SCHEDULE 5 Regulations 2(3) and 9(1)

(ANNEX V to Directive 97/68/EC)
ANALYTICAL AND SAMPLING SYSTEM

GASEOUS AND PARTICULATE SAMPLING SYSTEMS

Figure Number	*Description*
2	Exhaust gas analysis system for raw exhaust
3	Exhaust gas analysis system for dilute exhaust
4	Partial flow, isokinetic flow, suction blower control, fractional sampling
5	Partial flow, isokinetic flow, pressure blower control, fractional sampling
6	Partial flow, CO_2 or NOsubx; control, fractional sampling
7	Partial flow, CO_2 and carbon balance, total sampling
8	Partial flow, single venturi and concentration measurement, fractional sampling
9	Partial flow, twin venturi or orifice and concentration measurement, fractional sampling
10	Partial flow, multiple tube splitting and concentration measurement, fractional sampling
11	Partial flow, flow control, total sampling
12	Partial flow, flow control, fractional sampling
13	Full flow, positive displacement pump or critical flow venturi, fractional sampling
14	Particulate sampling system
15	Dilution system for full flow system

Determination of the gaseous emissions

1.1. Section 1.1.1 and Figures 2 and 3 contain detailed descriptions of the recommended sampling and analysing systems. 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.

Gaseous exhaust components CO, CO_2, HC, NO_X

1.1.1. An analytical system for the determination of the gaseous emissions in the raw or diluted exhaust gas is described based on the use of:

- HFID analyser for the measurement of hydrocarbons,
- NDIR analysers for the measurement of carbon monoxide and carbon dioxide,
- HCLD or equivalent analyser for the measurement of nitrogen oxide.

For the raw exhaust gas (see Figure 2), the sample for all components may be taken with one sampling probe or with two sampling probes located in close proximity and internally split to the different analysers. Care must be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

For the diluted exhaust gas (see Figure 3), the sample for the hydrocarbons shall be taken with another sampling probe than the sample for the other components. Care must be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

Figure 2

Flow diagram of exhaust gas analysis system for CO, CO_2 and HC

$$PT = \frac{PT_{mass}}{\sum_{i=1}^{n} P_i \times WF_i}$$

Figure 3

Flow diagram of dilute exhaust gas analysis system for CO, CO_2, NO_X and HC

$$PT = \frac{\sum_{i=1}^{n} PT_{mass,i} \times WF_i}{\sum_{i=1}^{n} P_i \times WF_i}$$

Descriptions—Figures 2 and 3

General statement

All components in the sampling gas path must be maintained at the temperature specified for the respective systems

- *SP1 raw exhaust gas sampling probe (Figure 2 only)*

  A stainless steel straight closed and multihole probe is recommended. The inside diameter shall not be greater than the inside diameter of the sampling line. The wall thickness of the probe shall not be greater than 1 mm. There shall be a minimum of three holes in three different radial planes sized to sample approximately the same flow. The probe must extend across at least 80% of the diameter of the exhaust pipe.

- *SP2 dilute exhaust gas HC sampling probe (Figure 3 only)*

  The probe shall:

  - be defined as the first 254 mm to 762 mm of the hydrocarbon sampling line (HSL3),

- have a 5 mm minimum inside diameter,
- be installed in the dilution tunnel DT (section 1.2.1.2) at a point where the dilution air and exhaust gas are well mixed (ie approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel),
- be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies,
- be heated so as to increase the gas stream temperature to 463 K (190°C)±10 K at the exit of the probe.

— *SP3 dilute exhaust gas CO, CO_2, NO_X sampling probe*(Figure 3 only)

The probe shall:

- be in the same plane as SP2,
- be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies,
- be heated and insulated over its entire length to a minimum temperature of 328 K (55°C) to prevent water condensation.

— *HSLI heated sampling line*

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

The sampling line shall:

- have a 5 mm minimum and a 13.5 mm maximum inside diameter,
- be made of stainless steel or PTFE,
- maintain a wall temperature of 463 (190°C)± 10 K as measured at every separately controlled heated section, if the temperature of the exhaust gas at the sampling probe is equal or below 463 K (190°C),
- maintain a wall temperature greater than 453 K (180°C) if the temperature of the exhaust gas at the sampling probe is about 463 K (190°C),
- maintain a gas temperature of 463 K (190°)± 10 K immediately before the heated filter (F2) and the HFID.

— *HSL2 heated NO_X sampling line*

The sampling line shall:

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

Since the sampling line need only be heated to prevent condensation of water and sulphuric acid, the sampling line temperature will depend on the sulphur content of the fuel.

— *SL sampling line for CO (CO_2)*

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

— *BK background bag* (optional; Figure 3 only)

For the measurement of the background concentrations.

— *BG sample bag* (optional; Figure 3 CO and CO_2 only)

For the measurement of the sample concentrations.

— F1 heated pre-filter (optional)

The temperature shall be the same as HSL1.

— *F2 heated filter*

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

— *P heated sampling pump*

The pump shall be heated to the temperature of HSL1.

— *HC*

Heated flame ionization detector (HFID) for the determination of the hydrocarbons. The temperature shall be kept at 453 to 473 K (180 to 200°C).

— *CO, CO_2*

NDIR analysers for the determination of carbon monoxide and carbon dioxide.

— *NO_2*

(H)CLD analyser for the determination of the oxides of nitrogen. If a HCLD is used it shall be kept at a temperature of 328 to 478 K (55 to 200°C).

— *C converter*

A converter shall be used for the catalytic reduction of NO2 to NO prior to analysis in the CLD or HCLD

— *B cooling bath*

To cool and condense water from exhaust sample. The bath shall be maintained at a temperature of 273 to 277 K (0 to 4°C) by ice or refrigeration. It is optional if the analyser is free from water vapour interference as determined in Annex III, Appendix 3, sections 1.9.1 and 1.9.2.

Chemical dryers are not allowed for removing water from the sample.

— *T1, T2, T3 temperature sensor*

To monitor the temperature of the gas stream.

— *T4 temperature sensor*

Temperature of the NO_2-NO converter.

— *T5 temperature sensor*

To monitor the temperature of the cooling bath.

— *G1, G2, G3 pressure gauge*

To measure the pressure of the sampling lines.

— *R1, R2 pressure regulator*

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

— *R3, R4, R5 pressure regulator*

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

— *FL1, FL2, FL3 flow-meter*

To monitor the sample bypass flow.

— *FL4 to FL7 flowmeter (optional)*

To monitor the flow rate through the analysers.

— *V1 to V6 selector valve*

Suitable valving for selecting sample, span gas or zero gas flow to the analyser.

— *V7, V8 solenoid valve*

To bypass the NO2-NO converter.

— *V9 needle valve*

To balance the flow through the NO2-NO converter and the bypass.

— *V10, V11 needle valve*

To regulate the flows to the analysers.

— *V12, V13 toggle valve*

To drain the condensate from the bath B.

— *V14 selector valve*

Selecting the sample or background bag.

Determination of the particulates

1.2 Sections 1.2.1 and 1.2.2 and Figures 4 to 15 contain detailed descriptions of the recommended dilution and sampling systems. Since various configurations can produce equivalent results, exact conformance with these figures is not required. Additional components such as instruments, valve, 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 on good engineering judgement.

1.2.1 *Dilution system*

Partial flow system (Figures 4 to 12)

1.2.1.1 A dilution system is described based on the dilution of a part of the exhaust stream. Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire dilute exhaust gas or only a portion of the dilute exhaust gas may be passed to the particulate sampling system (section 1.2.2, Figure 14). The first method is referred to as *total sampling type*, the second method as *fractional sampling type*.

The calculation of the dilution ratio depends on the type of system used.

The following types are recommended:

— *isokinetic systems* (Figures 4 and 5)

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

— *flow controlled systems with concentration measurement* (Figures 6 to 10)

— With these systems, a sample is taken from the bulk exhaust stream by adjusting the dilution air flow and the total dilution exhaust flow. The dilution ratio is determined from the concentrations of tracer gases, such as CO_2 or NO_X, naturally occurring in the engine exhaust. The concentrations in the dilution exhaust gas and in the dilution air are measured, whereas the concentration in the raw exhaust gas can be either measured directly or determined from fuel flow and the carbon balance equation, if the fuel composition is known. The systems may be controlled by the calculated dilution ratio (Figures 6 and 7) or by the flow into the transfer tube (Figures 8, 9 and 10),

— *flow controlled systems with flow measurement* (Figures 11 and 12)

- With these systems, a sample is taken from the bulk exhaust stream by setting the dilution air flow and the total dilution exhaust flow. The dilution ratio is determined from the difference of the two flow rates. Accurate calibration of the flow-meters relative to one another is required, since the relative magnitude of the two flow rates can lead to significant errors at higher dilution ratios (Figures 9 and above). Flow control is very straightforward by keeping the dilute exhaust flow rate constant and varying the dilution air flow rate, if needed.
- In order to realize the advantages of the partial flow dilution systems, attention must be paid to avoiding the potential problems of loss of particulates in the transfer tube, ensuring that a representative sample is taken from the engine exhaust, and determination of the split ratio.
- The systems described pay attention to these critical areas.

Figure 4

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

$$\boxed{P_i = P_{m,i} + P_{AE,i}}$$

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

Figure 5

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

$$WF_{E,i} = \frac{M_{SAM,i} \times (G_{EDFW})_{aver}}{M_{SAM} \times (G_{EDFW,i})}$$

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

Figure 6

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

$$WF_{E,i} = \frac{V_{SAM,i} \times (V_{EDFW})_{aver}}{V_{SAM} \times (V_{EDFW,i})}$$

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

Figure 7

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

$$\text{Specific energy (calorific value) (net) MJ/kg} = (46.423 - 8.792.d^2 + 3.17.d) \text{ x } (1 - (x + y + s)) + 9.42.s - 2.499.x.$$

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The CO_2 concentrations are measured in the diluted exhaust gas and in the dilution air with the exhaust gas analyser(s) EGA. The CO_2 and fuel flow G_{FUEL}signals are transmtted either to the flow controller FC2, or to the flow controller FC3 of the particulate sampling system (see Figure 14), FC2 controls the pressure blower PB, while FC3 controls the particulate sampling system (see Figure 14), thereby adjusting the flows into and out of the system so as to maintain the desired exhaust split and dilution ratio in DT. The dilution ratio is calculated from the CO_2 concentrations and G_{FUEL}using the carbon balance assumption.

Figure 8

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

$$PT_{adj} = PT + [SFC \text{ x } 0.0917 \text{ x } (NSLF - FSF)]$$

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

Figure 9

Partial flow dilution system twin venturi or twin orifice, concentration measurement and fractional sampling

$$SFC = \frac{\sum_{i=1}^{n} G_{FUEL,i} \text{ x } WF_i}{\sum_{i=1}^{n} P_i \text{ x } WF_i}$$

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

Figure 10

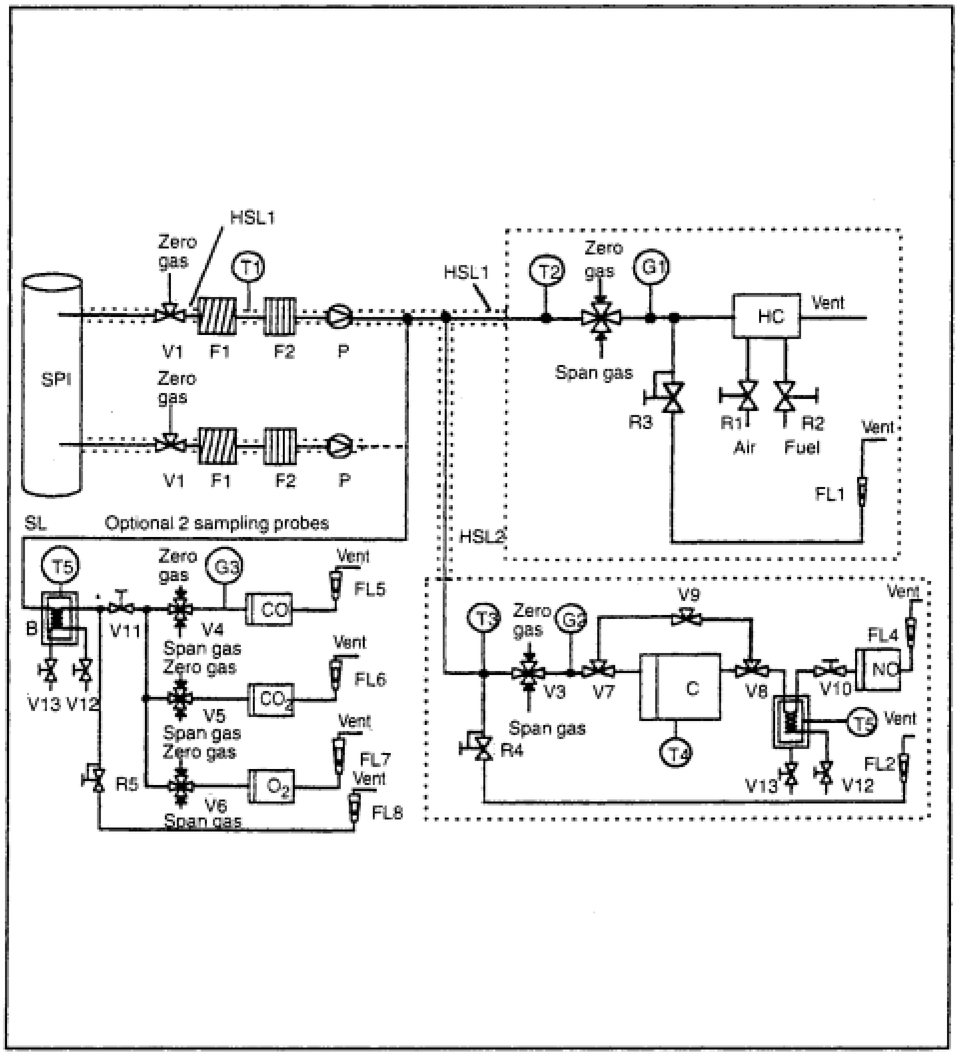
Partial flow dilution system with multiple tube splitting, concentration measurement and fractional sampling

$$\boxed{\mathbf{P}_i = \mathbf{P}_{m,i} + \mathbf{P}_{AE,i}}$$

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

Figure 11

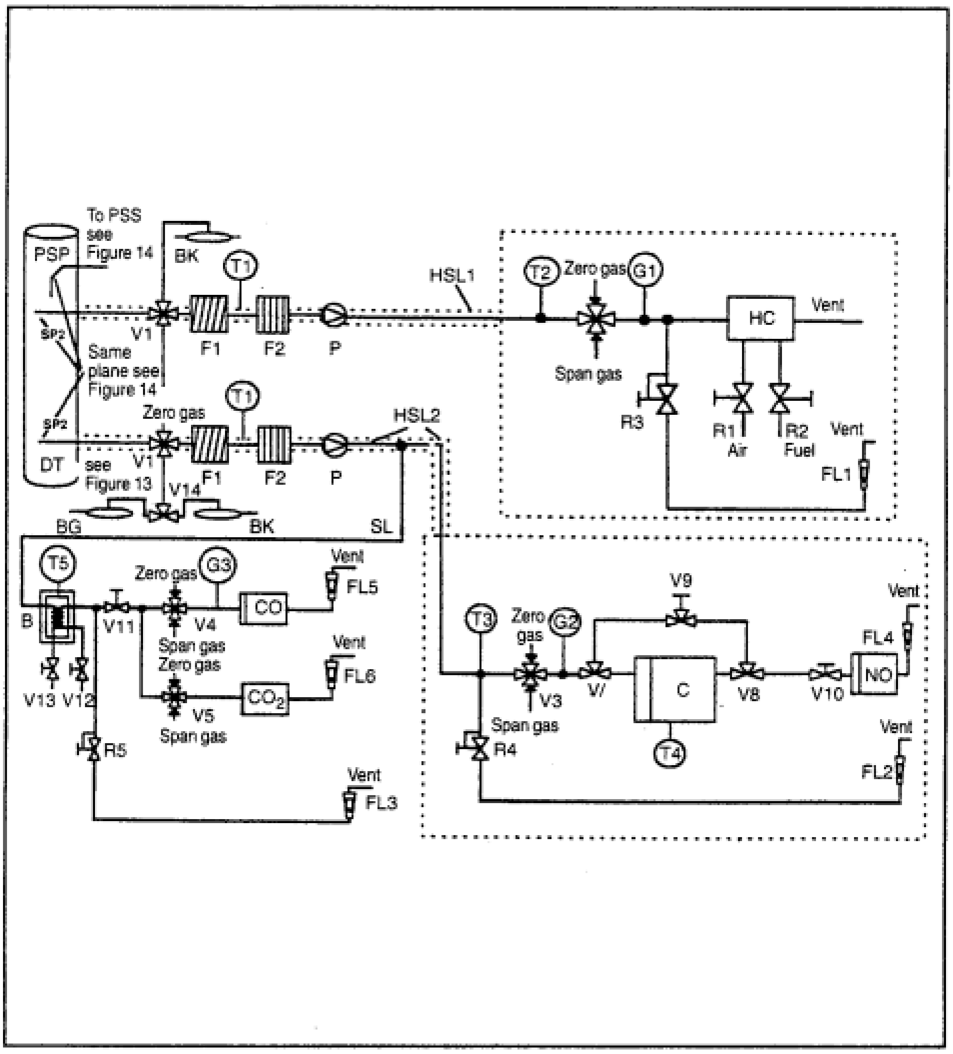
Partial flow dilution system with flow control and total sampling



Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The total flow through the tunnel is adjusted with the flow controller FC3 and the sampling pump P of the particulate sampling system (see Figure 16). The dilution air flow is controlled by the flow controller FC2, which may use $G_{EXH,}$ G_{AIR} or G_{FUEL}as command signals, for the desired exhaust split. The sample flow into DT is the difference of the total flow dilution air flow. The dilution air flow rate is measured with flow measurement device FM1, the total flow rate with the flow measurement device FM3 of the particulate sampling system (see Figure 14). The dilution ratio is calculated from these two flow rates.

Figure 12

Partial flow dilution system with flow control and fractional sampling



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

Description— Figures 4 to 12

— EP exhaust pipe

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

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

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

— *SP Sampling probe (Figures 6 to 12)*

The minimum inside diameter shall be 4 mm. The minimum diameter ratio between exhaust pipe and probe shall be four. The probe shall be an open tube facing upstream on the exhaust pipe centre-line, or a multiple hole probe as described under SP1 in section 1.1.1.

— *ISP isokinetic sampling probe (Figures 4 and 5)*

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

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

— *FD1, FD2 flow divider* **(Figure 9)**

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

— *FD3 flow divider* **(Figure 10)**

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

— *EGA exhaust gas analyser* **(Figures 6 to 10)**

CO_2 or NO_X analysers may be used (with carbon balance method CO_2 only). The analysers shall be calibrated like the analysers for the measurement of the gaseous emissions. One or several analysers may be used to determine the concentration differences.

The accuracy of the measuring systems has to be such that the accuracy of $G_{EDFW,,i}$ or $V_{EDFW,,i}$ is within ± 4%.

— *TT Transfer tube* **(Figures 4 to 12)**

The particulate sample transfer tube shall be:

- as short as possible, but not more than 5m in length,
- equal to or greater than the probe diameter, but not more than 25mm in diameter,
- exiting on the centre-line of the dilution tunnel and pointing down-stream.

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

Alternatively, the transfer tube wall temperatures required may be determined through standard heat transfer calculations.

— *DPT differential pressure transducer* **(Figures 4, 5 and 10)**

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

— *FCI flow controller* **(Figures 4, 5 and 10)**

For the isokinetic systems (Figures 4 and 5) a flow controller is necessary to maintain a differential pressure of zero between EP and ISP. The adjustment can be done by:

(a) controlling the speed or flow of the suction blower (SB) and keeping the speed of the pressure blower (PB) constant during each mode (Figure 4);

or

(b) adjusting the suction blower (SB) to a constant mass flow of the diluted exhaust and controlling the flow of the pressure blower PB, and therefore the exhaust sample flow in a region at the end of the transfer tube (TT) (Figure 5).

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

For a multi-tube system (Figure 10) a flow controller is necessary for proportional exhaust splitting to maintain a differential pressure of zero between the outlet of the multi-tube unit and the exit of TT. The adjustment can be done by controlling the injection air flow rate into DT at the exit of TT.

— *PCVI, PCV2 pressure control valve* **(Figure 9)**

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

— *DC damping chamber* **(Figure 10)**

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

— *VN venturi* **(Figure 8)**

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

FC2 flow controller **(Figures 6, 7, 11 and 12, optional)**

A flow controller may be used to control the flow of the pressure blower PB and/or the suction blower SB. It may be connected to the exhaust flow or fuel flow signal and/or to the CO_2 or NO_X differential signal.

When using a pressurized air supply (Figure 11) FC2 directly controls the air flow.

FM1 flow measurement device **(Figures 6, 7, 11 and 12)**

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

FM2 flow measurement device **(Figure 12)**

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

PB pressure blower **(Figures 4, 5, 6, 7, 8, 9 and 12)**

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

— *SB suction blower* (Figures 4, 5, 6, 9, 10 and 12)

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

— *DAF dilution air filter* **(Figures 4 to 12)**

It is recommended that the dilution air be filtered and charcoal scrubbed to eliminate background hydrocarbons. The dilution air shall have a temperature of 298 K (25°C) ± 5 K.

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

— *PSP particulate sampling probe* **(Figures 4, 5, 6, 8, 9, 10 and 12)**

The probe is the leading section of PTT and

- shall be installed facing upstream at a point where the dilution air and exhaust gas are well mixed, ie on the dilution tunnel DT centre-line of the dilution systems approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel,
- shall be 12 mm in minimum inside diameter,

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

— may be insulated.

— *DT dilution tunnel* **(Figures 4 to 12)**

The dilution tunnel:

— shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions,

— shall be constructed of stainless steel with:

  — a thickness to diameter ratio of 0.025 or less for dilution tunnels of greater than 75 mm inside diameter,

  — a nominal wall thickness of not less than 1.5 mm for dilution tunnels of equal to or less than 75 mm inside diameter,

— shall be at least 75 mm in diameter for the fractional sampling type,

— is recommended to be at least 25mm in diameter for the total sampling type.

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

May be insulated

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

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

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

— *HE heat exchanger* **(Figures 9 and 10)**

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

Full flow dilution system (Figure 13)

1.2.1.2. A dilution system is described based upon the dilution of the total exhaust using the constant volume sampling (CVS) concept. The total volume of the mixture of exhaust and dilution air must be measured. Either a PDP or a CFV system may be used.

For subsequent collection of the particulates, a sample of the dilute exhaust gas is passed to the particulate sampling system (section 1.2.2, Figures 14 and 15). If this is done directly, it is referred to as single dilution. If the sample is diluted once more in the secondary dilution tunnel, it is referred to as double dilution. This is useful, if the filter face temperature requirement cannot be met with single dilution. Although partly a dilution system, the double dilution system is described as a modification of a particulate sampling system in section 1.2.2, Figure 15, since it shares most of the parts with a typical particulate sampling system.

The gaseous emissions may also be determined in the dilution tunnel of a full flow dilution system. Therefore, the sampling probes for the gaseous components are shown in Figure 13 but do not appear in the description list. The respective requirements are described in section 1.1.1.

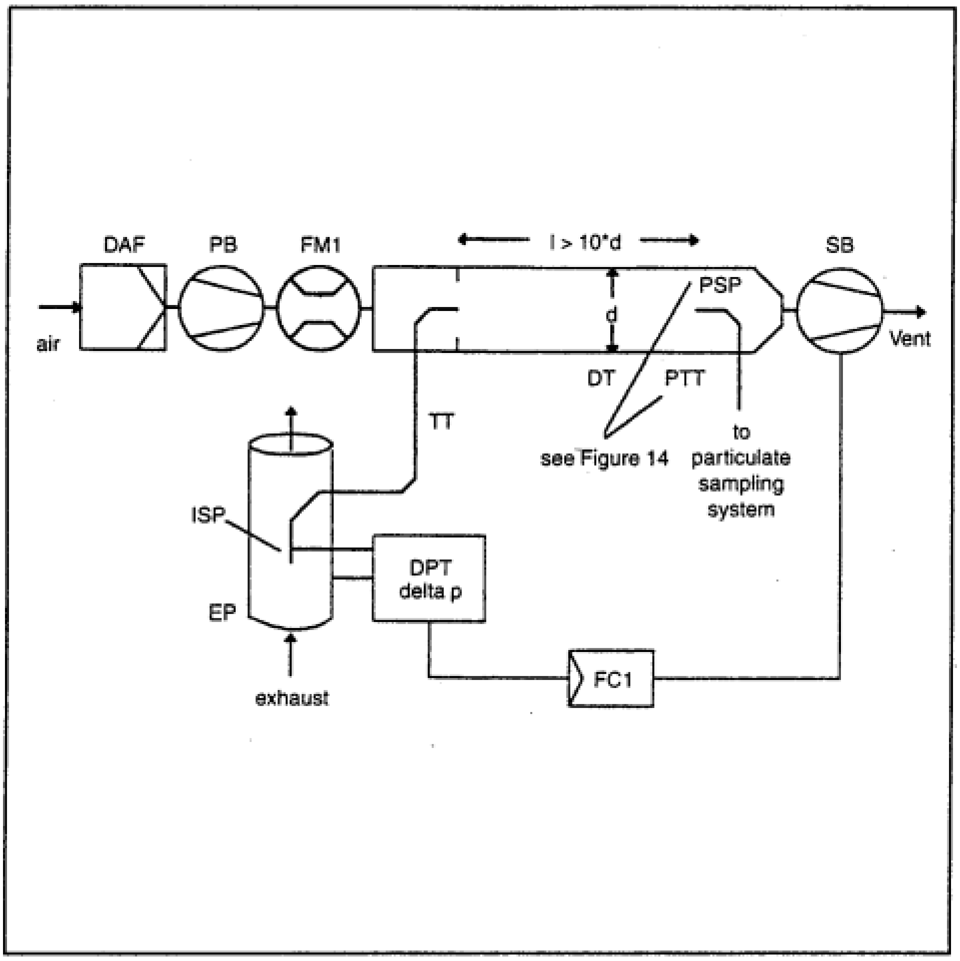
Descriptions—Figure 13

— EP exhaust pipe

The exhaust pipe length from the exit of the engine exhaust manifold, turbocharger outlet or after-treatment device to the dilution tunnel is required to be not more than 10 m. If the system exceeds 4 m in length, then all tubing in excess of 4 m shall be insulated, except for an in-line smoke-meter, if used. The radial thickness of the insulation must be at least 25 mm. The thermal conductivity of the insulating material must have a value no greater than 0.1 W/(m.K) measured at 673 K (400°C). To reduce the thermal inertia of the exhaust pipe a thickness to diameter ratio of 0.015 or less is recommended. The use of flexible sections shall be limited to a length to diameter ratio of 12 or less.

Figure 13

Full flow dilution system



The total amount of raw exhaust gas is mixed in the dilution tunnel DT with the dilution air.

The diluted exhaust gas flow rate is measured either with a positive displacement pump PDP or with a critical flow venturi CFV. A heat exchanger HE or electronic flow compensation EFC may be used for proportional particulate sampling and for flow determination. Since particulate mass determination is based on the total diluted exhaust gas flow, the dilution ratio is not required to be calculated.

— *PDP positive displacement pump*

The PDP meters total diluted exhaust flow from the number of the pump revolutions and the pump displacement. The exhaust system back pressure must not be artificially lowered by the PDP or dilution air inlet system. Static exhaust back pressure measured with the CVS system operating 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.

Flow compensation can only be used if the temperature at the inlet of the PDP does not exceed 50°C (323 K).

— *CFV critical flow venturi*

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

— *HE heat exchanger* **(optional if EFC is used)**

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

— *EFC electronic flow compensation* **(optional if HE is used)**

If the temperature at the inlet to either the PDP or CFV is not kept within the limits stated above, a flow compensation system is required for continuous measurement of the flow rate and control of the proportional sampling in the particulate system.

To that purpose, the continuously measured flow rate signals are used to correct the sample flow rate through the particulate filters of the particulate sampling system (see Figures 14 and 15), accordingly.

— *DT dilution tunnel*

The dilution tunnel:

- shall be small enough in diameter to cause turbulent flow (Reynolds number greater than 4000) of sufficient length to cause complete mixing of the exhaust and dilution air. A mixing orifice may be used,
- shall be at least 75 mm in diameter,
- may be insulated.

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

When using *single dilution*, a sample from the dilution tunnel is transferred to the particulate sampling system (section 1.2.2, Figure 14). The flow capacity of the PDP of CFV must be sufficient to maintain the diluted exhaust at a temperature of less than or equal to 325 K (52°C) immediately before the primary particulate filter.

When using *double dilution*, a sample from the dilution tunnel is transferred to the secondary dilution tunnel where it is further diluted, and then passed through the sampling filters (section 1.2.2, Figure 15).

The flow capacity of the PDP or CFV must be sufficient to maintain the diluted exhaust stream in the DT at a temperature of less than or equal to 464 K (191°C) at the sampling zone. The secondary dilution system must provide sufficient secondary dilution air to maintain the doubly-diluted exhaust stream at a temperature of less than or equal to 325 K (52°C) immediately before the primary particulate filter.

— *DAF dilution air filter*

It is recommended that the dilution air be filtered and charcoal scrubbed to eliminate background hydrocarbons. The dilution air shall have a temperature of 298 K (25°C) ± 5 K. At the manufacturer's request the dilution air shall be sampled according to good engineering practice to determine the background particulate levels, which can then be subtracted from the values measured in the diluted exhaust.

— *PSP particulate sampling probe*

The probe is the leading section of PTT and

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

Particulate sampling system (Figures 14 and 15)

1.2.2. 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 dilute exhaust sample through the filters, dilution (section 1.2.1.1, Figures 7 and 11) 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 (section 1.2.1.1, Figures 4, 5, 6, 8, 9, 10 and 12 and section 1.2.1.2, Figure 13) and sampling systems usually form different units.

In this Directive, the double dilution system DDS (Figure 15) of a full flow dilution system is considered as a specific modification of a typical particulate sampling system as shown in Figure 14. 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 shall 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.

Descriptions—Figures 14 and 15

— PSP particulate sampling probe (Figures 14 and 15)

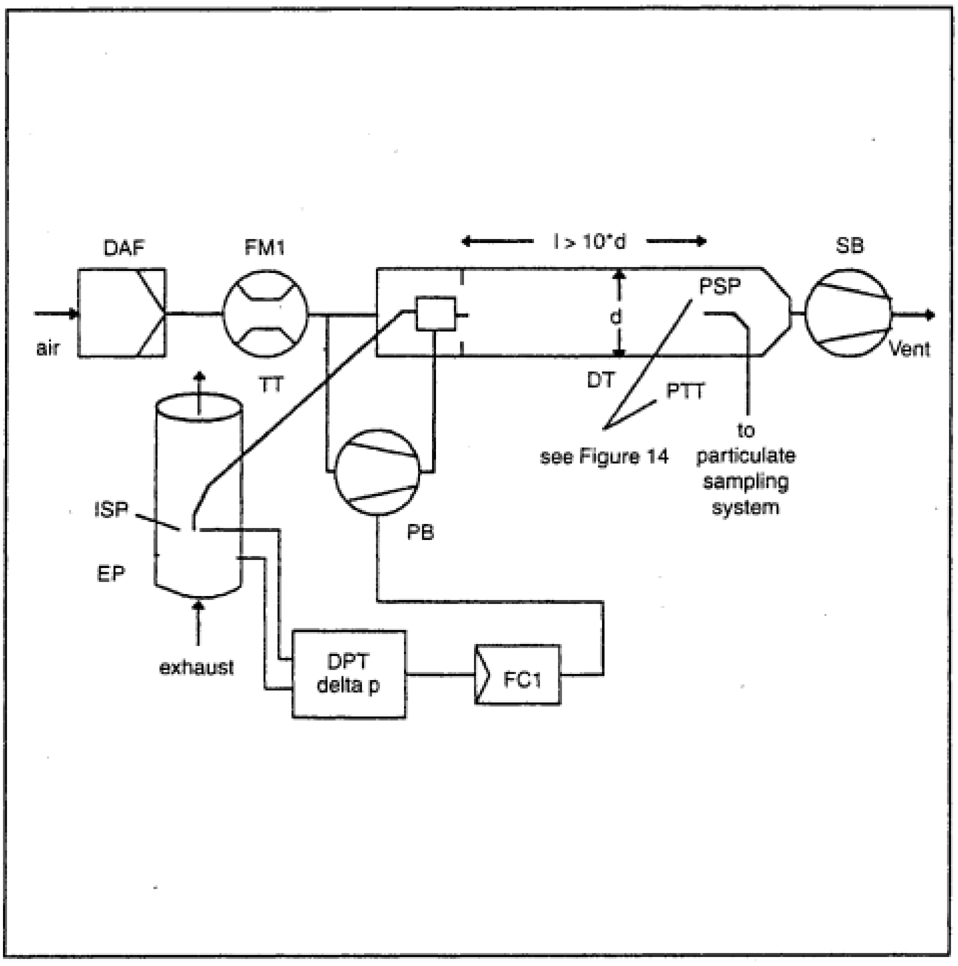
The particulate sampling probe shown in the figures is the leading section of the particulate transfer tube PTT.

The probe:

- — shall be installed facing upstream at a point where the dilution air and exhaust gas are well mixed, ie on the dilution tunnel DT centre-line of the dilution systems (see section 1.2.1), approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel),
- — shall be 12 mm in minimum inside diameter,
- — may be heated to no greater than 325 K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel,
- — may be insulated.

Figure 14

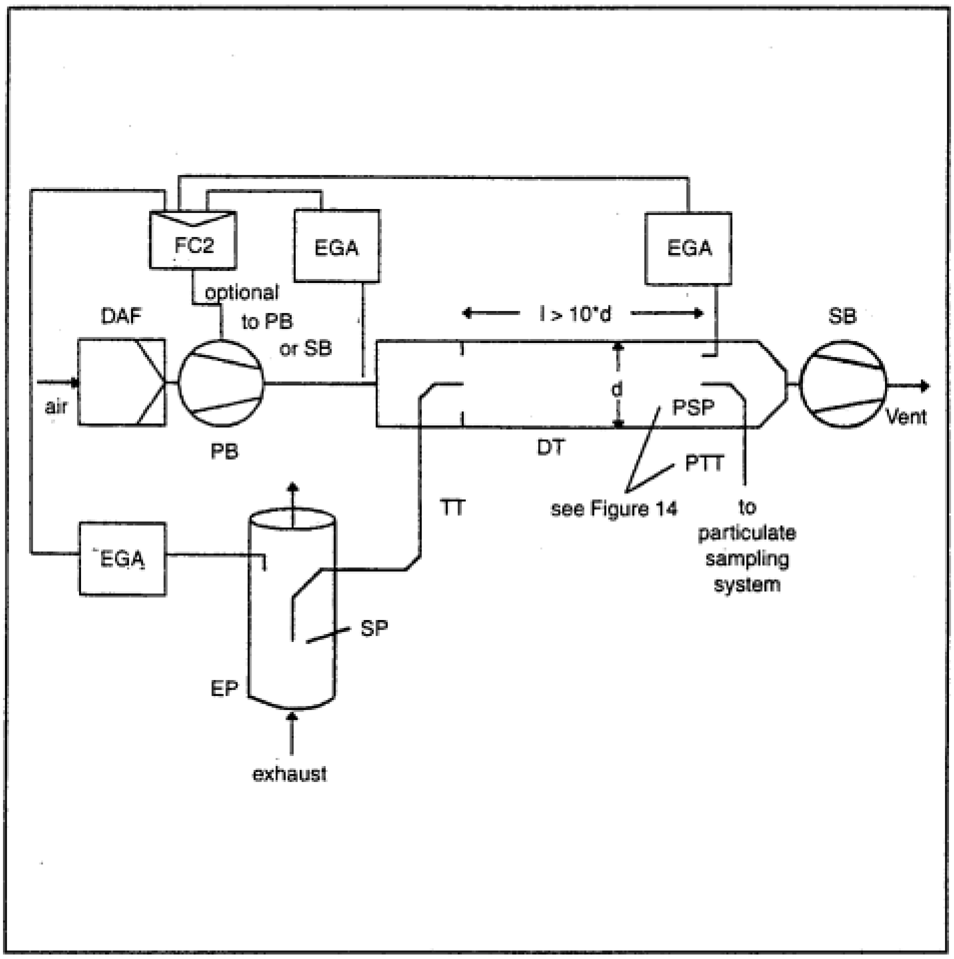
Particulate sampling system



A sample of the diluted exhaust gas is taken from the dilution tunnel DT of a partial flow or full flow dilution system through the particulate sampling probe PSP and the particulate transfer tube PTT by means of the sampling pump P. The sample is passed through the filter holder(s) FH that contain the particulate sampling filters. The sample flow rate is controlled by the flow controller FC3. If electronic flow compensation EFC (see Figure 13) is used, the diluted exhaust gas flow is used as command signal for FC3.

Figure 15

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

— *PTT particulate transfer tube* **(Figures 14 and 15)**

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

The dimensions are valid for:

- the partial flow dilution fractional sampling type and the full flow single dilution system from the probe up 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 probe tip to the secondary dilution tunnel.

The transfer tube:

- 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.

— *SDT secondary dilution tunnel* **(Figure 15)**

The second dilution tunnel should have a minimum diameter of 75mm and should be 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, shall be located within 300 mm of the exit of the SDT.

The secondary dilution tunnel:

- 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.

— *FH filter holder(s)* **(Figures 14 and 15)**

For primary and back-up filters one filter housing or separate filter housings may be used. The requirements of Annex III, Appendix 1, section 1.5.1.3 have to 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),
- may be insulated.

— *P sampling pump* **(Figures 14 and 15)**

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

— *DP dilution air pump* **(Figure 15) (full flow double dilution only)**

The dilution air pump shall be located so that the secondary dilution air is supplied at a temperature of 298 K (25°C) ± 5 K.

— *FC3 flow controller* **(Figures 14 and 15)**

A flow controller shall be used to compensate the particulate sample flow rate for temperature and backpressure variations in the sample path, if no other means are available. The flow controller is required if electronic flow compensation EFC (see Figure 13) is used.

— *FM3 flow measurement device* **(Figures 14 and 15) (particulate sample flow)**

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

— *FM4 flow measurement device* **(Figure 15) (dilution air, full flow double dilution only)**

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

— *BV ball valve* **(optional)**

The ball valve shall have a diameter not less than the inside diameter of the sampling tube 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 239 K (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 293 K (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 293 K (20°C).