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A WORKING DOCUMENT FOR THE UK DEPARTMENT FOR TRANSPORT PRESENTING AN UPDATED AND RESTRUCTURED VERSION OF REGULATION 49, ANNEX 4

R49 Annex Working Document

Annex 4

TEST PROCEDURE

1. INTRODUCTION

1.1. Overview

This Annex describes the methods of determining emissions of gaseous components, particulates (mass), particles (number) and smoke from the engines to be tested. Three test cycles are described that shall be applied according to the provisions of the Regulation, Paragraph 6.2:

1.1.1. the ESC which consists of a steady state 13-mode cycle,

1.1.2. the ELR which consists of transient load steps at different speeds, which are integral parts of one test procedure, and are run concurrently;

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

1.2. Measurement Principle

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

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 and particles (where applicable) 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. 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 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. **The engine exhaust shall be diluted**

with conditioned ambient air, and during the test cycle one particulate sample shall be collected on a single suitable filter. The particulate sample shall comprise a number of short duration sampling periods each taken during a separate speed and power mode. The duration of sampling shall be in proportion to the weighting factor at each mode. The grams of each pollutant emitted per kilowatt-hour (kWh) shall be calculated as described in section 4 of this Annex. Additionally, NO_x shall be measured at three test points within the control area selected by the Technical Service[1] 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.

1.4. 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 after diluting the total exhaust gas with conditioned ambient air. 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. The concentration of NO_x and HC shall be determined over the cycle by integration of the analyser signal. The concentration of CO, CO_2, and NMHC may be determined by integration of the analyser signal or by bag sampling. For the determination of the total mass of particulates, a proportional sample shall be collected on a suitable filter. The particle number shall be determined by integration over cycle time. The 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 (kWh), as described in section 7 of this Annex.

1.5. 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 per cent to 100 per cent load at three different engine speeds. Additionally, a fourth load step selected by the Technical Service[1] 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 section 5.5 of this Annex.

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

2. TEST CONDITIONS

2.1. Ambient Conditions

2.1.1. The absolute temperature (T_a) of the engine air at the inlet to the engine expressed in Kelvins, and the dry atmospheric pressure (p_s), expressed in kPa shall be measured and the parameter F shall be determined according to the following provisions:

(a) for diesel engines:

Naturally aspirated and mechanically supercharged engines:

$$F = \left(\frac{99}{p_s}\right) * \left(\frac{T_a}{298}\right)^{0,7}$$

Turbocharged engines with or without cooling of the intake air:

$$F = \left(\frac{99}{p_s}\right)^{0,7} * \left(\frac{T_a}{298}\right)^{1,5}$$

(b) for gas engines:

$$F = \left(\frac{99}{p_s}\right)^{1,2} * \left(\frac{T_a}{298}\right)^{0,6}$$

2.1.2. Test validity

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

$$0.96 \leq F \leq 1.06$$

2.2. Test Engine

2.2.1. 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 in Annex 1, Appendix 1, Paragraph 1.16.3. 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 in Annex 1, Appendix 1, Paragraph 1.16.3. 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.

2.2.2. 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.

2.2.3. 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 per cent 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 Appendix 3, section 1.1.1 and in Appendix 2, section 3.1., EP and Paragraph 2.3.1., EP.

If the engine is equipped with an exhaust after-treatment device, the exhaust pipe shall 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 back-pressure 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.

2.2.4. Cooling system

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

2.2.5. Testing of exhaust after-treatment systems

If the engine is equipped with an exhaust after-treatment system, the emissions measured on the test cycle(s) shall be representative of the emissions in the field. If this cannot be achieved with one single test cycle (e.g. for particulate filters with periodic regeneration), several test cycles shall be conducted and the test results averaged and/or weighted. The exact procedure shall be agreed between the engine manufacturer and the Technical Service based upon good engineering judgement.

2.3. 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 Annex 1, Appendix 1, Paragraph 7.1.

2.4. Fuel

The fuel shall be the reference fuel specified in Annexes 5, 6 or 7.

The fuel temperature and measuring point shall be specified by the manufacturer, these shall lie within the limits given in Annex 1, Appendix 1, Paragraph 1.16.5. 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 Annex 1, Appendix 1, Paragraph 1.16.5. or in Annex 1, Appendix 3, Paragraph 1.16.5. in cases where the engine is not a parent engine.

3. TEST EQUIPMENT

3.1. Engine Dynamometer & Test Cell Equipment

An engine dynamometer and other general test cell equipment as defined in Appendix 1 shall be used.

3.2. Full Flow Exhaust Dilution System

For the ETC, only a full flow dilution system as described in Appendix 2 shall be used for determining gaseous and particulate emissions, and is considered the reference system. However, partial flow dilution systems may be approved by the Technical Service, if their equivalency according to Paragraph 6.2. to the Regulation is proven, and if a detailed description of the data evaluation and calculation procedures is submitted to the Technical Service.

3.3. Gaseous Emissions Sampling and Analysis Equipment

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.

For the ETC, gaseous emissions shall be determined in the dilute exhaust gas of a full flow dilution system as described in Appendix 2.

3.4. Particulate Mass Emissions Measurement

For the ESC, the particulates shall be measured using a partial flow dilution particulate sampling system as described in Appendix 4. Optionally, a full flow system may be used.

For the ETC, the particulates shall be measured using a full flow dilution system, and a secondary dilution particulate sampling system as described in Appendix 4.

3.5. Particle Number Emissions Measurement (ETC only)

For the ETC, the particle numbers shall be measured using a full flow dilution system, and a secondary dilution particulate sampling system as described in Appendix 4. For the determination of particle numbers, a particle sampling system as described in Appendix 5 shall be employed.

3.6. Smoke Measurement Equipment (ELR only)

For the ELR, smoke shall be measured using an opacimeter according to Appendix 6.

4. ESC TEST PROCEDURE

4.1. Test Cycle

4.1.1. 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 per cent of the declared maximum net power P(n), as determined in Annex 1, Appendix 1, Paragraph 8.2. 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 per cent of the declared maximum net power P(n), as determined in Annex 1, Appendix 1, Paragraph 8.2. 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:

$$\text{Speed A} = n_{lo} + 25\,\%\,(n_{hi} - n_{lo})$$
$$\text{Speed B} = n_{lo} + 50\,\%\,(n_{hi} - n_{lo})$$
$$\text{Speed C} = n_{lo} + 75\,\%\,(n_{hi} - n_{lo})$$

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 Regulation No. 24 for an accurate determination of n_{hi} and n_{lo}. The maximum power, n_{hi} and n_{lo} 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, n_{hi} and n_{lo} 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 per cent 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.

4.1.2. Determination of dynamometer settings

4.1.3. 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 Annex 1, Appendix 1, Paragraph 8.2. 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:

$$s = P(n) * \frac{L}{100}$$

if tested under net conditions

$$s = P(n) * \frac{L}{100} + \left(P(a) - P(b)\right)$$

if not tested under net conditions

where:

s = dynamometer setting, kW

P(n)= net engine power as indicated in Annex 1, Appendix 1,Paragraph 8.2., kW

L = per cent load as indicated in Paragraph 4.1.4

P(a)= power absorbed by auxiliaries to be fitted as indicated in Annex 1, Appendix 1, Paragraph 6.1.

P(b)= power absorbed by auxiliaries to be removed as indicated in Annex 1, Appendix 1, Paragraph 6.2.

4.1.4. Test cycle

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

4.1.5. NO$_x$ check within the control area

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 Technical Service[1]. The time for each measurement shall be 2 minutes.

4.2. Test Preparation

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

4.2.1. Preparation of the sampling filters (Diesel engines only)

4.2.1.1. Particulate **mass** sampling filters shall be conditioned (as regards temperature and humidity) in an open dish that has been protected against dust ingress for at least **2** and for not more than **80** hours before the test in an air-conditioned chamber. After this conditioning the uncontaminated filters will be weighed and stored until they are used. If the filters are not used within one hour of their removal from the weighing chamber they shall be re-weighed.

4.2.1.2. The one-hour limit may be replaced by an eight-hour limit if one or both of the following conditions are met:

(a) a stabilised filter is placed and kept in a sealed filter holder assembly with the ends plugged, or;

(b) a stabilised filter is placed in a sealed filter holder assembly which is then immediately placed in a sample line through which there is no flow.

4.2.1.3. The particulate sampling system shall be started and prepared for sampling.

4.2.2. 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.

4.2.3. 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.

4.2.4. Starting the particulate sampling system

The particulate sampling system shall be started and running on by-pass.

4.2.5. Background Particulate **Mass** Measurement

The particulate background level of the dilution air may be determined by passing filtered dilution air through the particulate filter. **This shall be drawn from a point downstream of the particle and hydrocarbon filters.** One measurement may be performed prior to or after the test.

4.2.6. 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 shall 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 shall be within 100 ppm or 5 ppm of each other, respectively.

4.2.7. Checking the **gas** analysers

The emission analysers shall be set at zero and spanned. **The sample bags shall be evacuated.**

4.3. Test Procedure

4.3.1. Test sequence

The test sequence shall be started. The test shall be performed in the order of the mode numbers as set out in Paragraphs 4.1.4. and 0.

The engine shall 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 per cent 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.

4.3.2. 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.

4.3.3. Particulate sampling

A single 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 Paragraph 4.7.5. is met.

The sampling time per mode shall be at least 4 seconds per 0.01 weighting factor. Sampling shall 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.

4.3.4. Engine conditions

The engine speed and load, intake air temperature and depression, exhaust temperature and back pressure, 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 Paragraph 4.3.1) 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 Paragraphs 4.5, 4.7).

4.4. Post-Test Activities

4.4.1. Rechecking the analysers

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

4.4.2. Particulate Filter Weighing

For the evaluation of the particulates, the total sample masses ($M_{SAM,i}$) through the filter shall be recorded for each mode.

The filter shall be returned to the weighing chamber within one hour following the analyses of the exhaust gases. The filter shall be conditioned in the weighing room for at least **2** hours, but not more than 80 hours, and then weighed. The gross weight of the filter shall be recorded and the tare weight (Paragraph 1.3 of Annex 4) subtracted. **The particulate mass (M_f) is the net particulate mass collected on the single filter.**

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

4.5. Calculation of the Gaseous Emissions

4.5.1. 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 chart 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 G_{EXHW} or the diluted exhaust gas flow G_{TOTW}, if used optionally, shall be determined in accordance with Annex 4, Appendix 1, Paragraph 4.

4.5.2. 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.

$$\text{conc(wet)} = K_W * \text{conc(dry)}$$

For the raw exhaust gas:

$$K_{W,r} = \left(1 - F_{FH} * \frac{G_{FUEL}}{G_{AIRD}}\right) - K_{W2}$$

and

$$F_{FH} = \frac{1{,}969}{\left(1 + \frac{G_{FUEL}}{G_{AIRW}}\right)}$$

For the diluted exhaust gas:

$$K_{W,e,1} = \left(1 - \frac{HTCRAT * CO_2\%(wet)}{200}\right) - K_{W1}$$

or

$$K_{W,e,2} = \left(\frac{(1 - K_{W1)}}{1 + \frac{HTCRAT * CO_2\%(dry)}{200}} \right)$$

For the dilution air:

$K_{W,d} = 1 - K_{W1}$

$$K_{W1} = \frac{1{,}608 * H_d}{1000 + (1{,}608 * H_d)}$$

$$H_d = \frac{6{,}220 * R_d * p_d}{p_B - p_d * R_d * 10^{-2}}$$

For the intake air:
(if different from the dilution air)

$K_{W,a} = 1 - K_{W2}$

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

$$H_a = \frac{6{,}220 * R_a * p_a}{p_B - p_a * R_a * 10^{-2}}$$

where:

H_a, H_d = g water per kg dry air
R_d, R_a = relative humidity of the dilution/intake air, %
p_d, p_a = saturation vapour pressure of the dilution/intake air, kPa
p_B = total barometric pressure, kPa

4.5.3. NO_x Correction for humidity and temperature

As the NO_x emission depends on ambient air conditions, the NO_x concentration shall be corrected for ambient air temperature and humidity with the factors given in the following formulae:

$$K_{H,D} = \frac{1}{1 + A * (H_a - 10{,}71) + B * (T_a - 298)}$$

with:

A = $0.309\ G_{FUEL}/G_{AIRD} - 0.0266$
B = $-0.209\ G_{FUEL}/G_{AIRD} + 0.00954$
T_a = temperature of the air, K
H_a = humidity of the intake air, g water per kg dry air

in which:

$$H_a = \frac{6{,}220 * R_a * p_a}{p_B - p_a * R_a * 10^{-2}}$$

R_a = relative humidity of the intake air, %
ρ_a = saturation vapour pressure of the intake air, kPa
ρ_B = total barometric pressure, kPa

4.5.4. Calculation of the emission mass flow rates

The emission mass flow rates (g/h) for each mode shall be calculated as follows, assuming the exhaust gas density to be 1.293 kg/m³ at 273 K (0°C) and 101.3 kPa:

(1) $NO_{x\ mass} = 0.001587 * NO_{x\ conc} * K_{H,D} * G_{EXHW}$

(2) $CO_{mass} = 0.000966 * CO_{conc} * G_{EXHW}$

(3) $HC_{mass} = 0.000479 * HC_{conc} * G_{EXHW}$

where $NO_{x\ conc}$, CO_{conc}, HC_{conc} are the average concentrations (ppm) in the raw exhaust gas, as determined in Paragraph 4.5.1.

If, optionally, the gaseous emissions are determined with a full flow dilution system, the following formulae shall be applied:

(1) $NO_{x\ mass} = 0.001587 * NO_{x\ conc} * K_{H,D} * G_{TOTW}$

(2) $CO_{mass} = 0.000966 * CO_{conc} * G_{TOTW}$

(3) $HC_{mass} = 0.000479 * HC_{conc} * G_{TOTW}$

where $NO_{x\ conc}$, CO_{conc}, HC_{conc}[1] are the average background corrected concentrations (ppm) of each mode in the diluted exhaust gas, as determined in Paragraph 7.7.3.2.

4.5.5. Calculation of the specific emissions

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

$$\overline{NO_x} = \frac{\sum NO_{x,mass} * WF_i}{\sum P(n)_i * WF_i}$$

$$\overline{CO} = \frac{\sum CO_{mass} * WF_i}{\sum P(n)_i * WF_i}$$

$$\overline{HC} = \frac{\sum HC_{mass} * WF_i}{\sum P(n)_i * WF_i}$$

The weighting factors (WF) used in the above calculation are according to Paragraph 4.1.4.

4.6. Calculation of the area control values

For the three control points selected according to Paragraph 0., the NO_x emission shall be measured and calculated according to Paragraph 4.6.1. and also determined by interpolation from the modes of the test cycle closest to the respective control point according to Paragraph 4.6.2. The measured values are then compared to the interpolated values according to Paragraph 4.6.3.

4.6.1. Calculation of the specific emission

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

$$NO_{x\ mass,Z} = 0.001587 * NO_{x\ conc,Z} * K_{H,D} * G_{EXHW}$$

$$NO_{x,Z} = NO_{x\ mass,Z} / P(n)_Z$$

4.6.2. 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 1. For these modes (R, S, T, U), the following definitions apply:

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

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

$$E_Z = E_{RS} + (E_{TU} - E_{RS}) \cdot (M_Z - M_{RS}) / (M_{TU} - M_{RS})$$

and:

$$E_{TU} = E_T + (E_U - E_T) \cdot (n_Z - n_{RT}) / (n_{SU} - n_{RT})$$
$$E_{RS} = E_R + (E_S - E_R) \cdot (n_Z - n_{RT}) / (n_{SU} - n_{RT})$$
$$M_{TU} = M_T + (M_U - M_T) \cdot (n_Z - n_{RT}) / (n_{SU} - n_{RT})$$
$$M_{RS} = M_R + (M_S - M_R) \cdot (n_Z - n_{RT}) / (n_{SU} - n_{RT})$$

where:

E_R, E_S, E_T, E_U = specific NO_x emission of the enveloping modes calculated in accordance with Paragraph 4.6.1.

M_R, M_S, M_T, M_U = engine torque of the enveloping modes

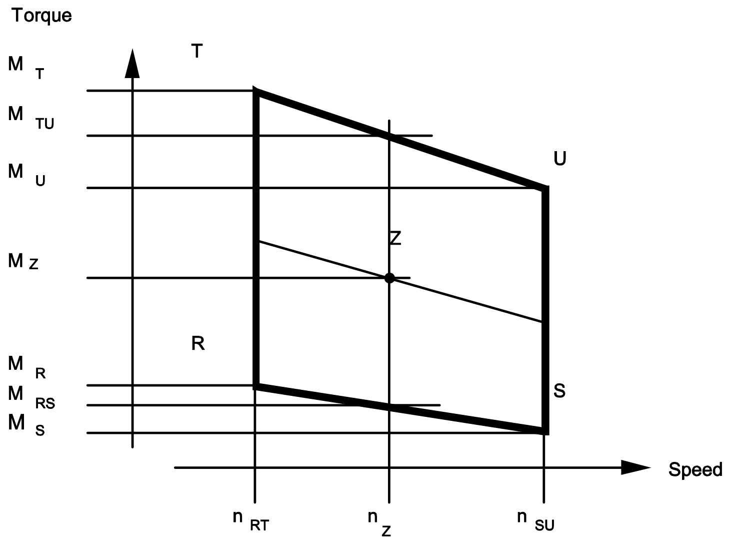

Figure 1: Interpolation of NO_x Control Point

4.6.3. Comparison of NO_x emission values

The measured specific NO_x emission of the control point Z ($NO_{x,Z}$) is compared to the interpolated value (E_Z) as follows:

$$NO_{x,diff} = 100 * (NO_{x,z} - E_z) / E_z$$

4.7. <u>Calculation of the Particulate Emissions</u>

4.7.1. 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 G_{EDFW} apply. All calculations shall be based upon the average values of the individual modes during the sampling period.

4.7.1.1. Isokinetic systems

$$G_{EDFW,i} = G_{EXHW,i} * q_I$$

$$q_i = \frac{G_{DILW,i} + \left(G_{EXHW,i} * r\right)}{\left(G_{EXHW,i} * r\right)}$$

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

$$r = \frac{A_p}{A_r}$$

4.7.1.2. Systems with measurement of CO_2 or NO_x concentration

$$G_{EDFW,i} = G_{EXHW,i} * q_i$$

$$q_i = \frac{conc_{E,i} - conc_{A,i}}{conc_{D,i} - conc_{A,i}}$$

where:

$conc_E$ = wet concentration of the tracer gas in the raw exhaust
$conc_D$ = wet concentration of the tracer gas in the dilute exhaust
$conc_A$ = 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 Paragraph 4.5.2.

4.7.1.3. Systems with CO_2 measurement and carbon balance method[2]

$$G_{EDFW,i} = \frac{206.5 - G_{FUEL,i}}{CO_{2D,i} - CO_{2A,i}}$$

where:

CO_{2D} = CO_2 concentration of the diluted exhaust
CO_{2A} = 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:

$$G_{EDFW,i} = G_{EXHW,i} * q_i$$

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[2] The value is only valid for the reference fuel specified in the Regulation.

$$q_i = \frac{206{,}5 * G_{FUEL,i}}{G_{EXW,i} * (CO_{2D,i} - CO_{2A,i})}$$

and,

4.7.1.4. Systems with flow measurement

$$G_{EDFW,i} = G_{EXHW,i} * q_i$$

$$q_i = \frac{G_{TOTW,i}}{(G_{TOTW,i} - G_{DILW,i})}$$

4.7.2. Full flow dilution system

The reported test results of the particulate emission shall be determined through the following steps. All calculations shall be based upon the average values of the individual modes during the sampling period.

$G_{EDFW,i} = G_{TOTW,i}$

4.7.3. Calculation of the particulate mass flow rate

The particulate mass flow rate shall be calculated as follows:

$$PT_{mass} = \frac{M_f}{M_{SAM}} * \frac{\overline{G_{EDFW}}}{1000}$$

where

$$\overline{G_{EDFW}} = \sum_{i=1}^{i=n} G_{EDFW,i} * WF_i$$

$$M_{SAM} = \sum_{i=1}^{i=n} M_{SAM,i}$$

i=1,...n

determined over the test cycle by summation of the average values of the individual modes during the sampling period.

The mass of the secondary dilution air shall be subtracted from the total mass of the double diluted exhaust gas sampled through the particulate filter.

$$M_{SAM} = M_{TOT} - M_{SEC}$$

where:

M_{TOT} = mass of double diluted exhaust gas through particulate filter, kg

M_{SEC} = mass of secondary dilution air, kg

The recommended procedure is that two, distinct secondary dilution systems are employed; one dedicated to particulate mass measurements and the other to particle number measurements. However, if the double diluted exhaust flow is split between particulate filter and the particle measurement system then the sample mass shall be adjusted to account for this

$$MP_{SAM} = (MP_{INS}/M_{TOT})*(M_{TOT} - M_{SEC})$$

where:

M_{INS} = mass of double diluted exhaust gas through particle measurement instrument, kg

M_{TOT} = total mass of double diluted exhaust gas

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

$$PT_{mass} = \left[\frac{M_f}{M_{SAM}} - \left(\frac{M_d}{M_{DIL}} * \left(\sum_{i=n}^{i=n} \left(1 - \frac{1}{DF_i} \right) * WF_i \right) \right) \right] * \frac{\overline{G_{EDFW}}}{1000}$$

If more than one measurement is made, (M_d/M_{DIL}) shall be replaced with the average value of (M_d/M_{DIL}).

$DF_i = 13.4/(concCO_2 + (concCO + concHC)*10^{-4}))$ for the individual modes
or,

$DF_i = 13.4/concCO_2$ for the individual modes

4.7.4. Calculation of the specific emission

The particulate emission shall be calculated in the following way:

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

4.7.5. Effective weighting factor

The effective weighting factor $WF_{E,i}$ for each mode shall be calculated in the following way:

$$WF_{E,i} = \frac{M_{SAM,i} * \overline{G_{EDFW}}}{M_{SAM} * G_{EDFW,i}}$$

The value of the effective weighting factors shall be within ± 0.003 (0.005 for the idle mode) of the weighting factors listed in Paragraph 4.1.4.

4.7.6. Allowance For Mass Emissions From Engines Equipped With Periodically Regenerating Devices

For engines equipped with particulate filters that undergo periodic regeneration, several test cycles shall be conducted and the test results averaged and/or weighted. The exact procedure shall be agreed between the engine manufacturer and the Technical Service based upon good engineering judgement (Annex 4, Paragraph 2.2.5).

5. ELR TEST PROCEDURE

5.1. Test Cycle

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 Annex 4, Paragraph 1.1., followed by cycle 4 at a speed within the control area and a load between 10 per cent and 100 per cent, selected by the Technical Service[1]. The following sequence shall be followed in dynamometer operation on the test engine, as shown in Figure 2.

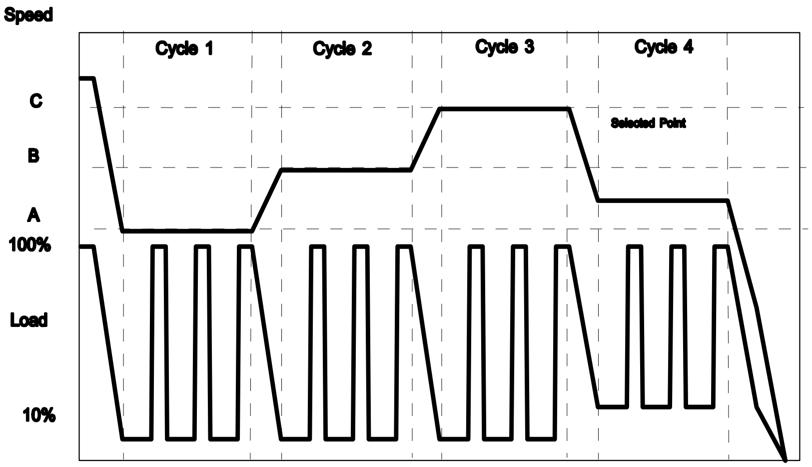

Figure 2: Sequence of ELR Test

(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 per cent 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.

5.2. Test Preparation

5.2.1. 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 Paragraph 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.

5.2.2. 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 per cent opacity and 100 per cent opacity. The light absorption coefficient is then correctly calculated based upon the measured opacity and the L_A, 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.

5.2.3. 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.

5.3. Test Procedure

5.3.1. Data evaluation

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

5.4. Post-Test Activities

5.4.1. Cycle validation

The relative standard deviations of the mean smoke values at each test speed (SV_A, SV_B, SV_C, as calculated in accordance with Paragraph 5.5.2.3 from the three successive load steps at each test speed) shall be lower than 15 per cent of the mean value, or 10 per cent of the limit value shown in Table 1 of the Regulation, whichever is greater. If the difference is greater, the sequence shall be repeated until 3 successive load steps meet the validation criteria.

5.4.2. Rechecking of the opacimeter

The post-test opacimeter zero drift value shall not exceed ± 5.0 per cent of the limit value shown in Table 1 of the Regulation.

5.5. Calculation of Smoke Values

5.5.1. Bessel algorithm

The Bessel algorithm shall be used to compute the 1 s average values from the instantaneous smoke readings, converted in accordance with Paragraph 5.5.2.3. 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, Paragraph 5.5.1.1. shall be repeated whenever the system response time and/or sampling rate changes.

5.5.1.1. 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 Annex 4, Appendix 6, Paragraph 1.2.4., 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 (f_c) are based on a step input of 0 to 1 in ≤ 0.01s (see Annex 8). The response time is defined as the time between when the Bessel output reaches 10 per cent (t_{10}) and when it reaches 90 per cent (t_{90}) of this step function. This shall be obtained by iterating on f_c until $t_{90} - t_{10} \approx t_F$. The first iteration for f_c is given by the following formula :

$$f_c = \pi / (10 * t_F)$$

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

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

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

where:

D = 0.618034
Δt = 1 / sampling rate
Ω = $1 / [\tan(\pi * \Delta t * f_c)]$

5.5.1.2. Calculation of the Bessel Algorithm

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

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

where:

$$S_{i-2} = S_{i-1} = 0$$
$$S_i = 1$$

$$Y_{i-2} = Y_{i-1} = 0$$

The times t_{10} and t_{90} 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 per cent of the required response as follows:

$$\left|(t_{90} - t_{10}) - t_F\right| \leq 0{,}01 * t_F$$

5.5.2. Determination of smoke

5.5.2.1. 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:

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

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.

5.5.2.2. 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 Paragraph 5.5.1.1., 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 Paragraph 5.5.1.1.:

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

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.

5.5.2.3. Final result

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

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

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

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

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:

$$SV = (0.43 * SV_A) + (0.56 * SV_B) + (0.01 * SV_C)$$

6. ETC MAPPING TEST PROCEDURE

6.1. Engine Mapping Procedure

6.1.1. 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

6.1.2. 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:

The engine shall be unloaded and operated at idle speed.

The engine shall be operated at full load setting of the injection pump at minimum mapping speed.

The engine speed shall be increased at an average rate of $8 \pm 1\ \text{min}^{-1}$ /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.

6.1.3. Mapping curve generation

All data points recorded under Paragraph 6.1.2. 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 Paragraph 6.2.

6.1.4. 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 shall satisfy the intent of the specified mapping procedures to determine the maximum available torque at all engine speeds achieved during the test cycles. Deviations from the mapping techniques specified in this Paragraph that are undertaken for reasons of safety or representativeness, shall be approved by the Technical Service. Justification for these deviations shall be provided to the Technical Service. In no case, however, shall descending continual sweeps of engine speed be used for governed or turbocharged engines.

6.1.5. 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 judgement,

or,

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

6.2. Generation Of The Reference Test Cycle

The transient test cycle is described in Appendix 7 to this Annex. The normalised values for torque and speed shall be changed to the actual values, as follows, resulting in the reference cycle.

6.2.1. Actual speed

The speed shall be unnormalised using the following equation:

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

The reference speed (n_{ref}) corresponds to the 100 per cent speed values specified in the engine dynamometer schedule of Appendix 7. It is defined as follows (see Figure 1 of the Regulation):

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

where n_{hi} and n_{lo} are either specified according to the Regulation, Paragraph 6.2 or determined according to Annex 4, Paragraph 4.1.1.

6.2.2. 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 6.1.3, as follows:

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

for the respective actual speed as determined in Paragraph 6.2.1.

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 per cent 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.

6.2.3. 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,

$$\text{actual speed} = \frac{43 * (2200 - 600)}{100} + 600 = 1288 \text{ min}^{-1}$$

$$\text{actual torque} = \frac{82 * 700}{100} = 574 Nm$$

where the maximum torque observed from the mapping curve at 1288 min^{-1} is 700 Nm.

7. ETC EMISSIONS TEST RUN

7.1. Test Cycle

7.2. Test Conditioning

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 per cent the CO emission measured over the previous ETC cycle.

7.3. Test Preparation

7.3.1. Preparation of the sampling filters (Diesel engines only)

7.3.1.1. Particulate **mass** sampling filters shall be conditioned (as regards temperature and humidity) in an open dish that has been protected against dust ingress for at least **2** and for not more than **80** hours before the test in an air-conditioned chamber. After this conditioning, the uncontaminated filters shall be weighed and stored until they are used. If the filters are not used within one hour of their removal from the weighing chamber they shall be re-weighed.

7.3.1.2. The one-hour limit may be replaced by an eight-hour limit if one or both of the following conditions are met:

7.3.1.3. a stabilised filter is placed and kept in a sealed filter holder assembly with the ends plugged, or;

7.3.1.4. a stabilised filter is placed in a sealed filter holder assembly which is then immediately placed in a sample line through which there is no flow.

7.3.1.5. The particulate sampling system shall be started and prepared for sampling.

7.3.2. 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.

7.3.3. 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.

7.3.4. Starting the particulate sampling system (where applicable)

7.3.4.1. The particulate sampling system shall be started and running on by-pass.

7.3.4.2. The particulate background level of the dilution air may be determined by passing filtered dilution air through the particulate filter. **This shall be drawn from a point downstream of the particle and hydrocarbon filters.** One measurement may be performed prior to or after the test.

7.3.5. Starting The Particle Sampling System

7.3.5.1. The particle specific dilution system and measurement equipment shall be started and readied for sampling.

7.3.5.2. Prior to the test(s) the correct function of the particle counter and volatile particle remover elements of the particle sampling system shall be confirmed:

The particle counter response shall be tested at near zero and high particle concentrations.

The volatile particle remover shall be tested for removal of volatile particles.

When the inlet is equipped with a HEPA filter, it shall be demonstrated that the entire particle sampling system is free from any leaks.

7.3.5.3. The subtraction of background particle numbers may be determined by sampling dilution air drawn from a point downstream of the primary tunnel particle and hydrocarbon filters into the particle number measurement system. This correction shall not be allowed for type approval, but may be used at the manufacturer's request for CoP where there are indications that tunnel contribution is significant.

7.3.6. Adjustment of the full flow dilution system

The total diluted exhaust gas flow shall be set to completely eliminate water condensation in the system but maintaining the temperature of the primary dilution tunnel at less than 192°C.

7.3.7. Checking the **gas** analysers

The emission analysers shall be set at zero and spanned. **The sample bags shall be evacuated.**

7.4. ETC Test Run

7.4.1. 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.

7.4.2. 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 Paragraph 6.2 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.

7.4.3. Analyser response

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 NO_x shall be measured continuously in the dilution tunnel with a frequency of 2 Hz. The average concentrations shall be determined by integrating the analyser 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, CO_2, NMHC and CH_4 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).

7.4.4. Particulate sampling (Diesel engines only)

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 per cent of the set flow rate. If flow compensation (i.e., proportional control of sample flow) is used, it shall be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ± 5 per cent 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 air flow 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 per cent) 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.

7.4.5. Particle Sampling

Particles shall be measured continuously in the particle sampling system. The average concentrations shall be determined by integrating the analyser signals over the test cycle.

7.4.6. 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.

7.5. Operations after test

7.5.1. Gas Analyses

At the completion of the test, the measurement of the diluted exhaust gas volume, 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 per cent of the span gas value.

7.5.2. Particulate Mass Analyses

For diesel engines only:

Reference filters shall be weighed within 4 hours of the test filter weighing.

The contaminated particulate filter shall be taken to the weighing chamber within one hour following the analyses of the exhaust gases. The filter shall be conditioned for at least 2 hours and not more than 80 hours and then weighed.

7.6. Verification of the test run

7.6.1. 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 shall be shifted the same amount in the same direction.

7.6.2. 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 Paragraph 7.7.4). 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}.

7.6.3. 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 1 shall be met.

Table 1: Regression line tolerances

	Speed	Torque	Power
Standard error of estimate (SE) of Y on X	max 100 min^{-1}	max 13 % of power map maximum engine torque	max 8% 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
Coefficient of determination, r^2	min 0.9700	min 0.8800	min 0.9100
Y intercept of the regression line, b	± 50 min^{-1}	± 20 Nm or ± 2 % of max torque whichever is greater	± 4 kW or ± 2 % of max power whichever is greater

Point deletions from the regression analyses are permitted where noted in Table 2.

Table 2: Permitted Point Deletions From Regression Analysis

Condition	Points to be deleted
Full load and torque feedback ≠ torque reference	Torque and/or power
No load, not an idle point, and torque feedback > torque reference	Torque and/or power
No load/closed throttle, idle point and speed > reference idle speed	Speed and/or power

7.7. Calculation of the Gaseous Emissions

7.7.1. 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 or K_V for CFV, as determined in Annex 4, Appendix 4, Paragraph 2.5.). 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, see Annex 4, Appendix 2, Paragraph 3.1).

For the PDP-CVS system

$$M_{TOTW} = 1.293 * V_0 * N_P * (p_B - p_1) * 273 / (101.3 * T)$$

where:

M_{TOTW} = mass of the diluted exhaust gas on wet basis over the cycle, kg
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

$$M_{TOTW} = 1.293 * t * K_v * p_A / T^{0.5}$$

where:

M_{TOTW} = mass of the diluted exhaust gas on wet basis over the cycle, kg
t = cycle time, s
K_V = calibration coefficient of the critical flow venturi for standard conditions,
p_A = absolute pressure at venturi inlet, kPa
T = absolute temperature at venturi inlet, K

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:

$$M_{TOTW,I} = 1.293 * V_0 * N_{P,i} * (p_B - p_1) * 273 / (101.3 \cdot {}^{T})$$

where:

$M_{TOTW,i}$ = instantaneous mass of the diluted exhaust gas on wet basis, kg
$N_{P,i}$ = total revolutions of pump per time interval

For the CFV-CVS system:

$$M_{TOTW,i} = 1.293 * \Delta t_i * K_V * p_A / T^{0.5}$$

where:

$M_{TOTW,i}$ = instantaneous mass of the diluted exhaust gas on wet basis, kg
Δti = time interval, s

If the total sample mass of particulates (MSAM) and gaseous pollutants exceeds 0.5 per cent of the total CVS flow (MTOTW), the CVS flow shall be corrected for MSAM or the particulate sample flow shall be returned to the CVS prior to the flow measuring device (PDP or CFV).

7.7.2. NO_x correction for humidity

As the NOx emission depends on ambient air conditions, the NOx concentration shall be corrected for ambient air humidity with the factors given in the following formulae.

(a) for diesel engines:

$$K_{H,D} = \frac{1}{1 - 0{,}0182 * (H_a - 10{,}71)}$$

(b) for gas engines:

$$K_{H,G} = \frac{1}{1 - 0{,}0329 * (H_a - 10{,}71)}$$

where:

Ha = humidity of the intake air, grams of water per kg of dry air,

in which:

$$H_a = \frac{6{,}220 * R_a * p_a}{p_B - p_a * R_a * 10^{-2}}$$

Ra = relative humidity of the intake air, %
pa = saturation vapour pressure of the intake air, kPa
pB = total barometric pressure, kPa

7.7.3. Calculation of the emission mass flow

7.7.3.1. Systems with constant mass flow

For systems with heat exchanger, the mass of the pollutants (g/test) shall be determined from the following equations:

(1) NO_x mass = 0.001587 * NOx conc * $K_{H,D}$ * MTOTW (diesel engines)

(2) NO_x mass = 0.001587 * NOx conc * $K_{H,G}$ * MTOTW (gas engines)

(3) CO mass = 0.000966 * CO conc * M_{TOTW}

(4) HC mass = 0.000479 * HC conc * M_{TOTW}' (diesel engines)

(5) HC mass = 0.000502 * HC conc * M_{TOTW}' (LPG fuelled engines)

(6) NMHC mass = 0.000516 * NMHC conc * M_{TOTW}' (NG fuelled engines)

(7) CH_4 mass = 0.000552 * CH_4 conc * M_{TOTW} (NG fuelled engines)

where:

NO_x conc, CO conc, HC conc, [3] NMHC conc = average background corrected concentrations over the cycle from integration (mandatory for NOx and HC) or bag measurement, ppm

M_{TOTW} = total mass of diluted exhaust gas over the cycle as determined in Paragraph 7.7.1., kg

$K_{H,D}$ = humidity correction factor for diesel engines as determined in Paragraph 7.7.2

$K_{H,G}$ = humidity correction factor for gas engines as determined in Paragraph 7.7.2

Concentrations measured on a dry basis shall be converted to a wet basis in accordance with Paragraph 4.5.2.

The determination of $NMHC_{conc}$ depends on the method used (see Annex 4, Appendix 3, Paragraph 1.3.4.). In both cases, the CH_4 concentration shall be determined and subtracted from the HC concentration as follows:

(a) GC method

$$NMHC_{conc} = HC_{conc} - CH_{4\,conc}$$

(b) NMC method

$$NMHC_{conc} = \frac{HC(w/o\ Cutter) * (1 - CE_M) - HC(w/\ Cutter)}{CE_C - CE_M}$$

where:

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

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

CE_M = methane efficiency as determined per Annex 4, Appendix 3, Paragraph 3.6.4.1

CE_E = ethane efficiency as determined per Annex 4, Appendix 3, Paragraph 3.6.4.2.

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[3] Based on C1 equivalent

7.7.3.2. Determination of the background corrected concentrations

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.

$$\mathrm{conc} = \mathrm{conc}_e - \mathrm{conc}_d * (1 - (1/\mathrm{DF}))$$

where:

conc = concentration of the respective pollutant in the diluted exhaust gas, corrected by the amount of the respective pollutant contained in the dilution air, ppm

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

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

DF = dilution factor

The dilution factor shall be calculated as follows:

(a) for diesel and LPG fuelled gas engines

$$\mathrm{DF} = \frac{F_S}{CO2_{conce} + (HC_{conce} + CO_{conce}) * 10^{-4}}$$

(b) for NG fuelled gas engines

$$\mathrm{DF} = \frac{F_S}{CO2_{conce} + (NMHC_{conca} + CO_{conca}) * 10^{-4}}$$

where:

$\mathrm{CO}_{2,\mathrm{conce}}$ = concentration of CO_2 in the diluted exhaust gas, % vol
$\mathrm{HC}_{\mathrm{conce}}$ = concentration of HC in the diluted exhaust gas, ppm C1
$\mathrm{NMHC}_{\mathrm{conce}}$ = concentration of NMHC in the diluted exhaust gas, ppm C1
$\mathrm{CO}_{\mathrm{conce}}$ = 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 Paragraph 4.5.2.

The stoichiometric factor shall be calculated as follows:

$$\mathrm{F_S} = 100 * \frac{x}{x + \frac{y}{2} + 3{,}76 * \left(x + \frac{y}{4}\right)}$$

where:

x,y = fuel composition C_xH_y

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

7.7.3.3. Systems with flow compensation

For systems without heat exchangers: the mass of the pollutants (g/test) shall be determined by calculating the instantaneous mass emissions, and integrating the instantaneous values over the cycle. Also, the background correction shall be applied directly to the instantaneous concentration value.
The following formulae shall be applied:

(1) $NO_{x\ mass} =$

$$\sum_{i=1}^{n} (M_{TOTW,i} * NOx_{conce,i} * 0{,}001587 * K_{H,D}) - (M_{TOTW} * NOx_{concd} * (1 - 1/DF) * 0{,}001587 * K_{H,D})$$

(diesel engines)

(2) $NO_{x\ mass} =$

$$\sum_{i=1}^{n} (M_{TOTW,i} * NOx_{conce,i} * 0{,}001587 * K_{H,G}) - (M_{TOTW} * NOx_{concd} * (1 - 1/DF) * 0{,}001587 * K_{H,G})$$

(gas engines)

(3) $CO_{mass} =$

$$\sum_{i=1}^{n} (M_{TOTW,i} * CO_{conce,i} * 0{,}000966) - (M_{TOTW} * CO_{concd} * (1 - 1/DF) * 0{,}000966)$$

(4) $HC_{mass} =$

$$\sum_{i=1}^{n} (M_{TOTW,i} * HC_{conce,i} * 0{,}000479) - (M_{TOTW} * HC_{concd} * (1 - 1/DF) * 0{,}000479)$$

(diesel engines)

(5) $HC_{mass} =$

$$\sum_{i=1}^{n} (M_{TOTW,i} * HC_{conce,i} * 0{,}000502) - (M_{TOTW} * HC_{concd} * (1 - 1/DF) * 0{,}000502$$

(LPG engines)

(6) $NMHC_{mass} =$

$$\sum_{i=1}^{n} (M_{TOTW,i} x NMHC_{conce,i} x 0{,}000516) - (M_{TOTW} x NMHCx_{concd} x (1 - 1/DF) x 0{,}000516$$

(NG engines)

(7) $CH_{4\,mass}$ =

$$\sum_{i=1}^{n}(M_{TOTW,i} x CH_{4conce,i} x 0,000552) - (M_{TOTW} x CH_{4concd} x (1 - 1/DF) x 0,000552)$$

(NG engines)

where:

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

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

$M_{TOTW,I}$ =instantaneous mass of the diluted exhaust gas (see Paragraph 7.7.1.), kg

M_{TOTW} = total mass of diluted exhaust gas over the cycle (see Paragraph 7.7.1.), kg

$K_{H,D}$ = humidity correction factor for diesel engines as determined in Paragraph 7.7.2.

$K_{H,G}$ = humidity correction factor for gas engines as determined in Paragraph 7.7.2.

DF = dilution factor as determined in Paragraph 7.7.3.2.

7.7.4. Calculation of the specific emissions

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

$\overline{NO_x} = NOx_{mass} / W_{act}$ (diesel and gas engines)

$\overline{CO} = CO_{mass} / W_{act}$ (diesel and gas engines)

$\overline{HC} = HC_{mass} / W_{act}$ (diesel and LPG fuelled gas engines)

$\overline{NMHC} = NMHC_{mass} / W_{act}$ (NG fuelled gas engines)

$\overline{CH_4} = CH_{4mass} / W_{act}$ (NG fuelled gas engines)

where:

W_{act}= actual cycle work as determined in Paragraph 7.6.2., kWh

7.8. Calculation of the Particulate Emissions

7.8.1. Calculation of the mass flow

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

$$PT_{mass} = \frac{M_f}{M_{SAM}} * \frac{M_{TOTW}}{1000}$$

where:

M_f = particulate mass sampled over the cycle, mg

M_{TOTW} = total mass of diluted exhaust gas over the cycle as determined in Paragraph 7.7.1, kg

M_{SAM}= mass of diluted exhaust gas taken from the dilution tunnel for collecting particulates, kg

and,

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 filter.

$$M_{SAM} = M_{TOT} - M_{SEC}$$

where:

M_{TOT} =mass of double diluted exhaust gas through particulate filter, kg

M_{SEC} =mass of secondary dilution air, kg

If the particulate background level of the dilution air is determined in accordance with Paragraph 4.2.5., the particulate mass may be background corrected. In this case, the particulate mass (g/test) shall be calculated as follows:

$$PT_{mass} = \left[\frac{M_f}{M_{SAM}} - \left(\frac{M_d}{M_{DIL}} * \left(1 - \frac{1}{DF} \right) \right) \right] * \frac{M_{TOTW}}{1000}$$

where:

M_f, M_{SAM}, M_{TOTW} = see above

M_{DIL} = mass of primary dilution air sampled by background particulate sampler, kg

M_d = mass of the collected background particulates of the primary dilution air, mg

D_f = dilution factor as determined in Paragraph 7.7.3.2

7.8.2. Calculation of the specific emission

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

$$\overline{PT} = PT_{mass} / W_{act}$$

where:

W_{act} = actual cycle work as determined in Paragraph 7.6.2., kWh.

7.9. Calculation of the Particle Emissions[4]

7.9.1. Calculation of the particle number flow

The particle number, *PN* (n/test) shall be calculated as follows:

$$\mathrm{PN} = \frac{\mathrm{N_P}}{\mathrm{M_{SAM}}} * \mathrm{M_{TOTW}}$$

$$\mathrm{N_P} = \frac{\mathrm{PC}}{\rho} * \mathrm{DF_3} * \mathrm{M_{TOT}}$$

$$DF_3 = PNDR1 * PNDR2$$

where:

$PNDR_1$ and $PNDR_2$ are the dilution factor settings for particle number diluters 1 (PND_1) and 2 (PND_2) respectively.

PC is mean measured particle number concentration (n/m^3 at particle counter operation temperature)

ρ is the reference air density for particle concentration at CPC operation temperature

N_P = particle number count recorded over the cycle

M_{TOTW} = total mass of diluted exhaust gas over the cycle as determined in Paragraph 7.7.1., kg

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[4] OICA wish to retain a particle number background correction. This has been added, for certain circumstances, in Section 7.3.5.3.

M_{SAM}= mass of diluted exhaust gas taken from the primary dilution tunnel for collecting particles, kg

The mass of the secondary dilution air shall be subtracted from the total mass of the double diluted exhaust gas.

$$M_{SAM} = M_{TOT} - M_{SEC}$$

where:

M_{TOT} = total mass of double diluted exhaust gas

M_{SEC} =mass of secondary dilution air, kg

The recommended procedure is that two, distinct secondary dilution systems are employed; one dedicated to particulate mass measurements and the other to particle number measurements. However, if the double diluted exhaust flow is split between particulate filter and the particle measurement system then the sample mass may need to be adjusted to account for this.

If the first **particle number** dilution system (PND_1) takes only a small fraction (≤2%) of the double diluted exhaust gas then M_{TOT} can be assumed to be equal to the double diluted exhaust gas mass as measured by the secondary dilution system controller.

If the PND_1 takes more than 2% of the double diluted exhaust gas then M_{TOT} shall be determined as follows:

$$M_{TOT} = M_{DLS} + M_{PSAM}$$

Where:

M_{DLS} is the balance of the double diluted exhaust mass that is not taken by the particle number dilution system.

M_{PSAM} is the mass of double diluted exhaust gas taken by the particle number dilution system.

$$M_{PSAM} = \frac{M_{PC}}{DF_3},$$

where M_{PC} is the mass of the triple diluted exhaust gas sampled by the particle counter.

7.9.2. Calculation of the specific emission

The particle emission (n/kWh) shall be calculated in the following way:

$$\overline{n / kWh} = PN / W_{act}$$

where:

W_{act} = actual cycle work as determined in (7.6.2.)., kWh.

7.10. **Allowance For Mass Emissions From Engines Equipped With Periodically Regenerating Devices**

For engines equipped with particulate filters that undergo periodic regeneration, several test cycles shall be conducted and the test results averaged and/or weighted. The exact procedure shall be agreed between the engine manufacturer and the Technical Service based upon good engineering judgement (Annex 4, Paragraph 2.2.5).

APPENDIX 1 – DYNAMOMETER AND TEST CELL EQUIPMENT

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

1. Engine Dynamometer

An engine dynamometer shall be used with adequate characteristics to perform the test cycles described in sections 4-7 of this Annex. The speed measuring system shall have an accuracy of ± 2 per cent of reading. The torque measuring system shall have an accuracy of ± 3 per cent of reading in the range > 20 per cent of full scale, and an accuracy of ± 0.6 per cent of full scale in the range ≤ 20 per cent of full scale.

2. General Test Cell Equipment

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 3:

Table 3: Accuracy of measuring instruments

Measuring instrument	Accuracy
Fuel Consumption	± 2 % of Engine's Maximum Value
Air Consumption	± 2 % of Engine's Maximum Value
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	± 3 % Absolute
Absolute Humidity	± 5 % of Reading

3. Exhaust gas flow

For calculation of the emissions in the raw exhaust, it is necessary to know the exhaust gas flow (see Paragraph 4.5.4). For the determination of the exhaust flow either of the following methods may be used:

Direct measurement of the exhaust flow by flow nozzle or equivalent metering system;
Measurement of the air flow and the fuel flow by suitable metering systems and calculation of the exhaust flow by the following equation:

$$G_{EXHW} = G_{AIRW} + G_{FUEL} \qquad \text{(for wet exhaust mass)}$$

The accuracy of exhaust flow determination shall be ± 2.5 per cent of reading or better.

4. Diluted exhaust gas flow

For calculation of the emissions in the diluted exhaust using a full flow dilution system (mandatory for the ETC), it is necessary to know the diluted exhaust gas flow (see Paragraph 7.7.1). The total mass flow rate of the diluted exhaust (G_{TOTW}) or the total mass of the diluted exhaust gas over the cycle (M_{TOTW}) shall be measured with a PDP or CFV (Annex 4, Appendix 2, Paragraph 2.3.1.). The accuracy shall be ± 2 per cent of reading or better, and shall be determined according to the provisions of Annex 4, Appendix 2, Paragraph 5.

APPENDIX 2 – FULL FLOW EXHAUST DILUTION SYSTEM

1. System Overview

For ETC, dilution shall be accomplished by a full flow dilution system[5]. The total exhaust from the engine is mixed with air in a dilution tunnel to produce an approximately constant flow rate of diluted exhaust gas. For subsequent collection of the particulates and particles, a sample of the dilute exhaust gas is passed to the particulate and particle sampling systems. A sample of dilute exhaust gas may also be taken for analysis of gaseous emissions.

2. Requirements

The total volume of the mixture of exhaust and dilution air shall be measured.

The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems.

Dehumidifying the dilution air before entering the dilution system is permitted, and especially useful if dilution air humidity is high.

The temperature of the dilution air shall be 298 K ± 5 K (25°C ± 5°C). If the ambient temperature is below 293K (20°C), dilution air pre-heating above the upper temperature limit of 303K (30°C) is recommended. However, the dilution air temperature shall not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel.

All parts of the dilution system that are in contact with raw and diluted exhaust gas, shall be designed to minimise deposition or alteration of the particulates or particles. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

3. Recommended System Description

This section contains a detailed description of the recommended full flow dilution system. Since various configurations can produce equivalent results, exact conformance with this specification is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

The dilution system is shown in Figure 3. The total amount of raw exhaust gas is mixed in the dilution tunnel DT with the dilution air. The diluted exhaust gas flow rate is measured either with a Positive Displacement Pump PDP or with a Critical Flow Venturi CFV. A heat exchanger HE or electronic flow compensation EFC may be used for proportional particulate sampling and for flow determination. Since particulate

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[5] Mandatory use of full flow for ETC to be subject of future discussion

mass determination is based on the total diluted exhaust gas flow, calculation of the dilution ratio is not required.

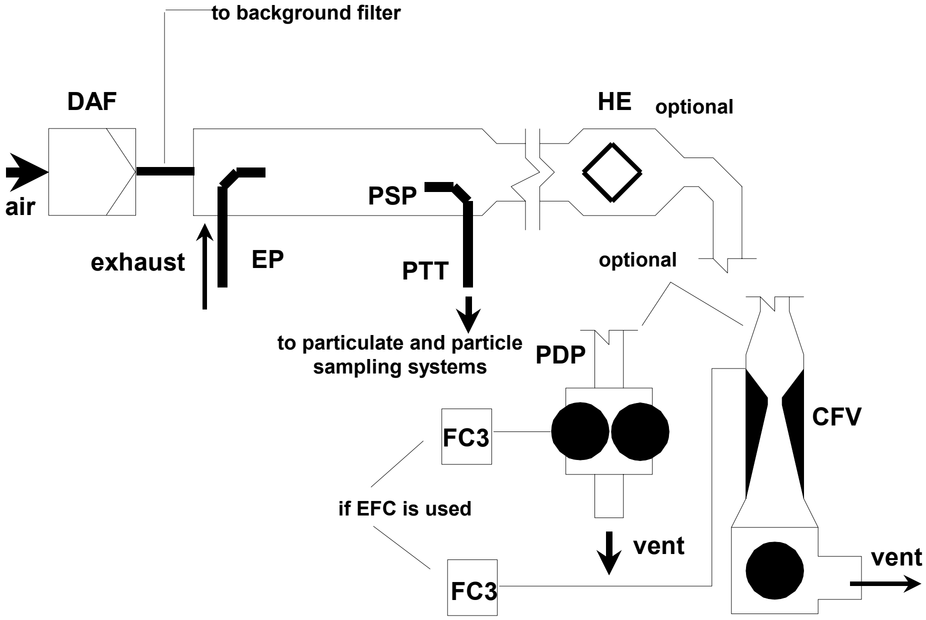

Figure 3: Full flow dilution system

3.1. System Components

EP Exhaust pipe

The exhaust pipe length from the exit of the engine exhaust manifold, turbocharger outlet or after-treatment device to the dilution tunnel shall not exceed 10 m. If the exhaust pipe downstream of the engine exhaust manifold, turbocharger outlet or after-treatment device exceeds 4 m in length, then all tubing in excess of 4 m shall be insulated, except for an in-line smokemeter, if used. The radial thickness of the insulation shall be at least 25 mm. The thermal conductivity of the insulating material shall have a value no greater than 0.1 W/mK measured at 673 K. To reduce the thermal inertia of the exhaust pipe a thickness to diameter ratio of 0.015 or less is recommended. The use of flexible sections shall be limited to a length to diameter ratio of 12 or less.

PDP Positive displacement pump

The PDP meters total diluted exhaust flow from the number of the pump revolutions and the pump displacement. The exhaust system back-pressure shall not be artificially lowered by the PDP or dilution air inlet system. Static exhaust back-pressure measured with the PDP system operating shall remain within ± 1.5 kPa of the static pressure measured without connection to the PDP at identical engine speed and load. The gas mixture temperature immediately ahead of the PDP shall be within ± 6 K of the average operating temperature observed during the test, when no flow compensation is used. Flow compensation may only be used if the temperature at the inlet to the PDP does not exceed 323K (50°C)

CFV Critical flow venturi

CFV measures total diluted exhaust flow by maintaining the flow at choked conditions (critical flow). Static exhaust back-pressure measured with the CFV system operating shall remain within ± 1.5 kPa of the static pressure measured without connection to the CFV at identical engine speed and load. The gas mixture temperature immediately ahead of the CFV shall be within ± 11 K of the average operating temperature observed during the test, when no flow compensation is used.

HE Heat exchanger (optional, if EFC is used)

The heat exchanger shall be of sufficient capacity to maintain the temperature within the limits required above.

EFC Electronic flow compensation (optional, if HE is used)

If the temperature at the inlet to either the PDP or CFV is not kept within the limits stated above, a flow compensation system is required for continuous measurement of the flow rate and control of the proportional sampling in the particulate system. To that purpose, the continuously measured flow rate signals are used to correct the sample flow rate through the particulate filters of the particulate sampling system (see Appendix 4, Figure 9), accordingly.

DT Dilution tunnel

The dilution tunnel:

- **shall consist of a straight tube of electrically-conductive material, which shall be earthed;**

- shall be small enough in diameter to cause turbulent flow (Reynolds Number greater than 4000) and of sufficient length to cause complete mixing of the exhaust and dilution air; a mixing orifice may be used;

- shall be at least **200 mm** in diameter;

- may be insulated.

The engine exhaust shall be directed downstream at the point where it is introduced into the dilution tunnel, and thoroughly mixed.

The flow capacity of the PDP or CFV shall be sufficient to maintain the diluted exhaust stream in the DT at a temperature of less than or equal to 464 K (191°C) at the sampling zone.

DAF Dilution air filtration

It is recommended that the dilution air used for the primary dilution of the exhaust in the CVS tunnel shall be first charcoal scrubbed and then passed through a medium capable of reducing particles in the most penetrating particle size of the filter material by at least 99.95%, or through a filter of at least class H13 of EN 1822. This represents the specification of High Efficiency Particulate Air (HEPA) filters.

At the engine manufacturer's request the dilution air shall be sampled according to good engineering practice to determine the tunnel contribution to background particulate levels, which can then be subtracted from the values measured in the diluted exhaust.

PSP Particulate sampling probe

The probe is the leading section of PTT and:

- shall be installed facing upstream at a point where the dilution air and exhaust gas are well mixed, i.e. on the dilution tunnel (DT) centreline 10 to 20 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;
- shall be of 12 mm minimum inside diameter;
- may be heated to no greater than 325 K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel;
- may be insulated.

4. CVS Calibration Procedure

4.1. General Requirements

The CVS system shall be calibrated by using an accurate flowmeter 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 flowmeters may be used, e.g. calibrated venturi, calibrated laminar flowmeter, calibrated turbinemeter.

4.2. Calibration of the positive displacement pump (PDP)

All parameters related to the pump shall be simultaneously measured with the parameters related to the flowmeter 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 that 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.

4.2.1. Data analysis

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

$$V_0 = \frac{Q_s}{n} * \frac{T}{273} * \frac{101{,}3}{P_A}$$

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:

$$X_0 = \frac{1}{n} * \sqrt{\frac{\Delta \rho_A}{\rho_A}}$$

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:

$$V_0 = D_0 - m * (X_0)$$

D_0 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 per cent 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 (Annex 4, Appendix 2, Paragraph 5) indicates a change of the slip rate.

4.3. 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:

$$Q_s = \frac{K_v \rho_A}{\sqrt{T}}$$

where:

K_v = calibration coefficient
p_A = absolute pressure at venturi inlet, kPa
T = temperature at venturi inlet, K

4.3.1. Data Analysis

The air flow rate (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:

$$K_v = \frac{Q_s * \sqrt{T}}{\rho_A}$$

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 per cent of the average K_V.

5. Total System Verification Procedure

5.1. General Requirements

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 Annex 4, Appendix 4, Paragraph 1.1., 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.

5.2. Critical Flow Orifice (CFO) Method

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 per cent of the known mass of the gas injected.

5.3. Gravimetric Method

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 per cent of the known mass of the gas injected.

APPENDIX 3 – GASEOUS EMISSIONS MEASUREMENT SYSTEMS

1. System Specification

1.1. Sampling System

1.1.1. Raw exhaust gas (ESC only)

The gaseous emissions sampling probes shall 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 permissible to acquire a sample from each group individually and calculate an average exhaust emission. Other methods that have been shown to correlate with the above methods may be used. For exhaust emission calculation the total exhaust mass flow shall 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.

1.1.2. Diluted exhaust gas (mandatory for ETC, optional for ESC)

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements of Annex 4, Appendix 2, Paragraph 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.

For the ETC, 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 NO_x.

1.1.3. Gas Drying

The sampling system may include a gas drying device if required to meet the requirements of of Appendix 3, Paragraph 3.7.1. This shall have a minimal effect on the concentration of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

1.2. Gas Analysers

1.2.1. General Requirements

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (Paragraph 1.2.2). It is recommended that the analysers be operated such that the measured concentration falls between 15 per cent and 100 per cent of full scale.

If read-out systems (computers, data loggers) can provide sufficient accuracy and resolution below 15 per cent of full scale, measurements below 15 per cent 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 Annex 4, Appendix 3, Paragraph 3.3.5.1.

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

1.2.2. Measurement error

The total measurement error, including the cross sensitivity to other gases (see Annex 4, Appendix 3, Paragraph 3.7.), shall not exceed ± 5 per cent of the reading or ± 3.5 per cent of full scale, whichever is smaller. For concentrations of less than 100 ppm the measurement error shall not exceed ± 4 ppm.

1.2.3. Repeatability

The repeatability, 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 ± 1 per cent of full scale concentration for each range used above 155 ppm (or ppm C) or ± 2 per cent of each range used below 155 ppm (or ppm C).

1.2.4. Noise

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

1.2.5. Zero drift

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

1.2.6. Span drift

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

1.3. Measurement Principles

Paragraphs 1.3.1. to 1.3.4. describe the measurement principles to be used. A detailed description of the measurement systems is given in Annex 4, Appendix 3. The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearising circuits is permitted.

1.3.1. Carbon monoxide (CO) analysis

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

1.3.2. Carbon dioxide (CO_2) analysis

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

1.3.3. 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, pipework, 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 Annex 4, Appendix 3, Paragraph 2.3.).

1.3.4. Non-methane hydrocarbon (NMHC) analysis (NG fuelled gas engines only)

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

1.3.4.1. 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 Paragraph 1.3.3.

1.3.4.2. 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 Paragraph 1.3.3. by subtraction of the methane from the hydrocarbons.

1.3.5. Oxides of nitrogen (NO_x) analysis

The oxides of nitrogen analyser shall be of the Chemi-Luminescent Detector (CLD) or Heated Chemi-Luminescent 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 Annex 4, Appendix 3, Paragraph 3.7.2.2.) is satisfied.

2. Recommended System Description

2.1. Introduction

Paragraph 1.2., Figure 4 and Figure 5 contain detailed descriptions of the recommended sampling and analysing systems. Since various configurations can produce equivalent results, exact conformance with Figure 4 and Figure 5 is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems. Other components that are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

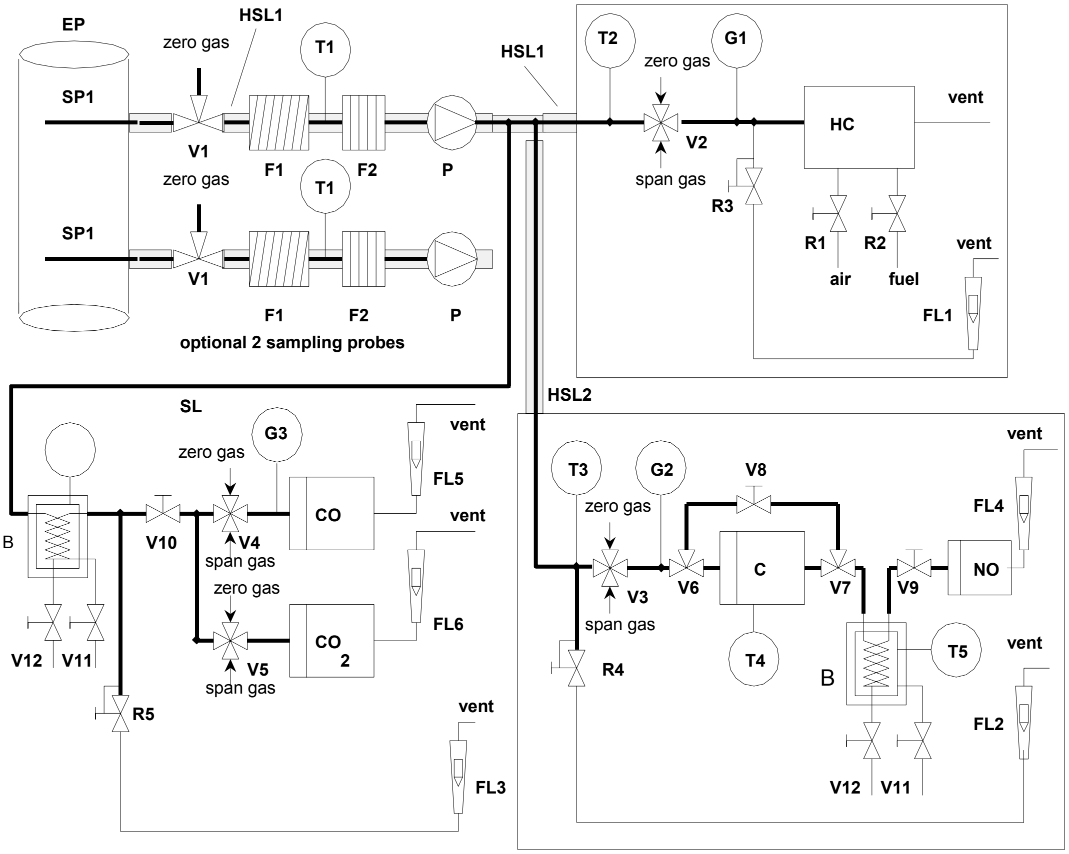

Figure 4: Flow diagram of raw exhaust gas analysis system for CO, CO2, NOx, HC ESC only

2.2. Description of the analytical system

An analytical system for the determination of the gaseous emissions in the raw (Figure 4, ESC only) or diluted (Figure 5. ETC and ESC) exhaust gas is described based on the use of:

- HFID analyser for the measurement of hydrocarbons;
- NDIR analysers for the measurement of carbon monoxide and carbon dioxide;
- HCLD or equivalent analyser for the measurement of the oxides of nitrogen;

The sample for all components may be taken with one sampling probe or with two sampling probes located in close proximity and internally split to the different analysers. Care shall be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

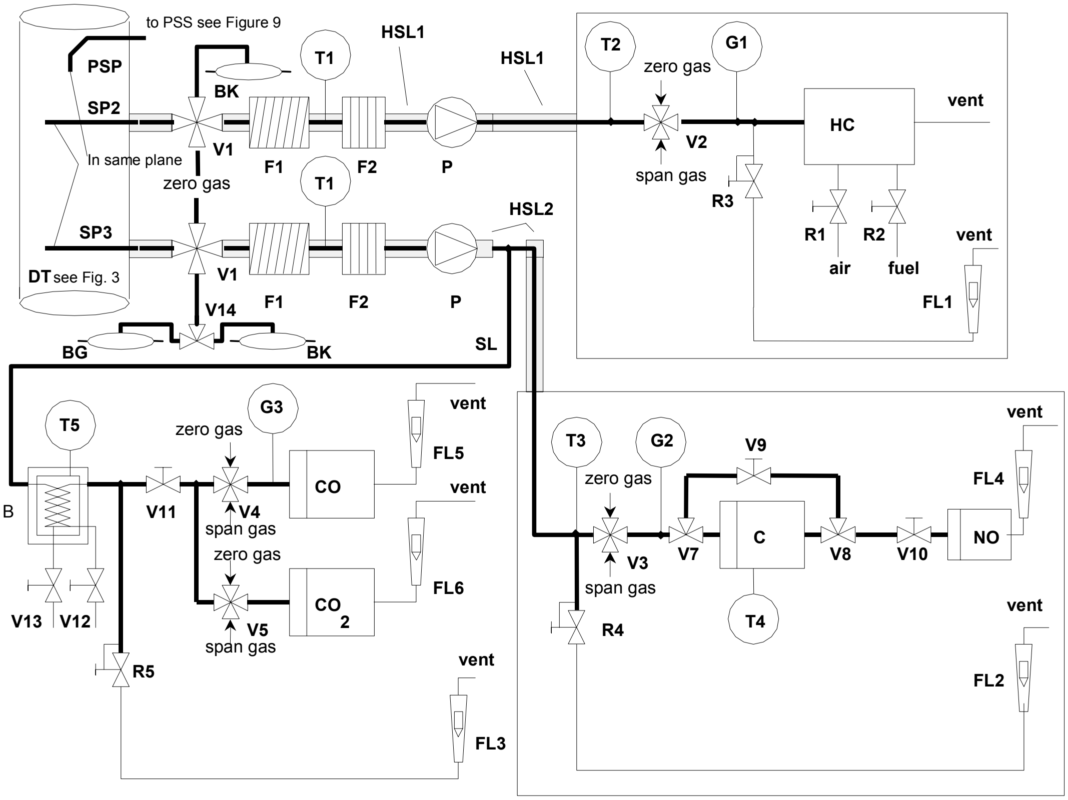

Figure 5: Flow diagram of diluted exhaust gas analysis system for CO, CO2, NOx, HC (ETC, optional for ESC)

2.2.1. Components of Figure 4 and Figure 5

EP Exhaust pipe

SP1 Exhaust gas sampling probe (Figure 4 only)

A stainless steel straight closed end multi-hole probe is recommended. The inside diameter shall not be greater than the inside diameter of the sampling line. The wall thickness of the probe shall not be greater than 1 mm. There shall be a minimum of 3 holes in 3 different radial planes sized to sample approximately the same flow. The probe shall extend across at least 80 per cent of the diameter of the exhaust pipe. One or two sampling probes may be used.

SP2 Diluted exhaust gas HC sampling probe (Figure 5 only)

The probe shall:

- be defined as the first 254 mm to 762 mm of the heated sampling line HSL1;
- have a 5 mm minimum inside diameter;
- be installed in the dilution tunnel DT (For example; Figure 3) at a point where the dilution air and exhaust gas are well mixed (i.e. between 10 and 20 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel);
- be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
- be heated so as to increase the gas stream temperature to 463 K ± 10 K (190°C ± 10°C) at the exit of the probe.

SP3 Diluted exhaust gas CO, CO_2, NO_x sampling probe (Figure 5 only)

The probe shall:

- be in the same plane as SP 2;
- be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
- be heated and insulated over its entire length to a minimum temperature of 328 K (55°C) to prevent water condensation.

HSL1 Heated sampling line

The sampling line provides a gas sample from a single probe to the split point(s) and the HC analyser.

The sampling line shall:

- have a 5 mm minimum and a 13.5 mm maximum inside diameter;
- be made of stainless steel or PTFE.

- maintain a wall temperature of 463 K ± 10 K (190°C ± 10°C) as measured at every separately controlled heated section, if the temperature of the exhaust gas at the sampling probe is equal to or below 463 K (190°C);

- maintain a wall temperature greater than 453 K (180°C), if the temperature of the exhaust gas at the sampling probe is above 463 K (190°C);

- maintain a gas temperature of 463 K ± 10 K (190°C ± 10°C) immediately before the heated filter F2 and the HFID;

HSL2 Heated NO_x sampling line

The sampling line shall:

- maintain a wall temperature of 328 K to 473 K (55°C to 200°C), up to the converter C when using a cooling bath B, and up to the analyser when a cooling bath B is not used.

- be made of stainless steel or PTFE.

SL Sampling line for CO and CO_2

The line shall be made of PTFE or stainless steel. It may be heated or unheated.

BK Background bag (optional; Figure 5 only)

For the sampling of the background concentrations

BG Sample bag (optional; Figure 5 CO and CO_2 only)

For the sampling of the sample concentrations.

F1 Heated pre-filter (optional)

The temperature shall be the same as HSL1.

F2 Heated filter

The filter shall extract any solid particles from the gas sample prior to the analyser. The temperature shall be the same as HSL1. The filter shall be changed as needed.

P Heated sampling pump

The pump shall be heated to the temperature of HSL1.

HC Heated flame ionisation detector (HFID) for the determination of the hydrocarbons.

The temperature shall be kept at 453 K to 473 K (180°C to 200°C).

CO, CO_2 NDIR analysers for the determination of carbon monoxide and carbon dioxide (optional for the determination of the dilution ratio for PT measurement).

NO CLD or HCLD analyser for the determination of the oxides of nitrogen.

If a HCLD is used it shall be kept at a temperature of 328 K to 473 K (55°C to 200°C).

C Converter

A converter shall be used for the catalytic reduction of NO_2 to NO prior to analysis in the CLD or HCLD.

B Cooling bath (optional)

To cool and condense water from the exhaust sample: the bath shall be maintained at a temperature of 273 K to 277 K (0°C to 4°C) by ice or refrigeration. It is optional if the analyser is free from water vapour interference as determined in Annex 4, Appendix 3, Paragraphs 3.7.1 and 3.7.2. If water is removed by condensation, the sample gas temperature or dew point shall be monitored either within the water trap or downstream. The sample gas temperature or dew point shall not exceed 280 K (7°C). Chemical dryers are not allowed for removing water from the sample.

T1, T2, T3 Temperature sensor

To monitor the temperature of the gas stream:

T4 Temperature sensor

To monitor the temperature of the NO_2 - NO converter:

T5 Temperature sensor

To monitor the temperature of the cooling bath:

G1, G2, G3 Pressure gauge

To measure the pressure in the sampling lines:

R1, R2 Pressure regulator

To control the pressure of the air and the fuel, respectively, for the HFID:

R3, R4, R5 Pressure regulator

To control the pressure in the sampling lines and the flow to the analysers:

FL1, FL2, FL3 Flowmeter

To monitor the sample by-pass flow rate:

FL4 to **FL6** Flowmeter (optional)

To monitor the flow rate through the analysers:

V1 to **V5** Selector valve

Suitable valves for selecting the sample, span gas or zero gas flow to the analysers.

V6, V7 Solenoid valve

To by-pass the NO_2 - NO converter:

V8 Needle valve

To balance the flow through the NO_2 - NO converter C and the by-pass:

V9, V10 Needle valve

To regulate the flows to the analysers:

V11, V12 Toggle valve (optional)

To drain the condensate from the bath B:

2.3. NMHC analysis (NG fuelled gas engines only)

2.3.1. Gas chromatographic method (GC, Figure 6)

When using the GC method, a small measured volume of a sample is injected onto an analytical column through which it is swept by an inert carrier gas. The column separates various components according to their boiling points so that they elute from the column at different times. They then pass through a detector that gives an electrical signal that depends on their concentration. Since it is not a continuous analysis technique, it can only be used in conjunction with the bag sampling method as described in Annex 4, Appendix 3, Paragraph 1.1.2.

For NMHC an automated GC with a FID shall be used. The exhaust gas shall be sampled into a sampling bag from which a part shall be taken and injected into the GC. The sample is separated into two parts (CH_4/Air/CO and NMHC/CO_2/H_2O) on the Porapak column. The molecular sieve column separates CH_4 from the air and CO before passing it to the FID where its concentration is measured. A complete cycle from injection of one sample to injection of a second can be made in 30 s. To determine NMHC, the CH_4 concentration shall be subtracted from the total HC concentration (see Annex 4, Paragraph 7.7.3.1.).

Figure 6 shows a typical GC assembled to routinely determine CH_4. Other GC methods can also be used based on good engineering judgement.

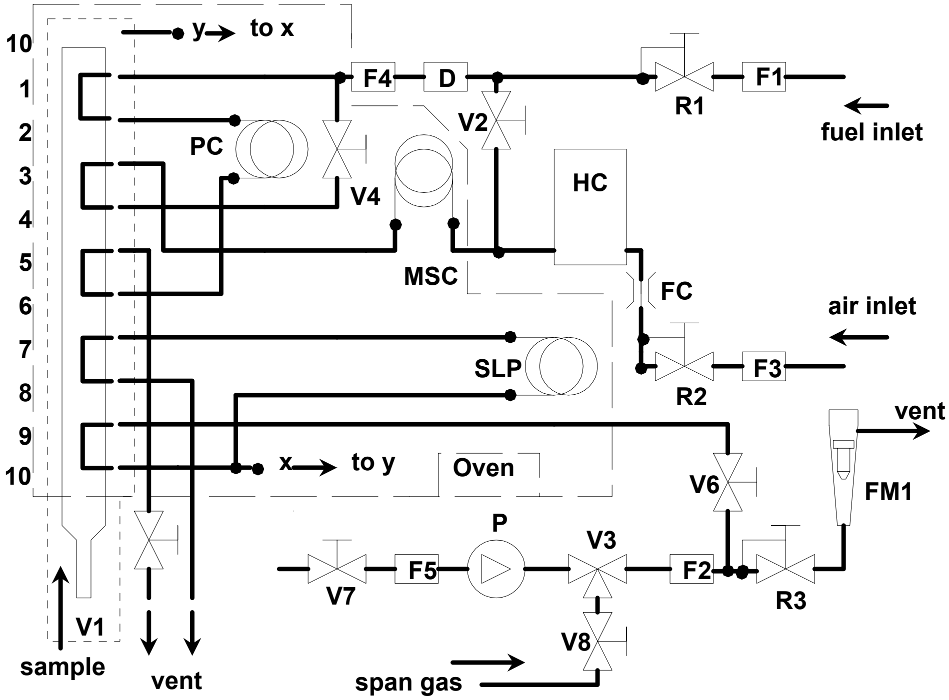

Figure 6: Flow diagram for methane analysis (GC method)

Components of Figure 6

PC Porapak column

Porapak N, 180/300 µm (50/80 mesh), 610 mm length x 2.16 mm ID shall be used and conditioned at least 12 h at 423 K (150°C) with carrier gas prior to initial use.

MSC Molecular sieve column

Type 13X, 250/350 µm (45/60 mesh), 1220 mm length x 2.16 mm ID shall be used and conditioned at least 12 h at 423 K (150°C) with carrier gas prior to initial use.

OV Oven

To maintain columns and valves at stable temperature for analyser operation, and to condition the columns at 423 K (150°C).

SLP Sample loop

A sufficient length of stainless steel tubing to obtain approximately 1 cm^3 volume.

P Pump

To bring the sample to the gas chromatograph.

D Dryer

A dryer containing molecular sieve shall be used to remove water and other contaminants which might be present in the carrier gas.

HC Flame ionisation detector (FID) to measure the concentration of methane.

V1 Sample injection valve

To inject the sample taken from the sampling bag via SL of Figure 5. It shall be low dead volume, gas tight, and heatable to 423 K (150°C).

V3 Selector valve

To select span gas, sample, or no flow.

V2, V4, V5, V6, V7, V8 Needle valve

To set the flows in the system.

R1, R2, R3 Pressure regulator

To control the flows of the fuel (= carrier gas), the sample, and the air, respectively.

FC Flow capillary

To control the rate of air flow to the FID

G1, G2, G3 Pressure gauge

To control the flows of the fuel (= carrier gas), the sample, and the air, respectively.

F1, F2, F3, F4, F5 Filter

Sintered metal filters to prevent grit from entering the pump or the instrument.

FL1 Flowmeter

To measure the sample bypass flow rate.

2.3.2. Non-methane cutter method (NMC, Figure 7)

The cutter oxidises all hydrocarbons except CH_4 to CO_2 and H_2O, so that by passing the sample through the NMC only CH_4 is detected by the FID. If bag sampling is used, a flow diverter system shall be installed at SL (see Appendix 3, Paragraph 2.2., Figure 5) with which the flow can be alternatively passed through or around the cutter according to the upper part of Figure 10. For NMHC measurement, both values (HC and CH_4) shall be observed on the FID and recorded. If the integration method is used, an NMC in line with a second FID shall be installed parallel to the regular FID into HSL1 (see Appendix 3, Paragraph 1.2., Figure 5) according to the lower part of Figure 7. For NMHC measurement, the values of the two FID's (HC and CH_4) shall be observed and recorded.

The cutter shall be characterised at or above 600 K (327°C) prior to test work with respect to its catalytic effect on CH_4 and C_2H_6 at H_2O values representative of exhaust stream conditions. The dew point and O_2 level of the sampled exhaust stream shall be known. The relative response of the FID to CH_4 shall be recorded
(see Annex 4, Appendix 3, Paragraph 3.6.2.).

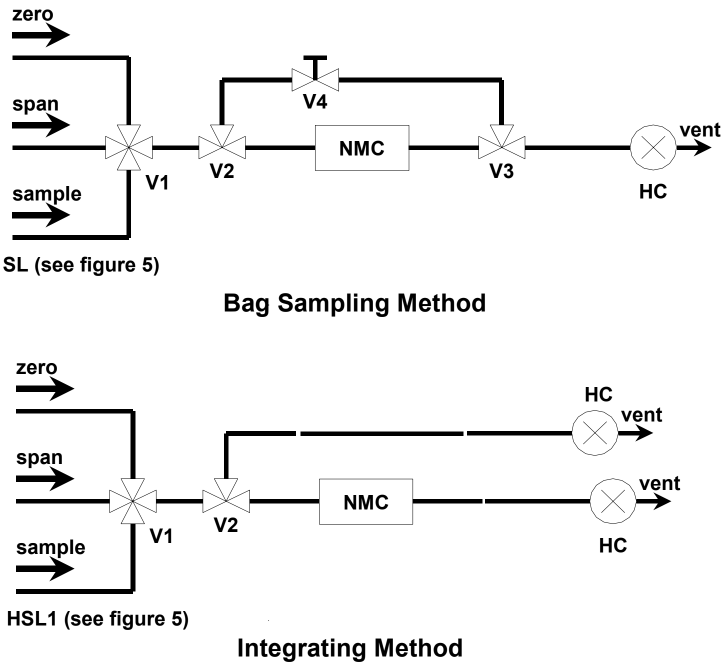

Figure 7: Flow diagram for methane analysis with the non-methane cutter (NMC)

Components of Figure 7:

NMC Non-methane cutter

To oxidise all hydrocarbons except methane.

HC Heated flame ionisation detector (HFID)

To measure the HC and CH_4 concentrations. The temperature shall be kept at 453 K to 473 K (180°C to 200°C).
V1 Selector valve

To select sample, zero and span gas. V1 is identical with V2 of Figure 5.

V2, V3 Solenoid valve

To by-pass the NMC

V4 Needle valve

To balance the flow through the NMC and the by-pass.

R1 Pressure regulator

To control the pressure in the sampling line and the flow to the HFID. R1 is identical with R3 of Figure 5.

FL1 Flowmeter

To measure the sample by-pass flow rate. FL1 is identical with FL1 of Figure 5.

3. Calibration Procedures

3.1. General Requirements

Each analyser shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method that shall be used is described in this Paragraph for the analysers indicated in Annex 4, Appendix 3, Paragraph 3.

The analysers shall be calibrated according to Appendix 3. Paragraph 3.3.1. at least every 3 months or whenever a system repair or change is made that could influence calibration.

The operating procedure for analysers shall follow the start-up and operating instructions of the instrument manufacturer. The minimum requirements given in Paragraphs 4, 5 and 7. shall be included.

3.2. Leakage Test Procedure

A system leakage test shall be performed. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilisation period all flow meters 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 per cent of the in-use flow rate for the portion of the system being checked. The analyser flows and bypass flows may be used to estimate the in-use flow rates.

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 shows a lower concentration compared to the introduced concentration, this points to calibration or leakage problems.

3.3. Analyser Calibration procedure

3.3.1. 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.

3.3.2. 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.

3.3.3. NDIR and HFID analyser

The NDIR analyser shall be tuned, as necessary, and the combustion flame of the HFID analyser shall be optimised (Appendix 3, Paragraph 3.6.1).

3.3.4. Calibration

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 according to Appendix 3, Paragraph 3.3.5.

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

3.3.5. Establishment of the calibration curve

3.3.5.1. General guidelines

The analyser calibration curve shall be established by at least five calibration points (excluding zero) spaced as uniformly as possible. The highest nominal concentration shall be equal to or higher than 90 per cent of full scale.

The calibration curve shall be calculated by the method of least squares. If the resulting polynomial degree is greater than 3, the number of calibration points (zero included) shall be at least equal to this polynomial degree plus 2.

The calibration curve shall not differ by more than ± 2 per cent from the nominal value of each calibration point and by more than ± 1 per cent of full scale at zero.
From the calibration curve and the calibration points, it is possible to verify that the calibration has been carried out correctly. The different characteristic parameters of the analyser shall be indicated, particularly:

- the measuring range;
- the sensitivity;
- the date of carrying out the calibration.

3.3.5.2. Calibration below 15 per cent of Full Scale

The analyser calibration curve shall be established by at least 4 additional calibration points (excluding zero) spaced nominally equally below 15 per cent of full scale.

The calibration curve is calculated by the method of least squares.

The calibration curve shall not differ by more than ± 4 per cent from the nominal value of each calibration point and by more than ± 1 per cent of full scale at zero.

3.3.5.3. 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.

3.4. Analyser Verification Procedure

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 per cent of full scale of the measuring range.

If, for the two points considered, the value found does not differ by more than ± 4 per cent 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 Appendix 3, Paragraph 3.3.5.

3.5. NO_x Converter Efficiency Test Procedure

The efficiency of the converter used for the conversion of NO_2 into NO shall be tested as given in Appendix 3, Paragraphs 3.5.1. to 3.5.8.(Figure 8).

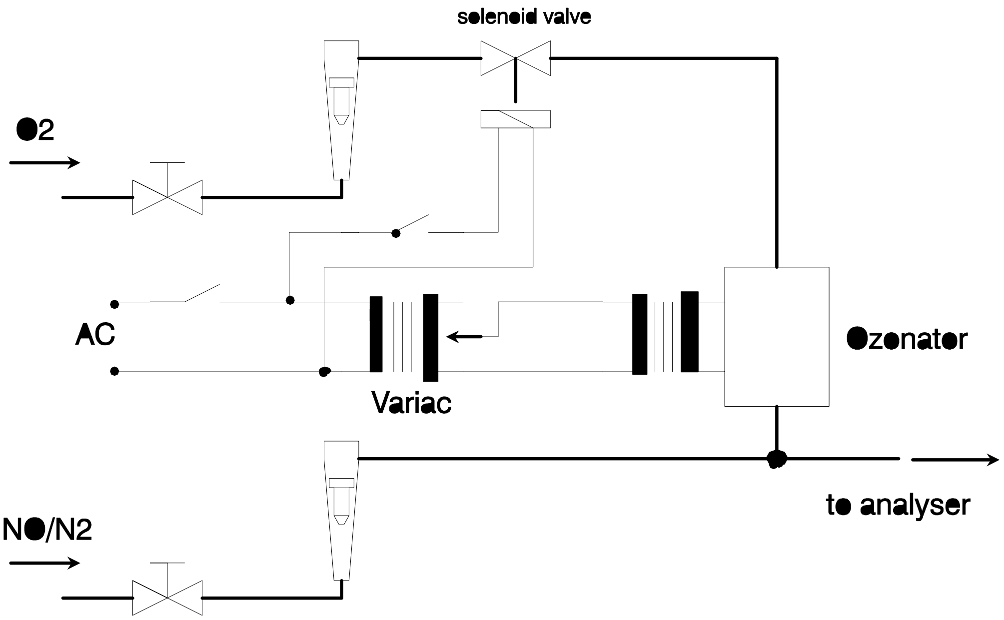

Figure 8: Schematic of NO_2 converter efficiency device

3.5.1. Test set-up

Using the test set-up as shown in Figure 8 (see also Annex 4, Appendix 3, Paragraph 1.3.5) and the procedure below, the efficiency of converters can be tested by means of an ozonator.

3.5.2. 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 shall amount to about 80 per cent of the operating range and the NO_2 concentration of the gas mixture to less than 5 per cent of the NO concentration). The NO_x analyser shall be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

3.5.3. Calculation

The efficiency of the NO_x converter is calculated as follows:

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

where:

a is the NO_x concentration according to Appendix 3, Paragraph 3.5.6
b is the NO_x concentration according to Appendix 3, Paragraph 3.5.7
c is the NO concentration according to Appendix 3, Paragraph 3.5.4
d is the NO concentration according to Appendix 3, Paragraph 3.5.5

3.5.4. 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 per cent less than the indicated calibration concentration given in Appendix 3, Paragraph 3.5.2.(The analyser is in the NO mode). The indicated concentration c shall be recorded. The ozonator is kept deactivated throughout the process.

3.5.5. Activation of the ozonator

The ozonator is now activated to generate enough ozone to bring the NO concentration down to about 20 per cent (minimum 10 per cent) of the calibration concentration given in Appendix 3, Paragraph 3.5.2. The indicated concentration d shall be recorded (The analyser is in the NO mode).

3.5.6. NO_x mode

The NO analyser is then switched to the NO_x 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).

3.5.7. Deactivation of the ozonator

The ozonator is now deactivated. The mixture of gases described in Appendix 3, Paragraph 3.5.6 passes through the converter into the detector. The indicated concentration b shall be recorded. (The analyser is in the NO_x mode).

3.5.8. NO mode

Switched to NO mode with the ozonator deactivated, the flow of oxygen or synthetic air is also shut off. The NO_x reading of the analyser shall not deviate by more than ± 5 per cent from the value measured according to Appendix 3, Paragraph 3.5.2. (The analyser is in the NO mode).

3.5.9. Test interval

The efficiency of the converter shall be tested prior to each calibration of the NO_x analyser.

3.5.10. Efficiency requirement

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

Note: If, with the analyser in the most common range, the ozonator cannot give a reduction from 80 per cent to 20 per cent according to Appendix 3, Paragraph 3.5.5., then the highest range which will give the reduction shall be used.

3.6. FID Analyser Adjustment Procedures

3.6.1. Optimisation of the detector response

The FID shall 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.

3.6.2. Hydrocarbon response factors

The analyser shall be calibrated using propane in air and purified synthetic air, according to Appendix 3, Paragraph 3.3.1.

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 shall be at a level to give a response of approximately 80 per cent of full scale. The concentration shall be known to an accuracy of ± 2 per cent in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder shall 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	$1.00 \leq R_f \leq 1.15$
Propylene and purified synthetic air	$0.90 \leq R_f \leq 1.1$
Toluene and purified synthetic air	$0.90 \leq R_f \leq 1.10$

These values are relative to the response factor (R_f) of 1.00 for propane and purified synthetic air.

3.6.3. Oxygen interference check

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

The response factor is defined and shall be determined as described in Appendix 3, Paragraph 3.6.2. 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 shall 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 shall be checked and the analyser adjusted, if necessary.

3.6.4. 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 (Annex 4, Paragraph 7.7.3.1).

3.6.4.1. Methane efficiency

Methane 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:

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

where:

$conc_w$ = HC concentration with CH_4 flowing through the NMC
$conc_{w/o}$ = HC concentration with CH_4 bypassing the NMC

3.6.4.2. 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:

$conc_w$ = HC concentration with C_2H_6 flowing through the NMC
$conc_{w/o}$ = HC concentration with C_2H_6 bypassing the NMC

3.7. CO, CO_2, and NO_x Analyser Interference Check Procedures

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 Appendix 3, Paragraphs 3.7.1. and 3.7.2. shall be performed prior to an analyser's initial use and after major service intervals.

3.7.1. 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 per cent 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 shall not be more than 1 per cent of full scale for ranges equal to or above 300 ppm or more than 3 ppm for ranges below 300 ppm.

3.7.2. 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.

3.7.2.1. CO_2 Quench Check

A CO_2 span gas having a concentration of 80 to 100 per cent 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 per cent 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 shall not be greater than 3 per cent of full scale, shall be calculated as follows:

$$\% \, Quench = \left[1 - \left(\frac{(C * A)}{(D * A) - (D * B)} \right) \right] * 100$$

where:

A is the undiluted CO_2 concentration measured with NDIR in per cent
B is the diluted CO_2 concentration measured with NDIR in per cent
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.

3.7.2.2. Water Quench Check Procedure

This check applies to wet gas concentration measurements only. Calculation of water quench shall 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 per cent 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:

$$H = 100*(G/E)$$

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

$$De = D* (1- H/100)$$

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 CO_2 span gas concentration (A, as measured in Appendix 3, Paragraph 3.7.2.1) as follows:

$$Hm = 0.9*A$$

The water quench, which shall not be greater than 3 per cent, shall be calculated as follows:

$$\% \text{ Quench} = 100 * ((De - C)/De) * (Hm/H)$$

where:

De	is the expected diluted NO concentration in ppm
C	is the diluted NO concentration in ppm
Hm	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.

4. Reference Gases

The shelf life of all calibration gases shall be respected.
The expiration date of the calibration gases stated by the manufacturer shall be recorded.

4.1. Pure gases

The required purity of the gases is defined by the contamination limits given below. The following gases shall 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 0_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

4.2. Calibration and span gases

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

C_3H_8 and purified synthetic air (see Appendix 3, Paragraph 4.1);

CO and purified nitrogen;

NO_x and purified nitrogen (the amount of NO_2 contained in this calibration gas shall 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 shall be within ± 2 per cent of the nominal value. All concentrations of calibration gas shall be given on a volume basis (volume percent or volume ppm).

The gases used for calibration and span may also be obtained by means of a gas divider, diluting with purified N_2 or with purified synthetic air. The accuracy of the mixing device shall be such that the concentration of the diluted calibration gases may be determined to within ± 2 per cent.

APPENDIX 4 PARTICULATE MASS MEASUREMENT EQUIPMENT

1. System Overview

For ETC, the particulates shall be measured using a secondary dilution system sampling from a full-flow dilution tunnel. For ESC, a partial flow sampling system may be used

The particulate sampling unit shall consist of a either a secondary dilution tunnel with a sample probe located in the full flow dilution system, or a partial flow dilution tunnel with a sampling probe located in the raw exhaust. In both cases a particle transfer tube and a filter holder are required, together with pumps, flow rate regulators and measuring units. A particulate sample is collected from the dilute exhaust gas on filter of the specified type. The weight of this filter is measured before and after sampling, and the particulate mass is derived from the measured difference.

It is recommended that a particle size pre-classifier (e.g. cyclone, impactor etc) be employed immediately upstream of the filter. However, **a** sampling probe acting as an appropriate size-classification **device is acceptable.**

2. System Specification

2.1. General Requirements

2.1.1. The particulate sample shall be collected on a single filter mounted within a holder in the sampled dilute exhaust gas flow. Back-up filters are not permitted.

2.1.2. The single filter method shall be applied which uses one **filter** for the whole test cycle. For the ESC, considerable attention shall be paid to sampling times and flows during the sampling phase of the test.

2.1.3. All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder, which are in contact with raw and diluted exhaust gas, shall be designed to minimise deposition or alteration of the particulates. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

2.1.4. Filter specification

Fluorocarbon coated glass fibre filters are required[6]. All filter types shall have a 0.3 µm DOP (di-octylphthalate) collection efficiency of at least [**99**][7] per cent at a gas face velocity of at least 35cm/s.

Particulate filters shall have a minimum diameter of 47 mm (37 mm stain diameter).

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[6] OICA requests that Teflo filters be permitted as an option

[7] OICA to provide data clarifying 99% rather than 95% efficiency

2.1.5. Filter Holder

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 both up and downstream of the filter in the direction of flow.

2.1.6. Filter face velocity

A gas face velocity through the filter of at least 35 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.

2.1.7. Filter loading

The recommended minimum filter loading shall be 0.11 mg/1075 mm² stain area. For the most common filter sizes the values are shown in Table 4.

Table 4: Recommended filter loadings

Filter Diameter(mm)	Stain Diameter (mm^2)	Stain Area (mm^2)	Minimum Filter loading (mg)
47	37	1075	0.11
70	60	2825	0.25
90	80	5025	0.41
110	100	31415	0.62

2.1.8. Weighing chamber

The weighing chamber (or room) shall meet the following conditions during all filter conditioning and weighing operations[8]:

Temperature maintained at 295 ± 3 K (22 ± 3°C)

Relative humidity maintained at 45 ± 8%.

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.

Limited deviations from weighing room temperature and humidity specifications will be allowed provided their total duration does not exceed 30 minutes in any one filter conditioning period. The weighing room should meet the required specifications prior to personal entrance into the weighing room. During the weighing operation no deviations from the specified conditions are permitted.

To eliminate the effects of static electricity: the balance should be grounded through placement upon an antistatic mat and particulate filters should be

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[8] OICA to supply contribution concerning weighing room set-point drift as an output of the PM-3 programme.

neutralised prior to weighing; this can be achieved by a Polonium neutraliser or a device of similar effect.

A test filter shall be removed from the chamber no earlier than an hour before the test begins.

2.1.9. Analytical balance

The analytical balance used to determine the weights of all filters shall have a precision (standard deviation) of 2 µg and a resolution of 1 µg (1 digit = 1 µg) **or better**.

2.1.10. Elimination of static electricity effects

To eliminate the effects of static electricity, the filters should be neutralised prior to weighing, e.g. by a Polonium neutraliser or a device of similar effect.

2.2. Double Dilution System - Requirements

To determine the mass of the particulates using the double dilution method, a **secondary dilution system shall be used to draw a sample of dilute exhaust gas from a primary full flow dilution system.**

2.2.1. The particulate sample flow rate shall be proportional to the total flow of diluted exhaust gas in the full flow dilution tunnel

2.2.2. The sampling probe for the test gas flow for particulates shall be so arranged within the **secondary dilution system** that a representative sample gas flow can be taken from the homogeneous air/exhaust mixture.

2.2.3. The sampled double diluted exhaust gas shall be maintained at a temperature of 320 ± 5 K (47 ± 5 °C) and have a residence time of at least **[0.2s]** at this temperature, immediately before the particulate filter.

2.2.4. The secondary dilution tunnel should have a minimum diameter of 25 mm, and should be of sufficient length so as to provide a residence time of at least 0.25 seconds for the doubly-diluted sample. The filter holder shall be located within 300 mm of the exit of the SDT.

2.3. Recommended System – Double Dilution System

The double or secondary dilution system to be used in conjunction with a full flow dilution system is shown in Figure 9.

The double dilution system includes all important parts of the particulate sampling system, like filter holders and sampling pump, and additionally some dilution features, like a dilution air supply and a secondary dilution tunnel.

In order to avoid any impact on the control loops, it is recommended that the sample pump be running throughout the complete test procedure. A bypass system shall be used for passing the sample through the sampling filter at the desired times. Interference of the switching procedure on the control loops shall be minimised.

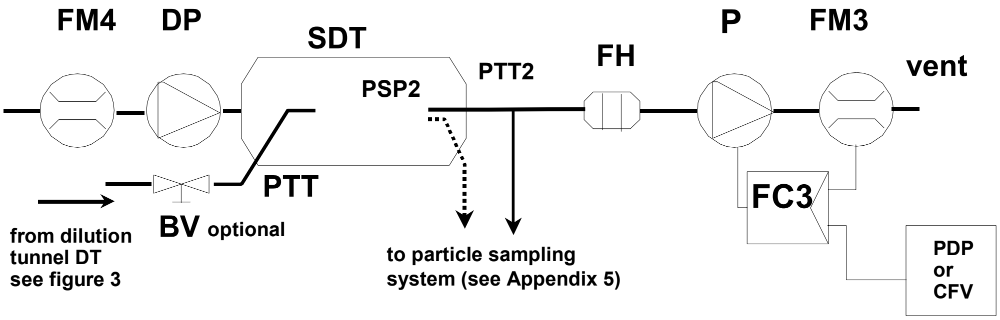

Figure 9: Double dilution system (full flow system only)

A sample of the diluted exhaust gas is transferred from the dilution tunnel DT of a full flow dilution system through the particulate sampling probe PSP and the particulate transfer tube PTT to the secondary dilution tunnel SDT, where it is diluted once more.

The sample is then passed through a further sampling probe (PSP2) and transfer tube (PTT2) to the filter holder(s) FH that contain the particulate sampling filters. The dilution air flow rate is usually constant whereas the sample flow rate is controlled by the flow controller FC3. If electronic flow compensation EFC (see Figure 3) is used, the total diluted exhaust gas flow is used as command signal for FC3.

2.3.1. Components of Figure 9

PTT Particulate transfer tube

The particulate transfer tube shall not exceed 1020 mm in length, including the sample probe (PSP) and shall be minimised in length whenever possible. The internal diameter of the tube shall be between 12mm and 26mm. The transfer should be designed to minimise particle loss during transfer, and if possible, be adiabatic, smooth and of low thermal inertia; which can be achieved by use of thin-walled, double-wall, internally polished, air-gap insulated tube.

The transfer tube:

– may be heated to no greater than 325K (52°C) wall temperature by direct heating or by dilution air pre- heating, provided the air temperature does not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel;

– may be insulated.

SDT Secondary dilution tunnel

The secondary dilution tunnel:

- may be heated to no greater than 325 K (52°C) wall temperature by dilution air pre-heating or by direct heating, provided the air temperature does not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel;
- may be insulated

PSP3 and PTT3 Particle Sampling Probe and Transfer Tube

A further sample probe (PSP3 and transfer tube PTT3) shall deliver the particle-size classification performance described below (PCF). It is recommended that this performance be achieved by the use of a sharp-edged, open-ended probe facing directly into the direction of flow plus a pre-classifier (cyclone impactor etc). **An appropriate sampling probe may alternatively be used provided it achieves the pre-classification performance described in Section** (PCF).

The sample probe shall be installed near the **secondary** tunnel centreline, **10 to 20** tunnel diameters downstream of the gas inlet and have an internal diameter of at least 12 mm.

If more than one simultaneous sample is drawn from a single sample probe, the flow drawn from that probe shall be split into identical sub-flows to avoid sampling artefacts.

If multiple probes are used, each probe shall be sharp-edged, open-ended and facing directly into the direction of flow. Probes shall be equally spaced around the central longitudinal axis of the dilution tunnel, with the spacing between probes at least 5cm.

PCF Particle Size Pre-classifier

Any particle size pre-classifier shall be located immediately upstream of the filter holder assembly. The pre-classifier 50% cut point particle diameter shall be between 2.5 µm and 10 µm at the volumetric flow rate selected for sampling particulate mass emissions. The pre-classifier shall allow at least 99% of the mass concentration of 1 µm particles entering the pre-classifier to pass through the exit of the pre-classifier at the volumetric flow rate selected for sampling particulate mass emissions. The volumetric flow rate selected shall not violate the filter face velocity conditions described in (Appendix 4, Paragraph 2.1.6)

FH Filter holder

For filtration one filter housing only shall be used. The requirements of Appendix 4, Paragraph 2.1.5. shall be met.

The filter holder:

- may be heated to no greater than 325 K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel;
- may be insulated.

P Sampling pump

The particulate sampling pump shall be located sufficiently distant from the tunnel so that the inlet gas temperature is maintained constant (± 3 K), if flow correction by FC3 is not used.

DP Dilution air pump

The dilution air pump shall be located so that the secondary dilution air is supplied at a temperature of 298 K ± 5 K (25°C ± 5°C), if the dilution air is not preheated.

FC3 Flow controller

A flow controller shall be used to compensate the particulate sample flow rate for temperature and back-pressure variations in the sample path, if no other means are available. The flow controller is required if electronic flow compensation EFC (see Figure 20) is used.

FM3 Flow measurement device

The gas meter or flow instrumentation for the particulate sample flow shall be located sufficiently distant from the sampling pump P so that the inlet gas temperature remains constant (± 3 K), if flow correction by FC3 is not used.

FM4 Flow measurement device

The gas meter or flow instrumentation for the dilution air flow shall be located so that the inlet gas temperature remains at 298 K ± 5 K (25°C ± 5°C).

Note: If the ambient temperature in the vicinity of PSP, PTT, SDT, and FH is below 293K (20°C), precautions should be taken to avoid particle losses onto the cool wall of these parts. Therefore, heating and/or insulating these parts within the limits given in the respective descriptions is recommended. It is also recommended that the filter face temperature during sampling be not below 293K (20°C).

At high engine loads, the above parts may be cooled by a non-aggressive means such as a circulating fan, as long as the temperature of the cooling medium is not below 293K (20°C).

2.4. Partial Flow Dilution – Requirements

2.4.1. The partial flow dilution system has to be designed to split the exhaust stream into two fractions, the smaller one being diluted with air and subsequently used for particulate measurement. For this it is essential that the dilution ratio be determined very accurately. Different splitting methods can be applied, whereby the type of splitting used dictates to a significant degree the sampling hardware and procedures to be used (Annex 4, Appendix 4, Paragraph 2.5.).

2.4.2. The particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, and the installation shall comply with the provisions of Appendix 4, Parargraph 2.2.

2.5. Recommended Systems - Partial Flow Dilution

The particulate sampling system is required for collecting the particulates on the particulate filter. In the case of total sampling partial flow dilution, which consists of passing the entire diluted exhaust sample through the filters, dilution and sampling system usually form an integral unit. In the case of fractional sampling partial flow dilution, which consists of passing through the filters only a small portion of the dilute exhaust, the dilution and sampling systems usually form different units.

Equivalent dilution systems are described in Figure 10 to Figure 18 based upon the dilution of a part of the exhaust stream. Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire dilute exhaust gas or only a portion of the dilute exhaust gas is passed to the particulate sampling system (Paragraph 2.4., Figure 19). The first method is referred to as total sampling type, the second method as fractional sampling type.

The calculation of the dilution ratio depends upon the type of system used. The following types are recommended:

Isokinetic systems (Figure 10, Figure 11)

With these systems, the flow into the transfer tube is matched to the bulk exhaust flow in terms of gas velocity and/or pressure, thus requiring an undisturbed and uniform exhaust flow at the sampling probe. This is usually achieved by using a resonator and a straight approach tube upstream of the sampling point. The split ratio is then calculated from easily measurable values like tube diameters. It should be noted that isokinesis is only used for matching the flow conditions and not for matching the size distribution. The latter is typically not necessary, as the particles are sufficiently small as to follow the fluid streamlines.

Flow controlled systems with concentration measurement (Figure 12 to Figure 16)

With these systems, a sample is taken from the bulk exhaust stream by adjusting the dilution air flow and the total dilute exhaust flow. The dilution ratio is determined from the concentrations of tracer gases, such as CO_2 or NO_x, naturally occurring in the engine exhaust. The concentrations in the dilute exhaust gas and in the dilution air are measured, whereas the concentration in the raw exhaust gas can be either measured directly or determined from fuel flow and the carbon balance equation, if the fuel composition is known. The systems may be controlled by the calculated dilution ratio (Figure 12, Figure 13) or by the flow into the transfer tube (Figure 11, Figure 12, Figure 13).

Flow controlled systems with flow measurement (Figure 17, Figure 18)

With these systems, a sample is taken from the bulk exhaust stream by setting the dilution air flow and the total dilute exhaust flow. The dilution ratio is determined from the difference of the two flow rates. Accurate calibration of the flow meters relative to one another is required, since the relative magnitude of the two flow rates can lead to significant errors at higher dilution ratios (of 15 and above). Flow control is very straightforward by keeping the dilute exhaust flow rate constant and varying the dilution air flow rate, if needed.

When using partial flow dilution systems, attention shall be paid to avoiding the potential problems of loss of particulates in the transfer tube, ensuring that a representative sample is taken from the engine exhaust, and determination of the split ratio. The systems described pay attention to these critical areas.

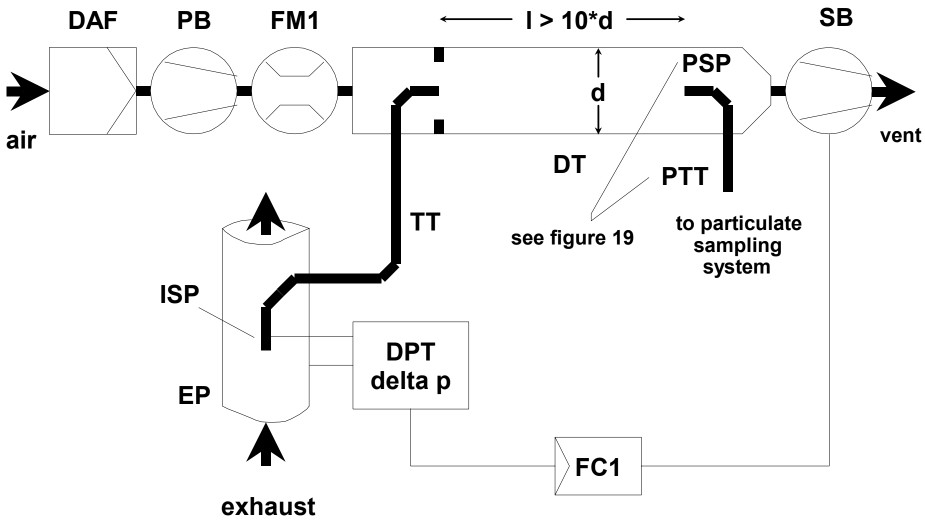

Figure 10: Partial flow dilution system with isokinetic probe and fractional sampling (SB control)

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the transfer tube TT by the isokinetic sampling probe ISP. The differential pressure of the exhaust gas between exhaust pipe and inlet to the probe is measured with the pressure transducer DPT. This signal is transmitted to the flow controller FC1 that controls the suction blower SB to maintain a differential pressure of zero at the tip of the probe. Under these conditions, exhaust gas velocities in EP and ISP are identical, and the flow through ISP and TT is a constant fraction (split) of the exhaust gas flow. The split ratio is determined from the cross sectional areas of EP and ISP. The dilution air flow rate is measured with the flow measurement device FM1. The dilution ratio is calculated from the dilution air flow rate and the split ratio.

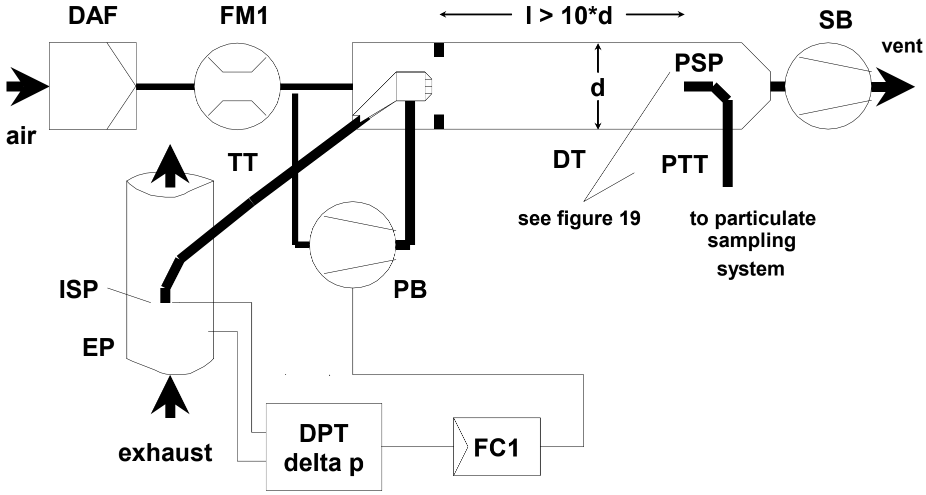

Figure 11: Partial flow dilution system with isokinetic probe and fractional sampling (PB control)

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the transfer tube TT by the isokinetic sampling probe ISP. The differential pressure of the exhaust gas between exhaust pipe and inlet to the probe is measured with the pressure transducer DPT. This signal is transmitted to the flow controller FC1 that controls the pressure blower PB to maintain a differential pressure of zero at the tip of the probe: this is done by taking a small fraction of the dilution air whose flow rate has already been measured with the flow measurement device FM1, and feeding it to TT by means of a pneumatic orifice. Under these conditions, exhaust gas velocities in EP and ISP are identical, and the flow through ISP and TT is a constant fraction (split) of the exhaust gas flow. The split ratio is determined from the cross sectional areas of EP and ISP. The dilution air is sucked through the DT (by the suction blower (SB)), and the flow rate is measured with FM1 at the inlet to DT. The dilution ratio is calculated from the dilution air flow rate and the split ratio.

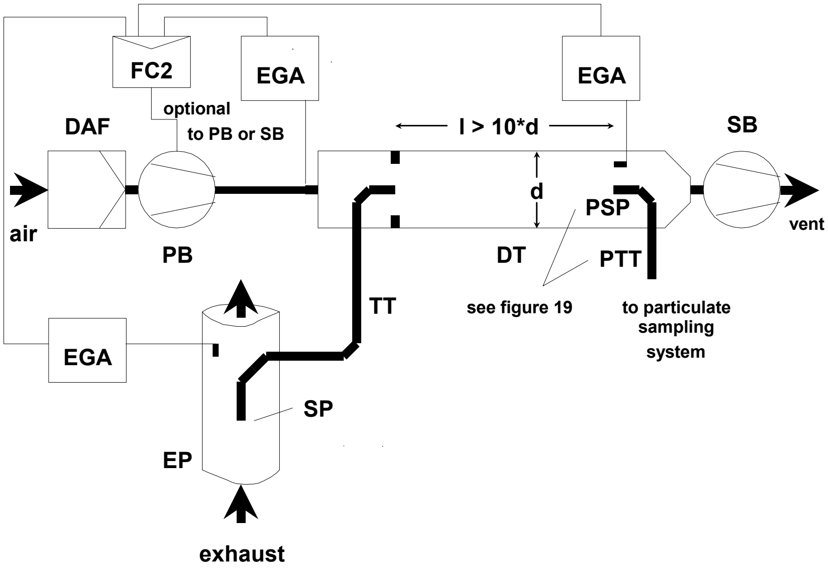

Figure 12: Partial flow dilution system with CO_2 or NO_X concentration measurement and fractional sampling

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The concentrations of a tracer gas (CO_2 or NO_x) are measured in the raw and diluted exhaust gas as well as in the dilution air with the exhaust gas analyser(s) EGA. These signals are transmitted to the flow controller FC2 that controls either the pressure blower PB or the suction blower SB to maintain the desired exhaust split and dilution ratio in DT. The dilution ratio is calculated from the tracer gas concentrations in the raw exhaust gas, the diluted exhaust gas, and the dilution air.

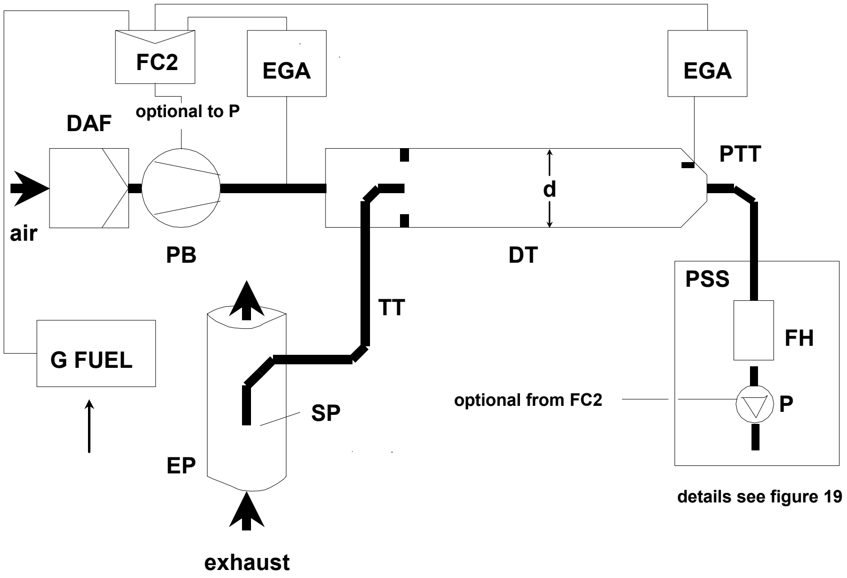

Figure 13: Partial flow dilution system with CO_2 concentration measurement, carbon balance and total sampling

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The CO_2 concentrations are measured in the diluted exhaust gas and in the dilution air with the exhaust gas analyser(s) EGA. The CO_2 and fuel flow G_{FUEL} signals are transmitted either to the flow controller FC2, or to the flow controller FC3 of the particulate sampling system (see Figure 19). FC2 controls the pressure blower PB, FC3 the sampling pump P (see Figure 19), thereby adjusting the flows into and out of the system so as to maintain the desired exhaust split and dilution ratio in DT. The dilution ratio is calculated from the CO_2 concentrations and G_{FUEL} using the carbon balance assumption.

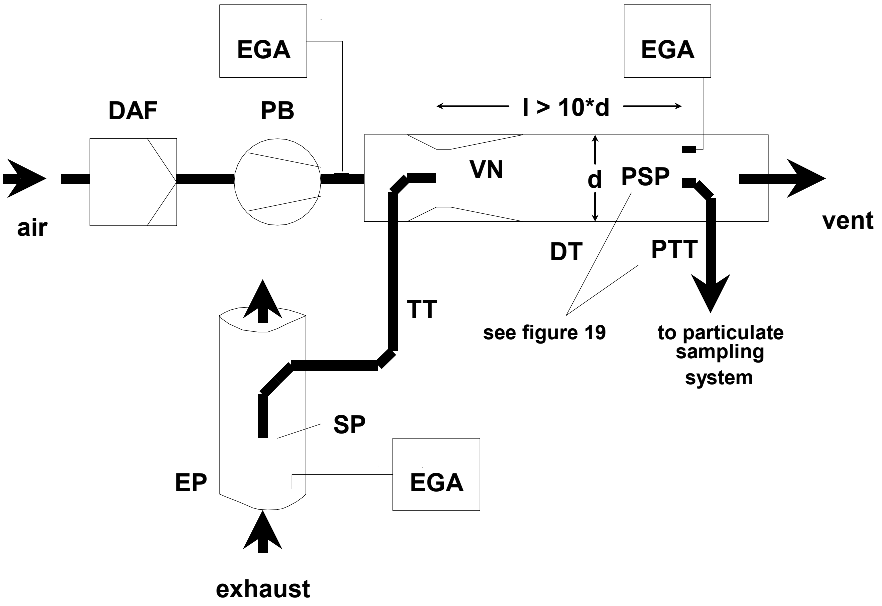

Figure 14: Partial flow dilution system with single venturi, concentration measurement and fractional sampling

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT due to the negative pressure created by the venturi VN in DT. The gas flow rate through TT depends on the momentum exchange at the venturi zone, and is therefore affected by the absolute temperature of the gas at the exit of TT. Consequently, the exhaust split for a given tunnel flow rate is not constant, and the dilution ratio at low load is slightly lower than at high load. The tracer gas concentrations (CO_2 or NO_x) are measured in the raw exhaust gas, the diluted exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA, and the dilution ratio is calculated from the values so measured.

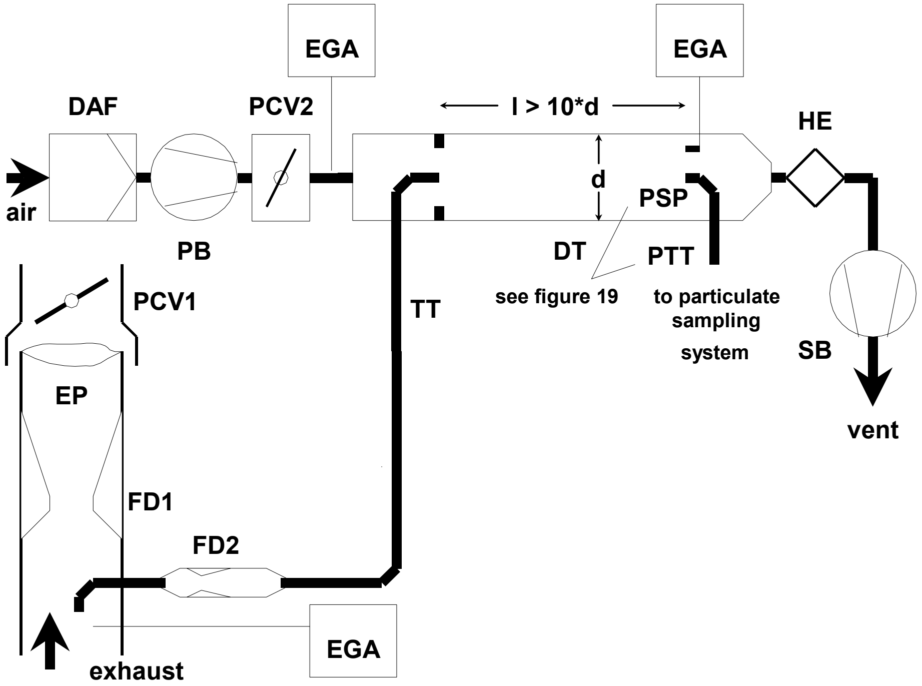

Figure 15: Partial flow dilution system with twin venturi or twin orifice, concentration measurement and fractional sampling

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT by a flow divider that contains a set of orifices or venturis. The first one (FD1) is located in EP, the second one (FD2) in TT. Additionally, two pressure control valves (PCV1 and PCV2) are necessary to maintain a constant exhaust split by controlling the back-pressure in EP and the pressure in DT. PCV1 is located downstream of SP in EP, PCV2 between the pressure blower PB and DT. The tracer gas concentrations (CO_2 or NO_x) are measured in the raw exhaust gas, the diluted exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA. They are necessary for checking the exhaust split, and may be used to adjust PCV1 and PCV2 for precise split control. The dilution ratio is calculated from the tracer gas concentrations.

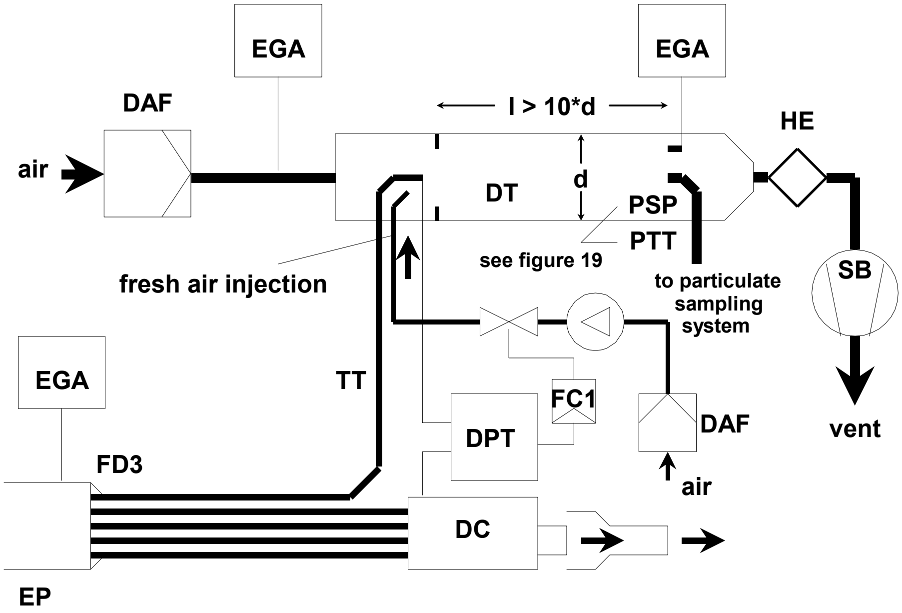

Figure 16: Partial flow dilution system with multiple tube splitting, concentration measurement and fractional sampling

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the transfer tube TT by the flow divider FD3 that consists of a number of tubes of the same dimensions (same diameter, length and bend radius) installed in EP. The exhaust gas through one of these tubes is lead to DT, and the exhaust gas through the rest of the tubes is passed through the damping chamber DC. Thus, the exhaust split is determined from the total number of tubes. A constant split control requires a differential pressure of zero between DC and the outlet of TT, which is measured with the differential pressure transducer DPT. A differential pressure of zero is achieved by injecting fresh air into DT at the outlet of TT. The tracer gas concentrations (CO_2 or NO_x) are measured in the raw exhaust gas, the diluted exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA. They are necessary for checking the exhaust split and may be used to control the injection air flow rate for precise split control. The dilution ratio is calculated from the tracer gas concentrations.

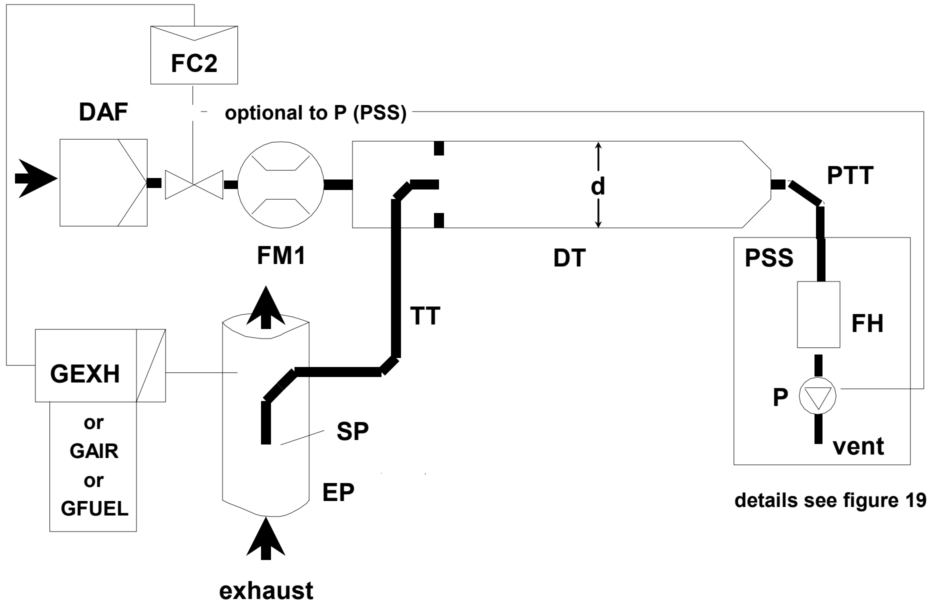

Figure 17: Partial flow dilution system with flow control and total sampling

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The total flow through the tunnel is adjusted with the flow controller FC3 and the sampling pump P of the particulate sampling system (see Figure 17). The dilution air flow is controlled by the flow controller FC2, which may use G_{EXHW}, G_{AIRW}, or G_{FUEL} as command signals, for the desired exhaust split. The sample flow into DT is the difference of the total flow and the dilution air flow. The dilution air flow rate is measured with the flow measurement device FM1, the total flow rate with the flow measurement device FM3 of the particulate sampling system (see Figure 19). The dilution ratio is calculated from these two flow rates.

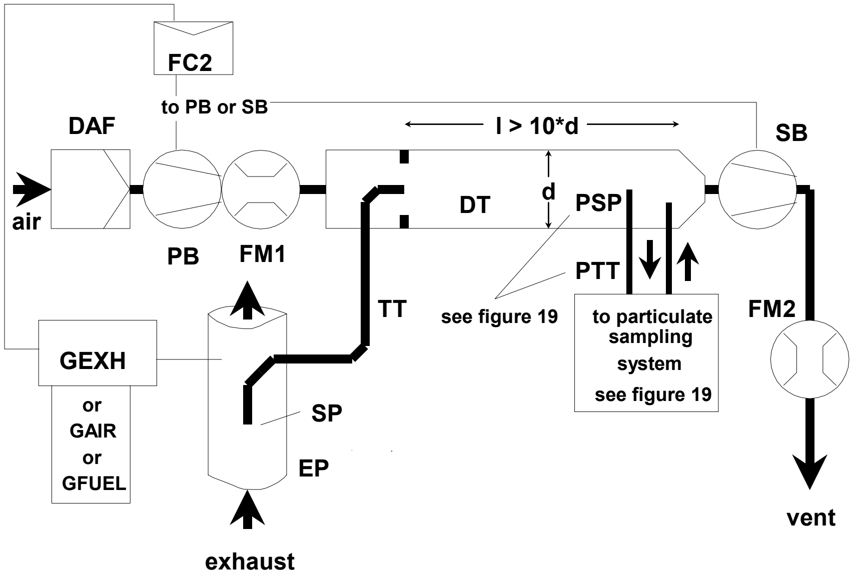

Figure 18: Partial flow dilution system with flow control and fractional sampling

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The exhaust split and the flow into DT are controlled by the flow controller FC2 that adjusts the flows (or speeds) of the pressure blower PB and the suction blower SB, accordingly. This is possible since the sample taken with the particulate sampling system is returned into DT. G_{EXHW}, G_{AIRW}, or G_{FUEL} may be used as command signals for FC2. The dilution air flow rate is measured with the flow measurement device FM1, the total flow with the flow measurement device FM2. The dilution ratio is calculated from these two flow rates.

2.5.1. Components of Partial Flow Dilution Systems

EP Exhaust pipe

The exhaust pipe may be insulated. To reduce the thermal inertia of the exhaust pipe a thickness to diameter ratio of 0.015 or less is recommended. The use of flexible sections shall be limited to a length to diameter ratio of 12 or less. Bends shall be minimised to reduce inertial deposition. If the system includes a test bed silencer the silencer may also be insulated.

For an isokinetic system, the exhaust pipe shall be free of elbows, bends and sudden diameter changes for at least 6 pipe diameters upstream and 3 pipe diameters downstream of the tip of the probe. The gas velocity at the sampling zone shall be higher than 10 m/s except at idle mode. Pressure oscillations of the exhaust gas shall not exceed ± 500 Pa on the average. Any steps to reduce pressure oscillations beyond using a chassis-type exhaust system (including silencer and after-treatment devices) shall not alter engine performance nor cause the deposition of particulates.

For systems without isokinetic probe, it is recommended to have a straight pipe of 6 pipe diameters upstream and 3 pipe diameters downstream of the tip of the probe.

PSP Sampling probe (Figure 13, Figure 14, Figure 15, Figure 17 and Figure 18)

The minimum inside diameter shall be 4 mm. The minimum diameter ratio between exhaust pipe and probe shall be 4. The probe shall be an open tube facing upstream on the exhaust pipe centreline, or a multiple hole probe as described under SP1 in Appendix 3, Paragraph 2.2.1., Figure 3.

ISP Isokinetic sampling probe (Figure 10, Figure 11)

The isokinetic sampling probe shall be installed facing upstream on the exhaust pipe centreline where the flow conditions in Paragraph EP are met, and designed to provide a proportional sample of the raw exhaust gas. The minimum inside diameter shall be 12 mm.

A control system is necessary for isokinetic exhaust splitting by maintaining a differential pressure of zero between EP and ISP. Under these conditions exhaust gas velocities in EP and ISP are identical and the mass flow through ISP is a constant fraction of the exhaust gas flow. ISP has to be connected to a differential pressure transducer DPT. The control to provide a differential pressure of zero between EP and ISP is done with the flow controller FC1.

FD1, FD2 Flow divider (Figure 15)

A set of venturis or orifices is installed in the exhaust pipe EP and in the transfer tube TT, respectively, to provide a proportional sample of the raw exhaust gas. A control system consisting of two pressure control valves PCV1 and PCV2 is necessary for proportional splitting by controlling the pressures in EP and DT.

FD3 Flow divider (Figure 16)

A set of tubes (multiple tube unit) is installed in the exhaust pipe EP to provide a proportional sample of the raw exhaust gas. One of the tubes feeds exhaust gas to the dilution tunnel DT, whereas the other tubes exit exhaust gas to a damping chamber DC. The tubes shall have the same dimensions (same diameter, length, bend radius), so that the exhaust split depends on the total number of tubes. A control system is necessary for proportional splitting by maintaining a differential pressure of zero between the exit of the multiple tube unit into DC and the exit of TT. Under these conditions, exhaust gas velocities in EP and FD3 are proportional, and the flow TT is a constant fraction of the exhaust gas flow. The two points have to be connected to a differential pressure transducer DPT. The control to provide a differential pressure of zero is done with the flow controller FC1.

EGA Exhaust gas analyser (Figure 12 to Figure 16)

CO_2 or NO_x analysers may be used (with carbon balance method CO_2 only). The analysers shall be calibrated like the analysers for the measurement of the gaseous emissions. One or several analysers may be used to determine the concentration differences. The accuracy of the measuring systems has to be such that the accuracy of $G_{EDFW,i}$ is within ± 4 per cent.

TT Transfer tube (Figure 10 to Figure 18)

The transfer tube shall be:

- As short as possible, but not more than 5 m in length.
- Equal to or greater than the probe diameter, but not more than 25 mm in diameter.
- Exiting on the centreline of the dilution tunnel and pointing downstream.

If the tube is 1 meter or less in length, it shall be insulated with a material with a maximum thermal conductivity of 0.05 W/m*K and a radial insulation thickness corresponding to the diameter of the probe. If the tube is longer than 1 meter, it shall be insulated and heated to a minimum wall temperature of 523 K (250°C).

DPT Differential pressure transducer (Figure 10,Figure 11, Figure 16)

The differential pressure transducer shall have a range of ± 500 Pa or less.

FC1 Flow controller (Figure 10,Figure 11, Figure 16)

For isokinetic systems (Figure 10,Figure 11),a flow controller is necessary to maintain a differential pressure of zero between EP and ISP. The adjustment can be done by:

(a) controlling the speed or flow of the suction blower SB and keeping the speed or flow of the pressure blower PB constant during each mode (Figure 11) or

(b) adjusting the suction blower SB to a constant mass flow of the diluted exhaust gas and controlling the flow of the pressure blower PB, and therefore the exhaust sample flow in a region at the end of the transfer tube TT (Figure 12).

In the case of a pressure controlled system the remaining error in the control loop shall not exceed ± 3 Pa. The pressure oscillations in the dilution tunnel shall not exceed ± 250 Pa on the average.

For a multi tube system (Figure 16), a flow controller is necessary for proportional exhaust splitting to maintain a differential pressure of zero between the exit of the multi tube unit and the exit of TT. The adjustment is done by controlling the injection air flow rate into DT at the exit of TT.

PCV1, PCV2 Pressure control valve (Figure 15)

Two pressure control valves are necessary for the twin venturi/twin orifice system for proportional flow splitting by controlling the back-pressure of EP and the pressure in DT. The valves shall be located downstream of SP in EP and between PB and DT.

DC Damping chamber (Figure 16)

A damping chamber shall be installed at the exit of the multiple tube unit to minimise the pressure oscillations in the exhaust pipe EP.

VN Venturi (Figure 14)

A venturi is installed in the dilution tunnel DT to create a negative pressure in the region of the exit of the transfer tube TT. The gas flow rate through TT is determined by the momentum exchange at the venturi zone, and is basically proportional to the flow rate of the pressure blower PB leading to a constant dilution ratio. Since the momentum exchange is affected by the temperature at the exit of TT and the pressure difference between EP and DT, the actual dilution ratio is slightly lower at low load than at high load.

FC2 Flow controller (Figure 12, Figure 13, Figure 17, Figure 18; optional)

A flow controller may be used to control the flow of the pressure blower PB and/or the suction blower SB. It may be connected to the exhaust, intake air, or fuel flow signals and/or to the CO_2 or NO_x differential signals.
When using a pressurised air supply (Figure 18), FC2 directly controls the air flow.

FM1 Flow measurement device (Figure 10, Figure 11, Figure 17, Figure 18)

Gas meter or other flow instrumentation to measure the dilution air flow. FM1 is optional if the pressure blower PB is calibrated to measure the flow.

FM2 Flow measurement device (Figure 18)

Gas meter or other flow instrumentation to measure the diluted exhaust gas flow. FM2 is optional if the suction blower SB is calibrated to measure the flow.

PB Pressure blower (Figure 10 to Figure 15 and Figure 18)

To control the dilution air flow rate, PB may be connected to the flow controllers FC1 or FC2. PB is not required when using a butterfly valve. PB may be used to measure the dilution air flow, if calibrated.

SB Suction blower (Figure 10, Figure 11, Figure 12, Figure 15, Figure 16, Figure 18)

For fractional sampling systems only. SB may be used to measure the diluted exhaust gas flow, if calibrated.

DAF Dilution air filter (Figure 10 to Figure 18)

It is recommended that the dilution air be filtered and charcoal scrubbed to eliminate background hydrocarbons. At the engine manufacturers request the dilution air shall be sampled according to good engineering practice to determine the background particulate levels, which can then be subtracted from the values measured in the diluted exhaust.

DT Dilution tunnel (Figure 10 to Figure 18)

The dilution tunnel:

- shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions;
- shall be constructed of stainless steel with:
    - thickness/diameter ratio of 0.025 or less for dilution tunnels with inside diameters greater than 75 mm;
    - a nominal thickness of no less than 1.5 mm for dilution tunnels with inside diameters of equal to or less than 75 mm;
- shall be at least 75 mm in diameter for the fractional sampling type;
- is recommended to be at least 25 mm in diameter for the total sampling type;

- may be heated to no greater than 325 K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel;

- may be insulated.

The engine exhaust shall be thoroughly mixed with the dilution air. For fractional sampling systems, the mixing quality shall be checked after introduction into service by means of a CO_2 -profile of the tunnel with the engine running (at least four equally spaced measuring points). If necessary, a mixing orifice may be used.

Note: If the ambient temperature in the vicinity of the dilution tunnel (DT) is below 293K (20°C), precautions should be taken to avoid particle losses onto the cool walls of the dilution tunnel. Therefore, heating and/or insulating the tunnel within the limits given above is recommended.

At high engine loads, the tunnel may be cooled by a non-aggressive means such as a circulating fan, as long as the temperature of the cooling medium is not below 293K (20°C).

HE Heat exchanger (Figure 15 and Figure 16)

The heat exchanger shall be of sufficient capacity to maintain the temperature at the inlet to the suction blower SB within ± 11K of the average operating temperature observed during the test.

2.6. Recommended System - Partial Flow Particulate Sampling System

The particulate sampling system to be used in conjunction with all of the partial flow dilution systems described in Section 2.5 is shown in Figure 19.

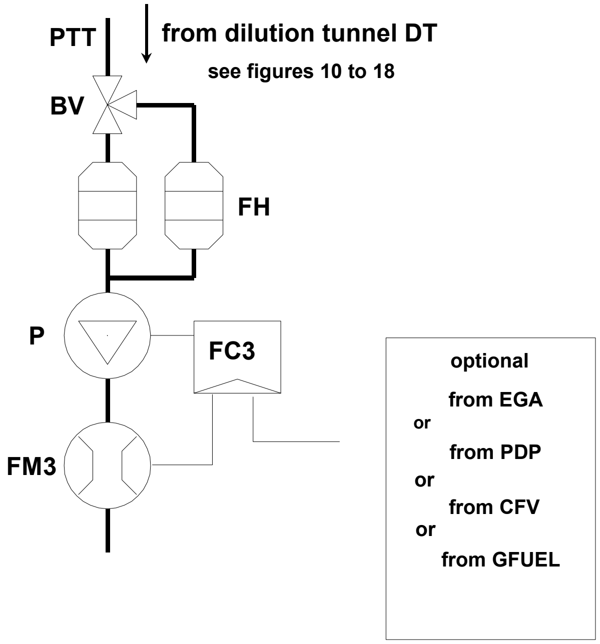

Figure 19: Partial Flow Particulate Sampling System

2.6.1. Components of Figure 19

PTT Particulate transfer tube

The particulate transfer tube shall not exceed 1020 mm in length, and shall be minimised in length whenever possible.

The dimensions are valid for:

– the partial flow dilution fractional sampling type from the tip of the probe (SP, ISP, PSP, respectively) to the filter holder;

– the partial flow dilution total sampling type from the end of the dilution tunnel to the filter holder;

The transfer tube:

– may be heated to no greater than 325K (52°C) wall temperature by direct heating or by dilution air pre- heating, provided the air temperature does not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel;

– may be insulated.

FH Filter holder(s)

For filtration one filter housing only shall be used. The requirements of (Appendix 4, Paragraph 2.1.5). shall be met.

The filter holder(s):

- may be heated to no greater than 325 K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel;
- may be insulated.

P Sampling pump

The particulate sampling pump must be located sufficiently distant from the tunnel so that the inlet gas temperature is maintained constant (± 3 K), if flow correction by FC3 is not used.

FC3 Flow controller

A flow controller must be used to compensate the particulate sample flow rate for temperature and back pressure variations in the sample path, if no other means are available. The flow controller is required if electronic flow compensation EFC (see Figure 20) is used.

FM3 Flow measurement device

The gas meter or flow instrumentation for the particulate sample flow must be located sufficiently distant from the sampling pump P so that the inlet gas temperature remains constant (± 3 K), if flow correction by FC3 is not used.

BV Ball valve (optional)

The ball valve must have an inside diameter not less than the inside diameter of the particulate transfer tube PTT, and a switching time of less than 0.5 seconds.

Note: If the ambient temperature in the vicinity of PSP, PTT, and FH is below 293K (20°C), precautions should be taken to avoid particle losses onto the cool wall of these parts. Therefore, heating and/or insulating these parts within the limits given in the respective descriptions is recommended. It is also recommended that the filter face temperature during sampling be not below 293K (20°C).

At high engine loads, the above parts may be cooled by a non-aggressive means such as a circulating fan, as long as the temperature of the cooling medium is not below 293K (20°C).

3. Calibration Procedures

3.1. Introduction

Each component shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method to be used is described in this Paragraph for the components indicated in Annex 4, Appendix 4, Paragraph 2.

3.2. Flow measurement

The calibration of gas flow meters or flow measurement instrumentation shall be traceable to international and/or national standards. The maximum error of the measured value shall be within ± 2 per cent of reading.

If the gas flow is determined by differential flow measurement, the maximum error of the difference shall be such that the accuracy of G_{EDF} is within ± 4 per cent (see also Annex 4, Appendix 4, Paragraph 2.5.1., EGA). It can be calculated by taking the Root-Mean-Square of the errors of each instrument.

3.3. 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 Annex 4, Appendix 4, Paragraph 2.5.1., EP, if applicable.

3.4. Calibration intervals

3.4.1. Flow Measurement

The Technical Service shall ensure the existence of a calibration certificate for the flow meter demonstrating compliance with a traceable standard within a 12 month period prior to the test, or since any repair or change which could influence calibration

3.4.2. Analytical Balance

The Technical Service shall ensure the existence of a calibration certificate for the microbalance demonstrating compliance with a traceable standard within a 12 month period prior to the test.

4. Reference Filter Weighing

At least two unused reference filters shall be weighed within 4 hours of, but preferably at the same time as the sample filter weighings. They shall be the same size and material as the sample filter. If the average weight of the reference filters changes between sample filter weighings by more than [± 5 per cent][9] of the recommended minimum filter loading (Paragraph 2.1.7. of this Appendix), then the sample filter shall be discarded and the emissions test repeated.

If the weighing room stability criteria outlined in Paragraph 2.1.8. are not met, but the reference filter weighings meet the above criteria, the engine manufacturer has the

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[9] Acceptability criterion of 5% sufficient?. +/- 5µg proposed for LD

option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system and rerunning the test.[10]

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[10] **OICA** - Requests inclusion of buoyancy correction as per US HD2007. **Chair** - Accepted. Buoyancy correction aligned with US FTP will be adopted following its publication by US EPA in June 2004

APPENDIX 5 – PARTICLE EMISSIONS MEASUREMENT EQUIPMENT

1. System Specification

1.1. System Overview

1.1.1. The particle sampling system shall consist of a **secondary dilution tunnel**, a sampling probe, a particle size pre-classifier and a volatile particle remover upstream of a particle concentration measurement device. The sample pre-conditioning unit shall include devices for sample dilution and for volatile particle removal. The sampling probe for the test gas flow shall be arranged within the secondary dilution system such that representative sample gas flow can be taken from the homogeneous air/exhaust mixture.

It is recommended that a particle size pre-classifier (e.g. cyclone, impactor etc) be employed immediately upstream of the sample preconditioning unit. However, if the sample probe acts as an appropriate size-classification device, a particle size pre-classifier shall not be required.

1.2. General Requirements

1.2.1. The particle sampling probe (Paragraph **1.4.2.1**) and particle size pre-classifier (Paragraph **1.4.2.3**) for particle measurements shall either be of the same specification and operating parameters as those used for particulate sampling.

or

Sampling of particles shall be undertaken from the same particle size pre-classifier as that used for particulate measurements and a sampling probe of the same specification and operating parameters as those used for particulate sampling shall be employed.

1.2.2. The sample pre-conditioning unit shall include devices for sample dilution and for volatile particle removal. The sampling probe for the test gas flow shall be so arranged within the dilution tract that a representative sample gas flow can be taken from the homogeneous air/exhaust mixture.

1.2.3. All parts of the dilution system and the sampling system from the exhaust pipe up to the particle concentration measurement system, which are in contact with raw and diluted exhaust gas, shall be designed to minimise deposition of the particles. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

1.2.4. The particle sampling system shall incorporate good aerosol sampling practice that includes the avoidance of sharp bends and abrupt changes in section, the use of smooth internal surfaces and the minimisation of the length of the sampling line. Tubing shall be electrically earthed, and if heated dilution is employed, thermally insulated.

Sampling tubing used for sampling from the secondary dilution system and to join **particle number** dilution systems to particle measurement instrumentation shall, wherever possible, be straight metallic (Cu or stainless steel) conductors of <1m length.

The dilution air used for the primary dilution of the exhaust in the CVS tunnel and for all subsequent dilution stages shall be passed through a medium capable of reducing particles in the most penetrating particle size of the filter material by at least 99.95%, or through a filter of at least class H13 of EN 1822; this represents the specification of High Efficiency Particulate Air (HEPA) filters.

1.3. Specific requirements

1.3.1. The particle number measurement device shall have size related inlet characteristics as defined in Section 1.3.4.8.

1.3.2. A sample pre-classifier is recommended.

1.3.3. The sample preconditioning unit shall:

1.3.3.1. be capable of diluting the sample in the range 1-1000 times in one or more stages to achieve a particle number concentration below 10000/cm3 at the particle number counter

1.3.3.2. Operate under conditions that achieve greater than 99% reduction of 30nm C_{40} particles and greater than 90% solid particle penetration at 30, 50 and 100nm particle diameter.

1.3.3.3. Include an initial heated dilution stage that outputs a diluted sample at a temperature of ≥150°C.

1.3.3.4. Contain a particle removal element which eliminates volatile particles with an efficiency equivalent to the performance of an evaporation tube with a minimum length of 350mm +/-10 mm and an internal diameter of 6mm +/- 0.1mm, with a controlled wall temperature greater than 150°C, and with a portion of the length, equivalent to a gas residence time of 0.5s +/- 0.05s, held at >=400°C +/- 10°C.

1.3.4. The particle concentration measurement device (PNC) shall:

1.3.4.1. operate under full flow operating conditions.

1.3.4.2. **have a counting accuracy of ± 10% across the range $100cm^{-3}$ to $10000cm^{-3}$ and a counting accuracy of +/-$10cm^{-3}$ below $100cm^{-3}$ against a traceable standard.**

1.3.4.3. have a readability of 0.1 particles cm^{-3}.

1.3.4.4. have a linear response to particle concentration over 1 to 10,000 particles cm^{-3}

1.3.4.5. have a data logging frequency equal to or greater than 0.5 Hz.

1.3.4.6. **have a T90 response time over the measured concentration range of less than 15s. It is recommended that the response time is ≥5s.**

1.3.4.7. have a data-averaging period of between 1 and 6s and shall not incorporate automatic data manipulation functions.

1.3.4.8. have lower particle size limit characteristics such that the 10% (D_{10}), 25% (D_{25}), 50% (D_{50}) and 90% (D_{90}) inlet efficiencies of the instrument correspond to the particle sizes 16nm (+/-1nm), 18nm (+/-2nm), 23nm (+/-3nm), and 37nm (+/-4nm) respectively. These inlet efficiencies may be achieved by internal (for example; control of instrument design) or external (for example; size pre-classification) means.

1.4. Recommended System Description

The following section contains the recommended practice for measurement of particle number. However, alternative procedures may be adopted provided that their equivalence with the recommended procedure is demonstrated to the satisfaction of the Technical Service. Figure 20 is a schematic of the recommended sampling set-up. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and co-ordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

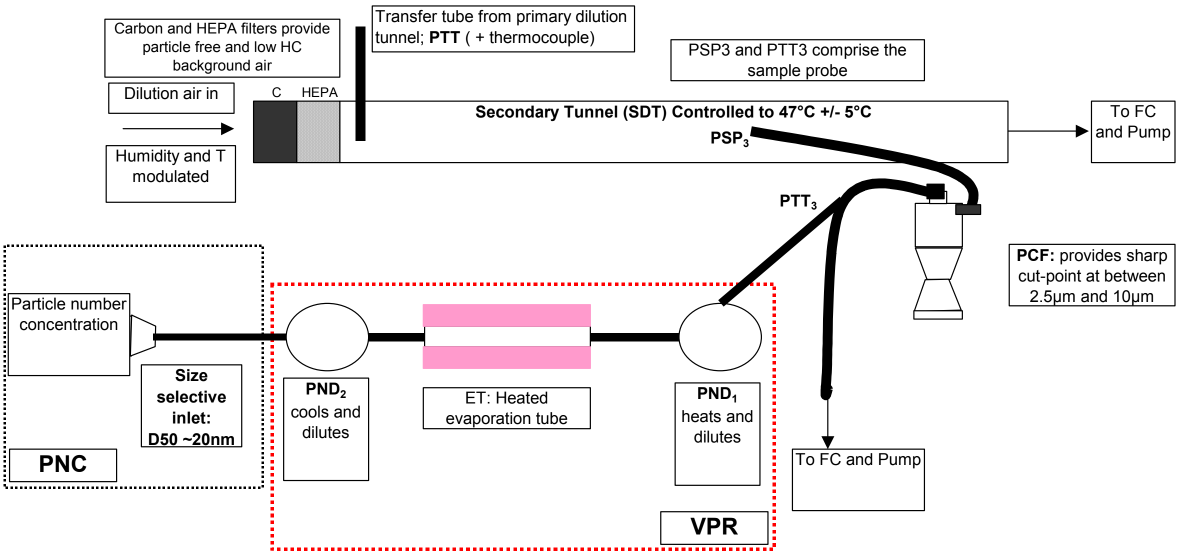

Figure 20: Schematic of Particle Sampling System

1.4.1. Particle Sampling System Description

The particle sampling system is required to draw a sample from the secondary dilution tunnel SDT, size classify it, dilute it further, condition the sample in such a way that only solid particles are measured and pass those solid particles to a particle number counting device.

A sample of the diluted exhaust is transferred from the primary dilution tunnel to the secondary dilution tunnel. With a residence period of >= **0.2s** at a temperature of 47°C +/-5°C, a sample is drawn into the particulate sampling probe tip (PSP$_3$) and through the particulate transfer tube (PTT$_3$) where it enters the particulate pre-classifier PCF. The sample is then passed into the sample pre-conditioning unit: a volatile particle remover (VPR).

The VPR comprises 3 stages: a **heated particle number dilution device (PND$_1$)** where the particle concentration is reduced by a factor between 1 and 1000. The sample then passes through a heated evaporation tube (ET) where volatile constituents are forced into the vapour phase, and then on to a further **particle number dilution device (PND$_2$)** where the particle concentration is reduced by a factor between **1 and 30** and the aerosol sample cooled to below 35°C.

The sample then passes to the particle number counting device: PNC.

The system response time shall be no greater than 20 s, and shall be co-ordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary

1.4.2. Components of **Figure 20**

1.4.2.1. Particle Sampling Probe

The sampling probe tip (**PSP_3**) and particle transfer tube (**PTT_3**) together comprise the particle sampling probe. The sampling probe shall meet the following conditions:

It shall be installed near the SDT centre line, **10 to 20** tunnel diameters downstream of the gas inlet, facing upstream into the tunnel gas flow with its axis at the tip parallel to that of the dilution tunnel.

The **PSP_3** should have an internal diameter equal to 12mm.

1.4.2.2. **PTT_3** Particle Transfer Tube

The particulate transfer tube shall not exceed 1020 mm in length, including the sample probe tip (PSP_3) and shall be minimised in length whenever possible. The internal diameter of the tube shall be between 12mm and 26mm. The transfer should be designed to minimise particle loss during transfer, and if possible, be adiabatic, smooth and of low thermal inertia; which can be achieved by use of thin-walled, double-wall, internally polished, air-gap insulated tube.

The **PTT_3** may be heated to no greater than 52°C.

The distance from the sampling tip **(PTT_3)** of the particle sampling probe to the point at which the probe leaves the dilution tunnel shall be less than 200 mm.

The distance from the sampling tip **(PTT_3)** of the particle sampling probe to the entrance to the sample pre-conditioning unit shall not exceed 1,000 mm.

The distance from the sampling tip **(PTT_3)** of the particle sampling probe to the entrance to the PNC instrument shall not exceed 2,500 mm.

1.4.2.3. PCF Particle Pre-classifier

The recommended particle pre-classifier shall be located immediately upstream of the sample pre-conditioning unit. The pre-classifier 50% cut point particle diameter shall be between 2.5 µm and 10 µm at the volumetric flow rate selected for sampling particle number emissions. The pre-classifier shall allow at least 99% of the mass concentration of 1 µm particles entering the pre-classifier to pass through the exit of the pre-classifier at the volumetric flow rate selected for sampling particle number emissions.

1.4.3. Volatile Particle Remover

The volatile particle remover (VPR) shall comprise one particle number diluter (PND_1), an evaporation tube and a second diluter (PND_2) in series. The VPR shall be capable of diluting the sample drawn from the primary dilution tunnel by a dilution ratio range from 1 to 1000. This dilution function (DR_{tot}) is to reduce the number concentration of the sample entering the particle concentration measurement unit to less than 10,000 particles cm^{-3} and to suppress nucleation and **recondensation** within the sample. DR_{tot} is calculated as the product of the dilution factor in PND_1 and the dilution factor in PND_2.

The VPR shall operate under conditions that achieve greater than 99% reduction of 30nm C_{40} particles and greater than 90% solid particle penetration at 30, 50 and 100nm particle diameter.

1.4.3.1. First Particle Number Dilution Device

The **first particle number dilution device** shall be specifically designed to dilute particle number concentration and output a diluted sample at a temperature equal to or greater than 150°C. The diluter should be supplied with HEPA filtered dilution air and be capable of a dilution ratio of 1 to 1000 times. The dilution ratio of **PND_1** shall be selected such that **peak** particle number concentration downstream of the first **particle number** diluter is $<10^5$ particles cm^{-3} and $>10^3$ particles cm^{-3}.

1.4.3.2. Evaporation Tube[11]

The evaporation tube shall have a minimum length 350mm +/-10 mm and an internal diameter of 6mm +/- 0.1mm and be equipped with a heating mantle. The entire length of the ET shall be controlled at a wall temperature greater than that of the first **particle number** dilution device and with a portion of the length, equivalent to a gas residence time of 0.5s +/- 0.05s, held at **300°C to 400°C**.

1.4.3.3. Second Particle Number Dilution Device

The second **particle number dilution** device **(PND_2)** shall be specifically designed to dilute particle number concentration. The diluter shall be supplied with HEPA filtered dilution air and be capable of a dilution ratio of 1 to **30** times. The dilution ratio of PND_2 shall be selected such that particle number concentration downstream of the second **particle number** diluter is $<10^4$ particles cm^{-3} and the gas temperature prior to entry to the PNC is <35°C.

1.4.4. Particle Number Concentration Measurement Device

The particle concentration measurement device (PNC) shall meet the requirements of Section 1.3.

2. Calibration Procedures

Each component shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation.

2.1. Calibration of the Particle Counter

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[11] **OICA** - Design rather than performance specification! **Ricardo** - Ultimate intention is to write a specification for the VPR based upon heat transfer, however, additional data are required to ascertain precise details. **Chair** - retain until a better option exists.

2.1.1. The Technical Service shall ensure the existence of a calibration certificate for the particle number counter demonstrating compliance with a traceable standard within a 12 month period prior to the emissions test.

2.1.2. Calibration shall be traceable to a standard calibration method:

comparison of the response of the counter under calibration with that of a calibrated aerosol electrometer when simultaneously sampling electrostatically classified calibration particles,

or

comparison of the response of the counter under calibration with that of a second counter which has been calibrated by the above method.

In either case, calibration shall be undertaken at least five concentrations spaced as uniformly as possible across the counter's measurement range. Measured concentrations shall be within ±10% of the standard concentration for each calibration concentration used. The gradient from a linear regression of the two data sets shall be calculated and recorded. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (R^2) of the two data sets and shall be equal to or greater than 0.95.

2.2. Calibration of the diluter

2.2.1. The Technical Service shall ensure the existence of a calibration certificate for the diluter demonstrating compliance with a traceable performance specification within a 6 month period prior to the emissions test.

2.2.1.1. The calibration certificate shall detail the diluter performance across the nominal dilution range of the diluter with respect to gases and with respect to solid particles. The diluter shall achieve minimum penetration performance of 0.aa, 0.bb, 0.cc, 0.dd, 0.ee[12] for 20nm, 100nm, 300nm, 500nm and 700nm particles respectively for the dilution ratio employed in the test and in comparison with the diluter performance for gases.

2.2.2. Calibration shall be undertaken by measuring the concentration of the standard gas with a calibrated gas monitor at the inlet and outlet of the diluter. Calibration shall be undertaken at least 5 dilution ratios spaced as uniformly as possible across the dilution ratio range from 0 to 1000. Measured dilution ratios shall be within ±10% of nominal dilution ratio settings. If a diluter is to be used over a narrower dilution range, then the 5-point calibration should span that range.

2.3. Calibration of the Volatile Particle Remover

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[12] **Ricardo** - aa,bb,cc,dd,ee need to be defined following real measurement experience. For example at nominal DR of 10: if the gas concentration is measured as [0.099 x the initial concentration] and the 20nm particle level is measured as [0.08 x the initial concentration], the penetration 0.aa will equal (1/0.099)/(1/0.08) = 0.81 (0.808). **Chair** - noted.

2.3.1. The Technical Service shall ensure the existence of a calibration certificate for the volatile particle remover demonstrating effective penetration efficiency within a 6 months period prior to the emissions test.

2.3.2. The test aerosol for these measurements shall be solid particles of diameters 30, 50 and 100 nm and a minimum concentration of 1,000 particles cm^{-3}. Particle concentrations shall be measured upstream and downstream of the apparatus operating at the temperature and flow conditions employed during an emission test. A minimum penetration efficiency of 90% shall be achieved at all three test particle diameters.

2.3.3. The Technical Service shall ensure the existence of a calibration certificate for the volatile particle remover demonstrating effective volatile particle removal efficiency within a 6 month period prior to the emissions test. The VPR shall demonstrate greater than 99% reduction of 30nm C_{40} particles at an upstream particle concentration of 10000cm^{-3}.

2.4. Particle Number System Check Procedures[13]

2.4.1. Linearity of the particle counter response shall be validated. The test aerosol for this validation shall show a particle size within the range 30-100nm at a stable concentration greater than 10,000 particles cm^{-3}. This calibration shall be carried out with at least five concentrations spaced as uniformly as possible across the counter's measurement range by diluting the test aerosol using a calibrated aerosol diluter. The gradient from a linear regression of the two data sets shall be within ±10% of that calculated from the annual calibration data. The Pearson product moment correlation coefficient (R^2) of the two data sets shall be equal to or greater than 0.95.

2.4.2. The particle counter shall report a measured concentration of less than 10 particle cm-3 when a HEPA filter is attached to the inlet of the entire particle sampling system (VPR and PNC).

2.4.3. The particle counter shall report a measured concentration of less than 1 particle cm^{-3} when a HEPA filter is attached to the sample inlet of the counter.

2.4.4. The particle counter shall report a measured concentration in excess of 10,000 particles cm^{-3} when challenged with an undiluted sample of the test aerosol used in the daily particle counter linearity validation.

2.4.5. The flow into the particle counter shall report a measured value within +/-5% of the particle counter nominal flow rate when checked with a calibrated flow meter.

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[13] **Ricardo** - Exact requirements for calibration shall be determined following the inter-laboratory correlation exercise. Considerations will include the need for frequent calibration, comprehensive daily validations and for verification of VPR on a regular basis. **Chair** - noted.

2.4.6. The evaporation tube shall indicate a reading of 300°C – 400°C and PND_1 diluter shall indicate a reading of ≥150°C

APPENDIX 6 – SMOKE MEASUREMENT EQUIPMENT

1. System Specification

This Appendix 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.

1.1. 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 Annex 4, Paragraph 5.2.

- A data processing unit capable of performing the functions described in Annex 4, Paragraph 5.5
- A printer and/or electronic storage medium to record and output the required smoke values specified in Annex 4, Paragraph 5.5.2.

1.2. Specific requirements

1.2.1. Linearity

The linearity shall be within ± 2 per cent opacity.

1.2.2. Zero drift

The zero drift during a one hour period shall not exceed ± 1 per cent opacity.

1.2.3. Opacimeter display and range

For display in opacity, the range shall be 0 - 100 per cent opacity, and the readability 0.1 per cent 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.

1.2.4. 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 per cent 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 per cent of the full scale when the light source is interrupted or completely extinguished in less than 0.01 s.

1.2.5. 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 per cent opacity. The filter's nominal value shall 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.

1.3. System Descriptions

Paragraphs 1.2. and 1.3. plus Figure 21 and Figure 22 contain detailed descriptions of the recommended opacimeter systems. Since various configurations can produce equivalent results, exact conformance with Figure 21 and Figure 22 is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems. Other components, which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

The principle of measurement is that light is transmitted through a specific length of the smoke to be measured and that proportion of the incident light which reaches a receiver is used to assess the light obscuration properties of the medium. The smoke measurement depends upon the design of the apparatus, and may be done in the exhaust pipe (full flow in-line opacimeter), at the end of the exhaust pipe (full flow end-of-line opacimeter) or by taking a sample from the exhaust pipe (partial flow opacimeter). For the determination of the light absorption coefficient from the opacity signal, the optical path length of the instrument shall be supplied by the instrument manufacturer.

1.3.1. Full Flow Opacimeter

Two general types of full flow opacimeters may be used (Figure 21). With the in-line opacimeter, the opacity of the full exhaust plume within the exhaust pipe is measured. With this type of opacimeter, the effective optical path length is a function of the opacimeter design.

With the end-of-line opacimeter, the opacity of the full exhaust plume is measured as it exits the exhaust pipe. With this type of opacimeter, the effective optical path length is a function of the exhaust pipe design and the distance between the end of the exhaust pipe and the opacimeter.

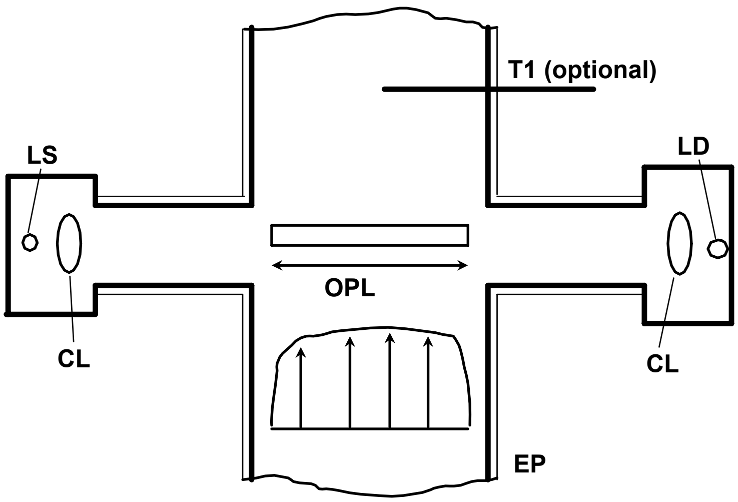

Figure 21: Full flow opacimeter

1.3.1.1. Components of Figure 21

EP Exhaust Pipe

With an in-line opacimeter, there shall be no change in the exhaust pipe diameter within 3 exhaust pipe diameters before or after the measuring zone. If the diameter of the measuring zone is greater than the diameter of the exhaust pipe, a pipe gradually convergent before the measuring zone is recommended.

With an end-of-line opacimeter, the terminal 0.6 m of the exhaust pipe shall be of circular cross section and be free from elbows and bends. The end of the exhaust pipe shall be cut off squarely. The opacimeter shall be mounted centrally to the plume within 25 ± 5 mm of the end of the exhaust pipe.

OPL Optical Path Length

The length of the smoke obscured optical path between the opacimeter light source and the receiver, corrected as necessary for non-uniformity due to density gradients and fringe effect. The optical path length shall be submitted by the instrument manufacturer taking into account any measures against sooting (e.g. purge air). If the optical path length is not available, it shall be determined in accordance with ISO IDS 11614, Paragraph 11.6.5. For the correct determination of the optical path length, a minimum exhaust gas velocity of 20 m/s is required.

LS Light source

The light source shall be an incandescent lamp with a colour temperature in the range of 2800 to 3250 K or a green light emitting diode (LED) with a spectral peak between

550 and 570 nm. The light source shall be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

LD Light detector

The detector shall be a photocell or a photodiode (with a filter, if necessary). In the case of an incandescent light source, the receiver shall have a peak spectral response similar to the phototopic curve of the human eye (maximum response) in the range of 550 to 570 nm, to less than 4 per cent of that maximum response below 430 nm and above 680 nm. The light detector shall be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

CL Collimating lens

The light output shall be collimated to a beam with a maximum diameter of 30 mm. The rays of the light beam shall be parallel within a tolerance of 3° of the optical axis.

T1 Temperature sensor (optional)

The exhaust gas temperature may be monitored over the test.

1.3.2. Partial Flow Opacimeter

With the partial flow opacimeter (Figure 22), a representative exhaust sample is taken from the exhaust pipe and passed through a transfer line to the measuring chamber. With this type of opacimeter, the effective optical path length is a function of the opacimeter design. The response times referred to in the following Paragraph apply to the minimum flow rate of the opacimeter, as specified by the instrument manufacturer.

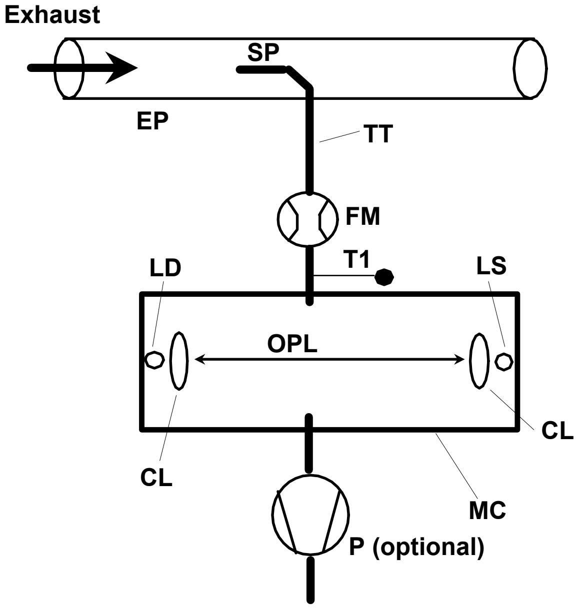

Figure 22: Partial flow opacimeter

3.3.1. Components of Figure 22

EP Exhaust pipe

The exhaust pipe shall be a straight pipe of at least 6 pipe diameters upstream and 3 pipe diameters downstream of the tip of the probe.

SP Sampling probe

The sampling probe shall be an open tube facing upstream on or about the exhaust pipe centreline. The clearance with the wall of the tailpipe shall be at least 5 mm. The probe diameter shall ensure a representative sampling and a sufficient flow through the opacimeter.

TT Transfer tube

The transfer tube shall:

- Be as short as possible and ensure an exhaust gas temperature of 373 ± 30 K (100°C ± 30°C) at the entrance to the measuring chamber.

- Have a wall temperature sufficiently above the dew point of the exhaust gas to prevent condensation.

- Be equal to the diameter of the sampling probe over the entire length.

- Have a response time of less than 0.05 s at minimum instrument flow, as determined according to Annex 4, Appendix 6, Paragraph 1.2.4.

- Have no significant effect on the smoke peak.

FM Flow measurement device

Flow instrumentation to detect the correct flow into the measuring chamber. The minimum and maximum flow rates shall be specified by the instrument manufacturer, and shall be such that the response time requirement of TT and the optical path length specifications are met. The flow measurement device may be close to the sampling pump, P, if used.

MC Measuring chamber

The measuring chamber shall have a non-reflective internal surface, or equivalent optical environment. The impingement of stray light on the detector due to internal reflections of diffusion effects shall be reduced to a minimum.

The pressure of the gas in the measuring chamber shall not differ from the atmospheric pressure by more than 0.75 kPa. Where this is not possible by design, the opacimeter reading shall be converted to atmospheric pressure.

The wall temperature of the measuring chamber shall be set to within ± 5 K between 343 K (70°C) and 373 K (100°C), but in any case sufficiently above the dew point of the exhaust gas to prevent condensation. The measuring chamber shall be equipped with appropriate devices for measuring the temperature.

OPL Optical path length

The length of the smoke obscured optical path between the opacimeter light source and the receiver, corrected as necessary for non-uniformity due to density gradients and fringe effect. The optical path length shall be provided by the instrument manufacturer, taking into account any measures against sooting (e.g. purge air). If the optical path length is not available, it shall be determined in accordance with ISO IDS 11614, Paragraph 11.6.5.

LS Light source

The light source shall be an incandescent lamp with a colour temperature in the range of 2800 to 3250 K or a green light emitting diode (LED) with a spectral peak between 550 and 570 nm. The light source shall be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

LD Light detector

The detector shall be a photocell or a photodiode (with a filter, if necessary). In the case of an incandescent light source, the receiver shall have a peak spectral response similar to the phototopic curve of the human eye (maximum response) in the range of 550 to 570 nm, to less than 4 per cent of that maximum response below 430 nm and above 680 nm. The light detector shall be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

CL Collimating lens

The light output shall be collimated to a beam with a maximum diameter of 30 mm. The rays of the light beam shall be parallel within a tolerance of 3° of the optical axis.

T1 Temperature sensor

To monitor the exhaust gas temperature at the entrance to the measuring chamber.

P Sampling pump (optional)

A sampling pump downstream of the measuring chamber may be used to transfer the sample gas through the measuring chamber.

2. Calibration Procedure

2.1. Introduction

The opacimeter shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method to be used is described in this Paragraph for the components indicated in Annex 4, Paragraph 1.3.

2.2. Procedure

2.2.1. 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.

2.2.2. 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 Annex 4, Appendix 6, Paragraph 1.2.5., 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 shall not differ by more than ± 2 per cent opacity from the nominal value of the neutral density filter. Any non-linearity exceeding the above value shall be corrected prior to the test.

2.3. Calibration intervals

The opacimeter shall be calibrated according to Appendix 6, Paragraph 2.2.2. at least every 3 months or whenever a system repair or change is made that could influence calibration.

APPENDIX 7 – NORMALISED ETC TEST SCHEDULE

Time	Norm. Speed	Norm. Torque
s	%	%
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0.1	1.5
17	23.1	21.5
18	12.6	28.5
19	21.8	71
20	19.7	76.8
21	54.6	80.9
22	71.3	4.9
23	55.9	18.1
24	72	85.4
25	86.7	61.8
26	51.7	0
27	53.4	48.9
28	34.2	87.6
29	45.5	92.7
30	54.6	99.5
31	64.5	96.8
32	71.7	85.4
33	79.4	54.8
34	89.7	99.4
35	57.4	0
36	59.7	30.6
37	90.1	"m"
38	82.9	"m"
39	51.3	"m"
40	28.5	"m"
41	29.3	"m"
42	26.7	"m"
43	20.4	"m"
44	14.1	0
45	6.5	0
46	0	0
47	0	0
48	0	0
49	0	0
50	0	0
51	0	0
52	0	0
53	0	0
54	0	0
55	0	0
56	0	0
57	0	0
58	0	0
59	0	0
60	0	0
61	0	0
62	25.5	11.1
63	28.5	20.9
64	32	73.9
65	4	82.3
66	34.5	80.4
67	64.1	86
68	58	0
69	50.3	83.4
70	66.4	99.1
71	81.4	99.6
72	88.7	73.4
73	52.5	0
74	46.4	58.5
75	48.6	90.9
76	55.2	99.4
77	62.3	99
78	68.4	91.5
79	74.5	73.7
80	38	0
81	41.8	89.6
82	47.1	99.2
83	52.5	99.8
84	56.9	80.8
85	58.3	11.8
86	56.2	"m"
87	52	"m"
88	43.3	"m"
89	36.1	"m"
90	27.6	"m"
91	21.1	"m"
92	8	0
93	0	0
94	0	0
95	0	0
96	0	0
97	0	0
98	0	0
99	0	0
100	0	0
101	0	0
102	0	0
103	0	0
104	0	0
105	0	0
106	0	0
107	0	0
108	11.6	14.8
109	0	0
110	27.2	74.8
111	17	76.9
112	36	78
113	59.7	86
114	80.8	17.9
115	49.7	0
116	65.6	86
117	78.6	72.2
118	64.9	"m"
119	44.3	"m"
120	51.4	83.4
121	58.1	97
122	69.3	99.3
123	72	20.8
124	72.1	"m"
125	65.3	"m"
126	64	"m"
127	59.7	"m"
128	52.8	"m"
129	45.9	"m"
130	38.7	"m"
131	32.4	"m"
132	27	"m"
133	21.7	"m"
134	19.1	0.4
135	34.7	14
136	16.4	48.6
137	0	11.2
138	1.2	2.1
139	30.1	19.3
140	30	73.9
141	54.4	74.4
142	77.2	55.6
143	58.1	0
144	45	82.1
145	68.7	98.1
146	85.7	67.2
147	60.2	0
148	59.4	98
149	72.7	99.6
150	79.9	45
151	44.3	0
152	41.5	84.4
153	56.2	98.2

Time s	Norm. Speed %	Norm. Torque %
154	65.7	99.1
155	74.4	84.7
156	54.4	0
157	47.9	89.7
158	54.5	99.5
159	62.7	96.8
160	62.3	0
161	46.2	54.2
162	44.3	83.2
163	48.2	13.3
164	51	"m"
165	50	"m"
166	49.2	"m"
167	49.3	"m"
168	49.9	"m"
169	51.6	"m"
170	49.7	"m"
171	48.5	"m"
172	50.3	72.5
173	51.1	84.5
174	54.6	64.8
175	56.6	76.5
176	58	"m"
177	53.6	"m"
178	40.8	"m"
179	32.9	"m"
180	26.3	"m"
181	20.9	"m"
182	10	0
183	0	0
184	0	0
185	0	0
186	0	0
187	0	0
188	0	0
189	0	0
190	0	0
191	0	0
192	0	0
193	0	0
194	0	0
195	0	0
196	0	0
197	0	0
198	0	0
199	0	0
200	0	0
201	0	0
202	0	0
203	0	0
204	0	0
205	0	0
206	0	0
207	0	0
208	0	0
209	0	0
210	0	0
211	0	0
212	0	0
213	0	0
214	0	0
215	0	0
216	0	0
217	0	0
218	0	0
219	0	0
220	0	0
221	0	0
222	0	0
223	0	0
224	0	0
225	21.2	62.7
226	30.8	75.1
227	5.9	82.7
228	34.6	80.3
229	59.9	87
230	84.3	86.2
231	68.7	"m"
232	43.6	"m"
233	41.5	85.4
234	49.9	94.3
235	60.8	99
236	70.2	99.4
237	81.1	92.4
238	49.2	0
239	56	86.2
240	56.2	99.3
241	61.7	99
242	69.2	99.3
243	74.1	99.8
244	72.4	8.4
245	71.3	0
246	71.2	9.1
247	67.1	"m"
248	65.5	"m"
249	64.4	"m"
250	62.9	25.6
251	62.2	35.6
252	62.9	24.4
253	58.8	"m"
254	56.9	"m"
255	54.5	"m"
256	51.7	17
257	56.2	78.7
258	59.5	94.7
259	65.5	99.1
260	71.2	99.5
261	76.6	99.9
262	79	0
263	52.9	97.5
264	53.1	99.7
265	59	99.1
266	62.2	99
267	65	99.1
268	69	83.1
269	69.9	28.4
270	70.6	12.5
271	68.9	8.4
272	69.8	9.1
273	69.6	7
274	65.7	"m"
275	67.1	"m"
276	66.7	"m"
277	65.6	"m"
278	64.5	"m"
279	62.9	"m"
280	59.3	"m"
281	54.1	"m"
282	51.3	"m"
283	47.9	"m"
284	43.6	"m"
285	39.4	"m"
286	34.7	"m"
287	29.8	"m"
288	20.9	73.4
289	36.9	"m"
290	35.5	"m"
291	20.9	"m"
292	49.7	11.9
293	42.5	"m"
294	32	"m"
295	23.6	"m"
296	19.1	0
297	15.7	73.5
298	25.1	76.8
299	34.5	81.4
300	44.1	87.4
301	52.8	98.6
302	63.6	99
303	73.6	99.7
304	62.2	"m"
305	29.2	"m"
306	46.4	22

Time s	Norm. Speed %	Norm. Torque %
307	47.3	13.8
308	47.2	12.5
309	47.9	11.5
310	47.8	35.5
311	49.2	83.3
312	52.7	96.4
313	57.4	99.2
314	61.8	99
315	66.4	60.9
316	65.8	"m"
317	59	"m"
318	50.7	"m"
319	41.8	"m"
320	34.7	"m"
321	28.7	"m"
322	25.2	"m"
323	43	24.8
324	38.7	0
325	48.1	31.9
326	40.3	61
327	42.4	52.1
328	46.4	47.7
329	46.9	30.7
330	46.1	23.1
331	45.7	23.2
332	45.5	31.9
333	46.4	73.6
334	51.3	60.7
335	51.3	51.1
336	53.2	46.8
337	53.9	50
338	53.4	52.1
339	53.8	45.7
340	50.6	22.1
341	47.8	26
342	41.6	17.8
343	38.7	29.8
344	35.9	71.6
345	34.6	47.3
346	34.8	80.3
347	35.9	87.2
348	38.8	90.8
349	41.5	94.7
350	47.1	99.2
351	53.1	99.7
352	46.4	0
353	42.5	0.7
354	43.6	58.6
355	47.1	87.5
356	54.1	99.5
357	62.9	99
358	72.6	99.6
359	82.4	99.5
360	88	99.4
361	46.4	0
362	53.4	95.2
363	58.4	99.2
364	61.5	99
365	64.8	99
366	68.1	99.2
367	73.4	99.7
368	73.3	29.8
369	73.5	14.6
370	68.3	0
371	45.4	49.9
372	47.2	75.7
373	44.5	9
374	47.8	10.3
375	46.8	15.9
376	46.9	12.7
377	46.8	8.9
378	46.1	6.2
379	46.1	"m"
380	45.5	"m"
381	44.7	"m"
382	43.8	"m"
383	41	"m"
384	41.1	6.4
385	38	6.3
386	35.9	0.3
387	33.5	0
388	53.1	48.9
389	48.3	"m"
390	49.9	"m"
391	48	"m"
392	45.3	"m"
393	41.6	3.1
394	44.3	79
395	44.3	89.5
396	43.4	98.8
397	44.3	98.9
398	43	98.8
399	42.2	98.8
400	42.7	98.8
401	45	99
402	43.6	98.9
403	42.2	98.8
404	44.8	99
405	43.4	98.8
406	45	99
407	42.2	54.3
408	61.2	31.9
409	56.3	72.3
410	59.7	99.1
411	62.3	99
412	67.9	99.2
413	69.5	99.3
414	73.1	99.7
415	77.7	99.8
416	79.7	99.7
417	82.5	99.5
418	85.3	99.4
419	86.6	99.4
420	89.4	99.4
421	62.2	0
422	52.7	96.4
423	50.2	99.8
424	49.3	99.6
425	52.2	99.8
426	51.3	100
427	51.3	100
428	51.1	100
429	51.1	100
430	51.8	99.9
431	51.3	100
432	51.1	100
433	51.3	100
434	52.3	99.8
435	52.9	99.7
436	53.8	99.6
437	51.7	99.9
438	53.5	99.6
439	52	99.8
440	51.7	99.9
441	53.2	99.7
442	54.2	99.5
443	55.2	99.4
444	53.8	99.6
445	53.1	99.7
446	55	99.4
447	57	99.2
448	61.5	99
449	59.4	5.7
450	59	0
451	57.3	59.8
452	64.1	99
453	70.9	90.5
454	58	0
455	41.5	59.8
456	44.1	92.6
457	46.8	99.2
458	47.2	99.3
459	51	100

Time	Norm. Speed	Norm. Torque
s	%	%
460	53.2	99.7
461	53.1	99.7
462	55.9	53.1
463	53.9	13.9
464	52.5	"m"
465	51.7	"m"
466	51.5	52.2
467	52.8	80
468	54.9	95
469	57.3	99.2
470	60.7	99.1
471	62.4	"m"
472	60.1	"m"
473	53.2	"m"
474	44	"m"
475	35.2	"m"
476	30.5	"m"
477	26.5	"m"
478	22.5	"m"
479	20.4	"m"
480	19.1	"m"
481	19.1	"m"
482	13.4	"m"
483	6.7	"m"
484	3.2	"m"
485	14.3	63.8
486	34.1	0
487	23.9	75.7
488	31.7	79.2
489	32.1	19.4
490	35.9	5.8
491	36.6	0.8
492	38.7	"m"
493	38.4	"m"
494	39.4	"m"
495	39.7	"m"
496	40.5	"m"
497	40.8	"m"
498	39.7	"m"
499	39.2	"m"
500	38.7	"m"
501	32.7	"m"
502	30.1	"m"
503	21.9	"m"
504	12.8	0
505	0	0
506	0	0
507	0	0
508	0	0
509	0	0
510	0	0
511	0	0
512	0	0
513	0	0
514	30.5	25.6
515	19.7	56.9
516	16.3	45.1
517	27.2	4.6
518	21.7	1.3
519	29.7	28.6
520	36.6	73.7
521	61.3	59.5
522	40.8	0
523	36.6	27.8
524	39.4	80.4
525	51.3	88.9
526	58.5	11.1
527	60.7	"m"
528	54.5	"m"
529	51.3	"m"
530	45.5	"m"
531	40.8	"m"
532	38.9	"m"
533	36.6	"m"
534	36.1	72.7
535	44.8	78.9
536	51.6	91.1
537	59.1	99.1
538	66	99.1
539	75.1	99.9
540	81	8
541	39.1	0
542	53.8	89.7
543	59.7	99.1
544	64.8	99
545	70.6	96.1
546	72.6	19.6
547	72	6.3
548	68.9	0.1
549	67.7	"m"
550	66.8	"m"
551	64.3	16.9
552	64.9	7
553	63.6	12.5
554	63	7.7
555	64.4	38.2
556	63	11.8
557	63.6	0
558	63.3	5
559	60.1	9.1
560	61	8.4
561	59.7	0.9
562	58.7	"m"
563	56	"m"
564	53.9	"m"
565	52.1	"m"
566	49.9	"m"
567	46.4	"m"
568	43.6	"m"
569	40.8	"m"
570	37.5	"m"
571	27.8	"m"
572	17.1	0.6
573	12.2	0.9
574	11.5	1.1
575	8.7	0.5
576	8	0.9
577	5.3	0.2
578	4	0
579	3.9	0
580	0	0
581	0	0
582	0	0
583	0	0
584	0	0
585	0	0
586	0	0
587	8.7	22.8
588	16.2	49.4
589	23.6	56
590	21.1	56.1
591	23.6	56
592	46.2	68.8
593	68.4	61.2
594	58.7	"m"
595	31.6	"m"
596	19.9	8.8
597	32.9	70.2
598	43	79
599	57.4	98.9
600	72.1	73.8
601	53	0
602	48.1	86
603	56.2	99
604	65.4	98.9
605	72.9	99.7
606	67.5	"m"
607	39	"m"
608	41.9	38.1
609	44.1	80.4
610	46.8	99.4
611	48.7	99.9
612	50.5	99.7

Time s	Norm. Speed %	Norm. Torque %
613	52.5	90.3
614	51	1.8
615	50	"m"
616	49.1	"m"
617	47	"m"
618	43.1	"m"
619	39.2	"m"
620	40.6	0.5
621	41.8	53.4
622	44.4	65.1
623	48.1	67.8
624	53.8	99.2
625	58.6	98.9
626	63.6	98.8
627	68.5	99.2
628	72.2	89.4
629	77.1	0
630	57.8	79.1
631	60.3	98.8
632	61.9	98.8
633	63.8	98.8
634	64.7	98.9
635	65.4	46.5
636	65.7	44.5
637	65.6	3.5
638	49.1	0
639	50.4	73.1
640	50.5	"m"
641	51	"m"
642	49.4	"m"
643	49.2	"m"
644	48.6	"m"
645	47.5	"m"
646	46.5	"m"
647	46	11.3
648	45.6	42.8
649	47.1	83
650	46.2	99.3
651	47.9	99.7
652	49.5	99.9
653	50.6	99.7
654	51	99.6
655	53	99.3
656	54.9	99.1
657	55.7	99
658	56	99
659	56.1	9.3
660	55.6	"m"
661	55.4	"m"
662	54.9	51.3
663	54.9	59.8
664	54	39.3
665	53.8	"m"
666	52	"m"
667	50.4	"m"
668	50.6	0
669	49.3	41.7
670	50	73.2
671	50.4	99.7
672	51.9	99.5
673	53.6	99.3
674	54.6	99.1
675	56	99
676	55.8	99
677	58.4	98.9
678	59.9	98.8
679	60.9	98.8
680	63	98.8
681	64.3	98.9
682	64.8	64
683	65.9	46.5
684	66.2	28.7
685	65.2	1.8
686	65	6.8
687	63.6	53.6
688	62.4	82.5
689	61.8	98.8
690	59.8	98.8
691	59.2	98.8
692	59.7	98.8
693	61.2	98.8
694	62.2	49.4
695	62.8	37.2
696	63.5	46.3
697	64.7	72.3
698	64.7	72.3
699	65.4	77.4
700	66.1	69.3
701	64.3	"m"
702	64.3	"m"
703	63	"m"
704	62.2	"m"
705	61.6	"m"
706	62.4	"m"
707	62.2	"m"
708	61	"m"
709	58.7	"m"
710	55.5	"m"
711	51.7	"m"
712	49.2	"m"
713	48.8	40.4
714	47.9	"m"
715	46.2	"m"
716	45.6	9.8
717	45.6	34.5
718	45.5	37.1
719	43.8	"m"
720	41.9	"m"
721	41.3	"m"
722	41.4	"m"
723	41.2	"m"
724	41.8	"m"
725	41.8	"m"
726	43.2	17.4
727	45	29
728	44.2	"m"
729	43.9	"m"
730	38	10.7
731	56.8	"m"
732	57.1	"m"
733	52	"m"
734	44.4	"m"
735	40.2	"m"
736	39.2	16.5
737	38.9	73.2
738	39.9	89.8
739	42.3	98.6
740	43.7	98.8
741	45.5	99.1
742	45.6	99.2
743	48.1	99.7
744	49	100
745	49.8	99.9
746	49.8	99.9
747	51.9	99.5
748	52.3	99.4
749	53.3	99.3
750	52.9	99.3
751	54.3	99.2
752	55.5	99.1
753	56.7	99
754	61.7	98.8
755	64.3	47.4
756	64.7	1.8
757	66.2	"m"
758	49.1	"m"
759	52.1	46
760	52.6	61
761	52.9	0
762	52.3	20.4
763	54.2	56.7
764	55.4	59.8
765	56.1	49.2

Time	Norm. Speed	Norm. Torque
s	%	%
766	56.8	33.7
767	57.2	96
768	58.6	98.9
769	59.5	98.8
770	61.2	98.8
771	62.1	98.8
772	62.7	98.8
773	62.8	98.8
774	64	98.9
775	63.2	46.3
776	62.4	"m"
777	60.3	"m"
778	58.7	"m"
779	57.2	"m"
780	56.1	"m"
781	56	9.3
782	55.2	26.3
783	54.8	42.8
784	55.7	47.1
785	56.6	52.4
786	58	50.3
787	58.6	20.6
788	58.7	"m"
789	59.3	"m"
790	58.6	"m"
791	60.5	9.7
792	59.2	9.6
793	59.9	9.6
794	59.6	9.6
795	59.9	6.2
796	59.9	9.6
797	60.5	13.1
798	60.3	20.7
799	59.9	31
800	60.5	42
801	61.5	52.5
802	60.9	51.4
803	61.2	57.7
804	62.8	98.8
805	63.4	96.1
806	64.6	45.4
807	64.1	5
808	63	3.2
809	62.7	14.9
810	63.5	35.8
811	64.1	73.3
812	64.3	37.4
813	64.1	21
814	63.7	21
815	62.9	18
816	62.4	32.7
817	61.7	46.2
818	59.8	45.1
819	57.4	43.9
820	54.8	42.8
821	54.3	65.2
822	52.9	62.1
823	52.4	30.6
824	50.4	"m"
825	48.6	"m"
826	47.9	"m"
827	46.8	"m"
828	46.9	9.4
829	49.5	41.7
830	50.5	37.8
831	52.3	20.4
832	54.1	30.7
833	56.3	41.8
834	58.7	26.5
835	57.3	"m"
836	59	"m"
837	59.8	"m"
838	60.3	"m"
839	61.2	"m"
840	61.8	"m"
841	62.5	"m"
842	62.4	"m"
843	61.5	"m"
844	63.7	"m"
845	61.9	"m"
846	61.6	29.7
847	60.3	"m"
848	59.2	"m"
849	57.3	"m"
850	52.3	"m"
851	49.3	"m"
852	47.3	"m"
853	46.3	38.8
854	46.8	35.1
855	46.6	"m"
856	44.3	"m"
857	43.1	"m"
858	42.4	2.1
859	41.8	2.4
860	43.8	68.8
861	44.6	89.2
862	46	99.2
863	46.9	99.4
864	47.9	99.7
865	50.2	99.8
866	51.2	99.6
867	52.3	99.4
868	53	99.3
869	54.2	99.2
870	55.5	99.1
871	56.7	99
872	57.3	98.9
873	58	98.9
874	60.5	31.1
875	60.2	"m"
876	60.3	"m"
877	60.5	6.3
878	61.4	19.3
879	60.3	1.2
880	60.5	2.9
881	61.2	34.1
882	61.6	13.2
883	61.5	16.4
884	61.2	16.4
885	61.3	"m"
886	63.1	"m"
887	63.2	4.8
888	62.3	22.3
889	62	38.5
890	61.6	29.6
891	61.6	26.6
892	61.8	28.1
893	62	29.6
894	62	16.3
895	61.1	"m"
896	61.2	"m"
897	60.7	19.2
898	60.7	32.5
899	60.9	17.8
900	60.1	19.2
901	59.3	38.2
902	59.9	45
903	59.4	32.4
904	59.2	23.5
905	59.5	40.8
906	58.3	"m"
907	58.2	"m"
908	57.6	"m"
909	57.1	"m"
910	57	0.6
911	57	26.3
912	56.5	29.2
913	56.3	20.5
914	56.1	"m"
915	55.2	"m"
916	54.7	17.5
917	55.2	29.2
918	55.2	29.2

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	%	%	s	%	%	s	%	%
919	55.9	16	970	49.9	99.7	1021	49.4	"m"
920	55.9	26.3	971	49.6	99.6	1022	48.3	"m"
921	56.1	36.5	972	49.4	99.6	1023	49.4	"m"
922	55.8	19	973	49	99.5	1024	48.5	"m"
923	55.9	9.2	974	49.8	99.7	1025	48.7	"m"
924	55.8	21.9	975	50.9	100	1026	48.7	"m"
925	56.4	42.8	976	50.4	99.8	1027	49.1	"m"
926	56.4	38	977	49.8	99.7	1028	49	"m"
927	56.4	11	978	49.1	99.5	1029	49.8	"m"
928	56.4	35.1	979	50.4	99.8	1030	48.7	"m"
929	54	7.3	980	49.8	99.7	1031	48.5	"m"
930	53.4	5.4	981	49.3	99.5	1032	49.3	31.3
931	52.3	27.6	982	49.1	99.5	1033	49.7	45.3
932	52.1	32	983	49.9	99.7	1034	48.3	44.5
933	52.3	33.4	984	49.1	99.5	1035	49.8	61
934	52.2	34.9	985	50.4	99.8	1036	49.4	64.3
935	52.8	60.1	986	50.9	100	1037	49.8	64.4
936	53.7	69.7	987	51.4	99.9	1038	50.5	65.6
937	54	70.7	988	51.5	99.9	1039	50.3	64.5
938	55.1	71.7	989	52.2	99.7	1040	51.2	82.9
939	55.2	46	990	52.8	74.1	1041	50.5	86
940	54.7	12.6	991	53.3	46	1042	50.6	89
941	52.5	0	992	53.6	36.4	1043	50.4	81.4
942	51.8	24.7	993	53.4	33.5	1044	49.9	49.9
943	51.4	43.9	994	53.9	58.9	1045	49.1	20.1
944	50.9	71.1	995	55.2	73.8	1046	47.9	24
945	51.2	76.8	996	55.8	52.4	1047	48.1	36.2
946	50.3	87.5	997	55.7	9.2	1048	47.5	34.5
947	50.2	99.8	998	55.8	2.2	1049	46.9	30.3
948	50.9	100	999	56.4	33.6	1050	47.7	53.5
949	49.9	99.7	1000	55.4	"m"	1051	46.9	61.6
950	50.9	100	1001	55.2	"m"	1052	46.5	73.6
951	49.8	99.7	1002	55.8	26.3	1053	48	84.6
952	50.4	99.8	1003	55.8	23.3	1054	47.2	87.7
953	50.4	99.8	1004	56.4	50.2	1055	48.7	80
954	49.7	99.7	1005	57.6	68.3	1056	48.7	50.4
955	51	100	1006	58.8	90.2	1057	47.8	38.6
956	50.3	99.8	1007	59.9	98.9	1058	48.8	63.1
957	50.2	99.8	1008	62.3	98.8	1059	47.4	5
958	49.9	99.7	1009	63.1	74.4	1060	47.3	47.4
959	50.9	100	1010	63.7	49.4	1061	47.3	49.8
960	50	99.7	1011	63.3	9.8	1062	46.9	23.9
961	50.2	99.8	1012	48	0	1063	46.7	44.6
962	50.2	99.8	1013	47.9	73.5	1064	46.8	65.2
963	49.9	99.7	1014	49.9	99.7	1065	46.9	60.4
964	50.4	99.8	1015	49.9	48.8	1066	46.7	61.5
965	50.2	99.8	1016	49.6	2.3	1067	45.5	"m"
966	50.3	99.8	1017	49.9	"m"	1068	45.5	"m"
967	49.9	99.7	1018	49.3	"m"	1069	44.2	"m"
968	51.1	100	1019	49.7	47.5	1070	43	"m"
969	50.6	99.9	1020	49.1	"m"	1071	42.5	"m"

Time s	Norm. Speed %	Norm. Torque %
1072	41	"m"
1073	39.9	"m"
1074	39.9	38.2
1075	40.1	48.1
1076	39.9	48
1077	39.4	59.3
1078	43.8	19.8
1079	52.9	0
1080	52.8	88.9
1081	53.4	99.5
1082	54.7	99.3
1083	56.3	99.1
1084	57.5	99
1085	59	98.9
1086	59.8	98.9
1087	60.1	98.9
1088	61.8	48.3
1089	61.8	55.6
1090	61.7	59.8
1091	62	55.6
1092	62.3	29.6
1093	62	19.3
1094	61.3	7.9
1095	61.1	19.2
1096	61.2	43
1097	61.1	59.7
1098	61.1	98.8
1099	61.3	98.8
1100	61.3	26.6
1101	60.4	"m"
1102	58.8	"m"
1103	57.7	"m"
1104	56	"m"
1105	54.7	"m"
1106	53.3	"m"
1107	52.6	23.2
1108	53.4	84.2
1109	53.9	99.4
1110	54.9	99.3
1111	55.8	99.2
1112	57.1	99
1113	56.5	99.1
1114	58.9	98.9
1115	58.7	98.9
1116	59.8	98.9
1117	61	98.8
1118	60.7	19.2
1119	59.4	"m"
1120	57.9	"m"
1121	57.6	"m"
1122	56.3	"m"
1123	55	"m"
1124	53.7	"m"
1125	52.1	"m"
1126	51.1	"m"
1127	49.7	25.8
1128	49.1	46.1
1129	48.7	46.9
1130	48.2	46.7
1131	48	70
1132	48	70
1133	47.2	67.6
1134	47.3	67.6
1135	46.6	74.7
1136	47.4	13
1137	46.3	"m"
1138	45.4	"m"
1139	45.5	24.8
1140	44.8	73.8
1141	46.6	99
1142	46.3	98.9
1143	48.5	99.4
1144	49.9	99.7
1145	49.1	99.5
1146	49.1	99.5
1147	51	100
1148	51.5	99.9
1149	50.9	100
1150	51.6	99.9
1151	52.1	99.7
1152	50.9	100
1153	52.2	99.7
1154	51.5	98.3
1155	51.5	47.2
1156	50.8	78.4
1157	50.3	83
1158	50.3	31.7
1159	49.3	31.3
1160	48.8	21.5
1161	47.8	59.4
1162	48.1	77.1
1163	48.4	87.6
1164	49.6	87.5
1165	51	81.4
1166	51.6	66.7
1167	53.3	63.2
1168	55.2	62
1169	55.7	43.9
1170	56.4	30.7
1171	56.8	23.4
1172	57	"m"
1173	57.6	"m"
1174	56.9	"m"
1175	56.4	4
1176	57	23.4
1177	56.4	41.7
1178	57	49.2
1179	57.7	56.6
1180	58.6	56.6
1181	58.9	64
1182	59.4	68.2
1183	58.8	71.4
1184	60.1	71.3
1185	60.6	79.1
1186	60.7	83.3
1187	60.7	77.1
1188	60	73.5
1189	60.2	55.5
1190	59.7	54.4
1191	59.8	73.3
1192	59.8	77.9
1193	59.8	73.9
1194	60	76.5
1195	59.5	82.3
1196	59.9	82.8
1197	59.8	65.8
1198	59	48.6
1199	58.9	62.2
1200	59.1	70.4
1201	58.9	62.1
1202	58.4	67.4
1203	58.7	58.9
1204	58.3	57.7
1205	57.5	57.8
1206	57.2	57.6
1207	57.1	42.6
1208	57	70.1
1209	56.4	59.6
1210	56.7	39
1211	55.9	68.1
1212	56.3	79.1
1213	56.7	89.7
1214	56	89.4
1215	56	93.1
1216	56.4	93.1
1217	56.7	94.4
1218	56.9	94.8
1219	57	94.1
1220	57.7	94.3
1221	57.5	93.7
1222	58.4	93.2
1223	58.7	93.2
1224	58.2	93.7

Time	Norm. Speed	Norm. Torque
s	%	%
1225	58.5	93.1
1226	58.8	86.2
1227	59	72.9
1228	58.2	59.9
1229	57.6	8.5
1230	57.1	47.6
1231	57.2	74.4
1232	57	79.1
1233	56.7	67.2
1234	56.8	69.1
1235	56.9	71.3
1236	57	77.3
1237	57.4	78.2
1238	57.3	70.6
1239	57.7	64
1240	57.5	55.6
1241	58.6	49.6
1242	58.2	41.1
1243	58.8	40.6
1244	58.3	21.1
1245	58.7	24.9
1246	59.1	24.8
1247	58.6	"m"
1248	58.8	"m"
1249	58.8	"m"
1250	58.7	"m"
1251	59.1	"m"
1252	59.1	"m"
1253	59.4	"m"
1254	60.6	2.6
1255	59.6	"m"
1256	60.1	"m"
1257	60.6	"m"
1258	59.6	4.1
1259	60.7	7.1
1260	60.5	"m"
1261	59.7	"m"
1262	59.6	"m"
1263	59.8	"m"
1264	59.6	4.9
1265	60.1	5.9
1266	59.9	6.1
1267	59.7	"m"
1268	59.6	"m"
1269	59.7	22
1270	59.8	10.3
1271	59.9	10
1272	60.6	6.2
1273	60.5	7.3
1274	60.2	14.8
1275	60.6	8.2
1276	60.6	5.5
1277	61	14.3
1278	61	12
1279	61.3	34.2
1280	61.2	17.1
1281	61.5	15.7
1282	61	9.5
1283	61.1	9.2
1284	60.5	4.3
1285	60.2	7.8
1286	60.2	5.9
1287	60.2	5.3
1288	59.9	4.6
1289	59.4	21.5
1290	59.6	15.8
1291	59.3	10.1
1292	58.9	9.4
1293	58.8	9
1294	58.9	35.4
1295	58.9	30.7
1296	58.9	25.9
1297	58.7	22.9
1298	58.7	24.4
1299	59.3	61
1300	60.1	56
1301	60.5	50.6
1302	59.5	16.2
1303	59.7	50
1304	59.7	31.4
1305	60.1	43.1
1306	60.8	38.4
1307	60.9	40.2
1308	61.3	49.7
1309	61.8	45.9
1310	62	45.9
1311	62.2	45.8
1312	62.6	46.8
1313	62.7	44.3
1314	62.9	44.4
1315	63.1	43.7
1316	63.5	46.1
1317	63.6	40.7
1318	64.3	49.5
1319	63.7	27
1320	63.8	15
1321	63.6	18.7
1322	63.4	8.4
1323	63.2	8.7
1324	63.3	21.6
1325	62.9	19.7
1326	63	22.1
1327	63.1	20.3
1328	61.8	19.1
1329	61.6	17.1
1330	61	0
1331	61.2	22
1332	60.8	40.3
1333	61.1	34.3
1334	60.7	16.1
1335	60.6	16.6
1336	60.5	18.5
1337	60.6	29.8
1338	60.9	19.5
1339	60.9	22.3
1340	61.4	35.8
1341	61.3	42.9
1342	61.5	31
1343	61.3	19.2
1344	61	9.3
1345	60.8	44.2
1346	60.9	55.3
1347	61.2	56
1348	60.9	60.1
1349	60.7	59.1
1350	60.9	56.8
1351	60.7	58.1
1352	59.6	78.4
1353	59.6	84.6
1354	59.4	66.6
1355	59.3	75.5
1356	58.9	49.6
1357	59.1	75.8
1358	59	77.6
1359	59	67.8
1360	59	56.7
1361	58.8	54.2
1362	58.9	59.6
1363	58.9	60.8
1364	59.3	56.1
1365	58.9	48.5
1366	59.3	42.9
1367	59.4	41.4
1368	59.6	38.9
1369	59.4	32.9
1370	59.3	30.6
1371	59.4	30
1372	59.4	25.3
1373	58.8	18.6
1374	59.1	18
1375	58.5	10.6
1376	58.8	10.5
1377	58.5	8.2

Time	Norm. Speed	Norm. Torque
s	%	%
1378	58.7	13.7
1379	59.1	7.8
1380	59.1	6
1381	59.1	6
1382	59.4	13.1
1383	59.7	22.3
1384	60.7	10.5
1385	59.8	9.8
1386	60.2	8.8
1387	59.9	8.7
1388	61	9.1
1389	60.6	28.2
1390	60.6	22
1391	59.6	23.2
1392	59.6	19
1393	60.6	38.4
1394	59.8	41.6
1395	60	47.3
1396	60.5	55.4
1397	60.9	58.7
1398	61.3	37.9
1399	61.2	38.3
1400	61.4	58.7
1401	61.3	51.3
1402	61.4	71.1
1403	61.1	51
1404	61.5	56.6
1405	61	60.6
1406	61.1	75.4
1407	61.4	69.4
1408	61.6	69.9
1409	61.7	59.6
1410	61.8	54.8
1411	61.6	53.6
1412	61.3	53.5
1413	61.3	52.9
1414	61.2	54.1
1415	61.3	53.2
1416	61.2	52.2
1417	61.2	52.3
1418	61	48
1419	60.9	41.5
1420	61	32.2
1421	60.7	22
1422	60.7	23.3
1423	60.8	38.8
1424	61	40.7
1425	61	30.6
1426	61.3	62.6
1427	61.7	55.9
1428	62.3	43.4
1429	62.3	37.4
1430	62.3	35.7
1431	62.8	34.4
1432	62.8	31.5
1433	62.9	31.7
1434	62.9	29.9
1435	62.8	29.4
1436	62.7	28.7
1437	61.5	14.7
1438	61.9	17.2
1439	61.5	6.1
1440	61	9.9
1441	60.9	4.8
1442	60.6	11.1
1443	60.3	6.9
1444	60.8	7
1445	60.2	9.2
1446	60.5	21.7
1447	60.2	22.4
1448	60.7	31.6
1449	60.9	28.9
1450	59.6	21.7
1451	60.2	18
1452	59.5	16.7
1453	59.8	15.7
1454	59.6	15.7
1455	59.3	15.7
1456	59	7.5
1457	58.8	7.1
1458	58.7	16.5
1459	59.2	50.7
1460	59.7	60.2
1461	60.4	44
1462	60.2	35.3
1463	60.4	17.1
1464	59.9	13.5
1465	59.9	12.8
1466	59.6	14.8
1467	59.4	15.9
1468	59.4	22
1469	60.4	38.4
1470	59.5	38.8
1471	59.3	31.9
1472	60.9	40.8
1473	60.7	39
1474	60.9	30.1
1475	61	29.3
1476	60.6	28.4
1477	60.9	36.3
1478	60.8	30.5
1479	60.7	26.7
1480	60.1	4.7
1481	59.9	0
1482	60.4	36.2
1483	60.7	32.5
1484	59.9	3.1
1485	59.7	"m"
1486	59.5	"m"
1487	59.2	"m"
1488	58.8	0.6
1489	58.7	"m"
1490	58.7	"m"
1491	57.9	"m"
1492	58.2	"m"
1493	57.6	"m"
1494	58.3	9.5
1495	57.2	6
1496	57.4	27.3
1497	58.3	59.9
1498	58.3	7.3
1499	58.8	21.7
1500	58.8	38.9
1501	59.4	26.2
1502	59.1	25.5
1503	59.1	26
1504	59	39.1
1505	59.5	52.3
1506	59.4	31
1507	59.4	27
1508	59.4	29.8
1509	59.4	23.1
1510	58.9	16
1511	59	31.5
1512	58.8	25.9
1513	58.9	40.2
1514	58.8	28.4
1515	58.9	38.9
1516	59.1	35.3
1517	58.8	30.3
1518	59	19
1519	58.7	3
1520	57.9	0
1521	58	2.4
1522	57.1	"m"
1523	56.7	"m"
1524	56.7	5.3
1525	56.6	2.1
1526	56.8	"m"
1527	56.3	"m"
1528	56.3	"m"
1529	56	"m"
1530	56.7	"m"

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	%	%	s	%	%	s	%	%
1531	56.6	3.8	1582	59.9	73.6	1633	62.5	31
1532	56.9	"m"	1583	59.8	74.1	1634	62.3	31.3
1533	56.9	"m"	1584	59.6	84.6	1635	62.6	31.7
1534	57.4	"m"	1585	59.4	76.1	1636	62.3	22.8
1535	57.4	"m"	1586	60.1	76.9	1637	62.7	12.6
1536	58.3	13.9	1587	59.5	84.6	1638	62.2	15.2
1537	58.5	"m"	1588	59.8	77.5	1639	61.9	32.6
1538	59.1	"m"	1589	60.6	67.9	1640	62.5	23.1
1539	59.4	"m"	1590	59.3	47.3	1641	61.7	19.4
1540	59.6	"m"	1591	59.3	43.1	1642	61.7	10.8
1541	59.5	"m"	1592	59.4	38.3	1643	61.6	10.2
1542	59.6	0.5	1593	58.7	38.2	1644	61.4	"m"
1543	59.3	9.2	1594	58.8	39.2	1645	60.8	"m"
1544	59.4	11.2	1595	59.1	67.9	1646	60.7	"m"
1545	59.1	26.8	1596	59.7	60.5	1647	61	12.4
1546	59	11.7	1597	59.5	32.9	1648	60.4	5.3
1547	58.8	6.4	1598	59.6	20	1649	61	13.1
1548	58.7	5	1599	59.6	34.4	1650	60.7	29.6
1549	57.5	"m"	1600	59.4	23.9	1651	60.5	28.9
1550	57.4	"m"	1601	59.6	15.7	1652	60.8	27.1
1551	57.1	1.1	1602	59.9	41	1653	61.2	27.3
1552	57.1	0	1603	60.5	26.3	1654	60.9	20.6
1553	57	4.5	1604	59.6	14	1655	61.1	13.9
1554	57.1	3.7	1605	59.7	21.2	1656	60.7	13.4
1555	57.3	3.3	1606	60.9	19.6	1657	61.3	26.1
1556	57.3	16.8	1607	60.1	34.3	1658	60.9	23.7
1557	58.2	29.3	1608	59.9	27	1659	61.4	32.1
1558	58.7	12.5	1609	60.8	25.6	1660	61.7	33.5
1559	58.3	12.2	1610	60.6	26.3	1661	61.8	34.1
1560	58.6	12.7	1611	60.9	26.1	1662	61.7	17
1561	59	13.6	1612	61.1	38	1663	61.7	2.5
1562	59.8	21.9	1613	61.2	31.6	1664	61.5	5.9
1563	59.3	20.9	1614	61.4	30.6	1665	61.3	14.9
1564	59.7	19.2	1615	61.7	29.6	1666	61.5	17.2
1565	60.1	15.9	1616	61.5	28.8	1667	61.1	"m"
1566	60.7	16.7	1617	61.7	27.8	1668	61.4	"m"
1567	60.7	18.1	1618	62.2	20.3	1669	61.4	8.8
1568	60.7	40.6	1619	61.4	19.6	1670	61.3	8.8
1569	60.7	59.7	1620	61.8	19.7	1671	61	18
1570	61.1	66.8	1621	61.8	18.7	1672	61.5	13
1571	61.1	58.8	1622	61.6	17.7	1673	61	3.7
1572	60.8	64.7	1623	61.7	8.7	1674	60.9	3.1
1573	60.1	63.6	1624	61.7	1.4	1675	60.9	4.7
1574	60.7	83.2	1625	61.7	5.9	1676	60.6	4.1
1575	60.4	82.2	1626	61.2	8.1	1677	60.6	6.7
1576	60	80.5	1627	61.9	45.8	1678	60.6	12.8
1577	59.9	78.7	1628	61.4	31.5	1679	60.7	11.9
1578	60.8	67.9	1629	61.7	22.3	1680	60.6	12.4
1579	60.4	57.7	1630	62.4	21.7	1681	60.1	12.4
1580	60.2	60.6	1631	62.8	21.9	1682	60.5	12
1581	59.6	72.7	1632	62.2	22.2	1683	60.4	11.8

Time	Norm. Speed	Norm. Torque
s	%	%
1684	59.9	12.4
1685	59.6	12.4
1686	59.6	9.1
1687	59.9	0
1688	59.9	20.4
1689	59.8	4.4
1690	59.4	3.1
1691	59.5	26.3
1692	59.6	20.1
1693	59.4	35
1694	60.9	22.1
1695	60.5	12.2
1696	60.1	11
1697	60.1	8.2
1698	60.5	6.7
1699	60	5.1
1700	60	5.1
1701	60	9
1702	60.1	5.7
1703	59.9	8.5
1704	59.4	6
1705	59.5	5.5
1706	59.5	14.2
1707	59.5	6.2
1708	59.4	10.3
1709	59.6	13.8
1710	59.5	13.9
1711	60.1	18.9
1712	59.4	13.1
1713	59.8	5.4
1714	59.9	2.9
1715	60.1	7.1
1716	59.6	12
1717	59.6	4.9
1718	59.4	22.7
1719	59.6	22
1720	60.1	17.4
1721	60.2	16.6
1722	59.4	28.6
1723	60.3	22.4
1724	59.9	20
1725	60.2	18.6
1726	60.3	11.9
1727	60.4	11.6
1728	60.6	10.6
1729	60.8	16
1730	60.9	17
1731	60.9	16.1
1732	60.7	11.4
1733	60.9	11.3
1734	61.1	11.2
1735	61.1	25.6
1736	61	14.6
1737	61	10.4
1738	60.6	"m"
1739	60.9	"m"
1740	60.8	4.8
1741	59.9	"m"
1742	59.8	"m"
1743	59.1	"m"
1744	58.8	"m"
1745	58.8	"m"
1746	58.2	"m"
1747	58.5	14.3
1748	57.5	4.4
1749	57.9	0
1750	57.8	20.9
1751	58.3	9.2
1752	57.8	8.2
1753	57.5	15.3
1754	58.4	38
1755	58.1	15.4
1756	58.8	11.8
1757	58.3	8.1
1758	58.3	5.5
1759	59	4.1
1760	58.2	4.9
1761	57.9	10.1
1762	58.5	7.5
1763	57.4	7
1764	58.2	6.7
1765	58.2	6.6
1766	57.3	17.3
1767	58	11.4
1768	57.5	47.4
1769	57.4	28.8
1770	58.8	24.3
1771	57.7	25.5
1772	58.4	35.5
1773	58.4	29.3
1774	59	33.8
1775	59	18.7
1776	58.8	9.8
1777	58.8	23.9
1778	59.1	48.2
1779	59.4	37.2
1780	59.6	29.1
1781	50	25
1782	40	20
1783	30	15
1784	20	10
1785	10	5
1786	0	0
1787	0	0
1788	0	0
1789	0	0
1790	0	0
1791	0	0
1792	0	0
1793	0	0
1794	0	0
1795	0	0
1796	0	0
1797	0	0
1798	0	0
1799	0	0
1800	0	0

"m" = motoring

A graphical display of the ETC dynamometer schedule is shown in Figure 23.

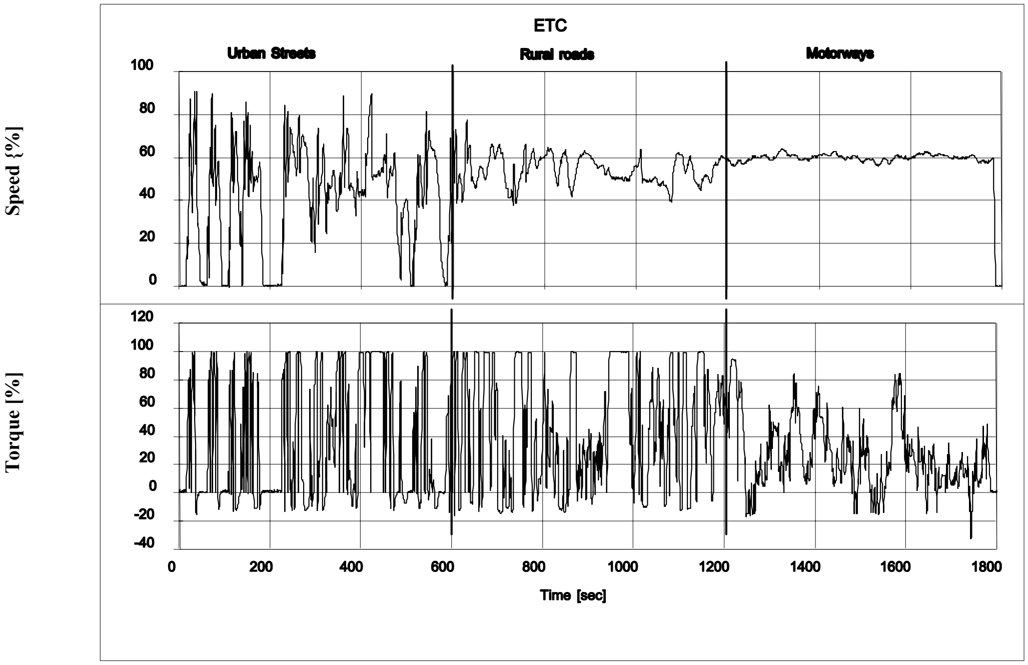

Figure 23: ETC Schedule