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PARTICLE MEASUREMENT PROGRAMME (PMP)

Prepared by Ricardo Consulting Engineers 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.

DISCUSSION DOCUMENT: DRAFT AMENDMENTS TO REGULATION NO. 49.

Note: The following pages contain commentary on certain annexes of Regulation 49 with respect to their amendment to take account of the new measuring procedures explored during the UK contribution to the Particles Measurement Programme. Working Document 7, distributed at the Special Informal GRPE held on 15 September 2003, represented a consolidation of both unaffected text and detailed recommendations for amendment. This summary document does not contain unnecessary sections of unaffected text but retains all of the points raised in the full Working Document 7.

Annex 4

TEST PROCEDURE

1. INTRODUCTION

1.1. This annex describes the methods of determining emissions of gaseous components, particulates, particles and smoke from the engines to be tested. Three test cycles are described that must be applied according to the provisions of the Regulation, paragraph 6.2:

1.3. Measurement principle

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

1.3.1. ESC test

During a prescribed sequence of warmed-up engine operating conditions the amounts of the above exhaust emissions must 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 must be determined, and the measured values weighted. The particulate and particle samples must be diluted with conditioned ambient air. One sample over the complete test procedure must be taken, and collected on suitable filters. The grams of each pollutant emitted per kilowatt-hour (kWh) must be calculated as described in appendix 1 to this annex. Additionally, NO_x must 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.

1.3.3. ETC test

During a prescribed transient cycle of warmed-up engine operating conditions, which is based closely on road-type-specific driving patterns of heavy-duty engines installed in trucks and buses, the above pollutants must 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 must 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 must 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 particulates, a proportional sample must be collected on suitable filters. The particle count must be determined by integration. The diluted exhaust gas flow rate must be determined over the cycle to calculate the mass emission values of the pollutants. The mass emission values must be related to the engine work to get the grams of each pollutant emitted per kilowatt-hour (kWh) and the particle emissions must similarly be

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

expressed as ~~and~~ number per kilowatt-hour, as described in appendix 2 to this annex.

Annex 4 - Appendix 1

ESC AND ELR TEST CYCLES

2. ESC TEST RUN

(At the manufacturer's request, a dummy test may be run for conditioning of the engine and exhaust system before the measurement cycle).

2.1. Preparation of the sampling filter

At least one hour before the test, each filter (pair) must be placed in a closed, but unsealed petri dish and placed in a weighing chamber for stabilisation. At the end of the stabilisation period, each filter (pair) must be weighed and the tare weight must be recorded. The filter (pair) must then be stored in a closed petri dish or sealed filter holder until needed for testing. If the filter (pair) is not used within eight hours of its removal from the weighing chamber, it must be conditioned and reweighed before use.

2.3. Starting the dilution system and the engine

Before the engine is started, the dilution system and emissions measurement systems must be started and left running in an appropriate 'stand-by' mode.

The engine must be started according to the manufacturers instructions, and the following conditioning procedure must be carried out:

Stage	Engine Condition	Duration (mins)
Warmup	Mode 9	30 (1)
Power Curve (2)	Full Load	15
Stabilisation	ESC Cycle (3)	28
Stabilisation	Mode 4	15
Continuity (4)	Idle	4
Continuity	Mode 4	6
Emissions Check (5)	Idle	<3

1) The duration of the warmup stage must be extended if the engine and dilution system temperatures are not fully stabilised after 30 minutes. If stable temperatures are achieved in less than 30 minutes then the stage duration may be reduced.

2) The power curve must commence at rated power (Mode 10), and be run with decreasing speed

3) This stabilisation ESC cycle provides a period of mixed condition operation which is representative of the subsequent test in terms of exhaust temperatures and emissions levels. It should not be regarded as a valid test.

4) If a series of consecutive ESC test cycles is to be performed, then the continuity and emissions check stages must be run between tests, without stopping the engine.

5) This stage is optional. If possible the emissions analysers should be zeroed and spanned during the Mode 4 continuity stage

If for any reason the engine is stopped, or run at unspecified conditions between tests, then sound engineering judgment should be used to decide whether or not part or all of the conditioning procedure should be repeated. In all cases the continuity procedure must immediately precede the start of the ESC test cycle.

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

2.4. Starting the particulate sampling system

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

~~The particulate background level of the dilution air may be determined by passing dilution air thrpogh the particulate filters. If flitered dilution air is used, one measurement may be done prior to or after the test. If the dilution air is not filtered, measurements at the beinning and at the end of the cycle, may be done, and the values averaged.~~

2.4A. Starting the particle sampling system

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

Prior to the test the correct function of the particle counter and volatile particle remover elements of the particle sampling system must be confirmed.

The particle counter response must be tested at near zero and high particle concentrations (Annex 4, Appendix 5, paragraph 3A.4)

The volatile particle remover must be tested for removal of volatile particles (Annex 4, Appendix 5, paragraph 3A.4).

The entire particle sampling system must be tested for leaks.

2.7.2. Test sequence

The test sequence must be started. The test must be performed in the order of the mode numbers as set out in paragraph 2.7.1.

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

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

2.7.4. Particulate sampling

~~One pair of~~ A single filter~~s~~ (~~primary and back-up filters,~~ see annex 4, appendix 4) must be used for the complete test procedure. The modal weighting factors specified in the test cycle procedure must 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 5.6. is met.
The sampling time per mode must be at least 4 seconds per 0.01 weighting factor. Sampling must be conducted as late as possible within each mode. Particulate sampling must be completed no earlier than 5 seconds before the end of each mode.

2.7.4A. Particle sampling

Particles must be drawn continuously throughout the ESC test via the particle sampling system (Annex 4, Appendix 4A). Commencement of sampling must coincide with the commencement of the test and must be complete no less than 30s following the completion of the test cycle. A single data file must be logged for the entire duration of the test procedure. The modal weighting factors specified in the test cycle procedure must be taken into account by taking the average concentration measured from a period during each mode and calculating the 'unweighted' particle/h emission for each mode. Multiplying these data by the appropriate effective weighting factors (paragraph 5.6) gives the 'weighted' particle/h value for each mode. The time period used for averaging should exclude the first 30 seconds and conclude sooner than 5 seconds before the end of each mode. The total averaging period for each mode should be at least 60 seconds.

2.7.5. 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 must be recorded during each mode, with the speed and load requirements (see paragraph 2.7.2) being met during the time of particulate and particle sampling, but in any case during the last minute of each mode.

Any additional data required for calculation must be recorded (see paragraphs 4 and 5).

2.7.7. ~~Rechecking the analysers~~ Operations after the test

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

For diesel engines only, the particulate filter shall be returned to the weighing chamber for conditioning and weighing.

Following the test, the correct function of the particle counter and volatile particle remover elements of the particle sampling system must be confirmed.

The particle counter response must be tested at near zero and high particle concentrations (Annex 4, Appendix 5, paragraph 3A.4)

The volatile particle remover must be tested for removal of volatile particles (Annex 4, Appendix 5, paragraph 3A.4).

The entire particle sampling system must be tested for leaks.

For the test to be deemed valid, all these confirmation tests must be passed.

3. ELR TEST RUN

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4. CALCULATION OF THE GASEOUS EMISSIONS

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5. CALCULATION OF THE PARTICULATE EMISSION

5.1. Data evaluation

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

The filter must be returned to the weighing chamber and conditioned for at least one hour, but not more than 80 hours, and then weighed. The gross weight of the filter must be recorded and the tare weight (see paragraph 1 of this appendix) subtracted. The particulate mass M_f is the ~~sum of the~~ particulate mass collected on the ~~primary and back-up~~ filter~~s~~.

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

5.2. Partial flow dilution system

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5.4. Calculation of the particulate mass flow rate

The particulate mass flow rate must 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.

If a double dilution system is used, the mass of the secondary dilution air must 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 double diluted exhaust flow is split between particulate filter and the particle measurement system then the sample mass must 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}) must be replaced with the average value of (M_d/M_{DIL}).

$DF_i = 13.4/(\text{conc } CO_2 + (\text{conc } CO + \text{conc } HC)*10^{-4}))$ for the individual modes

or,

$DF_i = 13.4/\text{conc}CO_2$ for the individual modes

5A. CALCULATION OF THE PARTICLE EMISSIONS

The final reported test results of the particle emission must be determined through the following steps.

5A.1. Data evaluation

For the evaluation of the particles, the total sample masses $(MP_{SAM,i})$ through the particle measurement system must be recorded for each mode.

*Need paragraph in here about integrating particle number trace to get total number (N_P)*For determination of the total particle number for a particular test, the average particle emission from each individual mode (paragraph 2.7.4A) is reduced according to the effective weighting factors specific to those modes and that test.The average of these weighted results constitutes the weighted cycle total number (Np).

5A.2. Partial flow dilution system

This section is intentionally blank

5A.3. Full flow dilution system

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

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

5A.4. Calculation of the particle number flow rate

The particle number rate must be calculated as follows:

$$PNnum = PNnum(dil) * 3°DR1 * 3°DR2$$

where: 3°DR1 and 3°DR2 are the dilution ratio settings for tertiary diluters 1 ($3°D_1$) and 2 ($3°D_2$) resepectively.

$$PNnum(dil) = \frac{N_P}{MP_{SAM}} * \frac{\overline{G_{EDFW}}}{1000}$$

where

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

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

i=1,...n

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

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

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

where:

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

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

If the double diluted exhaust flow is split between particulate filter and the particle measurement system then the sample mass must 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

5A.5. Calculation of the specific emission

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

$$\overline{PN} = \frac{PN_{num}}{\sum P(n)_i * WF_i}$$

5A.6. Effective weighting factor

The effective weighting factor $WF_{E,i}$ for each mode must 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 must be within ± 0.003 (0.005 for the idle mode) of the weighting factors listed in paragraph 2.7.1.

6. CALCULATION OF THE SMOKE VALUES

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ETC TEST CYCLE

3. EMISSIONS TEST RUN

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

NG and LPG fuelled engines must be run-in using the ETC test. The engine must 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.

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

At least one hour before the test, each filter ~~(pair)~~ must be placed in a closed, but unsealed petri dish and placed in a weighing chamber for stabilisation. At the end of the stabilisation period, each filter ~~(pair)~~ must be weighed and the tare weight must be recorded. The filter ~~(pair)~~ must then be stored in a closed petri dish or sealed filter holder until needed for testing. If the filter ~~(pair)~~ is not used within eight hours of its removal from the weighing chamber, it must be conditioned and reweighed before use.

3.3. Starting the dilution system and the engine

Before the engine is started, the dilution system and emissions measurement systems must be started and left running in an appropriate 'stand-by' mode.

The engine must be started according to the manufacturers instructions, and the following conditioning procedure must be carried out:

Stage	Engine Condition	Duration (mins)
Warmup	Mode 9	30 (1)
Power Curve (2)	Full Load	15
Stabilisation	ESC Cycle (3)	28
Stabilisation	Mode 4	15
Continuity (4)	Idle	4
Continuity	Mode 4	6
Emissions Check (5)	Idle	<3

6) The duration of the warmup stage must be extended if the engine and dilution system temperatures are not fully stabilised after 30 minutes. If stable temperatures are achieved in less than 30 minutes then the stage duration may be reduced.

7) The power curve must commence at rated power (Mode 10), and be run with decreasing speed

8) This stabilisation ESC cycle provides a period of mixed condition operation which is representative of the subsequent test in terms of exhaust temperatures and emissions levels. It should not be regarded as a valid test.

9) If a series of consecutive ETC test cycles is to be performed, then the continuity and emissions check stages must be run between tests, without stopping the engine.

10) This stage is optional. If possible the emissions analysers should be zeroed and spanned during the Mode 4 continuity stage

If for any reason the engine is stopped, or run at unspecified conditions between tests, then sound engineering judgment should be used to decide whether or not part or all of the conditioning procedure should be repeated. In all cases the continuity procedure must immediately precede the start of the ETC test cycle.

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

3.4. Starting the particulate sampling system (Diesel engines only)

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

~~The particulate background level of the dilution air may be determined by passing dilution air through the particulate filters. If filtered dilution air is used, one measurement may be done prior to or after the test. If the dilution air is not flltered, measurements at the beginninbg and at the end of the cycle, may be done, and the values averaged.~~

3.4.A Starting the Particle Sampling System

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

Prior to the test the correct function of the particle counter and volatile particle remover elements of the particle sampling system must be confirmed.

The particle counter response must be tested at near zero and high particle concentrations (Annex 4, Appendix 5, paragraph 3A.4)

The volatile particle remover must be tested for removal of volatile particles (Annex 4, Appendix 5, paragraph 3A.4).

The entire particle sampling system must be tested for leaks.

3.5. Adjustment of the full flow dilution system

The total diluted exhaust gas flow must be set to eliminate water condensation in the system, but maintaining a tunnel temperature of less than 191°C ~~and to obtain a maximum filter face temperature of 325 K (52°C) or less (see annex 4, appendix 7, paragraph 3.2.1., DT)~~.

3.7. Engine starting procedure

~~The stabilised engine must 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~~The test must be started directly from the engine preconditioning phase without shutting the engine off~~, when the engine has reached the idle speed~~.

3.8. Test cycle

3.8.3. Particulate and particle sampling (Diesel engines only)

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

Particles must be measured continuously in the particle sampling system with a frequency of >0.5 Hz. The average concentrations must be determined by integrating the analyser signals over the test cycle. The system response time must be no greater than 30 s, and must be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary.

If no flow compensation is used, the sample pump(s) must 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 must 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 must 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 must be voided. The test must be rerun using a lower flow rate and/or a larger diameter filter.

3.8.5. Operations after test

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 must be stopped. For an integrating analyser system, sampling must continue until system response times have elapsed.

The concentrations of the collecting bags, if used, must 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 must 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.

For diesel engines only, the particulate filter must be returned to the weighing chamber no later than one hour after completion of the test and must be conditioned in a closed, but unsealed petri dish for at least one hour, but not more than 80 hours before weighing.

Following the test, the correct function of the particle counter and volatile particle remover elements of the particle sampling system must be confirmed.

The particle counter response must be tested at near zero and high particle concentrations (Annex 4, Appendix 5, paragraph 3A.4)

The volatile particle remover must be tested for removal of volatile particles (Annex 4, Appendix 5, paragraph 3A.4).

The entire particle sampling system must be tested for leaks.

For the test to be deemed valid, all these confirmation tests must be passed.

4. CALCULATION OF THE GASEOUS EMISSIONS

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5A. CALCULATION OF THE PARTICLE EMISSION (DIESEL ENGINES ONLY)

5A.1. Calculation of the mass flow

The particle number (n/test) must be calculated as follows:

$$PNnum = PNnum(dil) * 3°DR1 * 3°DR2$$

where: 3°DR1 and 3°DR2 are the dilution ratio settings for tertiary diluters 1 ($3°D_1$) and 2 ($3°D_2$) resepectively.

$$PNnum(dil) = \frac{N_P}{M_{SAM}} * \frac{M_{TOTW}}{1000}$$

where:

N_P = partice number count recorded over the cycle

M_{TOTW} = total mass of diluted exhaust gas over the cycle as determined in paragraph 4.1., kg

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

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

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

where:

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

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

If the double diluted exhaust flow is split between particulate filter and the particle measurement system then the sample mass must 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

5A.2. Calculation of the specific emission

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

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

where:

W_{act} = actual cycle work as determined in paragraph 3.9.2., kWh.

Annex 4 - Appendix 4

MEASUREMENT AND SAMPLING PROCEDURES

1. INTRODUCTION

Gaseous components, particulates, particles, and smoke emitted by the engine submitted for testing must be measured by the methods described in annex 4, appendix 7. The respective paragraphs of annex 4, appendix 7 describe the recommended analytical systems for the gaseous emissions (paragraph 1.), the recommended particulate dilution and sampling systems (paragraph 2.), ~~and~~ the recommended opacimeters for smoke measurement (paragraph 3.), and the recommended particle measurement systems (paragraph 4.).

For the purposes of this discussion document, references to the use of partial flow dilution systems have been deleted from this section

For the ESC, the gaseous components ~~must~~ may be determined in the raw exhaust gas~~. Optionally, they may be determined~~, or in the diluted exhaust gas, if a full flow dilution system is used ~~for particulate determination~~. ~~Particulates must be determined with either a partial flow or full flow dilution system.~~

~~For the ETC, only only a full flow dilution system must be used for determining gaseous and particulate emission, 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 procedure is submitted to the Technical Service.~~

4. DETERMINATION OF THE PARTICULATES

The determination of the particulates requires a full flow, double dilution system. ~~Dilution may be accomplished by a partial flow dilution system (ESC only) or a full flow dilution system (mandatory for ETC).~~ The flow capacity of the dilution system must be large enough to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas at ~~or below 325 K~~ 320±5 K(~~52~~47± 5°C) immediately upstream of the filter holders. 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 must 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 must not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel.

~~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 7, paragraph 2.2.). The particulate sampling probe must be installed in close proximity to the gaseous emissions sampling probe, and the installation must comply with the provisions of paragraph 3.4.1.~~

To determine the mass of the particulates, a particulate sampling system, particle size preclassifier, particulate sampling filters, a microgram balance, and a temperature and humidity controlled weighing chamber, are required.

For particulate sampling, the single filter method must be applied which uses one ~~pair of~~ filter~~s~~ ~~(see paragraph 4.1.3)~~ for the whole test cycle. For the ESC, considerable attention must be paid to sampling times and flows during the sampling phase of the test.

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.

4.1. Particulate sampling filters

4.1.1. Filter specification

Fluorocarbon coated glass fibre filters or fluorocarbon based membrane filters are required. All filter types must have a 0.3 µm DOP (di-octylphthalate) collection efficiency of at least 95 per cent at a gas face velocity between 35 and ~~80~~100 cm/s.

4.1.2. Filter size

Particulate filters must have a minimum diameter of 47 mm (37mm stain diameter). Larger diameter filters are not acceptable ~~(paragraph 4.1.5.)~~.

4.1.3. Single Filter Only

~~The diluted exhaust must be sampled by a pair of filters placed in series (one primary and one back-up filter) during the test sequence. The back-up filter must be located no more than 100 mm downstream of, and must not be in contact with the promary filter. The filters may be weighed separately or as a pair with the filters placed stain side to stain side.~~

One single filter only must be used in the sampling of particulates. Back-up filters are not permitted.

4.1.4. Particulate Sampling Probe (PSP)

The particulate sampling probe must meet the following conditions:

The PSP must 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 must be at least five probe diameters, but must not exceed 1,020 mm.

4.1.5. Filter face velocity

A gas face velocity through the filter of at least 35 cms^{-1} must be achieved. The pressure drop increase between the beginning and the end of the test must be no more than 25 kPa.

4.1.6 Particle Size Preclassifier (PCF)

The particle size pre-classifier must be located immediately upstream of the filter holder assembly. The pre-classifier 50% cut point particle diameter must be between 2.5 µm and 10 µm at the volumetric flow rate selected for sampling particulate mass emissions. The pre-classifier must 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 must not violate the filter face velocity conditions described in paragraph 4.1.5.

4.1.7. Filter loading

The recommended minimum filter loading must be 0.511 mg/1075 mm² stain area. For the most common filter sizes theThis values are is shown in table 9.

Table 9: Recommended filter loadings

Filter Diameter (mm)	Recommended Stain	Recommended Minimum
47	37	0.11

4.2.3. Analytical balance

The analytical balance used to determine filter weight must have a precision (standard deviation) of better than 2 µg for a clean filter; better than 0.25µg for a reference weight and a resolution or readability of 1µg.
The analytical balance used to determine the weights of all filters must have a precision (standard deviation) of 20µgand a resolution of 10µg. For filters less than 70mm diameter, the precision and resolution must be 2µg and 1µg, respectively.

4A. DETERMINATION OF THE PARTICLES

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

The particle sampling probe (paragraph 4.1.4) and particle size pre-classifier (paragraph 4.1.6) for particle measurements must either be of the same specification and operating parameters as those used for particulate sampling

or

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

4A.1 Volatile Particle Remover Unit (VPR)

A hot dilution system in which high temperatures and dilution processes are employed to prevent the formation of nucleation mode particles and the condensation of water within the diluter or sample line is required.

The volatile particle remover unit must be capable of diluting the sample drawn from the primary dilution tunnel by a dilution ratio range from 1 to 1000. This dilution function 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 hydrocarbon nucleation within the sample.

The sample pre-conditioning unit must operate under conditions that achieve greater than 90% reduction in volatile particles as described in Annex 4, Appendix 5 paragraph 3A.1.1 and greater than 90% solid particle penetration as defined in Annex 4, Appendix 5 paragraph 3A.2.

4A.2 Particle Number Counting Instrument (PNC)

The particle concentration measurement unit must meet the following conditions:

The PNC must count single particles and have a counting accuracy of ± 10% against a traceable standard.

The PNC must have a readability of 0.01 particles cm^{-3} and a linear response to concentration over the range 1 to 10^4 particles cm^{-3}.

The PNC must have a linear response to particle concentration over 1 to 10,000 particles cm^{-3} as defined in Annex 4, Appendix 5 paragraph 3.A.1.

The PNC must have a data logging frequency of equal to or less than 2 s.

The PNC must not incorporate automatic data manipulation functions.

4A.3 Additional specifications for particles measurement

Sampling tubing used for sampling from the secondary dilution system and to join tertiary dilution systems to particle measurement instrumentation must, wherever possible, be straight metallic (Cu or stainless steel) conductors of <1m length. Tubing shall be electrically earthed, and if heated dilution is employed, thermally insulated.

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

CALIBRATION PROCEDURE

3A. CALIBRATION OF THE PARTICLE MEASURING SYSTEM

Introduction

Each component must 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 4A

3A.1 Calibration of the Particle Counter

Calibration must 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 (Marshall & Dickens (2001)), 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 must be undertaken over at least five concentrations spaced as uniformly as possible across the counter's measurement range. Measured concentrations must be within ±10% of the standard concentration for each calibration concentration used. The gradient from a linear regression of the two data sets must 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 must be equal to or greater than 0.95.

3A.1.1 Checking the Particle Counter Response

Linearity of the counter response must be validated daily. The test aerosol for this validation must be liquid droplets generated from a pneumatic medical nebuliser at a concentration greater than $1x10^4cm^{-3}$. The droplets must 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 must be undertaken over 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 must be within ±10% of that calculated from the annual calibration data. The Pearson product moment correlation coefficient (R2) of the two data sets must be equal to or greater than 0.95.

3A.2 Calibration of the Volatile Particle Remover

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

The test aerosol for these measurements must be solid particles of diameters 20, 50 and 100 nm and a minimum concentration of 10^4cm^{-3}. Particle concentrations must 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% must be achieved at all three test particle diameters.

3A.3 Calibration of Tertiary (3°) Dilution Devices

All tertiary diluters must be calibrated with a traceable standard gas mixture at least every 6 months.

Calibration must be undertaken by measuring the concentration of the standard gas with a calibrated gas monitor at the inlet and outlet of the diluter. Calibration must be undertaken at least 5 dilution ratios spaced as uniformly as possible across a dilution ratio range from 0 to 1000. Measured dilution ratios must 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.

3A.4 Checking the Particle Measurement System Response

The following functionality checks must be undertaken before and after each emission test. If several consecutive tests are to be performed, the post-test functionality check of a preceding test may act as the pre-test check of a following test, if the completion of the initial test is less than 30 minutes prior to the commencement of the following test.

The particle counter must report a measured concentration of less than $1 cm^{-3}$ when a HEPA filter is attached to the sample inlet of the counter. The particle counter must report a measured concentration in excess of $1x10^4$ cm^{-3} when challenged with an undiluted sample of the test aerosol used in the daily particle counter linearity validation (paragraph 3A.1.1).

The sampling system, consisting of the diluter, volatile particle remover and particle counter, must report a measured concentration of less than 1 cm^{-3} when a HEPA filter is attached to the inlet of the diluter. The sampling system must 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.

2. EXHAUST GAS DILUTION AND DETERMINATION OF THE PARTICULATES AND PARTICLES

2.2. Partial flow dilution system

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2.4. Particulate sampling system

References to partial flow sampling have been omitted from this section

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 (paragraph 2.2., figures 14, 18) and sampling system usually form an integral unit. In the case of fractional sampling partial flow dilution or full flow dilution, which consists of passing through the filters only a portion of the diluted exhaust, the dilution (paragraph 2.2., figures 11, 12, 13, 15, 16, 17, 19; paragraph 2.3., Figure 20) and sampling systems usually form different units.~~

The double or secondary dilution system to be used in conjunction with a full flow dilution system is shown in Figure 22.

~~In this Regulation, the double dilution system (Figure 22) of a full flow dilution system is considered as a specific modification of a typical particulate sampling system as shown in Figure 21. 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. For the single filter method, a bypass system must be used for passing the sample through the sampling filters at the desired times. Interference of the switching procedure on the control loops must be minimised.

~~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 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 20) is used, the total diluted exhaust gas flow is used as command signal for FC3.~~

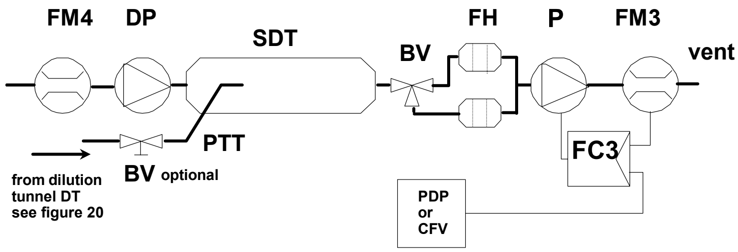

Figure 22 - Double dilution system (full flow system only)

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 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 20) is used, the total diluted exhaust gas flow is used as command signal for FC3.

2.4.1. Components of figures 21 and 22

PTT Particulate transfer tube (Figures 21, 22)
The particulate transfer tube must not exceed 1020 mm in length, including the sample probe (PSP) and must 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.

~~Where applicable (i.e. for partial flow dilution fractional sampling systems and for full flow dilution systems), the length of the sampling probes (SP, ISP, PSP, respectively, see paragraphs 2.2. and 2.3.) must be included.~~

~~The dimensions are valid for:~~

~~- the partial flow dilution fractional sampling type and the full flow single dilution system 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 full flow double dilution system from the tip of the probe (PSP) to the secondary dilution tunnel.~~

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 (Figure 22)

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 primary filter holder FH must be located within 300 mm of the exit of the SDT.

The secondary dilution tunnel:

- ~~may~~ must 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

PCF Particle Size Pre-classifier

Upstream of the filter holder, a pre-classifier must be employed to control the particle sizes reaching the particulate filter and particle measurement equipment.

The particle size pre-classifier must be located immediately upstream of the filter holder assembly. The pre-classifier 50% cut point particle diameter must be between 2.5 μm and 10 μm at the volumetric flow rate selected for sampling particulate mass emissions. The pre-classifier must 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 must not violate the filter face velocity conditions described in Annex 4, Appendix 4, paragraph 4.1.4.

FH Filter holder (Figures 21, 22)

For ~~primary and back-up filters~~filtration one filter housing only ~~or separate filter housings may~~ must be used. The requirements of annex 4, appendix 4, paragraph 4.1.3. must 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 (Figures 21, 22)

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.

DP Dilution air pump (Figure 22)

The dilution air pump must 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 (Figures 21, 22)

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 (Figures 21, 22)

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.

FM4 Flow measurement device (Figure 22)

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

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, 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).

2A. DETERMINATION OF THE PARTICLES

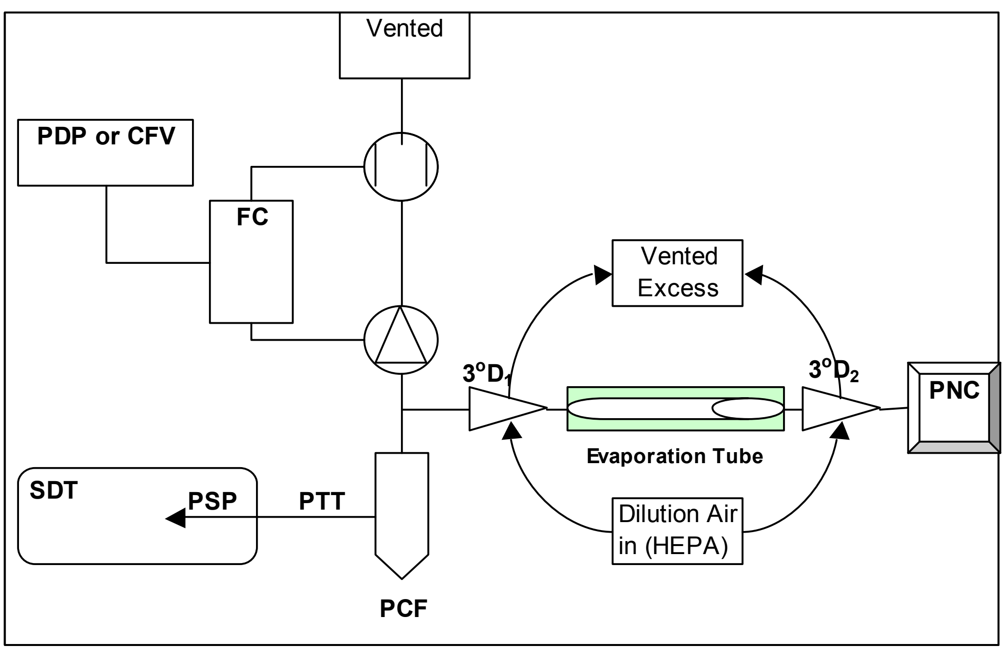

Figure 23 – Particle Sampling System

Figure 23 contains a detailed description of the recommended dilution and sampling systems required for particle measurement. Since various configurations can produce equivalent results, exact conformance with these figures 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.

2A.1 Particle Sampling System

The particle sampling system is required to draw a sample from the secondary dilution system, 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 secondary dilution tunnel SDT through the particulate sampling probe PSP_2 to the particulate transfer tube (PTT_2) where it enters the particulate preclassifier PCF. The sample is then passed into a heated tertiary dilution device ($3°D_1$) where the particle concentration is reduced by a factor between 1 and 1000.

The sample then passes through a heated evaporation tube where volatile constituents enter the vapour phase, and then on to a further heated tertiary dilution device ($3°D_2$) where the particle concentration is reduced by a factor between 1 and 10.

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

2A.1.1 Components of figure 23

PSP2 Particle Sampling Probe

The sampling probe should be designed to minimise particle loss during sampling, and if possible, be open-ended, adiabatic, smooth and of low thermal inertia; which can be achieved by use of thin-walled, double-wall, internally polished, air-gap insulated tube.

must be installed in the SDT facing upstream at a point where the dilution air and exhaust gas are well mixed, i.e. on the dilution tunnel (SDT) centreline approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;

must be of 12 mm minimum inside diameter;

may be heated to no greater than 325 K (52°C) wall temperature by dilution air pre-heating.

PTT2 Particle Transfer Tube

The particulate transfer tube must not exceed 1020 mm in length, including the sample probe (PSP_2) and must 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.

PCF Particle Preclassifier

The particle size pre-classifier must be located immediately upstream of the filter holder assembly. The pre-classifier must be designed to provide a 50% cut point particle diameter must be between 2.5 μm and 10 μm at the volumetric flow rate selected for sampling particulate mass emissions. The pre-classifier must 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.

$3°D_1$ First Tertiary Dilution Device

The diluter must be specifically designed to dilute particle number concentration and output diluter sample equal to or greater than 200°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 the 3°D_1 must be selected such that particle number concentration downstream of the first tertiary diluter is <10^5 particles/cm^3 and >10^3 particles/cm^3.

HEPA filter

The HEPA filter providing dilution air to the tertiary dilution device(s) must be a filter capable of reducing particle numbers of 0.3µm dioctylphthalate aerosol by 99.97%.

ET   Evaporation tube

The ET must be length of tubing of length 350mm +/-10 mm and I.D 6mm +/- 0.1mm equipped with a heating mantle. The entire length of the ET must be controlled to a temperature greater than that of the first tertiary dilution device, with a portion of the length equivalent to a gas residence time of 0.5s +/- 0.05s held at > 400°C.

3°D_2 Second Tertiary Dilution Device

The diluter must be specifically designed to dilute particle number concentration and output diluter sample equal to or greater than the control temperature of the ET. The diluter should be supplied with HEPA filtered dilution air and be capable of a dilution ratio of 1 to 10 times. The dilution ratio of 3°D_2 must be selected such that particle number concentration downstream of the second tertiary diluter is <10^4 particles/cm^3.