and instrument response.

(iv) The mean of 30 s of sampled data from the analyzer shall be calculated and this value recorded as NO_{xmeas}.

(v) The ozonator shall be turned off and stabilization allowed for, accounting only for transport delays and instrument response.

(vi) The mean of 30 seconds of sampled data from the analyzer shall be calculated and this value recorded as NO_{xref}.

(e) Performance evaluation. The quantity of ($NO_{xmeas} - NO_{ref}$) shall be divided by the quantity of ($NO_{xref} - NO_{ref}$). If the result is less than 95%, the NO_2-to-NO converter shall be repaired or replaced.

8.1.12. PM measurements

8.1.12.1. PM balance verifications and weighing process verification

8.1.12.1.1. Scope and frequency

This section describes three verifications.

(a) Independent verification of PM balance performance within 370 days prior to weighing any filter.

(b) Zero and span of the balance within 12 h prior to weighing any filter.

(c) Verification that the mass determination of reference filters before and after a filter weighing session be less than a specified tolerance within 12 h before weighing.

8.1.12.1.2. Independent verification

The balance manufacturer (or a representative approved by the balance manufacturer) shall verify the balance performance within 370 days of testing in accordance with internal audit procedures.

8.1.12.1.3. Zeroing and spanning

Balance performance must be verified by zeroing and spanning it with at least one calibration weight, and any weights that are used must meet the specifications in §9.5.2. to perform this verification. A manual or automated procedure shall be used:

(a) A manual procedure requires that the balance shall be used in which the balance shall be zeroed and spanned with at least one calibration weight. If normally mean values are obtained by repeating

the weighing process to improve the accuracy and precision of PM measurements, the same process shall be used to verify balance performance.

(b) An automated procedure is carried out with internal calibration weights that are used automatically to verify balance performance. These internal calibration weights must meet the specifications in §9.5.2. to perform this verification.

8.1.12.1.4. Reference sample weighing

All mass readings during a weighing session shall be verified by weighing reference PM sample media before and after a weighing session. A weighing session may be as short as desired, but no longer than 80 hours, and may include both pre- and post-test mass readings. Successive mass determinations of each reference PM sample media must return the same value within ±10 µg or ±10% of the expected net PM mass, whichever is higher. Should successive PM sample filter weighing events fail this criterion, all individual test filter mass readings mass readings occurring between the successive reference filter mass determinations shall be invalidated. These filters may be re-weighed in another weighing session. Should a post-test filter be invalidated then the test interval is void. This verification shall be performed as follows:

(a) At least two samples of unused PM sample media shall be kept in the PM-stabilization environment. These shall be used as references. Unused filters of the same material and size shall be selected for use as references.

(b) References shall be stabilized in the PM stabilization environment. References shall be considered stabilized if they have been in the PM-stabilization environment for a minimum of 30 min, and the PM-stabilization environment has been within the specifications of §9.3.4.4. for at least the preceding 60 min.

(c) The balance shall be exercised several times with a reference sample without recording the values.

(d) The balance shall be zeroed and spanned.

(e) Each of the reference samples shall be weighed and their masses recorded. If normally mean values obtained by repeating the weighing process to improve the accuracy and precision of PM measurements the same process to measure reference masses shall be used to measure reference masses.

(f) The balance environment dewpoint, ambient temperature, and atmospheric pressure shall be recorded.

(g) The recorded ambient conditions shall be used to correct results for buoyancy as described in §8.1.12.2. The buoyancy-corrected mass of each of the references shall be recorded.

(h) Each of the reference's buoyancy-corrected masses shall be subtracted from its most recent previously recorded buoyancy-corrected mass.

(i) If either of the reference filters' observed mass changes by more than that allowed under this paragraph, all PM mass determinations made since the last successful reference filter mass validation shall be invalidated, with one exception: if only one filter's mass changes by more than the allowable amount, and a special cause for that filter's mass change that would not have affected other in-process filters can be positively identified (as if a filter medium falls to the floor), then the validation can be considered successful. If this situation arises, the affected reference filter must be immediately discarded and replaced.

8.1.12.2. PM sample media buoyancy correction

8.1.12.2.1. General

PM sample media shall be corrected for their buoyancy in air. The buoyancy correction depends on the sample media density, the density of air, and the density of the calibration weight used to calibrate the balance. The buoyancy correction does not account for the buoyancy of the PM itself,

because the mass of PM typically accounts for only (0.01 to 0.10)% of the total weight. A correction to this small fraction of mass would be at the most 0.010%. These buoyancy-corrected values of the pre-test filter weighing are subsequently subtracted from the buoyancy-corrected values of the post-test weighing of the corresponding filter to determine the mass of PM emitted during the test.

8.1.12.2.2. PM sample media density

Different PM sample media have different densities. The known density of the sample media shall be used, or one of the densities for some common sampling media shall be used, as follows:
(a) For PTFE-coated borosilicate glass, a sample media density of 2300 kg/m^3 shall be used.
(b) For PTFE membrane (film) media with an integral support ring of polymethylpentene that accounts for 95% of the media mass, a sample media density of 920 kg/m^3 shall be used.
(c) For PTFE membrane (film) media with an integral support ring of PTFE, a sample media density of 2144 kg/m^3 shall be used.

8.1.12.2.3. Air density

Because a PM balance environment must be tightly controlled to an ambient temperature of (22 ±1) °C and a dewpoint of (9.5 ±1) °C, air density is primarily function of atmospheric pressure. Therefore a buoyancy correction is specified that is only a function of atmospheric pressure.

8.1.12.2.4. Calibration weight density

The stated density of the material of the metal calibration weight shall be used.

8.1.12.2.5. Correction calculation

The PM sample media shall be corrected for buoyancy using the following equations:

$$m_{cor} = m_{uncor} \left(\frac{1 - \dfrac{\rho_{air}}{\rho_{weight}}}{1 - \dfrac{\rho_{air}}{\rho_{media}}} \right) \qquad (8.1.12.3\text{-}1)$$

Where:
m_{cor} = PM mass corrected for buoyancy.
m_{uncor} = PM mass uncorrected for buoyancy.
ρ_{air} = density of air in balance environment.
ρ_{weight} = density of calibration weight used to span balance.
ρ_{media} = density of PM sample media, such as a filter.

$$\rho_{air} = \frac{p_{abs} \cdot M_{mix}}{R \cdot T_{amb}} \qquad (8.1.12.3\text{-}2)$$

Where:
p_{abs} = absolute pressure in balance environment.
M_{mix} = molar mass of air in balance environment.
R = molar gas constant.
T_{amb} = absolute ambient temperature of balance environment.

8.2. Instrument validation for test

8.2.1. Validation of proportional flow control for batch sampling

8.2.1.1. CVS validation

For any proportional batch sample such as a bag or PM filter, it shall be demonstrated that proportional sampling was maintained using one of the following, noting that up to 5% of the total number of data points may be omitted as outliers:

8.2.1.1.1. Proportional flows

For any pair of flow meters, the recorded sample and total flow rates or their 1 Hz means shall be used with the statistical calculations in §A.2.2. The standard error of the estimate, *SEE,* of the sample flow rate versus the total flow rate shall be determined. For each test interval, it shall be demonstrated that *SEE* was less than or equal to 3.5% of the mean sample flow rate.

8.2.1.1.2. Constant flows

For any pair of flow meters, the recorded sample and total flow rates or their 1 Hz means shall be used to demonstrate that each flow rate was constant within ±2.5% of its respective mean or target flow rate. The following options may be used instead of recording the respective flow rate of each type of meter:
(a) Critical-flow venturi option. For critical-flow venturis, the recorded venturi-inlet conditions or their 1 Hz means shall be used. It shall be demonstrated that the flow density at the venturi inlet was constant within ±2.5% of the mean or target density over each test interval. For a CVS critical-flow venturi, this may be demonstrated by showing that the absolute temperature at the venturi inlet was constant within ±4% of the mean or target absolute temperature over each test interval.
(b) Positive-displacement pump option. The recorded pump-inlet conditions or their 1 Hz means shall be used. It shall be demonstrated that the flow density at the pump inlet was constant within ±2.5% of the mean or target density over each test interval. For a CVS pump, this may be demonstrated by showing that the absolute temperature at the pump inlet was constant within ±2% of the mean or target absolute temperature over each test interval.

8.2.1.1.3. Demonstration of proportional sampling

Using good engineering judgment, it shall be demonstrated with an engineering analysis that the proportional-flow control system inherently ensures proportional sampling under all circumstances expected during testing. For example, CFVs may be used for both sample flow and total flow if it is demonstrated that they always have the same inlet pressures and temperatures and that they always operate under critical-flow conditions.

8.2.1.2. Partial flow dilution system validation

For the control of a partial flow dilution system, a fast system response is required; this is identified by the promptness of the partial flow dilution system. The transformation time for the system shall be determined by the procedure in §8.1.8.6. and the related figure (figure 1 of paragraph §3.1.). The actual control of the partial flow dilution system must be based on the current measured conditions. If the combined transformation time of the exhaust flow measurement and the partial flow system is

≤ 0.3 s, online control shall be used. If the transformation time exceeds 0.3 s, look-ahead control based on a pre-recorded test run shall be used. In this case, the combined rise time shall be ≤ 1 s and the combined delay time ≤ 10 s. The total system response shall be designed as to ensure a representative sample of the particulates, $q_{mp,i}$ (sample flow of exhaust gas into partial flow dilution system), proportional to the exhaust mass flow. To determine the proportionality, a regression analysis of $q_{mp,i}$ versus $q_{mew,i}$ (exhaust gas mass flow rate on wet basis) shall be conducted on a minimum 5 Hz data acquisition rate, and the following criteria shall be met:

(a) The correlation coefficient r^2 of the linear regression between $q_{mp,i}$ and $q_{mew,i}$ shall not be less than 0.95.

(b) The standard error of estimate of $q_{mp,i}$ on $q_{mew,i}$ shall not exceed 5 % of q_{mp} maximum.

(c) q_{mp} intercept of the regression line shall not exceed ± 2 % of q_{mp} maximum.

Look-ahead control is required if the combined transformation times of the particulate system, $t_{50,P}$ and of the exhaust mass flow signal, $t_{50,F}$ are > 0.3 s. In this case, a pre-test shall be run and the exhaust mass flow signal of the pre-test be used for controlling the sample flow into the particulate system. A correct control of the partial dilution system is obtained, if the time trace of $q_{mew,pre}$ of the pre-test, which controls q_{mp}, is shifted by a "look-ahead" time of $t_{50,P} + t_{50,F}$.

For establishing the correlation between $q_{mp,i}$ and $q_{mew,i}$ the data taken during the actual test shall be used, with $q_{mew,i}$ time aligned by $t_{50,F}$ relative to $q_{mp,i}$ (no contribution from $t_{50,P}$ to the time alignment). The time shift between q_{mew} and q_{mp} is the difference between their transformation times that were determined in §8.1.8.6.3.2.

8.2.2. Gas analyzer range validation, drift validation and drift correction

8.2.2.1. Range validation

If an analyzer operated above 100% of its range at any time during the test, the following steps shall be performed:

8.2.2.1.1. Batch sampling

For batch sampling, the sample shall be re-analyzed using the lowest analyzer range that results in a maximum instrument response below 100%. The result shall be reported from the lowest range from which the analyzer operates below 100% of its range for the entire test.

8.2.2.1.2. Continuous sampling

For continuous sampling, the entire test shall be repeated using the next higher analyzer range. If the analyzer again operates above 100% of its range, the test shall be repeated using the next higher range. The test shall be continued to be repeated until the analyzer operates at less than 100% of its range for the entire test.

8.2.2.2. Drift validation and drift correction

Two sets of brake-specific emission results shall be calculated. If the drift is:
within ± 2% the data can be accepted without correction;
between ± 2% and ± 4%, the test is void or a drift correction according to annex §A.2.3. shall be applied to the data;
beyond ≥ ± 4% the data is invalid and the test shall be repeated.

8.2.3. PM sample preconditioning and tare weighing

Before an emission test, the following steps shall be taken to prepare PM sample filter media and equipment for PM measurements:

8.2.3.1. Periodic verifications

It shall be made sure that the balance and PM-stabilization environments meet the periodic verifications in §8.1.12. The reference filter shall be weighed just before weighing test filters to establish an appropriate reference point (see section details of the procedure in 8.1.12.1.)

8.2.3.2. Visual Inspection

The unused sample filter media shall be visually inspected for defects, defective filters shall be discarded.

8.2.3.3. Grounding

Electrically grounded tweezers or a grounding strap shall be used to handle PM filters as described in §9.3.4.

8.2.3.4. Unused sample media

Unused sample media shall be placed in one or more containers that are open to the PM-stabilization environment. If filters are used, they may be placed in the bottom half of a filter cassette.

8.2.3.5. Stabilization

Sample media shall be stabilized in the PM-stabilization environment. An unused sample medium can be considered stabilized as long as it has been in the PM-stabilization environment for a minimum of 30 min, during which the PM-stabilization environment has been within the specifications of §9.3.4.

8.2.3.6. Weighing

The sample media shall be weighed automatically or manually, as follows:
(a) For automatic weighing, the automation system manufacturer's instructions shall be followed to prepare samples for weighing.
(b) For manual weighing, good engineering judgment shall be used to determine if substitution weighing is necessary to show that an engine meets the gtr emission limits.
(c) Once a filter is weighed it shall be returned to the petri dish and covered.

8.2.3.7. Buoyancy correction

The measured weight shall be corrected for buoyancy as described in § 8.1.12.2.

8.2.3.8. Repetition

The filter mass measurements may be repeated to determine the average mass of the filter using good engineering judgement and to exclude outliers from the calculation of the average.

8.2.3.9. Tare-weighing

Unused filters that have been tare-weighed shall be loaded into clean filter cassettes and the loaded cassettes shall be placed in a covered or sealed container before they are taken to the test cell for sampling.

8.2.4. PM sample post-conditioning and total weighing

8.2.4.1. Periodic verification

It shall be assured that the weighing and PM-stabilization environments have met the periodic verifications in §8.1.12.1. After testing is complete, the filters shall be returned to the weighing and PM-stabilisation environment. The weighing and PM-stabilisation environment shall meet the ambient conditions requirements in §9.3.4.4., otherwise the test filters shall be left covered until proper conditions have been met.

8.2.4.2. Removal from sealed containers

In the PM-stabilization environment, the PM samples shall be removed from the sealed containers. Filters may be removed from their cassettes before or after stabilization. When a filter is removed from a cassette, the top half of the cassette shall be separated from the bottom half using a cassette separator designed for this purpose.

8.2.4.3. Electrical grounding

To handle PM samples, electrically grounded tweezers or a grounding strap shall be used, as described in §9.3.4.5.

 8.2.4.4. Visual inspection

The collected PM samples and the associated filter media shall be inspected visually. If the conditions of either the filter or the collected PM sample appear to have been compromised, or if the particulate matter contacts any surface other than the filter, the sample may not be used to determine particulate emissions. In the case of contact with another surface; the affected surface shall be cleaned before proceeding.

8.2.4.5. Stabilisation of PM samples

To stabilise PM samples, they shall be placed in one or more containers that are open to the PM-stabilization environment, which is described in §9.3.4.4. A PM sample is stabilized as long as it has been in the PM-stabilization environment for one of the following durations, during which the stabilization environment has been within the specifications of §9.3.4.4. :
(a) If it is expected that a filter's total surface concentration of PM will be greater than about 0.353 $\mu g/mm^2$, [please check] the filter shall be exposed to the stabilization environment for at least 60 minutes before weighing.
(b) If it is expected that a filter's total surface concentration of PM will be less than about 0.353 $\mu g/mm^2$, the filter shall be exposed to the stabilization environment for at least 30 minutes before weighing.
(c) If a filter's total surface concentration of PM is unsure, the filter shall be exposed to the stabilization environment for at least 60 minutes before weighing.

8.2.4.6. Determination of post-test filter mass

The procedures in §8.2.3. shall be repeated (f) through (i) to determine the post-test filter mass. After correcting for buoyancy, the sample's post-test mass shall be referred to as its total mass.

8.2.4.7. Net PM mass

Each buoyancy-corrected filter tare mass shall be subtracted from its respective buoyancy-corrected post-test filter mass. The result is the net PM mass, m_{PM}, which shall be used in emission calculations in annexes §A.8. and §A.9.

9. MEASUREMENT EQUIPMENT

9.1. Engine dynamometer specification

9.1.1. Shaft work

An engine dynamometer shall be used that has adequate characteristics to perform the applicable duty cycle.
(a) Eddy-current and water-brake dynamometers may be used.
(b) Alternating-current or direct-current motoring dynamometers may be used for any type of testing.
(c) One or more dynamometers may be used.

9.1.2. Transient cycle

(a) When using a load cell, the torque signal shall be transferred to the engine axis and the inertia of the dyno shall be considered. The actual engine torque is the torque read on the load cell plus the moment of inertia of the brake multiplied by the angular acceleration. The control system has to perform such a calculation in real time.
(b) If the engine is tested with an eddy-current dynamometer, it is recommended that the number of points, where the difference $T_{sp} - \left(2 \cdot \pi \cdot \dot{n}_{sp} \cdot \Theta_D \right)$ is smaller than – 5% of the peak torque, does not exceed 30 (where the subscript "sp" means the set point, T_{sp} is the demanded torque, $\dot{n}_{sp}$ is the derivative of the engine speed and· Θ_D is the rotational inertia of the eddy-current dynamometer D).

9.1.3. Engine accessories

The work of engine accessories required to fuel, lubricate, or heat the engine, circulate liquid coolant to the engine, or to operate after-treatment devices shall be installed in accordance with paragraph §6.3.

9.1.4. Operator demand

Operator demand is an engine operator's input to control engine output either manually or automatically. A mechanical or electronic input is used to control operator demand such that the engine is able to perform the applicable duty cycle.

9.2. Dilution procedure (if applicable)

9.2.1. Introduction

9.2.1.1. Gaseous constituents

Gaseous constituents may be measured raw or dilute whereas PM measurement generally requires dilution. Dilution may be accomplished by a full flow or partial flow dilution system. When dilution is applied then the exhaust may be diluted with ambient air, synthetic air, or nitrogen. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems. De-humidifying the dilution air before entering the dilution system is permitted, if the air humidity is high. The temperature of the dilution air shall be between 293 and 303 K (20 and 30 °C).

9.2.1.2. Diluent conditions and background concentrations

Before a diluent is mixed with exhaust, it may be preconditioned by increasing or decreasing its temperature or humidity. Constituents may be removed from the diluent to reduce their background concentrations. The following provisions apply to removing constituents or accounting for background concentrations:
(a) Constituent concentrations in the diluent may be measured and compensated for background effects on test results. See §A.8.-A.9.. for calculations that compensate for background concentrations.
(b) To account for background PM the following options are available:
(i) For removing background PM, the diluent shall be filtered with high-efficiency particulate air (HEPA) filters that have an initial minimum collection efficiency specification of 99.97 % (see §3.1. for procedures related to HEPA-filtration efficiencies).
(ii) For correcting for background PM without HEPA filtration, the background PM shall not contribute more than 50% of the net PM collected on the sample filter.
(iii) Background correction with HEPA filtration is permitted.

9.2.2. Full flow system

Full-flow dilution; constant-volume sampling (CVS). The full flow of raw exhaust is diluted in a dilution tunnel. Constant flow may be maintained by maintaining the temperature and pressure at the flow meter within the limits. For non constant flow the flow shall be measured directly to allow for proportional sampling. The system shall be designed as follows (see figure 1 in §9.2.2.):
(a) Construction. A tunnel with inside surfaces of stainless steel shall be used. The entire dilution tunnel shall be electrically grounded.
(b) Pressure control. The exhaust system backpressure shall not be artificially lowered by the dilution air inlet system. The static pressure at the location where raw exhaust is introduced into the tunnel shall be maintained within 1.5 kPa of atmospheric pressure.
(c) Mixing. Raw exhaust shall be introduced into the tunnel by directing it downstream along the centreline of the tunnel. The Reynolds number, *Re*, shall be at least 4000 for the diluted exhaust stream, where *Re* is based on the inside diameter of the dilution tunnel. *Re* is defined in annexes §A.8-A.9. Verification of adequate mixing shall be performed while traversing a sampling probe across the tunnel's diameter, vertically and horizontally. If the analyzer response indicates any deviation exceeding ±2% of the mean measured concentration, the CVS shall be operated at a higher flow rate or a mixing plate or orifice shall be installed to improve mixing.
(d) Flow measurement preconditioning. The diluted exhaust may be conditioned before measuring its flow rate, as long as this conditioning takes place downstream of heated HC or PM sample probes, as follows:
(i) Flow straighteners, pulsation dampeners, or both of these maybe used.
(ii) A filter maybe used.
(iii) A heat exchanger maybe used to control the temperature upstream of any flow meter.

(e) Aqueous condensation. Aqueous condensation shall be prevented throughout the dilution tunnel. Certain exhaust components can be diluted or eliminated by the presence of moisture.
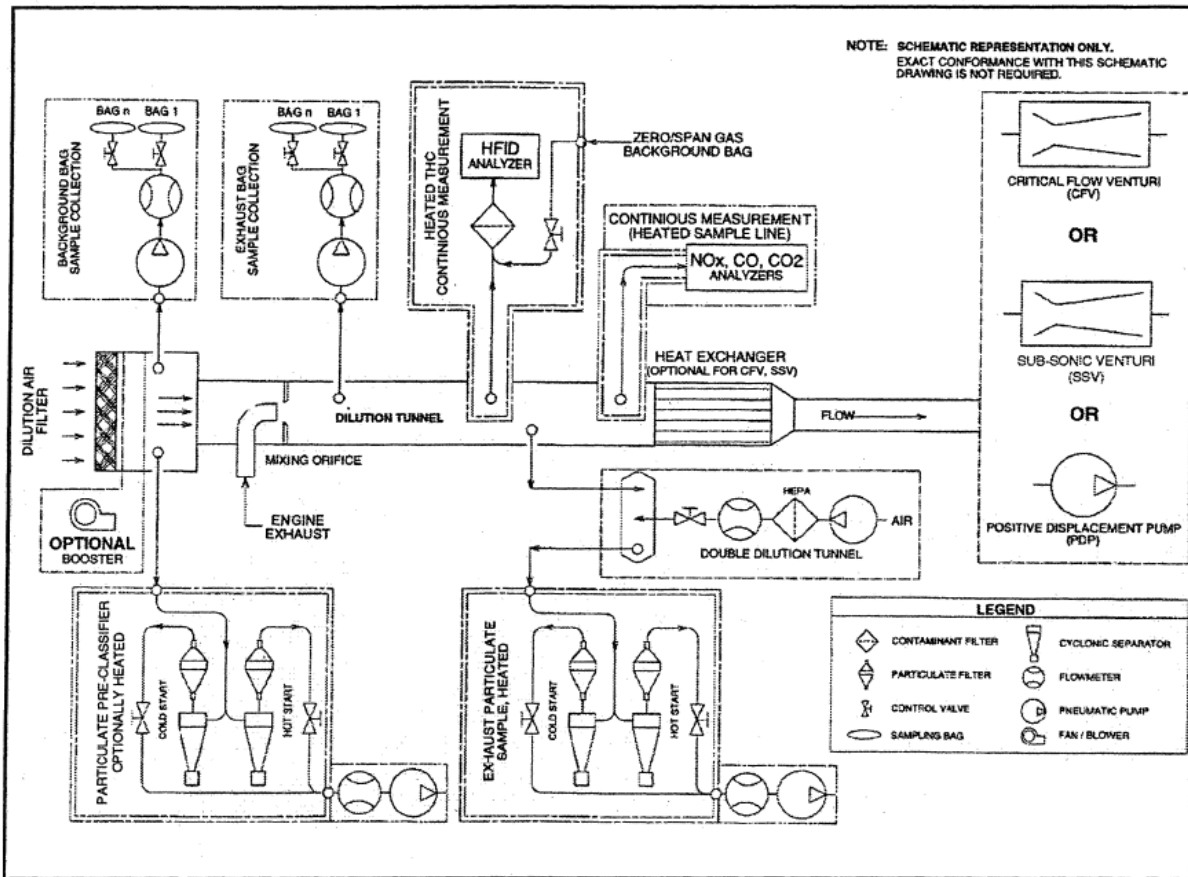

Figure 1 of §9.2.2. – Examples of full-flow dilution sampling configurations.

9.2.3. Partial flow dilution (PFD) system

9.2.3.1. Description of partial flow system

As shown in figure 1, the raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The total flow through the tunnel is adjusted with the flow controller FC2 and the sampling pump P of the particulate sampling system (PSS). The dilution air flow is controlled by the flow controller FC1, which may use q_{mew} (exhaust gas mass flow rate on wet basis) or q_{maw} (intake air mass flow rate on wet basis) and q_{mf} (fuel mass flow rate) as command signals, for the desired exhaust split. The sample flow into the dilution tunnel DT is the difference of the total flow and the dilution air flow. The dilution air flow rate is measured with the flow measurement device FM1, the total flow rate with the flow measurement device of the particulate sampling system (FM3 in figure 3 of annex §A.7.). The dilution ratio is calculated from these two flow rates.
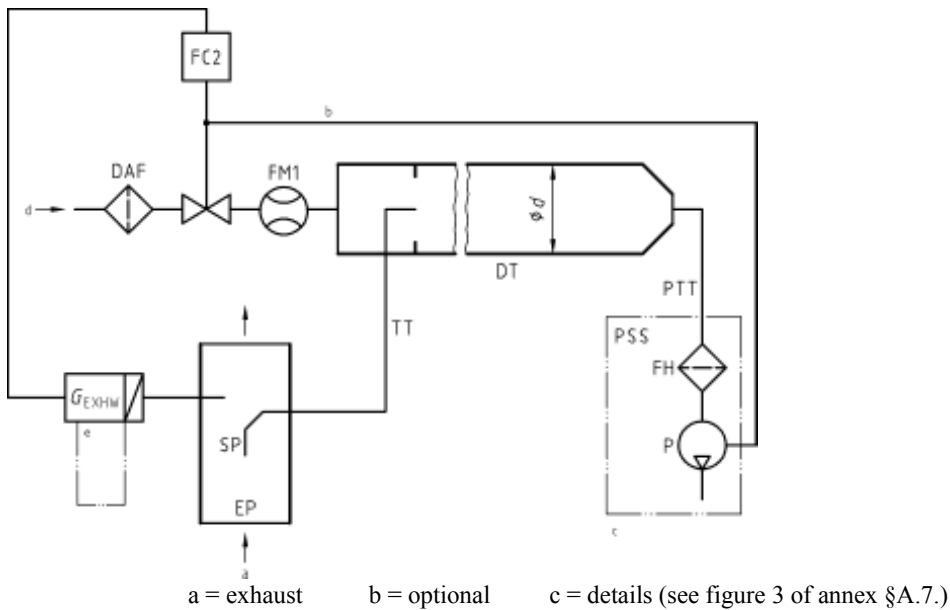
Figure 1 of §9.2.3. – Schematic of partial flow dilution system (total sampling type). Another configuration of the partial flow dilution system, i.e. the fractional sampling type, is illustrated in the annex §A.7.

Components of figure 1:
DAF = Dilution air filter – The dilution air (ambient air, synthetic air, or nitrogen) shall be filtered with a high-efficiency (HEPA) filter.
DT = Dilution tunnel
EP = Exhaust pipe
FC2 = Flow controller
FH = Filter holder
FM1 = Flow measurement device measuring the dilution air flow rate
q_{mew} = Exhaust gas mass gas flow rate on wet basis (q_{mew} instead of G_{EXHW})
P = Sampling pump
PSS = Particulate sampling system
PTT = Particulate transfer tube
SP = Dilute exhaust gas sampling probe

9.2.3.2. Applicability

PFD may be used to extract a proportional raw exhaust sample for any batch or continuous PM and gaseous emission sampling over any transient duty cycle, any steady-state duty cycle or any ramped-modal cycle.

9.2.3.3. Calibration

The calibration of the PFD is considered in paragraph §8.1.8.6.

9.3. Sampling procedures

9.3.1 General sampling requirements

9.3.1.1. Probe design and construction

Sample probes shall be made with inside surfaces of stainless steel or, for raw exhaust sampling, with any nonreactive material capable of withstanding raw exhaust temperatures. Sample probes shall be located where constituents are mixed to their mean sample concentration and where interference with other probes is minimised. It is recommended that all probes remain free from influences of boundary layers, wakes, and eddies – especially near the outlet of a raw-exhaust tailpipe where unintended dilution might occur. Purging or back-flushing of a probe shall not influence another probe during testing. A single probe to extract a sample of more than one constituent may be used as long as the probe meets all the specifications for each constituent.

9.3.1.2. Probe installation on multi-stack engines

Multiple stacks from multi-stack engines are recommended to be combined into a single stack. If this is not practical symmetrical probes and transfer lines shall be installed in each stack. (If this is not practical it is permissible to sample from the group with the highest CO_2 emissions).

9.3.1.3. Transfer lines

Transfer lines that transport an extracted sample from a probe to an analyzer, storage medium, or dilution system shall be minimized in length by locating analyzers, storage media, and dilution systems as close to the probes as practical. The number of bends in transfer lines are minimized and that the radius of any unavoidable bend should be maximized.

9.3.1.4. Sampling methods

For continuous and batch sampling, introduced in paragraph §7.2, the following conditions apply:
(a) When extracting from a constant flow rate, the sample shall also be carried out at a constant flow rate.
(b) When extracting from a varying flow rate, the sample flow rate shall be varied in proportion to the varying flow rate.
(c) Proportional sampling shall be validated as described in §8.2.1.

9.3.2. Gas sampling

9.3.2.1. Sampling probes

Either single-port or multi-port probes are used for sampling gaseous emissions. The probes may be oriented in any direction relative to the raw or diluted exhaust flow. For some probes, the sample temperatures shall be controlled, as follows:
(a) For probes that extract NO_x from diluted exhaust, the probe's wall temperature shall be controlled to prevent aqueous condensation.
(b) For probes that extract hydrocarbons from the diluted exhaust a probe wall temperature tolerance of (191 ± 11) °C shall be maintained.

9.3.2.2. Transfer lines

Transfer lines with inside surfaces of stainless steel, PTFE, Viton^{TM}, or any other material that has better properties for emission sampling shall be used. A non-reactive material capable of withstanding exhaust temperatures shall be used. In-line filters may be used if the filter and its housing meet the same temperature requirements as the transfer lines, as follows:
(a) For NO_x transfer lines upstream of either an NO_2-to-NO converter that meets the specifications of §8.1.11.5. or a chiller that meets the specifications of §8.1.11.4. a sample temperature that prevents aqueous condensation shall be maintained.

(b) For THC transfer lines for testing compression-ignition engines a wall temperature tolerance throughout the entire line of (191 ±11) °C shall be maintained. If sampled from raw exhaust, an unheated, insulated transfer line may be connected directly to a probe. The length and insulation of the transfer line shall be designed to cool the highest expected raw exhaust temperature to no lower than 191 °C, as measured at the transfer line outlet. For dilute sampling a transition zone between the probe and transfer line of up to 0.9 m in length is allowed to transition the wall temperature to (191 ±11) °C.

9.3.2.3 Sample-conditioning components

9.3.2.3.1. Sample dryers

The following sample-conditioning components may be used to prepare gaseous samples for analysis.
(a) NO_2-to-NO converter. If the Nox measurement instrument measures NO only an NO_2-to-NO converter that meets the efficiency-performance check specified in §8.1.11.5. at any point upstream of a NO_x analyzer, sample bag, or other storage medium shall be used.
(b) Sample dryer. Either type of sample dryer described in this paragraph to decrease the effects of water on gaseous emission measurements may be used.
(i) Osmotic-membrane. If an osmotic-membrane dryer upstream of any gaseous analyzer or storage medium is used, it shall meet the temperature specifications in paragraph 9.3.2.2. of this section. The dewpoint, T_{dew}, and absolute pressure, p_{total}, downstream of an osmotic-membrane dryer shall be monitored. Continuously recorded values of T_{dew} and p_{total} in the amount of water calculations specified in §A.8.-A.9. may be used. If these values are not continuously recorded, their peak values observed during a test or their alarm setpoints may be used as constant values in the calculations specified in §A.8.-A.9. A nominal p_{total}, which may be estimated as the dryer's lowest absolute pressure expected during testing may be used.
(ii) Thermal chiller. A thermal chiller upstream of a THC measurement system for compression-ignition engines shall not be used. If a thermal chiller upstream of an NO_2-to-NO converter or in a sampling system without an NO_2-to-NO converter is used, the chiller must meet the NO_2 loss-performance check specified in §8.1.11.4. The dewpoint, T_{dew}, and absolute pressure, p_{total}, downstream of a thermal chiller shall be monitored. Continuously recorded values of T_{dew} and p_{total} may be used in the emission calculations specified in §A.8.-A.9. If these values are not continuously recorded, their peak values observed during a test or their high alarm setpoints may be used as constant values in the amount of water calculations specified in §A.8.-A.9. A nominal p_{total}, which is estimated as the dryer's lowest absolute pressure expected during testing may also be used. If it is valid to assume the degree of saturation in the thermal chiller, T_{dew} based on the known chiller efficiency and continuous monitoring of chiller temperature, $T_{chiller}$ may be calculated. If values of $T_{chiller}$ are not continuously recorded, its peak value observed during a test, or its alarm setpoint, may be used as a constant value to determine a constant amount of water according to §A.8.-A.9. If it is valid to assume that $T_{chiller}$ is equal to T_{dew}, $T_{chiller}$ may be used in lieu of T_{dew} according to §A.8.-A.9. The validity of any assumptions allowed by this paragraph must be shown by engineering analysis or by data.

9.3.2.3.2. Sample pumps

Sample pumps upstream of an analyzer or storage medium for any gas shall be used. Sample pumps with inside surfaces of stainless steel, PTFE, or any other material having better properties for emission sampling shall be used. For some sample pumps, temperatures must be controlled, as follows:
(a) If a NO_x sample pump upstream of either an NO_2-to-NO converter that meets §8.1.11.5. or a chiller that meets §8.1.11.4. is used, it shall be heated to prevent aqueous condensation.

(b) When testing compression-ignition engines, if a THC sample pump upstream of a THC analyzer or storage medium is used, its inner surfaces shall be heated to a tolerance of (191 ±11) °C.

9.3.2.4. Sample storage media

In the case of bag sampling, gas volumes shall be stored in sufficiently clean containers that minimally off-gas or allow permeation of gases. Good engineering judgment shall be used to determine acceptable thresholds of storage media cleanliness and permeation. To clean a container, it may be repeatedly purged and evacuated and may be heated. A flexible container (such as a bag) within a temperature-controlled environment, or a temperature controlled rigid container that is initially evacuated or has a volume that can be displaced, such as a piston and cylinder arrangement, shall be used. Containers meeting the specifications in the following table shall be used:

Table 1 of §9.3.2.3 – Gaseous Batch Sampling Container Materials

Emissions	Compression-ignition Engines
CO, CO_2, O_2, CH_4, C_2H_6, C_3H_8, NO, NO_2 [1]	Tedlar™, [2] Kynar™, [2] Teflon™, [3] or stainless steel [3]
THC, NMHC	Teflon™ [4] or stainless steel [4]

[1] As long as aqueous condensation in storage container is prevented.
[2] Up to 40 °C.
[3] Up to 202 °C.
[4] At (191 ±11) °C.

9.3.3. PM sampling

9.3.3.1. Sampling probes

PM probes with a single opening at the end shall be used. PM probes shall be oriented to face directly upstream.
The PM probe may be shielded with a hat that conforms with the requirements in figure 1. In this case the pre-classifier described in section XYZ shall not be used.
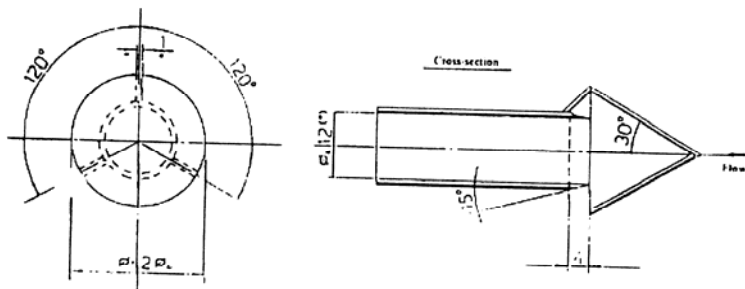

Figure 1 of §9.3.3.1. Scheme of a sampling probe with a hat hat-shaped pre-classifier

9.3.3.2. Transfer lines

Insulated or heated transfer lines or a heated enclosure are recommended to minimize temperature differences between transfer lines and exhaust constituents. Transfer lines that are inert with respect to PM and are electrically conductive on the inside surfaces shall be used. It is recommended using

66

PM transfer lines made of stainless steel. The inside surface of PM transfer lines shall be electrically grounded.

9.3.3.3. Pre-classifier

The use of a PM pre-classifier to remove large-diameter particles is permitted that is installed in the dilution system directly before the filter holder. Only one pre-classifier is permitted. If a hat shaped probe is used (see figure 1), the use of a pre-classifier is prohibited.
The PM pre-classifier may be either an inertial impactor or a cyclonic separator. It shall be constructed of stainless steel. The pre-classifier shall be rated to remove at least 50 % of PM at an aerodynamic diameter of 10 μm and no more than 1 % of PM at an aerodynamic diameter of 1 μm over the range of flow rates for which it is used. The pre-classifier manufacturer's instructions for any periodic servicing that may be necessary to prevent a build-up of PM shall be followed. The pre-classifier outlet shall be configured with a means of bypassing any PM sample media so that the pre-classifier flow can be stabilized before starting a test. PM sample media shall be located within 75 cm downstream of the pre-classifier's exit.

9.3.3.4. Sample filter

The diluted exhaust shall be sampled by a filter that meets the requirements of paragraphs 9.3.3.4.1. to 9.3.3.4.4. during the test sequence. Selection of the options in paragraphs 9.3.3.4.1. to 9.3.3.4.4. shall be decided by the Contracting Parties.

9.3.3.4.1. Filter specification

All filter types shall have a 0.3 μm DOP (di-octylphthalate) collection efficiency of at least 99.7 per cent. The filter material shall be either:
(a) fluorocarbon (PTFE) coated glass fibre, or
(b) fluorocarbon (PTFE) membrane.

If the expected filter total surface concentration of PM exceeds 0.3526 μg/mm^2 for a given test interval, a filter media with a minimum initial collection efficiency of 98 % may be used.

9.3.3.4.2. Filter size

The filter size shall be either:
(a) 47 mm diameter or
(b) 70 mm diameter.

9.3.3.4.3. Dilution and temperature control of PM samples

PM samples shall be diluted at least once upstream of transfer lines in case of a CVS system and downstream in case of PFD system (see §9.4.3.2. relating to transfer lines). Sample temperature is to be controlled to a (47 ± 5) °C tolerance, as measured anywhere within 20 cm upstream or downstream of the PM storage media. The PM sample is intended to be heated or cooled primarily by dilution conditions as specified in paragraph §9.2.1.(a).

9.3.3.4.4. Filter face velocity

The face velocity through the filter shall be larger than 0.25 m/s, but not exceed 1.00 m/s. It is recommended to maximise the flow close to 1.00 m/s, however if excessive PM loading conditions

exist, the filter face velocity may be decreased. The pressure drop increase between the beginning and the end of the test shall not exceed 25 kPa.

9.3.3.4.5 Filter holder

To minimize turbulent deposition and to deposit PM evenly on a filter, a 12.5° (from centre) divergent cone angle to transition from the transfer-line inside diameter to the exposed diameter of the filter face shall be used. Stainless steel for this transition shall be used.

9.3.4. PM-stabilization & weighing environments for gravimetric analysis

9.3.4.1. Environment for gravimetric analysis

This section describes the two environments required to stabilize and weigh PM for gravimetric analysis: the PM stabilization environment, where filters are stored before weighing; and the weighing environment, where the balance is located. The two environments may share a common space.

Both the stabilization and the weighing environments shall be kept free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could contaminate PM samples.

9.3.4.2. Cleanliness

The cleanliness of the PM-stabilization environment using reference filters shall be verified, as described in §8.1.12.1.(b).

9.3.4.3. Temperature of the chamber

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within 22 °C ± 1 °C during all filter conditioning and weighing. The humidity shall be maintained to a dew point of 9.5 °C ± 1 °C and a relative humidity of 45 per cent ± 8 per cent.

9.3.4.4. Verification of ambient conditions

When using measurement instruments that meet the specifications in §9.4 the following ambient conditions shall be verified:
(a) Dew point and ambient temperature shall be recorded. These values shall be used to determine if the stabilization and weighing environments have remained within the tolerances specified in paragraph 9.3.4.3. of this section for at least 60 min before weighing filters.
(b) Atmospheric pressure shall be continuously recorded within the weighing environment. A shared atmospheric pressure meter may be used as long as it can be shown that the equipment for handling the weighing environment air maintains ambient pressure at the balance within ±100 Pa of the shared atmospheric pressure. A means to record the most recent atmospheric pressure shall be provided when each PM sample is weighed. This value shall be used to calculate the PM buoyancy correction in §8.1.12.2.

9.3.4.5. Installation of balance

The balance shall be installed as follows:
(a) installed on a vibration-isolation platform to isolate it from external noise and vibration.
(b) shielded from convective airflow with a static-dissipating draft shield that is electrically grounded.

9.3.4.6. Static electric charge

Static electric charge shall be minimized in the balance environment, as follows:
(a) The balance is electrically grounded.
(b) Stainless steel tweezers shall be used if PM samples must be handled manually.
(c) Tweezers shall be grounded with a grounding strap, or a grounding strap shall be provided for the operator such that the grounding strap shares a common ground with the balance. Grounding straps shall have an appropriate resistor to protect operators from accidental shock.
(d) A static-electricity neutralizer shall be provided that is electrically grounded in common with the balance to remove static charge from PM samples.

9.4. Measurement instruments

9.4.1. Introduction

9.4.1.1. Scope

This paragraph specifies measurement instruments and associated system requirements related to emission testing. This includes laboratory instruments for measuring engine parameters, ambient conditions, flow-related parameters, and emission concentrations (raw or diluted).

9.4.1.2. Instrument types

Any of the specified instruments as described in this paragraph §9.4. shall be used to perform emission tests. If any of these instruments are used in a way that is not specified in this paragraph, or any different instrument is used, it becomes subject to compliance with alternate procedure under §5.3. Where more than one instrument for a particular measurement is specified, one of them is identified as the reference for showing that an alternative procedure is equivalent to the specified procedure.

9.4.1.3. Redundant systems

Data from multiple instruments to calculate test results for a single test may be used for all measurement instruments described in this paragraph, with prior approval of the type approval or certification authority. Results from all measurements shall be recorded, as described in §5.5. This requirement applies whether or not the measurements are actually used in the calculations.

9.4.2. Data recording and control

The test system must be able to update data, record data and control systems related to operator demand, the dynamometer, sampling equipment, and measurement instruments. Data acquisition and control systems shall be used that can record at the specified minimum frequencies, as shown in table 1 of paragraph §9.4.2. (this table does not apply to discrete mode testing).

Table 1 of §9.4.2 – Data recording and control minimum frequencies

Applicable Test Protocol Section	Measured Values	Minimum Command and Control Frequency	Minimum Recording Frequency
§7.6.1.1.	Speed and torque during an engine step-map	1 Hz	1 mean value per step
§7.6.3.1.	Speed and torque during an engine sweep-map	5 Hz	1 Hz means
§7.6.3.2.	Transient duty cycle reference and feedback speeds and torques	5 Hz	1 Hz means
§7.6.1.2.	Steady-state and ramped-modal duty cycle reference and feedback speeds and torques	1 Hz	1 Hz
§7.2.	Continuous concentrations of raw analyzers	N/A	2 Hz
§7.2	Continuous concentrations of dilute analyzers	N/A	1 Hz
§7.2	Batch concentrations of raw or dilute analyzers	N/A	1 mean value per test interval
§7.2. §8.2.1.	Diluted exhaust flow rate from a CVS with a heat exchanger upstream of the flow measurement	N/A	1 Hz
§7.2. §8.2.1.	Diluted exhaust flow rate from a CVS without a heat exchanger upstream of the flow measurement	5 Hz	1 Hz means
§7.6.3.4 §8.2.1.	Intake-air or exhaust flow rate (for raw transient measurement)	N/A	2 Hz means
§7.6.3.4. §8.2.1.	Intake-air for diluted transient measurement	N/A	1 Hz means
§7.6.3.4 §8.2.1.	Dilution air if actively controlled	5 Hz	1 Hz means
§7.6.3.4. §8.2.1.	Sample flow from a CVS with a heat exchanger	1 Hz	1 Hz
§7.6.3.4 §8.2.1.	Sample flow from a CVS without a heat exchanger	5 Hz	1 Hz mean

9.4.3. Performance specifications for measurement instruments

9.4.3.1. Overview

The test system as a whole must meet all the applicable calibrations, verifications, and test-validation criteria specified in paragraphs §8.1. and §8.2. Instruments shall meet the specifications in table 1 of this section for all ranges to be used for testing. Furthermore, any documentation received from instrument manufacturers showing that instruments meet the specifications in table 1 of this section shall be kept.

9.4.3.2. Component requirements

Table 1 of paragraph §9.4.3. shows the specifications of transducers of torque and speed, and instruments. The overall system for measuring the given physical and/or chemical quantity must meet the linearity verification in paragraph §8.1.4. For gaseous emissions measurements, analyzers may be used, that have compensation algorithms that are functions of other measured gaseous components, and of the known or assumed fuel properties for the specific engine test.

Table 1 of §9.4.3. – Recommended performance specifications for measurement instruments

Measurement Instrument	Measured quantity symbol	Complete System Rise time and Fall time	Recording update frequency	Accuracy[a]	Repeatability[a]	
Engine speed transducer	n	1 s	1 Hz means	2.0 % of pt. or 0.5 % of max.	1.0 % of pt. or 0.25 % of max.	
Engine torque transducer	T	1 s	1 Hz means	2.0 % of pt. or 1.0 % of max.	1.0 % of pt. or 0.5 % of max	
Fuel flow meter (Fuel totalizer in parentheses)		5 s (N/A)	1 Hz (N/A)	2.0 % of pt. or 1.5 % of max.	1.0 % of pt. or 0.75 % of max.	
Total diluted exhaust meter (CVS) (With heat exchanger before meter)		1 s (5 s)	1 Hz means (1 Hz)	2.0 % of pt. or 1.5 % of max.	1.0 % of pt. or 0.75 % of max.	
Dilution air, inlet air, exhaust, and sample flow meters		1 s	1 Hz means of 5 Hz samples	2.5 % of pt. or 1.5 % of max.	1.25 % of pt. or 0.75 % of max.	
Continuous gas analyzer raw	x	2.5 s	2 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	
Continuous gas analyzer dilute	x	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	
Continuous gas analyzer	x	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	
Batch gas analyzer	x	N/A	N/A	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	
Gravimetric PM balance	m_{PM}	N/A	N/A	See §7.7.11.	0.5 µg	
Inertial PM balance	m_{PM}	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	

[a] Accuracy and repeatability are all determined with the same collected data, as described in §9.4.3., and based on absolute values. "pt." refers to the overall mean value expected at the emission limit ; "max." refers to the peak value expected at the emission limit over the duty cycle , not the maximum of the instrument's range; "meas" refers to the actual mean measured over the duty cycle .

9.4.4. Measurement of engine parameters & ambient conditions

9.4.4.1. Speed and torque sensors

9.4.4.1.1. Application

Measurement instruments for work inputs and outputs during engine operation shall meet the specifications in this section. Sensors, transducers, and meters meeting the specifications in table 1 of §9.4.3. are recommended. Overall systems for measuring work inputs and outputs must meet the linearity verifications in §8.1.4.

9.4.4.1.2. Shaft work

Work and power shall be calculated from outputs of speed and torque transducers according to §9.4.4.1. Overall systems for measuring speed and torque shall meet the calibration and verifications in §8.1.7.2.
Torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor, shall be compensated for.

9.4.4.2 Pressure transducers, temperature sensors, and dewpoint sensors

Component requirements

Overall systems for measuring pressure, temperature, and dewpoint shall meet the calibration and verifications in §8.1.7.2.

9.4.5. Flow-related measurements

9.4.5.1 Fuel flow meter

Overall system for measuring fuel flow shall meet the calibration in §8.1.8.1.

9.4.5.2 Intake-air flow meter

Component requirements. Overall system for measuring intake-air flow shall meet the calibration in §8.1.8.2.

9.4.5.3. Raw exhaust flow meter

9.4.5.3.1. Component requirements.

The overall system for measuring raw exhaust flow must meet the calibration and verifications in §8.1.8.3. Any raw-exhaust meter must be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states.

9.4.5.3.2. Flow meter response time

For the purpose of controlling of a partial flow dilution system, a flow meter response time faster than indicated in table 1 of paragraph §9.4.3. is required. For partial flow dilution systems with online control, the flow meter response time shall meet the specifications of paragraph §8.2.1.2

9.4.5.3.3. Exhaust cooling

Exhaust cooling upstream of the flow meter is permitted with the following restrictions:
(a) PM shall not be sampled downstream of the cooling.
(b) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, NMHC shall not be sampled downstream of the cooling.
(c) If cooling causes aqueous condensation, NO_X shall not be sampled downstream of the cooling unless the cooler meets the performance verification in §8.1.11.4
(d) If cooling causes aqueous condensation before the flow reaches a flow meter, the water content ($g_{H2O}/kg_{dry\ air}$) shall be measured at the flow meter inlet. Flow calculations shall be adjusted according to §A.8.-A.9.

9.4.5.4 Dilution air and diluted exhaust flow meters

9.4.5.4.1. Application

Instantaneous diluted exhaust flow rates or total diluted exhaust flow over a test interval shall be determined by using a diluted exhaust flow meter. Raw exhaust flow rates or total raw exhaust flow over a test interval may be calculated from the difference between a diluted exhaust flow meter and a dilution air meter.

9.4.5.4.2. Component requirements

The overall system for measuring diluted exhaust flow must meet the calibration and verifications in §8.1.8.4. and §8.1.8.5. The following meters may be used:
(a) For constant-volume sampling (CVS) of the total flow of diluted exhaust, a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow meter (UFM) may be used. Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller by keeping the diluted exhaust temperature constant in a CVS system.
(b) For the Partial Flow Dilution (PFD) system the combination of any flow meter with any active flow control system to maintain proportional sampling of exhaust constituents may be used. The total flow of diluted exhaust, or one or more sample flows, or a combination of these flow controls may be controlled to maintain proportional sampling.

9.4.5.5 Sample flow meter for batch sampling

A sample flow meter shall be used to determine sample flow rates or total flow sampled into a batch sampling system over a test interval. The difference between two flow meters may be used to calculate sample flow into a dilution tunnel e.g. for partial flow dilution PM measurement and secondary dilution flow PM measurement. Specifications for differential flow measurement is given in paragraph §8.1.8.6.1 and the calibration of differential flow measurement is given in paragraph §8.1.8.6.2.

Overall system for the sample flow meter shall meet the calibration in §8.1.8.

9.4.5.6 Gas divider

A gas divider may be used to blend calibration gases.

A gas divider shall be used that blends gases to the specifications of §9.5.1. and to the concentrations expected during testing. Critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers may be used. Viscosity corrections shall be applied as necessary (if not done by gas divider internal software) to appropriately ensure correct gas division.

9.4.6. CO and CO_2 measurements

A non-dispersive infra-red (NDIR) analyzer shall be used to measure CO and CO_2 concentrations in raw or diluted exhaust for either batch or continuous sampling.

The NDIR-based system must meet the calibration and verifications in §8.1.8.1.

9.4.7. Hydrocarbon measurements

9.4.7.1. Flame-ionization detector

9.4.7.1.1. Application

A heated flame-ionization detector (FID) analyzer shall be used to measure hydrocarbon concentrations in raw or diluted exhaust for either batch or continuous sampling. Hydrocarbon concentrations shall be determined on a carbon number basis of one, C_1. Methane and nonmethane hydrocarbon values shall be determined as described in paragraph (d) of this section. Heated FID analyzers shall maintain all surfaces that are exposed to emissions at a temperature of $(191 \pm 11)\ °C$.

9.4.7.1.2. Component requirements

The FID-based system for measuring THC or CH_4 must meet all of the verifications for hydrocarbon measurement in paragraph §8.1.10.

9.4.7.1.3. FID fuel and burner air

FID fuel and burner air shall meet the specifications of §9.5.1. The FID fuel and burner air must not mix before entering the FID analyzer to ensure that the FID analyzer operates with a diffusion flame and not a premixed flame.

9.4.7.1.4. Methane

FID analyzers measure total hydrocarbons (THC). To determine nonmethane hydrocarbons (NMHC), methane, CH_4, shall be quantified either with a nonmethane cutter and a FID analyzer as described in §9.4.7.2., or with a gas chromatograph as described in §9.4.7.3. For a FID analyzer used to determine NMHC, its response factor to CH_4, RF_{CH4}, shall be determined as described in §8.1.10.1. NMHC-related calculations are described in annexes §A.8-A.9.

9.4.7.1.5.

Instead of measuring methane, it is allowed to assume that 2% of measured total hydrocarbons is methane, as described in annexes §A.8-A.9.

9.4.7.2. Nonmethane cutter

9.4.7.2.1. Application

A nonmethane cutter may be used to measure CH_4 with a FID analyzer. A nonmethane cutter oxidizes all nonmethane hydrocarbons to CO_2 and H_2O. A nonmethane cutter may be used for raw or diluted exhaust for batch or continuous sampling.

9.4.7.2.2. System performance

Nonmethane-cutter performance shall be determined as described in §8.1.10.3. and the results shall be used to calculate NMHC emission in §A.8. and §A.9.

9.4.7.2.3. Configuration

The nonmethane cutter shall be configured with a bypass line for the verification described in §8.1.10.3.

9.4.7.2.4. Optimization

A nonmethane cutter may be optimised to maximize the penetration of CH_4 and the oxidation of all other hydrocarbons. A sample may be humidified and a sample may be diluted with purified air or oxygen (O_2) upstream of nonmethane cutter to optimize its performance. Any sample humidification and dilution must be accounted for in emission calculations.

9.4.7.3. Gas chromatograph

Application. A gas chromatograph may be used to measure CH_4 concentrations of diluted exhaust for batch sampling. While also a nonmethane cutter may be used to measure CH_4, as described in §9.4.7.2. a reference procedure based on a gas chromatograph shall be used for comparison with any proposed alternate measurement procedure under §5.3.

9.4.8. NOx measurements

Two measurement instruments are specified for NO_X measurement and either instrument may be used provided it meets the criteria specified in 9.4.8.1. or 9.4.8.2., respectively. The chemiluminescent detector shall be used as the reference procedure for comparison with any proposed alternate measurement procedure under §5.3.

9.4.8.1. Chemiluminescent detector

9.4.8.1.1. Application

A chemiluminescent detector (CLD) coupled with an NO_2-to-NO converter is used to measure NO_X concentration in raw or diluted exhaust for batch or continuous sampling.

9.4.8.1.2. Component requirements

The CLD-based system must meet the quench verification in §8.1.11.1. A heated or unheated CLD may be used, and a CLD that operates at atmospheric pressure or under a vacuum may be used.

9.4.8.1.3. NO_2-to-NO converter

An internal or external NO_2-to-NO converter that meets the verification in §8.1.11.5. shall be placed upstream of the CLD, while the converter shall be configured with a bypass to facilitate this verification.

9.4.8.1.4. Humidity effects

All CLD temperatures must be maintained to prevent aqueous condensation. To remove humidity from a sample upstream of a CLD, one of the following configurations shall be used:
(a) A CLD connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in §8.1.11.5.
(b) A CLD connected downstream of any dryer or thermal chiller that meets the verification in §8.1.11.4.

9.4.8.1.5. Response time

A heated CLD may be used to improve CLD response time.

9.4.8.2. Nondispersive ultraviolet analyzer

9.4.8.2.1. Application

A non-dispersive ultraviolet (NDUV) analyzer is used to measure NO_X concentration in raw or diluted exhaust for batch or continuous sampling.

9.4.8.2.2. Component requirements

The NDUV-based system must meet the verifications in §8.1.11.3.

9.4.8.2.3. NO_2-to-NO converter

If the NDUV analyzer measures only NO, an internal or external NO_2-to-NO converter that meets the verification in §8.1.11.5. shall be placed upstream of the NDUV analyzer. The converter shall be configured with a bypass to facilitate this verification.

9.4.8.2.4. Humidity effects

The NDUV temperature shall be maintained to prevent aqueous condensation, unless one of the following configurations is used:
(a) An NDUV shall be connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in §8.1.11.5.
(b) An NDUV shall be connected downstream of any dryer or thermal chiller that meets the verification in §8.1.11.4.

9.4.9. O_2 measurements

Application. A paramagnetic detection (PMD) or magnetopneumatic detection (MPD) analyzer shall be used to measure O_2 concentration in raw or diluted exhaust for batch or continuous sampling.

9.4.10. Air-to-fuel ratio measurements

Application. A Zirconia (ZrO_2) analyser may be used to measure air-to-fuel ratio in raw exhaust for continuous sampling. O_2 measurements with intake air or fuel flow measurements may be used to calculate exhaust flow rate according to annexes §A.8.-A.9.

9.4.11. PM measurements with gravimetric balance

A balance shall be used to weigh net PM collected on sample filter media.

The minimum requirement on the balance resolution shall be equal or lower than the repeatability of 0.5 microgram recommended in Table 1 of paragraph 9.4.3. If the balance uses internal calibration weights for routine spanning and linearity verifications, the calibration weights must meet the specifications in §9.5.2.

The balance shall be configured for optimum settling time and stability at its location.

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