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15 December 1995

AGREEMENT

CONCERNING THE ADOPTION OF UNIFORM CONDITIONS OF APPROVAL AND RECIPROCAL RECOGNITION OF APPROVAL FOR MOTOR VEHICLE EQUIPMENT AND PARTS */

done at Geneva on 20 March 1958

Addendum 95: *Regulation No. 96*

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UNIFORM PROVISIONS CONCERNING THE APPROVAL OF COMPRESSION IGNITION (C.I.) ENGINES TO BE INSTALLED IN AGRICULTURAL AND FORESTRY TRACTORS WITH REGARD TO THE EMISSIONS OF POLLUTANTS BY THE ENGINE

UNITED NATIONS

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*/ **Note: New title of the Agreement (as of 16 October 1995):**

Agreement Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions

GE.95-25242

Regulation No. 96

UNIFORM PROVISIONS CONCERNING THE APPROVAL OF COMPRESSION IGNITION (C.I.) ENGINES TO BE INSTALLED IN AGRICULTURAL AND FORESTRY TRACTORS WITH REGARD TO THE EMISSIONS OF POLLUTANTS BY THE ENGINE

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1. SCOPE

This regulation applies to the emission of gaseous and particulate pollutants from C.I. engines used in Category T vehicles 1/ having an installed net power higher than 37 kW, provided that they have not been approved according to Regulation No. 49, as amended.

2. DEFINITIONS AND ABBREVIATIONS

For the purpose of this Regulation,

2.1. "Approval of an engine" means the approval of an engine type or family with regard to the level of emission of gaseous and particulate pollutants by the engine;

2.2. "Compression ignition (C.I.) engine" means an engine which works on the compression-ignition principle (e.g. diesel engine);

2.3. "Engine type" means a category of engines which do not differ in such essential engine characteristics as defined in paragraphs 1 to 4 of annex 1A to this Regulation;

2.4. "Engine Family" means a manufacturer's grouping of engines which, through their design, are expected to have similar exhaust emission characteristics and comply with the requirements in paragraph 7 of this Regulation;

2.5. "Parent Engine" means an engine selected from an engine family in such a way that it complies with the requirements set out in annex 1B of this Regulation;

2.6. "Gaseous pollutants" means carbon monoxide, hydrocarbons (assuming a ratio of $C_1H_{1.85}$) and oxides of nitrogen, the last named being expressed in nitrogen dioxide (NO_2) equivalent;

2.7. "Particulate pollutants" means any material collected on a specified filter medium after diluting C.I. engine exhaust gas with clean filtered air so that the temperature does not exceed 325K (52°C);

2.8. "Net power" means the power in "ECE kW" obtained on the test bench at the end of the crankshaft, or its equivalent, measured in accordance with the ECE method of measuring the power of internal combustion engines for road vehicles 2/ except that the power of the engine cooling fan is excluded and the test conditions and reference fuel specified in this Regulation are adhered to;

1/ **As described in the Consolidated Resolution on the Construction of Vehicles (R.E.3.) (TRANS/SC1/WP29/78/Amend.3).**

2/ As described in ECE Regulation No. 85.

2.9. "Rated speed" means the maximum full load speed allowed by the governor as specified by the manufacturer;

2.10. "Per cent load" means the fraction of the maximum available torque at an engine speed;

2.11. "Maximum torque speed" means the engine speed at which the maximum torque is obtained from the engine, as specified by the manufacturer;

2.12. "Intermediate speed" means that engine speed which meets one of the following requirements:

For engines which are designed to operate over a speed range on a full load torque curve, the intermediate speed shall be the declared maximum torque speed if it occurs between 60% and 75% of the rated speed;

If the declared maximum torque speed is less than 60% of the rated speed, then the intermediate speed shall be 60% of the rated speed;

If the declared maximum torque speed is greater than 75% of the rated speed then the intermediate speed shall be 75% of the rated speed.

2.13. Symbols and Abbreviations

2.13.1. Symbols for test parameters

Symbol	Unit	Term
A_p	m^2	Cross-sectional area of the isokinetic sampling probe.
A_T	m^2	Cross-sectional area of the exhaust pipe.
aver		Weighted average values for:
	m^3/h	volume flow;
	kg/h	mass flow;
	g/kWh	specific emission.
α	-	Hydrogen-to-carbon ratio of the fuel
C1	-	Carbon 1 equivalent hydrocarbon.
conc	ppm Vol%	Concentration (with suffix of the component nominating)
$conc_c$	ppm Vol%	Background corrected concentration.

$conc_d$	ppm Vol%	Concentration of dilution air.
DF	-	Dilution factor.
f_a	-	Laboratory atmospheric factor.
F_{FH}	-	Fuel specific factor used for the calculations of wet concentrations from dry concentrations hydrogen to carbon ratio.
G_{AIRW}	kg/h	Intake air mass flow rate on wet basis.
G_{AIRD}	kg/h	Intake air mass flow rate on dry basis.
G_{DILW}	kg/h	Dilution air mass flow rate on wet basis.
G_{EDFW}	kg/h	Equivalent diluted exhaust gas mass flow rate on wet basis.
G_{EXHW}	kg/h	Exhaust gas mass flow rate on wet basis.
G_{FUEL}	kg/h	Fuel mass flow rate.
G_{TOTW}	kg/h	Diluted exhaust gas mass flow rate on wet basis.
H_{REF}	g/kg	Reference value of absolute humidity 10.71 g/kg for calculation of NO_x and particulate humidity correction factors.
H_a	g/kg	Absolute humidity of the intake air.
H_d	g/kg	Absolute humidity of the dilution air.
i	-	Subscript denoting an individual mode.
K_H	-	Humidity correction factor for NO_x.
K_p	-	Humidity correction factor for particulate.
$K_{W,a}$	-	Dry to wet correction factor for the intake air.

$K_{W,d}$	-	Dry to wet correction factor for the dilution air.
$K_{W,e}$	-	Dry to wet correction factor for the diluted exhaust gas.
$K_{W,r}$	-	Dry to wet correction factor for the raw exhaust gas.
L	%	Percent torque related to the maximum torque for the test speed.
mass	g/h	Subscript denoting emissions mass flow rate.
M_{DIL}	kg	Mass of the dilution air sample passed through the particulate sampling filters.
M_{SAM}	kg	Mass of the diluted exhaust sample passed through the particulate sampling filters.
M_d	mg	Particulate sample mass of the dilution air collected.
M_f	mg	Particulate sample mass collected.
p_a	kPa	Saturation vapour pressure of the engine intake air (ISO 3046 p_{sy} = PSY test ambient).
p_B	kPa	Total barometric pressure (ISO 3046: P_x = PX Site ambient total pressure; P_y = PY Test ambient total pressure).
p_d	kPa	Saturation vapour pressure of the dilution air.
p_s	kPa	Dry atmospheric pressure.
P	kW	Power, brake uncorrected.
P_{AE}	kW	Declared total power absorbed by auxiliaries fitted for the test which are not required by paragraph 2.7. of this Regulation.

P_M	kW	Maximum measured power at the test speed under test conditions (see annex 1A).
P_m	kW	Power measured at the different test modes.
q	-	Dilution ratio.
r	-	Ratio of cross sectional areas of isokinetic probe and exhaust pipe.
R_a	%	Relative humidity of the intake air.
R_d	%	Relative humidity of the dilution air.
R_f	-	FID response factor.
S	kW	Dynamometer setting.
T_a	K	Absolute temperature of the intake air.
T_{Dd}	K	Absolute dewpoint temperature.
T_{SC}	K	Temperature of the intercooled air.
T_{ref}	K	Reference temperature (of combustion air 298K (25°C)).
T_{SCRef}	K	Intercooled air reference temperature.
V_{AIRD}	m^3/h	Intake air volume flow rate on dry basis.
V_{AIRW}	m^3/h	Intake air volume flow rate on wet basis.
V_{DIL}	m^3	Volume of the dilution air sample passed through the particulate sample filters.
V_{DILW}	m^3/h	Dilution air volume flow rate on wet basis.
V_{EDFW}	m^3/h	Equivalent diluted exhaust gas volume flow rate on wet basis.
V_{EXHD}	m^3/h	Exhaust gas volume flow rate on dry basis.

V_{EXHW}	m^3/h	Exhaust gas volume flow rate on wet basis.
V_{SAM}	m^3	Volume of sample through particulate sampling filters.
V_{TOTW}	m^3/h	Diluted exhaust gas volume flow rate on wet basis.
WF	-	Weighting factor.
WF_E	-	Effective weighting factor.

2.13.2. Symbols for the Chemical Components

CO	Carbon monoxide.
CO_2	Carbon dioxide.
HC	Hydrocarbons.
NO_x	Oxides of nitrogen.
NO	Nitric Oxide.
NO_2	Nitrogen Dioxide.
O_2	Oxygen.
C_2H_6	Ethane.
PT	Particulate.
DOP	Di-octylphthalate.
CH_4	Methane.
C_3H_8	Propane.
H_2O	Water.

2.13.3. Abbreviations

FID	Flame ionization detector.
HFID	Heated flame ionization detector.
NDIR	Non-dispersive infrared analyser.
CLD	Chemiluminescent detector.

HCLD	Heated chemiluminescent detector.
PDP	Positive displacement pump.
CFV	Critical flow venturi.

3. APPLICATION FOR APPROVAL

3.1. Application for approval of an engine as a separate technical unit

3.1.1. The application for approval of an engine or an engine family with regard to the level of the emission of gaseous and particulate pollutants shall be submitted by the engine manufacturer or by a duly accredited representative.

3.1.2. It shall be accompanied by the undermentioned documents in triplicate and the following particulars:

A description of the engine type comprising the particulars referred to in annex 1A of this Regulation and if applicable the particulars of the engine family as referred to in annex 1B of this Regulation.

3.1.3. An engine conforming to the engine type characteristics described in annex 1A shall be submitted to the technical service responsible for conducting the approval tests defined in paragraph 5. If the technical service determines that the submitted engine does not fully represent the engine family described in annex 1B, an alternative and, if necessary, an additional engine shall be submitted for test according to paragraph 5.

3.2. Arrangements for control of conformity of production

3.2.1. The competent authority shall verify the existence of satisfactory arrangements for ensuring effective control of the conformity of production before type approval is granted.

4. APPROVAL

4.1. If the engine submitted for approval pursuant to paragraphs 3.1. of this Regulation meets the requirements of paragraph 5.2. below, approval of that type of engine or family of engines shall be granted.

4.2. An approval number shall be assigned to each type or family approved. Its first two digits shall indicate the series of amendments incorporating the most recent major technical amendments made to the Regulation at the time of issue of the approval. The same Contracting Party shall not assign the same number to another engine type or family.

4.3. Notice of approval or of extension or refusal of approval of an engine type or family pursuant to this Regulation shall be communicated to the Parties to the 1958 Agreement which apply this Regulation, by means of a form conforming to the model in annex 2, as applicable, to this Regulation. Values measured during the type test shall also be shown.

4.4. There shall be affixed, conspicuously and in a readily accessible place to every engine conforming to an engine type or family approved under this Regulation, an international approval mark consisting of:

4.4.1. a circle surrounding the letter "E" followed by the distinguishing number of the country which has granted approval; [3]

4.4.2. the number of this Regulation, followed by the letter "R", a dash and the approval number to the right of the circle prescribed in paragraph 4.4.1.

4.5. If the engine conforms to an approved type or family under one or more Regulations annexed to the Agreement, in the country which has granted approval under this Regulation, the symbol prescribed need not be repeated; in such a case, the regulation and approval numbers and the additional symbols of all the Regulations under which approval has been granted under this Regulation shall be placed in vertical columns to the right of the symbol prescribed in paragraph 4.4.2.

4.6. The approval mark shall be placed close to or on the data plate affixed by the manufacturer to the approved type.

4.7. Annex 3 to this Regulation gives examples of arrangements of approval marks.

4.8. The engine approved as a technical unit must bear, in addition to the approval mark:

4.8.1. the trademark or trade name of the manufacturer of the engine;

4.8.2. the manufacturer's engine code;

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[3] 1 for Germany, 2 for France, 3 for Italy, 4 for the Netherlands, 5 for Sweden, 6 for Belgium, 7 for Hungary, 8 for the Czech Republic, 9 for Spain, 10 for Yugoslavia, 11 for the United Kingdom, 12 for Austria, 13 for Luxembourg, 14 for Switzerland, 15 (vacant), 16 for Norway, 17 for Finland, 18 for Denmark, 19 for Romania, 20 for Poland, 21 for Portugal, 22 for the Russian Federation, 23 for Greece, 24 (vacant), 25 for Croatia, 26 for Slovenia, 27 for Slovakia, 28 for Belarus and 29 for Estonia. Subsequent numbers shall be assigned to other countries in the chronological order in which they ratify or accede to the Agreement concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts, and the number thus assigned shall be communicated by the Secretary-General of the United Nations to the Contracting Parties to the Agreement.

4.9. These marks must be clearly legible and indelible.

5. SPECIFICATIONS AND TESTS

5.1. General

The components liable to affect the emission of gaseous and particulate pollutants shall be so designed, constructed and assembled as to enable the engine, in normal use, despite the vibrations to which it may be subjected, to comply with the provisions of this Regulation.

5.2. Specifications concerning the emissions of pollutants

The gaseous and particulate components emitted by the engine submitted for testing shall be measured by the methods described in annex 4, appendix 4.

Other systems or analysers may be accepted if they yield equivalent results to the following reference systems:

> for gaseous emissions measured in the raw exhaust, the system shown in Figure 2 of annex 4, appendix 4;
>
> for gaseous emissions measured in the dilute exhaust of a full flow dilution system, the system shown in Figure 3 of appendix 4 of annex 4;
>
> for particulate emissions, the full flow dilution system, operating with a separate filter for each mode, shown in Figure 13 of appendix 4 of annex 4.

The determination of system equivalency shall be based upon a seven test cycle (or larger) correlation study between the system under consideration and one or more of the above reference systems.

The equivalency criterion is defined as a ± 5% agreement of the averages of the weighted cycle emissions values. The cycle to be used shall be that given in annex 4, paragraph 3.6.1.

For introduction of a new system into the Regulation the determination of equivalency shall be based upon the calculation of repeatability and reproducibility, as described in ISO 5725.

5.2.1. The emissions of the carbon monoxide, the emissions of hydrocarbons, the emissions of the oxides of nitrogen and the emissions of particulate obtained shall not exceed the amount shown in the table below:

Net Power (P) (kW)	Carbon Monoxide (CO) (g/kWh)	Hydrocarbons (HC) (g/kWh)	Oxides of Nitrogen (NO_x) (g/kWh)	Particulates (PT) (g/kWh)
P ≥ 130	5	1.3	9.2	0.54
75 ≤ P < 130	5	1.3	9.2	0.70
37 ≤ P < 75	6.5	1.3	9.2	0.85

5.2.2. The emission limits given in paragraph 5.2.1. are engine-out limits and shall be achieved before any exhaust after-treatment device.

6. INSTALLATION ON THE VEHICLE

6.1. The engine installation on the vehicle shall comply with the following characteristics in respect to the approval of the engine.

6.1.1. Intake depression shall not exceed that specified for the approved engine in annex 1, appendix 1.

6.1.2. Exhaust back pressure shall not exceed that specified for the approved engine in annex 1, appendix 1.

7. CONFORMITY OF PRODUCTION

7.1. Every engine bearing an approval mark as prescribed under this Regulation shall be so manufactured as to conform to the description as given in the approval form and its annexes.

7.2. In order to verify that the requirements of paragraph 5.2 are met, suitable controls of the production shall be carried out.

7.3. The holder of the approval shall in particular:

7.3.1. ensure existence of procedures for the effective control of the quality of the product;

7.3.2. have access to the control equipment necessary for checking the conformity to each approved type;

7.3.3. ensure that data of test results are recorded and that annexed documents shall remain available for a period to be determined in accordance with the administrative service;

7.3.4. analyse the results of each type of test, in order to verify and ensure the stability of the engine characteristics, making allowance for variations in the industrial production process;

7.3.5. ensure that any sampling of engines or components giving evidence of non-conformity with the type of test considered shall give rise to another sampling and another test. All the necessary steps shall be taken to re-establish the conformity of the corresponding production.

7.4. The competent authority which has granted approval may at any time verify the conformity control methods applicable to each production unit.

7.4.1. In every inspection, the test books and production survey record shall be presented to the visiting inspector.

7.4.2. When the quality level appears unsatisfactory or when it seems necessary to verify the validity of the data presented in application of paragraph 5.2., the following procedure is adopted:

7.4.2.1. An engine is taken from the series and subjected to the test described in annex 4. The emissions of the carbon monoxide, the emissions of the hydrocarbons, the emissions of the oxides of nitrogen and the emissions of particulate obtained shall not exceed the amounts shown in the table in paragraph 5.2.1., subject to the requirements of paragraph 5.2.2.

7.4.2.2. If the engine taken from the series does not satisfy the requirements of paragraph 7.4.2.1. the manufacturer may ask for measurements to be performed on a sample of engines of the same specification taken from the series and including the engine originally taken. The manufacturer shall determine the size n of the sample in agreement with the technical service. Engines other than the engine originally taken shall be subjected to a test. The arithmetical mean $(\bar{x})$ of the results obtained with the sample shall then be determined for each pollutant. The production of the series shall then be deemed to confirm if the following condition is met:

$$\bar{x} + kS \leq l$$ 4/

where:

l is the limit value laid down in paragraph 5.2.1. for each pollutant considered;
k is a statistical factor depending on n and given in the following table:

4/ $S^2 = \frac{\sum (x-\bar{x})^2}{n-1}$ where x is any one of the individual results obtained with the sample n.

n	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
k	0.973	0.613	0.489	0.421	0.376	0.342	0.317	0.296	0.279
n	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
k	0.265	0.253	0.242	0.233	0.224	0.216	0.210	0.203	0.198

$$\text{if } n \geq 20, \qquad k = \frac{0.860}{\sqrt{n}}$$

7.4.3. The technical service responsible for verifying the conformity of production shall carry out tests on engines which have been run-in partially or completely, according to the manufacturer's specifications.

7.4.4. The normal frequency of inspections authorized by the competent authority shall be one per year. If the requirements of paragraph 7.4.2.1. are not met, the competent authority shall ensure that all necessary steps are taken to re-establish the conformity of production as rapidly as possible.

8. PENALTIES FOR NON-CONFORMITY OF PRODUCTION

8.1. The approval granted in respect of an engine type or family pursuant to this regulation may be withdrawn if the requirements laid down in paragraph 7.4. are not complied with or if the engine or engines taken fail to pass the tests prescribed in paragraph 7.4.2.1.

8.2. If a Contracting Party to the Agreement applying this Regulation withdraws an approval it has previously granted, it shall forthwith so notify the other Contracting Parties applying this Regulation by means of a communication form conforming to the model in annex 2 to this Regulation.

9. MODIFICATION AND EXTENSION OF APPROVAL OF THE APPROVED TYPE

9.1. Every modification of the approved type or family shall be notified to the administrative department which approved the type. The department may then either:

9.1.1. Consider that the modifications made are unlikely to have an appreciable adverse effect and that in any case the modified type still complies with the requirement; or

9.1.2. Require a further test report from the technical service conducting the tests.

9.2. Confirmation or refusal of approval, specifying the alterations, shall be communicated by the procedure specified to the Parties to the Agreement applying this Regulation.

9.3. The competent authority issuing the extension of approval shall assign a series number for such an extension and inform thereof the other Contracting Parties to the 1958 Agreement applying this Regulation by means of a communication form conforming to the model in annex 2 to this Regulation.

10. PRODUCTION DEFINITELY DISCONTINUED

If the holder of the approval completely ceases to manufacture the type or family approved in accordance with this Regulation he shall so inform the authority which granted the approval. Upon receiving the relevant communication that authority shall inform thereof the other Parties to the Agreement which apply this Regulation by means of a communication form conforming to the model in annex 2 to this Regulation.

11. NAMES AND ADDRESSES OF TECHNICAL SERVICES RESPONSIBLE FOR CONDUCTING APPROVAL TESTS AND OF ADMINISTRATIVE DEPARTMENTS

The Contracting Parties to the 1958 Agreement applying this Regulation shall communicate to the United Nations Secretariat the names and addresses of the technical services responsible for conducting approval tests and the administrative departments which grant approval and to which forms certifying approval or extension or refusal or withdrawal of approval, issued in other countries are to be sent.

Annex 1A

ESSENTIAL CHARACTERISTICS OF THE ENGINE AND INFORMATION CONCERNING THE CONDUCT OF THE TEST

1. Description of engine

1.1. Manufacturer: . . . .

1.2. Manufacturer's engine code: . . . .

1.3. Cycle: four stroke / two stroke 1/

1.4. Bore: . . . . mm

1.5. Stroke: . . . . mm

1.6. Number and layout of cylinders: . . . .

1.7. Engine capacity: . . . . cm^3

1.8. Rated speed: . . . .

1.9. Maximum torque speed: . . . .

1.10. Volumetric compression ratio 2/ : . . . .

1.11. Combustion system description: . . . .

1.12. Drawing(s) of combustion chamber and piston crown . . . .

1.13. Minimum cross sectional area of inlet and outlet ports: . . . . .

1.14. Cooling system

1.14.1. Liquid

1.14.1.1. Nature of liquid: . . . .

1.14.1.2. Circulating pump(s): yes/no 1/

1.14.1.3. Characteristics or make(s) and type(s) (if applicable): . . . . .

1.14.1.4. Drive ratio(s) (if applicable): . . . .

1.14.2. Air

1.14.2.1. Blower: yes/no 1/

1.14.2.2. Characteristics or make(s) and type(s) (if applicable): . . . . .

1.14.2.3. Drive ratio(s) (if applicable): . . . .

1.15. Temperature permitted by the manufacturer

1.15.1. Liquid cooling: Maximum temperature at outlet: . . . . K

1.15.2. Air cooling: Reference point: . . . .

Maximum temperature at reference point: . . . . K

1.15.3. Maximum charge air outlet temperature of the inlet intercooler (if applicable): . . . . K

1.15.4. Maximum exhaust temperature at the point in the exhaust pipe(s) adjacent to the outer flange(s) of the exhaust manifold(s): . . K

1.15.5. Fuel temperature: min: . . . . K
max: . . . . K

1.15.6. Lubricant temperature: min: . . . . K
max: . . . . K

1.16. Pressure charger: yes/no 1/

1.16.1. Make: . . . .

1.16.2. Type: . . . .

1.16.3. Description of the system (e.g. max charge pressure, waste-gate, if applicable): . . . .

1.16.4. Intercooler: yes/no 1/

1.17. Intake system: Maximum allowable intake depression at rated engine speed and at 100% load: . . . . kPa

1.18. Exhaust system: Maximum allowable exhaust backpressure at rated engine speed and at 100% load: . . . . kPa

2. Additional anti-pollution devices (if any, and if not covered by another heading) - Description and/or diagram(s): . . . .

3. Fuel feed

3.1. Feed pump

Pressure 2/ or characteristic diagram: . . . . kPa

3.2. Injection system

3.2.1. Pump

3.2.1.1. Make(s): . . . .

3.2.1.2. Type(s): . . . .

3.2.1.3. Delivery: ....mm^3 2/ per stroke or cycle at pump speed of: .... rpm at full injection, or characteristic diagram.

Mention the method used: On engine/on pump bench 1/

3.2.1.4. Injection advance

3.2.1.4.1. Injection advance curve 2/: . . . .

3.2.1.4.2. Timing 2/: . . . .

3.2.2. Injection piping

3.2.2.1. Length: . . . . mm

3.2.2.2. Internal diameter: . . . . mm

3.3. Injection system

3.3.1. Injector(s)

3.3.1.1. Make(s): . . . .

3.3.1.2. Type(s): . . . .

3.3.1.3. Opening pressure 2/ or characteristic diagram: . . . . kPa

3.3.2. Governor

3.3.2.1. Make(s): . . . .

3.3.2.2. Type(s): . . . .

3.3.2.3. Speed at which cut-off starts under full load 2/: . . . . rpm

3.3.2.4. Maximum no-load speed 2/: . . . . rpm

3.3.2.5. Idling speed 2/: . . . . rpm

3.4. Cold Start System

3.4.1. Make(s): . . . .

3.4.2. Type(s): . . . .

3.4.3. Description: . . . .

4. Valve timing

4.1. Maximum lift and angles of opening and closing in relation to dead centres or equivalent data: . . . .

4.2. Reference and/or setting ranges 1/

5. Additional information on test conditions

5.1. Reference fuel used for test

5.1.1. Cetane number: . . . .

5.1.2. Sulphur content: . . . .

5.2. Lubricant

5.2.1. Lubricant used: . . . .

5.2.2. Make(s): . . . .

5.2.3. Type(s): . . . .
(state percentage of oil in mixture if lubricant and fuel are mixed)

5.3. Engine driven equipment (if applicable)

5.3.1. Enumeration and identifying details: . . . .

5.3.2. Power absorbed at indicated engine speeds
(as specified by the manufacturer): . . . .

	Power absorbed (kW) at various engine speeds 3/	
Equipment	Intermediate	Rated
TOTAL:		

5.4. Determination of dynamometer settings

The settings of inlet restriction and exhaust pipe backpressure shall be adjusted to the manufacturer's upper limits, in accordance with annex 4, paragraphs 2.3. and 2.4.

The maximum torque values at the specified test speeds shall be determined by experimentation in order to calculate the torque values for the specified test modes. For engines which are not designed to operate over a speed range on a full load torque curve, the maximum torque at the test speeds shall be declared by the manufacturer.

The engine setting for each test mode shall be calculated using the formula:

$$S = \left((P_M + P_{AE}) \times \frac{L}{100} \right) - P_{AE}$$

If the ratio,

$$\frac{P_{AE}}{P_M} \geq 0.03$$

the value of P_{AE} may be verified by the technical authority granting type approval.

5.5. Dynamometer setting (kW)

	Dynamometer setting (kW) at various engine speeds	
Percent Load	Intermediate	Rated
10	XXXXXXX	
50		
75		
100		

6. Engine performance

6.1. Engine speeds:

Idle: . . . . rpm

Intermediate: . . . . . rpm

Rated: . . . . rpm

6.2. Engine power 4/

	Power setting (kW) at various engine speeds	
Condition	Intermediate	Rated
Maximum power measured on test (P_M) (kW) (a)		
Total power absorbed by engine driven equipment as per paragraph 5.3. of this annex (P_{AE}) (kW) (b)		
Net engine power as specified in paragraph 2.8. of this Regulation (kW) (c)		

c = a + b

1/ Strike out what does not apply.
2/ Specify the tolerance.
3/ Must not be greater than 10% of the power measured during the test.
4/ Uncorrected power measured in accordance with the provisions of paragraph 2.8. of this Regulation.

Annex 1B

ESSENTIAL CHARACTERISTICS OF THE ENGINE FAMILY

1. PARAMETERS DEFINING THE ENGINE FAMILY

The engine family may be defined by basic design parameters which must be common to engines within the family. In some cases there may be interaction of parameters. These effects must also be taken into consideration to ensure that only engines with similar exhaust emission characteristics are included within an engine family.

In order that engines may be considered to belong to the same engine family, the following list of basic parameters must be common:

1.1. Combustion cycle:

two stroke
four stroke

1.2. Cooling medium:

air
water
oil

1.3. Individual cylinder displacement:

engines to be within a total spread of 15%.

1.4. Method of air aspiration:

naturally aspirated
pressure charged
pressure charged with charge cooling

1.5. Combustion chamber type:

pre-chamber
swirl
open chamber

1.6. Valve, port and cylinder head configuration:

1.7. Fuel system:

rotary pump
in-line pump
single element
unit injector

1.8. Engine management systems:

fuel delivery
combustion air
exhaust gas recirculation
water injection
air injection

exhaust after-treatment

oxidation catalyst
reduction catalyst
thermal reactor
particulates trap

2. CHOICE OF THE PARENT ENGINE

2.1. The parent engine of the family shall be selected using the primary criteria of the highest fuel delivery per stroke at the declared maximum torque speed. In the event that two or more engines share this primary criteria, the parent engine shall be selected using the secondary criteria of highest fuel delivery per stroke at rated speed. Under certain circumstances, the approval authority may conclude that the worst case emission rate of the family can best be characterized by testing a second engine. Thus, the approval authority may select an additional engine for test based upon features which indicate that it may have the highest emission levels of the engines within that family.

2.2. If engines within the family incorporate other variable features which could be considered to affect exhaust emissions, these features must also be identified and taken into account in the selection of the parent engine.

3. ENGINE FAMILY LISTING

3.1. Engine family name: . . . .

3.2. Specification of engines within this family:

Engine Type	**No. of cylinders**	**Rated Speed**	**Rated Net Power (kW)**	**Maximum Torque Speed**	**Maximum Torque**	**Low Idle Speed**
PARENT ENGINE (FOR FULL DETAILS SEE ANNEX 1A)						

3.3. In addition, for each engine type within the family, the information required in appendix of this annex shall be submitted to the approval authority.

Annex 1B - Appendix

ESSENTIAL CHARACTERISTICS OF ENGINE TYPES WITHIN THE FAMILY

1. Description of engine

1.1. Manufacturer: . . . .

1.2. Manufacturer's engine code: . . . .

1.3. Cycle: four stroke/two stroke 1/

1.4. Bore: . . . . mm

1.5. Stroke: . . . . mm

1.6. Number and layout of cylinders: . . . .

1.7. Engine capacity: . . . . cm^3

1.8. Rated speed: . . . .

1.9. Maximum torque speed: . . . .

1.10. Volumetric compression ratio 2/: . . . .

1.11. Combustion system description: . . . .

1.12. Drawing(s) of combustion chamber and piston crown . . . .

1.13. Minimum cross-sectional area of inlet and outlet ports: . . . . .

1.14. Cooling system

1.14.1. Liquid

1.14.1.1. Nature of liquid: . . . .

1.14.1.2. Circulating pump(s): yes/no 1/

1.14.1.3. Characteristics or make(s) and type(s) (if applicable): . . . . .

1.14.1.4. Drive ratio(s) (if applicable): . . . .

1.14.2. Air

1.14.2.1. Blower: yes/no 1/

1.14.2.2. Characteristics or make(s) and type(s) (if applicable): . . . . .

1.14.2.3. Drive ratio(s) (if applicable): . . . .

1.15. Temperature permitted by the manufacturer

1.15.1. Liquid cooling: Maximum temperature at outlet: . . . . K

1.15.2. Air cooling: Reference point: . . . .

Maximum temperature at reference point: . . . . K

1.15.3. Maximum charge air outlet temperature of the inlet intercooler (if applicable): . . . . K

1.15.4. Maximum exhaust temperature at the point in the exhaust pipe(s) adjacent to the outer flange(s) of the exhaust manifold(s): . . K

1.15.5. Fuel temperature: min: . . . . K
max: . . . . K

1.15.6. Lubricant temperature: min: . . . . K
max: . . . . K

1.16. Pressure charger: yes/no 1/

1.16.1. Make: . . . .

1.16.2. Type: . . . .

1.16.3. Description of the system (e.g. max. charge pressure, waste-gate, if applicable): . . . .

1.16.4. Intercooler: yes/no 1/

1.17. Intake system: Maximum allowable intake depression at rated engine speed and at 100% load: . . . . kPa

1.18. Exhaust system: Maximum allowable exhaust backpressure at rated engine speed and at 100% load: . . . . kPa

2. Additional anti-pollution devices (if any, and if not covered by another heading) - Description and/or diagram(s): . . . .

3. Fuel feed

3.1. Feed pump

Pressure 2/ or characteristic diagram: . . . . kPa

3.2. Injection system

3.2.1. Pump

3.2.1.1. Make(s): . . . .

3.2.1.2. Type(s): . . . .

3.2.1.3. Delivery: ....mm^3 2/ per stroke or cycle at pump speed of: .... rpm at full injection, or characteristic diagram.

Mention the method used: On engine/on pump bench 1/

3.2.1.4. Injection advance

3.2.1.4.1. Injection advance curve 2/: . . . .

3.2.1.4.2. Timing 2/: . . . .

3.2.2. Injection piping

3.2.2.1. Length: . . . . mm

3.2.2.2. Internal diameter: . . . . mm

3.3. Injection system

3.3.1. Injector(s)

3.3.1.1. Make(s): . . . .

3.3.1.2. Type(s): . . . .

3.3.1.3. Opening pressure 2/ or characteristic diagram: . . . . kPa

3.3.2. Governor

3.3.2.1. Make(s): . . . .

3.3.2.2. Type(s): . . . .

3.3.2.3. Speed at which cut-off starts under full load 2/: . . . . rpm

3.3.2.4. Maximum no-load speed 2/: . . . . rpm

3.3.2.5. Idling speed 2/: . . . . rpm

3.4. Cold Start System

3.4.1. Make(s): . . . .

3.4.2. Type(s): . . . .

3.4.3. Description: . . . .

4. Valve timing

4.1. Maximum lift and angles of opening and closing in relation to dead centres or equivalent data: . . . .

4.2. Reference and/or setting ranges 1/

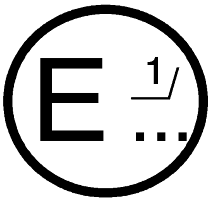
1/ Strike out what does not apply.

2/ Specify the tolerance.

Annex 2

COMMUNICATION

(Maximum format: A4 (210 x 297 mm))



issued by: Name of administration
....
....
....

concerning: 2/ APPROVAL GRANTED
APPROVAL EXTENDED
APPROVAL REFUSED
APPROVAL WITHDRAWN
PRODUCTION DEFINITELY DISCONTINUED

of a compression-ignition engine type or family of engine types as separate technical units with regard to the emission of pollutants pursuant to Regulation No. 96

Approval No: ..... Extension No: .....

1. Trade name or mark of the engine: . . . .

2. Engine type(s) : . . . .

3. Manufacturer's name and address: . . . .

4. If applicable, name and address of manufacturer's representative:

. . . .

5. Maximum allowable intake depression: . . . . kPa

6. Maximum allowable back pressure: . . . . kPa

7. Maximum permissible power absorbed by the engine-driven equipment:

Intermediate: . . . . kW

Rated: . . . . kW

8. Restriction of use (if any): . . . .

9. Emission levels - 8 mode emission test values:

CO: . . . . g/kWh

HC: . . . . g/kWh

NO_x: . . . . g/kWh

Particulates: . . g/kWh

10. Engine submitted for test on: . . . .

11. Technical service responsible for conducting the approval test:

. . . .

12. Date of test report issued by that service: . . . .

13. Number of test report issued by that service: . . . .

14. Site of approval mark on the engine: . . . .

15. Place: . . . .

16. Date: . . . .

17. Signature: . . . .

18. The following documents, bearing the approval number shown above, are annexed to this communication:

One copy of annex 1A or annex 1B to this Regulation completed and with drawings and diagrams referred to attached.

1/ Distinguishing number of the country which has granted/extended/refused/withdrawn approval (see approval provisions in the Regulation.

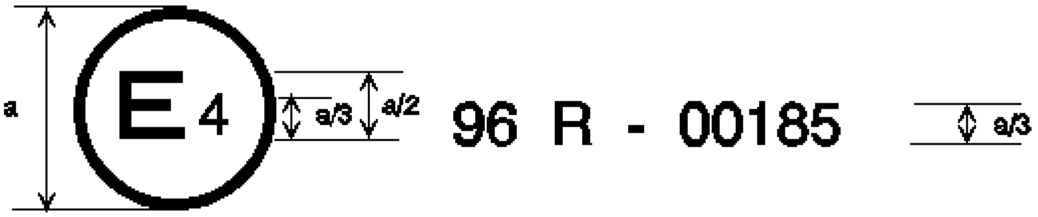
2/ Strike out what does not apply.

Annex 3

ARRANGEMENTS OF APPROVAL MARKS

MODEL A

(See paragraph 4.4. of this Regulation)

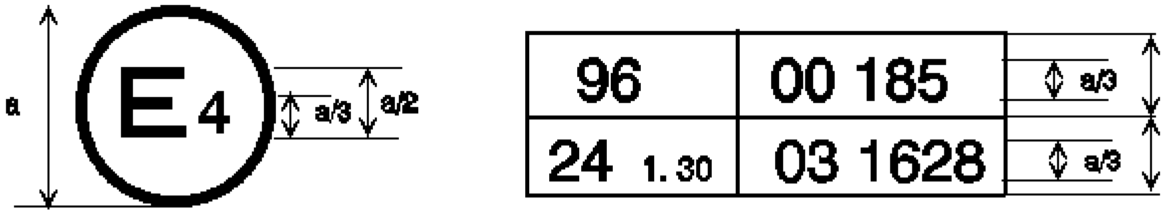


a = 8 mm min

The above approval mark affixed to an engine shows that the engine type concerned has been approved in the Netherlands (E4) pursuant to Regulation No. 96 and under approval number 00185. The first two digits of the approval number indicate that Regulation No. 96 was still in its original form when the approval was granted.

Model B

(See paragraph 4.5. of this Regulation)



a = 8 mm min

The above approval mark affixed to an engine shows that the engine type concerned has been approved in the Netherlands (E4) pursuant to Regulations Nos. 96 and 24 1/. The first two digits of the approval number indicate that, at the dates when the respective approvals were granted, Regulation No. 96 was still in its original form and Regulation No. 24 already included the 03 series of amendments.

1/ The second Regulation number is given merely as an example. The corrected absorption coefficient is 1.30 m^{-1}.

Annex 4

TEST PROCEDURE

1. Introduction

1.1. This annex describes the method of determining emissions of gaseous and particulate pollutants from the engines to be tested.

1.2. The test shall be carried out with the engine mounted on a test bench and connected to a dynamometer.

2. Test Conditions

2.1. General Requirements

All volumes and volumetric flow rates shall be related to 273K (0°C) and 101.3 kPa.

2.2. Engine Test Conditions

2.2.1. The absolute temperature T_a of the engine intake air expressed in Kelvin, and the dry atmospheric pressure p_s, expressed in kPa, shall be measured, and the parameter f_a shall be determined according to the following provisions:

Naturally aspirated and mechanically supercharged engines:

$$f_a = \left(\frac{99}{p_s}\right) \times \left(\frac{T}{298}\right)^{0.7}$$

Turbocharged engine with or without cooling of the intake air:

$$f_a = \left(\frac{99}{p_s}\right)^{0.7} \times \left(\frac{T}{298}\right)^{1.5}$$

2.2.2. Test Validity

For a test to be recognized as valid, the parameter f_a shall be such that:

$$0.98 \leq f_a \leq 1.02$$

2.2.3. Engines with Charge Air Cooling

The temperature of the cooling medium and the temperature of the charge air have to be recorded.

2.3. Engine Air Inlet System

The test engine shall be equipped with an air inlet system presenting an air inlet restriction at the upper limit specified by the manufacturer for a clean air cleaner at the engine operating conditions as specified by the manufacturer which result in maximum air flow.

A test shop system may be used, provided it duplicates actual engine operating conditions.

2.4. Engine Exhaust System

The test engine shall be equipped with an exhaust system presenting an exhaust back pressure at the upper limit specified by the manufacturer for the engine operating conditions which result in maximum declared power.

2.5. Cooling System

An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures prescribed by the manufacturer.

2.6. Lubricating Oil

Specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test.

2.7. Test Fuel

The fuel shall be the reference fuel specified in annex 5.

The cetane number and the sulphur content of the reference fuel used for test shall be recorded at paragraph 5.1. of annex 1A.

The fuel temperature at the injection pump inlet shall be 306-316K (33-43°C).

3. Test Run

3.1. Preparation of the Sampling Filters

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

3.2. Installation of the Measuring Equipment

The instrumentation and sample probes shall be installed as required. When using a full flow dilution system for exhaust gas dilution, the tailpipe shall be connected to the system.

3.3. Starting the Dilution System and Engine

The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilized at full load and rated speed (paragraph 3.6.2.).

3.4. Adjustment of the Dilution Ratio

The particulate sampling system shall be started and running on bypass for the single filter method (optional for the multiple filter method). The particulate background level of the dilution air may be determined by passing dilution air through the particulate filters. If filtered dilution air is used, one measurement may be done at any time prior to, during, or after the test. If the dilution air is not filtered, measurements at a minimum of three points, at the beginning, at the end, and a point near the middle of the cycle, are required, and the values averaged.

The dilution air shall be set to obtain a maximum filter face temperature of 325K (52°C) or less at each mode. The total dilution ratio shall not be less than four.

For the single filter method, the sample mass flow rate through the filter shall be maintained at a constant proportion of the dilute exhaust mass flow rate for full flow systems for all modes. This mass ratio shall be within ± 5%, except for the first 10 seconds of each mode for systems without bypass capability. For partial flow dilution systems, the mass flow rate through the filter shall be constant within ± 5% during each mode, except for the first 10 seconds of each mode for systems without bypass capability.

For CO_2 or NO_x concentration controlled systems, the CO_2 or NO_x content of the dilution air must be measured at the beginning and at the end of each test. The pre- and post-test background CO_2 or NO_x concentration measurements of the dilution air must be within 100 ppm or 5 ppm of each other, respectively.

When using a dilute exhaust gas analysis system, the relevant background concentrations shall be determined by sampling dilution air into a sampling bag over the complete test sequence.

Continuous (non bag) background concentration may be taken at the minimum of three points, at the beginning at the end, and a point near the middle of the cycle and averaged. At the manufacturers request background measurements may be omitted.

3.5. Checking the Analysers

The emission analysers shall be set at zero and spanned.

3.6. Test Cycle

3.6.1. The following 8-mode cycle shall be followed in dynamometer operation on the test engine:

Mode Number	Engine Speed	Percent Load	Weighting Factor
1	Rated	100	0.15
2	Rated	75	0.15
3	Rated	50	0.15
4	Rated	10	0.1
5	Intermediate	100	0.1
6	Intermediate	75	0.1
7	Intermediate	50	0.1
8	Idle	-	0.15

3.6.2. Conditioning of the Engine

Warming up of the engine and the system shall be at maximum speed and torque in order to stabilise the engine parameters according to the recommendations of the manufacturer.

Note: The conditioning period should also prevent the influence of deposits from a former test in the exhaust system. There is also a required period of stabilization between test points which has been included to minimise point to point influences.

3.6.3. Test Sequence

The test sequence shall be started. The test shall be performed in the order of the measuring points 1 to 8 of paragraph 3.6.1.

During each mode of the test cycle after the initial transition period, the specified speed shall be held to within ± 1% of rated speed or ± 3min^{-1} whichever is greater except for low idle which shall be within the tolerances declared by the manufacturer. The specified torque shall be held so that the average over the period during which the measurements are being taken is within ± 2% of the maximum torque at the test speed.

For each measuring point a minimum time of ten minutes is necessary. If for the testing of an engine longer sampling times are required for reasons of obtaining sufficient particulate mass on the measuring filter the test mode period can be extended as necessary.

The mode length shall be recorded and reported.

The gaseous exhaust emission concentration values shall be measured and recorded during the last three minutes of the mode.

The completion of particulate sampling must be coincident with the completion of the gaseous emission measurement and should not commence before engine stabilization as defined by the manufacturer, has been achieved.

The fuel temperature shall be measured at the inlet to the fuel injection pump or as specified by the manufacturer, and the location of measurement recorded.

3.6.4. Analyser Response

The output of the analysers shall be recorded on a strip chart recorder or measured with an equivalent data acquisition system with the exhaust gas flowing through the analysers at least during the last three minutes of each mode. If bag sampling is applied for the diluted CO and CO_2 measurement (see annex 4, appendix 1, paragraph 1.4.4.), a sample shall be bagged during the last three minutes of each mode, and the bag sample analysed and recorded.

3.6.5. Particulate Sampling

The particulate sampling can be done either with the single filter method or with the multiple filter method (annex 4, appendix 1, paragraph 1.5.).

Since the results of the methods may differ slightly, the method used must be declared with the results.

For the single filter method the modal weighting factors specified in the test cycle procedure shall be taken into account during sampling by adjusting sample flow rate and/or sampling time, accordingly.

Sampling must be conducted as late as possible within each mode. The sampling time per mode must be at least 20 seconds for the single filter method and at least 60 seconds for the multi-filter method. For systems without bypass capability, the sampling time per mode must be a least 60 seconds for single and multiple filter methods.

3.6.6. Engine Conditions

The engine speed and load, intake air temperature, fuel flow and air or exhaust gas flow shall be measured for each mode once the engine has been stabilized.

If the measurement of the exhaust gas flow or the measurement of combustion air and fuel consumption is not possible, it can be calculated using the carbon balance method (see annex 4, appendix 1, paragraph 1.2.3.).

Any additional data required for calculation shall be recorded (see annex 4, appendix 3, paragraphs 1.1. and 1.2.).

3.7. Re-checking the Analysers

After the emission test a zero gas and the same span gas will be used for re-checking. The test will be considered acceptable if the difference between the two measuring results is less than 2%.

Annex 4 - Appendix 1

1. Measurement and Sampling Procedures

Gaseous and particulate components emitted by the engine submitted for testing shall be measured by the methods described in annex 4, appendix 4. These paragraphs describe the recommended analytical systems for the gaseous emissions (paragraph 1.1.) and the recommended particulate dilution and sampling systems (paragraph 1.2.).

1.1. Dynamometer Specification

An engine dynamometer with adequate characteristics to perform the test cycle described in annex 4, paragraph 3.6.1. shall be used. The instrumentation for torque and speed measurement shall allow the measurement of the shaft power within the given limits. Additional calculations may be necessary.

The accuracy of the measuring equipment must be such that the maximum tolerances of the figures given in paragraph 1.3. are not exceeded.

1.2. Exhaust Gas Flow

The exhaust gas flow shall be determined by one of the methods mentioned in paragraphs 1.2.1. to 1.2.4.

1.2.1. Direct Measurement Method

Direct measurement of the exhaust flow by flow nozzle or equivalent metering system (for detail see ISO 5167).

Note: Direct gaseous flow measurement is a difficult task. Precautions must be taken to avoid measurement errors which will impact emission value errors.

1.2.2. Air and Fuel Measurement Method

Measurement of the air flow and the fuel flow.

Air flowmeters and fuel flowmeters with an accuracy defined in paragraph 1.3. shall be used.

The calculation of the exhaust gas flow is as follows:

$$G_{EXHW} = G_{AIRW} + G_{FUEL} \quad \text{(for wet exhaust mass)}$$

or:

$$V_{EXHD} = V_{AIRD} - 0.766 \times G_{FUEL} \quad \text{(for dry exhaust volume)}$$

or:

$$V_{EXHW} = V_{AIRW} + 0.746 \times G_{FUEL} \quad \text{(for wet exhaust volume)}$$

1.2.3. Carbon Balance Method

Exhaust mass calculation from fuel consumption and exhaust gas concentrations using the carbon balance method (see annex 4, appendix 3).

1.2.4. Total Dilute Exhaust Gas Flow

When using a full flow dilution system, the total flow of the dilute exhaust (G_{TOTW} , V_{TOTW}) shall be measured with a PDP or CFV - annex 4, appendix 4, paragraph 1.2.1.2. The accuracy shall conform to the provisions of annex 4, appendix 2, paragraph 2.2.

1.3. Accuracy

The calibration of all measurement instruments shall be traceable to national (international) standards and comply with the following requirements:

Number	Item	Permissible Deviation (± Values based on Engines Maximum Values)	Permissible Deviation (± Values According to ISO 3046)	Calibration Intervals (Months)
1	Engine Speed	2%	2%	3
2	Torque	2%	2%	3
3	Power	2% *	3%	N/A
4	Fuel Consumption	2% *	3%	6
5	Specific Fuel Consumption	N/A	3%	N/A
6	Air Consumption	2% *	5%	6
7	Exhaust Gas Flow	4% *	N/A	6
8	Coolant Temperature	2K	2K	3
9	Lubricant Temperature	2K	2K	3
10	Exhaust Gas Pressure	5% of max.	5%	3
11	Inlet Manifold Depressions	5% of max.	5%	3
12	Exhaust Gas Temperature	15K	15K	3
13	Air Inlet Temperature (Combustion Air)	2K	2K	3

14	Atmospheric Pressure	0.5% of reading	0.5%	3
15	Intake Air Humidity (Relative)	3%	N/A	1
16	Fuel Temperature	2K	5K	3
17	Dilution Tunnel Temperatures	1.5K	N/A	3
18	Dilution Air Humidity	3%	N/A	1
19	Diluted Exhaust Gas Flow	2% of reading	N/A	24 (Partial flow) (full flow) **

Key:

★ The calculations of the exhaust emissions as described in this Regulation are, in some cases, based on different measurement and/or calculation methods. Because of limited total tolerances for the exhaust emission calculation, the allowable values for some items, used in the appropriate equations, must be smaller than the allowed tolerances given in ISO 3046-3.

** Full flow systems - The CVS positive displacement pump or critical flow Venturi shall be calibrated following initial installation, major maintenance or as necessary when indicated by the CVS system verification described in annex 4, appendix 4.

1.4. Determination of the Gaseous Components

1.4.1. General Analyser Specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (paragraph 1.4.1.1.). It is recommended that the analysers be operated such that the measured concentration falls between 15% and 100% of full scale.

If the full scale value is 155 ppm (or ppm C) or less or if read-out systems (computers, data loggers) that provide sufficient accuracy and resolution below 15% of full scale are used concentrations below 15% of full scale are also acceptable. In this case, additional calibrations are to be made to ensure the accuracy of the calibration curves - annex 4, appendix 2, paragraph 1.5.5.2.

The electromagnetic compatibility (EMC) of the equipment shall be on a level as to minimize additional errors.

1.4.1.1. Measurement Error

The total measurement error, including the cross sensitivity to other gases - see annex 4, appendix 2, paragraph 1.9. shall not exceed ± 5% of the reading or 3.5 per cent of full scale, whichever is smaller. For concentrations of less than 100 ppm the measurement error shall not exceed ± 4 ppm.

1.4.1.2. Repeatability

The repeatability, defined as 2.5 times the standard deviation of ten repetitive responses to a given calibration or span gas, must be no greater than ± 1% of full scale concentration for each range used above 155 ppm (or ppm C) or ± 2% of each range used below 155 ppm (or ppm C).

1.4.1.3. Noise

The analyser peak-to-peak response to zero and calibration or span gases over any ten seconds period shall not exceed 2% of full scale on all ranges used.

1.4.1.4. Zero Drift

The zero drift during a one hour period shall be less than 2% of full scale on the lowest range used. The zero response is defined as the mean response, including noise, to a zero gas during a 30 seconds time interval.

1.4.1.5. Span Drift

The span drift during a one hour period shall be less than 2% of full scale on the lowest range used. Span is defined as the difference between the span response and the zero response. The span response is defined as the mean response, including noise, to a span gas during a 30 seconds time interval.

1.4.2. Gas Drying

The optional gas drying device must have a minimal effect on the concentration of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

1.4.3. Analysers

Paragraphs 1.4.3.1. to 1.4.3.5. of this appendix describe the measurement principles to be used. A detailed description of the measurement systems is given in annex 4, appendix 4.
The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted.

1.4.3.1. Carbon Monoxide (CO) Analysis

The carbon monoxide analyser shall be of the Non-Dispersive Infra-Red (NDIR) absorption type.

1.4.3.2. Carbon Dioxide (CO_2) Analysis

The carbon dioxide analyser shall be of the Non-Dispersive Infra-Red (NDIR) absorption type.

1.4.3.3. Oxygen (O_2) Analysis

Oxygen analysers shall be of the ParaMagnetic Detector (PMD), Zirconium Dioxide (ZRDO) or ElectroChemical Sensor (ECS) type.

1.4.3.4. Hydrocarbon (HC) Analysis

The hydrocarbon analyser shall be of the Heated Flame Ionisation Detector (HFID) type with detector, valves, pipework, etc, heated so as to maintain a gas temperature of 463K (190°C) ± 10K.

1.4.3.5. Oxides of Nitrogen (NO_x) Analysis

The oxides of nitrogen analyser shall be of the ChemiLuminescent Detector (CLD) or Heated ChemiLuminescent Detector (HCLD) type with a NO_2/NO converter, if measured on a dry basis. If measured on a wet basis, a HCLD with converter maintained above 333K (60°C) shall be used, provided the water quench check (annex 4, appendix 2, paragraph 1.9.2.2.) is satisfied.

1.4.4. Sampling for Gaseous Emissions

The gaseous emissions sampling probes must be fitted at least 0.5 m or three times the diameter of the exhaust pipe - whichever is the larger - upstream of the exit of the exhaust gas system as far as applicable and sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343K (70°C) at the probe.

In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a 'vee' engine configuration, it is permissable to acquire a sample from each group individually and calculate an average exhaust emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emissions calculation the total exhaust mass flow of the engine must be used.

If the composition of the exhaust gas is influenced by any exhaust after-treatment system, the exhaust sample must be taken downstream of this device. When a full flow dilution system is used for the determination of the particulates, the gaseous emissions may also be determined in the diluted exhaust gas. The sampling probes shall be close to the particulate sampling probe in the dilution tunnel (annex 4, appendix 4, paragraph 1.2.1.2. for DT and paragraph 1.2.2. for PSP). CO and CO_2 may optionally be determined by sampling into a bag and subsequent measurement of the concentration in the sampling bag.

1.5. Determination of the Particulates

The determination of the particulates requires a dilution system. Dilution may be accomplished by a partial flow dilution system or a full flow dilution system. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas at or below 325K (52°C) immediately upstream of the filter holders. De-humidifying the dilution air before entering the dilution system is permitted, if the air humidity is high. Dilution air pre-heating above the temperature limit of 303K (30°C) is recommended, if the ambient temperature is below 293K (20°C). However, the diluted air temperature must not exceed 325K (52°C) prior to the introduction of the exhaust in the dilution tunnel.

For a partial flow dilution system, the particulate sampling probe must be fitted close to and upstream of the gaseous probe as defined in paragraph 4.4. and in accordance with annex 4, appendix 4, paragraph 1.2.1.1., figures 4-12, EP and SP.

The partial flow dilution system has to be designed to split the exhaust stream into two fractions, the smaller one being diluted with air and subsequently used for particulate measurement. From that it is essential that the dilution ratio be determined very accurately. Different splitting methods can be applied, whereby the type of splitting used dictates to a significant degree the sampling hardware and procedures to be used (annex 4, appendix 4, paragraph 1.2.1.1.).

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

For particulate sampling, two methods may be applied:

The Single Filter Method uses one pair of filters (see paragraph 1.5.1.3. of this appendix) for all modes of the test cycle. Considerable attention must be paid to sampling times and flows during the sampling phase of the test. However, only one pair of filters will be required for the test cycle.

The Multiple Filter Method dictates that one pair of filters (see paragraph 1.5.1.3. of this appendix) is used for each of the individual modes of the test cycle. This method allows more lenient sample procedures but uses more filters.

1.5.1. Particulate Sampling Filters

1.5.1.1. Filter Specification

Fluorocarbon coated glass fibre filters or fluorocarbon based membrane filters are required for certification tests. For special applications different filter materials may be used. All filter types shall have a 0.3 μm DOP (di-octylphthalate) collection efficiency of at least 95% at a gas face velocity between 40 and 80 cm/s. When performing correlation tests between laboratories or between a manufacturer and a regulatory agency, filters of identical quality must be used.

1.5.1.2. Filter Size

Particulate filters must have a minimum diameter of 47 mm (37 mm stain diameter). Larger diameter filters are acceptable (paragraph 1.5.1.5.).

1.5.1.3. Primary and Back-up Filters

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

1.5.1.4. Filter Face Velocity

A gas face velocity through the filter of 35 to 80 cm/s shall be achieved. The pressure drop increase between the beginning and the end of the test shall be no more than 25 kPa.

1.5.1.5. Filter Loading

The recommended minimum filter loading shall be 0.5 mg/1075 mm^2 stain area for the single filter method. For the most common filter size the values are as follows:

Filter Diameter(mm)	Recommended Stain Diameter (mm)	Recommended Minimum Loading (mg)
47	37	0.5
70	60	1.3
90	80	2.3
110	100	3.6

For the multiple filter method, the recommended minimum filter loading for the sum of all filters shall be the product of the appropriate value above and the square root of the total number of modes.

1.5.2. Weighing Chamber and Analytical Balance Specifications

1.5.2.1. Weighing Chamber Conditions

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained at 295K (22°C) ± 3K during all filter conditioning and weighing. The humidity shall be maintained to a dewpoint of 282.5 (9.5°C) ± 3K and a relative humidity of 45 ± 8%.

1.5.2.2. Reference Filter Weighing

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilisation. Disturbances to weighing room specifications as outlined in paragraph 1.5.2.1. will be allowed if the duration of the disturbances does not exceed 30 minutes. The weighing room should meet the required specifications prior to personnel entrance into the weighing room. At least two unused reference filters or reference filter pairs shall be weighed within four hours of, but preferably at the same time as the sample filter (pair) weighings. They shall be the same size and material as the sample filters.

If the average weight of the reference filters (reference filter pairs) changes between sample filter weighings by more than ± 5% (± 7.5% for the filter pair) of the recommended minimum filter loading (paragraph 1.5.1.5.), then all sample filters shall be discarded and the emissions test repeated.

If the weighing room stability criteria outlined in paragraph 1.5.2.1. is not met, but the reference filter (pair) weighings meet the above criteria, the engine manufacturer has the option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system and re-running the test.

1.5.2.3. Analytical Balance

The analytical balance used to determine the weights of all filters shall have a precision (standard deviation) of 20µg and a resolution of 10µg (1 digit = 10µg). For filters less than 70 mm diameter, the precision and resolution shall be 2µg and 1µg, respectively.

1.5.2.4. Elimination of Static Electricity Effects

To eliminate the effects of static electricity, the filters shall be neutralized prior to weighing, for example, by a Polonium neutralizer or a device of similar effect.

1.5.3. Additional Specifications for Particulate Measurement

All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder, which are in contact with raw and diluted exhaust gas, must be designed to minimize deposition or alteration of the particulates. All parts must be made of electrically conductive materials that do not react with exhaust gas components, and must be electrically grounded to prevent electrostatic effects.

Annex 4 - Appendix 2

1. Calibration of the analytical instruments

1.1. Introduction

Each analyser shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method that shall be used is described in this paragraph for the analysers indicated in appendix 1, paragraph 1.4.3.

1.2. Calibration Gases

The shelf life of all calibration gases must be respected.

The expiry date of the calibration gases stated by the manufacturer shall be recorded.

1.2.1. Pure Gases

The required purity of the gases is defined by the contamination limits given below. The following gases must be available for operation:

Purified Nitrogen

(Contamination $\leq$ 1 ppm C, $\leq$ 1 ppm CO, $\leq$ 400 ppm CO_2, $\leq$ 0.1 ppm NO)

Purified Oxygen

(Purity > 99.5% vol O_2)

Hydrogen-Helium Mixture

(40 ± 2% hydrogen, balance helium)

(Contamination $\leq$ 1 ppm C, $\leq$ 400 ppm CO)

Purified Synthetic Air

(Contamination $\leq$ 1 ppm C, $\leq$ 1 ppm CO, $\leq$ 400 ppm CO_2, $\leq$ 0.1 ppm NO) (Oxygen content between 18-21% vol)

1.2.2. Calibration and Span Gases

Mixture of gases having the following chemical compositions shall be available:

C_3H_8 and purified synthetic air (see paragraph 1.2.1.)

CO and purified nitrogen

NO and purified nitrogen (the amount of NO_2 contained in this calibration gas must not exceed 5% of the NO content)

O_2 and purified nitrogen

CO_2 and purified nitrogen

CH_4 and purified synthetic air

C_2H_6 and purified synthetic air

Note: Other gas combinations are allowed provided the gases do not react with one another.

The true concentration of a calibration and span gas must be within ± 2% of the nominal value. All concentrations of calibration gas shall be given on a volume basis (volume percent or volume ppm).

The gases used for calibration and span may also be obtained by means of a gas divider, diluting with purified N_2 or with purified synthetic air. The accuracy of the mixing device must be such that the concentration of the diluted calibration gases may be determined to within ± 2%.

1.3. Operating Procedure for Analysers and Sampling System

The operating procedure for analysers shall follow the start-up and operating instructions of the instrument manufacturer. The minimum requirements given in paragraphs 1.4. to 1.9. shall be included.

1.4. Leakage Test

A system leakage test shall be performed. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilisation period all flow meters should read zero. If not, the sampling lines shall be checked and the fault corrected.

Another method is the introduction of a concentration step change at the beginning of the sampling line by switching from zero to span gas.

If after an adequate period of time the reading shows a lower concentration compared to the introduced concentration, this points to calibration or leakage problems.

1.5. Calibration Procedure

1.5.1. Instrument Assembly

The instrument assembly shall be calibrated and calibration curves checked against standard gases. The same gas flow rates shall be used as when sampling exhaust.

1.5.2. Warming-up Time

The warming-up time should be according to the recommendations of the manufacturer. If not specified, a minimum of two hours is recommended for warming-up the analysers.

1.5.3. NDIR and HFID Analyser

The NDIR analyser shall be tuned, as necessary, and the combustion flame of the HFID analyser shall be optimized (paragraph 1.8.1).

1.5.4. Calibration

Each normally used operating range shall be calibrated.

Using purified synthetic air (or nitrogen), the CO, CO_2, NO_x, HC and O_2 analysers shall be set at zero.

The appropriate calibration gases shall be introduced to the analysers, the values recorded, and the calibration curve established according to paragraph 1.5.6.

The zero setting shall be re-checked and the calibration procedure repeated, if necessary.

1.5.5. Establishment of the Calibration Curve

1.5.5.1. General Guidelines

The analyser calibration curve is established by at least five calibration points (excluding zero) spaced as uniformly as possible. The highest nominal concentration must be equal to or higher than 90% of full scale.

The calibration curve is calculated by the method of least squares. If the resulting polynomial degree is greater than three, the number of calibration points (zero included) must be at least equal to this polynomial degree plus two.

The calibration curve must not differ by more than ± 2% from the nominal value of each calibration point and by more than ± 1% of full scale at zero.

From the calibration curve and the calibration points, it is possible to verify that the calibration has been carried out correctly. The different characteristic parameters of the analyser must be indicated, particularly:

the measuring range
the sensitivity
the date of carrying out the calibration.

1.5.5.2. Calibration Below 15% of Full Scale

The analyser calibration curve is established by at least ten calibration points (excluding zero) spaced so that 50% of the calibration points are below 10% of full scale.
The calibration curve is calculated by the method of least squares. The calibration curve must not differ by more than ± 4% from the nominal value of each calibration point and by more than ± 1% of full scale at zero.

1.5.5.3. Alternative Methods

If it can be shown that alternative technology (e.g. computer, electronically controlled range switch, etc.) can give equivalent accuracy, then these alternatives may be used.

1.6. Verification of the Calibration

Each normally used operating range shall be checked prior to each analysis in accordance with the following procedure.

The calibration is checked by using a zero gas and a span gas whose nominal value is more than 80% of full scale of the measuring range.

If, for the two points considered, the value found does not differ by more than ± 4% of full scale from the declared reference value, the adjustment parameters may be modified. Should this not be the case, a new calibration curve shall be established in accordance with paragraph 1.5.4.

1.7. Efficiency Test of the NO_x Converter

The efficiency of the converter used for the conversion of NO_2 into NO is tested as given in paragraphs 1.7.1. to 1.7.8. (Figure 1).

1.7.1. Test Set-up

Using the test set-up as shown in figure 1 (see also appendix 1, paragraph 1.4.3.5.) and the procedure below, the efficiency of converters can be tested by means of an ozonator.

Figure 1

Schematic of NO_2 converter efficiency device

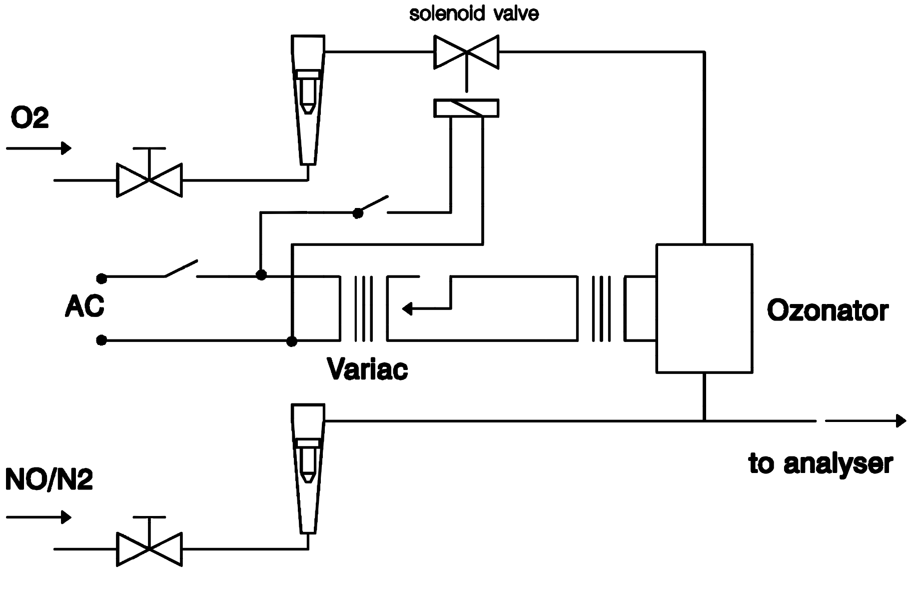


Figure 1

1.7.2. Calibration

The CLD and the HCLD shall be calibrated in the most common operating range following the manufacturer's specifications using zero and span gas (the NO content of which must amount to about 80% of the operating range and the NO_2 concentration of the gas mixture to less than 5% of the NO concentration). The NO_x analyser must be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

1.7.3. Calculation

The efficiency of the NO_x converter is calculated as follows:

$$Efficiency\ (\%) = \left(1 + \frac{a-b}{c-d}\right) \times 100$$

where:

a = NO_x concentration according to paragraph 1.7.6.;

b = NO_x concentration according to paragraph 1.7.7.;

c = NO concentration according to paragraph 1.7.4.;

d = NO concentration according to paragraph 1.7.5.

1.7.4. Adding of Oxygen

Via a T-fitting, oxygen or zero air is added continuously to the gas flow until the concentration indicated is about 20% less than the indicated calibration concentration given in paragraph 1.7.2. (The analyser is in the NO mode.)

The indicated concentration (c) shall be recorded. The ozonator is kept de-activated throughout the process.

1.7.5. Activation of the Ozonator

The ozonator is now activated to generate enough ozone to bring the NO concentration down to about 20% (minimum 10%) of the calibration concentration given in paragraph 1.7.2. The indicated concentration (d) shall be recorded. (The analyser is in the NO mode.)

1.7.6. NO_x Mode

The NO analyser is then switched to the NO_x mode so that the gas mixture (consisting of NO, NO_2, O_2 and N_2) now passes through the converter. The indicated concentration (a) shall be recorded. (The analyser is in the NO_x mode.)

1.7.7. De-activation of the Ozonator

The ozonator is now de-activated. The mixture of gases described in paragraph 1.7.6. passes through the converter into the detector. The indicated concentration (b) shall be recorded. (The analyser is in the NO_x mode.)

1.7.8. NO Mode

Switched to NO mode with the ozonator de-activated, the flow of oxygen or synthetic air is also shut off. The NO_x reading of the analyser shall not deviate by more than ± 5% from the value measured according to paragraph 1.7.2. (The analyser is in the NO mode.)

1.7.9. Test Interval

The efficiency of the converter must be tested prior to each calibration of the NO_x analyser.

1.7.10. Efficiency Requirement

The efficiency of the converter shall not be less than 90%, but a higher efficiency of 95% is strongly recommended.

Note: If, with the analyser in the most common range, the ozonator cannot give a reduction from 80% to 20% according to paragraph 1.7.5., then the highest range which will give the reduction shall be used.

1.8. Adjustment of the FID

1.8.1. Optimization of the Detector Response

The HFID must be adjusted as specified by the instrument manufacturer. A propane in air span gas should be used to optimize the response on the most common operating range.

With the fuel and air flow rates set at the manufacturer's recommendations, a 350 ±75 ppm C span gas shall be introduced to the analyser. The response at a given fuel flow shall be determined from the difference between the span gas response and the zero gas response. The fuel flow shall be incrementally adjusted above and below the manufacturer's specification. The span and zero response at these fuel flows shall be recorded. The difference between the span and zero response shall be plotted and the fuel flow adjusted to the rich side of the curve.

1.8.2. Hydrocarbon Response Factors

The analyser shall be calibrated using propane in air and purified synthetic air, according to paragraph 1.5.

Response factors shall be determined when introducing an analyser into service and after major service intervals. The response factor (R_f) for a particular hydrocarbon species is the ratio of the FID C1 reading to the gas concentration in the cylinder expressed by ppm C1.

The concentration of the test gas must be at a level to give a response of approximately 80% of full scale. The concentration must be known to an accuracy of ± 2% in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder must be pre-conditioned for 24 hours at a temperature of 298 (25°C) ± 5K.

The test gases to be used and the recommended relative response factor ranges are as follows:

Methane and purified synthetic air: $1.00 \leq R_f \leq 1.15$

Propylene and purified synthetic air: $0.90 \leq R_f \leq 1.1$

Toluene and purified synthetic air: $0.90 \leq R_f \leq 1.10$

These values are relative to the response factor (R_f) of 1.00 for propane and purified synthetic air.

1.8.3. Oxygen Interference Check

The oxygen interference check shall be determined when introducing an analyser into service and after major service intervals.

The response factor is defined and shall be determined as described in paragraph 1.8.2. The test gas to be used and the recommended relative response factor range are as follows:

Propane and nitrogen: $0.95 \leq R_f \leq 1.05$

This value is relative to the response factor (R_f) of 1.00 for propane and purified synthetic air.

The FID burner air oxygen concentration must be within ± 1 mole % of the oxygen concentration of the burner air used in the latest oxygen interference check. If the difference is greater, the oxygen interference must be checked and the analyser adjusted, if necessary.

1.9. Interference Effects with NDIR and CLD Analysers

Gases present in the exhaust other than the one being analysed can interfere with the reading in several ways. Positive interference occurs in NDIR instruments where the interfering gas gives the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments by the interfering gas broadening the absorption band of the measured gas, and in CLD instruments by the interfering gas quenching the radiation. The interference checks in paragraphs 1.9.1. and 1.9.2. shall be performed prior to an analyser's initial use and after major service intervals.

1.9.1. CO Analyser Interference Check

Water and CO_2 can interfere with the CO analyser performance. Therefore a CO_2 span gas having a concentration of 80 to 100% of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyser response recorded. The analyser response must not be more than 1% of full scale for ranges equal to or above 300 ppm or more than 3 ppm for ranges below 300 ppm.

1.9.2. NO_x Analyser Quench Checks

The two gases of concern for CLD (and HCLD) analysers are CO_2 and water vapour. Quench responses of these gases are proportional to their concentrations, and therefore require test techniques to determine the quench at the highest expected concentrations experienced during testing.

1.9.2.1. CO_2 Quench Check

A CO_2 span gas having a concentration of 80 to 100% of full scale of the maximum operating range shall be passed through the NDIR analyser and the CO_2 value recorded as A. It shall then be diluted approximately 50% with NO span gas and passed through the NDIR and (H)CLD with the CO_2 and NO values recorded as B and C, respectively. The CO_2 shall be shut off and only the NO span gas be passed through the (H)CLD and the NO value recorded as D.

The quench shall be calculated as follows:

$$\%\ CO_2\ Quench = \left[1 - \left(\frac{C\ x\ A}{(D \times A) - (D x B)} \right) \right] x\ 100$$

and must not be greater than 3% of full scale.

where:

A = Undiluted CO_2 concentration measured with NDIR %

B = Diluted CO_2 concentration measured with NDIR %

C = Diluted NO concentration measured with CLD ppm

D = Undiluted NO concentration measured with CLD ppm.

1.9.2.2. Water Quench Check

This check applies to wet gas concentration measurements only. Calculation of water quench must consider dilution of the NO span gas with water vapour and scaling of water vapour concentration of the mixture to that expected during testing. A NO span gas having a concentration of 80 to 100% of full scale to the normal operating range shall be passed through the (H)CLD and the NO value recorded as D. The NO gas shall be bubbled through water at room temperature and passed through the (H)CLD and the NO value recorded as C. The analyser's absolute operating pressure and the water temperature shall be determined and recorded as E and F, respectively. The mixture's saturation vapour pressure that corresponds to the bubbler water temperature (F) shall be determined and recorded as G. The water vapour concentration (in %) of the mixture shall be calculated as follows:

$$H = 100 \times \left(\frac{G}{E} \right)$$

and recorded as H. The expected diluted NO span gas (in water vapour) concentration shall be calculated as follows:

$$De = D \times \left(1 - \frac{H}{100} \right)$$

and recorded as De. For diesel exhaust, the maximum exhaust water vapour concentration (in %) expected during testing shall be estimated, under the assumption of a fuel atom H/C ratio of 1.8 to 1, from the undiluted CO_2 span gas concentration (A, as measured in paragraph 1.9.2.1.) as follows:

$$Hm = 0.9 \times A$$

and recorded as Hm.

The water quench shall be calculated as follows:

$$\%\ H_2O\ Quench = 100 \times \left(\frac{De - C}{De} \right) \times \left(\frac{Hm}{H} \right)$$

and must not be greater than 3%

De = Expected diluted NO concentration (ppm)
C = Diluted NO concentration (ppm)
Hm = Maximum water vapour concentration (%)
H = Actual water vapour concentration (%)

Note: It is important that the NO span gas contains minimal NO_2 concentration for this check, since absorption of NO_2 in water has not been accounted for in the quench calculations.

1.10. Calibration Intervals

The analysers shall be calibrated according to paragraph 1.5. at least every three months or whenever a system repair or change is made that could influence calibration.

2. Calibration of the Particulate Measuring System

2.1. Introduction

Each component shall be calibrated as often as necessary to fulfil the accuracy requirements of this standard. The calibration method to be used is described in this paragraph for the components indicated in annex 4, appendix 1, paragraph 1.5. and annex 4, appendix 4.

2.2. Flow Measurement

The calibration of gas flowmeters or flow measurement instrumentation shall be traceable to national and/or international standards.

The maximum error of the measured value shall be within ± 2% of reading.

If the gas flow is determined by differential flow measurement, the maximum error of the difference shall be such that the accuracy of G_{EDF} is within ± 4% (see also annex 4, appendix 4, paragraph 1.2.1.1. EGA). It can be calculated by taking the root-mean-square of the errors of each instrument.

2.3. Checking the Dilution Ratio

When using particulate sampling systems without EGA (annex 4, appendix 4, paragraph 1.2.1.1.), the dilution ratio shall be checked for each new engine installation with the engine running and the use of either the CO_2 or NO_x concentration measurements in the raw and dilute exhaust.

The measured dilution ratio shall be within ± 10% of the calculated dilution ratio from CO_2 or NO_x concentration measurement.

2.4. Checking the Partial Flow Conditions

The range of the exhaust gas velocity and the pressure oscillations shall be checked and adjusted according to the requirements of annex 4, appendix 4, paragraph 1.2.1.1., EP, if applicable.

2.5. Calibration Intervals

The flow measurement instrumentation shall be calibrated at least every three months, or whenever a system change is made that could influence calibration.

Annex 4 - Appendix 3

1. Data Evaluation and Calculations

1.1. Gaseous Emissions Data Evaluation

For the evaluation of the gaseous emissions, the chart reading of the last 60 seconds of each mode shall be averaged, and the average concentrations (conc) of HC, CO, NO_x and CO_2 if the carbon balance method is used, during each mode shall be determined from the average chart readings and the corresponding calibration data. A different type of recording can be used if it ensures an equivalent data acquisition.

The average background concentrations ($conc_d$) may be determined from the bag readings of the dilution air or from the continuous (non-bag) background reading and the corresponding calibration data.

1.2. Particulate Emissions

For the evaluation of the particulates, the total sample masses ($M_{SAM,i}$) or volumes ($V_{SAM,i}$) through the filters shall be recorded for each mode.

The filters shall be returned to the weighing chamber and conditioned for at least two hours, but not more than 80 hours, and then weighed. The gross weight of the filters shall be recorded and the tare weight (see paragraph 11.1.) subtracted. The particulate mass (M_f for the single filter method; $M_{f,i}$ for the multiple filter method) is the sum of the particulate masses collected on the primary and back-up filters.

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

1.3. Calculation of the Gaseous Emissions

The finally reported test results shall be derived through the following steps:

1.3.1. Determination of the Exhaust Gas Flow

The exhaust gas flow rate (G_{EXHW}, V_{EXHW} or V_{EXHD}) shall be determined for each mode according to annex 4, appendix 1, paragraphs 1.2.1. to 1.2.3.

When using a full flow dilution system, the total dilute exhaust gas flow rate (G_{TOTW}, V_{TOTW}) shall be determined for each mode according to annex 4, appendix 1, paragraph 1.2.4.

1.3.2. Dry/Wet Correction

When applying G_{EXHW}, V_{EXHW}, G_{TOTW} or V_{TOTW}, the measured concentration shall be converted to a wet basis according to the following formulae, if not already measured on a wet basis:

$$\text{conc (wet)} = K_w \times \text{conc (dry)}$$

For the raw exhaust gas:

$$K_{w,r,1} = \left(1 - F_{FH} \times \frac{G_{FUEL}}{G_{AIRD}}\right) - K_{w2}$$

or:

$$K_{w,r,2} = \left(\frac{1}{1 + \alpha \times 0.005 \times (\%CO + \%CO_2)}\right) - K_{w2}$$

For the diluted exhaust gas:

$$K_{w,e,1} = \left(1 - \frac{\alpha \times CO_2\%(wet)}{200}\right) - K_{w1}$$

or:

$$K_{w,e,2} = \left(1 + \frac{1 - K_{w1}}{\frac{\alpha \times CO_2\%(dry)}{200}}\right)$$

Values of F_{FH} vary according to the air: fuel ratio, Lambda:

$$F_{FH} = \frac{13.6 \; x \; 0.1448}{\left(1 + \frac{G_{FUEL}}{G_{AIRW}}\right)} = \frac{1.969}{\left(1 + \frac{G_{FUEL}}{G_{AIRW}}\right)}$$

For the dilution air:

$$K_{W,d} = 1 - K_{W1}$$

$$K_{W1} = \frac{1.608 \times [H_d \times (1 - 1/DF) + H_a \times (1/DF)]}{1000 + 1.608 \times [H_d \times (1 - 1/DF) + H_a \times (1/DF)]}$$

$$H_d = \frac{6.22 \times R_d \times p_d}{p_B - p_d \times R_d \times 10^{-2}}$$

For the intake air (if different from the dilution air):

$$K_{W,a} = 1 - K_{W2}$$

$$K_{W2} = \frac{1.608 \times H_a}{1000 + (1.608 \times H_a)}$$

$$H_a = \frac{6.22 \times R_a \times p_a}{p_B - p_a \times R_a \times 10^{-2}}$$

where:

H_a = g, water per kg dry air (intake air)
H_d = g, water per kg dry air (dilution air)
R_d = relative humidity of the dilution air, %
R_a = relative humidity of the intake air, %
p_d = saturation vapour pressure of the dilution air, kPa
p_a = saturation vapour pressure of the intake air, kPa
p_B = total barometric pressure, kPa

1.3.3. Humidity Correction for NO_x

As the NO_x emission depends on ambient air conditions, the NO_x concentration shall be corrected for ambient air temperature and humidity by the factors K_H given in the following formulae.

$$K_H = \frac{1}{1 + A \times (H_a - 10.71) + B \times (T_a - 298)}$$

where:

A = $0.309\ G_{Fuel} / G_{AIRD} - 0.0266$
B = $-0.209\ G_{Fuel} / G_{AIRD} + 0.00954$
T = temperatures of the air in K

$$\frac{G_{FUEL}}{G_{AIRD}} = \text{Fuel air ratio (dry air basis)}$$

H_a = humidity of the intake air, g water per kg dry air:

$$H_a = \frac{6.220 \times R_a \times p_a}{p_B - p_a \times R_a \times 10^{-2}}$$

R_a = relative humidity of the intake air, %
p_a = saturation vapour pressure of the intake air, kPa
p_B = total barometric pressure, kPa

For diesel engines with intermediate air cooler, the following alternative equation may be used:

$$K_H = \frac{1}{1 - 0.012 \times (H_a - 10.71) - 0.00275 \times (T_a - 298) + 0.00285 \times (T_{SC} - T_{SCRef})}$$

T_{SCRef} = to be specified by the manufacturer
T_{SC} = Temperature of the intercooled air.

1.3.4. Calculation of Emission Mass Flow Rates

The emission mass flow rates for each mode shall be calculated as follows:

(a) For the raw exhaust gas:

Gas mass = u × conc × G_{EXHW}

or:

Gas mass = v × conc × V_{EXHD}

or:

Gas mass = w × conc × V_{EXHW}

(b) For the dilute exhaust gas:

Gas mass = u × $conc_c$ × G_{TOTW}

or:

Gas mass = w × $conc_c$ × V_{TOTW}

where:

$conc_c$ is the background corrected concentration
$conc_c = conc - conc_d \times (1 - (1/DF))$
$DF = 13.4/(concCO_2 + (concCO + concHC) \times 10^{-4})$

or:

$DF = 13.4/concCO_2$

The coefficients u - wet, v - dry, w - wet shall be used according to the following table:

Gas	u	v	w	conc
NO_x	0.001587	0.002053	0.002053	ppm
CO	0.000966	0.00125	0.00125	ppm
HC	0.000479	-	0.000619	ppm
CO_2	15.19	19.64	19.64	percent

The density of HC is based upon an average carbon to hydrogen ratio of 1/1.85.

1.3.5. Calculation of the Specific Emissions

The emission shall be calculated for all individual components in the following way:

$$Individual\ gas = \frac{\sum_{i=1}^{n} Gas\ mass_i \times WF_i}{\sum_{i=1}^{n} p_i \times WF_i}$$

where $P_i = P_{m,i} + P_{AE,i}$

The weighting factors and the number of modes (n) used in the above calculation are according to annex 4, paragraph 3.6.1.

1.4. Calculation of the Particulate Emission

The particulate emission shall be calculated in the following way:

1.4.1. Humidity Correction Factor for Particulates

As the particulate emission of diesel engines depends on ambient air conditions, the particulate mass flow rate shall be corrected for ambient air humidity with the factor K_p given in the following formulae.

K_p = $1/ (1 + 0.0133 \times (H_a - 10.71))$

H_a = humidity of the intake air, grammes of water per kg dry air

$$H_a = \frac{6.22 \times R_a \times p_a}{p_B - p_a \times R_a \times 10^{-2}}$$

R_a = relative humidity of the intake air, %

p_a = saturation vapour pressure of the intake air, kPa

p_B = total barometric pressure, kPa

1.4.2. Partial Flow Dilution System

The final reported test results of the particulate emission shall be derived through the following steps. Since various types of dilution rate control may be used, different calculation methods for G_{EDF} or V_{EDF} apply. All calculations shall be based upon the average values of the individual modes during the sampling period.

1.4.2.1. Isokinetic Systems

$$G_{EDFW,i} = G_{EXHW,i} \times q_i$$

or:

$$V_{EDFW,i} = V_{EXHW,i} \times q_i$$

$$q_i = \frac{G_{DILW,i} + (G_{EXHW,i} \times r)}{(G_{EXHW,i} \times r)}$$

or:

$$q_i = \frac{V_{DILW,i} + (V_{EXHW,i} \times r)}{(V_{EXHW,i} \times r)}$$

where r corresponds to the ratio of the cross sectional areas of the isokinetic probe and the exhaust pipe:

$$r = \frac{A_p}{A_T}$$

1.4.2.2. Systems with Measurement of CO_2 or NO_X Concentration

$$G_{EDFW,i} = G_{EXHW,i} \times q_i$$

or:

$$V_{EDFW,i} = V_{EXHW,i} \times q_i$$

$$q_i = \frac{Conc_{E,i} - Conc_{A,i}}{Conc_{D,i} - Conc_{A,i}}$$

where:

$Conc_E$ = wet concentration of the tracer gas in raw exhaust
$Conc_D$ = wet concentration of the tracer gas in the diluted exhaust
$Conc_A$ = wet concentration of the tracer gas in the dilution air

Concentrations measured on a dry basis shall be converted to a wet basis according to paragraph 1.3.2. of this appendix.

1.4.2.3. Systems with CO_2 Measurement and Carbon Balance Method

$$G_{EDFW,i} = \frac{206.6 \times G_{FUEL,i}}{CO_{2D,i} - CO_{2A,i}}$$

where:

CO_{2D} = CO_2 concentration of the diluted exhaust

CO_{2A} = CO_2 concentration of the dilution air

(concentrations in volume % on wet basis)

This equation is based upon the carbon balance assumption (carbon atoms supplied to the engine are emitted as CO_2) and derived through the following steps:

$$G_{EDFW,i} = G_{EXHW,i} \times q_i$$

and:

$$q_i = \frac{206.6 \times G_{FUEL,i}}{G_{EXHW,i} \times (CO_{2D,i} - CO_{2A,i})}$$

1.4.2.4. Systems with Flow Measurement

$$G_{EDFW,i} = G_{EXHW,i} \times q_i$$

$$q_i = \frac{G_{TOTw,i}}{(G_{TOTw,i} - G_{DILW,i})}$$

1.4.3. Full Flow Dilution System

The final reported test results of the particulate emission shall be derived through the following steps.

All calculations shall be based upon the average values of the individual modes during the sampling period.

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

or:

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

1.4.4. Calculation of the Particulate Mass Flow Rate

The particulate mass flow rate shall be calculated as follows:

For the Single Filter Method:

$$PT_{mass} = \frac{M_f \times (G_{EDF})_{aver}}{M_{SAM} \times 1000}$$

or:

$$PT_{mass} = \frac{M_f \times (V_{EDFW})_{aver}}{V_{SAM} \times 1000}$$

where:

$(G_{EDFW})_{aver}$, $(V_{EDFW})_{aver}$, $(M_{SAM})_{aver}$, $(V_{SAM})_{aver}$ over the test cycle shall be determined by summation of the average values of the individual modes during the sampling period:

$$(G_{EDFW})_{aver} = \sum_{i=1}^{n} G_{EDFW,i} \times WF_i$$

$$(V_{EDFW})_{aver} = \sum_{i=1}^{n} V_{EDFW,i} \times WF_i$$

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

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

where i = 1,... n

For the Multiple Filter Method:

$$PT_{mass,i} = \frac{M_{f,i} \times (G_{EDFW,i})}{M_{SAM,i} \times 1000}$$

or:

$$PT_{mass,i} = \frac{M_{f,i} \times (V_{EDFW,i})}{V_{SAM,i} \times 1000}$$

where i = 1,...n

The particulate mass flow rate may be background corrected as follows:

For Single Filter Method:

$$PT_{mass} = \left[\frac{M_f}{M_{SAM}} - \left(\frac{M_d}{M_{DIL}} \times \left(1 - \frac{1}{DF}\right)\right)\right] \times \left[\frac{(G_{EDFW})_{aver}}{1000}\right]$$

or:

$$PT_{mass} = \left[\frac{M_f}{V_{SAM}} - \left(\frac{M_d}{V_{DIL}} \times \left(1 - \frac{1}{DF}\right)\right)\right] \times \left[\frac{(V_{EDFW})_{aver}}{1000}\right]$$

If more than one measurement is made, (M_d/M_{DIL}) or (M_d/V_{DIL}) shall be replaced with $(M_d/M_{DIL})_{aver}$ or $(M_d/V_{DIL})_{aver}$—, respectively.

$$DF = \frac{13.4}{concCO_2 + (concCO + concHC) \square 10^{-4}}$$

or:

$DF = 13.4/concCO_2$

For Multiple Filter Method:

$$PT_{mass,i} = \left[\frac{M_{f,i}}{M_{SAM,i}} - \left(\frac{M_d}{M_{DIL}} \times \left(1 - \frac{1}{DF}\right)\right)\right] \times \left[\frac{G_{EDFW,i}}{1000}\right]$$

or:

$$PT_{mass,i} = \left[\frac{M_{f,i}}{V_{SAM,i}} - \left(\frac{M_d}{V_{DIL}} \times \left(1 - \frac{1}{DF}\right)\right)\right] \times \left[\frac{V_{EDFW,i}}{1000}\right]$$

If more than one measurement is made, (M_d/M_{DIL}) or (M_d/V_{DIL}) shall be replaced with $(M_d/M_{DIL})_{aver}$ or $(M_d/V_{DIL})_{aver}$~~,~~ respectively.

$$DF = \frac{13.4}{concCO_2 + (concCO + concHC) \square 10^{-4}}$$

or:

$DF = 13.4/concCO_2$

1.4.5. Calculation of the Specific Emissions

The particulate emission shall be calculated in the following way:

For the single filter method:

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

For the multiple filter method:

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

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

1.4.6. Effective Weighting Factor

For the single filter method, the effective weighting factor $WF_{E,i}$ for each mode shall be calculated in the following way:

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

or:

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

where i = 1,...n

The value of the effective weighting factors shall be within ± 0.005 (absolute value) of the weighting factors listed in annex 4, paragraph 3.6.1.

Annex 4 - Appendix 4

1. 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 NO_x measurement, 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.

1.1. Determination of the Gaseous Emissions

Paragraph 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 co-ordinate 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.

1.1.1. Gaseous Exhaust Components CO, CO_2, HC, NO_x

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 detector for the measurement of hydrocarbons;

NDIR analysers for the measurement of carbon monoxide and carbon dioxide;

HCLD or equivalent detector 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, NO_x and HC

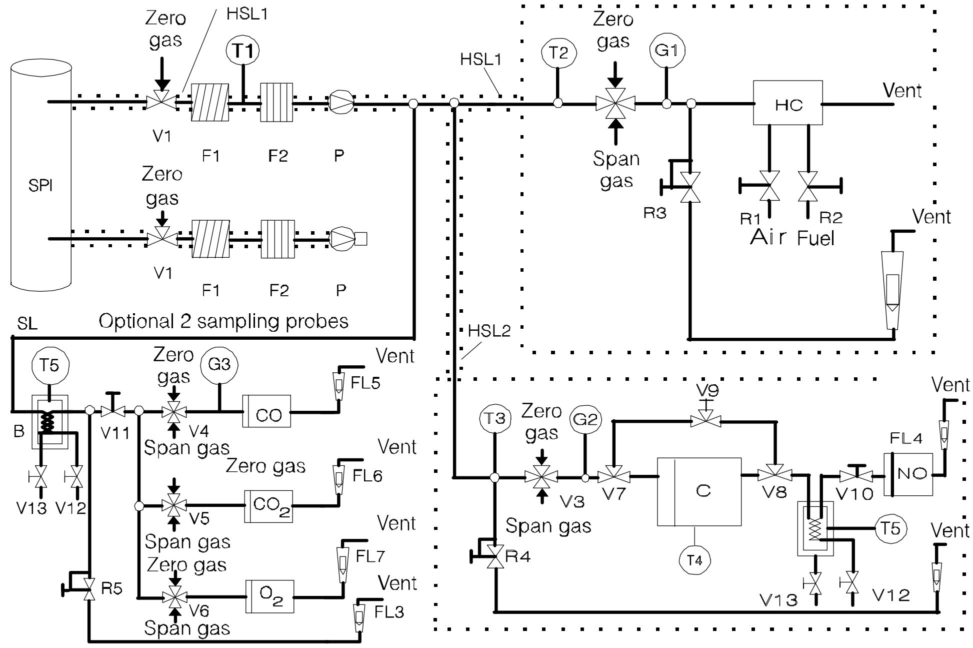
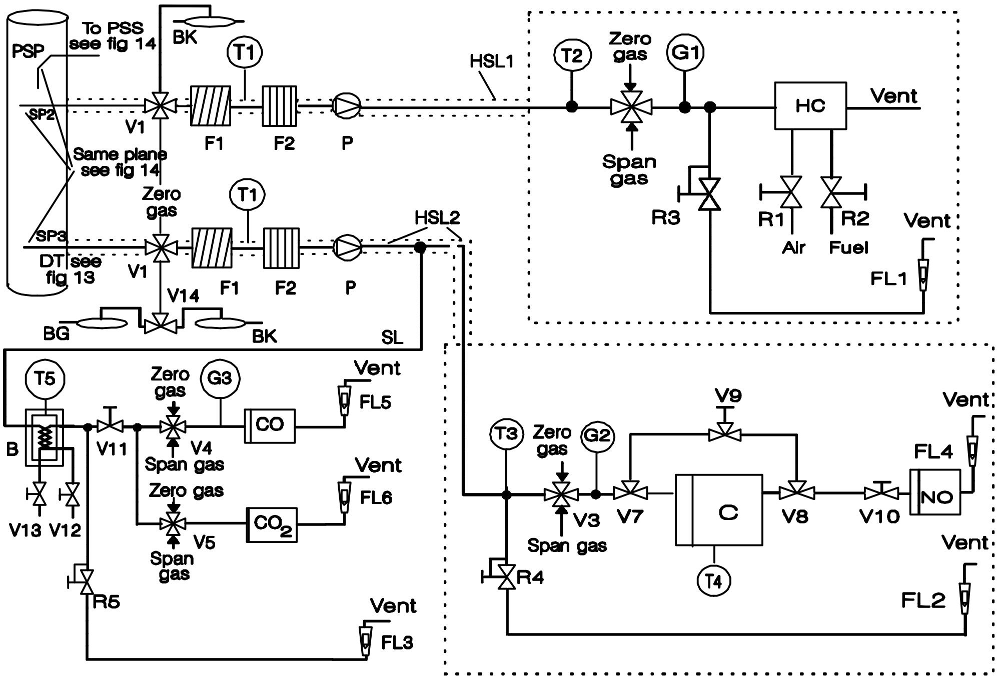


Figure 2

Figure 3

Flow Diagram of Dilute Exhaust Gas Analysis System for CO, CO_2, NO_x and HC



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 end multi-hole 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 (paragraph 1.2.1.1.) at a point where the dilution air and exhaust gas are well mixed (i.e. 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 463K (190°C) ± 10K 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 328K (55°C) to prevent water condensation.

HSL1 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) ± 10K as measured at every separately controlled heated section, if the temperature of the exhaust gas at the sampling probe is equal or below 463K (190°C);

Maintain a wall temperature greater than 453K (180°C) if the temperature of the exhaust gas at the sampling probe is above 463K (190°C);

Maintain a gas temperature of 463K (190°C) ± 10K 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 473K (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 ionisation detector (HFID) for the determination of the hydrocarbons. The temperature shall be kept at 453 to 473K (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 473K (55 to 200°C).

C Converter

A converter shall be used for the catalytic reduction of NO_2 to NO prior to analysis in the CLD or HCLD.

B Cooling Bath

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

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 air gas flow to the analyser.

V7, V8 Solenoid Valve

To bypass the NO_2 - NO converter.

V9 Needle Valve

To balance the flow through the NO_2 - 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.

1.2. Determination of the Particulates

Paragraphs 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 co-ordinate 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.

1.2.1. Dilution System

1.2.1.1. Partial Flow Dilution System (Figures 4 to 12)

A dilution system is described based upon 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 (paragraph 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 upon 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 measurable 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)

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 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.

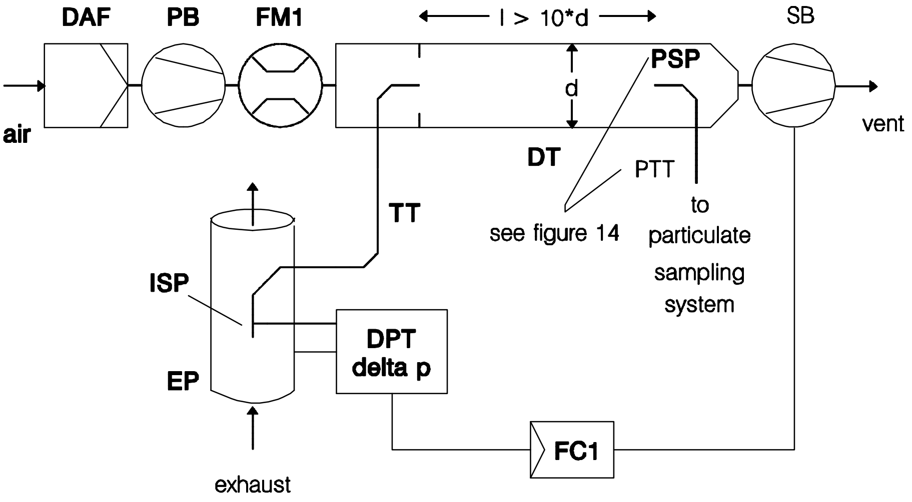


Figure 4

Figure 5

Partial Flow Dilution System with Isokinetic Probe and Fractional Sampling (PB Control)

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 a 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, and 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.

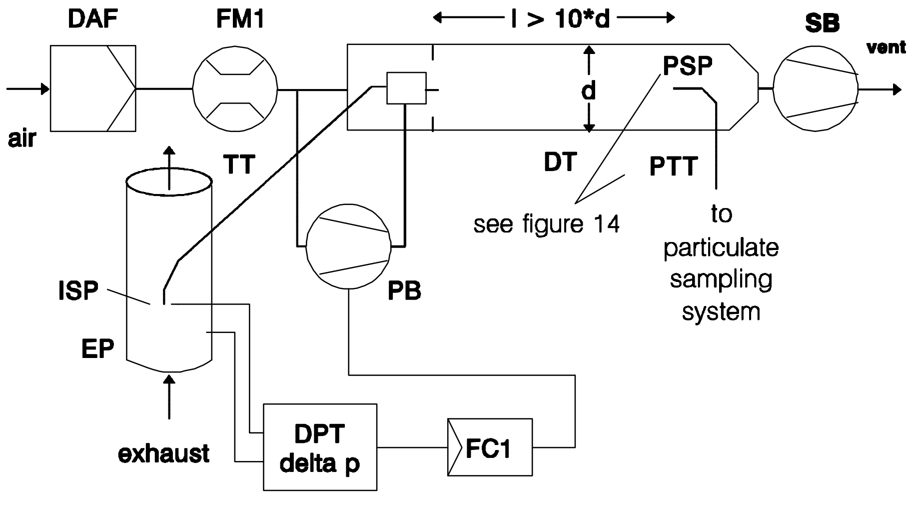


Figure 5

Figure 6

Partial Flow Dilution System with CO_2 or NO_x Concentration Measurement 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 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.

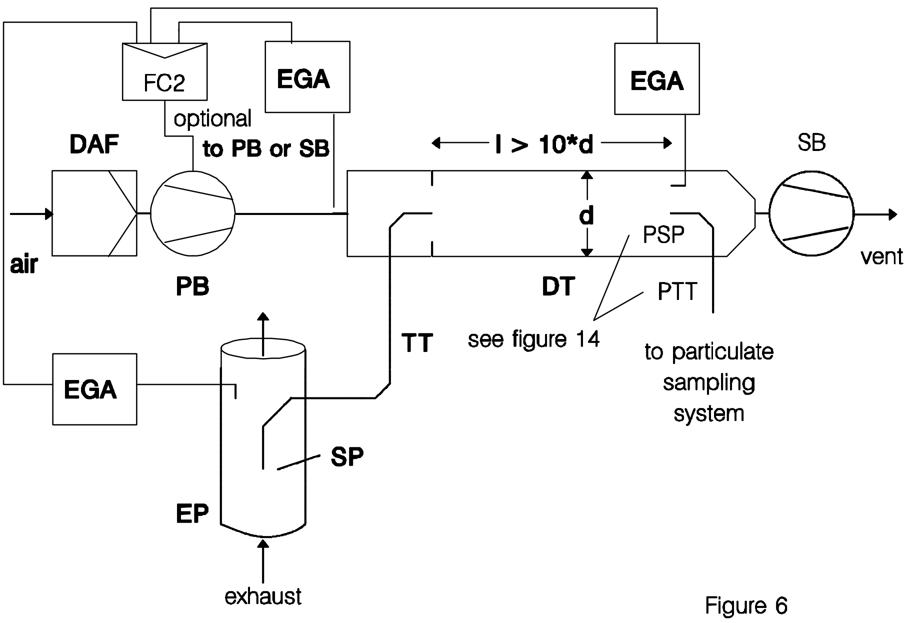


Figure 6

Figure 7

Partial Flow Dilution System with CO_2 Concentration Measurement, Carbon Balance 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 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 transmitted 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.

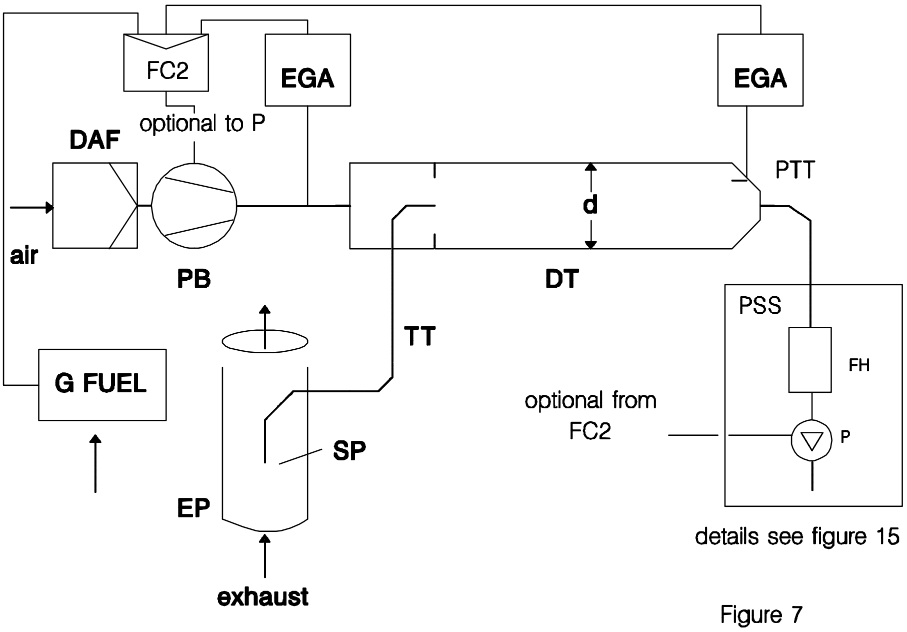


Figure 7

Figure 8

Partial Flow Dilution System with Single Venturi, Concentration Measurement 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 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 exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA, and the dilution ratio is calculated from the values so measured.

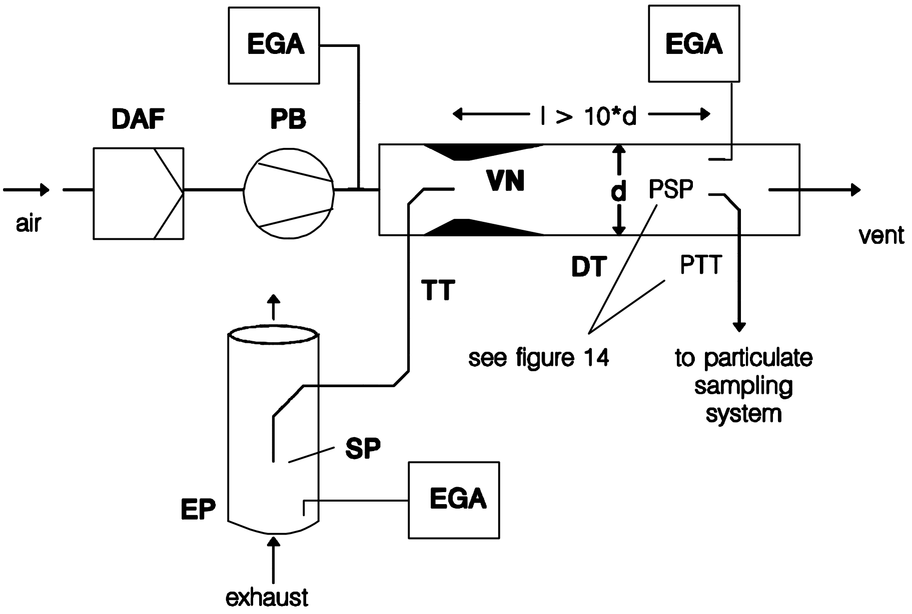


Figure 8

Figure 9

Partial Flow Dilution System Twin Venturi or Twin Orifice, Concentration Measurement 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 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.

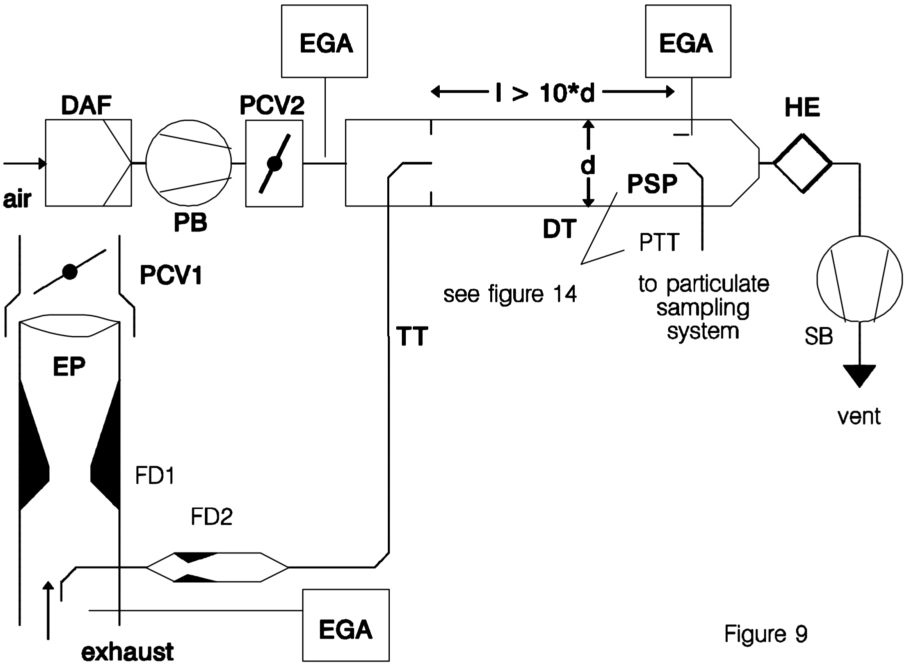


Figure 9

Figure 10

Partial Flow Dilution System with Multiple Tube Splitting, Concentration Measurement and Fractional Sampling

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 bend radius) installed in EP. The exhaust gas is passed through one of these tubes to DT, and the exhaust gas going through the remaining 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 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 control the injection air flow rate for precise split control. The dilution ratio is calculated from the tracer gas concentrations.

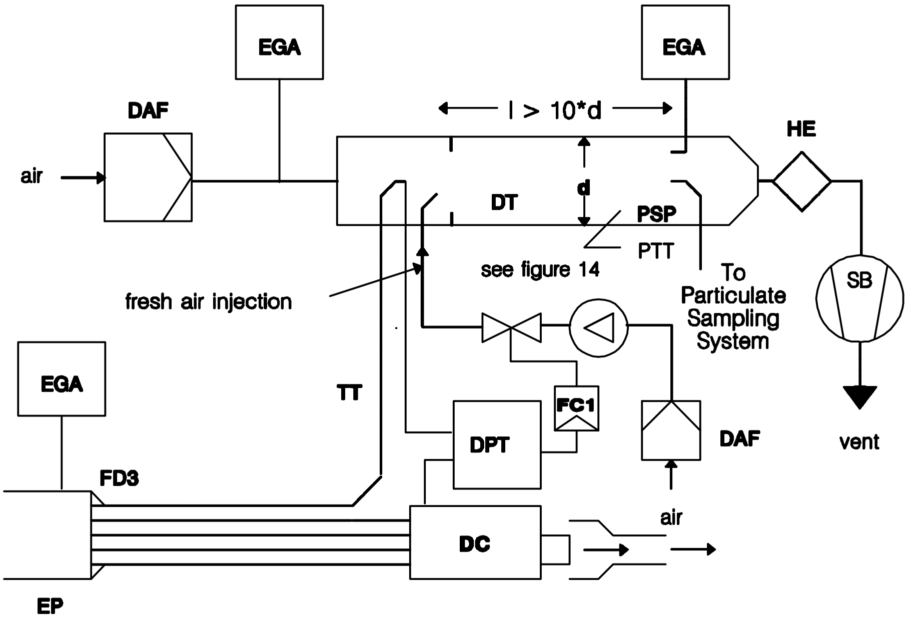


Figure 10

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 15). 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 and the 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.

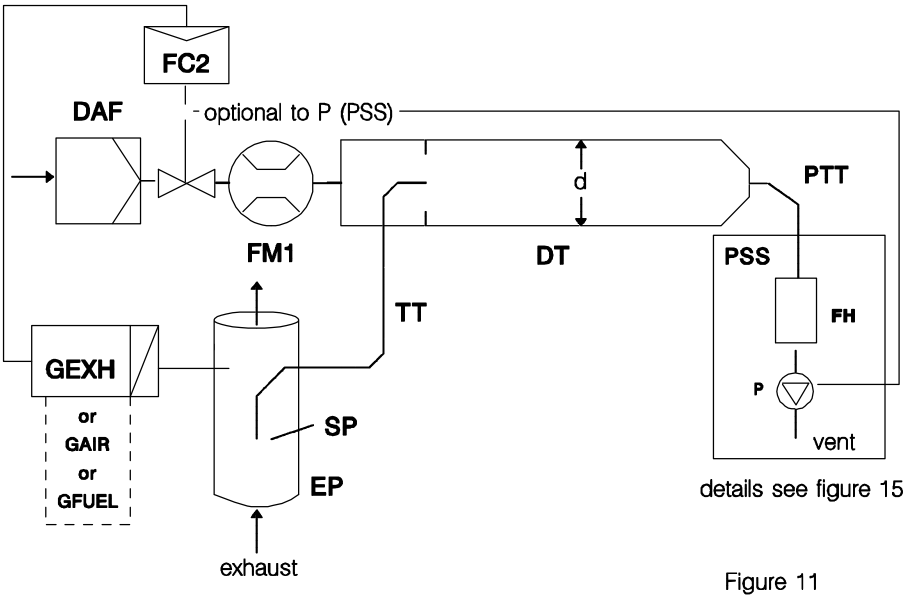


Figure 11

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. G_{EXH}, G_{AIR}, or G_{FUEL} 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 two flow rates.

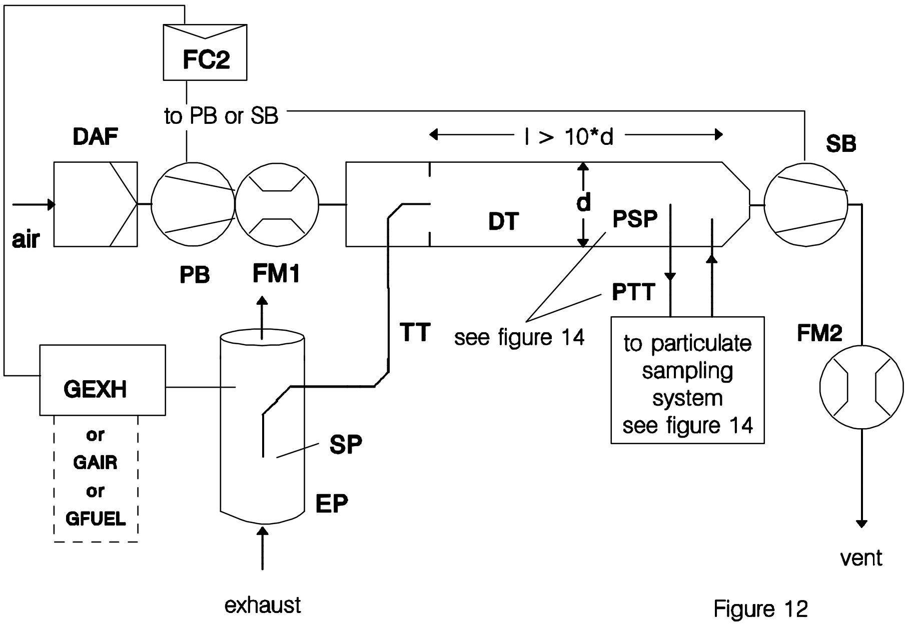


Figure 12

Description - Figures 4 to 12

EP Exhaust Pipe

The exhaust pipe may be insulated to within 0.5m of the engine. 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 the 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 annex 4, appendix 6, paragraph 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. The tubes must have the same dimensions (same diameter, length, bend radius), so that the exhaust split depends on the total number of tubes. A control system is necessary for proportional splitting by maintaining a 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 5 m in length;

Equal to or greater than the probe diameter, but not more than 25 mm in diameter;

Exiting on the centre-line of the dilution tunnel and pointing downstream.

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 523K (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.

FC1 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 the 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.

PCV1, 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 minimize 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 pressurised 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 flow 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 298K (25°C) ± 5K.

At the manufacturers' 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, i.e. 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 325K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325K (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 25 mm in diameter for the total sampling type.

May be heated to no greater than 325K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325K (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 293K (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 293K (20°C).

HE Heat Exchanger (figures 9 and 10)

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

1.2.1.2. Full Flow Dilution System (figure 13)

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 (paragraph 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 paragraph 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 paragraph 1.1.1.

Descriptions - Figure 13

EP Exhaust Pipe

The exhaust pipe length from the exit of the engine exhaust manifold, turbocharger outlet or aftertreatment 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 smokemeter, 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/mK measured at 673K (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.

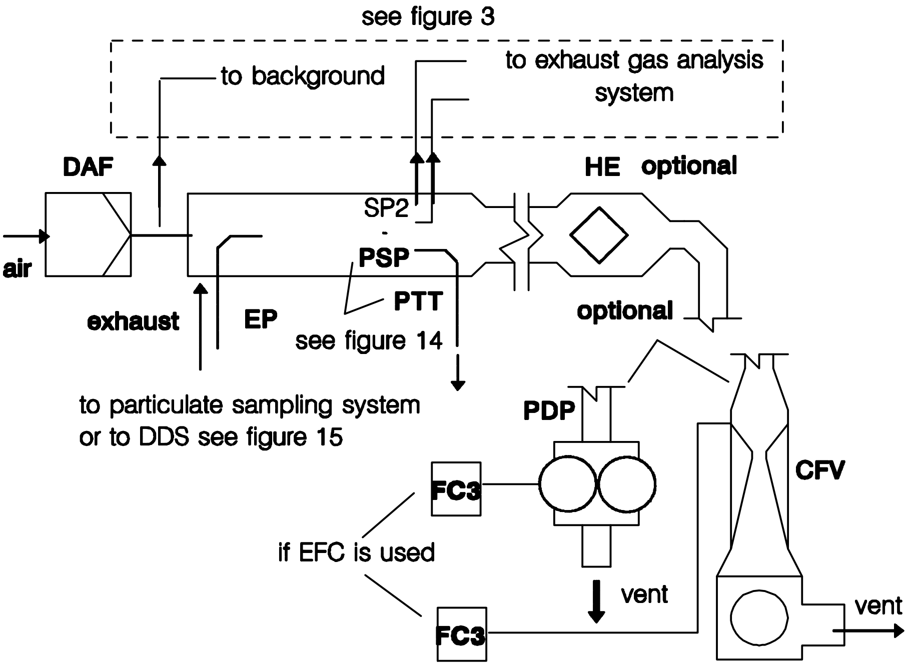


Figure 13

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 ± 6K 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 323K (50°C).

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 ± 11K 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 of sufficient capacity to maintain the temperature within the limits required above.

EFC Electronic Flow Computation (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 computation 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 4,000) and 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 (paragraph 1.2.2., figure 14). The flow capacity of the PDP or CFV must be sufficient to maintain the diluted exhaust at a temperature of less than or equal to 325K (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 (paragraph 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 464K (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 325K (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 298K (25°C) ± 5K. At the manufacturers' 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, i.e. 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 325K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325K (52°C) prior to the introduction of the exhaust in the dilution tunnel;

May be insulated.

1.2.2 Particulate Sampling System (figures 14 and 15)

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 (paragraph 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 (paragraph 1.2.1.1., figures 4, 5, 6, 8, 9, 10 and 12 and paragraph 1.2.1.2., figure 13) and sampling systems usually form different units.

In this regulation, the double dilution system (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 minimized.

Descriptions - Figure 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, i.e. on the dilution tunnel DT centre-line of the dilution systems (see paragraph 16.1.), 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 325K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325K (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.

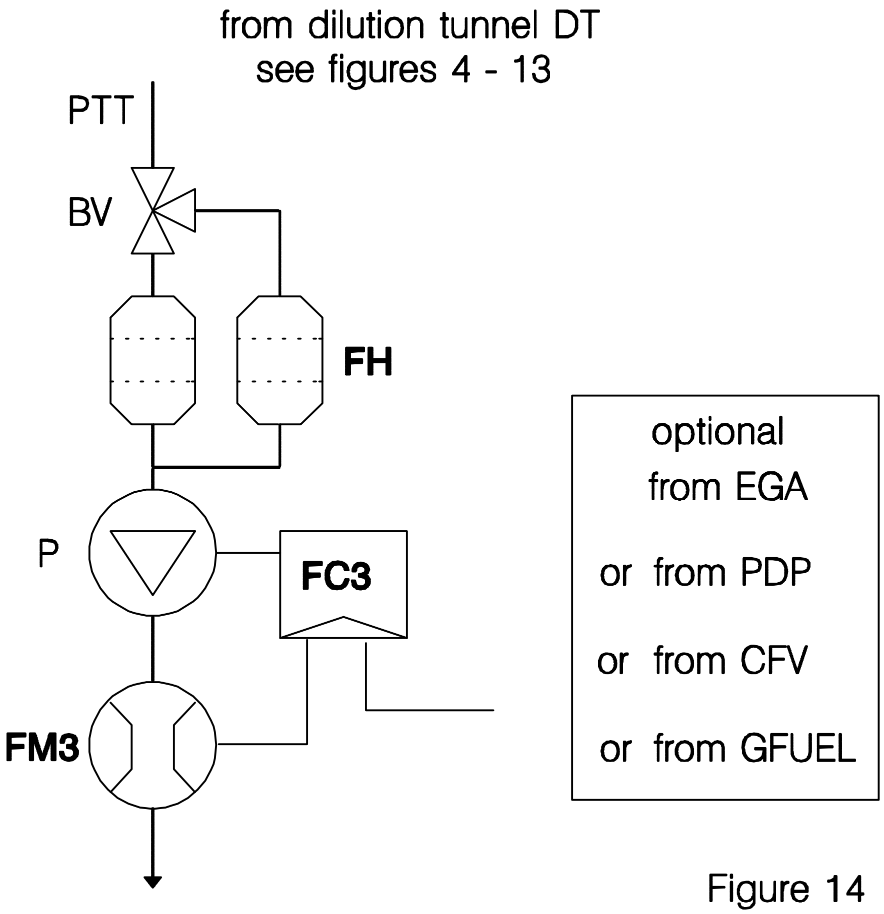


Figure 14

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.

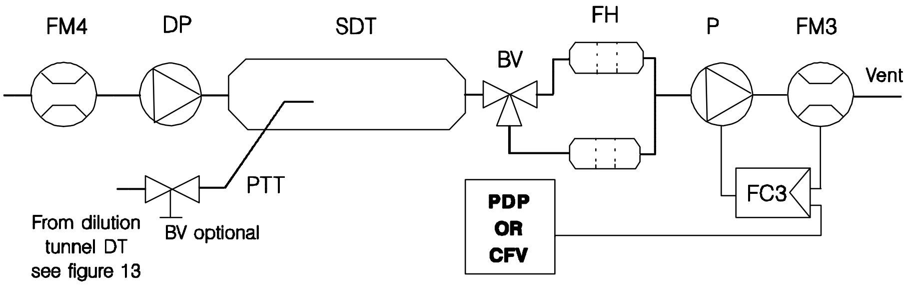


Figure 15

PTT Particulate Transfer Tube (figures 14 and 15)

The particulate transfer tube must not exceed 1,020 mm in length, and must be minimized 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 tip 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 325K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325K (52°C) prior to the introduction of the exhaust in the dilution tunnel;

May be insulated.

SDT Secondary Dilution Tunnel (figure 15)

The secondary dilution tunnel should have a minimum diameter of 75 mm and should be of sufficient length so as to provide a residence time of at least 0.25 seconds for the doubly-diluted sample. The primary filter holder, FH, shall be located within 300 mm of the exit of the SDT.

The secondary dilution tunnel:

May be heated to no greater than 325K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325K (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 4, appendix 1, paragraph 1.5.1.3. have to be met.

The filter holder(s):

May be heated to no greater than 325K (52°C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325K (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 (± 3K), 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 298K (25°C) ± 5K.

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 (± 3K), 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 temperature remains at 298K (25°C) ± 5K.

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 239K (20°C), precautions should be taken to avoid particle losses onto the cool wall of these parts. Therefore, heating and/or insulating these parts within the limits given in the respective descriptions is recommended. It is also recommended that the filter face temperature during sampling be not below 293K (20°C).

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

Annex 5

TECHNICAL CHARACTERISTICS OF REFERENCE FUEL PRESCRIBED FOR APPROVAL TESTS AND TO VERIFY CONFORMITY OF PRODUCTION

AGRICULTURAL AND FORESTRY TRACTOR REFERENCE FUEL

Note: Key properties for engine performance/exhaust emissions are highlighted.

	Limits and Units (1) (2)	**Test Method**
Cetane Number (4)	min. 45 (7) max. 50	ISO 5165
Density at 15°C	min. 835 kg/m^3 max. 845 kg/m^3	ISO 3675, ASTM D4052
Distillation (3) 95% point	Maximum 370°C	ISO 3405
Viscosity at 40°C	Minimum 2.5 mm^2/s Maximum 3.5 mm^2/s	ISO 3104
Sulphur content	Minimum 0.1% mass (9) Maximum 0.2% mass (8)	ISO 8754, EN 24260
Flash Point	Minimum 55°C	ISO 2719
CFPP	Minimum - Maximum +5°C	EN 116
Copper corrosion	Maximum 1	ISO 2160
Conradson carbon residue (10% DR)	Maximum 0.3% mass	ISO 10370
Ash content	Maximum 0.01% mass	ASTM D482
Water content	Maximum 0.05% mass	ASTM D95, D1744
Neutralisation (strong acid) number	Minimum 0.20 mg KOH/g	
Oxidation stability (5)	Maximum 2.5 mg/100 ml	ASTM D2274
Additives (6)		

Note 1: If it is required to calculate thermal efficiency of an engine or vehicle, the calorific value of the fuel can be calculated from:

Specific energy (calorific value) (net) MJ/kg =

$$(46.423 - 8.792\ d^2 + 3.170\ d) \times (1 - (x + y + s)) + 9.420\ s - 2.499\ x$$

where:

d is the density at 15°C
x is the proportion by mass of water (%/100)
y is the proportion by mass of ash (%/100)
s is the proportion by mass of sulphur (%/100)

Note 2: The values quoted in the specification are "true values". In establishment of their limit values the terms of ASTM D3244 "Defining a basis for petroleum produce quality disputes" have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility).

Notwithstanding this measure, which is necessary for statistical reasons, the manufacturer of fuel should nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify the question as to whether a fuel meets the requirements of the specifications, the terms of ASTM D3244 should be applied.

Note 3: The figures quoted show the evaporated quantities (percentage recovered + percentage loss).

Note 4: The range of cetane is not in accordance with the requirement of a minimum range of 4R. However, in cases of dispute between fuel supplier and fuel user, the terms in ASTM D3244 can be used to resolve such disputes provided replicate measurements, of sufficient number to achieve the necessary precision, are made in preference to single determinations.

Note 5: Even though oxidation stability is controlled, it is likely that shelf life will be limited. Advice should be sought from the supplier as to storage conditions and life.

Note 6: This fuel should be based straight run and cracked hydrocarbon distillate components only; desulphurization is allowed. It must not contain any metallic additives or cetane improver additives.

Note 7: Lower values are permitted, in which case the cetane number of the reference fuel used is to be reported.

Note 8: Higher values are permitted, in which case the sulphur content of the reference fuel used is to be reported.

Note 9: To be kept under constant review in the light of trends in the markets, e.g. 0.050% m/m sulphur maximum.

Note 10: All fuel characteristics and limit values are to be kept under review in light of trends in the markets.