Transmitted by the expert from
the United Kingdom

Informal document No. **GRPE-59-03**
(59th GRPE, 11-15 January 2010,
Agenda item 3)

**Insertion into Regulation No. 49 of the particle number measurement procedure**

Proposal for Supplement ? to the 05 series of amendments to Regulation No. 49
(Emissions of compression ignition and gas fuelled positive ignition engines for use in vehicles)

## A. PROPOSAL

The list of Contents, insert:

"......

Annex 4C - Particle Number Measurement Test Procedure

Appendix 1 - Particle Number Emissions Measurement Equipment
......"

Insert a new Annex 4C, to read:

"Annex 4C

PARTICLE NUMBER MEASUREMENT TEST PROCEDURE

1. APPLICABILITY

This annex is not applicable for the purpose of type approval according to this Regulation for the time being. It will be made applicable in the future.

2. INTRODUCTION

2.1 This annex describes the method of determining particle number emissions of engines being tested according to the test procedures defined in Annex 4B. Unless otherwise stated, all test conditions, procedures and requirements are as stated in Annex 4B.

3. SAMPLING

3.1 Particle number emissions shall be measured by continuous sampling from either a partial flow dilution system, as described in Annex 4B, Appendix 3, section A.3.2.1 and A.3.2.2 or a full flow dilution system as described in Annex 4B, Appendix 3, section A.3.2.3 and A.3.2.4.

3.2 Diluent Filtration

Diluent used for both the primary and, where applicable, secondary dilution of the exhaust in the dilution system shall be passed through filters meeting the high-efficiency particulate air (HEPA) filter requirements defined in the Diluent Filter (DAF) subsections of Annex 4B, Appendix 3, sections A.3.2.2 or A.3.2.4. The diluent may optionally be charcoal scrubbed before being passed to the HEPA filter to reduce and stabilize the hydrocarbon concentrations in the diluent. It is recommended that an additional coarse particle filter is situated before the HEPA filter and after the charcoal scrubber, if used.

4. OPERATION OF THE SAMPLING SYSTEM

4.1 Compensating For Particle Number Sample Flow - Full Flow Dilution Systems

4.1.1 To compensate for the mass flow extracted from the dilution system for particle number sampling the extracted mass flow (filtered) shall be returned to the dilution system. Alternatively the total mass flow in the dilution system may be mathematically corrected for the particle number sample flow extracted.

4.2 Compensating For Particle Number Sample Flow - Partial Flow Dilution Systems

4.2.1 For partial flow dilution systems the mass flow extracted from the dilution system for particle number sampling must be accounted for in controlling the proportionality of sampling. This shall be achieved either by feeding the particle number sample flow back into the dilution system upstream of the flow measuring device or by mathematical correction as outlined in paragraph 4.2.2. In the case of total sampling type partial flow dilution systems, the mass flow extracted for particle number sampling must also be corrected for in the particulate mass calculation as outlined in paragraph 4.2.3. Where the total mass flow extracted from the dilution system for particle number sampling is less than 0.1% of the total diluted exhaust gas flow in the dilution tunnel ($q_{mdew}$) these corrections may be neglected.

4.2.2 The instantaneous exhaust gas flow rate into the dilution system ($q_{mp}$), used for controlling the proportionality of sampling, shall be corrected according to one of the following methods;

(a) In the case where the extracted particle number sample flow is discarded, equation (83) in Annex 4B, paragraph 9.4.6.2 shall be replaced by the following:

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

Where:

$q_{mp}$ = sample flow of exhaust gas into partial flow dilution system, kg/s
$q_{mdew}$ = diluted exhaust mass flow rate, kg/s
$q_{mdw}$ = dilution air mass flow rate, kg/s
$q_{ex}$ = particle number sample mass flow rate, kg/s

The $q_{ex}$ signal sent to the partial flow system controller shall be accurate to within 0.1% of $q_{mdew}$ at all times and should be sent with frequency of at least 1 Hz.

(b) In the case where the extracted particle number sample flow is discarded, but an equivalent flow is fed back to the dilution system upstream of the flow measurement device, equation (83) in Annex 4B, paragraph 9.4.6.2. shall be replaced by the following:

$$q_{mp} = q_{mdew} - q_{mdw} - q_{ex} + q_{sw}$$

where:

$q_{mp}$ = sample flow of exhaust gas into partial flow dilution system, kg/s
$q_{mdew}$ = diluted exhaust mass flow rate, kg/s
$q_{mdw}$ = dilution air mass flow rate, kg/s
$q_{ex}$ = particle number sample mass flow rate, kg/s
$q_{sw}$ = mass flow rate fed back into dilution tunnel to compensate for particle number sample extraction, kg/s

The difference between $q_{ex}$ and $q_{sw}$ sent to the partial flow system controller shall be accurate to within 0.1% of $q_{mdew}$ at all times. The signal (or signals) should be sent with frequency of at least 1 Hz

4.2.3 Correction of PM measurement

When a particle number sample flow is extracted from a total sampling partial flow dilution system, the mass of particulates ($m_{PM}$) calculated in Annex 4B, paragraph 8.4.3.2.1. or 8.4.3.2.2 must be corrected as follows to account for the flow extracted. This correction is required even where filtered extracted flow is fed back into the partial flow dilution systems.

$$m_{PM,corr} = m_{PM} \times \frac{m_{sed}}{(m_{sed} - m_{ex})}$$

where:

$m_{PM,corr}$ = mass of particulates corrected for extraction of particle number sample flow, g/test,
$m_{PM}$ = mass of particulates determined according to Annex 4B paragraph 8.4.3.2.1. or 8.4.3.2.2., g/test,
$m_{sed}$ = total mass of diluted exhaust gas passing through the dilution tunnel, kg,
$m_{ex}$ = total mass of diluted exhaust gas extracted from the dilution tunnel for particle number sampling, kg,

4.3 Proportionality of partial flow dilution sampling.

4.3.1 For particle number measurement, exhaust mass flow rate, determined according to any of the methods described in Annex 4B sections 8.4.1.3 to 8.4.1.7, is used for controlling the partial flow dilution system to take a sample proportional to the exhaust mass flow rate. The quality of proportionality shall be checked by applying a regression analysis between sample and exhaust flow in accordance with Annex 4B paragraph 9.4.6.1.

5. DETERMINATION OF PARTICLE NUMBERS

5.1 Time Alignment

For partial flow dilution systems residence time in the particle number sampling and measurement system shall be accounted for by time aligning the particle number signal with the test cycle and the exhaust gas mass flow rate according to the procedures defined in Annex 4B paragraphs 3.1.30 and 8.4.2.2. The transformation time of the particle number sampling and measurement system shall be determined according to paragraph 1.3.6 of Appendix 1 to this Annex.

5.2 Determination of particle numbers with a partial flow dilution system

5.2.1 Where particle numbers are sampled using a partial flow dilution system according to the procedures set out in Annex 4B, section 8.4, the number of particles emitted over the test cycle shall be calculated by means of the following equation:

$$N = \frac{m_{edf}}{1.293}.k.\overline{c_s}.\overline{f_r}.10^6$$

where:

N = number of particles emitted over the test cycle,

$m_{edf}$ = mass of equivalent diluted exhaust gas over the cycle, determined according to Annex 4B paragraphs 8.4.3.2.2, kg/test,

k = calibration factor to correct the particle number counter measurements to the level of the reference instrument where this is not applied internally within the particle number counter. Where the calibration factor is applied internally within the particle number counter a value of 1 shall be used for k in the above equation,

$\bar{c}_s$ = average concentration of particles from the diluted exhaust gas corrected to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,

$\overline{f_r}$ = mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test,

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

$$\bar{c}_s = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n}$$

where:

$c_{s,i}$ = a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for coincidence and to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,

n = number of particle concentration measurements taken over the duration of the test.

5.3. Determination of particle numbers with a full flow dilution system

5.3.1 Where particle numbers are sampled using a full flow dilution system according to the procedures set out in Annex 4B, section 8.5, the number of particles emitted over the test cycle shall be calculated by means of the following equation:

$$N = \frac{m_{ed}}{1.293}.k.\bar{c}_s.\overline{f_r}.10^6$$

where:

N = number of particles emitted over the test cycle,

$m_{ed}$= total diluted exhaust gas flow over the cycle calculated according to any one of the methods described in Annex 4B, paragraphs 8.5.1.2 to 8.5.1.4, kg/test,

k = calibration factor to correct the particle number counter measurements to the level of the reference instrument where this is not applied internally within the particle number counter. Where the calibration factor is applied internally within the particle number counter a value of 1 shall be used for k in the above equation,

$\bar{c}_s$ = average corrected concentration of particles from the diluted exhaust gas corrected to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,

$\overline{f_r}$ = mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test,

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

$$\bar{c} = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n}$$

where:

$c_{s,i}$ = a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for coincidence and to standard conditions (273.2 K and 101.33 kPa), particles per cubic centimetre,

n = number of particle concentration measurements taken over the duration of the test.

5.4 Test result

5.4.1 For each individual WHSC, hot WHTC and cold WHTC the specific emissions in number of particles/kWh shall be calculated as follows:

$$e = \frac{N}{W_{act}}$$

Where:

e is the number of particles emitted per kWh

$W_{act}$ is the actual cycle work according to Annex 4B, paragraph 7.8.6, in kWh.

5.4.2 Exhaust after-treatment systems with periodic regeneration

For engines equipped with periodically regenerating aftertreatment systems the WHTC hot start emissions shall be weighted as follows:

$$e_{\mathrm{w}} = \frac{\mathrm{n} \times \bar{e} + \mathrm{n_r} \times \overline{e_{\mathrm{r}}}}{\mathrm{n} + \mathrm{n_r}}$$

where:

$e_w$ is the weighted average hot start WHTC specific emission, number of particles/kWh

n is the number of WHTC hot start tests without regeneration

$n_r$ is the number of WHTC hot start tests with regeneration (minimum one test)

$\bar{e}$ is the average specific emission without regeneration, number of particles/kWh

$\overline{e_r}$ is the average specific emission with regeneration, number of particles/kWh

For the determination of $\overline{e_{\mathrm{r}}}$, the following provisions apply:

(a) If regeneration takes more than one hot start WHTC, consecutive full hot start WHTC tests shall be conducted and emissions continued to be measured without soaking and without shutting the engine off, until regeneration is completed, and the average of the hot start WHTC tests be calculated.

(b) If regeneration is completed during any hot start WHTC, the test shall be continued over its entire length.

In agreement with the type approval authority, regeneration adjustment may be applied by either multiplicative or additive adjustment based on good engineering analysis.

Multiplicative regeneration adjustment factors $k_r$ shall be determined as follows:

$$k_{\mathrm{r,u}} = \frac{e_{\mathrm{w}}}{e} \text{ (upward)}$$

$$k_{\mathrm{r,d}} = \frac{e_{\mathrm{w}}}{e_r} \text{ (downward)}$$

The additive regeneration adjustment shall be determined as follows:

$k_{r,u} = e_w - e$ (upward)

$k_{r,d} = e_w - e_r$ (downward)

The regeneration adjustment $k_r$ :

(c) shall be applied to the weighted WHTC test result as per paragraph 5.4.3,

(d) may be applied to the WHSC and cold WHTC, if a regeneration occurs during the cycle,

(e) may be extended to other members of the same engine family,

(f) may be extended to other engine families using the same aftertreatment system with the prior approval of the type Approval Authority based on technical evidence to be supplied by the manufacturer that the emissions are similar.

5.4.3 Weighted average WHTC test result

For the WHTC, the final test result shall be a weighted average from cold start and hot start (including periodic regeneration where relevant) tests calculated using one of the following equations:

(a) in the case of multiplicative regeneration adjustment, or engines without periodically regenerating aftertreatment

$$e = k_r \left( \frac{(0.14 \times N_{cold}) + (0.86 \times N_{hot})}{(0.14 \times W_{act,cold}) + (0.86 \times W_{act.hot})} \right)$$

(b) in the case of additive regeneration adjustment

$$e = k_r + \left( \frac{(0.14 \times N_{cold}) + (0.86 \times N_{hot})}{(0.14 \times W_{act,cold}) + (0.86 \times W_{act.hot})} \right)$$

Where:

$N_{cold}$ is the total number of particles emitted over the WHTC cold test cycle

$N_{hot}$ is the total number of particles emitted over the WHTC hot test cycle

$W_{act,cold}$ is the actual cycle work according to Annex 4B, paragraph 7.8.6, in kWh.

$W_{act, hot}$ is the actual cycle work according to Annex 4B, paragraph 7.8.6, in kWh.

$k_r$ is the regenerative adjustment, according to paragraph 5.4.2, or in the case of engines without periodically regenerating aftertreatment $k_r = 1$

5.4.4 Rounding of Final Results

The final WHSC and weighted average WHTC test results shall be rounded in one step to three significant figures in accordance with ASTM **E 29-06B**. No rounding of intermediate values leading to the final brake specific emission result is permissible.

6. DETERMINATION OF PARTICLE NUMBER BACKGROUND

6.1 At the engine manufacturer's request, diluent may be sampled, according to Annex 4B paragraph 7.5.6, to determine the background particle concentrations.

6.2 Subtraction of particle number background concentrations shall not be allowed for type approval, but may be used at the manufacturer's request for conformity of production and in service conformity testing where there are indications that tunnel background contribution is significant., which can then be subtracted from the values measured in the diluted exhaust.

<u>Annex 4C - Appendix 1</u>

PARTICLE NUMBER EMISSIONS MEASUREMENT EQUIPMENT

1. SPECIFICATION

1.1. System Overview

1.1.1. The particle sampling system shall consist of a probe or sampling point extracting a sample from a homogenously mixed flow in a dilution system as described in Annex 4B, Appendix 3, section A3.2.1 and A.3.2.2 or A3.2.3 and A.3.2.4, a volatile particle remover (VPR) upstream of a particle number counter (PNC) and suitable transfer tubing.

1.1.2. It is recommended that a particle size pre-classifier (e.g. cyclone, impactor etc) be located prior to the inlet of the VPR. However, a sample probe acting as an appropriate size-classification device, such as that shown in Annex 4B, Appendix 3, Figure 14, is an acceptable alternative to the use of a particle size pre-classifier. In the case of partial flow dilution systems it is acceptable to use the same pre-classifier for particulate mass and particle number sampling, extracting the particle number sample from the dilution system downstream of the pre-classifier. Alternatively separate pre-classifiers may be used, extracting the particle number sample from the dilution system upstream of the particulate mass pre-classifier.

1.2. General Requirements

1.2.1. The particle sampling point shall be located within a dilution system.

The sampling probe tip or particle sampling point and particle transfer tube (PTT) together comprise the particle transfer system (PTS). The PTS conducts the sample from the dilution tunnel to the entrance of the VPR. The PTS shall meet the following conditions:

In the case of full flow dilution systems and partial flow dilution systems of the fractional sampling type (as described in Annex 4B, Appendix 3, section A.3.2.1) the sampling probe shall be installed near the tunnel 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 sampling probe shall be positioned within the dilution tract so that the sample is taken from a homogeneous diluent/exhaust mixture.

In the case of partial flow dilution systems of the total sampling type (as described in Annex 4B, section A.3.2.1) the particle sampling point or sampling probe shall be located in the particulate transfer tube, upstream of the particulate filter holder, flow measurement device and any sample/bypass bifurcation point. The sampling point or sampling probe shall be positioned so that the sample is taken from a homogeneous diluent/exhaust mixture.

Sample gas drawn through the PTS shall meet the following conditions:

It shall have a flow Reynolds number (Re) of < 1700;

It shall have a residence time in the PTS of ≤ 3 seconds.

Any other sampling configuration for the PTS for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable.

The outlet tube (OT) conducting the diluted sample from the VPR to the inlet of the PNC shall have the following properties:

It shall have an internal diameter of ≥ 4mm;

Sample Gas flow through the OT shall have a residence time of ≤0.8 seconds.
Any other sampling configuration for the OT for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable.

1.2.2. The VPR shall include devices for sample dilution and for volatile particle removal.

1.2.3. All parts of the dilution system and the sampling system from the exhaust pipe up to the PNC, 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 cross-section, the use of smooth internal surfaces and the minimisation of the length of the sampling line. Gradual changes in the cross-section are permissible.

1.3. Specific Requirements

1.3.1. The particle sample shall not pass through a pump before passing through the PNC.

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 one or more stages to achieve a particle number concentration below the upper threshold of the single particle count mode of the PNC and a gas temperature below 35 °C at the inlet to the PNC;

1.3.3.2. Include an initial heated dilution stage which outputs a sample at a temperature of ≥ 150 °C and ≤ 400 °C, and dilutes by a factor of at least 10;

1.3.3.3. Achieve a particle concentration reduction factor ($f_r(d_i)$), as defined in paragraph 2.2.2., for particles of 30 nm and 50 nm electrical mobility diameters, that is no more than 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole;

1.3.3.4. Also achieve > 99.0 per cent vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of ≥ 10,000 $cm^{-3}$, by means of heating and reduction of partial pressures of the tetracontane.

1.3.4. The PNC shall:

1.3.4.1. Operate under full flow operating conditions;

1.3.4.2. Have a counting accuracy of ±10 per cent across the range 1 $cm^{-3}$ to the upper threshold of the single particle count mode of the PNC against a traceable standard. At concentrations below 100 $cm^{-3}$ measurements averaged over extended sampling periods may be required to demonstrate the accuracy of the PNC with a high degree of statistical confidence;

1.3.4.3. Have a readability of at least 0.1 particles $cm^{-3}$ at concentrations below 100 $cm^{-3}$;

1.3.4.4. Have a linear response to particle concentrations over the full measurement range in single particle count mode;

1.3.4.5. Have a data reporting frequency equal to or greater than 0.5 Hz;

1.3.4.6. Have a $t_{90}$ response time over the measured concentration range of less than 5 s;

1.3.4.7. Incorporate a coincidence correction function up to a maximum 10 per cent correction, and may make use of an internal calibration factor as determined in paragraph 2.1.3., but shall not make use of any other algorithm to correct for or define the counting efficiency;

1.3.4.8. Have counting efficiencies at particle sizes of 23 nm (±1 nm) and 41 nm (±1 nm) electrical mobility diameter of 50 per cent (±12 per cent) and > 90 per cent respectively. These counting efficiencies may be achieved by internal (for example; control of instrument design) or external (for example; size pre-classification) means;

1.3.4.9. If the PNC makes use of a working liquid, it shall be replaced at the frequency specified by the instrument manufacturer.

1.3.5 The sum of the residence time of the PTS, VPR and OT plus the $t_{90}$ response time of the PNC shall be no greater than 20 s.

1.3.6 The transformation time of the entire particle number sampling system (PTS, VPR, OT and PNC) shall be determined by aerosol switching directly at the inlet of the PTS. The aerosol switching shall be done in less than 0.1 s. The aerosol used for the test shall cause a concentration change of at least 60 per cent full scale (FS).

The concentration trace shall be recorded. For time alignment of the particle number concentration and exhaust flow signals, the transformation time is defined as the time from the change ($t_0$) until the response is 50 per cent of the final reading ($t_{50}$).

1.4. Recommended System Description

The following section contains the recommended practice for measurement of particle number. However, any system meeting the performance specifications in paragraphs 1.2. and 1.3. is acceptable.

Figures 14 and 15 are schematic drawings of the recommended particle sampling system configures for partial and full flow dilution systems respectively.

Figure 14: Schematic of Recommended Particle Sampling System – Partial Flow Sampling

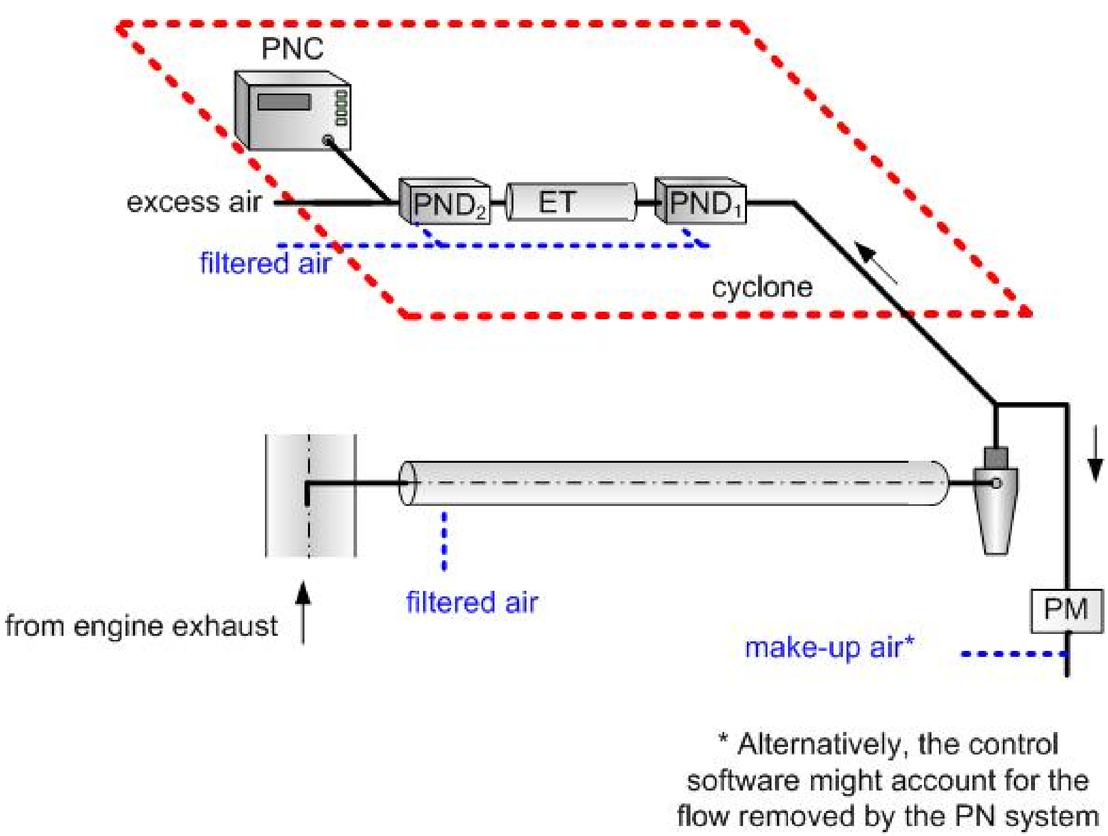
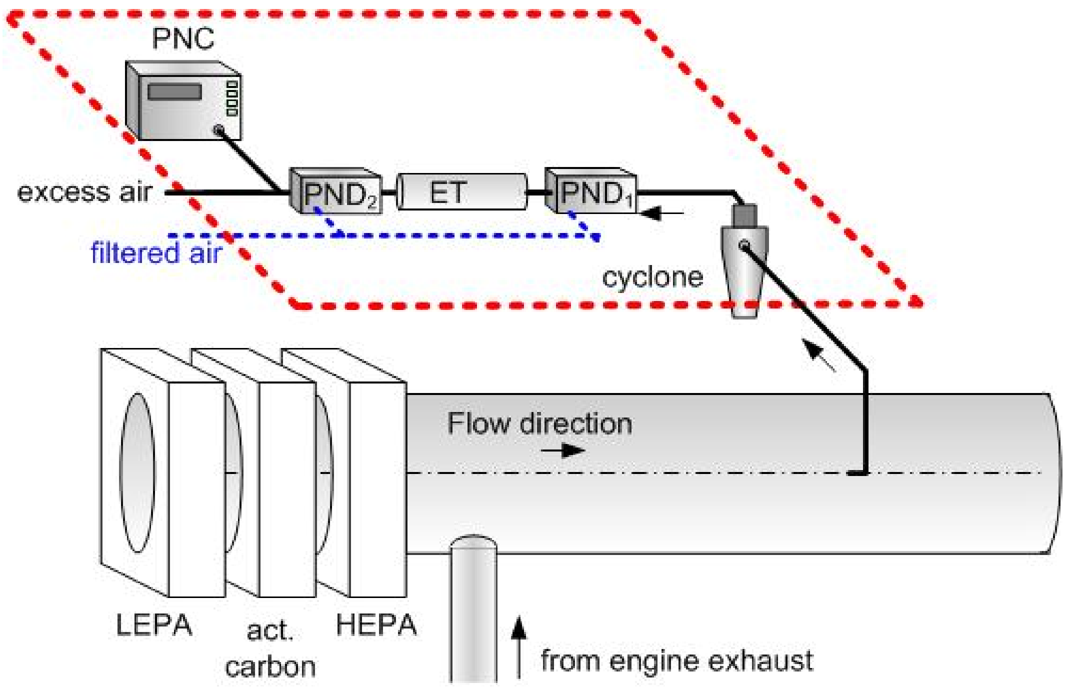



Figure 15: Schematic of Recommended Particle Sampling System – Full Flow Sampling




1.4.1. Sampling System Description

The particle sampling system shall consist of a sampling probe tip or particle sampling point in the dilution system, a particle transfer tube (PTT), a particle pre-classifier (PCF) and a volatile particle remover (VPR) upstream of the particle number concentration measurement (PNC) unit. The VPR shall include devices for sample dilution (particle number diluters: $PND_1$ and $PND_2$) and particle evaporation (Evaporation tube, ET). The sampling probe or sampling point for the test gas flow shall be so arranged within the dilution tract that a representative sample gas flow is taken from a homogeneous diluent/exhaust mixture. The sum of the residence time of the system plus the $t_{90}$ response time of the PNC shall be no greater than 20 s.

1.4.2. Particle Transfer System

The sampling probe tip or particle sampling point and particle transfer tube (PTT) together comprise the particle transfer system (PTS). The PTS conducts the sample from the dilution tunnel to the entrance to the first particle number diluter. The PTS shall meet the following conditions:

In the case of full flow dilution systems and partial flow dilution systems of the fractional sampling type (as described in Annex 4B, Appendix 3, section A.3.2.1) the sampling probe shall be installed near the tunnel 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 sampling probe shall be positioned within the dilution tract so that the sample is taken from a homogeneous diluent/exhaust mixture.

In the case of partial flow dilution systems of the total sampling type (as described in Annex 4B, section A.3.2.1) the particle sampling point shall be located in the particulate transfer tube, upstream of the particulate filter holder, flow measurement device and any sample/bypass bifurcation point. The sampling point or sampling probe shall be positioned so that the sample is taken from a homogeneous diluent/exhaust mixture.

Sample gas drawn through the PTS shall meet the following conditions:

It shall have a flow Reynolds number (Re) of $< 1700$;

It shall have a residence time in the PTS of $\leq 3$ seconds.

Any other sampling configuration for the PTS for which equivalent particle penetration for particles of 30 nm electrical mobility diameter can be demonstrated will be considered acceptable.

The outlet tube (OT) conducting the diluted sample from the VPR to the inlet of the PNC shall have the following properties:

It shall have an internal diameter of $\geq 4$ mm;

Sample Gas flow through the POT shall have a residence time of $\leq 0.8$ seconds.

Any other sampling configuration for the OT for which equivalent particle penetration for particles of 30 nm electrical mobility diameter can be demonstrated will be considered acceptable.

1.4.3. Particle Pre-classifier

The recommended particle pre-classifier shall be located upstream of the VPR. The pre-classifier 50 per cent 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 per cent 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. In the case of partial flow dilution systems, it is acceptable to use the same pre-classifier for particulate mass and particle number sampling, extracting the particle number sample from the dilution system downstream of the pre-classifier. Alternatively separate pre-classifiers may be used, extracting the particle number sample from the dilution system upstream of the particulate mass pre-classifier.

1.4.4. Volatile Particle Remover (VPR)

The VPR shall comprise one particle number diluter ($PND_1$), an evaporation tube and a second diluter ($PND_2$) in series. This dilution function is to reduce the number concentration of the sample entering the particle concentration measurement unit to less than the upper threshold of the single particle count mode of the PNC and to suppress nucleation within the sample.

The VPR shall achieve $> 99.0$ per cent vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of $\geq 10{,}000$ $cm^{-3}$, by means of heating and reduction of partial pressures of the tetracontane. It shall also achieve a particle concentration reduction factor ($f_r$) for particles of 30 nm and 50 nm electrical mobility diameters, that is no more than 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole.

1.4.4.1. First Particle Number Dilution Device ($PND_1$)

The first particle number dilution device shall be specifically designed to dilute particle number concentration and operate at a (wall) temperature of 150 °C - 400 °C. The wall temperature setpoint should not exceed the wall temperature of the ET (paragraph 1.4.4.2.). The diluter should be supplied with HEPA filtered dilution air and be capable of a dilution factor of 10 to 200 times.

1.4.4.2. Evaporation Tube

The entire length of the ET shall be controlled to a wall temperature greater than or equal to that of the first particle number dilution device and the wall temperature held at a fixed value between 300 °C and 400 °C.

1.4.4.3. Second Particle Number Dilution Device ($PND_2$)

$PND_2$ shall be specifically designed to dilute particle number concentration. The diluter shall be supplied with HEPA filtered dilution air and be capable of maintaining a single dilution factor within a range of 10 to 30 times. The dilution factor of $PND_2$ shall be selected in the range between 10 and 15 such that particle number concentration downstream of the second diluter is less than the upper threshold of the single particle count mode of the PNC and the gas temperature prior to entry to the PNC is < 35 °C.

1.4.5. Particle Number Counter (PNC)

The PNC shall meet the requirements of paragraph 1.3.4.

2. CALIBRATION/VALIDATION OF THE PARTICLE SAMPLING SYSTEM [1/]

2.1. Calibration of the Particle Number Counter

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

2.1.2 The PNC shall also be recalibrated and a new calibration certificate issued following any major maintenance.

---

1/ Example calibration/validation methods are available at http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/pmpFCP.html

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

(a) By comparison of the response of the PNC under calibration with that of a calibrated aerosol electrometer when simultaneously sampling electrostatically classified calibration particles, or

(b) By comparison of the response of the PNC under calibration with that of a second PNC which has been directly calibrated by the above method.

In the electrometer case, calibration shall be undertaken using at least six standard concentrations spaced as uniformly as possible across the PNC's measurement range. These points will include a nominal zero concentration point produced by attaching HEPA filters of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ±10 per cent of the standard concentration for each concentration used, with the exception of the zero point, otherwise the PNC under calibration shall be rejected. The gradient from a linear regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. 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 0.97. In calculating both the gradient and $R^2$ the linear regression shall be forced through the origin (zero concentration on both instruments).

In the reference PNC case, calibration shall be undertaken using at least six standard concentrations across the PNC's measurement range. At least 3 points shall be at concentrations below 1,000 $cm^{-3}$, the remaining concentrations shall be linearly spaced between 1,000 $cm^{-3}$ and the maximum of the PNC's range in single particle count mode. These points will include a nominal zero concentration point produced by attaching HEPA filters of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ±10 per cent of the standard concentration for each concentration, with the exception of the zero point, otherwise the PNC under calibration shall be rejected. The gradient from a linear regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. 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 0.97. In calculating both the gradient and $R^2$ the linear regression shall be forced through the origin (zero concentration on both instruments).

2.1.4 Calibration shall also include a check, against the requirements in paragraph 1.3.4.8., on the PNC's detection efficiency with particles of 23 nm electrical mobility diameter. A check of the counting efficiency with 41 nm particles is not required.

2.2. Calibration/Validation of the Volatile Particle Remover

2.2.1. Calibration of the VPR's particle concentration reduction factors across its full range of dilution settings, at the instrument manufacturer's recommended operating temperatures, shall be required when the unit is new and following any major maintenance. The periodic validation requirement for the VPR's particle concentration reduction factor is limited to a check at a single setting, typical of that used for measurement on diesel particulate filter equipped vehicles. The Technical Service shall ensure the existence of a calibration or validation certificate for the volatile particle remover within a 6 month period prior to the emissions test. If the volatile particle remover incorporates temperature monitoring alarms a 12 month validation interval shall be permissible.

The VPR shall be characterised for particle concentration reduction factor with solid particles of 30 nm, 50 nm and 100 nm electrical mobility diameter. Particle concentration reduction factors ($f_r(d)$) for particles of 30 nm and 50 nm electrical mobility diameters shall be no more than 30 per cent and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For the purposes of validation, the mean particle concentration reduction factor shall be within ±10 per cent of the mean particle concentration reduction factor ( $\overline{f_r}$ ) determined during the primary calibration of the VPR.

2.2.2. The test aerosol for these measurements shall be solid particles of 30, 50 and 100 nm electrical mobility diameter and a minimum concentration of 5,000 particles $cm^{-3}$ at the VPR inlet. Particle concentrations shall be measured upstream and downstream of the components.

The particle concentration reduction factor at each particle size ( $f_r(d_i)$ ) shall be calculated as follows;

$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)}$$

Where:

$N_{in}(d_i)$ = upstream particle number concentration for particles of diameter $d_i$;
$N_{out}(d_i)$ = downstream particle number concentration for particles of diameter $d_i$; and
$d_i$ = particle electrical mobility diameter (30, 50 or 100 nm).

$N_{in}(d_i)$ and $N_{out}(d_i)$ shall be corrected to consistent conditions.

The mean particle concentration reduction ( $\overline{f_r}$ ) at a given dilution setting shall be calculated as follows;

$$\overline{f_r} = \frac{f_r(30nm) + f_r(50nm) + f_r(100nm)}{3}$$

It is recommended that the VPR is calibrated and validated as a complete unit.

2.2.3. The Technical Service shall ensure the existence of a validation certificate for the VPR demonstrating effective volatile particle removal efficiency within a 6 month period prior to the emissions test. If the volatile particle remover incorporates temperature monitoring alarms a 12 month validation interval shall be permissible. The VPR shall demonstrate greater than 99.0 per cent removal of tetracontane ($CH_3(CH_2)_{38}CH_3$) particles of at least 30 nm electrical mobility diameter with an inlet concentration of $\geq$ 10,000 $cm^{-3}$ when operated at its minimum dilution setting and manufacturers recommended operating temperature.

2.3. Particle Number System Check Procedures

2.3.1. Prior to each test, the particle counter shall report a measured concentration of less than 0.5 particles $cm^{-3}$ when a HEPA filter of at least class H13 of EN 1822:2008, or equivalent performance, is attached to the inlet of the entire particle sampling system (VPR and PNC).

2.3.2. On a monthly basis, the flow into the particle counter shall report a measured value within 5 per cent of the particle counter nominal flow rate when checked with a calibrated flow meter.

2.3.3. Each day, following the application of a HEPA filter of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of the particle counter, the particle counter shall report a concentration of $\leq$ 0.2 $cm^{-3}$. Upon removal of this filter, the particle counter shall show an increase in measured concentration to at least 100 particles $cm^{-3}$ when challenged with ambient air and a return to $\leq$ 0.2 $cm^{-3}$ on replacement of the HEPA filter.

2.3.4. During each test it shall be confirmed that the evaporation tube, where featured in the system, is at a temperature of 300 °C to 400 °C.

2.3.5. During each test it shall be confirmed that the diluter $PND_1$ wall temperature is at 150 °C - 400 °C, but less than or equal to the set-point of the evaporation tube.

## B. JUSTIFICATION

The PMP Heavy Duty Validation Exercise, to demonstrate the suitability of PMP particle emissions measurement procedures for heavy duty engine testing, has now been completed and a draft report has been prepared. The exercise has concluded that the proposed particle number measurement technique, as already adopted in UNECE Regulation No. 83, is suitable for use in heavy duty engine testing.

This informal document presents a draft proposal to insert the particle number measurement procedure into Regulation No. 49 as an unreferenced Annex for future application. The text defines procedures for measuring particle number when testing according to Annex 4B (WHDC) procedures.

The proposal does not make any amendments to particulate mass measurement techniques, since improvements to this technique have already been agreed at an international level within the WHDC test procedures.

- - - - -