

CHAPTER 5 :ANALYTICAL AND SAMPLING SYSTEMS

1 SCOPE :

This chapter describes the analytical and sampling system mentioned in para 3.3 of Chapter 3 of this Part.

2 Analytical Systems for determination of gaseous emission. System (HCLA or Equivalent System)

A schematic diagram of the analytical and gas sampling system using HCLA or equivalent systems for measuring NO_x is shown in Figure 1 of this chapter.

SP - Stainless steel sample probe to obtain samples from exhaust system. A closed end, multi-hole straight probe extending at least 80% across the exhaust pipe is recommended. The exhaust gas temperature at the probe shall be not less than 343 K (70° C). In the case of NG engine, the sample probe shall be installed at minimum 1.5m and maximum 2.5m from exhaust manifold or turbocharger.

HSL 1 - Heated sampling line, temperature shall be kept at 453 K - 473 K (180° C - 200° C): the line shall be made in stainless steel or PTFE.

F1 - Heated pre-filter, if used; temperature shall be the same as HSL 1.

T1 - Temperature readout of sample streams entering oven compartment.

V1 - Suitable valve for selecting sample, span gas or air or gas flow to the system. The valve shall be in the oven compartment or heated to the temperature of the sampling line HSL1.

V2,V3 - Needle valves to regulate calibration gas and zero gas.

F2 - Filter to remove particulates. A 70 mm diameter glass fibre type filter disc is suitable. The filter shall be readily accessible and changed daily or more frequently, as needed.

PI - Heated sample pump

G1 - Pressure gauge to measure pressure in sample line HC-analyser.

R3 - Pressure regulator valve to control pressure in sample line and flow to detector.

HFID - Heated flame ionization detector for hydrocarbons. Temperature of oven shall be kept at 453 K - 473 K (180° C - 200° C).

- FL1,FL2,FL3 - Flow meter to measure sample bypass flow.
- RI,R2 - Pressure regulators for air and fuel.
- HSL2 - Heated sampling line, temperature shall be kept between 368 K - 473 K (95° C - 200° C); the line shall be made in stainless steel or PTFE.
- HCLA - Heated chemiluminescence analyser for oxides of nitrogen.
- T2 - Temperature readout of sample stream entering HCLA analyser.
- T3 - Temperature readout of NO₂ - NO converter.
- V9, V10 - Three-way valve to by-pass NO₂ - NO converter.
- V11 - Needle valve to balance flow through NO₂ - NO converter and by-pass.
- SL - Sample line. The line shall be made in PTFE or in stainless steel. It may be heated or unheated.
- B - Bath to cool and condense water from exhaust sample. The bath shall be maintained at a temperature of 273 K - 277 K (0°C - 4°C) by ice or refrigeration...
- C - Cooling coil and trap sufficient to condense and collect water vapour (optional with water insensitive analyser).
- T4 - Temperature readout of bath temperature.
- V5,V6 - Toggle valves to drain condensate traps and bath.
- R4,R5 - Pressure regulator to control sample flow.
- V7,V8 - Bail valve or solenoid valves to direct sample, zero gas or calibrating gas streams to the analysers.
- V12, V13 - Needle valves to regulate flows to the analysers.
- CO - NDIR analyser for carbon monoxide.
- NO_x - HCLA analyser for oxides of nitrogen.
- FL4,FL5 - By-pass flowmeter.

V4, V 14 - Three-way ball or solenoid valves. The valves shall be in an oven compartment or heated to the temperatures of the sampling line HSLI.

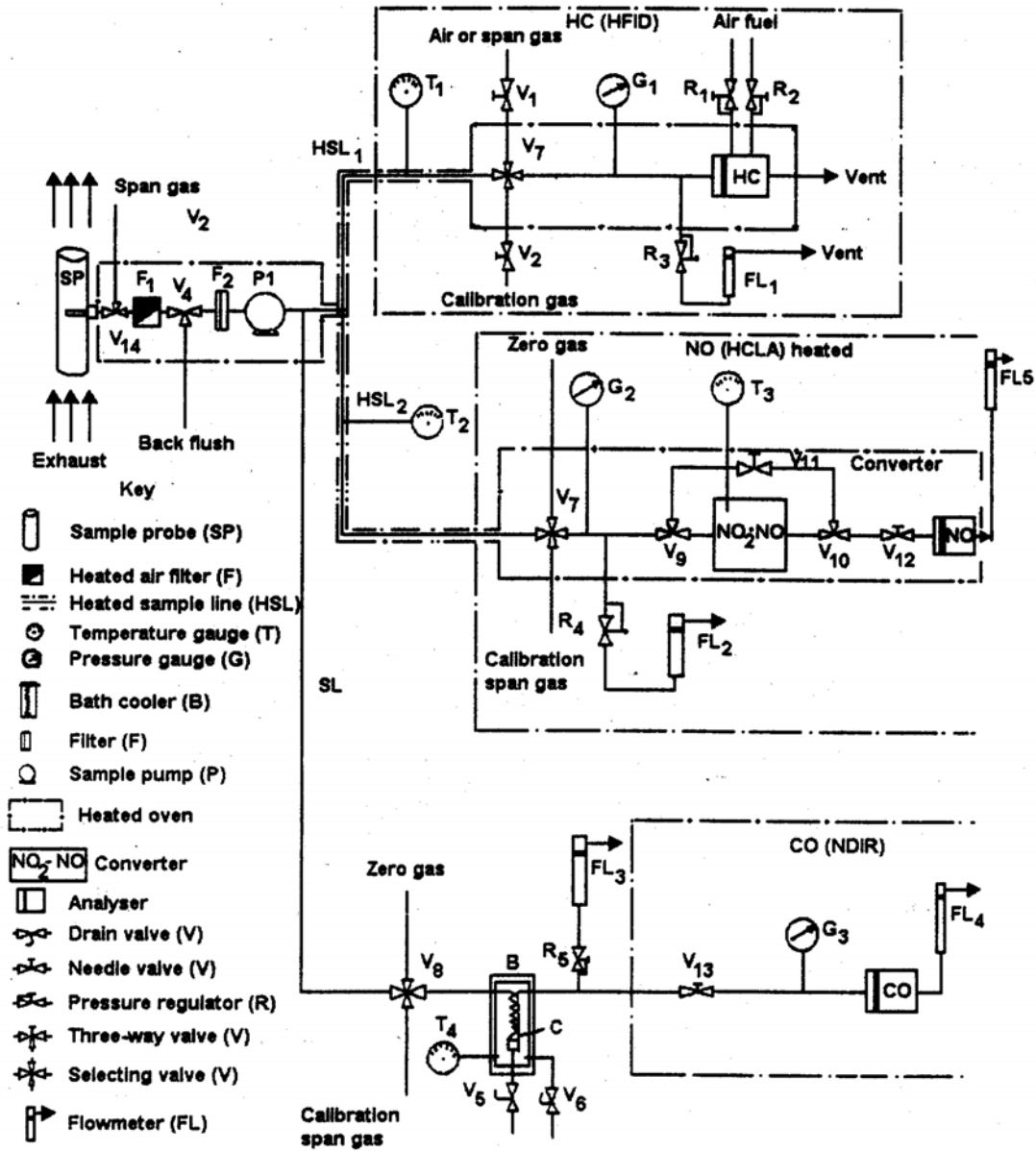


Figure 1

Flow Diagram of Exhaust Gas Analysis System for CO, NO_x and HC (Analysis by HCLA and Heated Sample Line).

3 DETERMINATION OF THE PARTICULATE EMISSION

The determination of particulate emissions requires dilution system capable of maintaining the temperature of the diluted exhaust gas at or below 325K (52 deg. C), the particulate sampling system, specified sampling filters and microgram balance which shall be placed in an air conditioned weighing chamber. Two principally different dilution and sampling systems (full-flow-dilution system and partial-flow-dilution-system) are used. The specification of filters, balance and the weighing chamber apply to both systems.

3.1 Particulate Sampling Filters

Fluorocarbon-coated glass fibre filters or fluorocarbon –based (membrane) filters are required.

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

The diluted exhaust are sampled by pair of filters placed in series (one primary and one back-up filter) during the test sequence. The back-up filter shall be located no more than 100mm down stream of and shall not be in contact with primary filter.

The recommended minimum loading on primary 47 mm filter (37 mm stain diameter) is 0.5 milligrams, on primary 70 mm filter (60 mm stain diameter) 1.3 milligrams.

Equivalent minimum loading of 0.5 –mg/1075 mm² (i.e mass/stain area) are recommended for other filters.

3.2 Weighing Chamber and Microbalance Specifications

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within $\pm 6K$ of set point between 293 and 303 K (20 ° C and 30 ° C) during all filter conditioning and weighing. The relative humidity shall be maintained to within $\pm 10\%$ relative humidity of a set point between 35% and 55 %.

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that could settle on particulate filtering during their stabilisation. At least two unused reference filters must be weighed within four hours of but preferably at the same time, as the sample filters weighing. If average weight of the reference filter changes between sample filter weighing by more than $\pm 6\%$ of the recommended minimum filter loading, then all sample filters discarded and the emission tests repeated.

In case of a weight change between -3.0% and -6.0% the manufacturer has

the option of either repeating the test or adding the average amount of weight loss to the net weight sample .

In case of a weight change between +3.0 % and +6.0 % the manufacturer has the option of either repeating the test or accepting the measured sample filter weight values.

If the average weight changes by not more than $\pm 3\%$ of minimum filter loading, the measured sample filter weights are used for calculations. The reference filters shall be of the same size and material as the sample filters and be changed at least once a month.

The microgram balance used to determine the weights of all the filters shall have a precision of 2% and readability of 1% of the recommended minimum filter loading.

3.3 Additional Specifications

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

3.4 System 2(Full-Flow-Dilution System)

A particulate sampling system is described based upon the dilution of the total exhaust using the CVS (Constant Volume Sampling) concept.

Figure 2 is a schematic drawing of this system. The total flow of the mixture of exhaust and dilution air shall be measured , and a sample shall be collected for analysis.

The mass of particulate emissions is subsequently determined from the mass sample collected on a pair of filters , the sample flow and the total flow of dilution air and exhaust over a test period. Either a PDP or a CFV and a single-dilution system may be used. Gaseous emissions shall not be determined with a CVS system. The components shall meet the following requirements

- EP- The exhaust pipe length from the exit of the engine exhaust manifold or turbocharger outlet to the dilution tunnel is required to be not more than 10m. If the system exceeds 4m in length then all tubing in excess of 4m shall be insulated. The radial thickness of the insulations must be at least 25 mm. The thermal conductivity of the insulating material shall have a value no greater than 0.1 W/mk measured at 673 k (300 ° K).

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

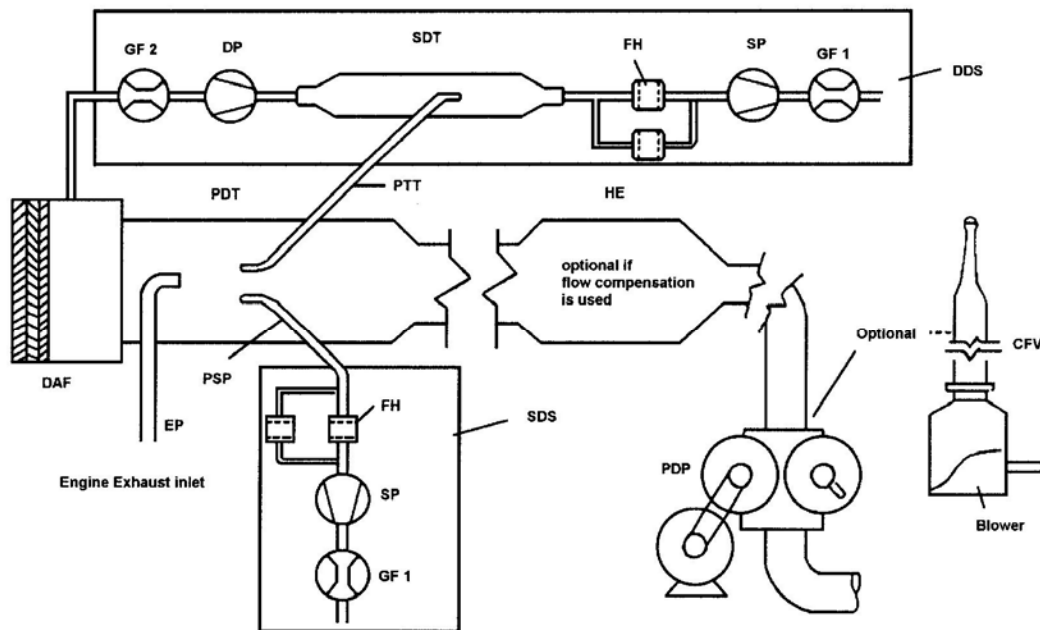


Figure 2 : Full-Flow dilution system

CFV- The critical flow venturi measures total diluted exhaust flow by maintaining the flow at choked conditions (critical flow). The static pressure variations in the raw exhaust shall conform to the specifications detailed for the PDP.

The gas mixture temperature immediately ahead of the CFV shall be within ± 11 K of the average operating temperature observed during the test, when flow compensation is used.

HE – The heat exchanger shall be of sufficient capacity to maintain the temperature within the limits required above(optional if EEC is used)

EFC- If the temperature at the inlet to either PDP or CFV is not kept constant, an electronic flow computation system is required for continuous measurement of the flow rate (optional if HE is used)

PDT- The primary dilution tunnel shall be: Small enough in diameter to cause turbulent flow (Reynolds Number > 4000) and of sufficient length to cause complete mixing of the exhaust and dilution air.

At least 460 mm in diameter with single – dilution system or at least 200 mm in diameter with a double –dilution system.

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

SDS – The single-dilution system collects sample from the primary tunnel and then passes this sample through the collection filters. The flow capacity of the PDP or CFV shall be sufficient to maintain the diluted exhaust at a temperature of no more than 325 K(52 °C) immediately before the primary particulate filter.

DDS- The double-dilution system collects sample form the primary tunnel and then transfers this sample to secondary dilution tunnel where the sample is further diluted. The double-diluted sample is then passed through the collection filters. The flow capacity of PDP or CFV shall be sufficient to maintain the diluted stream in the PDP at a temperature less than or equal to 464 K (191 ° C) at the sampling zone.The secondary dilution system shall provide sufficient secondary dilution air to maintain the double diluted exhaust stream temperature of less than or equal to 325 K(52°C) immediately before the primarily particulate filter.

PSP- The particulate sample probe (for SDS only) shall :

Be installed facing upstream at point where the dilution air exhaust gas are well mixed (i.e on the dilution tunnel centre – line, approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel)

Have an inside diameter at least 12 mm.

The distance from the probe tip to the filter holder shall not exceed 1020mm.
The sample probe shall not be heated.

PTT - The particulate transfer tube (for DDS only) shall be :

Installed facing upstream at a point where the dilution air and exhaust gas are well mixed (i.e on the dilution tunnel centre – line, approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel)
12mm minimum inside diameter.

Not more than 910 mm from the inlet plane to exit plane.

The particulate shall exit on the centre-line of the secondary dilution tunnel and point downstream. The sample shall not be heated.

- SDT- The secondary dilution tunnel (for DDS only) shall have minimum diameter of 75 mm and be of sufficient length so as to provide a residence time of at least 0.25 seconds for the double diluted sample. The primary filter holder shall be located within 300 mm of the exit of the secondary dilution tunnel
- DAF- The dilution air may be filtered at the dilution air inlet, shall have a temperature of 298 (25° C) \pm 5K and may be sampled to determine background particulate levels , which can then be subtracted from the values measured in diluted exhaust.
- FH – For primary and back-up filters housing the separate filter housing may be used. The requirements of paragraph 2.1.3 of this chapter have to be met. The filter holders shall not be heated
- SP- The particulate sample pump shall be located sufficiently distant from the tunnel so that the inlet gas temperature is maintained constant (\pm 3K) if flow computation is not used. The sample pump(s) shall be running throughout the complete test procedure. A bypass system is used for passing the sample through the sampling filters.
- DP- The dilution air pump (for DDS only) shall be located so that the secondary dilution air is supplied with a temperature of 298 (25 ° C) \pm 5K.
- GF1- The gas meter or flow instrumentation (for particulate sample flow) shall be located sufficiently distant from the tunnel so that the inlet gas temperature remain constant (\pm 3K), if flow computation is not used.
- GF2- The gas meter or flow instrumentation (dilution air, for DDS only) shall located so that the inlet gas temperature remains at 298 (25 ° C) \pm 5K.

3.5 System 3 (Partial – Flow –Dilution System)

A particulate sampling system is described based upon the dilution of part of the exhaust gas. Figure 3 is schematic drawing of this system. The mass of particulate emissions is determined from a mass sample collected on a pair of filter and from the dilution ratio sample flow and exhaust gas flow or fuel flow over the test period.

The calculation of the dilution ration depends upon type of system used . Only a fraction of diluted exhaust (fractional sampling type) or all of the diluted exhaust (total sampling type) may be sampled . All types described herein are

equivalent as long as they comply with the requirements of chapter 4 paragraph 4.2.6 ,appendix 3,paragraph 1.1.6.3.The Components shall meet the following requirements:

EP - For types without , isokinetic probe it is necessary to have a straight pipe of length of 6 pipe diameters upstream and 3 pipe diameters downstream of the tip of the probe .

For a type with isokinetic probe, the exhaust pipe shall be free of elbows, bends and sudden diameter changes for at least 15 pipe diameters upstream and 4 pipe diameters downstream of the tip of the probe. The exhaust gas velocity at the sampling zone shall be higher than 10 m/s and lower than 200 m/s.

Pressure oscillations of the exhaust gas shall not exceed ± 500 Pa on average. Any steps to reduce pressure oscillations beyond using a chasis – type exhaust system (including muffler) shall not alter engine performance nor cause the deposition of particulate.

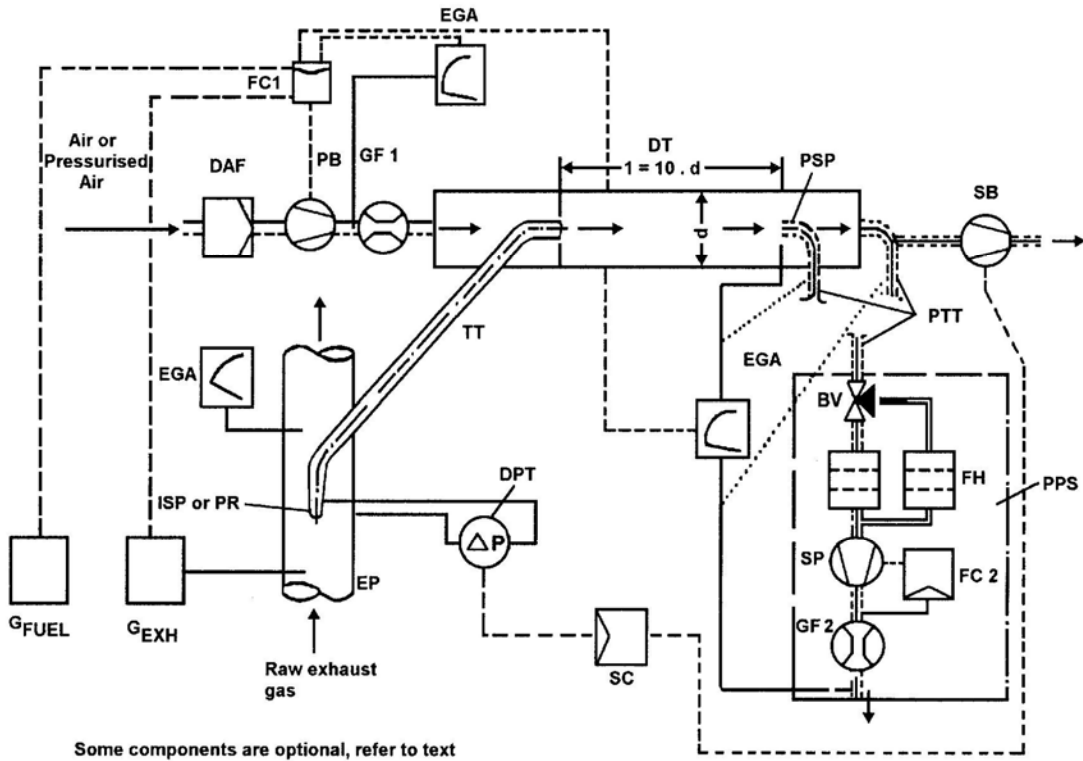


Figure 3 : Partial-flow dilution system

PR- The sampling probe shall be installed facing upstream on the exhaust

pipe centre-line at a point where the above flow conditions are met. the minimum inside diameter shall be 4 mm.

LSP- The isokinetic sampling probe (optional if EGA or mass flow control is used) shall be designed to provide a proportional sample of the raw exhaust gas. To that purpose, ISP replaces PR as described above and has to be connected to differential pressure transducer and a speed controller, to obtain isokinetic flow at the probe tip. The inside diameter shall be at least 12 mm.

EGA – Exhaust gas analysers (optional if EGA or a mass flow control is used) for CO₂ or NO_x analysis may be used (with carbon balance method CO₂ only). The analysers shall be calibrated in the same way as the analysers for the measurement of the gaseous pollutant. One or more analysers may be used for the determination of the concentration differences.

TT- The particulate sample transfer tube shall be :

Heated or insulated so that the gas temperature in the transfer tube be not below 423K (150° C). If the exhaust gas temperature is below 425 K (150° C) it shall not be below the exhaust gas temperature.

Equal to or greater in diameter than probe diameter, but no more than 25 mm in diameter.

Not more than 100 mm from inlet plane to exit plane.

The particulate sample shall exit on the centre-line of the dilution tunnel and point downstream.

SC- (For ISP Only) A pressure control system is necessary for isokinetic exhaust splitting by maintaining a differential pressure of zero between EP and ISP. Under these conditions, exhaust gas velocities in EP and ISP are identical, and mass flow through ISP is a constant fraction of the total exhaust gas flow. The adjustment is done by controlling the speed of the suction blower (SB) and keeping the speed of the pressure blower (SP) constant during each mode. The remaining error in the pressure control loop shall not exceed $\pm 0.5\%$ of the measuring range of the pressure transducer (DPT). The pressure oscillations in the dilution tunnel shall not exceed ± 250 Pa on average.

DPT- DPT - (for ISP only) the differential pressure transducer shall have a maximum range of ± 500 Pa.

FCI- A flow controller (dilution air) is necessary to control the dilution air mass flow. It may be connected to the exhaust flow or fuel flow and /or CO₂ differential signal.

When using pressurised air supply, FCI directly controls the air flow.

GF 1- The gas meter or flow instrumentation (particulate sample flow) shall be located so that the inlet gas temperature remains at 298 K(25° C) ± 5K.

SB – (For Fractional sampling type only)

PB – To control the dilution air mass flow rate, PB shall be connected to FCI. Exhaust flow or fuel flow and /or CO₂ differential signals may be used as command signals. PB is not required when using pressurised air supply.

DAF- The dilution air may be filtered at the dilution air inlet, shall have a temperature of 298 (25 °C) ± 5K and may be sampled to determine background particulate levels, which can then be subtracted from the values measured in the diluted exhaust.

DT- The dilution tunnel shall be :

Small enough in diameter to cause turbulent flow (Reynolds Number >4000) and of sufficient length to cause complete mixing of the exhaust and dilution air.

At least 25 mm in diameter for the total sampling type.

At least 25 mm in diameter for the fractional sampling type.

The engine exhaust shall be directed downstream at the point where it is introduced into the dilution tunnel. And thoroughly mixed with in the dilution air means of mixing orifice. For the fractional sampling type, the mixing quality shall be checked after introduction into service by means of a CO₂ profile the tunnel with the engine running (at least six equally spaced measuring points.)

PSS- The particulate sampling system shall be configured so as to collect a sample from the dilution tunnel and to pass this sample through the sampling filters (fractional sampling type) or to pass all of the diluted exhaust through the sampling filters (total sampling type). In order to avoid any impact on the control loops, it is recommended that the sample pump be running through out the complete test procedure . A bypass system with a ball valve between the sample probe and filter holder shall be used for passing the sample through the sampling filters

at the desired times. Interference of the switching procedure on the control loops shall be corrected within less than three seconds.

PSP- The particulate sample probe shall be:

Installed facing upstream at point where the dilution air and exhaust gas are well mixed (i.e on the dilution tunnel centre-line, approximately 10 tunnel diameter downstream of the point where the exhaust enters the dilution tunnel). Have inside diameter of at least 12 mm.

PTT- The particulate transfer tube shall not be heated and shall not exceed 1020 mm in length :

For fractional sampling type from the probe tip to the filter holder.

For the total sampling type from the end of the dilution tunnel to the filter holder.

FH- For primary and back-up filters one filter housings may be used. The requirements of paragraph 2.1.3 of this chapter shall be met. The filter holders shall not be heated.

SP- The particulate sample pump shall be located sufficiently distant from the tunnel so that the inlet gas temperature is maintained constant ($\pm 3K$), if flow computation is not used.

FC2 – A flow controller (particulate sample flow, optional) may be used, in order to improve accuracy of the particulate sample flow rate.

GF2- The gas meter or flow instrumentation (particulate sample flow) shall be located sufficiently distant from the tunnel so that the inlet gas temperature remains constant ($\pm 3K$), if flow computation is not used.

BV- The ball valve shall have a diameter no less than the sampling tube and a switching time less than 0.5 seconds.