CHAPTER 6 : GAS SAMPLING SYSTEMS

1 Scope :

1.1 This Chapter describes two types of gas sampling systems in paragraphs 2.1 and 2.2 meeting the requirements specified in para 4.2 of Chapter 3 of this Part. Another type described in paragraph 2.3, may be used if it meets these requirements.

1.2 The laboratory shall mention, in its communications, the system of sampling used when performing the test. Systems not described in this chapter could be used, if it is proven to give equivalent results.

2.0 Criteria relating to the variable-dilution system for measuring exhaust-Gas Emissions

2.1 Scope

This section specifies the operating characteristics of an exhaust-gas sampling system intended to be used for measuring the true mass emissions of a vehicle exhaust in accordance with the provisions of this Directive. The principle of variable-dilution sampling for measuring mass emissions requires three conditions to be satisfied:

2.1.1 The vehicle exhaust gases must be continuously diluted with ambient air under specified conditions;

2.1.2 The total volume of the exhaust gases and dilution air must be measured accurately;

2.1.3 A continuously proportional sample of the dilution exhaust gases and the dilution air must be collected for analysis.

The quantity of gaseous pollutants emitted is determined from the proportional sample concentrations and the total volume measured during the test. The sample concentrations are corrected to take account of the pollutant content of the ambient air. In addition, where vehicles are equipped with compression ignition engines, their particulate emissions are measured.

2.2 Technical summary :

Figure 7 gives a schematic diagram of the sampling system.

2.2.1 The vehicle exhaust gases must be diluted with a sufficient of ambient air to prevent any water condensation in the sampling and measuring system.

2.2.2 The exhaust-gas sampling system must be so designed as to make it possible to measure the average volume concentrations of the CO_2, CO, HC and NO_x, and in addition, in the case of vehicles equipped with compression-ignition engines, of the particulate emissions, contained in the exhaust gases emitted during the vehicle testing cycle.

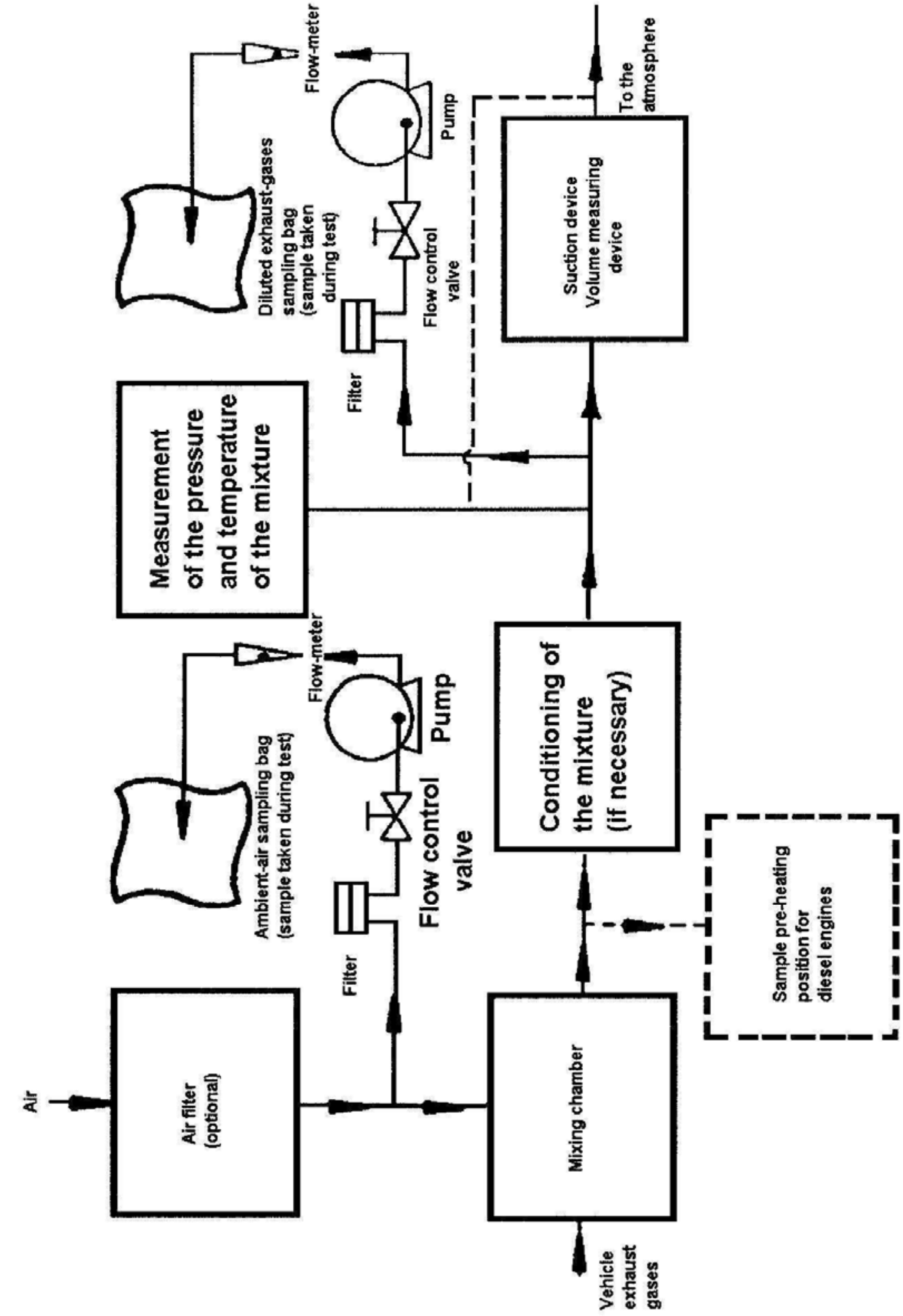

Figure 7 : Diagram of variable-dilution system for measuring exhaust-gas emissions

2.2.3 The mixture of air and exhaust gases must be homogeneous at the point where the sampling probe is located (see 2.3.1.2 below).

2.2.4 The probe must extract a representative sample of the diluted gases.

2.2.5 The system must make it possible to measure the total volume of the diluted exhaust gases from the vehicle being tested.

2.2.6 The sampling system must be gas-tight. The design of the variable-dilution sampling system and the material that go to make it up must be such that they do not affect the pollutant concentration in the diluted exhaust gases. Should any component in the system (heat exchanger, cyclone separator, blower etc) change the concentration of any of the pollutants in the diluted exhaust gases and the fault cannot be corrected, then sampling for that pollutant must be carried out before that component.

2.2.7 If the vehicle tested is equipped with an exhaust system comprising more than one tailpipe, the connecting tubes must be connected together by a manifold installed as near as possible to the vehicle.

2.2.8 The gas samples must be collected in sampling baggies of adequate capacity so as to hinder the gas flow during the sampling period. These baggies must be made of such materials as will not affect the concentration of pollutant gases (see 2.3.4.4 below).

2.2.9 The variable-dilution system must be so designed as to enable the exhaust gases to the sampled without appreciably changing the back-pressure at the exhaust pipe outlet (see 2.3.1.1 below).

2.3 Specific requirements :

2.3.1 Exhaust-gas collection and dilution device.

2.3.1.1 The connection tube between the vehicle exhaust tailpipe(s) and the mixing chamber must be as short as possible; it must in no case:

- cause the static pressure at he exhaust tailpipe(s) on the vehicle being tested to differ by more than ± 0.75 kPa at 50 km/h or more than ± 1.25 kPa for the whole duration of the test from the static pressures recorded when nothing is connected to the vehicle tailpipes. The pressure must be measured in the exhaust tailpipe or in an extension having the same diameter, as near as possible to the end of the pipe.

- Change the nature of the exhaust gas.

2.3.1.2 There must be a mixing chamber in which the vehicle exhaust gases and the dilution air are mixed so as to produce a homogeneous mixture at the chamber outlet.

The homogeneity of the mixture in any cross-section at the location of the sampling probe must not vary by more than ± 2 % from the average of the values obtained at least five points located at equal intervals on the diameter of the gas system. In order to minimize the effects on the conditions at the exhaust tailpipe and to limit the drop in pressure inside the dilution air-conditioning device, if any, the pressure inside the mixing chamber must not differ by more than 0.25 kPa from atmospheric pressure.

2.3.2 Suction device/volume measuring device
This device may have a range of fixed speeds so as to ensure sufficient flow to prevent any water condensation. This result is generally obtained by keeping the concentration of CO_2 in the dilute exhaust gas sampling bag lower than 3% by volume.

2.3.3 Volume measurement :

2.3.3.1 The volume-measuring device must retain its calibration accuracy to within ± 2% under all operating conditions. If the device cannot compensate for variations in the temperature of the mixture of exhaust gases and dilution air at the measuring point, a heat exchanger must be used to maintain the temperature to within ± 6 K of the specified operating temperature.

If necessary, a cyclone separator can be used to protect the volume-measuring device.

2.3.3.2 A temperature sensor must be installed immediately before the volume-measuring device. This temperature sensor must have an accuracy and a precision of ± 1 K and a response time of 0.1 second at 62% of a given temperature variation (value measured in silicone oil).

2.3.3.3 The pressure measurements must have a precision and an accuracy of ± 0.4 kPa during the test.

2.3.3.4 The measurement of the pressure difference from atmospheric pressure is taken before and, if necessary, after the volume-measuring device.

2.3.4 Gas sampling :

2.3.4.1 Dilute exhaust gases

2.3.4.1.1 The sample of dilute exhaust gases is taken before the suction devices but after the conditioning devices (if any).

2.3.4.1.2 The flow-rate must not deviate by more than ± 2% from the average.

2.3.4.1.3 The sampling rate must not fall below 5 litres per minute and must not exceed 0.2% of the flow-rate of the dilute exhaust gases.

2.3.4.1.4 An equivalent limit applies to constant-mass sampling systems.

2.3.4.2 Dilution air

2.3.4.2.1 A sample of the dilution air is taken at a constant flow-rate near the ambient air inlet (after the filter if one is fitted).

2.3.4.2.2 The air must not be contaminated by exhaust gases from the mixing area.

2.3.4.2.3 The sampling rate for the dilution air must be comparable to that used in the case of the dilute exhaust gases.

2.3.4.3 Sampling operations

2.3.4.3.1 The materials used for the sampling operations must be such that they do not change the pollutant concentration.

2.3.4.3.2 Filters may be used in order to extract the solid particles from the sample.

2.3.4.3.3 Pumps are required in order to convey the sample to the sampling bag(s).

2.3.4.3.4 Flow control valves and flow-meters are needed in order to obtain the flow-rates required for sampling.

2.3.4.3.5 Quick fastening gas-tight connections may be used between the three-way valves and the sampling bags, the connections sealing themselves automatically on the bag side. Other systems may be used for conveying the samples to the analyzer (three-way stop valves, for example).

2.3.4.3.6 The various valves used for directing the sampling gases must be of the quick-adjusting and quick-acting type.

2.3.4.4 Storage of the sample

The gas samples are collected in sampling bags of adequate capacity so as not to reduce the sampling rate. The bags must be made of such a material as will not change the concentration of synthetic pollutant gases by more than ± 2% after 20 minutes.

2.4 Additional sampling unit for the testing of vehicles equipped with a compression ignition engine

2.4.1 By way of a departure from the taking of gas samples from vehicles equipped with spark-ignition engines, the hydrocarbon and particulate sampling points are located in a dilution tunnel.

2.4.2 In order to reduce heat losses in the exhaust gases between the exhaust tail pipe and the dilution tunnel inlet, the pipe may not be more than 3.6 m long, or 6.1 m long if heat insulated. Its internal diameter may not exceed 105 mm.

2.4.3 Predominantly turbulent flow conditions (Reynolds number ≥ 4000) must apply in the dilution tunnel, which consist of a straight tube of electrically-conductive material, in order to guarantee that the diluted exhaust gas is homogeneous at the sampling points and that the samples consist of representative gases and particulate. The dilution tunnel must be at least 200 mm in diameter and the system must be earthed.

2.4.4 The particulate sampling system consist of a sampling probe in the dilution tunnel and two series-mounted filters. Quick-acting are located both up and downstream of the two filters in the direction of flow.
The configuration of the sample probe must be as indicated in Figure 8.

2.4.5 The particulate sampling probe must be arranged as follows :

It must be installed in the vicinity of the tunnel centerline, roughly 10 tunnel diameters downstream of the gas inlet, and have an internal diameter of at least 12 mm.

The distance form the sampling tip to the filter mount must be at least five probe diameters, but must not exceed 1020 mm.

2.4.6 The sample gas flow-measuring unit consists of pumps, gas flow regulators and flow measuring units.

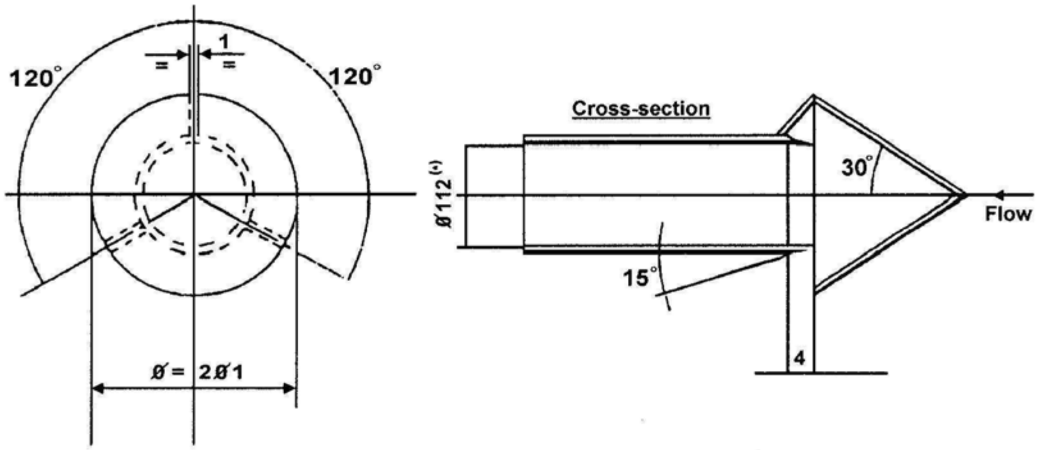

Figure 8 : <u>Particulate Sampling Probe Configuration</u>

(*) Minimum internal diameter

Wall thickness : ~1 mm; Material : Stainless Steel

2.4.7 The hydrocarbon sampling system consists of a heated sampling probe, line, filter and pump. The sampling probe must be installed in such a way, at the same distance from the exhaust gas inlet as the particulate sampling probe, that neither interferes with samples taken by the other. It must have a minimum internal diameter of 4 mm.

2.4.8 All heated parts must be maintained at a temperature of 463 K (190 °C) ± 10 K by heating system.

2.4.9 If it is not possible to compensate for variations in the flow rate there must be a heat exchanger and a temperature control device as specified in 2.3.3.1 above so as to ensure that the flow rate in the system is constant and the sampling rate is accordingly proportional.

3.0 Description of Devices :

3.1 Variable Dilution Device with Positive Displacement Pump (PDP-CVS) (Fig. 9).

3.1.1 The Positive Displacement Pump - Constant Volume Sampler (PDP-CVS) satisfies the requirements by metering at a constant temperature and pressure through the pump. The total volume is measured by counting the revolutions made by the calibrated positive displacement pump. The proportional sample is achieved by sampling with pump, flow meter and flow control valve at a constant flow rate.

3.1.2 Fig. 9 is a schematic drawing of such a sampling system. Since various configurations can produce accurate results, exact conformity with the drawings is not essential. Additional components such as instruments, valves, solenoids, and switches may be used to provide additional information and co-ordinate the functions of the component system.

3.1.3 The collecting equipment shall consist of :

3.1.3.1 A filter (B) for the dilution air, which can be preheated, if necessary. This filter shall consist of activated charcoal sandwiched between two layers of paper, and shall be used to reduce and stabilise the hydrocarbon concentrations of ambient emissions in the dilution air.

3.1.3.2 A mixing chamber (M) in which exhaust gas and air are mixed homogeneously.

3.1.3.3 A heat exchanger (H) of a capacity sufficient to ensure that throughout the test the temperature of the air/exhaust gas mixture measured at a point immediately upstream of the positive displacement pump is within ± 6 K of the designed operating temperature. This device shall not affect the pollutant concentrations of diluted gases taken off for analysis.

3.1.3.4 A temperature control system (TC), used to preheat the heat exchanger before the test and to control its temperature during the test, so that deviations from the designed operating temperature are limited to ± 6 K.

3.1.3.5 The positive displacement pump (PDP), used to transport a constant volume flow of the air / exhaust gas mixture. The flow capacity of the pump shall be large enough to eliminate water condensation in the system under all operating conditions which may occur during a test, this can be generally ensured by using a positive displacement pump with an adequate flow capacity.

3.1.3.5.1 Twice as high as the maximum flow of exhaust gas produced by accelerations of the driving cycle or

3.1.3.5.2 Sufficient to ensure that the CO_2 concentration in the dilute exhaust sample bag is less than 3 % by volume.

3.1.3.6 A temperature sensor (T_1) (accuracy and precision ± 1K) fitted at a point immediately upstream of the positive displacement pump. It shall be designed to monitor continuously the temperature of diluted exhaust gas mixture during the test.

3.1.3.7 A pressure gauge (G_1) (accuracy and precision ± 0.4 kPa) fitted immediately upstream of the volume meter and used to register the pressure gradient between the gas mixture and the ambient air.

3.1.3.8 Another pressure gauge (G_2) (accuracy and precision ± 0.4 kPa) fitted so that the differential pressure between pump inlet and pump outlet can be registered.

3.1.3.9 Two sampling outlets (S_1 and S_2) for taking constant samples of the dilution air and of the diluted exhaust gas/air mixture.

3.1.3.10A filter (F), to extract solid particles from the flow of gas collected for analysis.

3.1.3.11 Pumps (P), to collect a constant flow of the dilution air as well as of the diluted exhaust-gas/air mixture during the test.

3.1.3.12 Flow controllers (N), to ensure a constant uniform flow of the gas samples taken during the course of the test from sampling probes S_1 and S_2 , and flow of the gas samples shall be such that, at the end of each test, the quantity of the samples is sufficient for analysis (about 10 l/min.)

3.1.3.13 Flow meters (FL), for adjusting and monitoring the constant flow of gas samples during the test.

3.1.3.14 Quick-acting valves (V), to divert a constant flow of gas samples into the sampling bags or to the outside vent.

3.1.3.15 Gas-tight, quick-lock coupling elements (Q) between the quick-acting valves and the sampling bags; the coupling shall close automatically on the sampling-bag side; as an alternative, other ways of transporting the samples to the analyser may be used (three-way stopcocks, for instance).

3.1.3.16 Bags (B), for collecting samples of the diluted exhaust gas and of the dilution air during the test. They shall be of sufficient capacity not to impede the sample flow. The bag material shall be such as to affect neither the measurements themselves nor the chemical composition of the gas samples (for instance: laminated polyethylene/polyamide films, or fluorinated polyhydrocarbons).

3.1.3.17 A digital counter (C), to register the number of revolutions performed by the positive displacement pump during the test.

3.1.4 Additional equipment required when testing diesel engined vehicles.

3.1.4.1 The additional components shown within the dotted lines of Fig.9 shall be used when testing Diesel Engined Vehicles.

F_h is a heated filter

S_3 is a sample point close to the mixing chamber

V_h is a heated multiway valve

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

HFID is a heated flame, ionisation analyser.

R & I are means of integrating and recording the instantaneous hydrocarbon concentrations.

L_h is a heated sample line

All heated components will be maintained at 463 K (190 °C) ± 10 K.
Particulate sampling system
S4 Sampling probe in the dilution tunnel
F_P Filter unit consisting of two series mounted filters : Switching arrangement for further parallel mounted pairs of filters,
Sampling line,
Pumps, flow regulators, flow measuring units.

3.2 Critical-flow venturi dilution device/(CFV-CVS) (Fig.10).

3.2.1 Using a critical-flow venturi in connection with the CVS sampling procedure is based on the principles of flow mechanics for critical flow. The variable mixture flow rate of dilution and exhaust gas is maintained at sonic velocity which is directly proportional to the square root of the gas temperature. Flow is continually monitored, computed, and integrated over the test. If an additional critical-flow sampling venturi is used the proportionality of the gas samples taken is ensured. As both pressure and temperature are equal at the two venturi inlets, the volume of the gas flow diverted for sampling is proportional to the total volume of diluted exhaust gas mixture produced, and thus the requirements of this test are met.

3.2.2 Fig.10 is a schematic drawing of such a sampling system. Since various configurations can produce accurate results, exact conformity with the drawing is not essential. Additional components such as instruments, valve, solenoids, and switches may be used to provide additional information and co-ordinate the functions of the component system.

3.2.3 The collecting equipment shall consist of :

3.2.3.1 A filter (D), for the dilution air, which can be preheated if necessary; the filter shall consist of activated charcoal sandwiched between layers of paper, and shall be used to reduce and stabilize the hydrocarbon background emission of the dilution air.

3.2.3.2 A mixing chamber (M), in which exhaust gas and air are mixed homogeneously.

3.2.3.3 A cyclone separator (CS), to extract particles.

3.2.3.4 Two sampling probes (S_1 and S_2), for taking samples of the dilution air as well as of the diluted exhaust gas.

3.2.3.5 A sampling critical flow venturi (SV), to take proportional samples of the diluted exhaust gas at sampling probe, S_2.

3.2.3.6 A filter (F), to extract solid particles from the gas flows diverted for analysis.

3.2.3.7 Pumps (P), to collect part of the flow of air and diluted exhaust gas in bags during the test.

3.2.3.8 A flow controller (N), to ensure a constant flow of the gas samples taken in the course of the test from sampling probe S_1. The flow of the gas samples shall be such, that at the end of the test, the quantity of the samples is sufficient for analysis (about 10 l/min)

3.2.3.9 Flow meters (FL), for adjusting and monitoring the flow of gas samples during tests.

3.2.3.10 A scrubber (PS), in the sampling line.

3.2.3.11 Quick-acting solenoid valves (V), to divert a constant flow of gas samples into the sampling bags or to the vent.

3.2.3.12 Gas-tight, quick-lock coupling elements (Q), between the quick acting valves and the sampling bags; the couplings shall close automatically on the sampling bag side. As an alternative, other ways of transporting the samples to the analyser may be used (three-way stopcock, for instance).

3.2.3.13 Bags (B), for collecting samples of the diluted exhaust gas and the dilution air during the test; they shall be of sufficient capacity not to impede the sample flow. The bag material shall be such as to affect neither the measurements themselves nor the chemical composition of the gas samples (for instance, laminated polyethylene/polyamide films, or fluorinated polyhydrocarbons).

3.2.3.14 A pressure gauge (G), which shall be precise and accurate to within ±0.4 kPa.

3.2.3.15 A temperature sensor (T), which shall be precise and accurate to within ±1 K and have a response time of 0.1 seconds to 62 % of a temperature change (as measured in silicon oil).

3.2.3.16 A measuring critical flow venturi tube (MV), to measure the flow volume of the diluted exhaust gas.

3.2.3.17 A blower (BL), of sufficient capacity to handle the total volume of diluted gas.

3.2.3.18 The capacity of the CFV-CVS system shall be such that under all operating conditions which may possibly occur during a test there will be no condensation of water. This is generally ensured by using a blower whose capacity is;

3.2.3.18.1 Twice as high as the maximum flow of exhaust gas produced by accelerations of the driving cycle or

3.2.3.18.2 Sufficient to ensure that the CO_2 concentration in the dilute exhaust sample bag is less than 3 % by volume.

3.2.4 Additional equipment required when testing diesel engined vehicles.

3.2.4.1 The additional components shown within the dotted lines of Fig.10 shall be used when testing Diesel Engined Vehicles.

Fh : is a heated filter
S_3 : is a sample point close to the mixing chamber
V_h : is a heated multiway valve
Q : is a quick connector to allow the ambient air sample BA to be analysed on the HFID
HFID : is a heated flame, ionisation analyser.
R & I : are means of integrating and recording the instantaneous hydrocarbon concentrations.
Lh : is a heated sample line

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

3.2.4.2 If compensation for varying flow is not possible then a heat exchanger (H) and temperature control system (TC) as described in Paragraph 2.2.3 of this Chapter will be required to ensure constant flow through the ventury (MV) and thus proportional flow through S_3.

Particulate sampling system :
S_4 Sampling probe in dilution tunnel
F_P Filter series consisting of two series mounted filters : Switching

arrangement for further parallel mounted pairs of filters,
Sampling line,
Pumps, flow regulators, flow measuring units.

3.3 Variable dilution device with constant flow control by orifice (CFO-CVS) (Fig. 11).

3.3.1 The collection equipment shall consist of :

3.3.1.1 A sampling tube connecting the vehicle's exhaust pipe to the device itself;

3.3.1.2 A sampling device consisting of a pump for drawing in the diluted mixture of exhaust gas and air;

3.3.1.3 A mixing chamber (M) in which exhaust gas and air are mixed homogeneously.

3.3.1.4 A heat exchanger (H) of a capacity sufficient to ensure that throughout the test the temperature of the air/exhaust gas mixture measured at a point immediately before the positive displacement of the flow rate measuring device is within ± 6 K. This device shall not alter the pollutant concentration of diluted gases taken off for analysis. Should this condition not be satisfied for certain pollutants, sampling will be effected before the cyclone for one or several considered pollutants.

If necessary, a device for temperature control (TC) is used to preheat the heat exchanger before testing and to keep up its temperature during the test within ± 6 K of the designed operating temperature.

3.3.1.5 Two probes (S_1 and S_2) for sampling by means of pumps (P), flowmeters (FL) and, if necessary, filters (F) allowing for the collection of solid particles from gases used for the analysis.

3.3.1.6 One pump for dilution air and another one for diluted mixture.

3.3.1.7 A volume-meter with an orifice.

3.3.1.8 A temperature sensor (T_1) (accuracy and precision ± 1 K) fitted at a point immediately before the volume measurement device. It shall be designed to monitor continuously the temperature of the diluted exhaust gas mixture during the test.

3.3.1.9 A pressure gauge (G_1) (capacity and precision ± 0.4 kPa) fitted immediately before the volume meter and used to register the pressure gradient between the gas mixture and the ambient air.

3.3.1.10 Another pressure gauge (G_2) (accuracy and precision ± 0.4 kPa) fitted so that the differential pressure between pump inlet and pump outlet can be registered.

3.3.1.11 Flow controllers (N) to ensure a constant uniform flow of gas samples taken during the course of the test from sampling outlets S_1 and S_2 . The flow of the gas samples shall be such that, at the end of each test, the quantity of the samples is sufficient for analysis (about 10 l/min).

3.3.1.12 Flow meters (FL) for adjusting and monitoring the constant flow of gas samples during the test.

3.3.1.13 Three-way valves (V) to divert a constant flow of gas samples into the sampling bags or to the outside vent.

3.3.1.14 Gas-tight, quick lock sampling elements (Q) between the three-way valves and the sampling bags. The coupling shall close automatically on the sampling bag side. Other ways of transporting the samples to the analyser may be used (three-way stopcocks, for instance).

3.3.1.15 Bags (B) for collecting samples of diluted exhaust gas and of dilution air during the test. They shall be of sufficient capacity not to impede the sample flow. The bag material shall be such as to affect neither the measurements themselves nor the chemical composition of the gas samples for instance, laminated polyethylene/polyamide films, or fluorinated polyhydrocarbons).

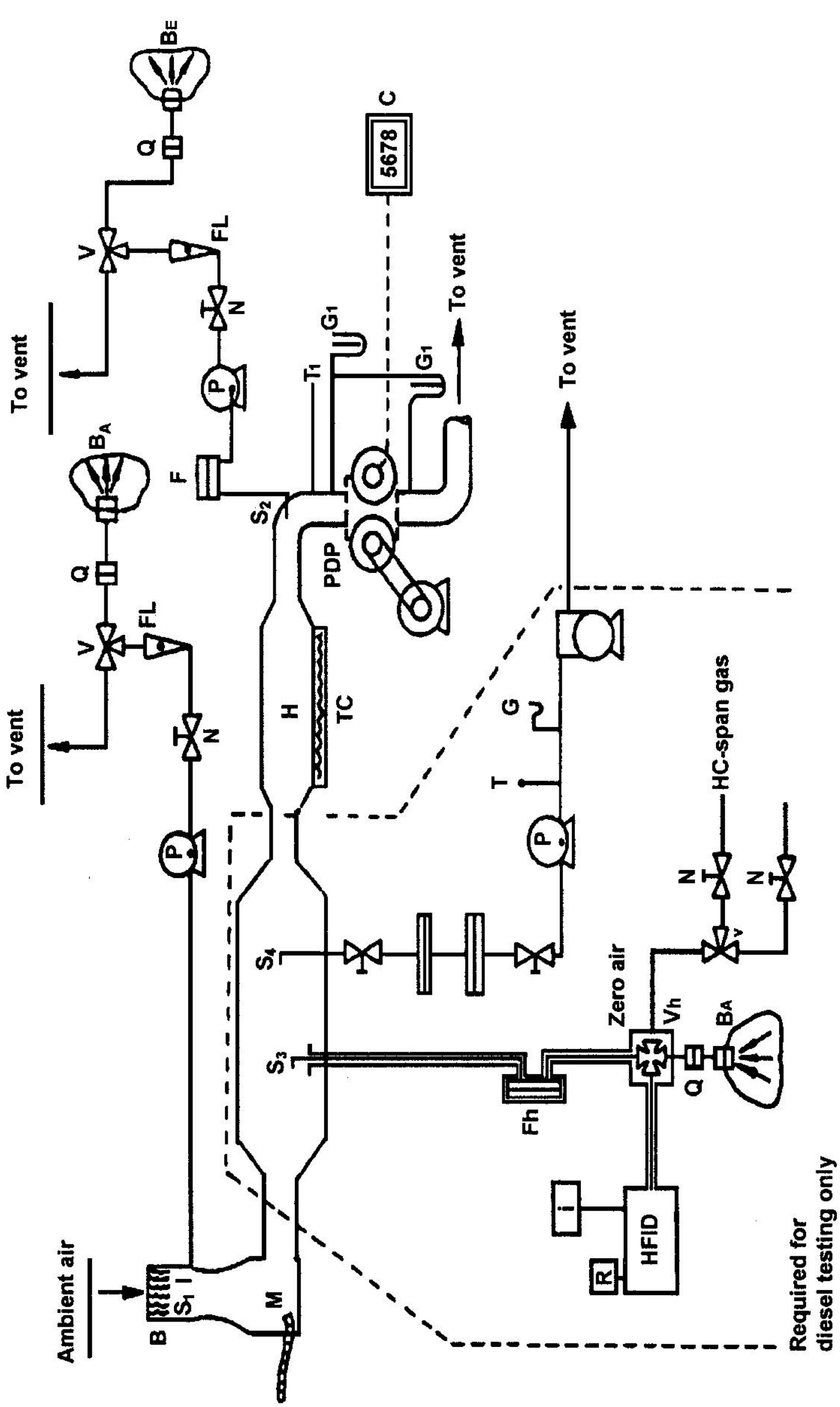

Figure 9 : <u>Schematic Constant Volume Sampler with Positive Displacement Pump (PDP-CVS)</u> (Pls. Ref. Para. 3.1 of this Chapter)

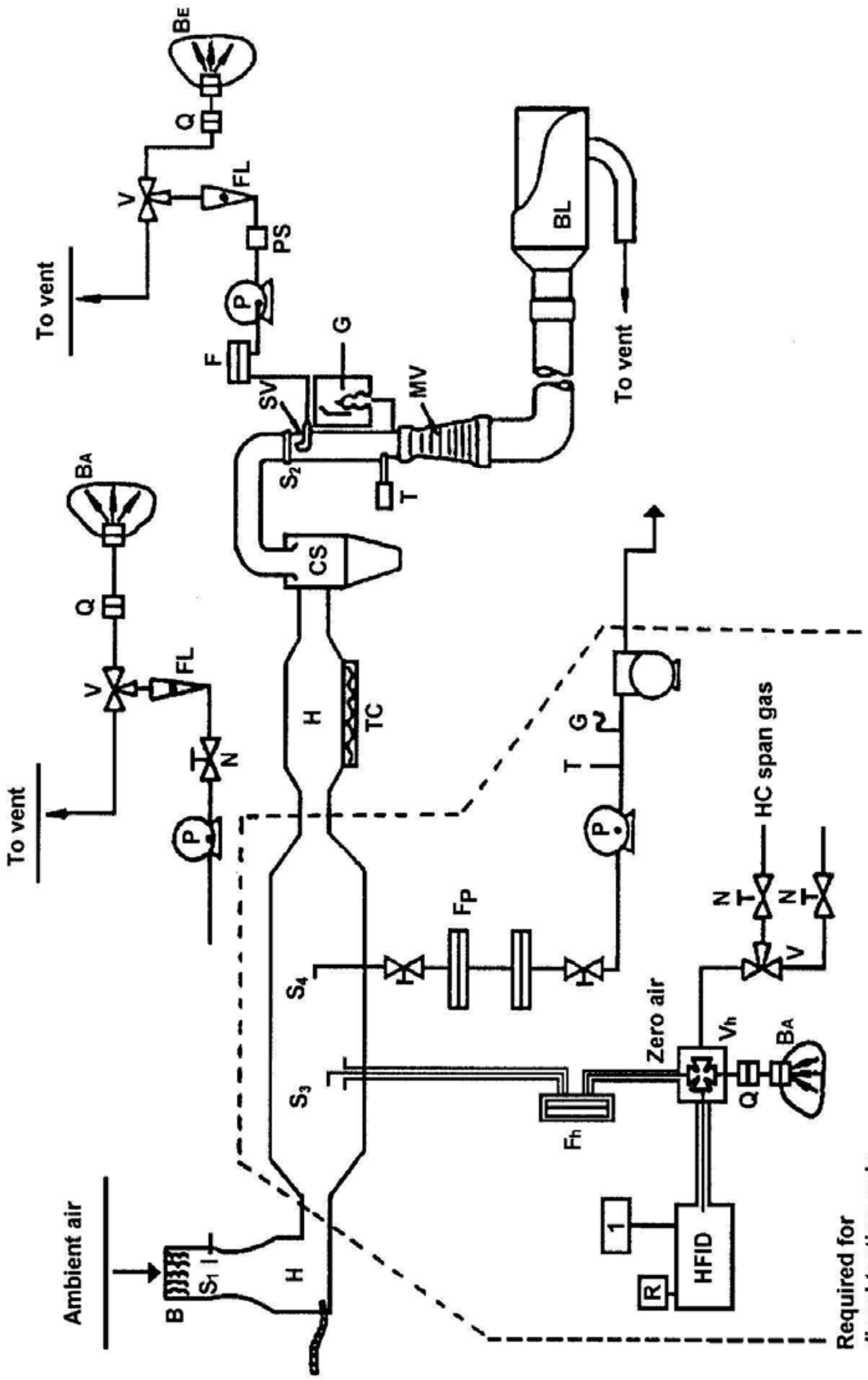

Figure 10 : <u>Schematic Constant Volume Sampler with Critical Flow Venturi (CFV-CVS)</u> (Pls.Ref.Para. 3.2 of this Chapter)

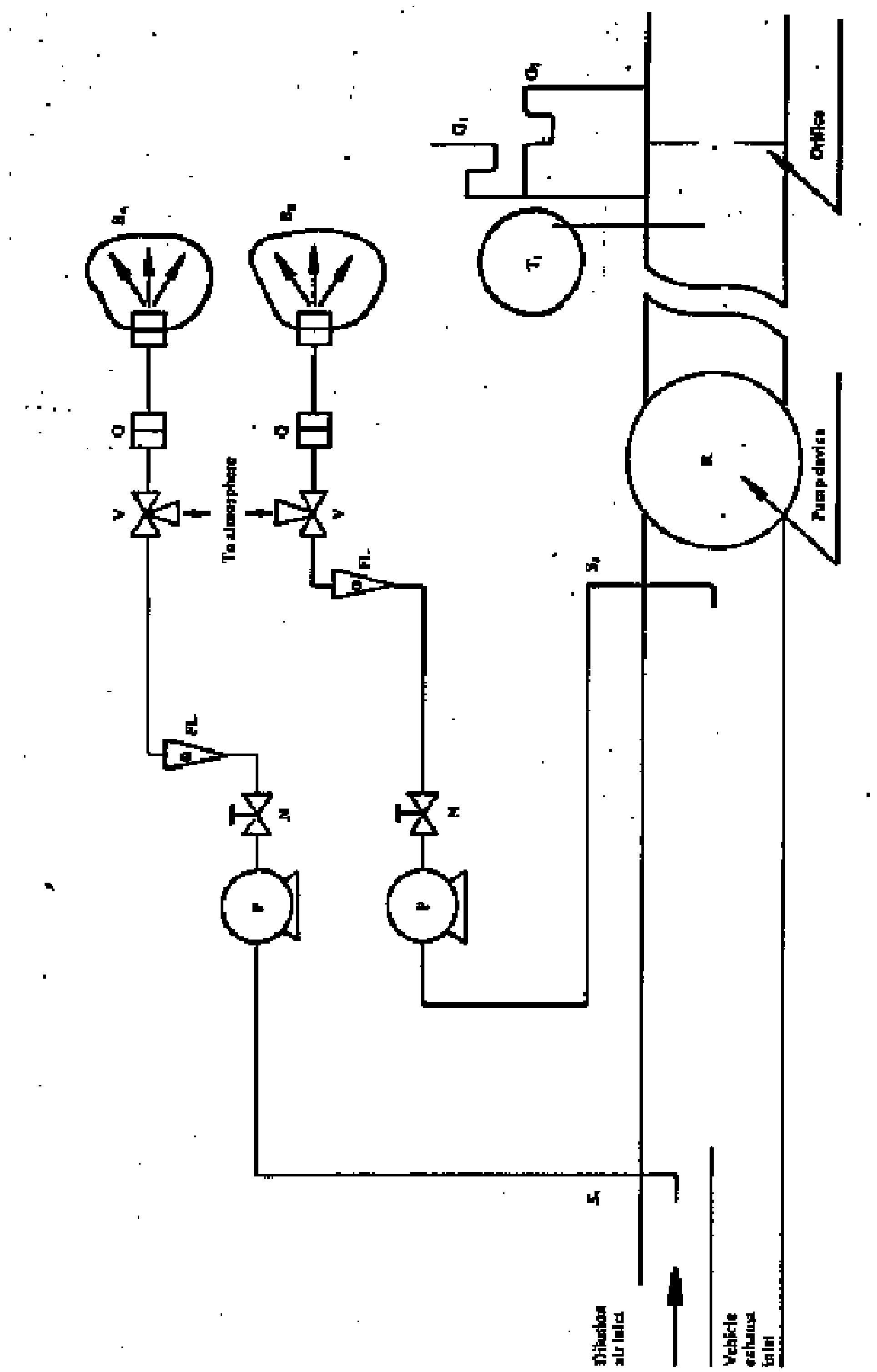

Figure 11 : Schematic of Variable Dilution DeFFigure 11 : Schematic of Variable Dilution Device with Constant Flow Control by Orifice (CFO-CVS)

(Pls. Ref. Para 3.3 of this Chapter)