

**PARTICLE MEASUREMENT PROGRAMME (PMP)**

**DISCUSSION DOCUMENT: DRAFT AMENDMENTS TO REGULATION NO. 83**

**Prepared by AEA Technology on behalf of the UK Department for Transport for presentation at the special informal meeting of the GRPE held in Geneva on 15 September 2003.**

***Description of this document***

- The starting point is Annex 4 taken from the latest version of the complete version (Reg. 83 – Rev.2) on the UNECE web site. (It therefore does not include, for example, any amendments dealing with periodically regenerating systems.)
- This document comprises only those sections containing proposed amendments.
- These sections are contained within the following parts of Reg. 83: Annex 4 and Appendices 5,6 & 8 of Annex 4. (Ultimately some minor changes would also have to be made in the introductory text to the regulation – notably sections 2 (definitions) and 5.3.1 (Type 1 test description)).
- The existing document architecture is retained as much as possible.
- Amendments will also have to be made to some figures once the measurement system(s) have been finalised. These figures are indicated by notes in *italics*.
- Additions are underlined. Deletions are crossed through.

***Basis of proposed amendments***

- Two new measurement systems, based on the recommendations of the LD vehicle work in the PMP, are introduced.
- One of these is an enhanced filter-based mass measurement system based on the principles underlying the US EPA 2007 HD approach. This would take the place of the existing PM measurement system.
- The other is a new number-based measurement system.
- It is assumed that the two new measurement systems would be applied independent of vehicle technology.
- This requires a change to the parts of the existing text that treat CI-engined vehicles as a special case for HC and particulates. The special case for HC only is retained and new special cases are introduced for PM and particle number .
- There may also be a case for specifying a vehicle conditioning procedure that is independent of vehicle technology.

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Annex 4

TYPE I TEST

(Verifying exhaust emissions after a cold start)

1. INTRODUCTION

*Sections 1, 2 and 3 remain unchanged*

4. TEST EQUIPMENT

4.1. Chassis dynamometer

*Section 4.1 remains unchanged*

4.2. Exhaust gas-sampling system

4.2.1. The exhaust gas sampling system shall be able to measure the actual quantities of pollutants emitted in the exhaust gases to be measured. The system that shall be used is the constant volume sampler (CVS) system. This requires that the vehicle exhaust be continuously diluted with ambient air under controlled conditions. In the constant volume sampler concept of measuring mass emissions, two conditions shall be satisfied, the total volume of the mixture of exhaust and dilution air shall be measured and a continuously proportional sample of the volume shall be collected for analysis. The quantities of pollutants are determined from the sample concentrations, corrected for the pollutant content of the ambient air and the totalised flow over the test period.

The particulate mass pollutant emission level is determined by using a suitable filter to collect the particulates from a proportional part flow throughout the test and determining the quantity thereof gravimetrically in accordance with paragraph 4.3.1.1.

The particle number pollutant emission level is determined by using a system that measures the number concentration of non-volatile particles from a proportional part flow throughout the test.

*Sections 4.2.2 to 4.2.10 remain unchanged*

4.3. Analytical equipment

4.3.1. Provisions

4.3.1.1. Pollutant gases shall be analysed with the following instruments:

Carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>) analysis:  
Analysers shall be of the non-dispersive infra-red (NDIR) absorption type.

Hydrocarbons (HC) analysis - spark-ignition engines:  
The analyser shall be of the flame ionisation (FID) type calibrated with propane gas expressed equivalent to carbon atoms (C<sub>1</sub>).

Hydrocarbons (HC) analysis - compression-ignition engines:  
The analyser shall be of the flame ionisation type with detector, valves, pipework, etc., heated to 463 K (190 °C) ± 10 K (HFID). It shall be calibrated with propane gas expressed equivalent to carbon atoms (C<sub>1</sub>).

Nitrogen oxide (NO<sub>x</sub>) analysis:  
The analyser shall be either of the chemi-luminescent (CLA) or of the non-dispersive ultra-violet resonance absorption (NDUVR) type, both with an NO<sub>x</sub>-NO converter.

Particulates - Gravimetric determination of the particulates collected:  
These particulates shall in each case be collected by ~~two series mounted filters~~ a filter in the sample gas flow. The quantity of particulates collected ~~by each pair of filters~~ on the filter shall be as follows:

$$M = \frac{V_{\text{mix}}}{V_{\text{ep}} \cdot d} m = M \cdot d \frac{V_{\text{ep}}}{V_{\text{mix}}}$$

where:

- V<sub>ep</sub> : flow through filters;
- V<sub>mix</sub> : flow through tunnel;
- M : particulate mass (g/km);
- M<sub>limit</sub> : limit mass of particulates (limit mass in force, g/km);
- m : mass of particulates collected by filters (g);
- d : distance corresponding to the operating cycle (km).

The particulates sample rate (V<sub>ep</sub>/V<sub>mix</sub>) shall be adjusted so that for M = M<sub>limit</sub>, 1 ≤ m ≤ 5 mg ~~(when on 47 mm diameter filters are used)~~.  
*(Note: this sample rate condition will need to be adjusted once other key parameters have been defined)*

The filter surface shall consist of a material that is hydrophobic and inert towards the components of the exhaust gas (fluorocarbon coated glass fibre filters or equivalent).

4.3.1.2. Accuracy

The analysers shall have a measuring range compatible with the accuracy required to measure the concentrations of the exhaust gas sample pollutants. Measurement error shall not exceed  $\pm 2$  per cent (intrinsic error of analyser) disregarding the true value for the calibration gases. For concentrations of less than 100 ppm the measurement error shall not exceed  $\pm 2$  ppm.

The ambient air sample shall be measured on the same analyser with an appropriate range.

The microgram balance used to determine the weight of all filters shall have ~~accuracy of 5  $\mu$ g~~ a precision (standard deviation) of better than 0.25  $\mu$ g and readability of 0.1  $\mu$ g.

The particle concentration measuring instrument shall have a readability of 0.01 particle/cm<sup>3</sup> and a linear response to concentration over the range 1 to 10<sup>4</sup> particles/cm<sup>3</sup> ( $R^2 > 0.85$ ).

4.3.1.3. Ice-trap

No gas drying device shall be used before the analysers unless shown to have no effect on the pollutant content of the gas stream.

4.3.2. Particular requirements for compression-ignition engines

A heated sample line for a continuous HC-analysis with the flame ionisation detector (HFID), including recorder (R) shall be used. The average concentration of the measured hydrocarbons shall be determined by integration. Throughout the test, the temperature of the heated sample line shall be controlled at 463 K (190 °C)  $\pm 10$  K. The heated sampling line shall be fitted with a heated filter ( $F_H$ ) 99 per cent efficient with particles  $\geq 0.3 \mu\text{m}$ , to extract any solid particles from the continuous flow of gas required for analysis.

The sampling system response time (from the probe to the analyser inlet) shall be no more than four seconds.

The HFID shall be used with a constant flow (heat exchanger) system to ensure a representative sample, unless compensation for varying CFV or CFO flow is made.

4.3.3. Particular requirements for sampling for particulate mass measurement

4.3.3.1. The particulate sampling unit shall consist of a dilution tunnel, a sampling probe, a cyclone pre-classifier, a filter unit, a partial-flow pump, and flow rate regulators and measuring units. The

particulate-sampling part flow is drawn through ~~two series mounted filters~~ a filter. The sampling probe for the test gas flow for particulates shall be so arranged within the dilution tract that a representative sample gas flow can be taken from the homogeneous air/exhaust mixture and an. ~~An air/exhaust gas mixture temperature of 325 K (52°C) is not exceeded~~ 320 ± 5 K (47 ± 5 °C) shall be maintained, with a residence time of at least 1 s, immediately before the particulate filter. The temperature of the gas flow in the flow meter may not fluctuate by more than ± 3 K, nor may the mass flow rate fluctuate by more than ± 5 per cent. Should the volume of flow change unacceptably as a result of excessive filter loading, the test shall be stopped. When it is repeated, the rate of flow shall be decreased ~~and/or a larger filter used~~. The filters shall be removed from the chamber no earlier than an hour before the test begins.

4.3.3.2. 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, must be designed to minimise deposition or alteration of the particulates. All parts must be made of electrically conductive materials that do not react with exhaust gas components, and must be electrically grounded to prevent electrostatic effects.

4.3.3.3. The weighing chamber (or room) shall meet the following conditions during all filter conditioning and weighing operations:

Temperature maintained at 295 ± 3 K (22 ± 3°C)  
Relative humidity maintained at 45 ± 8%.

4.3.3.4. The necessary particle filters shall be conditioned (as regards temperature and humidity) in an open dish which has been protected against dust ingress for at least 8 and for not more than 56 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.

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

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

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.

4.3.4. ~~4.3.3.~~ Particular requirement for sampling for particle number measurement

4.3.4.1. The particle sampling system shall consist of a dilution tunnel, a sampling probe, a cyclone pre-classifier and a sample pre-conditioning unit upstream

of the particle concentration measurement system. 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.

4.3.4.2. 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, must be designed to minimise deposition or alteration of the particles. All parts must be made of electrically conductive materials that do not react with exhaust gas components, and must be electrically grounded to prevent electrostatic effects.

4.3.4.3. The dilution air used for the primary dilution of the exhaust in the CVS tunnel and any subsequent dilution stages shall be HEPA filtered.

4.3.5. Calibration

Each analyser shall be calibrated as often as necessary and in any case in the month before type approval testing and at least once every six months for verifying conformity of production.

The calibration method to be used is described in appendix 6 to this annex for the analysers referred to in paragraph 4.3.1. above.

4.4. Volume measurement

*Sections 4.4 to 4.7 remain unchanged*

5. PREPARING THE TEST

*Sections 5.1 and 5.2 remain unchanged*

5.3. Conditioning of vehicle

5.3.1. ~~For compression ignition engined vehicles for the purpose of measuring particulates, at~~ At most 36 hours and at least 6 hours before testing, the Part Two cycle described in appendix 1 to this annex shall be used for vehicle conditioning. Three consecutive cycles shall be driven. The dynamometer setting shall be indicated in paragraphs 5.1. and 5.2. above.

At the request of the manufacturer, vehicles fitted with positive-ignition engines may be preconditioned with one Part One and two Part Two driving cycles.

After this preconditioning, ~~specific for compression ignition engines,~~ and before testing, ~~compression~~

~~ignition and positive ignition engine~~ vehicles shall be kept in a room in which the temperature remains relatively constant between 293 and 303 K (20 and 30 °C). This conditioning shall be carried out for at least six hours and continue until the engine oil temperature and coolant, if any, are within  $\pm 2$  K of the temperature of the room.

- 5.3.1.1. If the manufacturer so requests, the test shall be carried out not later than 30 hours after the vehicle has been run at its normal temperature.
- 5.3.1.2. For positive-ignition engine vehicles fuelled with LPG or NG or so equipped that they can be fuelled with either petrol or LPG or NG, between the tests on the first gaseous reference fuel and the second gaseous reference fuel, the vehicle shall be preconditioned before the test on the second reference fuel. This preconditioning is done on the second reference fuel by driving a preconditioning cycle consisting of ~~one Part One (urban part) and two~~ three times Part Two (extra-urban part) of the test cycle described in appendix 1 to this annex. On the manufacturer's request and with the agreement of the technical service this preconditioning may be extended. The dynamometer setting shall be the one indicated in paragraphs 5.1. and 5.2. of this annex.
- 5.3.2. The tyre pressures shall be the same as that specified by the manufacturer and used for the preliminary road test for brake adjustment. The tyre pressure may be increased by up to 50 per cent from the manufacturer's recommended setting in the case of a two-roller dynamometer. The actual pressure used shall be recorded in the test report.

6. PROCEDURE FOR BENCH TESTS

*Sections 6 and 7 remain unchanged*

8. DETERMINATION OF THE QUANTITY OF GASEOUS AND PARTICULATE POLLUTANTS EMITTED

8.1. The volume considered

The volume to be considered shall be corrected to conform to the conditions of 101.33 kPa and 273.2 K.

8.2. Total mass of gaseous and particulate pollutants emitted

The mass M of each pollutant emitted by the vehicle during the test shall be determined by obtaining the product of the volumetric concentration and the volume of the gas in question, with due regard for the following densities under above-mentioned reference conditions:

In the case of carbon monoxide (CO):  $d = 1.25 \text{ g/l}$

In the case of hydrocarbons:  
for petrol ( $\text{CH}_{1.85}$ )  $d = 0.619 \text{ g/l}$

for diesel (CH <sub>1.86</sub> )	d = 0.619 g/l
for LPG (CH <sub>2.525</sub> )	d = 0.649 g/l
for NG (CH <sub>4</sub> )	d = 0.714 g/l

In the case of nitrogen oxides (NO<sub>x</sub>): d = 2.05 g/l

~~The mass m of particulate pollutant emissions from the vehicle during the test shall be defined by weighing the mass of particulates collected by the two filters, m<sub>1</sub> by the first filter, m<sub>2</sub> by the second filter:~~

~~if  $0.95 (m_1 + m_2) > m_{1,T}$  then  $m = m_{1,T}$~~

~~if  $0.95 (m_1 + m_2) > m_{1,T}$  then  $m = m_1 + m_{2,T}$~~

~~if  $m_2 > m_{1,T}$  then the test is cancelled.~~

Appendix 8 to this annex gives calculations, followed by examples, used to determine the mass emissions of gaseous and particulate pollutants and calculations for particle mass and particle number emissions.



Annex 4 - Appendix 5

DEFINITION OF GAS-SAMPLING SYSTEMS

1. INTRODUCTION
  - 1.1. There are several types of sampling devices capable of meeting the requirements set out in paragraph 4.2. of annex 4.  
The devices described in ~~paragraph~~ sections 3.1., 3.2. and 3.3. shall be deemed acceptable if they satisfy the main criteria relating to the variable dilution principle.
  - 1.2. In its communications, the laboratory shall mention the system of sampling used when performing the test.
2. CRITERIA RELATING TO THE VARIABLE-DILUTION SYSTEM FOR MEASURING EXHAUST-GAS EMISSIONS
  - 2.1. Scope  
  
This section shall specify the operating characteristics of an exhaust-gas sampling system intended to be used for measuring the true mass emissions of a vehicle exhaust in accordance with the provisions of this Regulation.  
  
The principle of variable-dilution sampling for measuring mass emissions shall require three conditions to be satisfied:
    - 2.1.1. The vehicle exhaust gases shall be continuously diluted with ambient air under specified conditions;
    - 2.1.2. The total volume of the mixture of exhaust gases and dilution air shall be measured accurately;
    - 2.1.3. A continuously proportional sample of the diluted exhaust gases and the dilution air shall be collected for analysis.  
  
Mass gaseous emissions shall be determined from the proportional sample concentrations and the total volume measured during the test. The sample concentrations shall be corrected to take account of the pollutant content of the ambient air.  
  
~~In addition, where vehicles are equipped with compression ignition engines, their particulate~~ Particulate mass emissions and particle number emissions shall be plotted determined from the proportional sample concentrations and the total volume measured during the test.
  - 2.2. Technical summary  
  
Figure 5/1 gives a schematic diagram of the sampling system.
    - 2.2.1. The vehicle exhaust gases shall be diluted with a sufficient amount of ambient air to prevent any water condensation in the sampling and measuring system.

- 2.2.2. The exhaust-gas sampling system shall be so designed as to make it possible to measure the average volume concentrations of the CO<sub>2</sub>, CO, HC and NO<sub>x</sub>, and, ~~in addition, in the case of vehicles equipped with compression-ignition engines,~~ of the particulate mass and particle number emissions, contained in the exhaust gases emitted during the vehicle testing cycle.

*Sections 2.2.3 to 2.2.9 and section 2.3 remain unchanged*

- 2.4. Additional sampling unit for the testing of vehicles equipped with a compression-ignition engine
- 2.4.1. Unlike the taking of gas samples from vehicles equipped with spark-ignition engines, the hydrocarbon ~~and particulate sampling points are~~ point is located in a dilution tunnel.
- 2.4.2. In order to reduce heat losses in the exhaust gases between the exhaust outlet and the dilution tunnel inlet, the pipe may not be more than 3.6 m long, or 6.1 m long if heat insulated. Its internal diameter may not exceed 105 mm.
- 2.4.3. Predominantly turbulent flow conditions (Reynolds number  $\geq 4000$ ) shall apply in the dilution tunnel, which shall consist of a straight tube of electrically-conductive material, in order to guarantee that the diluted exhaust gas is homogeneous at the sampling points and that the samples consist of representative gases and particulates. The dilution tunnel shall be at least 200 mm in diameter and the system shall be earthed.
- ~~2.4.4. The particulate sampling system shall consist of a sampling probe in the dilution tunnel and two series-mounted filters. Quick-acting valves shall be located both up and downstream of the two filters in the direction of flow.~~
- ~~The configuration of the sample probe shall be as indicated in Figure 5/2.~~
- ~~2.4.5. The particulate sampling probe shall meet the following conditions:~~
- ~~It shall be installed near the tunnel centreline, roughly ten tunnel diameters downstream of the gas inlet, and have an internal diameter of at least 12 mm.~~
- ~~The distance from the sampling tip to the filter mount shall be at least five probe diameters, but shall not exceed 1,020 mm.~~
- 2.4.4. The sample gas flow measuring unit shall consist of pumps, gas flow regulators and flow measuring units.
- 2.4.5. The hydrocarbon sampling system shall consist of a heated sampling probe, line, filter and pump. The sampling probe shall be installed at the same distance from the exhaust gas inlet as the particulate mass and particle number ~~sampling probe, probes~~ in such a way that ~~neither interferes with~~ there is no mutual interference of the

samples taken by ~~the other~~ any of these probes. It shall have a minimum internal diameter of 4 mm.

- 2.4.6. All heated parts shall be maintained at a temperature of 463 K (190 °C)  $\pm$  10 K by the heating system.
- 2.4.7. If it is not possible to compensate for variations in the flow rate provision shall be made for a heat exchanger and a temperature control device as specified in paragraph 2.3.3.1. so as to ensure that the flow rate in the system is constant and the sampling rate accordingly proportional.
- 2.5. Additional sampling system for the measurement of particulate mass
- 2.5.1. The particulate mass sampling point shall be located in the dilution tunnel as described in paragraph 2.4.5. above.
- 2.5.2. The particulate sampling system shall consist of a sampling probe in the dilution tunnel, a cyclone pre-classifier and a filter housed in a cassette within a filter holder. Quick-acting valves shall be located both up and downstream of the filter in the direction of flow.
- 2.5.3. The configuration of the sample probe shall be as indicated in Figure 5/2. (THIS FIGURE WILL NEED MODIFICATION)
- 2.5.4. The particulate sampling probe shall meet the following conditions:
- It shall be installed near the tunnel centreline, roughly ten tunnel diameters downstream of the gas inlet and have an internal diameter of at least 12 mm.
- The distance from the sampling tip to the filter shall be at least five probe diameters, but shall not exceed 1,020 mm.
- 2.5.5. The cyclone 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  $\mu$ m and 10  $\mu$ m 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  $\mu$ m 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.
- 2.5.6. The filters used shall be of the fluorocarbon-coated glass fibre or fluorocarbon-based membrane type, shall have a diameter of 47 mm and shall have a 0.3  $\mu$ m DOP collection efficiency of at least 95% at a gas face velocity of between 35 and 100 cm/s.
- 2.5.7. The filter holder assembly shall be of a design that provides an even flow distribution across the filter stain area. The filter stain area shall be 1075 mm<sup>2</sup>.

- 2.6. Additional sampling system for the measurement of particle number
- 2.6.1. The particle sampling system shall consist of a sampling probe in the dilution tunnel, a cyclone pre-classifier and a sample pre-conditioning unit upstream of the particle concentration measurement unit. 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.
- 2.6.2. The particulate sampling probe shall meet the following conditions.
- It shall be installed near the tunnel centreline, roughly ten 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 distance from the sampling tip to the point at which the probe leaves the dilution tunnel shall be less than 200 mm.
- The distance from the sampling tip to the entrance to the sample pre-conditioning unit shall not exceed 1,000 mm.
- The distance from the sampling tip to the entrance to the particle counting instrument shall not exceed 2,500 mm.
- 2.6.3. The cyclone 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  $\mu\text{m}$  and 10  $\mu\text{m}$  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  $\mu\text{m}$  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.
- 2.6.4. The sample pre-conditioning unit shall be capable of diluting the sample drawn from the primary dilution tunnel by a dilution ratio range from 0 to 1000. This dilution function is to allow the number concentration of the sample entering the particle concentration measurement unit to less than 10,000 particles  $\text{cm}^{-3}$  and to suppress hydrocarbon nucleation within the sample.
- 2.6.5. The sample pre-conditioning unit shall operate under conditions that achieve greater than 90% reduction in volatile particles as described in section 5.4.2. of Appendix 6 and greater than 90% solid particle penetration as defined in section 5.3.2. of Appendix 6.
- 2.6.6. The particle concentration measurement unit shall meet the following conditions.
- It shall have a counting accuracy of  $\pm 10\%$  against a traceable standard.

It shall have a readability of 0.01 particles cm<sup>-3</sup>.

It shall have a linear response to particle concentration over 1 to 10,000 particles cm<sup>-3</sup> as defined in section 5.1.2. of Appendix 6.

It shall have a data logging frequency of equal to or less than 2 s.

It shall have a response time of between 5 and 10 s.

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

2.6.7. The particle sampling system shall incorporate good aerosol sampling practice which 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.

2.6.8. The dilution air used in the primary dilution and in all other dilution stages in the sampling system shall be HEPA filtered (as defined in BS EN 1822).

### 3. DESCRIPTION OF THE DEVICES

*Sections 3.1.1 to 3.1.3 remain unchanged*

3.1.4. Additional equipment required when testing compression-ignition-engined vehicles

To comply with the requirements of paragraphs 4.3.1.1. and 4.3.2. of annex 4, the additional components within the dotted lines in Figure 5/3 (THIS FIGURE WILL NEED MODIFICATION) shall be used when testing compression-ignition-engined vehicles:

F<sub>h</sub> is a heated filter,

S<sub>3</sub> is a sampling point close to the mixing chamber,

V<sub>h</sub> is a heated multi-way valve,

Q is a quick connector to allow the ambient air sample BA to be analysed on the HFID,

HFID is a heated flame ionisation analyser,

R and I are a means of integrating and recording the instantaneous hydrocarbon concentrations,

L<sub>h</sub> is a heated sample line.

All heated components shall be maintained at 463 K (190 °C) ± 10 K.

~~Particulate Sampling System~~ 3.1.5. Additional equipment required for measuring particulate mass emissions

To comply with the requirements of section 4.3.3. of annex 4, additional components within the dotted lines in Figure 5/3 shall be used when testing for particulate mass emissions:

~~S<sub>4</sub> Sampling~~ sampling probe in the dilution tunnel

~~Sampling line,~~ cyclone pre-classifier

filter unit

~~Pumps,~~ sampling line, pumps, switching units, flow regulators, flow meters, temperature sensors, pressure sensors.

(FIGS 5/3 & 5/4 WILL NEED TO BE MODIFIED TO TAKE ACCOUNT OF CHANGES TO PRE-CLASSIFIER AND FILTER UNIT)

3.1.6. Additional equipment required for measuring ~~units~~ particle number emissions

To comply with the requirements of section 4.3.4. of annex 4, additional components within the dotted lines in Figure 5/3 shall be used when testing for particulate mass emissions:

sampling probe in the dilution tunnel

cyclone pre-classifier

sample preconditioning unit

particle concentration measurement unit

sampling line, pumps, switching units, flow regulators, flow meters, temperature sensors, pressure sensors.

(FIGS 5/3 & 5/4 WILL NEED TO BE MODIFIED TO TAKE ACCOUNT OF THE NEW PARTICLE NUMBER MEASUREMENT SYSTEM)

3.2.4. Additional equipment required when testing compression-ignition-engined vehicles

To comply with the requirements of paragraphs 4.3.1.1. and 4.3.2. of annex 4, the additional components shown within the dotted lines of Figure 5/4 shall be used when testing compression-ignition-engined vehicles.

F<sub>h</sub> is a heated filter,

S<sub>3</sub> is a sample point close to the mixing chamber,

V<sub>h</sub> is a heated multi-way valve,

Q is a quick connector to allow the ambient air sample BA to be analysed on the HFID,

HFID is a heated flame ionisation analyser,

R and I are a means of integrating and recording the instantaneous hydrocarbon concentrations,

L<sub>h</sub> is a heated sample line.

All heated components shall be maintained at 463 K (190 °C) ± 10 K.

If compensation for varying flow is not possible, then a heat exchanger (H) and temperature control system (T<sub>c</sub>) as described in paragraph 3.1.3. of this appendix will be required to ensure constant flow through the venturi (M<sub>v</sub>) and thus proportional flow through S<sub>3</sub> particulate sampling system.

~~S<sub>4</sub> — Sampling probe in dilution tunnel,~~

~~F<sub>p</sub> — Filter unit, consisting of two series-mounted filters; switching unit for further parallel-mounted pairs of filters,~~

3.2.5. Sampling line, Additional equipment required for measuring particulate mass emissions

To comply with the requirements of section 4.3.3. of annex 4, additional components within the dotted lines in Figure 5/3 shall be used when testing for particulate mass emissions:

sampling probe in the dilution tunnel

cyclone pre-classifier

filter unit

Pumps, sampling line, pumps, switching units, flow regulators, flow meters, temperature sensors, pressure sensors.

Annex 4 - Appendix 6

METHOD OF CALIBRATING THE EQUIPMENT

1. ESTABLISHMENT OF THE CALIBRATION CURVE
  - 1.1. Each normally used operating range is calibrated in accordance with the requirements of paragraph ~~4.3.3.~~ 4.3.5. of annex 4 by the following procedure:
    - 1.2. The analyser calibration curve is established by at least five calibration points spaced as uniformly as possible. The nominal concentration of the calibration gas of the highest concentration shall be not less than 80 per cent of the full scale.
    - 1.3. The calibration curve is calculated by the least squares method. If the resulting polynomial degree is greater than 3, the number of calibration points shall be at least equal to this polynomial degree plus 2.
    - 1.4. The calibration curve shall not differ by more than  $\pm 2$  per cent from the nominal value of each calibration gas.
    - 1.5. Trace of the calibration curve

From the trace of 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 scale,
      - the sensitivity,
      - the zero point,
      - the date of carrying out the calibration.
    - 1.6. If it can be shown to the satisfaction of the technical service that alternative technology (e.g. computer, electronically controlled range switch, etc.) can give equivalent accuracy, then these alternatives may be used.
    - 1.7. Verification of the calibration
      - 1.7.1. Each normally used operating range shall be checked prior to each analysis in accordance with the following:
        - 1.7.2. The calibration shall be checked by using a zero gas and a span gas whose nominal value is within 80-95 per cent of the supposed value to be analysed.
        - 1.7.3. If, for the two points considered, the value found does not differ by more than  $\pm 5$  per cent of the full scale from the theoretical value, the adjustment parameters may be modified. Should this not be the case, a new calibration curve shall be established in accordance with ~~paragraph 1~~ paragraphs 1.1 to 1.4. of this appendix.
        - 1.7.4. After testing, zero gas and the same span gas are used for re-checking. The analysis is considered acceptable if the difference between the two measuring results is less than 2 per cent.



2. CHECKING FOR FID HYDROCARBON RESPONSE

*This section and sections 3 and 4 remain unchanged*

5. CALIBRATION OF PARTICLE NUMBER MEASUREMENT SYSTEM

5.1. Calibration of particle counter

5.1.1. The particle counter shall be calibrated according to the manufacturer's specification at least every 12 months.

5.1.2. Calibration shall be traceable to primary standards either by:

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 both cases, calibration shall be undertaken at least five concentrations spaced as uniformly as possible across the counter's measurement range. Measured concentrations shall be within  $\pm 10\%$  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.

5.2. Calibration of the diluter

5.2.1. The diluter shall be calibrated with a traceable standard gas mixture at least every 6 months.

5.2.2. 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  $\pm 10\%$  of nominal dilution ratio settings.

5.3. Calibration of volatile particle remover

5.3.1. The penetration efficiency of solid particles through the apparatus shall be established at least every 6 months.

5.3.2. The test aerosol for these measurements shall be solid particles of diameters 20, 50 and 100 nm and a minimum concentration of 1,000 particles  $\text{cm}^{-3}$ . 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.

5.4. Verification of the calibration

5.4.1. Linearity of the particle counter response shall be validated daily. The test aerosol for this validation shall be liquid droplets generated from a pneumatic medical nebuliser at a concentration greater than 10,000 particles cm<sup>-3</sup>. The droplets shall consist of a material with a minimum saturation vapour pressure of 0.01 mm Hg, and that exists in the liquid phase, at room temperature. The validation shall be undertaken at least five concentrations spaced as uniformly as possible across the counter's measurement range by diluting the output from the nebuliser using a calibrated aerosol diluter operating at room temperature. 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<sup>2</sup>) of the two data sets shall be equal to or greater than 0.95.

5.4.2. The following functionality checks shall be undertaken before each emission test.

The particle counter shall report a measured concentration of less than 1 particle cm<sup>-3</sup> when a HEPA filter is attached to the sample inlet of the counter. The particle counter shall report a measured concentration in excess of 10,000 particles cm<sup>-3</sup> when challenged with an undiluted sample of the test aerosol used in the daily particle counter linearity validation.

The sampling system, consisting of the diluter, volatile particle remover and particle counter, shall report a measured concentration of less than 1 particle cm<sup>-3</sup> when a HEPA filter is attached to the inlet of the diluter. The sampling system shall also remove at least 90% of the upstream particle concentration when challenged with a sample of a test aerosol used in the daily particle counter linearity validation.

6. CALIBRATION OF FILTER WEIGHING SYSTEM

6.1. The microbalance shall be calibrated according to the manufacturer's specification at least every 12 months.

6.2. At least two unused reference filters or reference filter pairs must be weighed within 4 hours of, but preferably at the same time as the sample filter weighings. They must be the same size and material as the sample filters. If the average weight of the reference filters changes between sample filter weighings by more than ± 5 per cent of the recommended minimum filter loading (paragraph 4.3.1.1. of annex 4), then the sample filter must be discarded and the emissions test repeated.

Annex 4 - Appendix 8

CALCULATION OF THE MASS AND NUMBER EMISSIONS OF POLLUTANTS

1. GENERAL PROVISIONS

*This section remains unchanged*

2. SPECIAL PROVISIONS FOR VEHICLES EQUIPPED WITH COMPRESSION-IGNITION ENGINES

~~2.1.~~ To calculate HC-mass emission for compression-ignition engines, the average HC concentration is calculated as follows:

$$C_e = \frac{\int_{t_1}^{t_2} C_{HC} \cdot dt}{t_2 - t_1} \quad (7)$$

where:

$\int_{t_1}^{t_2} C_{HC} \cdot dt$  = integral of the recording of the heated FID over the test ( $t_2 - t_1$ )

$C_e$  = concentration of HC measured in the diluted exhaust in ppm of  $C_i$  is substituted for  $C_{HC}$  in all relevant equations.

~~2.2.~~3. DETERMINATION OF PARTICULATES

Particulate emission  $M_p$  (g/km) is calculated by means of the following equation:

$$M_p = \frac{(V_{mix} + V_{ep}) \cdot P_e}{V_{ep} \cdot d}$$

where exhaust gases are vented outside tunnel;

$$M_p = \frac{V_{mix} \cdot P_e}{V_{ep} \cdot d}$$

where exhaust gases are returned to the tunnel.

where:

$V_{mix}$  = Volume of diluted exhaust gases (see para. 1.1.), under standard conditions,

$V_{ep}$  = Volume of exhaust gas flowing through particulate filter under standard conditions,

$P_e$  = Particulate mass collected by filters,

$d$  = Distance corresponding to the operating cycle in km,

$M_p$  = Particulate emission in g/km.

4. CALCULATION OF PARTICLE NUMBER EMISSIONS

Number emission of particles shall be calculated by means of the following equation:

$$N = \frac{V \cdot \bar{C} \cdot D \cdot 10^3}{d}$$

where:

$N$  = particle number emission expressed in particles per kilometre

$V$  = volume of the diluted exhaust gas expressed in litres per test and corrected to standard conditions (273.2 K and 101.33 kPa)

$\bar{C}$  = average concentration of particles in the diluted exhaust gas expressed in particles per cubic centimetre

$D$  = dilution ratio of the diluter in the pre-conditioning system

$d$  = distance corresponding to the operating cycle expressed in kilometres.

$\bar{C}$  shall be calculated from the following equation:

$$\bar{C} = \frac{\sum_{i=1}^{i=n} C_i}{n}$$

where:

$C_i$  = a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter expressed in particles per cubic centimetre

$n$  = total number of discrete particle concentration measurements made during the operating cycle.

$n$  shall be calculated from the following equation:

$$n = T \cdot f$$

where:

$T$  = time duration of the operating cycle expressed in seconds

$f$  = data logging frequency of the particle counter.