Chapter 3

Test Procedure

1. INTRODUCTION

1.1 This Chapter describes the methods of determining emissions of, particulates and smoke from the engines to be tested. Three test cycles are described that shall be applied according to the provisions of chapter-I, section 6.2 of this part:

- The ESC which consists of a steady state 13-mode cycle,

- The ELR which consists of transient load steps at different speeds, which are integral parts of one test procedure, and are run concurrently,

- The ETC which consists of a second-by-second sequence of transient modes.

1.2 The test shall be carried out with the engine mounted on a test bench and connected to a dynamometer.

1.3 Measurement principle

The emissions to be measured from the exhaust of the engine include the gaseous components (carbon monoxide, total hydrocarbons for diesel engines on the ESC test only; non-methane hydrocarbons for diesel and gas engines on the ETC test only; methane for gas engines on the ETC test only and oxides of nitrogen), the particulates (diesel engines only) and smoke (diesel engines on the ELR test only). Additionally, carbon dioxide is often used as a tracer gas for determining the dilution ratio of partial and full flow dilution systems. Good engineering practice recommends the general measurement of carbon dioxide as an excellent tool for the detection of measurement problems during the test run.

1.3.1 ESC Test

During a prescribed sequence of warmed-up engine operating conditions the amounts of the above exhaust emissions shall be examined continuously by taking a sample from the raw or diluted exhaust gas. The test cycle consists of a number of speed and power modes, which cover the typical operating, range of diesel engines. During each mode the concentration of each gaseous pollutant, exhaust flow and power output shall be determined, and the measured values weighted. For particulate measurement, the exhaust gas shall be diluted with conditioned ambient air using either a partial flow or full flow dilution system. The particulates shall be collected on a single suitable filter in proportion to the

weighting factors of each mode. The grams of each pollutant emitted per kilowatt-hour shall be calculated as described in appendix 1 of this chapter. Additionally, NO_X shall be measured at three test points within the control area (only for diesel engines) selected by the test agency and the measured values compared to the values calculated from those modes of the test cycle enveloping the selected test points. The NO_X control check ensures the effectiveness of the emission control of the engine within the typical engine operating range.

1.3.2 ELR Test

During a prescribed load response test, the smoke of a warmed-up engine shall be determined by means of an opacimeter. The test consists of loading the engine at constant speed from 10 % to 100 % load at three different engine speeds. Additionally, a fourth load step selected by the test agency shall be run, and the value compared to the values of the previous load steps. The smoke peak shall be determined using an averaging algorithm, as described in appendix 1 of this chapter.

[1] The test points shall be selected using approved statistical methods of randomisation.

1.3.3 ETC Test

During a prescribed transient cycle of warmed-up engine operating conditions, which is based closely on road-type-specific driving patterns of heavy-duty engines installed in trucks and buses, the above pollutants shall be examined either after diluting the total exhaust gas with conditioned ambient air (CVS system with double dilution for particulates) or by determining the gaseous components in the raw exhaust gas and the particulates with a partial flow dilution system. Using the engine torque and speed feedback signals of the engine dynamometer, the power shall be integrated with respect to time of the cycle resulting in the work produced by the engine over the cycle. For a CVS system, the concentration of NO_X and HC shall be determined over the cycle by integration of the analyzer signal, whereas the concentration of CO, CO_2, and NMHC may be determined by integration of the analyzer signal or by bag sampling. If measured in the raw exhaust gas, all gaseous components shall be determined over the cycle by integration of the analyzer signal or bag sample. For particulates, a proportional sample shall be collected on a suitable filter. The raw or diluted exhaust gas flow rate shall be determined over the cycle to calculate the mass emission values of the pollutants. The mass emission values shall be related to the engine work to get the grams of each pollutant emitted per kilowatt hour, as described in appendix 2 of this chapter.

2.1 Engine Test Conditions

2.1.1 The absolute temperature (T_a) of the engine air at the inlet to the engine expressed in Kelvin, and the dry atmospheric pressure (p_s), expressed in kPa shall be measured and the parameter f_a shall be determined according to the following provisions. In multi-cylinder engines having distinct groups of intake manifolds, for example, in a "V" engine configuration, the average temperature of the distinct groups shall be taken.

(a) For diesel engines:

Naturally aspirated and mechanically supercharged engines:

$$fa = \left(\frac{99}{p_s}\right) \times \left(\frac{Ta}{298}\right)^{0.7}$$

(b) Turbocharged engines with or without cooling of the intake air:

$$fa = \left(\frac{99}{p_s}\right)^{0,7} \times \left(\frac{Ta}{298}\right)^{1,5}$$

(c) For gas engines:

$$fa = \left(\frac{99}{p_s}\right)^{1,2} \times \left(\frac{Ta}{298}\right)^{0,6}$$

2.1.2 Test Validity:

For a test to be recognised as valid, the parameter f_a shall be such that:

$$0,96 \leq f_a \leq 1,06$$

2.2 Engines with Charge Air Cooling

The charge air temperature shall be recorded and shall be, at the speed of the declared maximum power and full load, within ± 5 K of the maximum charge air temperature specified by the manufacturer in the application. The temperature of the cooling medium shall be at least 293 K (20 °C).

If a test shop system or external blower is used, the charge air temperature shall be within ± 5 K of the maximum charge air temperature specified by the manufacturer at the speed of the declared maximum power and full load. The

setting of the charge air cooler for meeting the above conditions shall be used for the whole test cycle.

2.3 Engine Air Intake System

An engine air intake system shall be used presenting an air intake restriction within ± 100 Pa of the upper limit of the engine operating at the speed at the declared maximum power and full load.

2.4 Engine Exhaust System

An exhaust system shall be used presenting an exhaust back pressure within ± 1000 Pa of the upper limit of the engine operating at the speed of declared maximum power and full load and a volume within ± 40 % of that specified by the manufacturer. A test shop system may be used, provided it represents actual engine operating conditions. The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in chapter III, appendix 4, section 3.4 of this part and in chapter V, section 2.2.1, EP and section 2.3.1, EP.

If the engine is equipped with an exhaust after treatment device, the exhaust pipe must have the same diameter as found in-use for at least 4 pipe diameters upstream to the inlet of the beginning of the expansion section containing the after treatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust after treatment device shall be the same as in the vehicle configuration or within the distance specifications of the manufacturer. The exhaust backpressure or restriction shall follow the same criteria as above, and may be set with a valve. The after treatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

2.5 Cooling System

An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures prescribed by the manufacturer shall be used.

2.6 Lubricating Oil

Specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test, as specified in the application.

2.7 Fuel

The fuel shall be the reference fuel specified in chapter IV of this part.

The fuel temperature and measuring point shall be specified by the manufacturer within the limits given in the application. The fuel temperature shall not be lower

than 306 K (33 °C). If not specified, it shall be 311 K ± 5 K (38 °C ± 5 °C) at the inlet to the fuel supply.

For NG and LPG fuelled engines, the fuel temperature and measuring point shall be within the limits given in application.

2.8 Testing of exhaust after treatment systems

If the engine is equipped with an exhaust after treatment system, the emissions measured on the test cycle shall be representative of the emissions in the field. In the case of an engine equipped with a exhaust after treatment system that requires the consumption of a reagent, the reagent used for all tests shall comply with Part 1 and Part 2 of ISO 22241-2006.

2.8.1. For an exhaust after treatment system based on a continuous regeneration process the emissions shall be measured on a stabilized after treatment system.

The regeneration process shall occur at least once during the ETC test and the manufacturer shall declare the normal conditions under which regeneration occurs (soot load, temperature, exhaust back-pressure, etc).

In order to verify the regeneration process at least 5 ETC tests shall be conducted. During the tests the exhaust temperature and pressure shall be recorded (temperature before and after the after treatment system, exhaust back pressure, etc).

The after treatment system is considered to be satisfactory if the conditions declared by the manufacturer occur during the test during a sufficient time.

The final test result shall be the arithmetic mean of the different ETC test results.

If the exhaust after treatment has a security mode that shifts to a periodic regeneration mode it should be checked following section 2.8.2 of this chapter. For that specific case the emission limits in 6.2.1 (ii) of chapter I of this part could be exceeded and would not be weighted.

2.8.2. For an exhaust after treatment based on a periodic regeneration process, the emissions shall be measured on at least two ETC tests, one during and one outside a regeneration event on a stabilized after treatment system, and the results be weighted.

The regeneration process shall occur at least once during the ETC test. The engine may be equipped with a switch capable of preventing or permitting the regeneration process provided this operation has no effect on the original engine calibration.

The manufacturer shall declare the normal parameter conditions under which the regeneration process occurs (soot load, temperature, exhaust back-pressure etc) and its duration time (n2). The manufacturer shall also provide all the data to determine the time between two regenerations (n1). The exact procedure to determine this time shall be agreed by the Technical Service based upon good engineering judgment.

The manufacturer shall provide an after treatment system that has been loaded in order to achieve regeneration during an ETC test. Regeneration shall not occur during this engine-conditioning phase.

Average emissions between regeneration phases shall be determined from the arithmetic mean of several approximately equidistant ETC tests. It is recommended to run at least one ETC as close as possible prior to a regeneration test and one ETC immediately after a regeneration test. As an alternative, the manufacturer may provide data to show that the emissions remain constant (± 15 %) between regeneration phases. In this case, the emissions of only one ETC test may be used.

During the regeneration test, all the data needed to detect regeneration shall be recorded (CO or NO_X emissions, temperature before and after the after treatment system, exhaust back pressure etc).

During the regeneration process, the emission limits in 6.2.1 (ii) of chapter I of this part can be exceeded. The measured emissions shall be weighted according to section 5.5 and 6.3 of appendix 2 to this chapter and the final result shall not exceed the limits in 6.2.1 (ii) of chapter I of this part.

Appendix 1

ESC & ELR Test cycles

1. ENGINE AND DYNAMOMETER SETTINGS

1.1 Determination of Engine Speeds A, B and C

The engine speeds A, B and C shall be declared by the manufacturer in accordance with the following provisions:

The high speed n_{hi} shall be determined by calculating 70 % of the declared maximum net power P(n), as determined in Chapter II. The highest engine speed where this power value occurs on the power curve is defined as n_{hi}.

The low speed n_{lo} shall be determined by calculating 50 % of the declared maximum net power P(n), as determined in Chapter II. The lowest engine speed where this power value occurs on the power curve is defined as n_{lo}.

The engine speeds A, B and C shall be calculated as follows:

Speed A = n_{lo} + 25% (n_{hi} – n_{lo})

Speed B = n_{lo} + 50% (n_{hi} – n_{lo})

Speed C = n_{lo} + 75% (n_{hi} – n_{lo})

The engine speeds A, B and C may be verified by either of the following methods

a) Additional test points shall be measured during engine power approval according to MORTH/CMVR/TAP-115 / 116 for an accurate determination of nhi and n_{lo}. The maximum power, nhi and nlo shall be determined from the power curve, and engine speeds A, B and C shall be calculated according to the above provisions.

b) The engine shall be mapped along the full load curve, from maximum no load speed to idle speed, using at least 5 measurement points per 1000 rpm intervals and measurement points within ± 50 rpm of the speed at declared maximum power. The maximum power, nhi and nlo shall be determined from this mapping curve, and engine speeds A, B and C shall be calculated according to the above provisions.

If the measured engine speeds A, B and C are within ± 3 % of the engine speeds as declared by the manufacturer, the declared engine speeds shall be used for the emissions test. If the tolerance is exceeded for any of the engine speeds, the measured engine speeds shall be used for the emissions test.

1.2 Determination of Dynamometer Settings

The torque curve at full load shall be determined by experimentation to calculate the torque values for the specified test modes under net conditions, as specified in Chapter II of this part. The power absorbed by engine-driven equipment, if applicable, shall be taken into account. The dynamometer setting for each test mode shall be calculated using the formula:

$$s = P(n) \times L \ / \ 100 \quad \text{if tested under net conditions}$$

$$s = P(n) \times L \ / \ 100 + (P(a) - P(b)) \quad \text{if not tested under net conditions}$$

where:

s = dynamometer setting, kW

P(n) = net engine power as indicated in chapter II of this part, kW

L = per cent load as indicated in Section 2.7.1, of this chapter %

P(a) = power absorbed by auxiliaries to be fitted as indicated in chapter II of this part.

P(b) = power absorbed by auxiliaries to be removed as indicated in chapter II of this part.

2 ESC Test run

At the manufacturers request, a dummy test may be run for conditioning of the engine and exhaust system before the measurement cycle.

2.1 Preparation of the Sampling Filter

At least one hour before the test, each filter shall be placed in a partially covered petri dish, which is protected against dust contamination, and placed in a weighing chamber for stabilisation. At the end of the stabilisation period each filter shall be weighed and the tare weight shall be recorded. The filter shall then be stored in a closed petri dish or sealed filter holder until needed for testing. The filter shall be used within eight hours of its removal from the weighing chamber. The tare weight shall be recorded.

2.2 Installation of the Measuring Equipment

The instrumentation and sample probes shall be installed as required. When using a full flow dilution system for exhaust gas dilution, the tailpipe shall be connected to the system.

2.3 Starting the Dilution System and the Engine

The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilised at maximum power according to the recommendation of the manufacturer and good engineering practice.

2.4 Starting the Particulate Sampling System

The particulate sampling system shall be started and running on by-pass. The particulate background level of the dilution air may be determined by passing dilution air through the particulate filters. If filtered dilution air is used, one measurement may be done prior to or after the test. If the dilution air is not filtered, measurements at the beginning and at the end of the cycle, may be done, and the values averaged.

2.5 Adjustment of the Dilution Ratio

The dilution air shall be set such that the temperature of the diluted exhaust gas measured immediately prior to the primary filter shall not exceed 325 K (52 °C) at any mode. The dilution ratio (q) shall not be less than 4.

For systems that use CO_2 or NO_X concentration measurement for dilution ratio control, the CO_2 or NO_X content of the dilution air must be measured at the beginning and at the end of each test. The pre- and post test background CO_2 or NO_X concentration measurements of the dilution air must be within 100 ppm or 5ppm of each other, respectively.

2.6 Checking the Analysers

The emission analysers shall be set at zero and spanned.

2.7 Test Cycle

2.7.1 The following 13-mode cycle shall be followed in dynamometer operation on the test engine

Mode Number	Engine speed	Percent load	Weighting factor	Mode length
1	Idle	--	0.15	4 minutes
2	A	100	0.08	2 minutes
3	B	50	0.10	2 minutes
4	B	75	0.10	2 minutes
5	A	50	0.05	2 minutes
6	A	75	0.05	2 minutes
7	A	25	0.05	2 minutes
8	B	100	0.09	2 minutes
9	B	25	0.10	2 minutes
10	C	100	0.08	2 minutes
11	C	25	0.05	2 minutes
12	C	75	0.05	2 minutes
13	C	50	0.05	2 minutes

2.7.2 Test Sequence

The test sequence shall be started. The test shall be performed in the order of he mode numbers as set out in section 2.7.1 of this chapter.

The engine must be operated for the prescribed time in each mode, completing engine speed and load changes in the first 20 seconds. The specified speed shall be held to within ± 50 rpm and the specified torque shall be held to within ± 2 % of the maximum torque at the test speed.

At the manufacturers request, the test sequence may be repeated a sufficient number of times for sampling more particulate mass on the filter. The manufacturer shall supply a detailed description of the data evaluation and calculation procedures. The gaseous emissions shall only be determined on the first cycle.

2.7.3 Analyser Response

The output of the analysers shall be recorded on a strip chart recorder or measured with an equivalent data acquisition system with the exhaust gas flowing through the analysers throughout the test cycle.

2.7.4 Particulate Sampling

One filter shall be used for the complete test procedure. The modal weighting factors specified in the test cycle procedure shall be taken into account by taking a sample proportional to the exhaust mass flow during each individual mode of the cycle. This can be achieved by adjusting sample flow rate, sampling time, and/or dilution ratio, accordingly, so that the criterion for the effective weighting factors in section 5.6 of this chapter is met.

The sampling time per mode must be at least 4 seconds per 0,01 weighting factor. Sampling must be conducted as late as possible within each mode. Particulate sampling shall be completed no earlier than 5 seconds before the end of each mode.'

2.7.5 Engine Conditions

The engine speed and load, intake air temperature and depression, exhaust temperature and backpressure, fuel flow and air or exhaust flow, charge air temperature, fuel temperature and humidity shall be recorded during each mode, with the speed and load requirements (see section 2.7.2 of this chapter) being met during the time of particulate sampling, but in any case during the last minute of each mode.

Any additional data required for calculation shall be recorded (see sections 4 and 5 of this chapter).

2.7.6 NO$_X$ Check within the Control Area (only for Diesel engines)

The NO$_X$ check within the control area shall be performed immediately upon completion of mode 13.

The engine shall be conditioned at mode 13 for a period of three minutes before the start of the measurements. Three measurements shall be made at different locations within the control area, selected by the test agency. The time for each measurement shall be 2 minutes.

The measurement procedure is identical to the NOx measurement on the 13-mode cycle, and shall be carried out in accordance with sections 2.7.3, 2.7.5, and 4.1 of this appendix, and chapter III, appendix 4, section 3 of this part.

The calculation shall be carried out in accordance with section 4 of this chapter.

[1] The test points shall be selected using approved statistical methods of randomisation.

2.7.7 Rechecking the Analysers

After the emission test a zero gas and the same span gas shall be used for rechecking. The test will be considered acceptable if the difference between the pre-test and post-test results is less than 2 % of the span gas value.

3 ELR TEST RUN

3.1 Installation of the Measuring Equipment

The opacimeter and sample probes, if applicable, shall be installed after the exhaust silencer or any after treatment device, if fitted, according to the general installation procedures specified by the instrument manufacturer. Additionally, the requirements of section 10 of ISO IDS 11614 shall be observed, where appropriate.

Prior to any zero and full scale checks, the opacimeter shall be warmed up and stabilised according to the instrument manufacturer's recommendations. If the opacimeter is equipped with a purge air system to prevent sooting of the meter optics, this system shall also be activated and adjusted according to the manufacturer's recommendations.

3.2 Checking of the Opacimeter

The zero and full-scale checks shall be made in the opacity readout mode, since the opacity scale offers two truly definable calibration points, namely 0 % opacity and 100 % opacity. The light absorption coefficient is then correctly calculated based upon the measured opacity and the La, as submitted by the opacimeter manufacturer, when the instrument is returned to the k readout mode for testing.

With no blockage of the opacimeter light beam, the readout shall be adjusted to 0,0 % ± 1,0 % opacity. With the light being prevented from reaching the receiver, the readout shall be adjusted to 100,0 % ± 1,0 % opacity.

3.3 Test Cycle

3.3.1 Conditioning of the Engine

Warming up of the engine and the system shall be at maximum power in order to stabilise the engine parameters according to the recommendation of the manufacturer. The preconditioning phase should also protect the actual measurement against the influence of deposits in the exhaust system from a former test.

When the engine is stabilised, the cycle shall be started within 20 ± 2 s after the preconditioning phase. At the manufacturers request, a dummy test may be run for additional conditioning before the measurement cycle.

3.3.2 Test Sequence

The test consists of a sequence of three load steps at each of the three engine speeds A (cycle 1), B (cycle 2) and C (cycle 3) determined in accordance with

chapter III, section 1.1 of this part, followed by cycle 4 at a speed within the control area and a load between 10 % and 100 %, selected by the test agency. The following sequence shall be followed in dynamometer operation on the test engine, as shown in Figure 3.

(1) The test points shall be selected using approved statistical methods of randomisation.

Figure 3

Sequence of ELR Test
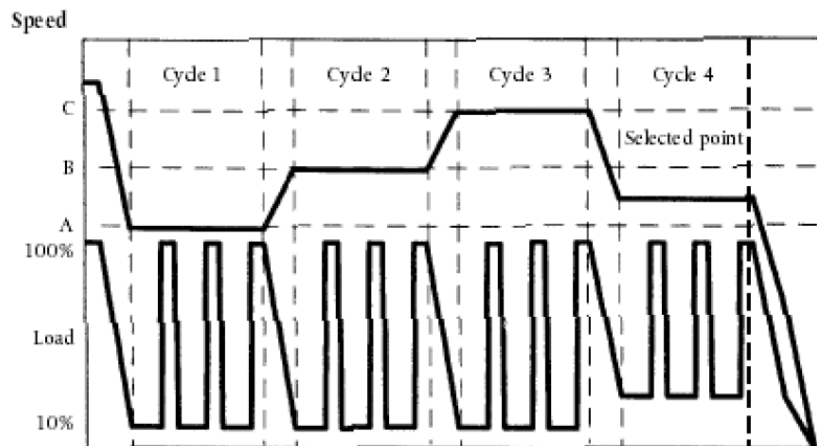
(a) The engine shall be operated at engine speed A and 10 per cent load for 20 ± 2 s. The specified speed shall be held to within ± 20 rpm and the specified torque shall be held to within ± 2 % of the maximum torque at the test speed.

(b) At the end of the previous segment, the speed control lever shall be moved rapidly to, and held in, the wide open position for 10 ± 1 s. The necessary dynamometer load shall be applied to keep the engine speed within ± 150 rpm during the first 3 s, and within ± 20 rpm during the rest of the segment.

(c) The sequence described in (a) and (b) shall be repeated two times.

(d) Upon completion of the third load step, the engine shall be adjusted to engine speed B and 10 per cent load within 20 ± 2 s.

(e) The sequence (a) to (c) shall be run with the engine operating at engine speed B.

(f) Upon completion of the third load step, the engine shall be adjusted to engine speed C and 10 per cent load within 20 ± 2 s.

(g) The sequence (a) to (c) shall be run with the engine operating at engine speed C.

(h) Upon completion of the third load step, the engine shall be adjusted to the selected engine speed and any load above 10 per cent within 20 ± 2 s.

(i) The sequence (a) to (c) shall be run with the engine operating at the selected engine speed.

3.4 Cycle Validation

The relative standard deviations of the mean smoke values at each test speed (SVA, SVB, SVC, as calculated in accordance with section 6.3.3 of this appendix from the three successive load steps at each test speed) shall be lower than 15% of the mean value, or 10 % of the limit value shown in 6.2.1 (i) of chapter I of this part, whichever is greater. If the difference is greater, the sequence shall be repeated until 3 successive load steps meet the validation criteria.

3.5 Rechecking of the Opacimeter

The post-test opacimeter zero drift value shall not exceed ± 5,0 % of the limit value shown in 6.2.1 (i) of chapter I of this part.

4 CALCULATION OF THE EXHAUST GAS FLOW

4.1 Determination of Raw Exhaust Gas Mass Flow

For calculation of the emissions in the raw exhaust, it is necessary to know the exhaust gas flow. The exhaust gas mass flow rate shall be determined in accordance with section 4.1.1 or 4.1.2 of this chapter. The accuracy of exhaust flow determination shall be ± 2,5 % of reading or ± 1,5 % of the engine's maximum value whichever is the greater. Equivalent methods (e.g. those described in section 4.2 of appendix 2 of this chapter may be used.

4.1.1 Direct measurement method

Direct measurement of the exhaust flow may be done by systems such as:

— pressure differential devices, like flow nozzle,

— ultrasonic flow meter,

— vortex flow meter.

Precautions shall be taken to avoid measurement errors, which will impact emission value errors. Such precautions include the careful installation of the device in the engine exhaust system according to the instrument manufacturers' recommendations and to good engineering practice. Especially, engine performance and emissions shall not be affected by the installation of the device.

4.1.2 Air and fuel measurement method

This involves measurement of the airflow and the fuel flow. Air flow meters and fuel flow meters shall be used that meet the total accuracy requirement of section 4.1 of this chapter. The calculation of the exhaust gas flow is as follows:

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

4.2 Determination of Diluted Exhaust Gas Mass Flow

For calculation of the emissions in the diluted exhaust using a full flow dilution system it is necessary to know the diluted exhaust gas flow. The flow rate of the diluted exhaust (q_{mdew}) shall be measured over each mode with a PDP-CVS, CFV-CVS or SSV-CVS in line with the general formulae given in section 4.1 of appendix 2 of this Chapter. The accuracy shall be ± 2 % of reading or better, and shall be determined according to the provisions of section 2.4 of appendix 5 of this Chapter.

5 CALCULATION OF THE GASEOUS EMISSIONS

5.1 Data Evaluation

For the evaluation of the gaseous emissions, the chart reading of the last 30 seconds of each mode shall be averaged, and the average concentrations (conc) of HC, CO and NO_X during each mode shall be determined from the average hart readings and the corresponding calibration data. A different type of recording can be used if it ensures an equivalent data acquisition.

For the NO_X check within the control area, the above requirements apply for NO_X, only.

The exhaust gas flow q_{mew} or the diluted exhaust gas flow q_{mdew}, if used optionally, shall be determined in accordance with appendix 4, section 2.3 of this chapter.

5.2. Dry/Wet Correction

The measured concentration shall be converted to a wet basis according to the following formulae, if not already measured on a wet basis. The conversion shall be done for each individual mode.

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

For the raw exhaust gas:

$$k_{W,r} = \left(1 - \frac{1{,}2442 \times H_a + 111{,}19 \times w_{ALF} \times \dfrac{q_{mf}}{q_{mad}}}{773{,}4 + 1{,}2442 \times H_a + \dfrac{q_{mf}}{q_{mad}} \times k_f \times 1000} \right) \times 1{,}008$$

or

$$k_{W,r} = \left(1 - \frac{1{,}2442 \times H_a + 111{,}19 \times w_{ALF} \times \dfrac{q_{mf}}{q_{mad}}}{773{,}4 + 1{,}2442 \times H_a + \dfrac{q_{mf}}{q_{mad}} \times k_f \times 1000} \right) \Big/ \left(1 - \frac{p_r}{p_b} \right)$$

where:

p_r = water vapour pressure after cooling bath, kPa,

p_b = total atmospheric pressure, kPa,

H_a = intake air humidity, g water per kg dry air,

k_f = 0,055584 × w_{ALF} − 0,0001083 × w_{BET} − 0,0001562 × w_{GAM} + 0,0079936 × w_{DEL} + 0,0069978 × w_{EPS}

For the diluted exhaust gas:

$$K_{We1} = \left(1 - \frac{\alpha \times \% \, c_{wCO_2}}{200}\right) - K_{W1}$$

or,

$$K_{We2} = \left(\frac{(1 - K_{W1})}{1 + \dfrac{\alpha \times \% \, c_{dCO_2}}{200}}\right)$$

For the dilution air:

$$K_{Wd} = 1 - K_{W1}$$

$$K_{W1} = \frac{1{,}608 \times \left[H_d \times \left(1 - \dfrac{1}{D}\right) + H_a \times \left(\dfrac{1}{D}\right)\right]}{1000 + \left\{1{,}608 \times \left[H_d \times \left(1 - \dfrac{1}{D}\right) + H_a \times \left(\dfrac{1}{D}\right)\right]\right\}}$$

For the intake air:

$$K_{Wa} = 1 - K_{W2}$$

$$K_{W2} = \frac{1{,}608 \times H_a}{1000 + (1{,}608 \times H_a)}$$

where:

H_a = intake air humidity, g water per kg dry air
H_d = dilution air humidity, g water per kg dry air

and may be derived from relative humidity measurement, dew point measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

5.3 NOx correction for humidity and temperature

As the NOx emission depends on ambient air conditions, the NOx concentration shall be corrected for ambient air temperature and humidity with the factors given in the following formulae. The factors are valid in the range between 0 and 25 g/kg dry air.

(a) For compression ignition engines

$$k_{h,D} = \frac{1}{1 - 0{,}0182 \times (H_a - 10{,}71) + 0{,}0045 \times (T_a - 298)}$$

with:

T_a = temperature of the intake air, K

H_a = humidity of the intake air, g water per kg dry air

Where:

H_a may be derived from relative humidity measurement, dew point measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

(b) For Spark- ignition Engines:

$$k_{h.G} = 0{,}6272 + 44{,}030 \times 10^{-3} \times H_a - 0{,}862 \times 10^{-3} \times H_a^2$$

Where:

Ha is Humidity of Intake Air in g of water per kg of Dry Air.

5.4. Calculation of the emission mass flow rates

The emission mass flow rate (g/h) for each mode shall be calculated as follows. For the calculation of NOx, the humidity correction factor $k_{h,D}$, or $k_{h,G}$, as applicable, as determined according to section 5.3 of this chapter, shall be used.

The measured concentration shall be converted to a wet basis according to section 5.2 of this chapter if not already measured on a wet basis. Values for u_{gas} are given in Table 5 of this chapter for selected components based on ideal gas properties and the fuels relevant for this part.

(a) for the raw exhaust gas4

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

where:

u_{gas} = ratio between density of exhaust component and density of exhaust gas

c_{gas} = concentration of the respective component in the raw exhaust gas, ppm

q_{mew} = exhaust mass flow rate, kg/h

(b) for diluted gas

$$m_{gas} = u_{gas} \times c_{gas,c} \times q_{mdew}$$

where

u_{gas} = ratio between density of exhaust component and density of air

$c_{gas,c}$ = background corrected concentration of the respective component in the diluted exhaust gas, ppm

q_{mdew} = diluted exhaust mass flow rate, kg/h

where:

$$c_{gas,c} = c - c_d \times \left[1 - \frac{1}{D} \right]$$

The dilution factor D shall be calculated according to section 5.4.1 of appendix 2 of this chapter.

5.5 Calculation of the specific emissions

The emissions (g/kWh) shall be calculated for all individual components in the following way: where:

$$GAS_s = \frac{\sum_{i=1}^{i=n}(m_{Gas} \times W_{Fi})}{\sum_{i=1}^{i=n}(P(n)_i \times W_{Fi})}$$

m_{gas} is the mass of individual gas

P_n is the net power determined according to chapter II of this part.

The weighting factors used in the above calculation are according to section 2.7.1.of this chapter

Table 5

Values of u_{gas} in the raw and dilute exhaust gas for various exhaust components

Fuel		NO_x	CO	THC/NMHC	CO_2	CH_4
Diesel	Exhaust raw	0,001587	0,000966	0,000479	0,001518	0,000553
	Exhaust dilute	0,001588	0,000967	0,000480	0,001519	0,000553
Ethanol	Exhaust raw	0,001609	0,000980	0,000805	0,001539	0,000561
	Exhaust dilute	0,001588	0,000967	0,000795	0,001519	0,000553
CNG	Exhaust raw	0,001622	0,000987	0,000523	0,001552	0,000565
	Exhaust dilute	0,001588	0,000967	0,000584	0,001519	0,000553
Propane	Exhaust raw	0,001603	0,000976	0,000511	0,001533	0,000559
	Exhaust dilute	0,001588	0,000967	0,000507	0,001519	0,000553
Butane	Exhaust raw	0,001600	0,000974	0,000505	0,001530	0,000558
	Exhaust dilute	0,001588	0,000967	0,000501	0,001519	0,000553

Notes:
— u values of raw exhaust based on ideal gas properties at λ = 2, dry air, 273 K, 101,3 kPa
— u values of dilute exhaust based on ideal gas properties and density of air
— u values of CNG accurate within 0,2 % for mass composition of: C = 66 – 76 %; H = 22 – 25 %; N = 0 – 12 %
— u value of CNG for HC corresponds to $CH_{2,93}$ (for total HC use u value of CH_4).

5.6 Calculation of Area control values:

For the three control points selected according to section 2.7.6 of this chapter, the NO_X emission shall be measured and calculated according to section 5.6.1 of this chapter and also determined by interpolation from the modes of the test cycle closest to the respective control point according to section 5.6.2 of this chapter. The measured values are then compared to the interpolated values according to section 5.6.3 of this chapter.

5.6.1. Calculation of the Specific Emission

The NO_X emission for each of the control points (Z) shall be calculated as follows:

$$m_{NO_x},Z = 0,001587 \times c_{NO_x},Z \times k_{h,D} \times q_{mew}$$

$$NOx_Z = \frac{m_{NOx,Z}}{P(n)_Z}$$

5.6.2. Determination of the Emission Value from the Test Cycle

The NO_X emission for each of the control points shall be interpolated from the four closest modes of the test cycle that envelop the selected control point Z as shown in Figure 4. For these modes (R, S, T, U), the following definitions apply:

Speed(R) = Speed (T) = n_{RT}
Speed (S) = Speed (U) = n_{SU}
Per cent load(R) = Per cent load (S)
Per cent load (T) = Per cent load (U).

The NOx emission of the selected control point Z shall be calculated as follows:

$$Ez = \frac{E_{RS} + (E_{TU} - E_{RS}) \times (M_Z - M_{RS})}{M_{TU} - M_{RS}}$$

and:

$$E_{TU} = \frac{E_T + (E_{TU} - E_T) \times (n_Z - n_{RT})}{n_{SU} - n_{RT}}$$

$$E_{RS} = \frac{E_R + (E_S - E_R) \times (n_Z - n_{RT})}{n_{SU} - n_{RT}}$$

$$M_{TU} = \frac{M_T + (M_U - M_T) \times (n_Z - n_{RT})}{n_{SU} - n_{RT}}$$

$$M_{RS} = \frac{M_R + (M_S - M_R) \times (n_Z - n_{RT})}{n_{SU} - n_{RT}}$$

where:

ER, ES, ET, EU = specific NOx emission of the enveloping modes calculated in accordance with section 5.6.1 of this chapter.

MR, MS, MT, MU = engine torque of the enveloping modes.

Figure 4
Interpolation of NO$_X$ Control Point
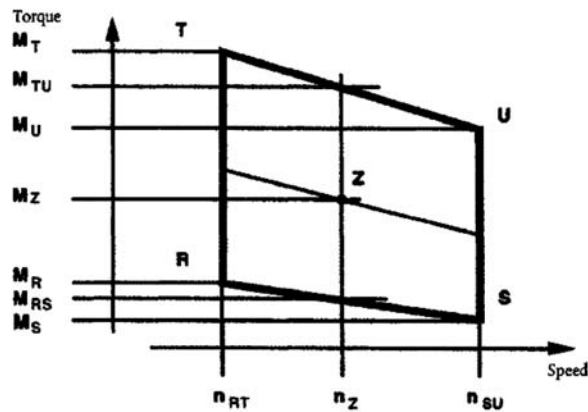
5.6.3. Comparison of NOx Emission Values

The measured specific NOx emission of the control point Z (NOx,Z) is compared to the interpolated value (EZ) as follows:

$$NOx_{diff} = 100 \times \frac{NOx_Z - E_Z}{E_Z}$$

6 CALCULATION OF THE PARTICULATE EMISSIONS

6.1 Data evaluation

For the evaluation of the particulates, the total sample masses (m_{sep}) through the filters shall be recorded for each mode.

The filters shall be returned to the weighing chamber and conditioned for at least one hour, but not more than 80 hours, and then weighed. The gross weight of the filters shall be recorded and the tare weight (see section 1 of this appendix) subtracted, which results in the particulate sample mass m_f.

If background correction is to be applied, the dilution air mass (m_d) through the filters and the particulate mass ($m_{f,d}$) shall be recorded. If more than one measurement was made, the quotient $m_{f,d}/m_d$ must be calculated for each single measurement and the values averaged.

6.2 Partial flow Dilution system

The final reported test results of the particulate emission shall be determined through the following steps. Since various types of dilution rate control may be used, different calculation methods for q_{medf} apply. All calculations shall be based upon the average values of the individual modes during the sampling period.
6.2.1. Isokinetic Systems

$$q_{medf} = q_{mew} \times r_d$$

$$r_d = \frac{q_{mdw} + \left(q_{mew} \times r_a\right)}{q_{mew} \times r_a}$$

where r_a corresponds to the ratio of the cross sectional areas of the isokinetic probe and the exhaust pipe:

$$r_a = \frac{A_p}{A_T}$$

6.2.2. Systems with Measurement of CO_2 or NO_X Concentration

$$q_{medf} = q_{mew} \times r_d$$

$$r_d = \frac{c_{wE} - c_{wA}}{c_{wD} - c_{wA}}$$

where:

c_{wE} = wet concentration of the tracer gas in the raw exhaust

c_{wD} = wet concentration of the tracer gas in the diluted exhaust

c_{wA} = wet concentration of the tracer gas in the dilution air

Concentrations measured on a dry basis shall be converted to a wet basis according to section 5.2 of this appendix.

6.2.3. Systems with CO_2 Measurement and Carbon Balance Method (*):

$$q_{medf} = \frac{206,5 \times q_{mf}}{c_{(CO_2)D} - c_{(CO_2)A}}$$

where:

$c_{(CO2)D}$ = CO_2 concentration of the diluted exhaust

$c_{(CO2)A}$ = CO_2 concentration of the dilution air

(concentrations in vol % on wet basis)

This equation is based upon the carbon balance assumption (carbon atoms supplied to the engine are emitted as CO_2) and determined through the following steps:

$$q_{medf} = q_{mew} \times r_d$$

(*) – The value is only valid for the reference fuel specified in chapter IV of this part

and

$$r_d = \frac{206,5 \times q_{mf}}{q_{mew} \times \left[c_{(CO_2)D} - c_{(CO_2)A}\right]}$$

6.2.4 Systems with Flow Measurement:

$$q_{medf} = q_{mew} \times r_d$$

$$r_d = \frac{q_{mdew}}{q_{mdew} - q_{mdw}}$$

6.3 Full Flow Dilution System

All calculations shall be based upon the average values of the individual modes during the sampling period. The diluted exhaust gas flow q_{mdew} shall be determined in accordance with section 4.1 of appendix 2 of this chapter. The total sample mass m_{sep} shall be calculated in accordance with section 6.2.1 of appendix 2 of this chapter.

6.4. Calculation of the Particulate Mass Flow Rate

The particulate mass flow rate shall be calculated as follows. If a full flow dilution system is used, q_{medf} as determined according to section 6.2 of this appendix shall be replaced with q_{mdew} as determined according to section 6.3 of this appendix.

$$PT_{mass} = \frac{m_f}{m_{sep}} \times \frac{q_{medf}}{1000}$$

$$\overline{q_{medf}} = \sum_{i=1}^{i=n} q_{medfi} \times W_{fi}$$

$$m_{sep} = \sum_{i=1}^{i=n} m_{sepi}$$

i = 1, … n

The particulate mass flow rate may be background corrected as follows:

$$PT_{mass} = \left\{ \frac{m_f}{m_{sep}} - \left[\frac{m_{f,d}}{m_d} \times \sum_{i=1}^{i=n} \left(1 - \frac{1}{Di} \right) \times W_{f_i} \right] \right\} \times \frac{\overline{q_{medf}}}{1000}$$

where D shall be calculated in accordance with section 5.4.1 of appendix 2 of this chapter.

6.5 Calculation of the Specific Emission

The particulate emission shall be calculated in the following way:

$$\overline{PT} = \frac{PT_{mass}}{\sum P(n)i \times WF_i}$$

6.6 Effective Weighting Factor

The effective weighting factor WFE,i for each mode shall be calculated in the following way:

$$WFE,I = \frac{\overline{m_{sep,i} \times q_{medf}}}{m_{sep} \times q_{medf,I}}$$

The value of the effective weighting factors shall be within ± 0,003 (± 0,005 for the idle mode) of the weighting factors listed in section 2.7.1 of this appendix.

7 Calculation of Smoke values

7.1 Bessel Algorithm

The Bessel algorithm shall be used to compute the 1 s average values from the instantaneous smoke readings, converted in accordance with section 7.3.1 of this appendix. The algorithm emulates a low pass second order filter, and its use requires iterative calculations to determine the coefficients. These coefficients are a function of the response time of the opacimeter system and the sampling rate. Therefore, section 7.1.1 of this appendix must be repeated whenever the system response time and/or sampling rate changes.

7.1.1. Calculation of Filter Response Time and Bessel Constants

The required Bessel response time (t_F) is a function of the physical and electrical response times of the opacimeter system, as specified in chapter III, appendix 4, section 5.2.4 of this part, and shall be calculated by the following equation:

$$t_F = \sqrt{1-(t_p^2 + t_e^2)}$$

where:

t_p = physical response time, s

t_e = electrical response time, s

The calculations for estimating the filter cut-off frequency (fc) are based on a step input 0 to 1 in < = 0,01 s (see chapter VI of this part). The response time is defined as the time between when the Bessel output reaches 10 % (t_{10}) and when it reaches 90 % (t_{90}) of this step function. This must be obtained by iterating on fc until $t_{90}-t_{10} \approx t_F$. The first iteration for fc is given by the following formula:

$$f_c = \Pi/(10 \times t_F)$$

The Bessel constants E and K shall be calculated by the following equations:

$$E = \frac{1}{1 + \Omega \times \sqrt{3 \times D} + D \times \Omega^2}$$

$$K = 2 \times E \times (D \times \Omega^2 - 1) - 1$$

where:

D = 0,618034

Δ t = 1/sampling rate

Ω = 1/[tan (Π x Δ t * fc)]

7.1.2 Calculation of the Bessel Algorithm

Using the values of E and K, the 1 s Bessel averaged response to a step input Si shall be calculated as follows:

$Y_i = Y_{i-1} + E \times (S_{i+2} \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + K \times (Y_{i-1} - Y_{i-2})$
where:
$S_{i-2} = S_{i-1} = 0$
$S_i = 1$
$Y_{i-2} = Y_{i-1} = 0$

The times t10 and t90 shall be interpolated. The difference in time between t_{90} and t_{10} defines the response time t_F for that value of f_c. If this response time is not close enough to the required response time, iteration shall be continued until the actual response time is within 1 % of the required response as follows:

$$\left| (t_{90} - t_{10}) - t_F \right| \le 0.01 \text{ x } t_F$$

7.2 Data Evaluation

The smoke measurement values shall be sampled with a minimum rate of 20 Hz.

7.3 Determination of Smoke

7.3.1 Data Conversion

Since the basic measurement unit of all opacimeters is transmittance, the smoke values shall be converted from transmittance (τ) to the light absorption coefficient (k) as follows:

$$k = -\frac{1}{L_A} \times \ln\left(1 - \frac{N}{100}\right)$$

and

$$N = 100 - \tau$$

where:

k = light absorption coefficient, m^{-1}
L_A = effective optical path length, as submitted by instrument manufacturer, m
N = opacity, %
τ = transmittance, %

The conversion shall be applied, before any further data processing is made.

7.3.2 Calculation of Bessel Averaged Smoke

The proper cut-off frequency f_c is the one that produces the required filter response time t_F. Once this frequency has been determined through the iterative process of section 7.1.1 of this appendix, the proper Bessel algorithm constants E and K shall be calculated. The Bessel algorithm shall then be applied to the instantaneous smoke trace (k-value), as described in section 7.1.2 of this appendix:

$$Y_i = Y_{i-1} + E \times (S_{i+2} \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + K \times (Y_{i-1} - Y_{i-2})$$

The Bessel algorithm is recursive in nature. Thus, it needs some initial input values of S_{i-1} and S_{i-2} and initial output values Y_{i-1} and Y_{i-2} to get the algorithm started. These may be assumed to be 0.

For each load step of the three speeds A, B and C, the maximum 1s value Y_{max} shall be selected from the individual Y_i values of each smoke trace.

7.3.3 Final Result

The mean smoke values (SV) from each cycle (test speed) shall be calculated as follows:

For test speed A: $SVA = (Y_{max1,A} + Y_{max2,A} + Y_{max3,A}) / 3$

For test speed B: $SVB = (Y_{max1,B} + Y_{max2,B} + Y_{max3,B}) / 3$

For test speed C: $SVC = (Y_{max1,C} + Y_{max2,C} + Y_{max3,C}) / 3$

where:

Y_{max1}, Y_{max2}, Y_{max3} = highest 1 s Bessel averaged smoke value at each of the three load steps

The final value shall be calculated as follows:

$$SV = (0,43 * SV_A) + (0,56 *SV_B) + (0,01 * SV_C)$$

Appendix 2:

ETC TEST CYCLE

1 ENGINE MAPPING PROCEDURE:

1.1 Determination of the Mapping Speed Range

For generating the ETC on the test cell, the engine needs to be mapped prior to the test cycle for determining the speed vs. torque curve. The minimum and maximum mapping speeds are defined as follows:

Minimum mapping speed =   idle speed

Maximum mapping speed = n_{hi} * 1,02 or speed where full load torque drops off to zero, whichever is lower

1.2 Performing the Engine Power Map

The engine shall be warmed up at maximum power in order to stabilise the engine parameters according to the recommendation of the manufacturer and good engineering practice. When the engine is stabilised, the engine map shall be performed as follows:

(a) the engine shall be unloaded and operated at idle speed;

(b) the engine shall be operated at full load setting of the injection pump at minimum mapping speed;

(c) 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 a least one point per second.

1.3 Mapping Curve Generation

All data points recorded under section 1.2 of this appendix shall be connected using linear interpolation between points. The resulting torque curve is the mapping curve and shall be used to convert the normalised torque values of the engine cycle into actual torque values for the test cycle, as described in section 2 of this appendix.

1.4 Alternate Mapping

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 section for reasons of safety or representativeness shall be approved by the test agency along with the justification for their use. In no case, however, shall descending continual sweeps of engine speed be used for governed or turbocharged engines.

1.5 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:

- an unreasonable amount of time has transpired since the last map, as determined by engineering judgments,

or,

- physical changes or recalibrations have been made to the engine which may potentially affect engine performance.

2 Generation of the Reference Test cycle

The transient test cycle is described in appendix 3 of this chapter. The normalised values for torque and speed shall be changed to the actual values, as follows, resulting in the reference cycle.

2.1 Actual Speed

The speed shall be unnormalised using the following equation:

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

The reference speed (nref) corresponds to the 100 % speed values specified in the engine dynamometer schedule of appendix 3 of this chapter. It is defined as follows (see Figure 1 of chapter I of this part):

$$n_{ref} = n_{lo} + 95\% \times (n_{hi} - n_{lo})$$

where n_{hi} and n_{lo} are either specified according to chapter I, section 2 of this part or determined according to chapter III, appendix 1, section 1.1 of this part.

2.2 Actual torque

The torque is normalised to the maximum torque at the respective speed. The torque values of the reference cycle shall be unnormalised, using the mapping curve determined according to section 1.3 of this appendix, as follows:

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

for the respective actual speed as determined in Section 2.1 of this appendix.

The negative torque values of the motoring points ("m") shall take on, for purposes of reference cycle generation, unnormalised values determined in either of the following ways:

- negative 40 % of the positive torque available at the associated speed point,

- mapping of the negative torque required to motor the engine from minimum to maximum mapping speed,

- determination of the negative torque required to motor the engine at idle and reference speeds and linear interpolation between these two points.

2.3 Example of the Unnormalisation Procedure

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

% speed = 43
% torque = 82

Given the following values:

reference speed = 2200 min-1
idle speed = 600 min-1
results in,

actual speed = (43 × (2 200 − 600)/100) + 600 = 1 288 min−1
actual torque = (82 × 700/100) = 574 Nm

where the maximum torque observed from the mapping curve at 1 288 min−1 is 700 Nm.

3 EMISSIONS TEST RUN:

At the manufacturers request, a dummy test may be run for conditioning of the engine and exhaust system before the measurement cycle.

NG and LPG fuelled engines shall be run-in using the ETC test. The engine shall be run over a minimum of two ETC cycles and until the CO emission measured over one ETC cycle does not exceed by more than 10 % the CO emission measured over the previous ETC cycle.

3.1 Preparation of the sampling filters (if applicable)

At least one hour before the test, each filter shall be placed in a partially covered petri dish, which is protected against dust contamination, and placed in a weighing chamber for stabilisation. At the end of the stabilisation period, each filter shall be weighed and the tare weight shall be recorded. The filter shall then be stored in a closed petri dish or sealed filter holder until needed for testing. The filter shall be used within eight hours of its removal from the weighing chamber. The tare weight shall be recorded.

3.2 Installation of the measuring equipment

The instrumentation and sample probes shall be installed as required. The tailpipe shall be connected to the full flow dilution system, if used.

3.3 Starting the dilution system and the engine

The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilised at maximum power according to the recommendation of the manufacturer and good engineering practice.

3.4 Starting the particulate sampling system (diesel engines only)

The particulate sampling system shall be started and running on by-pass. The particulate background level of the dilution air may be determined by passing dilution air through the particulate filters. If filtered dilution air is used, one measurement may be done prior to or after the test. If the dilution air is not

filtered, measurements at the beginning and at the end of the cycle may be done and the values averaged.

The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilised according to the recommendation of the manufacturer and good engineering practice.

In case of periodic regeneration after treatment, the regeneration shall not occur during the warm-up of the engine.

3.5 Adjustment of the dilution system

The flow rates of the dilution system (full flow or partial flow) shall be set to eliminate water condensation in the system, and to obtain a maximum filter face temperature of 325 K (52 °C) or less (see section 2.3.1 of chapter V, DT of this part).

3.6 Checking the analysers

The emission analysers shall be set at zero and spanned. If sample bags are used, they shall be evacuated.

3.7 Engine starting procedure

The stabilised engine shall be started according to the manufacturer's recommended starting procedure in the owner's manual, using either a production starter motor or the dynamometer. Optionally, the test may start directly from the engine preconditioning phase without shutting the engine off, when the engine has reached the idle speed.

3.8 Test cycle

3.8.1 Test sequence

The test sequence shall be started, if the engine has reached idle speed. The test shall be performed according to the reference cycle as set out in section 2 of this appendix. Engine speed and torque command set points shall be issued at 5

Hz (10 Hz recommended) or greater. Feedback engine speed and torque shall be recorded at least once every second during the test cycle, and the signals may be electronically filtered.

3.8.2 Gaseous emissions measurement

3.8.2.1 Full flow dilution system

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, the measuring equipment shall be started, simultaneously:

- start collecting or analysing dilution air,

- start collecting or analysing diluted exhaust gas,

- start measuring the amount of diluted exhaust gas (CVS) and the required temperatures and pressures,

- start recording the feedback data of speed and torque of the dynamometer.

HC and NOx shall be measured continuously in the dilution tunnel with a frequency of 2 Hz. The average concentrations shall be determined by integrating the analyzer signals over the test cycle. The system response time shall be no greater than 20 s, and shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary. CO, CO2, NMHC and CH4 shall be determined by integration or by analysing the concentrations in the sample bag, collected over the cycle. The concentrations of the gaseous pollutants in the dilution air shall be determined by integration or by collecting into the background bag. All other values shall be recorded with a minimum of one measurement per second (1 Hz).

3.8.2.2 Raw exhaust measurement

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, the measuring equipment shall be started, simultaneously:

- start analysing the raw exhaust gas concentrations,

- start measuring the exhaust gas or intake air and fuel flow rate,

- start recording the feedback data of speed and torque of the dynamometer.

For the evaluation of the gaseous emissions, the emission concentrations (HC, CO and NOx) and the exhaust gas mass flow rate shall be recorded and stored with at least 2 Hz on a computer system. The system response time shall be no greater than 10 s. All other data may be recorded with a sample rate of at least 1 Hz. For analogue analysers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

For calculation of the mass emission of the gaseous components the traces of the recorded concentrations and the trace of the exhaust gas mass flow rate shall be time aligned by the transformation time as defined in section 2 of chapter I of this part. Therefore, the response time of each gaseous emissions analyser and of the exhaust gas mass flow system shall be determined according to the provisions of section 4.2.1 and section 1.5 of appendix 5 to this chapter and recorded.

3.8.3 Particulate sampling (if applicable)

3.8.3.1 Full flow dilution system

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, the particulate sampling system shall be switched from by-pass to collecting particulates.

If no flow compensation is used, the sample pump(s) shall be adjusted so that the flow rate through the particulate sample probe or transfer tube is maintained at a value within ± 5 % of the set flow rate. If flow compensation (i.e., proportional control of sample flow) is used, it must be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ± 5 % of its set value (except for the first 10 seconds of sampling).

Note: For double dilution operation, sample flow is the net difference between the flow rate through the sample filters and the secondary dilution airflow rate.

The average temperature and pressure at the gas meter(s) or flow instrumentation inlet shall be recorded. If the set flow rate cannot be maintained over the complete cycle (within ± 5 %) because of high particulate loading on the filter, the test shall be voided. The test shall be rerun using a lower flow rate and/or a larger diameter filter.

3.8.3.2 Partial flow dilution system

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, the particulate sampling system shall be switched from by-pass to collecting particulates.

For the control of a partial flow dilution system, a fast system response is required. The transformation time for the system shall be determined by the procedure in section 3.3 of appendix 5 to chapter III of this part. If the combined transformation time of the exhaust flow measurement (see section 4.2.1 of this appendix) and the partial flow system is less than 0,3 sec, online control may be used. If the transformation time exceeds 0,3 sec, look ahead control based on a pre- recorded test run must be used. In this case, the rise time shall be ≤ 1 sec and the delay time of the combination ≤ 10 sec.

The total system response shall be designed as to ensure a representative sample of the particulates, $q_{mp,i}$, proportional to the exhaust mass flow. To determine the proportionality, a regression analysis of $q_{mp,i}$ versus $q_{mew,i}$ shall be conducted on a minimum 1 Hz data acquisition rate, and the following criteria shall be met:

   - The correlation coefficient R^2 of the linear regression between $q_{mp,i}$ and $q_{mew,i}$ shall not be less than 0,95,

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

   - q_{mp} intercept of the regression line shall not exceed $\pm$ 2 % of q_{mp} maximum.

Optionally, a pretest may be run, and the exhaust mass flow signal of the pretest be used for controlling the sample flow into the particulate system (look-ahead control). Such a procedure is required if the transformation time of the particulate system, $t_{50,P}$ or the transformation time of the exhaust mass flow signal, $t_{50,F}$, or both, are > 0,3 sec. A correct control of the partial dilution system is obtained, if the time trace of $q_{mew,pre}$ of the pretest, 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). That is, the time shift between q_{mew} and q_{mp} is the difference in their transformation times that were determined in section 3.3 of appendix 5 to chapter III of this part.

3.8.4 Engine stalling

If the engine stalls anywhere during the test cycle, the engine shall be preconditioned and restarted, and the test repeated. If a malfunction occurs in any of the required test equipment during the test cycle, the test shall be voided.

3.8.5 Operations after test

At the completion of the test, the measurement of the diluted exhaust gas volume or raw exhaust gas flow rate, the gas flow into the collecting bags and the particulate sample pump shall be stopped. For an integrating analyser system, sampling shall continue until system response times have elapsed.

The concentrations of the collecting bags, if used, shall be analysed as soon as possible and in any case not later than 20 minutes after the end of the test cycle.

After the emission test, a zero gas and the same span gas shall be used for re-checking the analysers. The test will be considered acceptable if the difference between the pre-test and post-test results is less than 2 % of the span gas value.

3.9 Verification of the test run

3.9.1 Data shift

To minimise the biasing effect of the time lag between the feedback and reference cycle values, the entire engine speed and torque feedback signal sequence may be advanced or delayed in time with respect to the reference speed and torque sequence. If the feedback signals are shifted, both speed and torque must be shifted the same amount in the same direction.

3.9.2 Calculation of the cycle work

The actual cycle work W_{act} (kWh) shall be calculated using each pair of engine feedback speed and torque values recorded. This shall be done after any feedback data shift has occurred, if this option is selected. 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 sections 4.4 and 5.2). The same methodology shall be used for integrating both reference and actual engine power. If values are to be determined between adjacent reference or adjacent measured values, linear interpolation shall be used.

In integrating the reference and actual cycle work, all negative torque values shall be set equal to zero and included. If integration is performed at a frequency of less than 5 Hertz, and if, during a given time segment, the torque value changes from positive to negative or negative to positive, the negative portion

shall be computed and set equal to zero. The positive portion shall be included in the integrated value.

W_{act} shall be between - 15 % and + 5 % of W_{ref}

3.9.3. Validation statistics of the test cycle

Linear regressions of the feedback values on the reference values shall be performed for speed, torque and power. This shall be done after any feedback data shift has occurred, if this option is selected. The method of least squares shall be used, with the best fit equation having the form:

$$y = mx + b$$

where:
y = Feedback (actual) value of speed (min-1), torque (Nm), or power (kW)
m = slope of the regression line
x = reference value of speed (min-1), torque (Nm), or power (kW)
b = y intercept of the regression line

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

It is recommended that this analysis be performed at 1 Hertz. All negative reference torque values and the associated feedback values shall be deleted from the calculation of cycle torque and power validation statistics. For a test to be considered valid, the criteria of table 6 must be met.

Table 6

Regression line tolerances

	Speed	Torque	Power
Standard error of estimate (SE) of Y on X	Max 100 min^{-1}	Max 13 % (15 %) (*) of power map maximum engine torque	Max 8 % (15 %) (*) of power map maximum engine power
Slope of the regression line, m	0,95 to 1,03	0,83–1,03	0,89–1,03 (0,83–1,03) (*)
Coefficient of determination, r^2	min 0,9700 (min 0,9500) (*)	min 0,8800 (min 0,7500) (*)	min 0,9100 (min 0,7500) (*)
Y intercept of the regression line, b	± 50 min^{-1}	± 20 Nm or ± 2 % (± 20 Nm or ± 3 %) (*) of max torque whichever is greater	± 4 kW or ± 2 % (± 4 kW or ± 3 %) (*) of max power which-ever is greater

(*) Until 31st March, 2011 the figure shown in brackets may be used for the type-approval testing of gas engines.

Point deletions from the regression analyses are permitted where noted in Table 7.

Permitted point deletions from regression analysis

Conditions	Points to be deleted
Full load demand and torque feedback < 95 % torque reference	Torque and/or power
Full load demand and speed feedback < 95 % speed reference	Speed and/or power
No load, not an idle point, and torque feedback > torque reference	Torque and/or power
No load, speed feedback ≤ idle speed + 50 min⁻¹ and torque feedback = manufacturer defined/measured idle torque ± 2 % of max. torque	Speed and/or power
No load, speed feedback > idle speed + 50 min⁻¹ and torque feedback > 105 % torque reference	Torque and/or power
No load and speed feedback > 105 % speed reference	Speed and/or power'

Table 7

4 CALCULATION OF THE EXHAUST GAS FLOW

4.1 Determination of the diluted exhaust gas flow

The total diluted exhaust gas flow over the cycle (kg/test) shall be calculated from the measurement values over the cycle and the corresponding calibration data of the flow measurement device (V_0 for PDP, K_V for CFV, C_d for SSV), as determined in section 2 of appendix 5 to chapter III of this part. The following formulae shall be applied, if the temperature of the diluted exhaust is kept constant over the cycle by using a heat exchanger (± 6 K for a PDP-CVS, ± 11 K for a CFV-CVS or ± 11 K for a SSV-CVS), see section 2.3 of chapter V of this part.

For the PDP-CVS system:

$$m_{ed} = 1,293 \times V_0 \times N_P \times (p_b - p_1) \times 273 / (101,3 \times T)$$

where:

V_0 = volume of gas pumped per revolution under test conditions, m^3/rev
N_P = total revolutions of pump per test
p_b = atmospheric pressure in the test cell, kPa
p_1 = pressure depression below atmospheric at pump inlet, kPa
T = average temperature of the diluted exhaust gas at pump inlet over the cycle, K

For the CFV-CVS system:

$$m_{ed} = 1,293 \times t \times K_v \times p_p / T^{0.5}$$
where:
t = cycle time, s

K_v = calibration coefficient of the critical flow venturi for standard conditions,

p_p = absolute pressure at venturi inlet, kPa

T = absolute temperature at venturi inlet, K

For the SSV-CVS system

m_{ed} = 1,293 × Q_{SSV}

where,

$$Q_{SSV} = A_0 d^2 C_d p_p \sqrt{\left[\frac{1}{T}\left(r_p^{1,4286} - r_p^{1,7143}\right) \times \left(\frac{1}{1 - r_D^4 r_p^{1,4286}}\right)\right]}$$

with:

A_0 = collection of constants and units conversions

$$\left(\frac{m^3}{min}\right)\left(\frac{K^{\frac{1}{2}}}{kPa}\right)\left(\frac{1}{mm^2}\right)$$

= 0,006111 in SI units of

d = diameter of the SSV throat, m

C_d = discharge coefficient of the SSV

p_p = absolute pressure at venturi inlet, kPa

T = temperature at the venturi inlet, K

r_p = ratio of the SSV throat to inlet absolute, static pressure $=1 - \dfrac{\Delta P}{P_A}$

r_D = ratio of the SSV throat diameter, d, to the inlet pipe inner diameter = d/ D

If a system with flow compensation is used (i.e. without heat exchanger), the instantaneous mass emissions shall be calculated and integrated over the cycle. In this case, the instantaneous mass of the diluted exhaust gas shall be calculated as follows.

For the PDP-CVS system:

$m_{ed,i}$ = 1,293 × V_0 × $N_{P,i}$ × $(p_b - p_1)$ × 273 / (101,3 × T),

where

$N_{P,i}$ = total revolutions of pump per time interval

For the CFV-CVS system:

$m_{ed,i}$ = 1,293 × Δ_{ti} × K_V × p_p / $T^{0,5}$

where:

Δ_{ti} = time interval, s

For the SSV-CVS system:

m_{ed} = 1,293 × Q_{SSV} × Δ_{ti}
where:
Δ_{ti} = time interval, s

The real time calculation shall be initialised with either a reasonable value for C_d, such as 0,98, or a reasonable value of Q_{ssv}. If the calculation is initialised with Q_{ssv}, the initial value of Q_{ssv} shall be used to evaluate Re.

During all emissions tests, the Reynolds number at the SSV throat must be in the range of Reynolds numbers used to derive the calibration curve developed in section 2.4 of appendix 5 of this Chapter.

4.2 Determination of raw exhaust gas mass flow

For calculation of the emissions in the raw exhaust gas and for controlling of a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For the determination of the exhaust mass flow rate, either of the methods described in sections 4.2.2 to 4.2.5 of this appendix may be used.

4.2.1 Response time

For the purpose of emissions calculation, the response time of either method described below shall be equal to or less than the requirement for the analyzer response time, as defined in section 1.5 of appendix 5 of this Chapter.

For the purpose of controlling of a partial flow dilution system, a faster response is required. For partial flow dilution systems with online control, a response time of ≤ 0,3 seconds is required. For partial flow dilution systems with look ahead control based on a pre-recorded test run, a response time of the exhaust flow measurement system of ≤ 5 seconds with a rise time of ≤ 1 second is required. The system response time shall be specified by the instrument manufacturer. The combined response time requirements for exhaust gas flow and partial flow dilution system are indicated in section 3.8.3.2. of this appendix.

4.2.2 Direct measurement method

Direct measurement of the instantaneous exhaust flow may be done by systems such as:

       - pressure differential devices, like flow nozzle,
       - ultrasonic flowmeter,
       - vortex flowmeter.

Precautions shall be taken to avoid measurement errors which will impact emission value errors. Such precautions include the careful installation of the device in the engine exhaust system according to the instrument manufacturers' recommendations and to good engineering practice. Engine performance and emissions shall especially not be affected by the installation of the device.

The accuracy of exhaust flow determination shall be at least ± 2,5 % of reading or ± 1,5 % of engine's maximum value, whichever is the greater.

4.2.3 Air and fuel measurement method

This involves measurement of the air flow and the fuel flow. Air flow meters and fuel flow meters shall be used that meet the total exhaust flow accuracy requirement of section 4.2.2 of this appendix. The calculation of the exhaust gas flow is as follows:

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

4.2.4 Tracer measurement method

This involves measurement of the concentration of a tracer gas in the exhaust. A known amount of an inert gas (e.g. pure helium) shall be injected into the exhaust gas flow as a tracer. The gas is mixed and diluted by the exhaust gas, but shall not react in the exhaust pipe. The concentration of the gas shall then be measured in the exhaust gas sample.

In order to ensure complete mixing of the tracer gas, the exhaust gas sampling probe shall be located at least 1 m or 30 times the diameter of the exhaust pipe, whichever is larger, downstream of the tracer gas injection point. The sampling probe may be located closer to the injection point if complete mixing is verified by comparing the tracer gas concentration with the reference concentration when the tracer gas is injected upstream of the engine.

The tracer gas flow rate shall be set so that the tracer gas concentration at engine idle speed after mixing becomes lower than the full scale of the trace gas analyser.

The calculation of the exhaust gas flow is as follows:

$$q_{mew,i} = \frac{q_{vt} \times \rho_e}{60 \times (c_{mix,i} - c_a)}$$

where:

$q_{mew,i}$ = instantaneous exhaust mass flow, kg/s

q_{vt} = tracer gas flow, cm^3/min

$c_{mix.i}$ = instantaneous concentration of the tracer gas after mixing, ppm

ρ_e = density of the exhaust gas, kg/m^3 (Refer Table 6, Page 98 of 2005/55/EC)

c_a = background concentration of the tracer gas in the intake air, ppm

When the background concentration is less than 1 % of the concentration of the tracer gas after mixing ($c_{mix.i}$) at maximum exhaust flow, the background concentration may be neglected.

The total system shall meet the accuracy specifications for the exhaust gas flow, and shall be calibrated according to section 1.7 of appendix 5 of this Chapter.

4.2.5 Air flow and air-to-fuel ratio measurement method

This involves exhaust mass calculation from the airflow and the air to fuel ratio. The calculation of the instantaneous exhaust gas mass flow is as follows:

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

with:

$$A/F_a = \frac{138,0 \times \left(\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right)}{12,011 \times \beta + 1,00794 \times \alpha + 15,9994 \times \varepsilon + 14,0067 \times \delta + 32,065 \times \gamma}$$

$$\lambda_i = \frac{\beta \times \left(100 - \frac{c_{co} \times 10^{-4}}{2} - c_{HC} \times 10^{-4} \right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{CO} \times 10^{-4}}{3,5 \times c_{CO}}}{1 + \frac{c_{CO} \times 10^{-4}}{3,5 \times c_{CO2}}} - \frac{\varepsilon}{2} - \frac{\delta}{2} \right) \times \left(c_{CO2} + c_{CO} \times 10^{-4} \right)}{4,764 \times \left(\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right) \times \left(c_{CO2} + c_{CO} \times 10^{-4} + c_{HC} \times 10^{-4} \right)}$$

where:

A/F_{st} = stoichiometric air to fuel ratio, kg/kg

λ = excess air ratio

c_{CO2} = dry CO_2 concentration, %

c_{CO} = dry CO concentration, ppm

c_{HC} = HC concentration, ppm

Note: β can be 1 for fuels containing carbon and 0 for hydrogen fuel.

The air flowmeter shall meet the accuracy specifications of section 2.2 of appendix 4 of this chapter, the CO_2 analyser used shall meet the specifications of section 3.3.2 of appendix 4 of this chapter and the total system shall meet the accuracy specifications for the exhaust gas flow.

Optionally, air to fuel ratio measurement equipment such as a zirconia type sensor may be used for the measurement of the excess air ratio which meets the specifications of section 3.3.6 of appendix 4 of this chapter.

5 CALCULATION OF THE GASEOUS EMISSIONS:

5.1 Data evaluation

For the evaluation of the gaseous emissions in the diluted exhaust gas, the emission concentrations (HC, CO and NO_X) and the diluted exhaust gas mass flow rate shall be recorded according to section 3.8.2.1 of this appendix and stored on a computer system. For analogue analysers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

For the evaluation of the gaseous emissions in the raw exhaust gas, the emission concentrations (HC, CO and NO_X) and the exhaust gas mass flow rate shall be recorded according to section 3.8.2.2 of this appendix and stored on a computer system. For analogue analysers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

5.2 Dry/wet correction

If the concentration is measured on a dry basis, it shall be converted to a wet basis according to the following formula. For continuous measurement, the conversion shall be applied to each instantaneous measurement before any further calculation.

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

The conversion equations of section 5.2 of appendix 1 of this Chapter shall apply.

5.3 NO_X correction for humidity and temperature

As the NO_X emission depends on ambient air conditions, the NOx concentration shall be corrected for ambient air temperature and humidity with the factors given in section 5.3 of appendix 1 of this chapter. The factors are valid in the range between 0 and 25 g/kg dry air.

5.4 Calculation of the emission mass flow rates

The emission mass over the cycle (g/test) shall be calculated as follows depending on the measurement method applied. The measured concentration shall be converted to a wet basis according to section 5.2 of appendix 1 of this chapter, if not already measured on a wet basis. The respective values for u_{gas} shall be applied that are given in Table 5 of appendix 1 of this chapter for selected components based on ideal gas properties and the fuels relevant for this part.

(a) for the raw exhaust gas:

$$m_{gas} = u_{gas} \times \sum_{i=1}^{i=n} c_{gas,i} \times q_{mew,i} \times \frac{1}{f}$$

where:

u_{gas} = ratio between density of exhaust component and density of exhaust gas from table5 of this part.

$c_{gas,i}$ = instantaneous concentration of the respective component in the raw exhaust gas, ppm

$q_{mew,i}$ = instantaneous exhaust mass flow rate, kg/s

f = data sampling rate, Hz

n = number of measurements

(b) for the diluted exhaust gas without flow compensation:

$$m_{gas} = u_{gas} \times c_{gas} \times m_{ed}$$

where:

u_{gas} = ratio between density of exhaust component and density of air from table 5 of this part

c_{gas} = average background corrected concentration of the respective component, ppm

m_{ed} = total diluted exhaust mass over the cycle, kg

(c) for the diluted exhaust gas with flow compensation:

$$m_{gas} = \left[u_{gas} \times \sum_{i=1}^{i=n} \left(c_{e,i} \times q_{mdew,i} \times \frac{1}{f} \right) \right] - \left[\left(m_{ed} \times c_d \times (1 - 1/D) \times u_{gas} \right) \right]$$

where:

$c_{e,i}$ = instantaneous concentration of the respective component measured in the diluted exhaust gas, ppm

c_d = concentration of the respective component measured in the dilution air, ppm

$q_{mdew,i}$ = instantaneous diluted exhaust gas mass flow rate, kg/s

m_{ed} = total mass of diluted exhaust gas over the cycle, kg

u_{gas} = ratio between density of exhaust component and density of air from table 5 of this part

D = dilution factor (see section 5.4.1 of this appendix)

If applicable, the concentration of NMHC and CH4 shall be calculated by either of the methods shown in section 3.3.4 of appendix 4 of this chapter, as follows:

(a) GC method (full flow dilution system, only):

$c_{NMHC} = c_{HC} - c_{CH4}$

(b) NMC method:

$$c_{NMHC} = \frac{c_{HC(w/oCutter)} \times (1 - E_M) - c_{HC(w/Cutter)}}{E_E - E_M}$$

$$c_{CH_4} = \frac{c_{HC(w/Cutter)} - c_{HC(w/oCutter)} \times (1 - E_E)}{E_E - E_M}$$

c_{HC}(w/Cutter) = HC concentration with the sample gas flowing through the NMC

c_{HC}(w/o Cutter) = HC concentration with the sample gas bypassing the NMC

5.4.1 Determination of the background corrected concentrations (full flow dilution system, only)

The average background concentration of the gaseous pollutants in the dilution air shall be subtracted from measured concentrations to get the net concentrations of the pollutants. The average values of the background concentrations can be determined by the sample bag method or by continuous measurement with integration. The following formula shall be used.

$$c = c_e - c_d \times \left(1 - \frac{1}{D}\right)$$

where:

c_e = concentration of the respective pollutant measured in the diluted exhaust gas, ppm

c_d = concentration of the respective pollutant measured in the dilution air, ppm

D = dilution factor

The dilution factor shall be calculated as follows:

(a) for diesel and LPG fueled gas engines

$$D = \frac{F_s}{c_{CO_2} + (c_{HC} + c_{CO}) \times 10^{-4}}$$

(b) for NG fueled gas engines

$$D = \frac{F_s}{c_{CO_2} + (c_{NMHC} + c_{CO}) \times 10^{-4}}$$

where:

c_{CO2} = concentration of CO_2 in the diluted exhaust gas, % vol

c_{HC} = concentration of HC in the diluted exhaust gas, ppm C1

c_{NMHC} = concentration of NMHC in the diluted exhaust gas, ppm C1

c_{CO} = concentration of CO in the diluted exhaust gas, ppm

F_S = stoichiometric factor

Concentrations measured on dry basis shall be converted to a wet basis in accordance with section 5.2 of appendix 1 of this chapter.

The stoichiometric factor shall be calculated as follows:

$$F_S = 100 \times \frac{1}{1 + \frac{\alpha}{2} + 3,76 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2}\right)}$$

where:

α, ε are the molar ratios referring to a fuel $CH_\alpha O_\varepsilon$

Alternatively, if the fuel composition is not known, the following stoichiometric factors may be used:

F_S (diesel) = 13,4

F_S (LPG) = 11,6

F_S (NG) = 9,5

5.5 Calculation of the specific emissions

The emissions (g/kWh) shall be calculated in the following way:

(a) all components, except NOx:

$$M_{gas} = \frac{m_{gas}}{W_{act}}$$

(b) NOx:

$$M_{gas} = m_{gas} \times \frac{k_h}{W_{act}}$$

where:

W_{act} = actual cycle work as determined according to section 3.9.2 of this appendix.

5.5.1. In case of a periodic exhaust after treatment system, the emissions shall be weighted as follows:

$$\overline{M_{Gas}} = (n1 \times \overline{M_{Gas,n1}} + n2 \times \overline{M_{Gas,n2}})/(n1 + n2)$$

where:

n1 = number of ETC tests between two regenerations

n2 = number of ETC during a regeneration (minimum of one ETC test)

$M_{gas,n2}$ = emissions during a regeneration

$M_{gas,n1}$ = emissions after a regeneration.

6 CALCULATION OF THE PARTICULATE EMISSION (IF APPLICABLE)

6.1 Data evaluation

The particulate filter shall be returned to the weighing chamber no later than one hour after completion of the test. It shall be conditioned in a partially covered petri dish, which is protected against dust contamination, for at least one hour, but not more than 80 hours, and then weighed. The gross weight of the filters shall be recorded and the tare weight subtracted, which results in the particulate sample mass m_f. For the evaluation of the particulate concentration, the total sample mass (m_{sep}) through the filters over the test cycle shall be recorded.

If background correction is to be applied, the dilution air mass (m_d) through the filter and the particulate mass ($m_{f,d}$) shall be recorded.

6.2 Calculation of the mass flow

6.2.1 Full flow dilution system

The particulate mass (g/test) shall be calculated as follows:

$$m_{PT} = \frac{m_f}{m_{sep}} \times \frac{m_{ed}}{1000}$$

where:

m_f = particulate mass sampled over the cycle, mg

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters, kg

m_{ed} = mass of diluted exhaust gas over the cycle, kg

If a double dilution system is used, the mass of the secondary dilution air shall be subtracted from the total mass of the double diluted exhaust gas sampled through the particulate filters.

$$m_{sep} = m_{set} - m_{ssd}$$

where:

m_{set} = mass of double diluted exhaust gas through particulate filter, kg

m_{ssd} = mass of secondary dilution air, kg

If the particulate background level of the dilution air is determined in accordance with section 3.4 of this appendix, the particulate mass may be background corrected. In this case, the particulate mass (g/test) shall be calculated as follows:

$$m_{PT} = \left[\frac{m_f}{m_{sep}} - \left(\frac{m_{f,d}}{m_d} \times \left(1 - \frac{1}{D} \right) \right) \right] \times \frac{m_{ed}}{1000}$$

where,

m_{PT}, m_{sep}, m_{ed} = see above

m_d = mass of primary dilution air sampled by background particulate sampler, kg

$m_{f,d}$ = mass of the collected background particulates of the primary dilution air, mg

D = dilution factor as determined in section 5.4.1 of this appendix.

6.2.2. Partial flow dilution system

The mass of particulates (g/test) shall be calculated by either of the following methods:

(a)
$$m_{PT} = \frac{m_f}{m_{sep}} \times \frac{m_{edf}}{1000}$$

where,

m_f = particulate mass sampled over the cycle, mg

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters, kg

m_{edf} = mass of equivalent diluted exhaust gas over the cycle, kg

The total mass of equivalent diluted exhaust gas mass over the cycle shall be determined as follows:

The total mass of equivalent diluted exhaust gas mass over the cycle shall be determined as follows:

$$m_{edf} = \sum_{i=1}^{i=n} q_{medf,i} \times \frac{1}{f}$$

$$q_{medf,i} = q_{mew,i} \times r_{d,i}$$

$$r_{d,i} = \frac{q_{mdew,,i}}{\left(q_{mdew,,i} - q_{mdw,,i} \right)}$$

where:

$q_{medf,i}$ = instantaneous equivalent diluted exhaust mass flow rate, kg/s

$q_{mew,i}$ = instantaneous exhaust mass flow rate, kg/s

$r_{d,i}$ = instantaneous dilution ratio

$q_{mdew,i}$ = instantaneous diluted exhaust mass flow rate through dilution tunnel, kg/s

$q_{mdw,i}$ = instantaneous dilution air mass flow rate, kg/s

f = data sampling rate, Hz

n = number of measurements

(b)

$$m_{PT} = \frac{m_f}{r_s \times 1000}$$

where,

m_f = particulate mass sampled over the cycle, mg

r_s = average sample ratio over the test cycle

with:

$$r_s = \frac{m_{se}}{m_{ew}} \times \frac{\dot{m}_{sep}}{m_{sed}}$$

where:

m_{se} = sample mass over the cycle, kg

m_{ew} = total exhaust mass flow over the cycle, kg

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters, kg

m_{sed} = mass of diluted exhaust gas passing the dilution tunnel, kg.

Note: In case of the total sampling type system, msep and Msed are identical.

6.3 Calculation of the Specific Emission

The particulate emission (g/kWh) shall be calculated in the following way:

$$M_{PT} = \frac{m_{PT}}{W_{act}}$$

where:

W_{act} = actual cycle work as determined according to section 3.9.2 of this appendix, kWh.

6.3.1. In case of a periodic regeneration after treatment system, the emissions shall be weighted as follows:

$$\overline{PT} = (n1 \times \overline{PT_{n1}} + n2 \times \overline{PT_{n2}}) / (n1 + n2)$$

where:

n1 = number of ETC tests between two regeneration events

n2 = number of ETC tests during a regeneration (minimum of one ETC)

$\overline{PT_{n2}}$ = emissions during a regeneration

$\overline{PT_{n1}}$ = emissions outside a regeneration."

ETC ENGINE DYNAMOMETER SCHEDULE

ETC ENGINE DYNAMOMETER SCHEDULE

Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %
1	0	0	63	28,5	20,9	125	65,3	'm'
2	0	0	64	32	73,9	126	64	'm'
3	0	0	65	4	82,3	127	59,7	'm'
4	0	0	66	34,5	80,4	128	52,8	'm'
5	0	0	67	64,1	86	129	45,9	'm'
6	0	0	68	58	0	130	38,7	'm'
7	0	0	69	50,3	83,4	131	32,4	'm'
8	0	0	70	66,4	99,1	132	27	'm'
9	0	0	71	81,4	99,6	133	21,7	'm'
10	0	0	72	88,7	73,4	134	19,1	0,4
11	0	0	73	52,5	0	135	34,7	14
12	0	0	74	46,4	58,5	136	16,4	48,6
13	0	0	75	48,6	90,9	137	0	11,2
14	0	0	76	55,2	99,4	138	1,2	2,1
15	0	0	77	62,3	99	139	30,1	19,3
16	0,1	1,5	78	68,4	91,5	140	30	73,9
17	23,1	21,5	79	74,5	73,7	141	54,4	74,4
18	12,6	28,5	80	38	0	142	77,2	55,6
19	21,8	71	81	41,8	89,6	143	58,1	0
20	19,7	76,8	82	47,1	99,2	144	45	82,1
21	54,6	80,9	83	52,5	99,8	145	68,7	98,1
22	71,3	4,9	84	56,9	80,8	146	85,7	67,2
23	55,9	18,1	85	58,3	11,8	147	60,2	0
24	72	85,4	86	56,2	'm'	148	59,4	98
25	86,7	61,8	87	52	'm'	149	72,7	99,6
26	51,7	0	88	43,3	'm'	150	79,9	45
27	53,4	48,9	89	36,1	'm'	151	44,3	0
28	34,2	87,6	90	27,6	'm'	152	41,5	84,4
29	45,5	92,7	91	21,1	'm'	153	56,2	98,2
30	54,6	99,5	92	8	0	154	65,7	99,1
31	64,5	96,8	93	0	0	155	74,4	84,7
32	71,7	85,4	94	0	0	156	54,4	0
33	79,4	54,8	95	0	0	157	47,9	89,7
34	89,7	99,4	96	0	0	158	54,5	99,5
35	57,4	0	97	0	0	159	62,7	96,8
36	59,7	30,6	98	0	0	160	62,3	0
37	90,1	'm'	99	0	0	161	46,2	54,2
38	82,9	'm'	100	0	0	162	44,3	83,2
39	51,3	'm'	101	0	0	163	48,2	13,3
40	28,5	'm'	102	0	0	164	51	'm'
41	29,3	'm'	103	0	0	165	50	'm'
42	26,7	'm'	104	0	0	166	49,2	'm'
43	20,4	'm'	105	0	0	167	49,3	'm'
44	14,1	0	106	0	0	168	49,9	'm'
45	6,5	0	107	0	0	169	51,6	'm'
46	0	0	108	11,6	14,8	170	49,7	'm'
47	0	0	109	0	0	171	48,5	'm'
48	0	0	110	27,2	74,8	172	50,3	72,5
49	0	0	111	17	76,9	173	51,1	84,5
50	0	0	112	36	78	174	54,6	64,8
51	0	0	113	59,7	86	175	56,6	76,5
52	0	0	114	80,8	17,9	176	58	'm'
53	0	0	115	49,7	0	177	53,6	'm'
54	0	0	116	65,6	86	178	40,8	'm'
55	0	0	117	78,6	72,2	179	32,9	'm'
56	0	0	118	64,9	'm'	180	26,3	'm'
57	0	0	119	44,3	'm'	181	20,9	'm'
58	0	0	120	51,4	83,4	182	10	0
59	0	0	121	58,1	97	183	0	0
60	0	0	122	69,3	99,3	184	0	0
61	0	0	123	72	20,8	185	0	0
62	25,5	11,1	124	72,1	'm'	186	0	0

Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %
187	0	0	255	54,5	'm'	323	43	24,8
188	0	0	256	51,7	17	324	38,7	0
189	0	0	257	56,2	78,7	325	48,1	31,9
190	0	0	258	59,5	94,7	326	40,3	61
191	0	0	259	65,5	99,1	327	42,4	52,1
192	0	0	260	71,2	99,5	328	46,4	47,7
193	0	0	261	76,6	99,9	329	46,9	30,7
194	0	0	262	79	0	330	46,1	23,1
195	0	0	263	52,9	97,5	331	45,7	23,2
196	0	0	264	53,1	99,7	332	45,5	31,9
197	0	0	265	59	99,1	333	46,4	73,6
198	0	0	266	62,2	99	334	51,3	60,7
199	0	0	267	65	99,1	335	51,3	51,1
200	0	0	268	69	83,1	336	53,2	46,8
201	0	0	269	69,9	28,4	337	53,9	50
202	0	0	270	70,6	12,5	338	53,4	52,1
203	0	0	271	68,9	8,4	339	53,8	45,7
204	0	0	272	69,8	9,1	340	50,6	22,1
205	0	0	273	69,6	7	341	47,8	26
206	0	0	274	65,7	'm'	342	41,6	17,8
207	0	0	275	67,1	'm'	343	38,7	29,8
208	0	0	276	66,7	'm'	344	35,9	71,6
209	0	0	277	65,6	'm'	345	34,6	47,3
210	0	0	278	64,5	'm'	346	34,8	80,3
211	0	0	279	62,9	'm'	347	35,9	87,2
212	0	0	280	59,3	'm'	348	38,8	90,8
213	0	0	281	54,1	'm'	349	41,5	94,7
214	0	0	282	51,3	'm'	350	47,1	99,2
215	0	0	283	47,9	'm'	351	53,1	99,7
216	0	0	284	43,6	'm'	352	46,4	0
217	0	0	285	39,4	'm'	353	42,5	0,7
218	0	0	286	34,7	'm'	354	43,6	58,6
219	0	0	287	29,8	'm'	355	47,1	87,5
220	0	0	288	20,9	73,4	356	54,1	99,5
221	0	0	289	36,9	'm'	357	62,9	99
222	0	0	290	35,5	'm'	358	72,6	99,6
223	0	0	291	20,9	'm'	359	82,4	99,5
224	0	0	292	49,7	11,9	360	88	99,4
225	21,2	62,7	293	42,5	'm'	361	46,4	0
226	30,8	75,1	294	32	'm'	362	53,4	95,2
227	5,9	82,7	295	23,6	'm'	363	58,4	99,2
228	34,6	80,3	296	19,1	0	364	61,5	99
229	59,9	87	297	15,7	73,5	365	64,8	99
230	84,3	86,2	298	25,1	76,8	366	68,1	99,2
231	68,7	'm'	299	34,5	81,4	367	73,4	99,7
232	43,6	'm'	300	44,1	87,4	368	73,3	29,8
233	41,5	85,4	301	52,8	98,6	369	73,5	14,6
234	49,9	94,3	302	63,6	99	370	68,3	0
235	60,8	99	303	73,6	99,7	371	45,4	49,9
236	70,2	99,4	304	62,2	'm'	372	47,2	75,7
237	81,1	92,4	305	29,2	'm'	373	44,5	9
238	49,2	0	306	46,4	22	374	47,8	10,3
239	56	86,2	307	47,3	13,8	375	46,8	15,9
240	56,2	99,3	308	47,2	12,5	376	46,9	12,7
241	61,7	99	309	47,9	11,5	377	46,8	8,9
242	69,2	99,3	310	47,8	35,5	378	46,1	6,2
243	74,1	99,8	311	49,2	83,3	379	46,1	'm'
244	72,4	8,4	312	52,7	96,4	380	45,5	'm'
245	71,3	0	313	57,4	99,2	381	44,7	'm'
246	71,2	9,1	314	61,8	99	382	43,8	'm'
247	67,1	'm'	315	66,4	60,9	383	41	'm'
248	65,5	'm'	316	65,8	'm'	384	41,1	6,4
249	64,4	'm'	317	59	'm'	385	38	6,3
250	62,9	25,6	318	50,7	'm'	386	35,9	0,3
251	62,2	35,6	319	41,8	'm'	387	33,5	0
252	62,9	24,4	320	34,7	'm'	388	53,1	48,9
253	58,8	'm'	321	28,7	'm'	389	48,3	'm'
254	56,9	'm'	322	25,2	'm'	390	49,9	'm'

Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %
391	48	'm'	459	51	100	527	60,7	'm'
392	45,3	'm'	460	53,2	99,7	528	54,5	'm'
393	41,6	3,1	461	53,1	99,7	529	51,3	'm'
394	44,3	79	462	55,9	53,1	530	45,5	'm'
395	44,3	89,5	463	53,9	13,9	531	40,8	'm'
396	43,4	98,8	464	52,5	'm'	532	38,9	'm'
397	44,3	98,9	465	51,7	'm'	533	36,6	'm'
398	43	98,8	466	51,5	52,2	534	36,1	72,7
399	42,2	98,8	467	52,8	80	535	44,8	78,9
400	42,7	98,8	468	54,9	95	536	51,6	91,1
401	45	99	469	57,3	99,2	537	59,1	99,1
402	43,6	98,9	470	60,7	99,1	538	66	99,1
403	42,2	98,8	471	62,4	'm'	539	75,1	99,9
404	44,8	99	472	60,1	'm'	540	81	8
405	43,4	98,8	473	53,2	'm'	541	39,1	0
406	45	99	474	44	'm'	542	53,8	89,7
407	42,2	54,3	475	35,2	'm'	543	59,7	99,1
408	61,2	31,9	476	30,5	'm'	544	64,8	99
409	56,3	72,3	477	26,5	'm'	545	70,6	96,1
410	59,7	99,1	478	22,5	'm'	546	72,6	19,6
411	62,3	99	479	20,4	'm'	547	72	6,3
412	67,9	99,2	480	19,1	'm'	548	68,9	0,1
413	69,5	99,3	481	19,1	'm'	549	67,7	'm'
414	73,1	99,7	482	13,4	'm'	550	66,8	'm'
415	77,7	99,8	483	6,7	'm'	551	64,3	16,9
416	79,7	99,7	484	3,2	'm'	552	64,9	7
417	82,5	99,5	485	14,3	63,8	553	63,6	12,5
418	85,3	99,4	486	34,1	0	554	63	7,7
419	86,6	99,4	487	23,9	75,7	555	64,4	38,2
420	89,4	99,4	488	31,7	79,2	556	63	11,8
421	62,2	0	489	32,1	19,4	557	63,6	0
422	52,7	96,4	490	35,9	5,8	558	63,3	5
423	50,2	99,8	491	36,6	0,8	559	60,1	9,1
424	49,3	99,6	492	38,7	'm'	560	61	8,4
425	52,2	99,8	493	38,4	'm'	561	59,7	0,9
426	51,3	100	494	39,4	'm'	562	58,7	'm'
427	51,3	100	495	39,7	'm'	563	56	'm'
428	51,1	100	496	40,5	'm'	564	53,9	'm'
429	51,1	100	497	40,8	'm'	565	52,1	'm'
430	51,8	99,9	498	39,7	'm'	566	49,9	'm'
431	51,3	100	499	39,2	'm'	567	46,4	'm'
432	51,1	100	500	38,7	'm'	568	43,6	'm'
433	51,3	100	501	32,7	'm'	569	40,8	'm'
434	52,3	99,8	502	30,1	'm'	570	37,5	'm'
435	52,9	99,7	503	21,9	'm'	571	27,8	'm'
436	53,8	99,6	504	12,8	0	572	17,1	0,6
437	51,7	99,9	505	0	0	573	12,2	0,9
438	53,5	99,6	506	0	0	574	11,5	1,1
439	52	99,8	507	0	0	575	8,7	0,5
440	51,7	99,9	508	0	0	576	8	0,9
441	53,2	99,7	509	0	0	577	5,3	0,2
442	54,2	99,5	510	0	0	578	4	0
443	55,2	99,4	511	0	0	579	3,9	0
444	53,8	99,6	512	0	0	580	0	0
445	53,1	99,7	513	0	0	581	0	0
446	55	99,4	514	30,5	25,6	582	0	0
447	57	99,2	515	19,7	56,9	583	0	0
448	61,5	99	516	16,3	45,1	584	0	0
449	59,4	5,7	517	27,2	4,6	585	0	0
450	59	0	518	21,7	1,3	586	0	0
451	57,3	59,8	519	29,7	28,6	587	8,7	22,8
452	64,1	99	520	36,6	73,7	588	16,2	49,4
453	70,9	90,5	521	61,3	59,5	589	23,6	56
454	58	0	522	40,8	0	590	21,1	56,1
455	41,5	59,8	523	36,6	27,8	591	23,6	56
456	44,1	92,6	524	39,4	80,4	592	46,2	68,8
457	46,8	99,2	525	51,3	88,9	593	68,4	61,2
458	47,2	99,3	526	58,5	11,1	594	58,7	'm'

Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %
595	31,6	'm'	663	54,9	59,8	731	56,8	'm'
596	19,9	8,8	664	54	39,3	732	57,1	'm'
597	32,9	70,2	665	53,8	'm'	733	52	'm'
598	43	79	666	52	'm'	734	44,4	'm'
599	57,4	98,9	667	50,4	'm'	735	40,2	'm'
600	72,1	73,8	668	50,6	0	736	39,2	16,5
601	53	0	669	49,3	41,7	737	38,9	73,2
602	48,1	86	670	50	73,2	738	39,9	89,8
603	56,2	99	671	50,4	99,7	739	42,3	98,6
604	65,4	98,9	672	51,9	99,5	740	43,7	98,8
605	72,9	99,7	673	53,6	99,3	741	45,5	99,1
606	67,5	'm'	674	54,6	99,1	742	45,6	99,2
607	39	'm'	675	56	99	743	48,1	99,7
608	41,9	38,1	676	55,8	99	744	49	100
609	44,1	80,4	677	58,4	98,9	745	49,8	99,9
610	46,8	99,4	678	59,9	98,8	746	49,8	99,9
611	48,7	99,9	679	60,9	98,8	747	51,9	99,5
612	50,5	99,7	680	63	98,8	748	52,3	99,4
613	52,5	90,3	681	64,3	98,9	749	53,3	99,3
614	51	1,8	682	64,8	64	750	52,9	99,3
615	50	'm'	683	65,9	46,5	751	54,3	99,2
616	49,1	'm'	684	66,2	28,7	752	55,5	99,1
617	47	'm'	685	65,2	1,8	753	56,7	99
618	43,1	'm'	686	65	6,8	754	61,7	98,8
619	39,2	'm'	687	63,6	53,6	755	64,3	47,4
620	40,6	0,5	688	62,4	82,5	756	64,7	1,8
621	41,8	53,4	689	61,8	98,8	757	66,2	'm'
622	44,4	65,1	690	59,8	98,8	758	49,1	'm'
623	48,1	67,8	691	59,2	98,8	759	52,1	46
624	53,8	99,2	692	59,7	98,8	760	52,6	61
625	58,6	98,9	693	61,2	98,8	761	52,9	0
626	63,6	98,8	694	62,2	49,4	762	52,3	20,4
627	68,5	99,2	695	62,8	37,2	763	54,2	56,7
628	72,2	89,4	696	63,5	46,3	764	55,4	59,8
629	77,1	0	697	64,7	72,3	765	56,1	49,2
630	57,8	79,1	698	64,7	72,3	766	56,8	33,7
631	60,3	98,8	699	65,4	77,4	767	57,2	96
632	61,9	98,8	700	66,1	69,3	768	58,6	98,9
633	63,8	98,8	701	64,3	'm'	769	59,5	98,8
634	64,7	98,9	702	64,3	'm'	770	61,2	98,8
635	65,4	46,5	703	63	'm'	771	62,1	98,8
636	65,7	44,5	704	62,2	'm'	772	62,7	98,8
637	65,6	3,5	705	61,6	'm'	773	62,8	98,8
638	49,1	0	706	62,4	'm'	774	64	98,9
639	50,4	73,1	707	62,2	'm'	775	63,2	46,3
640	50,5	'm'	708	61	'm'	776	62,4	'm'
641	51	'm'	709	58,7	'm'	777	60,3	'm'
642	49,4	'm'	710	55,5	'm'	778	58,7	'm'
643	49,2	'm'	711	51,7	'm'	779	57,2	'm'
644	48,6	'm'	712	49,2	'm'	780	56,1	'm'
645	47,5	'm'	713	48,8	40,4	781	56	9,3
646	46,5	'm'	714	47,9	'm'	782	55,2	26,3
647	46	11,3	715	46,2	'm'	783	54,8	42,8
648	45,6	42,8	716	45,6	9,8	784	55,7	47,1
649	47,1	83	717	45,6	34,5	785	56,6	52,4
650	46,2	99,3	718	45,5	37,1	786	58	50,3
651	47,9	99,7	719	43,8	'm'	787	58,6	20,6
652	49,5	99,9	720	41,9	'm'	788	58,7	'm'
653	50,6	99,7	721	41,3	'm'	789	59,3	'm'
654	51	99,6	722	41,4	'm'	790	58,6	'm'
655	53	99,3	723	41,2	'm'	791	60,5	9,7
656	54,9	99,1	724	41,8	'm'	792	59,2	9,6
657	55,7	99	725	41,8	'm'	793	59,9	9,6
658	56	99	726	43,2	17,4	794	59,6	9,6
659	56,1	9,3	727	45	29	795	59,9	6,2
660	55,6	'm'	728	44,2	'm'	796	59,9	9,6
661	55,4	'm'	729	43,9	'm'	797	60,5	13,1
662	54,9	51,3	730	38	10,7	798	60,3	20,7

Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %
799	59,9	31	867	52,3	99,4	935	52,8	60,1
800	60,5	42	868	53	99,3	936	53,7	69,7
801	61,5	52,5	869	54,2	99,2	937	54	70,7
802	60,9	51,4	870	55,5	99,1	938	55,1	71,7
803	61,2	57,7	871	56,7	99	939	55,2	46
804	62,8	98,8	872	57,3	98,9	940	54,7	12,6
805	63,4	96,1	873	58	98,9	941	52,5	0
806	64,6	45,4	874	60,5	31,1	942	51,8	24,7
807	64,1	5	875	60,2	'm'	943	51,4	43,9
808	63	3,2	876	60,3	'm'	944	50,9	71,1
809	62,7	14,9	877	60,5	6,3	945	51,2	76,8
810	63,5	35,8	878	61,4	19,3	946	50,3	87,5
811	64,1	73,3	879	60,3	1,2	947	50,2	99,8
812	64,3	37,4	880	60,5	2,9	948	50,9	100
813	64,1	21	881	61,2	34,1	949	49,9	99,7
814	63,7	21	882	61,6	13,2	950	50,9	100
815	62,9	18	883	61,5	16,4	951	49,8	99,7
816	62,4	32,7	884	61,2	16,4	952	50,4	99,8
817	61,7	46,2	885	61,3	'm'	953	50,4	99,8
818	59,8	45,1	886	63,1	'm'	954	49,7	99,7
819	57,4	43,9	887	63,2	4,8	955	51	100
820	54,8	42,8	888	62,3	22,3	956	50,3	99,8
821	54,3	65,2	889	62	38,5	957	50,2	99,8
822	52,9	62,1	890	61,6	29,6	958	49,9	99,7
823	52,4	30,6	891	61,6	26,6	959	50,9	100
824	50,4	'm'	892	61,8	28,1	960	50	99,7
825	48,6	'm'	893	62	29,6	961	50,2	99,8
826	47,9	'm'	894	62	16,3	962	50,2	99,8
827	46,8	'm'	895	61,1	'm'	963	49,9	99,7
828	46,9	9,4	896	61,2	'm'	964	50,4	99,8
829	49,5	41,7	897	60,7	19,2	965	50,2	99,8
830	50,5	37,8	898	60,7	32,5	966	50,3	99,8
831	52,3	20,4	899	60,9	17,8	967	49,9	99,7
832	54,1	30,7	900	60,1	19,2	968	51,1	100
833	56,3	41,8	901	59,3	38,2	969	50,6	99,9
834	58,7	26,5	902	59,9	45	970	49,9	99,7
835	57,3	'm'	903	59,4	32,4	971	49,6	99,6
836	59	'm'	904	59,2	23,5	972	49,4	99,6
837	59,8	'm'	905	59,5	40,8	973	49	99,5
838	60,3	'm'	906	58,3	'm'	974	49,8	99,7
839	61,2	'm'	907	58,2	'm'	975	50,9	100
840	61,8	'm'	908	57,6	'm'	976	50,4	99,8
841	62,5	'm'	909	57,1	'm'	977	49,8	99,7
842	62,4	'm'	910	57	0,6	978	49,1	99,5
843	61,5	'm'	911	57	26,3	979	50,4	99,8
844	63,7	'm'	912	56,5	29,2	980	49,8	99,7
845	61,9	'm'	913	56,3	20,5	981	49,3	99,5
846	61,6	29,7	914	56,1	'm'	982	49,1	99,5
847	60,3	'm'	915	55,2	'm'	983	49,9	99,7
848	59,2	'm'	916	54,7	17,5	984	49,1	99,5
849	57,3	'm'	917	55,2	29,2	985	50,4	99,8
850	52,3	'm'	918	55,2	29,2	986	50,9	100
851	49,3	'm'	919	55,9	16	987	51,4	99,9
852	47,3	'm'	920	55,9	26,3	988	51,5	99,9
853	46,3	38,8	921	56,1	36,5	989	52,2	99,7
854	46,8	35,1	922	55,8	19	990	52,8	74,1
855	46,6	'm'	923	55,9	9,2	991	53,3	46
856	44,3	'm'	924	55,8	21,9	992	53,6	36,4
857	43,1	'm'	925	56,4	42,8	993	53,4	33,5
858	42,4	2,1	926	56,4	38	994	53,9	58,9
859	41,8	2,4	927	56,4	11	995	55,2	73,8
860	43,8	68,8	928	56,4	35,1	996	55,8	52,4
861	44,6	89,2	929	54	7,3	997	55,7	9,2
862	46	99,2	930	53,4	5,4	998	55,8	2,2
863	46,9	99,4	931	52,3	27,6	999	56,4	33,6
864	47,9	99,7	932	52,1	32	1000	55,4	'm'
865	50,2	99,8	933	52,3	33,4	1001	55,2	'm'
866	51,2	99,6	934	52,2	34,9	1002	55,8	26,3

Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %
1003	55,8	23,3	1071	42,5	'm'	1139	45,5	24,8
1004	56,4	50,2	1072	41	'm'	1140	44,8	73,8
1005	57,6	68,3	1073	39,9	'm'	1141	46,6	99
1006	58,8	90,2	1074	39,9	38,2	1142	46,3	98,9
1007	59,9	98,9	1075	40,1	48,1	1143	48,5	99,4
1008	62,3	98,8	1076	39,9	48	1144	49,9	99,7
1009	63,1	74,4	1077	39,4	59,3	1145	49,1	99,5
1010	63,7	49,4	1078	43,8	19,8	1146	49,1	99,5
1011	63,3	9,8	1079	52,9	0	1147	51	100
1012	48	0	1080	52,8	88,9	1148	51,5	99,9
1013	47,9	73,5	1081	53,4	99,5	1149	50,9	100
1014	49,9	99,7	1082	54,7	99,3	1150	51,6	99,9
1015	49,9	48,8	1083	56,3	99,1	1151	52,1	99,7
1016	49,6	2,3	1084	57,5	99	1152	50,9	100
1017	49,9	'm'	1085	59	98,9	1153	52,2	99,7
1018	49,3	'm'	1086	59,8	98,9	1154	51,5	98,3
1019	49,7	47,5	1087	60,1	98,9	1155	51,5	47,2
1020	49,1	'm'	1088	61,8	48,3	1156	50,8	78,4
1021	49,4	'm'	1089	61,8	55,6	1157	50,3	83
1022	48,3	'm'	1090	61,7	59,8	1158	50,3	31,7
1023	49,4	'm'	1091	62	55,6	1159	49,3	31,3
1024	48,5	'm'	1092	62,3	29,6	1160	48,8	21,5
1025	48,7	'm'	1093	62	19,3	1161	47,8	59,4
1026	48,7	'm'	1094	61,3	7,9	1162	48,1	77,1
1027	49,1	'm'	1095	61,1	19,2	1163	48,4	87,6
1028	49	'm'	1096	61,2	43	1164	49,6	87,5
1029	49,8	'm'	1097	61,1	59,7	1165	51	81,4
1030	48,7	'm'	1098	61,1	98,8	1166	51,6	66,7
1031	48,5	'm'	1099	61,3	98,8	1167	53,3	63,2
1032	49,3	31,3	1100	61,3	26,6	1168	55,2	62
1033	49,7	45,3	1101	60,4	'm'	1169	55,7	43,9
1034	48,3	44,5	1102	58,8	'm'	1170	56,4	30,7
1035	49,8	61	1103	57,7	'm'	1171	56,8	23,4
1036	49,4	64,3	1104	56	'm'	1172	57	'm'
1037	49,8	64,4	1105	54,7	'm'	1173	57,6	'm'
1038	50,5	65,6	1106	53,3	'm'	1174	56,9	'm'
1039	50,3	64,5	1107	52,6	23,2	1175	56,4	4
1040	51,2	82,9	1108	53,4	84,2	1176	57	23,4
1041	50,5	86	1109	53,9	99,4	1177	56,4	41,7
1042	50,6	89	1110	54,9	99,3	1178	57	49,2
1043	50,4	81,4	1111	55,8	99,2	1179	57,7	56,6
1044	49,9	49,9	1112	57,1	99	1180	58,6	56,6
1045	49,1	20,1	1113	56,5	99,1	1181	58,9	64
1046	47,9	24	1114	58,9	98,9	1182	59,4	68,2
1047	48,1	36,2	1115	58,7	98,9	1183	58,8	71,4
1048	47,5	34,5	1116	59,8	98,9	1184	60,1	71,3
1049	46,9	30,3	1117	61	98,8	1185	60,6	79,1
1050	47,7	53,5	1118	60,7	19,2	1186	60,7	83,3
1051	46,9	61,6	1119	59,4	'm'	1187	60,7	77,1
1052	46,5	73,6	1120	57,9	'm'	1188	60	73,5
1053	48	84,6	1121	57,6	'm'	1189	60,2	55,5
1054	47,2	87,7	1122	56,3	'm'	1190	59,7	54,4
1055	48,7	80	1123	55	'm'	1191	59,8	73,3
1056	48,7	50,4	1124	53,7	'm'	1192	59,8	77,9
1057	47,8	38,6	1125	52,1	'm'	1193	59,8	73,9
1058	48,8	63,1	1126	51,1	'm'	1194	60	76,5
1059	47,4	5	1127	49,7	25,8	1195	59,5	82,3
1060	47,3	47,4	1128	49,1	46,1	1196	59,9	82,8
1061	47,3	49,8	1129	48,7	46,9	1197	59,8	65,8
1062	46,9	23,9	1130	48,2	46,7	1198	59	48,6
1063	46,7	44,6	1131	48	70	1199	58,9	62,2
1064	46,8	65,2	1132	48	70	1200	59,1	70,4
1065	46,9	60,4	1133	47,2	67,6	1201	58,9	62,1
1066	46,7	61,5	1134	47,3	67,6	1202	58,4	67,4
1067	45,5	'm'	1135	46,6	74,7	1203	58,7	58,9
1068	45,5	'm'	1136	47,4	13	1204	58,3	57,7
1069	44,2	'm'	1137	46,3	'm'	1205	57,5	57,8
1070	43	'm'	1138	45,4	'm'	1206	57,2	57,6

Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %
1207	57,1	42,6	1275	60,6	8,2	1343	61,3	19,2
1208	57	70,1	1276	60,6	5,5	1344	61	9,3
1209	56,4	59,6	1277	61	14,3	1345	60,8	44,2
1210	56,7	39	1278	61	12	1346	60,9	55,3
1211	55,9	68,1	1279	61,3	34,2	1347	61,2	56
1212	56,3	79,1	1280	61,2	17,1	1348	60,9	60,1
1213	56,7	89,7	1281	61,5	15,7	1349	60,7	59,1
1214	56	89,4	1282	61	9,5	1350	60,9	56,8
1215	56	93,1	1283	61,1	9,2	1351	60,7	58,1
1216	56,4	93,1	1284	60,5	4,3	1352	59,6	78,4
1217	56,7	94,4	1285	60,2	7,8	1353	59,6	84,6
1218	56,9	94,8	1286	60,2	5,9	1354	59,4	66,6
1219	57	94,1	1287	60,2	5,3	1355	59,3	75,5
1220	57,7	94,3	1288	59,9	4,6	1356	58,9	49,6
1221	57,5	93,7	1289	59,4	21,5	1357	59,1	75,8
1222	58,4	93,2	1290	59,6	15,8	1358	59	77,6
1223	58,7	93,2	1291	59,3	10,1	1359	59	67,8
1224	58,2	93,7	1292	58,9	9,4	1360	59	56,7
1225	58,5	93,1	1293	58,8	9	1361	58,8	54,2
1226	58,8	86,2	1294	58,9	35,4	1362	58,9	59,6
1227	59	72,9	1295	58,9	30,7	1363	58,9	60,8
1228	58,2	59,9	1296	58,9	25,9	1364	59,3	56,1
1229	57,6	8,5	1297	58,7	22,9	1365	58,9	48,5
1230	57,1	47,6	1298	58,7	24,4	1366	59,3	42,9
1231	57,2	74,4	1299	59,3	61	1367	59,4	41,4
1232	57	79,1	1300	60,1	56	1368	59,6	38,9
1233	56,7	67,2	1301	60,5	50,6	1369	59,4	32,9
1234	56,8	69,1	1302	59,5	16,2	1370	59,3	30,6
1235	56,9	71,3	1303	59,7	50	1371	59,4	30
1236	57	77,3	1304	59,7	31,4	1372	59,4	25,3
1237	57,4	78,2	1305	60,1	43,1	1373	58,8	18,6
1238	57,3	70,6	1306	60,8	38,4	1374	59,1	18
1239	57,7	64	1307	60,9	40,2	1375	58,5	10,6
1240	57,5	55,6	1308	61,3	49,7	1376	58,8	10,5
1241	58,6	49,6	1309	61,8	45,9	1377	58,5	8,2
1242	58,2	41,1	1310	62	45,9	1378	58,7	13,7
1243	58,8	40,6	1311	62,2	45,8	1379	59,1	7,8
1244	58,3	21,1	1312	62,6	46,8	1380	59,1	6
1245	58,7	24,9	1313	62,7	44,3	1381	59,1	6
1246	59,1	24,8	1314	62,9	44,4	1382	59,4	13,1
1247	58,6	'm'	1315	63,1	43,7	1383	59,7	22,3
1248	58,8	'm'	1316	63,5	46,1	1384	60,7	10,5
1249	58,8	'm'	1317	63,6	40,7	1385	59,8	9,8
1250	58,7	'm'	1318	64,3	49,5	1386	60,2	8,8
1251	59,1	'm'	1319	63,7	27	1387	59,9	8,7
1252	59,1	'm'	1320	63,8	15	1388	61	9,1
1253	59,4	'm'	1321	63,6	18,7	1389	60,6	28,2
1254	60,6	2,6	1322	63,4	8,4	1390	60,6	22
1255	59,6	'm'	1323	63,2	8,7	1391	59,6	23,2
1256	60,1	'm'	1324	63,3	21,6	1392	59,6	19
1257	60,6	'm'	1325	62,9	19,7	1393	60,6	38,4
1258	59,6	4,1	1326	63	22,1	1394	59,8	41,6
1259	60,7	7,1	1327	63,1	20,3	1395	60	47,3
1260	60,5	'm'	1328	61,8	19,1	1396	60,5	55,4
1261	59,7	'm'	1329	61,6	17,1	1397	60,9	58,7
1262	59,6	'm'	1330	61	0	1398	61,3	37,9
1263	59,8	'm'	1331	61,2	22	1399	61,2	38,3
1264	59,6	4,9	1332	60,8	40,3	1400	61,4	58,7
1265	60,1	5,9	1333	61,1	34,3	1401	61,3	51,3
1266	59,9	6,1	1334	60,7	16,1	1402	61,4	71,1
1267	59,7	'm'	1335	60,6	16,6	1403	61,1	51
1268	59,6	'm'	1336	60,5	18,5	1404	61,5	56,6
1269	59,7	22	1337	60,6	29,8	1405	61	60,6
1270	59,8	10,3	1338	60,9	19,5	1406	61,1	75,4
1271	59,9	10	1339	60,9	22,3	1407	61,4	69,4
1272	60,6	6,2	1340	61,4	35,8	1408	61,6	69,9
1273	60,5	7,3	1341	61,3	42,9	1409	61,7	59,6
1274	60,2	14,8	1342	61,5	31	1410	61,8	54,8

Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %
1411	61,6	53,6	1479	60,7	26,7	1547	58,8	6,4
1412	61,3	53,5	1480	60,1	4,7	1548	58,7	5
1413	61,3	52,9	1481	59,9	0	1549	57,5	'm'
1414	61,2	54,1	1482	60,4	36,2	1550	57,4	'm'
1415	61,3	53,2	1483	60,7	32,5	1551	57,1	1,1
1416	61,2	52,2	1484	59,9	3,1	1552	57,1	0
1417	61,2	52,3	1485	59,7	'm'	1553	57	4,5
1418	61	48	1486	59,5	'm'	1554	57,1	3,7
1419	60,9	41,5	1487	59,2	'm'	1555	57,3	3,3
1420	61	32,2	1488	58,8	0,6	1556	57,3	16,8
1421	60,7	22	1489	58,7	'm'	1557	58,2	29,3
1422	60,7	23,3	1490	58,7	'm'	1558	58,7	12,5
1423	60,8	38,8	1491	57,9	'm'	1559	58,3	12,2
1424	61	40,7	1492	58,2	'm'	1560	58,6	12,7
1425	61	30,6	1493	57,6	'm'	1561	59	13,6
1426	61,3	62,6	1494	58,3	9,5	1562	59,8	21,9
1427	61,7	55,9	1495	57,2	6	1563	59,3	20,9
1428	62,3	43,4	1496	57,4	27,3	1564	59,7	19,2
1429	62,3	37,4	1497	58,3	59,9	1565	60,1	15,9
1430	62,3	35,7	1498	58,3	7,3	1566	60,7	16,7
1431	62,8	34,4	1499	58,8	21,7	1567	60,7	18,1
1432	62,8	31,5	1500	58,8	38,9	1568	60,7	40,6
1433	62,9	31,7	1501	59,4	26,2	1569	60,7	59,7
1434	62,9	29,9	1502	59,1	25,5	1570	61,1	66,8
1435	62,8	29,4	1503	59,1	26	1571	61,1	58,8
1436	62,7	28,7	1504	59	39,1	1572	60,8	64,7
1437	61,5	14,7	1505	59,5	52,3	1573	60,1	63,6
1438	61,9	17,2	1506	59,4	31	1574	60,7	83,2
1439	61,5	6,1	1507	59,4	27	1575	60,4	82,2
1440	61	9,9	1508	59,4	29,8	1576	60	80,5
1441	60,9	4,8	1509	59,4	23,1	1577	59,9	78,7
1442	60,6	11,1	1510	58,9	16	1578	60,8	67,9
1443	60,3	6,9	1511	59	31,5	1579	60,4	57,7
1444	60,8	7	1512	58,8	25,9	1580	60,2	60,6
1445	60,2	9,2	1513	58,9	40,2	1581	59,6	72,7
1446	60,5	21,7	1514	58,8	28,4	1582	59,9	73,6
1447	60,2	22,4	1515	58,9	38,9	1583	59,8	74,1
1448	60,7	31,6	1516	59,1	35,3	1584	59,6	84,6
1449	60,9	28,9	1517	58,8	30,3	1585	59,4	76,1
1450	59,6	21,7	1518	59	19	1586	60,1	76,9
1451	60,2	18	1519	58,7	3	1587	59,5	84,6
1452	59,5	16,7	1520	57,9	0	1588	59,8	77,5
1453	59,8	15,7	1521	58	2,4	1589	60,6	67,9
1454	59,6	15,7	1522	57,1	'm'	1590	59,3	47,3
1455	59,3	15,7	1523	56,7	'm'	1591	59,3	43,1
1456	59	7,5	1524	56,7	5,3	1592	59,4	38,3
1457	58,8	7,1	1525	56,6	2,1	1593	58,7	38,2
1458	58,7	16,5	1526	56,8	'm'	1594	58,8	39,2
1459	59,2	50,7	1527	56,3	'm'	1595	59,1	67,9
1460	59,7	60,2	1528	56,3	'm'	1596	59,7	60,5
1461	60,4	44	1529	56	'm'	1597	59,5	32,9
1462	60,2	35,3	1530	56,7	'm'	1598	59,6	20
1463	60,4	17,1	1531	56,6	3,8	1599	59,6	34,4
1464	59,9	13,5	1532	56,9	'm'	1600	59,4	23,9
1465	59,9	12,8	1533	56,9	'm'	1601	59,6	15,7
1466	59,6	14,8	1534	57,4	'm'	1602	59,9	41
1467	59,4	15,9	1535	57,4	'm'	1603	60,5	26,3
1468	59,4	22	1536	58,3	13,9	1604	59,6	14
1469	60,4	38,4	1537	58,5	'm'	1605	59,7	21,2
1470	59,5	38,8	1538	59,1	'm'	1606	60,9	19,6
1471	59,3	31,9	1539	59,4	'm'	1607	60,1	34,3
1472	60,9	40,8	1540	59,6	'm'	1608	59,9	27
1473	60,7	39	1541	59,5	'm'	1609	60,8	25,6
1474	60,9	30,1	1542	59,6	0,5	1610	60,6	26,3
1475	61	29,3	1543	59,3	9,2	1611	60,9	26,1
1476	60,6	28,4	1544	59,4	11,2	1612	61,1	38
1477	60,9	36,3	1545	59,1	26,8	1613	61,2	31,6
1478	60,8	30,5	1546	59	11,7	1614	61,4	30,6

Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %	Time s	Normal speed %	Normal torque %
1615	61,7	29,6	1677	60,6	6,7	1739	60,9	'm'
1616	61,5	28,8	1678	60,6	12,8	1740	60,8	4,8
1617	61,7	27,8	1679	60,7	11,9	1741	59,9	'm'
1618	62,2	20,3	1680	60,6	12,4	1742	59,8	'm'
1619	61,4	19,6	1681	60,1	12,4	1743	59,1	'm'
1620	61,8	19,7	1682	60,5	12	1744	58,8	'm'
1621	61,8	18,7	1683	60,4	11,8	1745	58,8	'm'
1622	61,6	17,7	1684	59,9	12,4	1746	58,2	'm'
1623	61,7	8,7	1685	59,6	12,4	1747	58,5	14,3
1624	61,7	1,4	1686	59,6	9,1	1748	57,5	4,4
1625	61,7	5,9	1687	59,9	0	1749	57,9	0
1626	61,2	8,1	1688	59,9	20,4	1750	57,8	20,9
1627	61,9	45,8	1689	59,8	4,4	1751	58,3	9,2
1628	61,4	31,5	1690	59,4	3,1	1752	57,8	8,2
1629	61,7	22,3	1691	59,5	26,3	1753	57,5	15,3
1630	62,4	21,7	1692	59,6	20,1	1754	58,4	38
1631	62,8	21,9	1693	59,4	35	1755	58,1	15,4
1632	62,2	22,2	1694	60,9	22,1	1756	58,8	11,8
1633	62,5	31	1695	60,5	12,2	1757	58,3	8,1
1634	62,3	31,3	1696	60,1	11	1758	58,3	5,5
1635	62,6	31,7	1697	60,1	8,2	1759	59	4,1
1636	62,3	22,8	1698	60,5	6,7	1760	58,2	4,9
1637	62,7	12,6	1699	60	5,1	1761	57,9	10,1
1638	62,2	15,2	1700	60	5,1	1762	58,5	7,5
1639	61,9	32,6	1701	60	9	1763	57,4	7
1640	62,5	23,1	1702	60,1	5,7	1764	58,2	6,7
1641	61,7	19,4	1703	59,9	8,5	1765	58,2	6,6
1642	61,7	10,8	1704	59,4	6	1766	57,3	17,3
1643	61,6	10,2	1705	59,5	5,5	1767	58	11,4
1644	61,4	'm'	1706	59,5	14,2	1768	57,5	47,4
1645	60,8	'm'	1707	59,5	6,2	1769	57,4	28,8
1646	60,7	'm'	1708	59,4	10,3	1770	58,8	24,3
1647	61	12,4	1709	59,6	13,8	1771	57,7	25,5
1648	60,4	5,3	1710	59,5	13,9	1772	58,4	35,5
1649	61	13,1	1711	60,1	18,9	1773	58,4	29,3
1650	60,7	29,6	1712	59,4	13,1	1774	59	33,8
1651	60,5	28,9	1713	59,8	5,4	1775	59	18,7
1652	60,8	27,1	1714	59,9	2,9	1776	58,8	9,8
1653	61,2	27,3	1715	60,1	7,1	1777	58,8	23,9
1654	60,9	20,6	1716	59,6	12	1778	59,1	48,2
1655	61,1	13,9	1717	59,6	4,9	1779	59,4	37,2
1656	60,7	13,4	1718	59,4	22,7	1780	59,6	29,1
1657	61,3	26,1	1719	59,6	22	1781	50	25
1658	60,9	23,7	1720	60,1	17,4	1782	40	20
1659	61,4	32,1	1721	60,2	16,6	1783	30	15
1660	61,7	33,5	1722	59,4	28,6	1784	20	10
1661	61,8	34,1	1723	60,3	22,4	1785	10	5
1662	61,7	17	1724	59,9	20	1786	0	0
1663	61,7	2,5	1725	60,2	18,6	1787	0	0
1664	61,5	5,9	1726	60,3	11,9	1788	0	0
1665	61,3	14,9	1727	60,4	11,6	1789	0	0
1666	61,5	17,2	1728	60,6	10,6	1790	0	0
1667	61,1	'm'	1729	60,8	16	1791	0	0
1668	61,4	'm'	1730	60,9	17	1792	0	0
1669	61,4	8,8	1731	60,9	16,1	1793	0	0
1670	61,3	8,8	1732	60,7	11,4	1794	0	0
1671	61	18	1733	60,9	11,3	1795	0	0
1672	61,5	13	1734	61,1	11,2	1796	0	0
1673	61	3,7	1735	61,1	25,6	1797	0	0
1674	60,9	3,1	1736	61	14,6	1798	0	0
1675	60,9	4,7	1737	61	10,4	1799	0	0
1676	60,6	4,1	1738	60,6	'm'	1800	0	0

'm' = motoring.

Figure 5

ETC dynamometer schedule
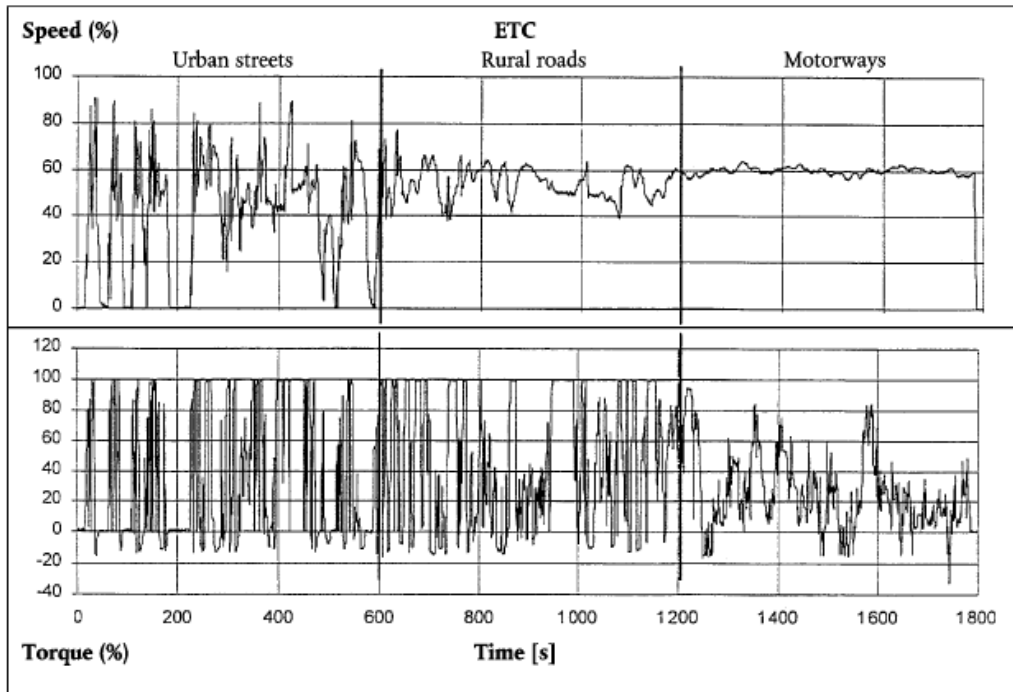
Appendix 4:

MEASUREMENT AND SAMPLING PROCEDURES

1 INTRODUCTION

Gaseous components, particulates, and smoke emitted by the engine submitted for testing shall be measured by the methods described in chapter V of this part. The respective sections of chapter V of this part describe the recommended analytical systems for the gaseous emissions (section 1), the recommended particulate dilution and sampling systems (section 2), and the recommended opacimeters for smoke measurement (section 3).

For the ESC, the gaseous components shall be determined in the raw exhaust

gas. Optionally, they may be determined in the diluted exhaust gas, if a full flow

dilution system is used for particulate determination. Particulates shall be

determined with either a partial flow or a full flow dilution system.

For the ETC, the following systems may be used

- a CVS full flow dilution system for determining gaseous and particulate emissions (double dilution systems are permissible),

or

- a combination of raw exhaust measurement for the gaseous emissions and a partial flow dilution system for particulate emissions,

or

- any combination of the two principles (e.g. raw gaseous measurement and full flow particulate measurement).'

2 DYNAMOMETER AND TEST CELL EQUIPMENT

The following equipment shall be used for emission tests of engines on engine

dynamometers.

2.1 Engine dynamometer

An engine dynamometer shall be used with adequate characteristics to perform the test cycles described in appendices 1 and 2 of this chapter. The speed measuring system shall have an accuracy of ± 2 % of reading. The torque measuring system shall have an accuracy of ± 3 % of reading in the range > 20 % of full scale, and an accuracy of ± 0,6 % of full scale in the range < = 20 % of full scale.

2.2 Other instruments

Measuring instruments for fuel consumption, air consumption, temperature of coolant and lubricant, exhaust gas pressure and intake manifold depression, exhaust gas temperature, air intake temperature, atmospheric pressure, humidity and fuel temperature shall be used, as required. These instruments shall satisfy the requirements given in table 8:

TABLE 8
Accuracy of measuring instruments

Measuring Instrument	Accuracy
Fuel Consumption	± 2 % of Engine's Maximum Value
Air Consumption	± 2 % of reading or ± 1 % of engine's maximum value whichever is greater
Exhaust Gas Flow	± 2,5 % of reading or ± 1,5 % of engine's maximum value whichever is greater
Temperatures ≤ 600 K (327 °C)	± 2 K Absolute
Temperatures ≥ 600 K (327 °C)	± 1 % of Reading
Atmospheric Pressure	± 0,1 kPa Absolute
Exhaust Gas Pressure	± 0,2 kPa Absolute
Intake Depression	± 0,05 kPa Absolute
Other Pressures	± 0,1 kPa Absolute

Relative Humidity	$\pm$ 3 % Absolute
Absolute Humidity	$\pm$ 5 % of Reading
Dilution Air Flow	$\pm$ 2 % of Reading
Diluted Exhaust Gas Flow	$\pm$ 2 % of Reading

3 DETERMINATION OF THE GASEOUS COMPONENTS:

3.1 General analyser specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (section 3.1.1 of this appendix). It is recommended that the analysers be operated such that the measured concentration falls between 15 % and 100 % of full scale.

If read-out systems (computers, data loggers) can provide sufficient accuracy and resolution below 15 % of full scale, measurements below 15 % of full scale are also acceptable. In this case, additional calibrations of at least 4 non-zero nominally equally spaced points are to be made to ensure the accuracy of the calibration curves according to chapter III, appendix 5, section 1.5.5.2 of this part

The electromagnetic compatibility (EMC) of the equipment shall be on a level as to minimise additional errors.

3.1.1 Accuracy

The analyser shall not deviate from the nominal calibration point by more than $\pm$ 2 % of the reading over the whole measurement range except zero, or $\pm$ 0,3 % of full scale whichever is larger. The accuracy shall be determined according to the calibration requirements laid down in section 1.6 of appendix 5 of this chapter.

Note: For the purpose of this part, accuracy is defined as the deviation of the analyser reading from the nominal calibration values using a calibration gas (= true value).

3.1.2 Precision

The precision, defined as 2,5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, has to be not greater than $\pm$ 1 % of

full scale concentration for each range used above 155 ppm (or ppmC) or $\pm$ 2 % of each range used below 155 ppm (or ppmC).

3.1.3 Noise

The analyser peak-to-peak response to zero and calibration or span gases over any 10 second period shall not exceed 2 % of full scale on all ranges used.

3.1.4 Zero Drift

Zero response is defined as the mean response, including noise, to a zero gas during a 30 seconds time interval. The drift of the zero response during a one hour period shall be less than 2 % of full scale on the lowest range used.

3.1.5 Span Drift

Span response is defined as the mean response, including noise, to a span gas during a 30 seconds time interval. The drift of the span response during a one hour period shall be less than 2 % of full scale on the lowest range used.

3.1.6 Rise time

The rise time of the analyser installed in the measurement system shall not exceed 3,5s.

Note: Only evaluating the response time of the analyser alone will not clearly define the suitability of the total system for transient testing. Volumes and especially dead volumes through out the system will not only effect the transportation time from the probe to the analyser, but also effect the rise time. Also transport times inside of an analyser would be defined as analyser response time, like the converter or water traps inside NO_X analysers. The determination of the total system response time is described in section 1.5 of appendix 5 of this chapter.

3.2 Gas Drying

The optional gas drying device must have a minimal effect on the concentration of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

3.3 Analysers

Sections 3.3.1 to 3.3.4 of this appendix describe the measurement principles to be used. A detailed description of the measurement systems is given in chapter

V of this part. The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearising circuits is permitted.

3.3.1 Carbon Monoxide (CO) Analysis

The carbon monoxide analyser shall be of the Non-Dispersive InfraRed (NDIR) absorption type.

3.3.2 Carbon Dioxide (CO2) Analysis

The carbon dioxide analyser shall be of the Non-Dispersive InfraRed (NDIR) absorption type.

3.3.3 Hydrocarbon (HC) analysis

For diesel and LPG fuelled gas engines, the hydrocarbon analyser shall be of the Heated Flame Ionisation Detector (HFID) type with detector, valves, pipe work, etc. heated so as to maintain a gas temperature of 463K ± 10K (190 ± 10 °C). For NG fuelled gas engines, the hydrocarbon analyser may be of the non-heated Flame Ionisation Detector (FID) type depending upon the method used (see chapter V, section 1.3 of this part).

3.3.4 Non-Methane Hydrocarbon (NMHC) Analysis (NG Fuelled Gas Engines Only)

Non-methane hydrocarbons shall be determined by either of the following methods:

3.3.4.1 Gas Chromatographic (GC) Method

Non-methane hydrocarbons shall be determined by subtraction of the methane analysed with a Gas Chromatograph (GC) conditioned at 423 K (150 °C) from the hydrocarbons measured according to section 3.3.3 of this appendix.

3.3.4.2 Non-Methane Cutter (NMC) Method

The determination of the non-methane fraction shall be performed with a heated NMC operated in line with an FID as per section 3.3.3 of this appendix by subtraction of the methane from the hydrocarbons.

3.3.5 Oxides of Nitrogen (NOx) Analysis

The oxides of nitrogen analyser shall be of the Chemi Luminescent Detector (CLD) or Heated ChemiLuminescent Detector (HCLD) type with a NO_2/NO converter, if measured on a dry basis. If measured on a wet basis, a HCLD with converter maintained above 328 K (55 °C) shall be used, provided the water quench check (see chapter III, appendix 5, section 1.9.2.2 of this part) is satisfied.

3.3.6. Air-to-fuel measurement

The air to fuel measurement equipment used to determine the exhaust gas flow as specified in section 4.2.5 of appendix 2 of this Chapter shall be a wide range air to fuel ratio sensor or lambda sensor of Zirconia type. The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.

The accuracy of the sensor with incorporated electronics shall be within:

$\pm$ 3 % of reading $\lambda < 2$

$\pm$ 5 % of reading $2 \leq \lambda < 5$

$\pm$10 % of reading $5 \leq \lambda$

To fulfil the accuracy specified above, the sensor shall be calibrated as specified by the instrument manufacturer.

3.4 Sampling of Gaseous Emissions

3.4.1 Raw Exhaust Gas (ESC only)

The gaseous emissions sampling probes must be fitted at least 0,5 m or 3 times the diameter of the exhaust pipe-whichever is the larger-upstream of the exit of the exhaust gas system as far as applicable and sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe.

In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from each group with the highest CO_2 emission. Other methods which have been

shown to correlate with the above methods may be used. For exhaust emission calculation the total exhaust mass flow must be used.

If the engine is equipped with an exhaust after treatment system, the exhaust sample shall be taken downstream of the exhaust after treatment system.

3.4.2 Diluted Exhaust Gas

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements of chapter V, section 2.3.1, EP.

The gaseous emissions sample probe(s) shall be installed in the dilution tunnel at a point where the dilution air and exhaust gas are well mixed, and in close proximity to the particulates sampling probe.

Sampling can generally be done in two ways:

- the pollutants are sampled into a sampling bag over the cycle and measured after completion of the test;

- the pollutants are sampled continuously and integrated over the cycle; this method is mandatory for HC and NOx.

4. DETERMINATION OF THE PARTICULATES:

The determination of the particulates requires a dilution system. Dilution may be accomplished by a partial flow dilution system or a full flow double dilution system. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems. The temperature of the diluted exhaust gas shall be below 325 K (52 °C) immediately upstream of the filter holders. Humidity control of the dilution air before entering the dilution system is permitted, and especially dehumidifying is useful if dilution air humidity is high. The temperature of the dilution air shall be higher than 288 K (15 °C) in close proximity to the entrance into the dilution tunnel.

The partial flow dilution system has to be designed to extract a proportional raw exhaust sample from the engine exhaust stream, thus responding to excursions in the exhaust stream flow rate, and introduce dilution air to this sample to achieve a temperature below 325 K (52 °C) at the test filter. For this it is essential that the dilution ratio or the sampling ratio r_{dil} or r_s be determined such that the accuracy limits of section 3.2.1 of appendix 5 of this chapter are fulfilled. Different extraction methods can be applied, whereby the type of extraction used dictates

to a significant degree the sampling hardware and procedures to be used (section 2.2 of chapter V of this part).

In general, the particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, but sufficiently distant as to not cause interference. Therefore, the installation provisions of section 3.4.1 of this appendix also apply to particulate sampling. The sampling line shall conform to the requirements of section 2 of chapter V of this part.

In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest particulate emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emission calculation the total exhaust mass flow shall be used.

To determine the mass of the particulates, a particulate sampling system, particulate sampling filters, a microgram balance, and a temperature and humidity controlled weighing chamber, are required. For particulate sampling, the single filter method shall be applied which uses one filter (see section 4.1.3 of this appendix) for the whole test cycle. For the ESC, considerable attention must be paid to sampling times and flows during the sampling phase of the test.

4.1 Particulate Sampling Filters

The diluted exhaust shall be sampled by a filter that meets the requirements of sections 4.1.1 and 4.1.2 of this appendix during the test sequence.

4.1.1 Filter Specification

Fluorocarbon coated glass fibre filters or fluorocarbon based membrane filters are required. All filter types shall have a 0,3 µ DOP (di-octylphthalate) collection efficiency of at least 99 % at a gas face velocity between 35 and 100 cm/s.

4.1.2 Filter Size

Particulate filters must have a minimum diameter of 47 mm or 70 mm are recommended. Larger diameter filters are acceptable (section 4.1.4 of this appendix) but smaller diameter filters are not permitted.

4.1.3 Filter Face Velocity

A gas face velocity through the filter of 35 to 100 cm/s shall be achieved. The pressure drop increase between the beginning and the end of the test shall be no more than 25 kPa.

4.1.4 Filter Loading

The required minimum filter loadings for the most common filter sizes are shown in table 10. For larger filter sizes, the minimum filter loading shall be 0,065 mg/1 000 mm2 filter area.

Table 9
Minimum Filter Loadings

Filter Diameter (mm)	Minimum loading (mg)
47	0,11
70	0,25
90	0,41
110	0,62

If, based on previous testing, the required minimum filter loading is unlikely to be reached on a test cycle after optimisation of flow rates and dilution ratio, a lower filter loading may be acceptable, with the agreement of the parties involved, if it can be shown to meet the accuracy requirements of section 4.2, e.g. with a 0,1 μg balance.

4.1.5 Filter holder

For the emissions test, the filters shall be placed in a filter holder assembly meeting the requirements of section 2.2 of chapter V of this part. The filter holder assembly shall be of a design that provides an even flow distribution across the filter stain area. Quick acting valves shall be located either upstream or downstream of the filter holder. An inertial pre-classifier with a 50 % cut point between 2,5 μm and 10 μm may be installed immediately upstream of the filter holder. The use of the pre-classifier is strongly recommended if an open tube sampling probe facing upstream into the exhaust flow is used.

4.2 Weighing Chamber and Analytical Balance Specifications
The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilization.

Disturbance to weighing room specification as outlined in section 4.2.1 will be allowed if the duration of disturbance does not exceed 30 minutes. The weighing room should meet the required specification prior to personal entrance into the weighing room. At least two unused reference filter shall be weigh within 4 hours of, but preferably at the same time as sample filter weightings. They shall be the same size & material as the sample filter.

If the average weight of the reference filter changes between sample filter weightings by more than 10μg, then all sample filter shall be discarded & the emission test repeated.

If the weighing room stability criteria outlined in section 4.2.1 is not met, but the reference filter weightings meet the above criteria, the engine manufacturer has the option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system & re-running the test.

4.2.1 Weighing Chamber Conditions

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within 295K ± 3 K (22 °C ± 3 °C) during all filter conditioning and weighing. The humidity shall be maintained to a dew point of 282,5K ± 3 K (9,5 °C ± 3 °C) and a relative humidity of 45 % ± 8 %.

4.2.2 Reference Filter Weighing

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilisation. Disturbances to weighing room specifications as outlined in section 4.2.1 will be allowed if the duration of the disturbances does not exceed 30 minutes. The weighing room should meet the required specifications prior to personal entrance into the weighing room. At least two unused reference filters shall be weighed within 4 hours of, but preferably at the same time as the sample filter weightings. They shall be the same size and material as the sample filters.

If the average weight of the reference filters changes between sample filter weightings by more than 10 μg, then all sample filters shall be discarded and the emissions test repeated.

If the weighing room stability criteria outlined in section 4.2.1 is not met, but the reference filter weightings meet the above criteria, the engine manufacturer has the option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system and re-running the test.

4.2.3 Analytical Balance

The analytical balance used to determine the filter weight shall have a precision (standard deviation) of at least 2 μg and a resolution of at least 1 μg (1 digit = 1 μg) specified by the balance manufacturer.

4.2.4 Elimination of static electricity effects

To eliminate the effects of static electricity, the filters shall be neutralized prior to weighing, e.g. by a Polonium neutralizer, a Faraday cage or a device of similar effect.

4.2.5 Specifications for flow measurement

4.2.5.1 General requirements

Absolute accuracies of flow meter or flow measurement instrumentation shall be as specified in section 2.2 of this appendix.

4.2.5.2 Special provision for partial flow dilution system

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:

$$q_{mp} = q_{mdew} - q_{mdw}$$

In this case an accuracy of ± 2 % for q_{mdew} and q_{mdw} is not sufficient to guarantee acceptable accuracies of q_{mp}. If the gas flow is determined by differential flow measurement, the maximum error of the difference shall be such that the accuracy of q_{mp} is within ± 5 % 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:

The absolute accuracies of q_{mdew} and q_{mdw} are ± 0,2 % which guarantees an accuracy of q_{mp} of ≤ 5 % at a dilution ratio of 15. However, greater errors will occur at higher dilution ratios;

calibration of q_{mdw} relative to q_{mdew} is carried out such that the same accuracies

for q_{mp} as in a) are obtained. For the details of such a calibration see section

3.2.1 of appendix 5 of chapter III of this part;

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. Again, accuracies equivalent to method a) for q_{mp} are required;

the absolute accuracy of q_{mdew} and q_{mdw} is within ± 2 % of full scale, the maximum error of the difference between q_{mdew} and q_{mdw} is within 0,2 %, and the linearity error is within ± 0,2 % of the highest q_{mdew} observed during the test.

5 DETERMINATION OF SMOKE

This section provides specifications for the required and optional test equipment to be used for the ELR test. The smoke shall be measured with an opacimeter having an opacity and a light absorption coefficient readout mode. The opacity readout mode shall only be used for calibration and checking of the opacimeter. The smoke values of the test cycle shall be measured in the light absorption coefficient readout mode.

5.1 General Requirements:

The ELR requires the use of a smoke measurement and data processing system which includes three functional units. These units may be integrated into a single component or provided as a system of interconnected components. The three functional units are:

- an opacimeter meeting the specifications of chapter V, section 3 of this part.

- a data processing unit capable of performing the functions described in chapter III, appendix 1, section 6 of this part.

- a printer and/or electronic storage medium to record and output the required smoke values specified in chapter III, appendix 1, section 6.3 of this part.

5.2 Specific Requirements

5.2.1. Linearity

The linearity shall be within ± 2 % opacity.

5.2.2. Zero Drift

The zero drift during a one-hour period shall not exceed ± 1 % opacity.

5.2.3. Opacimeter Display and Range

For display in opacity, the range shall be 0-100 % opacity, and the readability 0,1 % opacity. For display in light absorption coefficient, the range shall be 0-30 m-1 light absorption coefficient, and the readability 0,01 m-1 light absorption coefficient.

5.2.4. Instrument Response Time

The physical response time of the opacimeter shall not exceed 0,2 s. The physical response time is the difference between the times when the output of a rapid response receiver reaches 10 and 90 % of the full deviation when the opacity of the gas being measured is changed in less than 0,1 s.

The electrical response time of the opacimeter shall not exceed 0,05 s. The electrical response time is the difference between the times when the opacimeter output reaches 10 and 90 % of the full scale when the light source is interrupted or completely extinguished in less than 0,01 s.

5.2.5. Neutral Density Filters

Any neutral density filter used in conjunction with opacimeter calibration, linearity measurements, or setting span shall have its value known to within 1,0 % opacity. The filter's nominal value must be checked for accuracy at least yearly using a reference traceable to a national or international standard.

Neutral density filters are precision devices and can easily be damaged during use. Handling should be minimised and, when required, should be done with care to avoid scratching or soiling of the filter.

APPENDIX 5

CALIBRATION PROCEDURE

1 Calibration of the analytical instruments:

1.1 Introduction

Each analyser shall be calibrated as often as necessary to fulfill the accuracy requirements of this part. The calibration method that shall be used is described in this section for the analysers indicated in chapter III, appendix 4, section 3 and chapter V, section 1 of this part.

1.2 Calibration gases

The shelf life of all calibration gases must be respected.

The expiration date of the calibration gases stated by the manufacturer shall be recorded.

1.2.1 Pure gases:

The required purity of the gases is defined by the contamination limits given below. The following gases must be available for operation:

Purified nitrogen

(Contamination ≤ 1 ppm C1, ≤ 1 ppm CO, ≤ 400 ppm CO_2, ≤ 0,1 ppm NO)

Purified oxygen

(Purity > 99,5 % vol O_2)

Hydrogen-helium mixture

(40 ± 2 % hydrogen, balance helium)
(Contamination ≤ 1 ppm C1, ≤ 400 ppm CO_2)

Purified synthetic air

(Contamination ≤ 1 ppm C1, ≤ 1 ppm CO, ≤ 400 ppm CO_2, ≤ 0,1 ppm NO)
(Oxygen content between 18-21 % vol.)
Purified propane or CO for the CVS verification

1.2.2 Calibration and span gases:

Mixtures of gases having the following chemical compositions shall be available:

C_3H_8 and purified synthetic air (see section 1.2.1 of this appendix);

CO and purified nitrogen;

NO_X and purified nitrogen (the amount of NO_2 contained in this calibration gas must not exceed 5 % of the NO content);

CO_2 and purified nitrogen

CH_4 and purified synthetic air

C_2H_6 and purified synthetic air

Note: Other gas combinations are allowed provided the gases do not react with one another.

The true concentration of a calibration and span gas must be within ± 2 % of the nominal value. All concentrations of calibration gas shall be given on a volume basis (volume percent or volume ppm).

1.2.3 Use of precision blending devices

The gases used for calibration and span may also be obtained by means of precision blending devices (gas dividers), diluting with purified N_2 or with purified synthetic air. The accuracy of the mixing device must be such that the concentration of the blended calibration gases is accurate to within ± 2 %. This accuracy implies that primary gases used for blending must be known to an accuracy of at least ± 1 %, traceable to national or international gas standards. The verification shall be performed at between 15 and 50 % of full scale for each calibration incorporating a blending device.

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

1.3 Operating Procedure for Analysers and Sampling System

The operating procedure for analysers shall follow the start-up and operating instructions of the instrument manufacturer. The minimum requirements given in sections 1.4 to 1.9 of this appendix shall be included.

1.4 Leakage test

A system leakage test shall be performed. The probe shall be disconnected from the exhaust system and the end plugged. The analyzer pump shall be switched on. After an initial stabilisation period all flow meters should read zero. If not, the sampling lines shall be checked and the fault corrected.

The maximum allowable leakage rate on the vacuum side shall be 0,5 % of the in-use flow rate for the portion of the system being checked. The analyser flows and bypass flows may be used to estimate the in-use flow rates.

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

$$\Delta p = p / V_s \times 0,005 \times q_{vs}$$

Where,

V_s = system volume, l

q_{vs} = system flow rate, l/min

Another method is the introduction of a concentration step change at the beginning of the sampling line by switching from zero to span gas. If after an adequate period of time the reading is about 1 % low compared to the introduced concentration, these points to calibration or leakage problems.

1.5 Response time check of analytical system :

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 second. The gases used for the test shall cause a concentration change of at least 60 % 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 % of the final reading (t_{10}). The rise time is defined as the time between 10 % and 90 % response of the final reading (t_{90} - t_{10}).

For time alignment of the analyzer and exhaust flow signals in the case of raw measurement, the transformation time is defined as the time from the change (t_0) until the response is 50 % of the final reading (t_{50}).

The system response time shall be $\leq$ 10 seconds with a rise time $\leq$ 3,5 seconds for all limited components (CO, NO_x, HC or NMHC) and all ranges used.

1.6 Calibration Procedure:

1.6.1 Instrument Assembly

The instrument assembly shall be calibrated and calibration curves checked against standard gases. The same gas flow rates shall be used as when sampling exhaust.

1.6.2 Warming-up Time

The warming-up time should be according to the recommendations of the manufacturer. If not specified, a minimum of two hours is recommended for warming up the analysers.

1.6.3 NDIR and HFID Analyser

The NDIR analyser shall be tuned, as necessary, and the combustion flame of the HFID analyser shall be optimised (section 1.8.1 of this appendix).

1.6.4 Establishment of the calibration curve

- Each normally used operating range shall be calibrated

- Using purified synthetic air (or nitrogen), the CO, CO_2, NO_X and HC analysers shall be set at zero

- The appropriate calibration gases shall be introduced to the analysers, the values recorded, and the calibration curve established

- The calibration curve shall be established by at least 6 calibration points (excluding zero) approximately equally spaced over the operating range.

The highest nominal concentration shall be equal to or higher than 90 % of full scale.

- The calibration curve shall be calculated by the method of least squares. A best-fit linear or non-linear equation may be used

- The calibration points shall not differ from the least-squares best-fit line by more than ± 2 % of reading or ± 0,3 % of full scale whichever is larger

- The zero setting shall be rechecked and the calibration procedure repeated, if necessary.

1.6.5 Alternative methods

If it can be shown that alternative technology (e.g. computer, electronically controlled range switch, etc.) can give equivalent accuracy, then these alternatives may be used.

1.6.6 Calibration of tracer gas analyser for exhaust flow measurement

The calibration curve shall be established by at least 6 calibration points (excluding zero) approximately equally spaced over the operating range. The highest nominal concentration shall be equal to or higher than 90 % of full scale. The calibration curve is calculated by the method of least squares.

The calibration points shall not differ from the least-squares best-fit line by more than ± 2 % of reading or ± 0,3 % of full scale whichever is larger.

The analyser shall be set at zero and spanned prior to the test run using a zero gas and a span gas whose nominal value is more than 80 % of the analyser full scale.

1.6.7 Verification of the Calibration

Each normally used operating range shall be checked prior to each analysis in accordance with the following procedure.

The calibration shall be checked by using a zero gas and a span gas whose nominal value is more than 80 % of full scale of the measuring range.

If, for the two points considered, the value found does not differ by more than ± 4 % of full scale from the declared reference value, the adjustment parameters may be modified. Should this not be the case, a new calibration curve shall be established in accordance with section 1.5.5 of this appendix.

1.7 Efficiency test of the NOx Converter

The efficiency of the converter used for the conversion of NO_2 into NO shall be tested as given in sections 1.7.1 to 1.7.8 (Figure 6) of this appendix.

1.7.1 Test Set-up

Using the test set-up as shown in Figure 6 (see also chapter III, appendix 4, section 3.3.5 of this part) and the procedure below, the efficiency of converters can be tested by means of an ozonator.

1.7.2 Calibration

The CLD and the HCLD shall be calibrated in the most common operating range following the manufacturer's specifications using zero and span gas (the NO content of which must amount to about 80 % of the operating range and the NO_2 concentration of the gas mixture to less than 5 % of the NO concentration). The NO_X analyser must be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

1.7.3 Calculation

The efficiency of the NO_x converter is calculated as follows:

$$\text{Efficiency (\%)} = \left(1 + \frac{a - b}{c - d} \right) \times 100$$

where,

a is the NOx concentration according to section 1.7.6

b is the NOx concentration according to section 1.7.7

c is the NO concentration according to section 1.7.4

d is the NO concentration according to section 1.7.5

1.7.4 Adding of Oxygen

Via a T-fitting, oxygen or zero air is added continuously to the gas flow until the concentration indicated is about 20 % less than the indicated calibration concentration given in section 1.7.2 of this appendix (The analyser is in the NO mode). The indicated concentration c shall be recorded. The ozonator is kept deactivated throughout the process.

1.7.5 Activation of the Ozonator

The ozonator is now activated to generate enough ozone to bring the NO concentration down to about 20 % (minimum 10 %) of the calibration concentration given in section 1.7.2 of this appendix. The indicated concentration d shall be recorded (The analyser is in the NO mode).

1.7.6 NO$_X$ Mode

The NO analyser is then switched to the NOx mode so that the gas mixture (consisting of NO, NO$_2$, O$_2$ and N$_2$) now passes through the converter. The indicated concentration a shall be recorded. (The analyser is in the NO$_X$ mode).

1.7.7 Deactivation of the Ozonator

The ozonator is now deactivated. The mixture of gases described in section 1.7.6 of this appendix passes through the converter into the detector. The indicated concentration b shall be recorded. (The analyser is in the NO$_X$ mode).

1.7.8 NO Mode

Switched to NO mode with the ozonator deactivated, the flow of oxygen or synthetic air is also shut off. The NOx reading of the analyser shall not deviate by more than ± 5 % from the value measured according to section 1.7.2. of this appendix (The analyser is in the NO mode).

1.7.9 Test Interval

The efficiency of the converter must be tested prior to each calibration of the NO$_X$ analyser.

1.7.10 Efficiency Requirement

The efficiency of the converter shall not be less than 90 %, but a higher efficiency of 95 % is strongly recommended.

Note: If, with the analyser in the most common range, the ozonator cannot give a reduction from 80 % to 20 % according to section 1.7.5 of this appendix, then the highest range which will give the reduction shall be used.

Figure 6

Schematic of NOₓ converter efficiency device
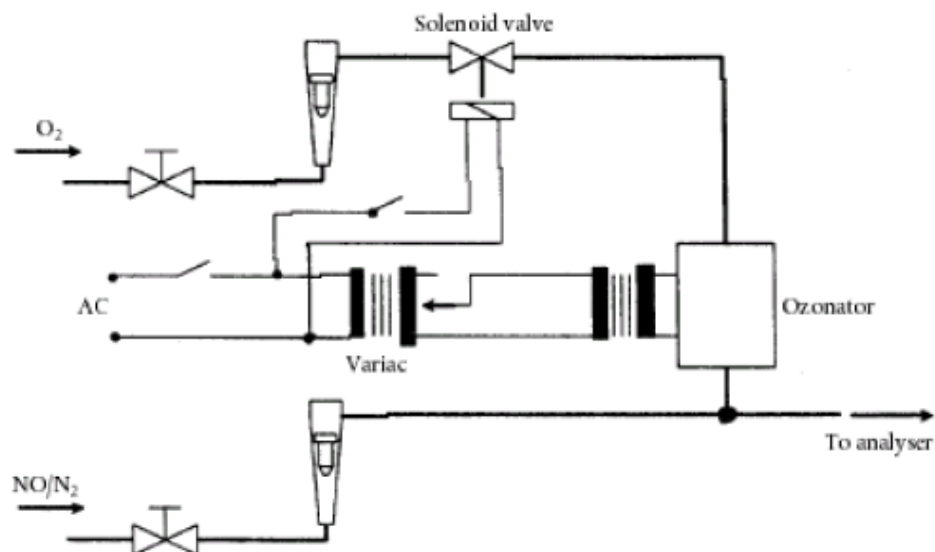
1.8 Adjustment of the FID

1.8.1 Optimisation of the Detector Response

The FID must be adjusted as specified by the instrument manufacturer. A propane in air span gas should be used to optimise the response on the most common operating range.

With the fuel and air flow rates set at the manufacturer's recommendations, a 350 ± 75 ppm C span gas shall be introduced to the analyser. 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.

1.8.2 Hydrocarbon Response Factors

The analyser shall be calibrated using propane in air and purified synthetic air, according to section 1.5 of this appendix.

Response factors shall be determined when introducing an analyser into service and after major service intervals. The response factor (R_f) for a particular hydrocarbon species is the ratio of the FID C1 reading to the gas concentration in the cylinder expressed by ppm C1.

The concentration of the test gas must be at a level to give a response of approximately 80 % of full scale. The concentration must be known to an accuracy of ± 2 % in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder must be preconditioned for 24 hours at a temperature of 298 K ± 5 K (25 °C ± 5 °C).

The test gases to be used and the recommended relative response factor ranges are as follows:

Methane and purified synthetic air $1,00 < = R_f < = 1,15$

Propylene and purified synthetic air $0,90 < = R_f < = 1,10$

Toluene and purified synthetic air $0,90 < = R_f < = 1,10$

These values are relative to the response factor (R_f) of 1,00 for propane and purified synthetic air.

1.8.3 Oxygen Interference Check

The oxygen interference check shall be determined when introducing an analyzer into service and after major service intervals.

The response factor is defined and shall be determined as described in section 1.8.2 of this appendix. The test gas to be used and the recommended relative response factor range are as follows:

Propane and nitrogen $0,95 \leq R_f \leq 1,05$

This value is relative to the response factor (R_f) of 1,00 for propane and purified synthetic air.

The FID burner air oxygen concentration must be within ± 1 mole% of the oxygen concentration of the burner air used in the latest oxygen interference check. If the difference is greater, the oxygen interference must be checked and the analyzer adjusted, if necessary.

1.8.4 Efficiency of the Non-Methane Cutter (NMC, For NG Fuelled Gas Engines Only)

The NMC is used for the removal of the non-methane hydrocarbons from the sample gas by oxidising all hydrocarbons except methane. Ideally, the conversion for methane is 0 %, and for the other hydrocarbons represented by ethane is 100 %. For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emission mass flow rate (see chapter III, appendix 2, section 4.3 of this part).

1.8.4.1 Methane Efficiency

Methane calibration gas shall be flown through the FID with and without by passing the NMC and the two concentrations recorded. The efficiency shall be determined as follows:

$$CE_M = 1 - \frac{conc_w}{conc_{w/o}}$$

where,

concw = HC concentration with CH_4 flowing through the NMC

concw/o = HC concentration with CH_4 bypassing the NMC

1.8.4.2 Ethane Efficiency

Ethane calibration gas shall be flown through the FID with and without bypassing the NMC and the two concentrations recorded. The efficiency shall be determined as follows:

$$CE_E = 1 - \frac{conc_w}{conc_{w/o}}$$

where,

concw = HC concentration with C_2H_6 flowing through the NMC

concw/o = HC concentration with C_2H_6 bypassing the NMC

1.9 Interference Effects with CO, CO_2, and NO_X Analysers

Gases present in the exhaust other than the one being analysed can interfere with the reading in several ways. Positive interference occurs in NDIR instruments where the interfering gas gives the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments by the interfering gas broadening the absorption band of the measured gas, and in CLD instruments by the interfering gas quenching the radiation. The interference checks in sections 1.9.1 and 1.9.2 of this appendix

shall be performed prior to an analyser's initial use and after major service intervals.

1.9.1 CO Analyser Interference Check

Water and CO_2 can interfere with the CO analyser performance. Therefore, a CO_2 span gas having a concentration of 80 to 100 % of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyser response recorded. The analyser response must not be more than 1 % of full scale for ranges equal to or above 300 ppm or more than 3 ppm for ranges below 300 ppm.

1.9.2 NO_X Analyser Quench Checks

The two gases of concern for CLD (and HCLD) analysers are CO_2 and water vapour. Quench responses to these gases are proportional to their concentrations, and therefore require test techniques to determine the quench at the highest expected concentrations experienced during testing.

1.9.2.1 CO_2 Quench Check

A CO_2 span gas having a concentration of 80 to 100 % of full scale of the maximum operating range shall be passed through the NDIR analyser and the CO_2 value recorded as A. It shall then be diluted approximately 50 % with NO span gas and passed through the NDIR and (H)CLD, with the CO_2 and NO values recorded as B and C, respectively. The CO_2 shall then be shut off and only the NO span gas be passed through the (H)CLD and the NO value recorded as D.

The quench, which must not be greater than 3 % of full scale, shall be calculated as follows:

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

where,

A is the undiluted CO_2 concentration measured with NDIR in %

B is the diluted CO_2 concentration measured with NDIR in %

C is the diluted NO concentration measured with (H)CLD in ppm

D is the undiluted NO concentration measured with (H)CLD in ppm

Alternative methods of diluting and quantifying of CO_2 and NO span gas values such as dynamic mixing/blending can be used.

1.9.2.2 Water Quench Check

This check applies to wet gas concentration measurements only. Calculation of water quench must consider dilution of the NO span gas with water vapour and scaling of water vapour concentration of the mixture to that expected during testing.

A NO span gas having a concentration of 80 to 100 % of full scale of the normal operating range shall be passed through the (H)CLD and the NO value recorded as D. The NO span gas shall then be bubbled through water at room temperature and passed through the (H)CLD and the NO value recorded as C. The analyser's absolute operating pressure and the water temperature shall be determined and recorded as E and F, respectively. The mixture's saturation vapour pressure that corresponds to the bubbler water temperature F shall be determined and recorded as G. The water vapour concentration (H, in %) of the mixture shall be calculated as follows:

$$H = 100 \times (G/E)$$

The expected diluted NO span gas (in water vapour) concentration (D_e) shall be calculated as follows:

$$D_e = D \times (1 - H/100)$$

For diesel exhaust, the maximum exhaust water vapour concentration (Hm, in %) expected during testing shall be estimated, under the assumption of a fuel atom H/C ratio of 1,8:1, from the undiluted CO2 span gas concentration (A, as measured in section 1.9.2.1 of this appendix) as follows:

$$Hm = 0{,}9 \times A$$

The water quench, which must not be greater than 3 %, shall be calculated as follows:

$$\% \text{ Quench} = 100 \times ((D_e - C) / D_e) \times H_m / H)$$

where,

D_e= is the expected diluted NO concentration in ppm

C= is the diluted NO concentration in ppm

H_m= is the maximum water vapour concentration in %

H= is the actual water vapour concentration in %

Note: It is important that the NO span gas contains minimal NO_2 concentration for this check, since absorption of NO_2 in water has not been accounted for in the quench calculations.

1.10 Calibration Intervals

The analysers shall be calibrated according to section 1.5 at least every 3 months or whenever a system repair or change is made that could influence calibration.

2 CALIBRATION OF THE CVS-SYSTEM

2.1 General

The CVS system shall be calibrated by using an accurate flow meter traceable to national or international standards and a restricting device. The flow through the system shall be measured at different restriction settings, and the control parameters of the system shall be measured and related to the flow.

Various types of flow meters may be used, e.g. calibrated venturi, calibrated laminar flow meter, calibrated turbine meter.

2.2 Calibration of the Positive Displacement Pump (PDP)

All parameters related to the pump shall be simultaneously measured with the parameters related to the flow meter, which is connected in series with the pump. The calculated flow rate (in m^3/min at pump inlet, absolute pressure and temperature) shall be plotted versus a correlation function, which is the value of a specific combination of pump parameters. The linear equation which relates the pump flow and the correlation function shall then be determined. If a CVS has a multiple speed drive, the calibration shall be performed for each range used. Temperature stability shall be maintained during calibration.

2.2.1 Data Analysis

The airflow rate (Q_s) at each restriction setting (minimum 6 settings) shall be calculated in standard m^3/min from the flow meter data using the manufacturer's prescribed method. The airflow rate shall then be converted to pump flow (V_0) in m^3/rev at absolute pump inlet temperature and pressure as follows:

$$V_o = \frac{Q_s}{n} \times \frac{T}{273} \times \frac{101.3}{PA}$$

where,

Q$_s$ = air flow rate at standard conditions (101,3 kPa, 273 K), m^3/s

T = temperature at pump inlet, K

p$_A$ = absolute pressure at pump inlet (p_B-p_1), kPa

n = pump speed, rev/s

To account for the interaction of pressure variations at the pump and the pump slip rate, the correlation function (X_0) between pump speed, pressure differential from pump inlet to pump outlet and absolute pump outlet pressure shall be calculated as follows:

$$X_o = \frac{1}{n} \times \sqrt{\frac{\Delta Pp}{P_A}}$$

where,

Δp_p = pressure differential from pump inlet to pump outlet, kPa

p$_A$ = absolute outlet pressure at pump outlet, kPa

A linear least-square fit shall be performed to generate the calibration equation as follows:

$$V_o = D_o - m \times (X_o)$$

D$_o$ and m are the intercept and slope constants, respectively, describing the regression lines.

For a CVS system with multiple speeds, the calibration curves generated for the different pump flow ranges shall be approximately parallel, and the intercept values (D_0) shall increase as the pump flow range decreases.

The calculated values from the equation shall be within ± 0,5 % of the measured value of V_0. Values of m will vary from one pump to another. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for m. Therefore, calibration shall be performed at pump start-up, after major maintenance, and if the total system verification (section 2.4 of this appendix) indicates a change of the slip rate.

2.3 Calibration of the Critical Flow Venturi (CFV)

Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of inlet pressure and temperature, as shown below:

$$Qs = \frac{K_V \times P_A}{\sqrt{T}}$$

where,

K$_v$ = calibration coefficient

P$_A$ = absolute pressure at venturi inlet, kPa

T= temperature at venturi inlet, K

2.3.1 Data Analysis

The air flowrate (Q$_s$) at each restriction setting (minimum 8 settings) shall be calculated in standard m^3/min from the flowmeter data using the manufacturer's prescribed method. The calibration coefficient shall be calculated from the calibration data for each setting as follows:

$$K_V = \frac{Q_s \sqrt{T}}{PA}$$

where,

Q$_s$ = air flow rate at standard conditions (101,3 kPa, 273 K), m^3/s

T = temperature at the venturi inlet, K

p$_A$ = absolute pressure at venturi inlet, kPa

To determine the range of critical flow, K$_v$ shall be plotted as a function of venturi inlet pressure. For critical (choked) flow, K$_v$ will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and K$_v$ decreases, which indicates that the CFV is operated outside the permissible range.

For a minimum of eight points in the region of critical flow, the average K$_v$ and the standard deviation shall be calculated. The standard deviation shall not exceed ± 0,3 % of the average Kv.

2.4 Calibration of the Subsonic Venturi (SSV)

Calibration of the SSV is based upon the flow equation for a subsonic venturi. Gas flow is a function of inlet pressure and temperature, pressure drop between the SSV inlet and throat.

2.4.1 Data analysis

The air flowrate (Q_{SSV}) at each restriction setting (minimum 16 settings) shall be calculated in standard m^3/min from the flowmeter data using the manufacturer's prescribed method. The discharge coefficient shall be calculated from the calibration data for each setting as follows:

$$Q_{SSV} = A_0 d^2 C_d p_p \sqrt{\frac{1}{T}\left(r_p^{1,4286} - r_p^{1,7143}\right) \times \left(\frac{1}{1 - r_D^4 r_p^{1,4286}}\right)}$$

where:

Q_{SSV} = air flow rate at standard conditions (101,3 kPa, 273 K), m^3/s

T = temperature at the venturi inlet, K

d = diameter of the SSV throat, m

r_p = ratio of the SSV throat to inlet absolute, static pressure = $1 - \dfrac{\Delta P}{P_A}$

r_D = ratio of the SSV throat diameter, d, to the inlet pipe inner diameter = d / D

To determine the range of subsonic flow, C_d shall be plotted as a function of Reynolds number at the SSV throat. The Re at the SSV throat is calculated with the following formula:

$$Re = A_1 \frac{Q_{SSV}}{d\mu}$$

where:

A_1 = a collection of constants and units conversions

$$= 25,55152 \frac{\left(\frac{1}{m^3}\right)\left(\frac{min}{s}\right)\left(\frac{mm}{m}\right)}{}$$

Q_{SSV} = air flow rate at standard conditions (101,3 kPa, 273 K), m³/s

d = diameter of the SSV throat, m

μ = absolute or dynamic viscosity of the gas, calculated with the following formula:

$$\mu = \frac{bT^{3/2}}{S+T} = \frac{bT^{1/2}}{1+\frac{S}{T}} \text{ kg/m-s}$$

b = empirical constant = $1{,}458 \times 10^6 \dfrac{kg}{msK^{\frac{1}{2}}}$

S = empirical constant = 110,4 K

Because Q_{SSV} is an input to the Re formula, the calculations must be started with an initial guess for Q_{SSV} or C_d of the calibration venturi, and repeated until Q_{SSV} converges. The convergence method must be accurate to 0,1 % of point or better.

For a minimum of sixteen points in the region of subsonic flow, the calculated values of C_d from the resulting calibration curve fit equation must be within ±0,5% of the measured C_d for each calibration point.

2.5 Total System Verification:

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 analysed, and the mass calculated according to chapter III, appendix 2, section 4.3 of this part except in the case of propane where a factor of 0,000472 is used in place of 0,000479 for HC. Either of the following two techniques shall be used.

2.5.1 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 analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined shall be within ± 3 % of the known mass of the gas injected.

2.5.2 Metering by Means of a Gravimetric Technique

The weight of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ± 0,01 gram. 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 analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined shall be within ± 3 % of the known mass of the gas injected.

3 CALIBRATION OF THE PARTICULATE MEASURING SYSTEM

3.1 Introduction

The calibration of the particulate measurement is limited to the flow meters used to determine sample flow and dilution ratio. Each flow meter shall be calibrated as often as necessary to fulfill the accuracy requirements of this Document. The calibration method that shall be used is described in section 3.2 of this appendix.

3.2 Flow measurement

3.2.1 Periodical calibration

- To fulfill the absolute accuracy of the flow measurements as specified in section 2.2 of appendix 4 of this Chapter, the flow meter or the flow measurement instrumentation shall be calibrated with an accurate flow meter traceable to international and/or national standards.

- If the sample gas flow is determined by differential flow measurement 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 fulfill the accuracy requirements of section 4.2.5.2 of appendix 4 of this Chapter:

> a) The flow meter for q_{mdw} shall be connected in series to the flow meter for q_{mdew}, 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_{mdw} value used during the test and the value of q_{mdew} used during the test. The dilution tunnel may be bypassed.
>
> b) A calibrated mass flow device shall be connected in series to the flow meter for q_{mdew} and the accuracy shall be checked for the value used for the test. Then the calibrated mass flow device shall be connected in series to the flow meter for q_{mdw}, and the accuracy

shall be checked for at least 5 settings corresponding to dilution ratio between 3 and 50, relative to q_{mdew} used during the test.

c) The transfer tube TT 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. Then q_{mdew} shall be set to the value used during the test, and q_{mdw} shall be sequentially set to at least 5 values corresponding to dilution ratios q between 3 and 50. 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 50. The accuracy of the sample flow shall be determined from the dilution ration r_d:

$$q_{mp} = \frac{q_{mdew}}{r_d}$$

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

3.2.2 Carbon flow check

- 1A carbon flow check using actual exhaust is recommended for detecting measurement and control problems and verifying the proper operation of the partial flow system. The carbon flow check should be run at least each time a new engine is installed, or something significant is changed in the test cell configuration.

- The engine shall be operated at peak torque load and speed or any other steady state mode that produces 5 % or more of CO_2. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.

- If a carbon flow check is conducted, the procedure given in appendix 6 of this Chapter shall be applied. The carbon flow rates shall be calculated according to sections 2.1 to 2.3 of appendix 6 of this Chapter. All carbon flow rates should agree to within 6 % of each other.

3.2.3 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 section 3.2.1 of this appendix) for at least two points, including flow values of q_{mdw} that correspond to dilution ratios between 5 and 15 for the q_{mdew} value used during the test.
- If it can be demonstrated by records of the calibration procedure under section 3.2.1 of this appendix that the flow meter calibration is stable over a longer period of time, the pre-test check may be omitted.

3.3 Determination of transformation time (for partial flow dilution systems on ETC only)

- The system settings for the transformation time evaluation shall be exactly the same as during measurement of the test run. The transformation time 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 flow meter response. In a similar manner, the transformation times of the q_{mp} signal of the partial flow dilution system and of the $q_{mew,i}$ signal of the exhaust flow meter shall be determined. These signals are used in the regression checks performed after each test (see section 3.8.3.2 of appendix 2 of this chapter).

- The calculation shall be repeated for at least 5 rise and fall stimuli, and the results shall be averaged. The internal transformation time (< 100 msec) of the reference flowmeter shall be subtracted from this value. This is the "look-ahead" value of the partial flow dilution system, which shall be applied in accordance with section 3.8.3.2 of appendix 2 of this chapter.

3.4 Checking the partial flow conditions

The range of the exhaust gas velocity and the pressure oscillations shall be checked and adjusted according to the requirements of section 2.2.1 of chapter V (EP), if applicable.

3.5 Calibration intervals

The flow measurement instrumentation shall be calibrated at least every 3 months or whenever a system repair or change is made that could influence calibration.

4 CALIBRATION OF THE SMOKE MEASUREMENT EQUIPMENT

4.1 Introduction

The opacimeter shall be calibrated as often as necessary to fulfill the accuracy requirements of this part. The calibration method to be used is described in this section for the components indicated in chapter III, appendix 4, section 5 of this part and chapter V, section 3 of this part.

4.2 Calibration Procedure

4.2.1 Warming-up Time

The opacimeter shall be warmed up and stabilised according to the manufacturer's recommendations. If the opacimeter is equipped with a purge air system to prevent sooting of the instrument optics, this system should also be activated and adjusted according to the manufacturer's recommendations.

4.2.2 Establishment of the Linearity Response

The linearity of the opacimeter shall be checked in the opacity readout mode as per the manufacturer's recommendations. Three neutral density filters of known transmittance, which shall meet the requirements of chapter III, appendix 4,section 5.2.5 of this part, shall be introduced to the opacimeter and the value recorded. The neutral density filters shall have nominal opacities of approximately 10 %, 20 and 40 %.

The linearity must not differ by more than ± 2 % opacity from the nominal value of the neutral density filter. Any non-linearity exceeding the above value must be corrected prior to the test.

4.3 Calibration Intervals
The opacimeter shall be calibrated according to section 4.2.2 of this appendix at least every 3 months or whenever a system repair or change is made that could influence calibration.

Appendix 6

## CARBON FLOW CHECK

1. INTRODUCTION

All but a tiny part of the carbon in the exhaust comes from the fuel, and all but a minimal part of this is manifest in the exhaust gas as CO_2. This is the basis for a system verification check based on CO_2 measurements.

The flow of carbon into the exhaust measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO_2 concentrations and gas flow rates at those points.

In this sense, the engine provides a known source of carbon flow, and observing the same carbon flow in the exhaust pipe and at the outlet of the partial flow PM sampling system verifies leak integrity and flow measurement accuracy. This check has the advantage that the components are operating under actual engine test conditions of temperature and flow.

The following diagram shows the sampling points at which the carbon flows shall be checked. The specific equations for the carbon flows at each of the sample points are given below.

Figure 7

Measuring points for carbon flow check

Partial Flow System
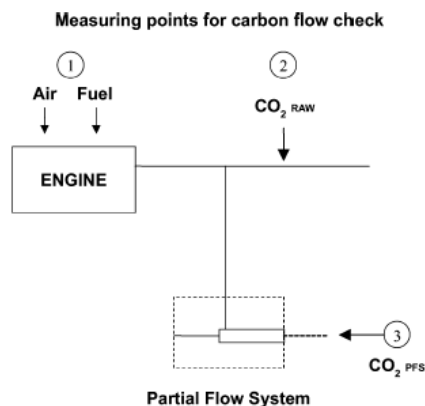
2 CALCULATIONS

2.1 Carbon flow rate into the engine (location 1)

The carbon mass flow rate into the engine for a fuel $CH_\alpha O_\varepsilon$ is given by:

$$q_{mCf} = \frac{12,011}{12,011 + \alpha + 15,9994 \times \varepsilon} \times q_{mf}$$

where:

q_{mf} = fuel mass flow rate, kg/s

2.2 Carbon flow rate in the raw exhaust (location 2)

The carbon mass flow rate in the exhaust pipe of the engine shall be determined from the raw CO_2 concentration and the exhaust gas mass flow rate:

$$q_{mCe} = \left(\frac{c_{CO2,r} - c_{CO2,a}}{100} \right) \times q_{mew} \times \frac{12,011}{M_{re}}$$

where:

$c_{CO2,r}$ = wet CO_2 concentration in the raw exhaust gas, %

$c_{CO2,a}$ = wet CO_2 concentration in the ambient air, % (around 0,04 %)

q_{mew} = exhaust gas mass flow rate on wet basis, kg/s

M_{re} = molecular mass of exhaust gas

If CO_2 is measured on a dry basis it shall be converted to a wet basis according to section 5.2 of appendix 1 of this chapter.

2.3 Carbon flow rate in the dilution system (location 3)

The carbon flow rate shall be determined from the dilute CO_2 concentration, the exhaust gas mass flow rate and the sample flow rate:

$$q_{mCp} = \left(\frac{c_{CO2,d} - c_{CO2,a}}{100} \right) \times q_{mdew} \times \frac{12,011}{M_{re}} \times \frac{q_{mew}}{q_{mp}}$$

where:

$c_{CO2,d}$ = wet CO_2 concentration in the dilute exhaust gas at the outlet of the dilution tunnel, %

$c_{CO2,a}$ = wet CO_2 concentration in the ambient air, % (around 0,04 %)

q_{mdew} = diluted exhaust gas mass flow rate on wet basis, kg/s

q_{mew} = exhaust gas mass flow rate on wet basis, kg/s (partial flow system only)

q_{mp} = sample flow of exhaust gas into partial flow dilution system, kg/s (partial flow system only)

M_{re} = molecular mass of exhaust gas

If CO_2 is measured on a dry basis, it shall be converted to wet basis according to section 5.2 of appendix 1 of this chapter.

2.4 The molecular mass (M_{re}) of the exhaust gas shall be calculated as follows:

$$M_{re} = \frac{1 + \frac{q_{mf}}{q_{maw}}}{\frac{q_{mf}}{q_{maw}} \times \frac{\frac{\alpha}{4} + \frac{\varepsilon}{2} + \frac{\delta}{2}}{12,011 + 1,00794 \times \alpha + 15,9994 \times \varepsilon + 14,0067 \times \delta + 32,065 \times \gamma} + \frac{\frac{H_a \times 10^{-3}}{2 \times 1,00794 + 15,9994} + \frac{1}{M_m}}{1 + H_a \times 10^{-3}}}$$

where:

q_{mf} = fuel mass flow rate, kg/s

q_{maw} = intake air mass flow rate on wet basis, kg/s

H_a = humidity of intake air, g water per kg dry air

M_{ra} = molecular mass of dry intake air (= 28,9 g/mol)

$\alpha, \delta, \varepsilon, \gamma$ = molar ratios referring to a fuel $CH_\alpha O_\delta N_\varepsilon S_\gamma$

Alternatively, the following molecular masses may be used:

M_{re} (diesel) = 28,9 g/mol

M_{re} (LPG) = 28,6 g/mol

M_{re} (NG) = 28,3 g/mol