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# Worldwide Harmonized Heavy Duty Emissions Certification Procedure



## **DRAFT GLOBAL TECHNICAL REGULATION (GTR)**

**UNECE-WP.29 - GRPE  
WHDC Working Group**

This document covers the general technical contents of the GTR procedure, as approved by the 48<sup>th</sup> GRPE on 03.06.2004, comments from the WHDC Drafting Committee, and cold start provisions as proposed by the USA at the 49<sup>th</sup> GRPE on 13.01.2005. The changes compared to the 2004 draft version are marked in bold letters and mainly appear in the following parts:

- **Statement of technical rationale**
- **Paragraphs 5 and 5.1**
- **Paragraphs 6.6 and 6.9**
- **Paragraphs 7.4, 7.7 and 7.8**
- **Paragraphs 8.3.2.4 (Table 4 corrected), 8.3.2.6 and 8.3.3.6**
- **Paragraph 9.2 (table 6)**
- **Paragraph 10.4**

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World Forum for Harmonisation of Vehicle Regulations (WP.29)

DRAFT GLOBAL TECHNICAL REGULATION (GTR)

**UNIFORM PROVISIONS CONCERNING THE TEST PROCEDURE FOR COMPRESSION-IGNITION (C.I.)  
AND POSITIVE-IGNITION (P.I) ENGINES FUELLED WITH NATURAL GAS (NG) AND LIQUEFIED  
PETROLEUM GAS (LPG) AND VEHICLES EQUIPPED WITH C.I. AND P.I. ENGINES FUELLED WITH  
NG AND LPG, WITH REGARD TO THE EMISSIONS OF POLLUTANTS BY THE ENGINE**

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## **A. Statement of Technical Rationale and Justification**

### **1. Technical and Economic Feasibility**

The objective of this proposal is to establish a harmonised global technical regulation (gtr) covering the type-approval procedure for heavy-duty engine exhaust emissions. The basis will be the test procedure developed by the WHDC informal group of GRPE (see final summary, [informal document no. 4] to the 46<sup>th</sup> GRPE).

Regulations governing the exhaust emissions from heavy-duty engines have been in existence for many years but the test cycles and methods of emissions measurement vary significantly. To be able to correctly determine the impact of a heavy-duty vehicle on the environment in terms of its exhaust pollutant emissions, a laboratory test procedure, and consequently the GTR, needs to be adequately representative of real-world vehicle operation.

The proposed regulation is based on new research into the world-wide pattern of real heavy commercial vehicle use. From the collected data, two representative test cycles, one transient test cycle (WHTC) and one steady state test cycle (WHSC), have been created covering typical driving conditions in the European Union, the United States of America, Japan **and Australia**. Alternative emission measurement procedures have been developed by an expert committee in ISO and have been published in ISO 16183. This standard reflects the state-of-the-art in exhaust emissions measurement technology with the potential for accurately measuring the pollutant emissions from future low emission engines.

The WHTC and WHSC test procedures reflect world-wide on-road heavy-duty engine operation as closely as possible and provide a marked improvement in the realism of the test procedure for measuring the emission performance of existing and future heavy-duty engines. **In summary, the test procedure was developed so that it would be:**

- **representative of world-wide on-road vehicle operation,**
- **able to provide the highest possible level of efficiency in controlling on-road emissions,**
- **corresponding to state-of-the-art testing, sampling and measurement technology,**
- **applicable in practice to existing and foreseeable future exhaust emissions abatement technologies, and**
- **capable of providing a reliable ranking of exhaust emission levels from different engine types.**

**As a first step, the gtr is being presented without limit values. In this way the test procedure can be given a legal status which also requires the Contracting Parties to start the process of implementing it into their national law.**

**When implementing the test procedure contained in this gtr as part of their national legislation or regulation, Contracting Parties are invited to use limit values which represent at least the same level of severity as their existing regulations, pending the development of harmonized limit values by the Executive Committee (AC.3) under the 1998 Agreement administered by the World Forum for Harmonization of Vehicle Regulations (WP.29).** The performance levels (emissions test results) to be achieved in the gtr will therefore be discussed on the basis of the most recently agreed legislation in the Contracting Parties, as required by the 1998 Agreement.

### **2. Anticipated benefits**

Heavy commercial vehicles and their engines are increasingly produced for the world market. It is economically inefficient for manufacturers to have to prepare substantially different models in order to meet different emission regulations and methods of measuring emissions, which, in principle, aim at achieving the same objective. To enable manufacturers to develop new models more effectively and within shorter time it is desirable that a gtr should be developed. **These savings will accrue not only to the manufacturer, but more importantly, to the consumer as well.**

**However, developing a test procedure just to address the economic question does not completely address the mandate given when work on this gtr was first started. The test procedure must also improve the state of testing heavy duty engines, and better reflect how heavy duty engines are used today.** Compared to the measurement methods defined in existing legislation of the Contracting Parties to the 1998 agreement, the testing methods defined in this gtr are much more representative of in-use driving behaviour of commercial vehicles world-wide.

As a consequence, it can be expected that the application of this gtr for emissions legislation within the Contracting Parties to the 1998 agreement will result in a higher control of in-use emissions due to the improved correlation of the test methods with in-use driving behaviour.

### **3. Potential cost effectiveness**

**Specific cost effectiveness values for this gtr have not been calculated. The decision by the Executive Committee to the 1998 Agreement to move forward with this gtr without limit values is the key reason why this analysis has not been completed. This agreement has been made knowing that specific cost effectiveness values are not immediately available. However, it is fully expected that this information will be developed, generally in response to the adoption of this regulation in national requirements and also in support of developing harmonized limit values for the next step in this gtr's development. For example, each Contracting Party adopting this gtr into its national regulations will be expected to determine the appropriate level of stringency associated with using these new test procedures, with these new values being at least as stringent as comparable existing requirements. Also, experience will be gained by the heavy duty engine industry as to any costs and costs savings associated with using this test procedure. This cost and emissions performance data can then be analyzed as part of the next step in this gtr development to determine the cost effectiveness values of the test procedures being adopted today along with new harmonized limit values. While there are no calculated cost per ton values, the belief of the WHDC group is that there are clear benefits associated with this regulation.**

## **B. Text of Regulation**

### **1 Purpose**

This regulation aims at providing a world-wide harmonised method for the determination of the levels of pollutant emissions **from engines used in heavy vehicles of category 2** in a manner which is representative of real world vehicle operation. The results can be the basis for the regulation of pollutant emissions indicated by the manufacturer within regional type-approval and certification procedures.

### **2 Scope**

This Regulation applies to the emission of gaseous and particulate pollutants from compression-ignition engines **and positive-ignition engines fuelled with natural gas and LPG**, used for propelling motor **vehicles of category 2** having a design speed exceeding 25 km/h and having a maximum mass exceeding 3.5 tonnes.

## **3 Definitions, Symbols and Abbreviations**

### **3.1 Definitions**

For the purposes of this Regulation, the following terms and definitions apply.

**Other definitions from ECE R49 will be added later.**

**continuous regeneration:** The regeneration process of an exhaust aftertreatment system that occurs either permanently or at least once per WHTC test. Such a regeneration process will not require a special test procedure

**periodic regeneration:** The regeneration process of an exhaust aftertreatment system that occurs periodically in less than 100 hours of normal engine operation. During cycles where regeneration occurs, emission standards may be exceeded

**particulate matter:** Any material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature **between 315 K (42°C) and 325 K (52°C)**, as measured at a point immediately upstream of the filter; this is primarily carbon, condensed hydrocarbons, and sulfates with associated water

**gaseous pollutants:** Carbon monoxide, hydrocarbons and/or non-methane hydrocarbons, oxides of nitrogen (expressed in nitrogen dioxide (NO<sub>2</sub>) equivalent), formaldehyde, and methanol

**partial flow dilution method:** Process of separating a part of the raw exhaust from the total exhaust flow, then mixing it with an appropriate amount of dilution air prior to the particulate sampling filter

**full flow dilution method:** Process of mixing dilution air with the total exhaust flow prior to separating a fraction of the diluted exhaust stream for analysis

**specific emissions:** Mass emissions expressed in g/kWh

**steady-state test cycle:** Test cycle with a sequence of engine test modes in which the engine is given sufficient time to achieve defined speed, torque, and stability criteria at each mode

**transient test cycle:** Test cycle with a sequence of normalized speed and torque values that vary relatively quickly with time

**response time:** Difference in time between a rapid change of the component to be measured at the reference point and the appropriate change in the response of the measuring system whereby the change of the measured component is at least 60% FS and takes place in less than 0,1 second

NOTE The system response time ( $t_{90}$ ) consists of the delay time to the system and of the rise time of the system. The response time may vary dependent on where the reference point for the change of the component to be measured is defined, either at the sampling probe or directly at the port entrance of the analyzer; in this International Standard, the sampling probe is defined as the reference point.

**delay time:** Time between the change of the component to be measured at the reference point and a system response of 10% of the final reading ( $t_{10}$ )

NOTE For the gaseous components, this is basically the transport time of the measured component from the sampling probe to the detector. For the delay time, the sampling probe is defined as the reference point.

**rise time:** Time between the 10% and 90% response of the final reading ( $t_{90} - t_{10}$ )

NOTE This is the instrument response after the component to be measured has reached the instrument. For the rise time, the sampling probe is defined as the reference point.

**transformation time:** Time between the change of the component to be measured at the reference point and a system response of 50% of the final reading ( $t_{50}$ )

NOTE For the transformation time, the sampling probe is defined as the reference point. The transformation time is used for the signal alignment of different measurement instruments.

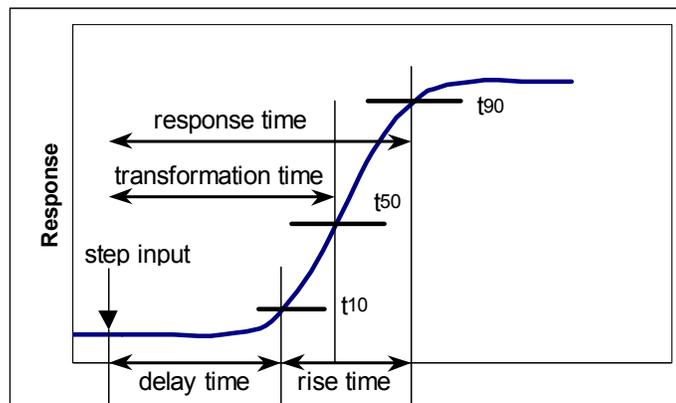


Figure 1 — Definitions of system response

### 3.2 General symbols

Symbol	Unit	Term
$A/F_{st}$	-	Stoichiometric air to fuel ratio
$c$	ppm / Vol%	Concentration
$C_c$	-	Slip Factor
$d_e$	m	Exhaust pipe diameter
$d_p$	m	Sampling probe diameter
$d_{PM}$	m	Particle diameter
$f$	Hz	Data sampling rate
$f_a$	-	Laboratory atmospheric factor
$E_{CO_2}$	%	CO <sub>2</sub> quench of NO <sub>x</sub> analyzer
$E_E$	%	Ethane efficiency

Symbol	Unit	Term
$E_{H_2O}$	%	Water quench of NO <sub>x</sub> analyzer
$E_M$	%	Methane efficiency
$E_{NO_x}$	%	Efficiency of NO <sub>x</sub> converter
$\eta$	Pa*s	Dynamic viscosity of exhaust gas
$H_a$	g/kg	Absolute humidity of the intake air
$i$	-	Subscript denoting an instantaneous measurement (e.g.1 Hz)
$k_f$	-	Fuel specific factor
$k_{h,D}$	-	Humidity correction factor for NO <sub>x</sub> for CI engines
$k_{h,G}$	-	Humidity correction factor for NO <sub>x</sub> for SI engines
$k_w$	-	Dry to wet correction factor for the raw exhaust gas
$\lambda$	-	Excess air ratio
$m_{edf}$	kg	Mass of equivalent diluted exhaust gas over the cycle
$m_f$	mg	Particulate sample mass collected
$m_{gas}$	g	Mass of gaseous emissions (over the test cycle)
$m_{PM}$	g	Mass of particulate emissions (over the test cycle)
$m_{se}$	kg	Exhaust sample mass over the cycle
$m_{sed}$	kg	Mass of diluted exhaust gas passing the dilution tunnel
$m_{sep}$	kg	Mass of diluted exhaust gas passing the particulate collection filters
$M_{gas}$	g/kWh	Specific emission of gaseous emissions
$M_{PM}$	g/kWh	Specific emission of particulate emissions
$n$	-	Number of measurements
$p_a$	kPa	Saturation vapor pressure of the engine intake air
$p_b$	kPa	Total atmospheric pressure
$p_r$	kPa	Water vapor pressure after cooling bath
$p_s$	kPa	Dry atmospheric pressure
$P$	-	Particle penetration
$q_{mad}$	kg/s	Intake air mass flow rate on dry basis
$q_{maw}$	kg/s	Intake air mass flow rate on wet basis
$q_{mCe}$	kg/s	Carbon mass flow rate in the raw exhaust gas
$q_{mCf}$	kg/s	Carbon mass flow rate into the engine
$q_{mCp}$	kg/s	Carbon mass flow rate in the partial flow dilution system
$q_{mdew}$	kg/s	Diluted exhaust gas mass flow rate on wet basis
$q_{mdw}$	kg/s	Dilution air mass flow rate on wet basis

Symbol	Unit	Term
$q_{medf}$	kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
$q_{mew}$	kg/s	Exhaust gas mass flow rate on wet basis
$q_{mex}$	kg/s	Sample mass flow rate extracted from dilution tunnel
$q_{mf}$	kg/s	Fuel mass flow rate
$q_{mp}$	kg/s	Sample flow of exhaust gas into partial flow dilution system
$q_{vs}$	l/min	System flow rate of exhaust analyzer system
$q_{vt}$	cm <sup>3</sup> /min	Tracer gas flow rate
$r_d$	-	Dilution ratio
$r_h$	-	Hydrocarbon response factor of the FID
$r_m$	-	Methanol response factor of the FID
$r_s$	-	Average sample ratio
$\rho$	kg/m <sup>3</sup>	Density
$\rho_e$	kg/m <sup>3</sup>	Exhaust gas density
$\rho_{PM}$	kg/m <sup>3</sup>	Particle density
$\sigma$		Standard deviation
$T$	K	Absolute temperature
$T_a$	K	Absolute temperature of the intake air
$t_{10}$	s	Time between step input and 10% of final reading
$t_{50}$	s	Time between step input and 50% of final reading
$t_{90}$	s	Time between step input and 90% of final reading
$\tau$	s	Particle relaxation time
$u$	-	Ratio between densities of gas component and exhaust gas
$V_s$	l	Total volume of exhaust analyzer system
$W_{act}$	kWh	Actual cycle work of the respective test cycle
$v_e$	m/s	Gas velocity in the exhaust pipe
$v_p$	m/s	Gas velocity in the sampling probe

### 3.3 Symbols and abbreviations for the fuel composition

$w_{ALF}$	hydrogen content of fuel, % mass
$w_{BET}$	carbon content of fuel, % mass
$w_{GAM}$	sulfur content of fuel, % mass
$w_{DEL}$	nitrogen content of fuel, % mass
$w_{EPS}$	oxygen content of fuel, % mass

$\alpha$	molar hydrogen ratio (H/C)
$\beta$	molar carbon ratio (C/C)
$\gamma$	molar sulfur ratio (S/C)
$\delta$	molar nitrogen ratio (N/C)
$\varepsilon$	molar oxygen ratio (O/C)

referring to a fuel  $C_{\beta}H_{\alpha}O_{\varepsilon}N_{\delta}S_{\gamma}$

### 3.4 Symbols and abbreviations for the chemical components

ACN	Acetonitrile
C1	Carbon 1 equivalent hydrocarbon
CH <sub>4</sub>	Methane
CH <sub>3</sub> OH	Methanol
C <sub>2</sub> H <sub>6</sub>	Ethane
C <sub>3</sub> H <sub>8</sub>	Propane
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
DNPH	Dinitrophenyl hydrazine
DOP	Di-octylphthalate
HC	Hydrocarbons
HCHO	Formaldehyde
H <sub>2</sub> O	Water
NMHC	Non-methane hydrocarbons
NO <sub>x</sub>	Oxides of nitrogen
NO	Nitric oxide
NO <sub>2</sub>	Nitrogen dioxide
PM	Particulate matter
RME	Rapeseed oil methylester

### 3.5 Abbreviations

CLD	Chemiluminescent Detector
FID	Flame Ionization Detector
FTIR	Fourier Transform Infrared (Analyzer)
GC	Gas Chromatograph
HCLD	Heated Chemiluminescent Detector
HFID	Heated Flame Ionization Detector
HPLC	High Pressure Liquid Chromatograph
MW	Molecular Weight
NDIR	Non-Dispersive Infrared (Analyzer)
NMC	Non-Methane Cutter

% FS	Percent of full scale
SIMS	Soft Ionization Mass Spectrometer
Stk	Stokes number

## 4 GENERAL REQUIREMENTS

The components liable to affect the emission of gaseous and particulate pollutants shall be so designed, constructed and assembled as to enable the vehicle in normal use to comply with the provisions of this regulation.

## 5 PERFORMANCE REQUIREMENTS

**When implementing the test procedure contained in this gtr as part of their national legislation, Contracting Parties to the 1998 agreement are invited to use limit values which represent at least the same level of severity as their existing regulations; pending the development of harmonized limit values, by the Executive Committee (AC.3) of the 1998 agreement, for inclusion in the gtr at a later date.**

### 5.1 Emission of gaseous and particulate pollutants

The emissions of gaseous and particulate pollutants by the engine shall be determined on the WHTC and WHSC tests. The WHTC and WHSC test procedures **and the performance requirements for the analytical systems are described in paragraph 7**. Paragraph 9 describes the recommended analytical systems for the gaseous pollutants and the recommended particulate sampling systems.

Other systems or analyzers may be approved by the **type approval or certification authority** if it is found that they yield equivalent results according to the statistical approach of paragraph 5.1.1.

#### 5.1.1 Equivalency

The determination of system equivalency shall be based on a 7 sample pair (or larger) correlation study between the system under consideration and one of the systems of this regulation. "Results" refer to the specific cycle weighted emissions value. The correlation testing is to be performed at the same laboratory, test cell, and on the same engine, and is preferred to be run concurrently. The equivalency of the sample pair averages shall be determined by **F-test and t-test** statistics as described in Annex 10.4 obtained under the laboratory test cell and the engine conditions described above. Outliers shall be determined in accordance with ISO 5725 and excluded from the database. The systems to be used for correlation testing shall be declared prior to the test and shall be approved by the **type approval or certification authority**.

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

### 5.2 Engine family

#### 5.2.1 General

An engine family is characterized by design parameters. These shall be common to all engines within the family. In some cases there may be interaction of parameters. The engine manufacturer may decide, which engines belong to an engine family, as long as the membership criteria listed in 5.5.3 are respected.

#### 5.2.2 Special cases

In some cases there may be interaction between parameters. This shall be taken into consideration to

ensure that only engines with similar exhaust emission characteristics are included within in the same engine family. These cases shall be identified by the manufacturer and notified to the type approval authority. E.g., the number of cylinders may become a significant parameter on certain engines due to the fuel supply or air intake system, while with other designs the exhaust emissions characteristics are independent of the number of cylinders or their configuration.

In case of devices or features, which are not listed in 5.2.3 and which may have a strong influence on the level of emissions, this equipment shall be identified by the manufacturer on the basis of good engineering practice, and shall be notified to the type approval authority. It shall then be taken into account as a criterion for belonging to an engine family.

In addition to the parameters listed in 5.2.3, the manufacturer may introduce additional criteria allowing the definition of families of more restricted size. These parameters are not necessarily parameters that have an influence on the level of emissions.

### **5.2.3 Parameters Defining the Engine Family**

#### **5.2.3.1 Combustion cycle**

- 2 stroke cycle
- 4 stroke cycle
- Rotary engine
- Others

#### **5.2.3.2 Configuration of the cylinders**

##### **5.2.3.2.1 Position of the cylinders in the block**

- V
- In line
- Radial
- Others (F, W, etc.)

##### **5.2.3.2.2 Relative position of the cylinders**

Engines with the same block may belong to the same family as long as their bore center-to-center dimensions are the same.

#### **5.2.3.3 Main cooling medium**

- air
- water
- oil

#### **5.2.3.4 Individual cylinder displacement**

##### **5.2.3.4.1 Engine with a unit cylinder displacement $\geq 0,75 \text{ dm}^3$**

In order for engines with a unit cylinder displacement of  $\geq 0,75 \text{ dm}^3$  to be considered to belong to the same engine family, the spread of their individual cylinder displacements shall not exceed 15 % of the largest individual cylinder displacement within the family.

##### **5.2.3.4.2 Engine with a unit cylinder displacement $< 0,75 \text{ dm}^3$**

In order for engines with a unit cylinder displacement of  $< 0,75 \text{ dm}^3$  to be considered to belong to the same engine family, the spread of their individual cylinder displacements shall not exceed 30 % of the largest individual cylinder displacement within the family.

##### **5.2.3.4.3 Engine with other unit cylinder displacement limits**

Engines with an individual cylinder displacement that exceeds the limits defined in 5.2.3.4.1 and 5.2.3.4.2 may be considered to belong to that family with the agreement of the parties involved. This agreement should be based on technical elements (calculations, simulations, experimental results etc.) showing that this excess does not have a significant influence on the exhaust emissions.

**5.2.3.5 Method of air aspiration**

- naturally aspirated
- pressure charged
- pressure charged with charge cooler

**5.2.3.6 Fuel type**

- **Diesel**
- **Gaseous fuel**
  - **Natural gas (NG)**
  - **Liquefied petroleum gas (LPG)**
- **Ethanol**

NOTE If the engine is designed for a given fuel, but used without basic design modifications with another fuel, the necessity for two different families should be based on technical elements. E.g., it is possible to consider a gas engine fueled with gasoline during warm-up as belonging to the same family as a pure gas engine.

**5.2.3.7 Combustion chamber type**

- Open chamber
- Divided chamber
- Other types

**5.2.3.8 Ignition Type**

- Positive ignition
- Compression ignition

**5.2.3.9 Valves and porting**

- Configuration
- Number of valves per cylinder

**5.2.3.10 Fuel supply type**

- Liquid fuel supply type
  - Pump and (high pressure) line and injector
  - In-line or distributor pump
  - Unit pump or unit injector
  - Common rail
  - Carburettor(s)
  - Others
- Gas fuel supply type
  - Gaseous
  - Liquid
  - Mixing units
  - Others
- Other types

**5.2.3.11 Miscellaneous devices**

- Exhaust gas recirculation (EGR)
- Water injection
- Air injection

- Others

NOTE The influence of the listed devices on exhaust emissions depends largely on the specific layout and adapted control strategy. The decision as to whether an engine with these devices can be considered as a part of the family shall be left to the manufacturer, provided he can give the technical elements for the decision (e.g. calculation, simulations, experimental results).

#### **5.2.3.12 Electronic control strategy**

The presence or absence of an electronic control unit (ECU) on the engine is regarded as a basic parameter of the family.

In the case of electronically controlled engines, the manufacturer shall present the technical elements explaining the grouping of these engines in the same family, i.e. the reasons why these engine can be expected to satisfy the same emission requirements.

These elements can be calculations, simulations, estimations, description of injection parameters, experimental results, etc.

Examples of controlled features are:

- Timing
- Injection pressure
- Multiple injection
- Boost pressure
- VGT
- EGR

#### **5.2.3.13 Aftertreatment systems**

The function and combination of the following devices are regarded as membership criteria for an engine family:

- Oxidation catalyst
- Three-way catalyst
- DeNOx system with selective reduction of NOx (addition of reducing agent)
- Other DeNOx systems
- Particulate trap with passive regeneration
- Particulate trap with active regeneration
- Other particulate traps
- Other devices

When an engine has been certified without aftertreatment system, whether as parent engine or as member of the family, then this engine, when equipped with a non-controlled aftertreatment system, may be included in the same engine family, if it does not require different fuel characteristics (e.g. most of the oxidation catalysts).

If it requires specific fuel characteristics (e.g. particulate traps requiring special additives in the fuel to ensure the regeneration process), the decision to include it in the same family shall be based on technical elements provided by the manufacturer. These elements should indicate that the expected emission level of the equipped engine satisfies the same limit value as the non-equipped engine.

When an engine has been certified with aftertreatment system, whether as parent engine or as member of a family, whose parent engine is equipped with the same aftertreatment system, then this engine, when equipped without aftertreatment system, must not be added to the same engine family.

### **5.2.4 Choice of the parent engine**

#### **5.2.4.1 Compression ignition engines**

The parent engine of the family shall be selected using the primary criterion of the highest fuel delivery per stroke at the declared maximum torque speed. In the event that two or more engines share this primary criterion, the parent engine shall be selected using the secondary criterion of highest fuel

delivery per stroke at rated speed.

#### 5.2.4.2 Spark ignition engines

The parent engine of the family shall be selected using the primary criterion of the largest displacement. In the event that two or more engines share this primary criterion, the parent engine shall be selected using the secondary criterion in the following order of priority:

- a) the highest fuel delivery per stroke at the speed of declared rated power
- b) the most advanced spark timing
- c) the lowest EGR rate

#### 5.2.4.3 Remarks on the choice of the parent engine

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 level of the engines within that family. In this case, the parties involved shall have the appropriate information to determine the engine within the family likely to have the highest emissions level. This engine may be directly selected for testing without any prior test of any engine selected according to 5.2.4.1 or 5.2.4.2.

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

If engines within the family meet the same emission values over different useful life periods, this shall be taken into account in the selection of the parent engine.

## 6 TEST CONDITIONS

### 6.1 Laboratory Test Conditions

#### 6.1.1 Test condition parameter

The absolute temperature ( $T_a$ ) of the engine air at the inlet to the engine 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. In multi-cylinder engines having distinct groups of intake manifolds, such as in a "Vee" engine configuration, the average temperature of the distinct groups shall be taken.

a) for compression-ignition engines:

Naturally aspirated and mechanically supercharged engines:

$$f_a = \left( \frac{99}{p_s} \right) \times \left( \frac{T_a}{298} \right)^{0,7} \quad (1)$$

Turbocharged engines with or without cooling of the intake air:

$$f_a = \left( \frac{99}{p_s} \right)^{0,7} \times \left( \frac{T_a}{298} \right)^{1,5} \quad (2)$$

b) for spark ignition engines:

$$f_a = \left( \frac{99}{p_s} \right)^{1,2} \times \left( \frac{T_a}{298} \right)^{0,6} \quad (3)$$

### 6.1.2 Test validity

It is recommended that the parameter  $f_a$  be such that:  $0,93 \leq f_a \leq 1,07$ .

The parameter  $f_a$  shall be reported with the test results.

**Note: Deviations from the above limits may be expected due to specific atmospheric conditions (e.g. test laboratory located at high altitude or in hot area).**

## 6.2 Engines with charge air cooling

The charge air temperature shall be recorded and shall be, at the speed of the declared maximum power and full load, within  $\pm 5$  K of the maximum charge air temperature specified by the manufacturer. The temperature of the cooling medium shall be at least 293 K (20°C).

If a test shop system or external blower is used, the charge air temperature shall be set to within  $\pm 5$  K of the maximum charge air temperature specified by the manufacturer at the speed of the declared maximum power and full load. Coolant temperature and coolant flow rate of the charge air cooler at the above set point shall not be changed for the whole test cycle. The charge air cooler volume shall be based upon good engineering practice and typical vehicle/machinery applications.

## 6.3 Engine power

The basis of specific emissions measurement is uncorrected net power.

Certain auxiliaries necessary only for the operation of the vehicle and which may be mounted on the engine should be removed for the test. The following incomplete list is given as an example:

- air compressor for brakes
- power steering compressor
- air conditioning compressor
- pumps for hydraulic actuators

Where auxiliaries have not been removed, the power absorbed by them shall be determined in order to adjust the set values and to calculate the work produced by the engine over the test cycle.

## 6.4 Engine air intake system

An engine air intake system or a test shop system shall be used presenting an air intake restriction within  $\pm 300$  Pa of the maximum value specified by the manufacturer for a clean air cleaner at the speed of rated power and full load.

## 6.5 Engine exhaust system

An engine exhaust system or a test shop system shall be used presenting an exhaust backpressure within  $\pm 650$  Pa of the maximum value specified by the manufacturer at the speed of rated power and full load. The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in 8.3.2.2 and 8.3.3.2.

## 6.6 Engine with aftertreatment system

If the engine is equipped with an exhaust aftertreatment device, the exhaust pipe shall have the same diameter as found in-use for at least 4 pipe diameters upstream to the inlet of the beginning of the expansion section containing the aftertreatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust aftertreatment device shall be the same as in the vehicle configuration or within the distance specifications of the manufacturer. The exhaust backpressure or restriction shall follow the same criteria as above, and may be set with a valve. The aftertreatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalytic support.

The emissions measured on the test cycle shall be representative of the emissions in the field. In the case of an engine equipped with a exhaust aftertreatment system that requires the consumption of a reagent, the reagent used for all tests shall be declared by the manufacturer.

#### **6.6.1 Continuous regeneration**

For an exhaust aftertreatment system based on a continuous regeneration process the emissions shall be measured on a stabilised aftertreatment system.

The regeneration process shall occur at least once during the WHTC test and the manufacturer shall declare the normal conditions under which regeneration occurs (soot load, temperature, exhaust back-pressure, etc).

In order to verify the regeneration process at least 5 WHTC hot start tests shall be conducted. During the tests the exhaust temperature and pressure shall be recorded (temperature before and after the aftertreatment system, exhaust back pressure, etc).

The aftertreatment system is considered to be satisfactory if the conditions declared by the manufacturer occur during the test during a sufficient time.

The final test result shall be the arithmetic mean of the different WHTC hot start test results.

If the exhaust aftertreatment has a security mode that shifts to a periodic regeneration mode, it should be checked according to paragraph 6.6.2. For that specific case, the applicable emission limits could be exceeded and would not be weighted.

#### **6.6.2 Periodic regeneration**

For an exhaust aftertreatment based on a periodic regeneration process, the emissions shall be measured on at least two WHTC tests, one during and one outside a regeneration event on a stabilised aftertreatment system, and the results be weighted.

The regeneration process shall occur at least once during the WHTC test. The engine may be equipped with a switch capable of preventing or permitting the regeneration process provided this operation has no effect on the original engine calibration.

The manufacturer shall declare the normal parameter conditions under which the regeneration process occurs (soot load, temperature, exhaust back-pressure etc) and its duration time (n2). The manufacturer shall also provide all the data to determine the time between two regenerations (n1). The exact procedure to determine this time shall be agreed by the Technical Service based upon good engineering judgement.

The manufacturer shall provide an aftertreatment system that has been loaded in order to achieve regeneration during a WHTC test. Regeneration shall not occur during this engine conditioning phase.

Average emissions between regeneration phases shall be determined from the arithmetic mean of several approximately equidistant WHTC hot start tests. It is recommended to run at least one WHTC as close as possible prior to a regeneration test and one WHTC immediately after a regeneration test. As an alternative, the manufacturer may provide data to show that the emissions remain constant ( $\pm 15\%$ ) between regeneration phases. In this case, the emissions of only one WHTC test may be used.

During the regeneration test, all the data needed to detect regeneration shall be recorded (CO or NOx emissions, temperature before and after the aftertreatment system, exhaust back pressure etc).

During the regeneration process, the applicable emission limits may be exceeded.

The measured emissions shall be weighted according to paragraph 8.3.2.6 and 8.4.3.4, and the final result shall not exceed the applicable emission limits.

#### **6.7 Cooling system**

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

## 6.8 Lubricating oil

The lubricating oil shall be specified by the manufacturer **and be representative of lubricating oil available in the market**; the specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test.

## 6.9 Specification of the reference fuel

The appropriate reference fuels as defined in Annex 10.3 **shall** be used for testing. Since fuel characteristics influence the engine exhaust gas emission, the characteristics of the fuel used for the test shall be determined, recorded and declared with the results of the test. The reference code and the analysis of the fuel shall be provided.

The fuel temperature shall be in accordance with the manufacturers recommendations.

**The use of one standardized reference fuel has always been considered as an ideal condition for ensuring the reproducibility of regulatory emission testing, and Contracting Parties are encouraged to use such fuel in their compliance testing. However, until performance requirements (i.e. limit values) have been introduced into this GTR, Contracting Parties to the 1998 agreement are allowed to define a different reference fuel to that specified in Annex 10.3 for its national legislation, to address the actual situation of market fuel for vehicles in use. The reason for the use of such a different reference fuel and the specification of the parameters shall be reported to the Secretary-General of UNECE.**

# 7 TEST PROCEDURES

## 7.1 Principles of emissions measurement

In this regulation, two measurement principles are described that are functionally equivalent: Both principles may be used for both the WHTC and the WHSC cycle:

- the gaseous components are measured in the raw exhaust gas on a real time basis, and the particulates are determined using a partial flow dilution system;
- the gaseous components and the particulates are determined using a full flow dilution system (CVS system).
- any combination of the two principles (e.g. raw gaseous measurement and full flow particulate measurement) is permitted.

The engine shall be subjected to the tests specified below.

## 7.2 Transient test cycle WHTC

The transient test cycle WHTC is listed in Annex 10.2 as a second-by second sequence of normalized speed and torque values applicable to all engines covered by this GTR. In order to perform the test on an engine test cell, the normalized values shall be converted to the actual values for the individual engine under test based on the engine mapping curve. The conversion is referred to as denormalization, and the test cycle so developed as the reference cycle of the engine to be tested. With those reference speed and torque values, the cycle shall be run on the test cell, and the feedback speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and feedback speed, torque and power values shall be conducted upon completion of the test. For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle. For cycle validation, the actual cycle work must be within prescribed limits of the cycle work of the reference cycle (reference cycle work). **The gaseous pollutantants may be recorded continuously or sampled into a sampling bag. The particulate sample shall be diluted with conditioned ambient air, and collected on a single suitable filter.**

The WHTC is shown schematically in figure 2.

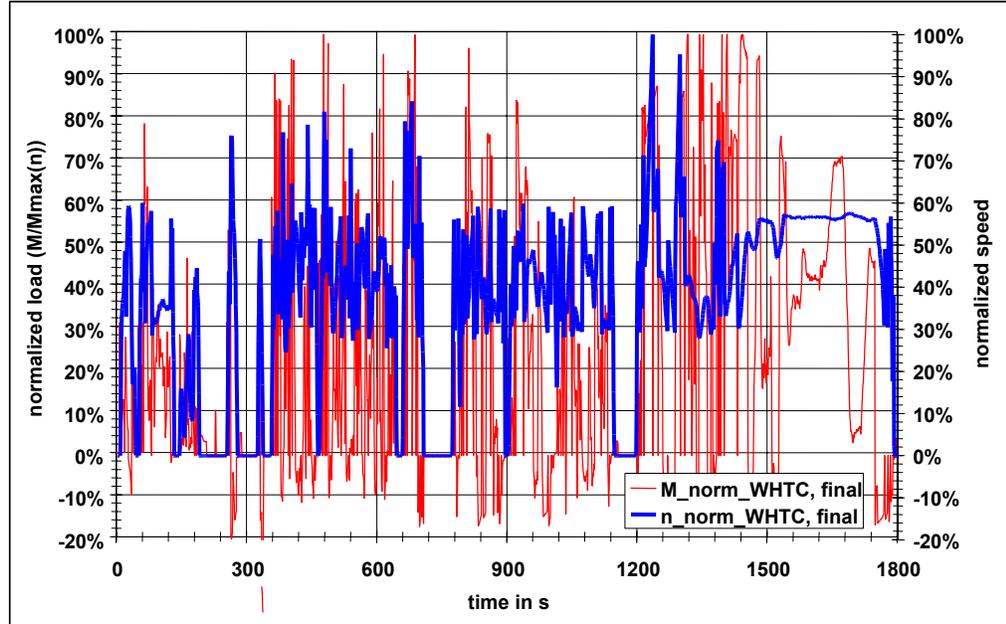


Figure 2 — WHTC test cycle

### 7.3 Steady state test cycle WHSC

The steady state test cycle WHSC consists of a number of speed and power modes which cover the typical operating range of heavy duty engines. During each mode and the ramps between the modes the concentration of each gaseous pollutant, exhaust flow and power output shall be determined, and the measured values weighted. The particulate sample shall be diluted with conditioned ambient air. One sample over the complete test procedure shall be taken, and collected on a **single** suitable filter.

The WHSC is shown schematically in table 1.

Basis:		Total PM sampling time close to WHTC = 1520 sec			
		Mode length dependent on WF (J13 procedure proposed by Mr. Schweizer)			
		Mode stabilization time = 30 sec			
		Idle mode determines length of other modes due to the highest WF (ca. 5,7 minutes)			
		Total cycle length is 31.3 minutes			
		Motoring is accounted for mathematically by a WF of 0.24 and zero emissions/zero power)			
		Motoring does not add to sample time, mode length and cycle length			
Mode No	Speed [%]	Load [%]	WF	Sample time [s]	Mode length [s]
0	Motoring		24%		
1	0	0	17%	340	370
2	55	100	2%	40	70
3	55	25	10%	200	230
4	55	70	3%	60	90
5	35	100	2%	40	70
6	25	25	8%	160	190
7	45	70	3%	60	90
8	45	25	6%	120	150
9	55	50	5%	100	130
10	75	100	2%	40	70
11	35	50	8%	160	190
12	35	25	10%	200	230
Sum			100%	1520	1880

Table 1 WHSC test cycle

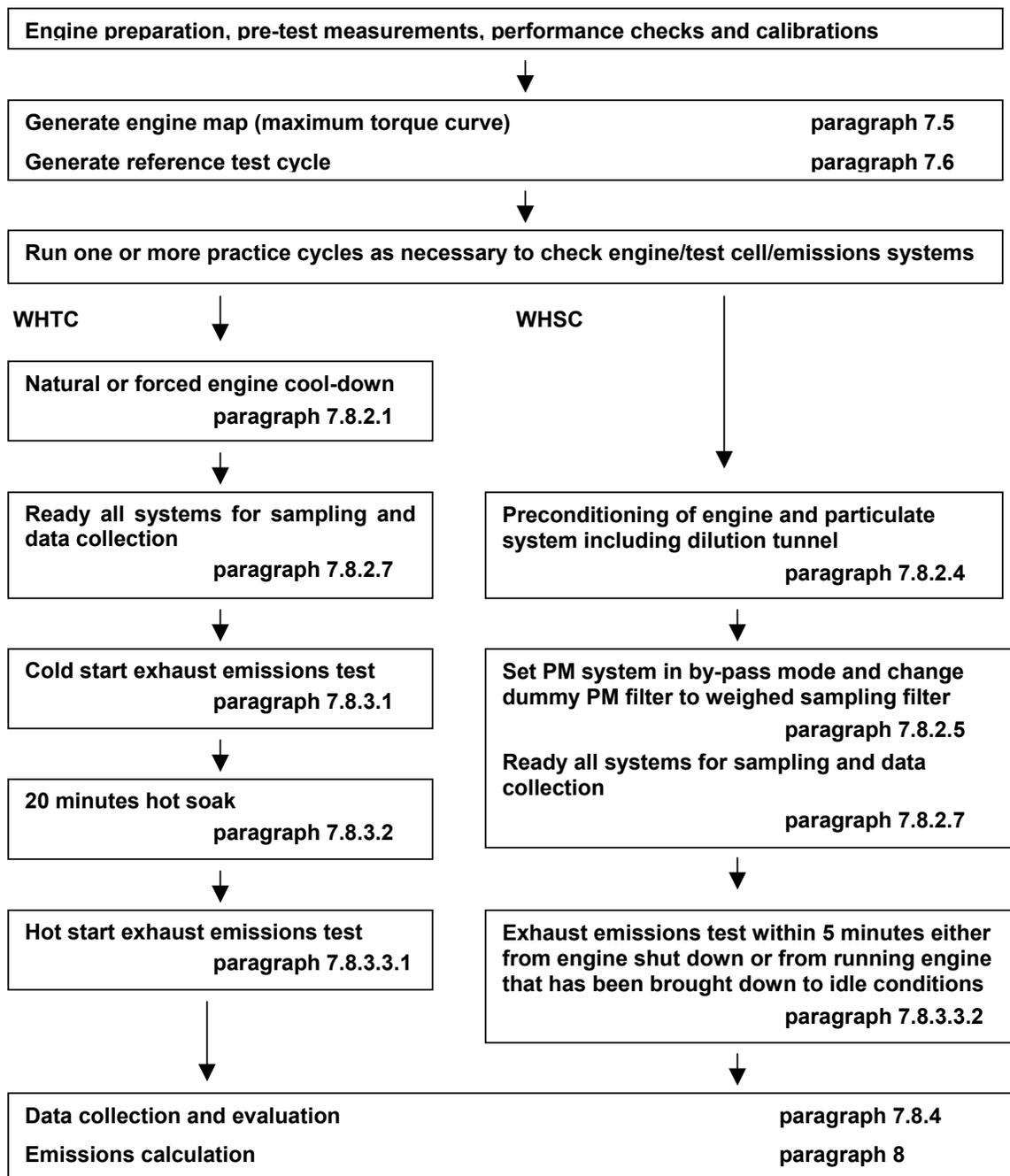
## 7.4 General Test Sequence

The following flow chart outlines the general guidance that should be followed during testing. The details of each step are described in the relevant paragraphs. Deviations from the guidance are permitted where appropriate, but the specific requirements of the relevant paragraphs are mandatory.

For the WHTC, the test procedure consists of a cold start test following either natural or forced cool-down of the engine, a 20 minutes hot soak period and a hot start test.

For the WHSC, the test procedure consists of a hot start test following engine preconditioning.

One or more practice cycles may be run as necessary to check engine, test cell and emissions systems before the measurement cycle.



## 7.5 Engine Mapping Procedure

For generating the WHTC and WHSC on the test cell, the engine shall be mapped prior to the run of the test cycle for determining the speed vs. torque curve.

### 7.5.1 Determination of the mapping speed range

The minimum and maximum mapping speeds are defined as follows:

Minimum mapping speed = idle speed

Maximum mapping speed =  $n_{hi} * 1,02$  or speed where full load torque drops off to zero, whichever is smaller

### 7.5.2 Engine mapping curve

The engine shall be warmed up at maximum power in order to stabilize the engine parameters according to the recommendation of the manufacturer and good engineering practice. When the engine is stabilized, the engine mapping shall be performed according to the following procedure.

- (a) The engine shall be unloaded and operated at idle speed.
- (b) The engine shall be operated at full load setting of the injection pump at minimum mapping speed.
- (c) The engine speed shall be increased at an average rate of  $8 \pm 1$  /min/s from minimum to maximum mapping speed. Engine speed and torque points shall be recorded at a sample rate of at least one point per second.

### 7.5.3 Alternate mapping

If a manufacturer believes that the above mapping techniques are unsafe or unrepresentative for any given engine, alternate mapping techniques may be used. These alternate techniques must satisfy the intent of the specified mapping procedures to determine the maximum available torque at all engine speeds achieved during the test cycles. Deviations from the mapping techniques specified in this paragraph for reasons of safety or representativeness shall be approved by the parties involved along with the justification for their use. In no case, however, the torque curve shall be run by descending engine speeds for governed or turbocharged engines.

### 7.5.4 Replicate tests

An engine need not be mapped before each and every test cycle. An engine shall be remapped prior to a test cycle if:

- an unreasonable amount of time has transpired since the last map, as determined by engineering judgement,

or,

- physical changes or recalibrations have been made to the engine which may potentially affect engine performance.

## 7.6 Generation of the reference test cycle

### 7.6.1 Denormalization of engine speed

The speed shall be denormalized using the following equation:

$$\text{Actual speed} = n_{\text{norm}} * (0,45 * n_{\text{lo}} + 0,45 * n_{\text{pref}} + 0,1 * n_{\text{hi}} - n_{\text{idle}}) * 2,0327 + n_{\text{idle}} \quad (4)$$

where

$n_{\text{lo}}$  is the lowest speed where the power is 55% of maximum power

$n_{\text{pref}}$ : The integral of the max. torque has to be calculated from  $n_{\text{idle}}$  up to  $n_{95h}$  in steps of 8 min-1.

$n_{95h}$  is the highest speed where the power is 95% of maximum power

$n_{\text{pref}}$  is then defined as that engine speed, where the max. torque integral is 51% of the whole

integral.

$n_{hi}$  is the highest speed where the power is 70% of maximum power.

$n_{idle}$  is the idle speed

### 7.6.2 Denormalization of engine torque

The torque values in the engine dynamometer schedule of Annex 10.2 are normalized to the maximum torque at the respective speed. The torque values of the reference cycle shall be denormalized, using the mapping curve determined according to paragraph 7.5, as follows:

$$\text{Actual torque} = \frac{\% \text{ torque} \times \text{max. torque}}{100} \quad (5)$$

for the respective actual speed as determined in 7.6.1.

### 7.6.3 Example of denormalization procedure

As an example, the following test point shall be denormalized:

$$\% \text{ speed} = 43 \%$$

$$\% \text{ torque} = 82 \%$$

Given the following values:

$$n_{lo} = 1015 \text{ /min}$$

$$n_{hi} = 2200 \text{ /min}$$

$$n_{pref} = 1300 \text{ /min}$$

$$n_{idle} = 600 \text{ /min}$$

results in

$$\text{actual speed} = \frac{43 \times (0,45 \times 1015 + 0,45 \times 1300 + 0,1 \times 2200 - 600) \times 2,0327}{100} + 600 = 1178 \text{ /min}$$

With the maximum torque of 700 Nm observed from the mapping curve at 1178 /min

$$\text{actual torque} = \frac{82 \times 700}{100} = 574 \text{ Nm}$$

## 7.7 Verification of the test run

### 7.7.1 Calculation of the cycle work

**Before calculating cycle work, any points recorded during engine starting shall be omitted. The cycle work  $W_{act}$  (kWh) shall be calculated based on engine feedback speed and torque values. The reference cycle work  $W_{ref}$  (kWh) shall be calculated based on engine reference speed and torque values** The actual cycle work  $W_{act}$  is used for comparison to the reference cycle work  $W_{ref}$  and for calculating the brake specific emissions (see paragraph 8.3.2.6).

The same methodology shall be used for integrating both reference and actual engine power. If values are to be determined between adjacent reference or adjacent measured values, linear interpolation shall be used. In integrating the actual cycle work, any negative torque values shall be set equal to zero and included. If integration is performed at a frequency of less than 5 Hertz, and if, during a given time segment, the torque value changes from positive to negative or negative to positive, the negative portion shall be computed and set equal to zero. The positive portion shall be included in the integrated value.

$W_{act}$  shall be between -15 % and + 5 % of  $W_{ref}$ .

### 7.7.2 Validation statistics of the test cycle

Linear regressions of the feedback values on the reference values shall be performed for speed, torque and power.

To minimize the biasing effect of the time lag between the feedback and reference cycle values, the

entire engine speed and torque feedback signal sequence may be advanced or delayed in time with respect to the reference speed and torque sequence. If the feedback signals are shifted, both speed and torque must be shifted the same amount in the same direction.

The method of least squares shall be used, with the best fit equation having the form:

$$y = mx + b \tag{6}$$

where:

- y = feedback (actual) value of speed ( $\text{min}^{-1}$ ), torque (Nm), or power (kW)
- m = slope of the regression line
- x = reference value of speed ( $\text{min}^{-1}$ ), torque (Nm), or power (kW)
- b = y intercept of the regression line

The standard error of estimate (SE) of y on x and the coefficient of determination ( $r^2$ ) shall be calculated for each regression line.

It is recommended that this analysis be performed at 1 Hertz. For a test to be considered valid, the criteria of table 2 must be met.

**Table 2 Regression Line Tolerances**

	Speed	Torque	Power
Standard error of estimate (SEE) of Y on X	max 100 $\text{min}^{-1}$	max 13 % of power map maximum engine torque	max 8% of power map maximum engine power
Slope of the regression line, m	0,95 to 1,03	0,83 – 1,03	0,89 – 1,03
Coefficient of determination, $r^2$	min 0,970	min 0,850	min 0,910
Y intercept of the regression line, b	$\pm 50 \text{ min}^{-1}$	$\pm 20 \text{ Nm}$ or $\pm 2 \%$ of max torque whichever is greater	$\pm 4 \text{ kW}$ or $\pm 2 \%$ of max power whichever is greater

For regression purposes only, point deletions are permitted where noted in table 3 before doing the regression calculation. However, those points must not be deleted for the calculation of cycle work and emissions. An idle point is defined as a point having a normalized reference torque of 0 % and a normalized reference speed of 0 %. Point deletion may be applied to the whole or to any part of the cycle.

**Table 3 Permitted Point Deletions From Regression Analysis**

Condition	Points to be deleted
<b>First 6 <math>\pm 1</math> seconds</b>	Speed, torque, power
Full load demand and torque feedback < 95% torque reference	Torque and/or power
Full load demand and speed feedback < 95% speed reference	Speed and/or power
No load demand, speed feedback > idle speed + 50 $\text{min}^{-1}$ , and torque feedback > 105 % torque reference	Torque and/or power
No load demand, speed feedback $\leq$ idle speed + 50 $\text{min}^{-1}$ , and <b>torque feedback &gt; <math>\pm 2 \%</math> of max. torque (idle point)</b>	Speed and/or power
No load demand and speed feedback > 105 % speed reference	Speed and/or power
<b>No load demand and torque reference &lt; 0 % (motoring point)</b>	<b>Torque and/or power</b>

## 7.8 Emissions Test Run

### 7.8.1 Introduction

The emissions to be measured from the exhaust of the engine include the gaseous components (carbon monoxide, total hydrocarbons or non-methane hydrocarbons and oxides of nitrogen), and the particulates. Additionally, carbon dioxide is often used as a tracer gas for determining the dilution ratio of partial and full flow dilution systems.

The above pollutants shall be examined during the prescribed test cycles. Using the engine torque and speed feedback signals of the engine dynamometer, the power shall be integrated with respect to time of the cycle resulting in the work produced by the engine over the cycle. The concentrations of the gaseous components shall be determined over the cycle either in the raw exhaust gas by integration of the analyzer signal, or in the diluted exhaust gas of a CVS full flow dilution system by integration or by bag sampling. For particulates, a proportional sample shall be collected from the diluted exhaust gas on a specified filter by either partial flow dilution or full flow dilution. Depending on the method used, the diluted or undiluted exhaust gas flow rate shall be determined over the cycle to calculate the mass emission values of the pollutants. The mass emission values shall be related to the engine work to get the grams of each pollutant emitted per kilowatt hour.

### 7.8.2 Pre-test procedures

**Pre-test engine measurements , pre-test engine performance checks and pre-test system calibrations shall be made prior to the engine mapping procedure.**

#### 7.8.2.1 Engine cool-down (cold start test only)

**A natural or forced cool-down procedure may be applied. For forced cool-down, good engineering judgment shall be used to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to remove heat from coolant through the engine cooling system, and to remove heat from an exhaust aftertreatment system. In the case of a forced aftertreatment cooldown, cooling air shall not be applied until the aftertreatment system has cooled below its catalytic activation temperature. Any cooling procedure that results in unrepresentative emissions is not permitted.**

#### 7.8.2.2 Preparation of the sampling filters

At least one hour before the test, each filter shall be placed in a petri dish, which is protected against dust contamination and allows air exchange, and placed in a weighing chamber for stabilization. At the end of the stabilization period, each filter shall be weighed and the tare weight shall be recorded. The filter shall then be stored in a closed petri dish or sealed filter holder until needed for testing. The filter shall be used within eight hours of its removal from the weighing chamber.

#### 7.8.2.3 Installation of the measuring equipment

The instrumentation and sample probes shall be installed as required. The tailpipe shall be connected to the full flow dilution system, if used.

#### 7.8.2.4 Preconditioning the dilution system and the engine (hot start only)

The dilution system and the engine shall be started and warmed up. The sampling system shall be preconditioned by operating the engine at a condition of rated speed, 100 percent torque for a minimum of 20 minutes while simultaneously operating either the partial flow dilution system or the full flow dilution system with secondary dilution system. Dummy particulate emissions samples may be collected. Those sample filters need not be stabilized or weighed, and may be discarded. Filter media may be changed during conditioning as long as the total sampled time through the filters and sampling system exceeds 20 minutes. Flow rates shall be set at the approximate flow rates selected for testing. Torque shall be reduced from 100 percent torque while maintaining the rated speed condition as necessary to prevent exceeding the 464 K (191 °C) maximum sample zone temperature specifications, if a full flow dilution system is used.

#### 7.8.2.5 Starting the particulate sampling system

The particulate sampling system shall be started and running on by-pass. The particulate background level of the dilution air may be determined by sampling the dilution air prior to the entrance of the exhaust gas into the dilution tunnel. If filtered dilution air is used, one measurement may be done prior to or after the test. If the dilution air is not filtered, measurements at the beginning and at the end of the

cycle, may be done, and the values averaged. If a different sampling system is used for background measurement, the measurement shall be done over the period of the test run.

#### **7.8.2.6 Adjustment of the dilution system**

The total diluted exhaust gas flow of a full flow dilution system or the diluted exhaust gas flow through a partial flow dilution system shall be set to eliminate water condensation in the system, and to obtain a filter face temperature between 315 K (42°C) and 325 K (52°C).

#### **7.8.2.7 Checking the analyzers**

The emission analyzers shall be set at zero and spanned. If sample bags are used, they shall be evacuated.

### **7.8.3 Engine starting procedure**

#### **7.8.3.1 Cold start test (WHTC only)**

The cold-start test shall be started when the temperatures of an engine's lubricant, coolant, and aftertreatment systems are all between 293 and 303 K (20 and 30°C). The engine shall be started using one of the following methods:

(1) Start the engine as recommended in the owners manual using a production starter motor and adequately charged battery or a suitable power supply.

(2) Use the dynamometer to start the engine. To do this, motor the engine within  $\pm 25\%$  of its typical in-use cranking speed. Stop cranking within 1 second of starting the engine.

If the engine does not start after 15 seconds of cranking, stop cranking and determine why the engine failed to start, unless the owners manual or the service-repair manual describes the longer cranking time as normal.

#### **7.8.3.2 Hot soak procedure (WHTC only)**

Immediately upon completion of the cold start test, the engine shall be soaked for  $20 \pm 1$  minutes.

#### **7.8.3.3 Hot start test**

##### **7.8.3.3.1 WHTC**

The engine shall be started at the end of the hot soak period as defined in paragraph 7.8.3.2 using the procedures given in paragraph 7.8.3.1

##### **7.8.3.3.2 WHSC**

The engine shall be started within 5 min after completion of the preconditioning phase described in paragraph 7.8.2.4 according to the manufacturer's recommended starting procedure in the owner's manual, using either a production starter motor or the dynamometer in accordance with paragraph 7.8.3.1. Optionally, the test may start directly from the engine preconditioning phase without shutting the engine off, within 5 minutes after the engine has been brought to idle condition.

### **7.8.4 Cycle run**

#### **7.8.4.1 Test sequence**

The test sequence shall commence either at the start of the engine or within 5 minutes after the engine has been brought to idle condition (option permitted in paragraph 7.8.3.3.2).

The WHTC shall be performed according to the reference cycle as set out in paragraph 7.2. Engine speed and torque command set points shall be issued at 5 Hz (10 Hz recommended) or greater. The set points shall be calculated by linear interpolation between the 1 Hz set points of the reference cycle. Feedback engine speed and torque shall be recorded at least once every second during the test cycle, and the signals may be electronically filtered.

The WHSC shall be performed according to the order of test modes listed in table 1 of paragraph 7.3

#### **7.8.4.2 Analyzer response**

At the start of the test sequence, the measuring equipment shall be started, simultaneously:

- start collecting or analyzing dilution air, if a full flow dilution system is used;
- start collecting or analyzing raw or diluted exhaust gas, depending on the method used;
- start measuring the amount of diluted exhaust gas and the required temperatures and pressures;
- start recording the exhaust gas mass flow rate, if raw exhaust gas analysis is used;
- start recording the feedback data of speed and torque of the dynamometer.

If raw exhaust measurement is used, the emission concentrations (HC, CO and NO<sub>x</sub>) and the exhaust gas mass flow rate shall be measured continuously and stored with at least 2 Hz on a computer system. All other data may be recorded with a sample rate of at least 1 Hz. For analog analyzers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

If a full flow dilution system is used, HC and NO<sub>x</sub> shall be measured continuously in the dilution tunnel with a frequency of at least 2 Hz. The average concentrations shall be determined by integrating the analyzer signals over the test cycle. The system response time shall be no greater than 20 s, and shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary. CO, CO<sub>2</sub>, and NMHC shall be determined by integration or by analyzing the concentrations in the sample bag, collected over the cycle. The concentrations of the gaseous pollutants in the dilution air shall be determined by integration or by collecting into the background bag. All other parameters that need to be measured shall be recorded with a minimum of one measurement per second (1 Hz).

#### **7.8.4.3 Particulate sampling**

At the start of the test sequence, the particulate sampling system shall be switched from by-pass to collecting particulates.

If a partial flow dilution system is used, the sample pump(s) shall be adjusted so that the flow rate through the particulate sample probe or transfer tube is maintained proportional to the exhaust mass flow rate.

If a full flow dilution system is used, the sample pump(s) shall be adjusted so that the flow rate through the particulate sample probe or transfer tube is maintained at a value within  $\pm 5\%$  of the set flow rate. If flow compensation (i.e., proportional control of sample flow) is used, it must be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than  $\pm 5\%$  of its set value (except for the first 10 seconds of sampling). The average temperature and pressure at the gas meter(s) or flow instrumentation inlet shall be recorded. If the set flow rate cannot be maintained over the complete cycle (within  $\pm 5\%$ ) because of high particulate loading on the filter, the test shall be voided. The test shall be rerun using a lower flow rate and/or a larger diameter filter.

#### **7.8.4.4 Engine stalling and equipment malfunction**

**If the engine stalls anywhere during the cold start test of the WHTC or during the WHSC, the test shall be voided. The engine shall be preconditioned and restarted according to the requirements of paragraph 7.8.3, and the test repeated.**

**If the engine stalls anywhere during the hot start test of the WHTC, the test shall be voided. The engine shall be soaked for 20 minutes according to paragraph 7.8.3.2, and the hot start test repeated. In this case, the cold start test need not be repeated.**

If a malfunction occurs in any of the required test equipment during the test cycle, the test shall be voided **and repeated in line with the above provisions in dependence of the test cycle.**

#### **7.8.4.5 Operations after test**

At the completion of the test, the measurement of the exhaust gas mass flow rate, the diluted exhaust gas volume, the gas flow into the collecting bags and the particulate sample pump shall be stopped. For an integrating analyzer system, sampling shall continue until system response times have elapsed.

The concentrations of the collecting bags, if used, shall be analyzed as soon as possible and in any case not later than 20 minutes after the end of the test cycle.

After the emission test, a zero gas and the same span gas shall be used for re-checking the analyzers. The test will be considered acceptable if the difference between the pre-test and post-test results is less than 2 % of the span gas value.

The particulate filters shall be returned to the weighing chamber no later than one hour after completion of the test. They shall be conditioned in a petri dish, which is protected against dust contamination and

allows air exchange, for at least one hour, and then weighed. The gross weight of the filters shall be recorded.

## 8 Emissions Measurement and Calculation

The final test result shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure, in accordance with ASTM E 29-04.

### 8.1 Dry/wet correction

If the emissions are not measured on a wet basis the measured concentration shall be converted to a wet basis according to either of the following formulae.

$$c_w = K_w \times c_d \quad (7)$$

a) For the raw exhaust gas:

$$k_w = \left( 1 - \frac{1,2442 \times H_a + 111,19 \times w_{ALF} \times \frac{q_{mf,i}}{q_{mad,i}}}{773,4 + 1,2442 \times H_a + \frac{q_{mf,i}}{q_{mad,i}} \times k_f \times 1000} \right) \times 1,008 \quad (8)$$

or

$$k_w = \left( 1 - \frac{1,2442 \times H_a + 111,19 \times w_{ALF} \times \frac{q_{mf,i}}{q_{mad,i}}}{773,4 + 1,2442 \times H_a + \frac{q_{mf,i}}{q_{mad,i}} \times k_f \times 1000} \right) \left/ \left( 1 - \frac{p_r}{p_b} \right) \right. \quad (9)$$

b) For the diluted exhaust gas:

$$K_{we1} = \left[ \left( 1 - \frac{\alpha \times c_{CO2w}}{200} \right) - K_{w1} \right] \times 1,008 \quad (10)$$

or

$$K_{we2} = \left[ \frac{(1 - K_{w1})}{1 + \frac{\alpha \times c_{CO2d}}{200}} \right] \times 1,008 \quad (11)$$

$$K_{w1} = \frac{1,608 \times \left[ H_d \times \left( 1 - \frac{1}{D} \right) + H_a \times \left( \frac{1}{D} \right) \right]}{1000 + \left\{ 1,608 \times \left[ H_d \times \left( 1 - \frac{1}{D} \right) + H_a \times \left( \frac{1}{D} \right) \right] \right\}} \quad (12)$$

c) For the dilution air

$$K_{wd} = (1 - K_{w2}) \times 1,008 \quad (13)$$

$$k_{W2} = \frac{1,608 \times H_d}{1000 + (1,608 * H_d)} \quad (14)$$

where

$$\begin{aligned} p_r &= \text{Water vapor pressure after cooling bath, kPa} \\ p_b &= \text{Total atmospheric pressure, kPa} \\ \alpha &= \text{molar hydrogen ratio of the fuel} \\ c_{CO_2} &= \text{dry CO}_2 \text{ concentration, \%} \\ c_{CO} &= \text{dry CO concentration, \%} \\ H_a &= \text{intake air humidity, g water per kg dry air} \\ H_d &= \text{dilution air humidity, g water per kg dry air} \\ k_f &= 0,055594 \times w_{ALF} + 0,0080021 \times w_{DEL} + 0,0070046 \times w_{EPS} \end{aligned} \quad (15)$$

NOTE Equations 8 and 9 are principally identical with the factor 1,008 in equation 8 being an approximation for the more accurate denominator in equation 9.

## 8.2 NO<sub>x</sub> correction for humidity and temperature

As the NO<sub>x</sub> emission depends on ambient air conditions, the NO<sub>x</sub> concentration shall be corrected for humidity and ambient air temperature with the factors given in either of the following formulae.

a) for compression ignition engines

$$k_{h,D} = \frac{1}{1 - 0,0182 \times (H_a - 10,71) + 0,0045 \times (T_a - 298)} \quad (16)$$

with:

$$\begin{aligned} T_a &= \text{temperature of the intake air, K} \\ H_a &= \text{humidity of the intake air, g water per kg dry air} \end{aligned}$$

b) for spark ignition engines

$$k_{h,G} = 0,6272 + 44,030 \times 10^{-3} \times H_a - 0,862 \times 10^{-3} \times H_a^2 \quad (17)$$

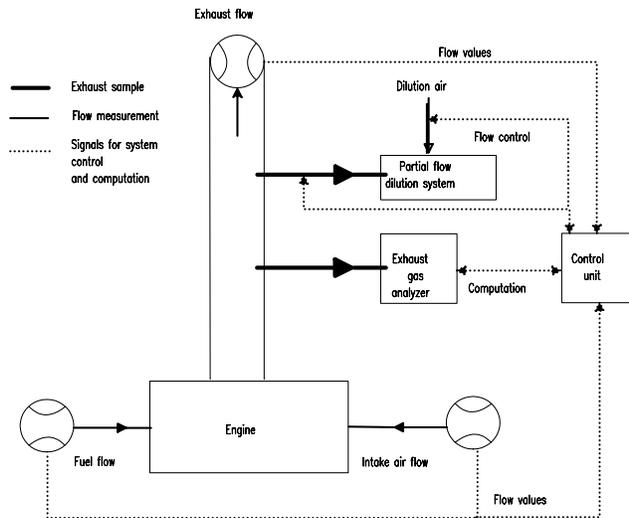
where  $H_a$  may be derived from relative humidity measurement, dewpoint measurement, vapor pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

## 8.3 Partial Flow Dilution (PFS) and Raw Gaseous Measurement

The instantaneous concentration signals of the gaseous components are used for the calculation of the mass emissions by multiplication with the instantaneous exhaust mass flow rate. The exhaust mass flow rate may be measured directly, or calculated using the methods of intake air and fuel flow measurement, tracer method or intake air and air/fuel ratio measurement. Special attention shall be paid to the response times of the different instruments. These differences shall be accounted for by time aligning the signals.

For particulates, the exhaust mass flow rate signals are used for controlling the partial flow dilution system to take a sample proportional to the exhaust mass flow rate. The quality of proportionality is checked by applying a regression analysis between sample and exhaust flow.

The complete test set up is schematically shown in figure 3.



**Figure 3 Schematic of raw/partial flow measurement system**

### 8.3.1 Determination of exhaust gas mass flow

#### 8.3.1.1 Introduction

For calculation of the emissions in the raw exhaust gas and for controlling of a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For the determination of the exhaust mass flow rate, either of the methods described in 8.3.1.3 to 8.3.1.6 may be used.

#### 8.3.1.2 Response time

For the purpose of emissions calculation, the response time of either method described below shall be equal to or less than the requirement for the analyzer response time, as defined in 9.3.3.5 .

For the purpose of controlling of a partial flow dilution system, a faster response is required. For partial flow dilution systems with online control, a response time of  $\leq 0,3$  seconds is required. For partial flow dilution systems with look ahead control based on a pre-recorded test run, a response time of the exhaust flow measurement system of  $\leq 5$  seconds with a rise time of  $\leq 1$  second is required. The system response time shall be specified by the instrument manufacturer. The combined response time requirements for exhaust gas flow and partial flow dilution system are indicated in 8.3.3.3.

#### 8.3.1.3 Direct measurement method

Direct measurement of the instantaneous exhaust flow may be done by systems, such as:

- pressure differential devices, like flow nozzle, (details see ISO 5167)
- ultrasonic flowmeter
- vortex flowmeter

Precautions shall be taken to avoid measurement errors which will impact emission value errors. Such precautions include the careful installation of the device in the engine exhaust system according to the instrument manufacturers' recommendations and to good engineering practice. Especially, engine performance and emissions must not be affected by the installation of the device.

The flowmeters shall meet the accuracy specifications of 9.2.

#### 8.3.1.4 Air and fuel measurement method

This involves measurement of the air flow and the fuel flow with suitable flowmeters. The calculation of the instantaneous exhaust gas flow is as follows:

$$q_{mew,i} = q_{maw,i} + q_{mf,i} \text{ (for wet exhaust mass)}$$

The flowmeters shall meet the accuracy specifications of 9.2 , but shall be accurate enough to also meet the accuracy specifications for the exhaust gas flow.

### 8.3.1.5 Tracer measurement method

This involves measurement of the concentration of a tracer gas in the exhaust.

A known amount of an inert gas (e.g. pure helium) shall be injected into the exhaust gas flow as a tracer. The gas is mixed and diluted by the exhaust gas, but shall not react in the exhaust pipe. The concentration of the gas shall then be measured in the exhaust gas sample.

In order to ensure complete mixing of the tracer gas, the exhaust gas sampling probe shall be located at least 1 m or 30 times the diameter of the exhaust pipe, whichever is larger, downstream of the tracer gas injection point. The sampling probe may be located closer to the injection point if complete mixing is verified by comparing the tracer gas concentration with the reference concentration when the tracer gas is injected upstream of the engine.

The tracer gas flow rate shall be set so that the tracer gas concentration at engine idle speed after mixing becomes lower than the full scale of the trace gas analyzer.

The calculation of the exhaust gas flow is as follows:

$$q_{mew,i} = \frac{q_{vt} \times \rho_e}{60 \times (c_{mix,i} - c_a)} \quad (19)$$

where

- $q_{mew,i}$  = instantaneous exhaust mass flow, kg/s
- $q_{vt}$  = tracer gas flow, cm<sup>3</sup>/min
- $c_{mix,i}$  = instantaneous concentration of the tracer gas after mixing, ppm
- $\rho_e$  = density of the exhaust gas, kg/m<sup>3</sup> (cf. table 3)
- $c_a$  = background concentration of the tracer gas in the intake air, ppm

The background concentration of the tracer gas ( $c_a$ ) may be determined by averaging the background concentration measured immediately before the test run and after the test run.

When the background concentration is less than 1% of the concentration of the tracer gas after mixing ( $c_{mix,i}$ ) at maximum exhaust flow, the background concentration may be neglected.

The total system shall meet the accuracy specifications for the exhaust gas flow, and shall be calibrated according to 9.3.3.8.

### 8.3.1.6 Air flow and air to fuel ratio measurement method

This involves exhaust mass calculation from the air flow and the air to fuel ratio. The calculation of the instantaneous exhaust gas mass flow is as follows:

$$q_{mew,i} = q_{maw,i} \times \left( 1 + \frac{1}{A/F_{st} \times \lambda_i} \right) \quad (20)$$

with

$$A / F_{st} = \frac{138,0 \times \left( \beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right)}{12,011 \times \beta + 1,00794 \times \alpha + 15,9994 \times \varepsilon + 14,0067 \times \delta + 32,065 \times \gamma} \quad (21)$$

$$\lambda_i = \frac{\beta \times \left( 100 - \frac{c_{CO} \times 10^{-4}}{2} - c_{HC} \times 10^{-4} \right) + \left( \frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{CO} \times 10^{-4}}{3,5 \times c_{CO_2}}}{1 + \frac{c_{CO} \times 10^{-4}}{3,5 \times c_{CO_2}}} - \frac{\varepsilon}{2} - \frac{\delta}{2} \right) \times (c_{CO_2} + c_{CO} \times 10^{-4})}{4,764 \times \left( \beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right) \times (c_{CO_2} + c_{CO} \times 10^{-4} + c_{HC} \times 10^{-4})} \quad (22)$$

where  $A/F_{st}$  = stoichiometric air to fuel ratio, kg/kg  
 $\lambda$  = excess air ratio  
 $c_{CO_2}$  = dry CO<sub>2</sub> concentration, %  
 $c_{CO}$  = dry CO concentration, ppm  
 $c_{HC}$  = HC concentration, ppm

The air flowmeter shall meet the accuracy specifications of 9.2, the CO<sub>2</sub> analyzer used shall meet the specifications of 9.3.1, and the total system shall meet the accuracy specifications for the exhaust gas flow.

Optionally, air to fuel ratio measurement equipment such as a zirconia type sensor may be used for the measurement of the excess air ratio which meets the specifications of 9.3.2.7.

## 8.3.2 Determination of the gaseous components

### 8.3.2.1 Introduction

The gaseous components emitted by the engine submitted for testing shall be measured by the methods described in 0. They shall be determined in the raw exhaust gas. Data evaluation and calculation procedures are described in 8.4.2.3 and 8.3.2.4.

### 8.3.2.2 Sampling for gaseous emissions

The gaseous emissions sampling probes shall be fitted at least 0,5 m or 3 times the diameter of the exhaust pipe - whichever is the larger - upstream of the exit of the exhaust gas system but sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (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 recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest CO<sub>2</sub> emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emission calculation the total exhaust mass flow shall be used.

If the engine is equipped with an exhaust aftertreatment system, the exhaust sample shall be taken downstream of the exhaust aftertreatment system.

### 8.3.2.3 Data evaluation

For the evaluation of the gaseous emissions, the raw emission concentrations (HC, CO and NO<sub>x</sub>) and the exhaust gas mass flow rate shall be recorded and stored with at least 2 Hz on a computer system. All other data may be recorded with a sample rate of at least 1 Hz. For analog analyzers the response will be recorded, and the calibration data may be applied online or offline during the data evaluation.

For calculation of the mass emission of the gaseous components the traces of the recorded concentrations and the trace of the exhaust gas mass flow rate shall be time aligned by the transformation time as defined in 3.1. Therefore, the response time of each gaseous emissions analyzer and of the exhaust gas mass flow system shall be determined according to 8.3.1.2 and 9.3.3.5, respectively, and recorded.

### 8.3.2.4 Calculation of mass emission

The mass of the pollutants (g/test) shall be preferably determined by calculating the instantaneous mass emissions from the raw concentrations of the pollutants, the  $u$  values from table 4 and the exhaust mass flow, aligned for the transformation time as determined in accordance with 8.3.2.3, and integrating the instantaneous values over the cycle in accordance with equation 20. If measured on a dry basis, the dry/wet correction according to 8.1 shall be applied to the instantaneous concentration values before any further calculation is done.

An example of the calculation procedures is given in Annex 10.6.

The following formulae shall be applied.

a) for the WHTC

$$m_{\text{gas}} = \sum_{i=1}^{i=n} u_{\text{gas}} \times c_{\text{gas},i} \times q_{mew,i} \times \frac{1}{f} \quad (\text{in g/test}) \quad (23)$$

where

- $u_{\text{gas}}$  = ratio between density of exhaust component and density of exhaust gas  
 $c_{\text{gas},i}$  = instantaneous concentration of the component in the raw exhaust gas, ppm  
 $q_{\text{mew},i}$  = instantaneous exhaust mass flow, kg/s  
 $f$  = data sampling rate, Hz  
 $n$  = number of measurements

b) for each mode of the WHSC

$$m_{\text{gas}} = u_{\text{gas}} \times c_{\text{gas}} \times q_{\text{mew}} \quad (\text{in g/h}) \quad (24)$$

where

- $u_{\text{gas}}$  = ratio between density of exhaust component and density of exhaust gas  
 $c_{\text{gas}}$  = concentration of the respective component in the raw exhaust gas, ppm  
 $q_{\text{mew}}$  = exhaust gas mass flow rate, kg/s

For the calculation of  $\text{NO}_x$ , the humidity correction factor  $k_{\text{h,D}}$ , or  $k_{\text{h,G}}$ , as applicable, as determined according to 8.2, shall be used.

The measured concentration shall be converted to a wet basis according to 8.1, if not already measured on a wet basis

Values for  $u$  are given in table 4 below for selected components and a range of fuels:

**Table 4 Values of  $u$  in the raw exhaust gas and density for various exhaust components**

Gas	$\text{NO}_x$	CO	HC	$\text{CO}_2$	$\text{O}_2$	$\text{CH}_4$		
$\rho_{\text{gas}} \text{ [kg/m}^3\text{]}$	2,053	1,250	<sup>a)</sup>	1,9636	1,4277	0,716		
<b>FUEL</b>	$\rho_e$	<b>Coefficient <math>u_{\text{gas}}</math> <sup>b)</sup></b>						
Diesel	<b>1,2943</b>	<b>0,001586</b>	0,000966	0,000479	<b>0,001517</b>	0,001103	0,000553	
Ethanol	<b>1,2757</b>	0,001609	0,000980	0,000805	0,001539	0,001119	0,000561	
Natural Gas <sup>c)</sup>	<b>1,2661</b>	<b>0,001621</b>	0,000987	<b>0,000558<sup>d)</sup></b>	<b>0,001551</b>	0,001128	0,000565	
Propane	1,2805	0,001603	0,000976	<b>0,000512</b>	0,001533	0,001115	0,000559	
Butane	<b>1,2832</b>	0,001600	0,000974	0,000505	0,001530	0,001113	0,000558	
a) depending on fuel b) at $\lambda = 2$ , wet air, 273 K, 101,3 kPa c) $u$ accurate within 0,2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 % d) NMHC on the basis of $\text{CH}_{2,93}$ (for total HC the $u_{\text{gas}}$ coefficient of $\text{CH}_4$ shall be used)								

### 8.3.2.5 Calculation of NMHC and $\text{CH}_4$ with the non-methane cutter

The concentration of NMHC and  $\text{CH}_4$  shall be calculated as follows:

$$c_{\text{NMHC}} = \frac{c_{\text{HC(w/oCutter)}} \times (1 - E_M) - c_{\text{HC(w/Cutter)}}}{E_E - E_M} \quad (25)$$

$$c_{\text{CH}_4} = \frac{c_{\text{HC(w/Cutter)}} - c_{\text{HC(w/oCutter)}} \times (1 - E_E)}{E_E - E_M} \quad (26)$$

where:

- $c_{\text{HC(w/Cutter)}}$  = HC concentration with the sample gas flowing through the NMC  
 $c_{\text{HC(w/oCutter)}}$  = HC concentration with the sample gas bypassing the NMC

$E_M$  = methane efficiency as determined per 9.3.3.11.1  
 $E_E$  = ethane efficiency as determined per 9.3.3.11.2

NOTE If a non-methane cutter is used, the system response time may exceed 10 s.

### 8.3.2.6 Calculation of the specific emissions

The emissions (g/kWh) shall be calculated for each individual component in the following way.

#### a) for the WHTC as a weighted average from cold start test and hot start test

$$M_{gas} = \frac{(0,1 \times m_{gas,cold}) + (0,9 \times m_{gas,hot})}{(0,1 \times W_{act,cold}) + (0,9 \times W_{act,hot})} \quad (27)$$

where

$W_{act}$  = actual cycle work as determined according to 7.7.1, kWh

**In case of a periodic exhaust aftertreatment system, the hot start emissions shall be weighted as follows:**

$$\overline{M}_{Gas} = (n1 \times \overline{M}_{Gas,n1} + n2 \times \overline{M}_{Gas,n2}) / (n1 + n2) \quad (28)$$

where:

**n1** = number of WHTC hot start tests between two regenerations

**n2** = number of WHTC hot start tests during a regeneration (minimum of one WHTC test)

**$\overline{M}_{gas,n2}$**  = emissions during a regeneration

**$\overline{M}_{gas,n1}$**  = emissions after a regeneration

#### b) for the WHSC

$$M_{gas} = \frac{\sum_{i=1}^{i=n} (m_{GASi} \times W_{Fi})}{\sum_{i=1}^{i=n} (P_i \times W_{Fi})} \quad (29)$$

where

$m_{gas}$  is the mass of individual gas

$P_i$  is the measured power of the individual mode

### 8.3.3 Particulate determination

#### 8.3.3.1 Introduction

The determination of the particulates requires a dilution system. In this paragraph, dilution shall be accomplished by a partial flow dilution system. The dilution system shall be set to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas between 315 K (42°C) and 325 K (52°C) immediately upstream of the filter holders. Dehumidifying the dilution air before entering the dilution system is permitted, and especially useful if dilution air humidity is high. The temperature of the dilution air shall be higher than 288 K (15°C) in close proximity to the entrance into the dilution tunnel.

The partial flow dilution system has to be designed to extract a proportional raw exhaust sample from the engine exhaust stream, thus responding to excursions in the exhaust stream flow rate, and introduce dilution air to this sample to achieve a temperature between 315 K (42°C) and 325 K (52°C) at the test filter. For this it is essential that the dilution ratio or the sampling ratio  $r_{dil}$  or  $r_s$  be determined such that the accuracy requirements of 9.4.4 are fulfilled. Different extraction methods can be applied, whereby the type of extraction used dictates to a significant degree the sampling hardware and procedures to be used.

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. The details of the system are described in 9.4.

### 8.3.3.2 Particulate sampling

In general, the particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, but sufficiently distant as to not cause interference. Therefore, the installation provisions of 8.3.2.2 also apply to particulate sampling. The sampling line shall conform to the requirements of 9.3.4.3.

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 recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest particulate emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emission calculation the total exhaust mass flow shall be used.

### 8.3.3.3 System response time

For the control of a partial flow dilution system, a fast system response is required. The transformation time for the system shall be determined by the procedure in 9.6.3. If the combined transformation time of the exhaust flow measurement (see 8.3.1.2) and the partial flow system is less than 0,3 sec, online control may be used. If the transformation time exceeds 0,3 sec, look ahead control based on a pre-recorded test run must be used. In this case, the rise time shall be  $\leq 1$  sec and the delay time of the combination  $\leq 10$  sec.

The total system response shall be designed as to ensure a representative sample of the particulates,  $q_{mp,i}$ , proportional to the exhaust mass flow. To determine the proportionality, a regression analysis of  $q_{mp,i}$  versus  $q_{mew,i}$  shall be conducted on a minimum 5 Hz data acquisition rate, and the following criteria shall be met:

- The correlation coefficient  $r^2$  of the linear regression between  $q_{mp,i}$  and  $q_{mew,i}$  shall not be less than 0,95
- The standard error of estimate of  $q_{mp,i}$  on  $q_{mew,i}$  shall not exceed 5 % of  $q_{mp}$  maximum.
- $q_{mp}$  intercept of the regression line shall not exceed  $\pm 2$  % of  $q_{mp}$  maximum."

Optionally, a pretest may be run, and the exhaust mass flow signal of the pretest be used for controlling the sample flow into the particulate system ("look-ahead control"). Such a procedure is required if the transformation time of the particulate system,  $t_{50,P}$  or/and the transformation time of the exhaust mass flow signal,  $t_{50,F}$  are  $> 0,3$  sec. A correct control of the partial dilution system is obtained, if the time trace of  $q_{mew,pre}$  of the pretest, which controls  $q_{mp}$ , is shifted by a "look-ahead" time of  $t_{50,P} + t_{50,F}$ .

For establishing the correlation between  $q_{mp,i}$  and  $q_{mew,i}$  the data taken during the actual test shall be used, with  $q_{mew,i}$  time aligned by  $t_{50,F}$  relative to  $q_{mp,i}$  (no contribution from  $t_{50,P}$  to the time alignment). That is, the time shift between  $q_{mew}$  and  $q_{mp}$  is the difference in their transformation times that were determined in 9.6.3

### 8.3.3.4 Data evaluation

The tare weight of the filter, as determined according to clause 7.8.2.2, shall be subtracted from the gross weight of the filter, as determined according to clause 7.8.4.5, which results in the particulate sample mass  $m_f$ . For the evaluation of the particulate concentration, the total sample mass ( $m_{sep}$ ) through the filters over the test cycle shall be recorded.

With the prior approval of the parties involved, the particulate mass may be corrected for the particulate level of the dilution air, as determined in clause 7.8.2.5, in line with good engineering practice and the

specific design features of the particulate measurement system used.

### 8.3.3.5 Calculation of mass emission

The mass of particulates (g/test) shall be calculated by either of the following methods. An example of the calculation procedures is given in Annex 10.6.

a)

$$m_{PM} = \frac{m_f}{m_{sep}} \times \frac{m_{edf}}{1000} \quad (30)$$

where

- $m_f$  = particulate mass sampled over the cycle, mg
- $m_{sep}$  = mass of diluted exhaust gas passing the particulate collection filters, kg
- $m_{edf}$  = mass of equivalent diluted exhaust gas over the cycle, kg

The total mass of equivalent diluted exhaust gas mass over the cycle shall be determined as follows:

$$m_{edf} = \sum_{i=1}^{i=n} q_{medf,i} \times \frac{1}{f} \quad (31)$$

$$q_{medf,i} = q_{mew,i} \times r_{dil,i} \quad (32)$$

$$r_{dil,i} = \frac{q_{mdew,i}}{(q_{mdew,i} - q_{mdw,i})} \quad (33)$$

where

- $q_{medf,i}$  = instantaneous equivalent diluted exhaust mass flow rate, kg/s
- $q_{mew,i}$  = instantaneous exhaust mass flow rate, kg/s
- $r_{dil,i}$  = instantaneous dilution ratio
- $q_{mdew,i}$  = instantaneous diluted exhaust mass flow rate through dilution tunnel, kg/s
- $q_{mdw,i}$  = instantaneous dilution air mass flow rate, kg/s
- $f$  = data sampling rate, Hz
- $n$  = number of measurements

b)

$$m_{PM} = m_f / (r_s \times 1000) \quad (34)$$

where

- $m_f$  = particulate mass sampled over the cycle, mg
- $r_s$  = average sample ratio over the test cycle

with

$$r_s = \frac{m_{se}}{m_{ew}} \times \frac{m_{sep}}{m_{sed}} \quad (35)$$

where

- $m_{se}$  = sample mass over the cycle, kg
- $m_{ew}$  = total exhaust mass flow over the cycle, kg
- $m_{sep}$  = mass of diluted exhaust gas passing the particulate collection filters, kg
- $m_{sed}$  = mass of diluted exhaust gas passing the dilution tunnel, kg

NOTE In case of the total sampling type system,  $m_{sep}$  and  $m_{sed}$  are identical.

### 8.3.3.6 Calculation of the specific emissions

The particulate emission (g/kWh) shall be calculated in the following way.

#### a) for the WHTC as a weighted average from cold start test and hot start test

$$M_{PM} = \frac{(0,1 \times m_{PM,cold}) + (0,9 \times m_{PM,hot})}{(0,1 \times W_{act,cold}) + (0,9 \times W_{act,hot})} \quad (36)$$

where

$m_{PM}$  = particulate mass sampled over the cycle

$W_{act}$  = actual cycle work as determined according to 7.7.1, kWh

**In case of a periodic exhaust aftertreatment system, the hot start emissions shall be weighted as follows:**

$$\overline{M}_{PM} = \frac{(n1 \times \overline{M}_{PM,n1} + n2 \times \overline{M}_{PM,n2})}{(n1 + n2)} \quad (37)$$

where:

**n1** = number of WHTC hot start tests between two regenerations

**n2** = number of WHTC hot start tests during a regeneration (minimum of one WHTC test)

$M_{PM,n2}$  = emissions during a regeneration

$M_{PM,n1}$  = emissions after a regeneration

#### b) for the WHSC

$$M_{PM} = \frac{m_{PM}}{\sum_{i=1}^{i=n} P_i \times W_{fi}} \quad (38)$$

where

$m_{PM}$  is the particulate mass sampled over the cycle

$P_i$  is the measured power of the individual mode

### 8.3.3.7 Effective weighting factor (WHSC only)

For the WHSC, the effective weighting factor  $W_{FEi}$ , for each mode shall be calculated in the following way.

$$W_{fei} = \frac{m_{sepi} \times q_{medf}}{m_{sep} \times q_{medfi}} \quad (39)$$

$i = 1, \dots, n$

The value of the effective weighting factors shall be within  $\pm 0,005$  (absolute value) of the weighting factors listed in 7.3.

## 8.4 Full Flow Dilution Measurement (CVS)

The concentration signals, either by integration over the cycle or by bag sampling, of the gaseous components shall be used for the calculation of the mass emissions by multiplication with the diluted exhaust mass flow rate. The exhaust mass flow rate shall be measured with a constant volume sampling (CVS) system, which may use a positive displacement pump (PDP), a critical flow venturi

(CFV) or a subsonic venturi (SSV).

For particulates, a proportional sample is taken from the diluted exhaust gas of the CVS system.

The complete test set up is schematically shown in figure 4.

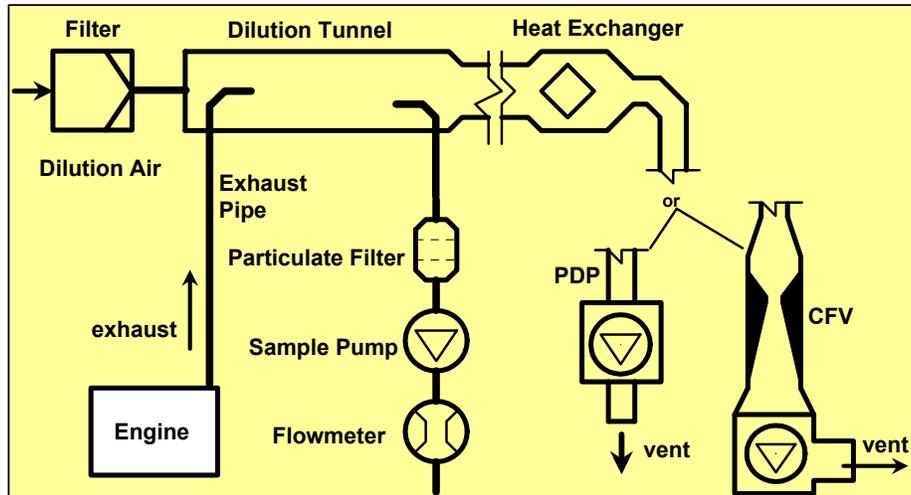


Figure 4 Schematic of CVS full flow dilution system

### 8.4.1 Determination of the diluted exhaust gas flow

#### 8.4.1.1 Introduction

For calculation of the emissions in the diluted exhaust gas, it is necessary to know the diluted exhaust gas mass flow rate. The total diluted exhaust gas flow over the cycle (kg/test) shall be calculated from the measurement values over the cycle and the corresponding calibration data of the flow measurement device ( $V_0$  for PDP,  $K_V$  for CFV,  $C_d, Y$  for SSV) by either of the methods described in 8.4.1.2 to 8.4.1.4 may be used. If the total sample mass of particulates ( $m_{sep}$ ) and gaseous pollutants exceeds 0,5 % of the total CVS flow ( $m_{ed}$ ), the CVS flow shall be corrected for  $m_{sep}$  or the particulate sample flow shall be returned to the CVS prior to the flow measuring device.

#### 8.4.1.2 PDP-CVS system

The calculation of the mass flow over the cycle is as follows, if the temperature of the diluted exhaust is kept within  $\pm 6$  K over the cycle by using a heat exchanger:

$$m_{ed} = 1,293 \cdot V_0 \cdot N_P \cdot (p_B - p_1) \cdot 273 / (101,3 \cdot T) \quad (40)$$

where

$V_0$  = volume of gas pumped per revolution under test conditions,  $m^3/rev$

$N_P$  = total revolutions of pump per test

$p_B$  = atmospheric pressure in the test cell, kPa

$p_1$  = pressure depression below atmospheric at pump inlet, kPa

$T$  = average temperature of the diluted exhaust gas at pump inlet over the cycle, K

If a system with flow compensation is used (i.e. without heat exchanger), the instantaneous mass emissions shall be calculated and integrated over the cycle. In this case, the instantaneous mass of the diluted exhaust gas shall be calculated as follows:

$$m_{ed,i} = 1,293 \cdot V_0 \cdot N_{P,i} \cdot (p_B - p_1) \cdot 273 / (101,3 \cdot T) \quad (41)$$

$N_{P,i}$  = total revolutions of pump per time interval

#### 8.4.1.3 CFV-CVS system

The calculation of the mass flow over the cycle is as follows, if the temperature of the diluted exhaust is

kept within  $\pm 11\text{K}$  over the cycle by using a heat exchanger:

$$m_{ed} = 1,293 * t * K_v * p_A / T^{0,5} \quad (42)$$

where

- t = cycle time, s  
 $K_v$  = calibration coefficient of the critical flow venturi for standard conditions,  
 $p_A$  = absolute pressure at venturi inlet, kPa  
 T = absolute temperature at venturi inlet, K

If a system with flow compensation is used (i.e. without heat exchanger), the instantaneous mass emissions shall be calculated and integrated over the cycle. In this case, the instantaneous mass of the diluted exhaust gas shall be calculated as follows:

$$m_{ed,i} = 1,293 * \Delta t_i * K_v * p_A / T^{0,5} \quad (43)$$

where

- $\Delta t_i$  = time interval, s

#### 8.4.1.4 SSV-CVS system

The calculation of the mass flow over the cycle is as follows, if the temperature of the diluted exhaust is kept within  $\pm 11\text{K}$  over the cycle by using a heat exchanger::

$$m_{ed} = 1,293 * Q_{SSV} \quad (44)$$

where

$$Q_{SSV} = A_0 d^2 C_d p_a \sqrt{\left[ \frac{1}{T} \left( r_x^{1,4286} - r_x^{1,7143} \right) \cdot \left( \frac{1}{1 - r_y^4 r_x^{1,4286}} \right) \right]} \quad (45)$$

with

$A_0$  = collection of constants and units conversions

$$= 0,006111 \text{ in SI units of } \left( \frac{m^3}{\text{min}} \right) \left( \frac{K^{\frac{1}{2}}}{kPa} \right) \left( \frac{1}{mm^2} \right)$$

- d = diameter of the SSV throat, m  
 $C_d$  = discharge coefficient of the SSV  
 $p_A$  = absolute pressure at venturi inlet, kPa  
 T = temperature at the venturi inlet, K

$$r_x = \text{ratio of the SSV throat to inlet absolute static pressure} = 1 - \frac{\Delta p}{p_a}$$

$$r_y = \text{ratio of the SSV throat diameter, } d, \text{ to the inlet pipe inner diameter } D = d/D$$

If a system with flow compensation is used (i.e. without heat exchanger), the instantaneous mass emissions shall be calculated and integrated over the cycle. In this case, the instantaneous mass of the diluted exhaust gas shall be calculated as follows:

$$m_{ed} = 1,293 * Q_{SSV} * \Delta t_i \quad (46)$$

where

$$Q_{SSV} = A_0 d^2 C_d p_a * \sqrt{\left[ \frac{1}{T} \left( r_x^{1,4286} - r_x^{1,7143} \right) \cdot \left( \frac{1}{1 - r_y^4 r_x^{1,4286}} \right) \right]} \quad (47)$$

$\Delta t_i$  = time interval, s

The real time calculation shall be initialized with either a reasonable value for  $C_d$ , such as 0.98, or a reasonable value of  $Q_{SSV}$ . If the calculation is initialized with  $Q_{SSV}$ , the initial value of  $Q_{SSV}$  shall be used to evaluate Re.

During all emissions tests, the Reynolds number at the SSV throat must be in the range of Reynolds numbers used to derive the calibration curve developed in 9.6.4.4.

## 8.4.2 Determination of the gaseous components

### 8.4.2.1 Introduction

The gaseous components emitted by the engine submitted for testing shall be measured by the methods described in 9.5. They shall be determined in the diluted exhaust gas. Data evaluation and calculation procedures are described in 8.4.2.3 and 8.4.2.4.

### 8.4.2.2 Sampling for gaseous emissions

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements of 9.5.3.1. The gaseous emissions sample probe(s) shall be installed in the dilution tunnel at a point where the dilution air and exhaust gas are well mixed, and in close proximity to the particulates sampling probe.

Sampling can generally be done in two ways:

- the pollutants are sampled into a sampling bag over the cycle and measured after completion of the test; for HC, the sample bag must be heated to  $464 \pm 11$  K ( $191 \pm 11$  °C), for NO<sub>x</sub>, the sample bag temperature must be above the dew point temperature;
- the pollutants are sampled continuously and integrated over the cycle.

The background concentrations shall be sampled upstream of the dilution tunnel into a sampling bag, and shall be subtracted from the emissions concentration according to 8.4.2.4.2.

### 8.4.2.3 Data evaluation

For the evaluation of the gaseous emissions, the emission concentrations (HC, CO and NO<sub>x</sub>) and the diluted exhaust gas mass flow rate shall be recorded and stored with at least 1 Hz on a computer system. All other data may be recorded with a sample rate of at least 1 Hz. For analog analyzers the response will be recorded, and the calibration data may be applied online or offline during the data evaluation.

### 8.4.2.4 Calculation of mass emission

#### 8.4.2.4.1 Systems with constant mass flow

For systems with heat exchanger, the mass of the pollutants shall be determined from the following equation:

a) for the WHTC

$$m_{\text{gas}} = u_{\text{gas}} \times c_{\text{gas}} \times m_{\text{ed}} \quad (\text{in g/test}) \quad (48)$$

b) for each mode of the WHSC

$$m_{\text{gas}} = u_{\text{gas}} \times c_{\text{gas}} \times q_{\text{dmew}} \quad (\text{in g/h}) \quad (49)$$

where

- $u_{\text{gas}}$  = ratio between density of exhaust component and density of air
- $c_{\text{gas}}$  = average background corrected concentration of the respective component, ppm
- $m_{\text{ed}}$  = total diluted exhaust mass over the cycle, kg
- $q_{\text{dmew}}$  = diluted exhaust gas mass flow rate, kg/s

For the calculation of NO<sub>x</sub>, the humidity correction factor  $k_{\text{h,D}}$ , or  $k_{\text{h,G}}$ , as applicable, as determined according to 8.2 shall be used.

The measured concentration shall be converted to a wet basis according to 8.1, if not already measured on a wet basis

Values for  $u$  are given in table 5 below for selected components:

**Table 5 — Values of  $u$  in the diluted exhaust gas**

Gas	NO <sub>x</sub>	CO	HC	CO <sub>2</sub>	O <sub>2</sub>	CH <sub>4</sub>		
$\rho_{\text{gas}}$ [kg/m <sup>3</sup> ]	2,053	1,250	a)	1,9636	1,4277	0,716		
<b>FUEL</b>	$\rho_{\text{air}} = 1,293 \text{ kg/m}^3$		<b>Coefficient <math>u_{\text{gas}}</math> b)</b>					
Diesel	0,001588	0,000967	0,000480	0,001519	0,001104	0,000553		
Ethanol	0,001588	0,000967	0,000795	0,001519	0,001104	0,000553		
Natural Gas <sup>c)</sup>	0,001588	0,000967	0,000584 <sup>d)</sup>	0,001519	0,001104	0,000553		
Propane	0,001588	0,000967	0,000507	0,001519	0,001104	0,000553		
Butane	0,001588	0,000967	0,000501	0,001519	0,001104	0,000553		
a) depending on fuel b) at $\lambda = 2$ , dry air, 273 K, 101,3 kPa c) $u$ accurate within 0,2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 % d) NMHC on the basis of CH <sub>2,93</sub> (for total HC the $u_{\text{gas}}$ coefficient of CH <sub>4</sub> shall be used)								

NOTE For calculating the  $u_{\text{gas}}$  values, the density of the diluted exhaust gas has been assumed to be equal to air density. Therefore, the  $u_{\text{gas}}$  values are identical for single gas components, but different for HC.

#### 8.4.2.4.2 Determination of the background corrected concentrations

The average background concentration of the gaseous pollutants in the dilution air shall be subtracted from measured concentrations to get the net concentrations of the pollutants. The average values of the background concentrations can be determined by the sample bag method or by continuous measurement with integration. The following formula shall be used.

$$c = c_e - c_d \times (1 - (1/DF)) \quad (50)$$

where

$c_e$  = concentration of the respective pollutant measured in the diluted exhaust gas, ppm

$c_d$  = concentration of the respective pollutant measured in the dilution air, ppm

$DF$  = dilution factor

The dilution factor shall be calculated as follows:

a) for diesel and LPG fueled gas engines

$$DF = \frac{F_S}{\text{CO}_{2,\text{conce}} + (\text{HC}_{\text{conce}} + \text{CO}_{\text{conce}}) * 10^{-4}} \quad (51)$$

b) for NG fueled gas engines

$$DF = \frac{F_S}{\text{CO}_{2,\text{conce}} + (\text{NMHC}_{\text{conce}} + \text{CO}_{\text{conce}}) * 10^{-4}} \quad (52)$$

where

$\text{CO}_{2,\text{conce}}$  = concentration of CO<sub>2</sub> in the diluted exhaust gas, % vol

$\text{HC}_{\text{conce}}$  = concentration of HC in the diluted exhaust gas, ppm C1

$\text{NMHC}_{\text{conce}}$  = concentration of NMHC in the diluted exhaust gas, ppm C1

$\text{CO}_{\text{conce}}$  = concentration of CO in the diluted exhaust gas, ppm

$F_S$  = stoichiometric factor

Concentrations measured on dry basis shall be converted to a wet basis in accordance with clause

The stoichiometric factor shall be calculated as follows:

$$F_S = 100 * \frac{x}{x + \frac{y}{2} + 3,76 * \left(x + \frac{y}{4}\right)} \quad (53)$$

where

x,y = fuel composition C<sub>x</sub>H<sub>y</sub>

Alternatively, if the fuel composition is not known, the following stoichiometric factors may be used:

$$\begin{aligned} F_S \text{ (diesel)} &= 13,4 \\ F_S \text{ (LPG)} &= 11,6 \\ F_S \text{ (NG)} &= 9,5 \end{aligned}$$

#### 8.4.2.4.3 Systems with Flow Compensation (WHTC only)

For systems without heat exchanger, the mass of the pollutants (g/test) shall be determined by calculating the instantaneous mass emissions and integrating the instantaneous values over the cycle. Also, the background correction shall be applied directly to the instantaneous concentration value. The following formulae shall be applied:

$$m_{\text{gas}} = \sum_{i=1}^n \left[ (m_{\text{ed},i} \times c_e \times u_{\text{gas}}) \right] - \left[ (m_{\text{ed}} \times c_d \times (1 - 1/DF) \times u_{\text{gas}}) \right] \quad (54)$$

where

$c_e$  = concentration of the respective pollutant measured in the diluted exhaust gas, ppm  
 $c_d$  = concentration of the respective pollutant measured in the dilution air, ppm  
 $m_{\text{ed},i}$  = instantaneous mass of the diluted exhaust gas, kg  
 $m_{\text{ed}}$  = total mass of diluted exhaust gas over the cycle, kg  
 $u_{\text{gas}}$  = tabulated value from table 5  
 $DF$  = dilution factor

#### 8.4.2.4.4 Calculation of NMHC and CH<sub>4</sub> with the non-methane cutter

The concentration of NMHC and CH<sub>4</sub> shall be calculated as follows:

$$c_{\text{NMHC}} = \frac{c_{\text{HC(w/oCutter)}} \times (1 - E_M) - c_{\text{HC(w/Cutter)}}}{E_E - E_M} \quad (55)$$

$$c_{\text{CH}_4} = \frac{c_{\text{HC(w/Cutter)}} - c_{\text{HC(w/oCutter)}} \times (1 - E_E)}{E_E - E_M} \quad (56)$$

where:

$c_{\text{HC(w/Cutter)}}$  = HC concentration with the sample gas flowing through the NMC  
 $c_{\text{HC(w/oCutter)}}$  = HC concentration with the sample gas bypassing the NMC  
 $E_M$  = methane efficiency as determined per 9.3.3.11.1  
 $E_E$  = ethane efficiency as determined per 9.3.3.11.2

#### 8.4.2.5 Calculation of the specific emissions

The emissions (g/kWh) shall be calculated for all components in accordance with 8.3.2.6.

### 8.4.3 Particulate determination

#### 8.4.3.1 Introduction

The determination of the particulates requires a dilution system. In this clause, dilution shall be accomplished by 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 between 315 K (42°C) and 325 K (52°C) immediately upstream of the filter holders. Dehumidifying the dilution air before entering the dilution system is permitted, and especially useful if dilution air humidity is high. The temperature of the dilution air shall be higher than 288 K (15°C) in close proximity to the entrance into the dilution tunnel.

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. The details of the system are described in 9.4.

#### 8.4.3.2 Particulate sampling

The particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, but sufficiently distant as to not cause interference, in the dilution tunnel. Therefore, the installation provisions of clause 8.3.2.2 also apply to particulate sampling. The sampling line shall conform to the requirements of 9.5.3.1.

#### 8.4.3.3 Calculation of mass emission

The particulate mass (g/test) shall be calculated as follows:

$$m_{PM} = \frac{m_f}{m_{sep}} \times \frac{m_{ed}}{1000} \quad (57)$$

where

- $m_f$  = particulate mass sampled over the cycle, mg
- $m_{sep}$  = mass of diluted exhaust gas passing the particulate collection filters, kg
- $m_{ed}$  = mass of diluted exhaust gas over the cycle, kg

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

$$m_{sep} = m_{set} - m_{ssd} \quad (58)$$

where

- $m_{set}$  = mass of double diluted exhaust gas through particulate filter, kg
- $m_{ssd}$  = mass of secondary dilution air, kg

If the particulate background level of the dilution air is determined in accordance with clause 7.8.2.5, the particulate mass may be background corrected. In this case, the particulate mass (g/test) shall be calculated as follows:

$$m_{PM} = \left[ \frac{m_f}{m_{sep}} - \left( \frac{m_b}{m_{sd}} \times \left( 1 - \frac{1}{DF} \right) \right) \right] \times \frac{m_{ed}}{1000} \quad (59)$$

where

- $m_{PM}$ ,  $m_{sep}$ ,  $m_{ed}$  = see above
- $m_{sd}$  = mass of primary dilution air sampled by background particulate sampler, kg
- $m_b$  = mass of the collected background particulates of the primary dilution air, mg
- $DF$  = dilution factor as determined in 8.4.2.4.2

#### 8.4.3.4 Calculation of the specific emissions

The particulate emission (g/kWh) shall be calculated in accordance with 8.3.3.6.

#### 8.4.3.5 Effective weighting factor (WHSC only)

For the WHSC, the effective weighting factor  $W_{FEI}$ , for each mode shall be calculated according to 8.3.3.7.

## 9 Measurement Equipment

### 9.1 Dynamometer specification

An engine dynamometer with adequate characteristics to perform the appropriate test cycle described in 7.2 and 7.3 shall be used.

The instrumentation for torque and speed measurement shall allow the measurement accuracy 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 9.2 are not exceeded.

## 9.2 Accuracy

The equipment described in this regulation shall be used for emissions tests of engines. This regulation does not contain details of flow, pressure, and temperature measuring equipment. Instead, only the accuracy requirements of such equipment necessary for conducting an emissions test are given in this paragraph. The instruments shall be calibrated as required by internal audit procedures, by the instrument manufacturer or in accordance with ISO 9000 requirements.

The calibration of all measuring instruments shall be traceable to national (international) standards and comply with the **linearity requirements** given in table 6:

**Table 6 — Linearity requirements of instruments**

No	Measurement system	Intercept b	Slope m	Standard error SEE	Coefficient of determination $r^2$
1	Engine speed	≤0.05 % max	0.98-1.02	≤2 % max	≥0.990
2	Torque	≤1 % max	0.98-1.02	≤2 % max	≥0.990
3	Fuel consumption	≤1 % max	0.98-1.02	≤2 % max	≥0.990
4	Air consumption	≤1 % max	0.98-1.02	≤2 % max	≥0.990
5	Exhaust gas flow	≤1 % max	0.98-1.02	≤2 % max	≥0.990
6	Dilution air flow	≤1 % max	0.98-1.02	≤2 % max	≥0.990
7	Diluted exhaust gas flow	≤1 % max	0.99-1.01	≤1 % max	≥0.990
8	Constituent concentrations (all gas analyzers)	≤0,5 % max	0.98-1.02	≤2 % max	≥0.998
9	Temperatures	≤1 % max	0.98-1.02	≤ 1 % max	≥0.998
10	Pressures	≤1 % max	0.99-1.01	≤ 1 % max	≥0.998
11	PM balance	≤1 % max	0.99-1.01	≤ 1 % max	≥0.998
12					

## 9.3 Gaseous Emissions Measurement and Sampling System

### 9.3.1 Analyzer specifications

#### 9.3.1.1 general

The analyzers shall have a measuring range and response time appropriate for the accuracy required to measure the concentrations of the exhaust gas components under transient and steady state conditions. The analyzer range shall be selected such that the average concentration measured over the test cycle falls between 15 % and 100 % of full scale, except the accuracy of the analyzer does not exceed ± 2 % of reading for the average concentration.

If read-out systems (computers, data loggers) can provide sufficient accuracy and resolution below 15 % of full scale, measurements below 15 % of full scale are also acceptable. In this case, additional calibrations of at least 4 non-zero nominally equally spaced points are to be made to ensure the accuracy of the calibration curves according to clause 9.3.3.6.3.

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

#### **9.3.1.2 Accuracy**

The analyzer shall not deviate from the nominal calibration point by more than  $\pm 2\%$  of the reading or  $\pm 0,3\%$  of full scale whichever is larger. The accuracy shall be determined according to the calibration requirements laid down in clause 9.3.3.6.

NOTE For the purpose of this standard, accuracy is defined as the deviation of the analyzer reading from the nominal calibration values using a calibration gas ( $\equiv$  true value)

#### **9.3.1.3 Precision**

The precision, defined as 2,5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, has to be not greater than  $1\%$  of full scale concentration for each range used above 155 ppm (or ppmC) or  $2\%$  of each range used below 155 ppm (or ppmC).

#### **9.3.1.4 Noise**

The analyzer peak-to-peak response to zero and calibration or span gases over any 10 seconds period shall not exceed  $2\%$  of full scale on all ranges used.

#### **9.3.1.5 Zero drift**

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

#### **9.3.1.6 Span drift**

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

#### **9.3.1.7 Rise time**

The rise time of the analyzer installed in the measurement system shall not exceed 2,5 s.

NOTE Only evaluating the response time of the analyzer alone will not clearly define the suitability of the total system for transient testing. Volumes and especially dead volumes through out the system will not only effect the transportation time from the probe to the analyzer, but also effect the rise time. Also transport times inside of an analyzer would be defined as analyzer response time, like the converter or water traps inside of a NOx analyzers. The determination of the total system response time is described in clause 9.3.3.5.

#### **9.3.1.8 Gas drying**

Exhaust gases may be measured wet or dry. A gas drying device, if used, shall have a minimal effect on the composition of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

### **9.3.2 Analyzers**

#### **9.3.2.1 Introduction**

9.3.2.2 to 9.2.3.7 describe the measurement principles to be used. A detailed description of the measurement systems is given in 9.3.4. The gases to be measured shall be analyzed with the following instruments. For non-linear analyzers, the use of linearizing circuits is permitted.

#### **9.3.2.2 Carbon monoxide (CO) analysis**

The carbon monoxide analyzer shall be of the non-dispersive infrared (NDIR) absorption type.

#### **9.3.2.3 Carbon dioxide (CO<sub>2</sub>) analysis**

The carbon dioxide analyzer shall be of the non-dispersive infrared (NDIR) absorption type.

#### **9.3.2.4 Hydrocarbon (HC) analysis**

The hydrocarbon analyzer shall be of the heated flame ionization detector (HFID) type with detector, valves, pipework, etc. heated so as to maintain a gas temperature of  $463\text{K} \pm 10\text{K}$  ( $190 \pm 10^\circ\text{C}$ ). Optionally, for NG fueled and SI engines, the hydrocarbon analyzer may be of the non heated flame ionization detector (FID) type depending upon the method used (see 9.3.4.3).

### 9.3.2.5 Non-methane hydrocarbon (NMHC) analysis

The determination of the non-methane hydrocarbon fraction shall be performed with a heated non-methane cutter (NMC) operated in line with an FID as per 9.3.4.4 by subtraction of the methane from the hydrocarbons.

### 9.3.2.6 Oxides of nitrogen (NO<sub>x</sub>) analysis

If measured on a dry basis, the oxides of nitrogen analyzer shall be of the chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD) type with a NO<sub>2</sub>/NO converter. If measured on a wet basis, a HCLD with converter maintained above 328 K (55°C) shall be used, provided the water quench check (see 9.3.3.12) is satisfied. For both CLD and HCLD, the sampling path shall be maintained at a wall temperature of 328 K to 473 K (55°C to 200°C) up to the converter for dry measurement, and up to the analyzer for wet measurement.

### 9.3.2.7 Air to fuel measurement

The air to fuel measurement equipment used to determine the exhaust gas flow as specified in 8.3.1.6 shall be a wide range air to fuel ratio sensor or lambda sensor of Zirconia type.

The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.

The accuracy of the sensor with incorporated electronics shall be within:

± 3 % of reading	$\lambda < 2$
± 5 % of reading	$2 \leq \lambda < 5$
± 10 % of reading	$5 \leq \lambda$

To fulfill the accuracy specified above, the sensor shall be calibrated as specified by the instrument manufacturer.

## 9.3.3 Calibration

### 9.3.3.1 Introduction

Each analyzer shall be calibrated as often as necessary to fulfill the accuracy requirements of this Regulation. The calibration method that shall be used is described in this paragraph for the analyzers indicated in 9.3.2 and 9.3.4.

### 9.3.3.2 Calibration gases

The shelf life of all calibration gases shall be respected. The expiration date of the calibration gases stated by the manufacturer shall be recorded.

#### 9.3.3.2.1 Pure gases

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

Purified nitrogen  
(Contamination  $\leq 1$  ppm C1,  $\leq 1$  ppm CO,  $\leq 400$  ppm CO<sub>2</sub>,  $\leq 0,1$  ppm NO)

Purified oxygen  
(Purity  $> 99.5$  % vol O<sub>2</sub>)

Hydrogen-helium mixture  
( $40 \pm 2\%$  hydrogen, balance helium)  
(Contamination  $\leq 1$  ppm C1,  $\leq 400$  ppm CO<sub>2</sub>)

Purified synthetic air  
(Contamination  $\leq 1$  ppm C1,  $\leq 1$  ppm CO,  $\leq 400$  ppm CO<sub>2</sub>,  $\leq 0,1$  ppm NO)  
(Oxygen content between 18-21 % vol.)

#### 9.3.3.2.2 Calibration and span gases

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

C<sub>3</sub>H<sub>8</sub> and purified synthetic air (see 9.3.3.2.1);

CO and purified nitrogen;

NO<sub>x</sub> and purified nitrogen (the amount of NO<sub>2</sub> contained in this calibration gas shall not exceed 5 % of the NO content);

CO<sub>2</sub> and purified nitrogen

CH<sub>4</sub> and purified synthetic air

C<sub>2</sub>H<sub>6</sub> 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 shall be within  $\pm 1\%$  of the nominal value, and shall be traceable to national and international standards. All concentrations of calibration gas shall be given on a volume basis (volume percent or volume ppm).

#### 9.3.3.2.3 Use of precision blending devices

The gases used for calibration and span may also be obtained by means of precision blending devices (gas dividers), diluting with purified N<sub>2</sub> or with purified synthetic air. The accuracy of the mixing device shall be such that the concentration of the blended calibration gases is accurate to within  $\pm 2\%$ . This accuracy implies that primary gases used for blending shall be known to an accuracy of at least  $\pm 1\%$ , traceable to national or international gas standards. The verification shall be performed at between 15 and 50 % of full scale for each calibration incorporating a blending device. An additional verification may be performed using another calibration gas, if the first verification has failed.

Optionally, the blending device may be checked with an instrument which by nature is linear, e.g. using NO gas with a CLD. The span value of the instrument shall be adjusted with the span gas directly connected to the instrument. The blending device shall be checked at the used settings and the nominal value shall be compared to the measured concentration of the instrument. This difference shall in each point be within  $\pm 1\%$  of the nominal value.

Other methods may be used based on good engineering practice and with the prior agreement of the parties involved.

NOTE The precision gas divider whose accuracy is within  $\pm 1\%$ , is recommended to establish the accurate analyzer calibration curve. The gas divider shall be calibrated by the instrument manufacture in accordance with ISO 9000 requirements.

#### 9.3.3.2.4 Oxygen interference check gases

Oxygen interference check gases are a blend of propane, oxygen and nitrogen. They shall contain propane with 350 ppmC  $\pm$  75 ppmC hydrocarbon. The concentration value shall be determined to calibration gas tolerances by chromatographic analysis of total hydrocarbons plus impurities or by dynamic blending. The oxygen concentrations required for gasoline and diesel engine testing are listed in table 7 with the remainder being purified nitrogen:

**Table 7 — Oxygen interference check gases**

Type of engine	O <sub>2</sub> concentration [%]
Diesel	21 (20 to 22)
Diesel and gasoline	10 (9 to 11)
Diesel and gasoline	5 (4 to 6)
Gasoline	0 (0 to 1)

#### 9.3.3.3 Operating procedure

The operating procedure for analyzers shall follow the start-up and operating instructions of the instrument manufacturer. The minimum requirements given in clauses 9.3.3.4 to 9.3.3.9 shall be included.

#### 9.3.3.4 Leakage test

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

The maximum allowable leakage rate on the vacuum side shall be 0,5% of the in-use flow rate for the portion of the system being checked. The analyzer flows and bypass flows may be used to estimate the in-use flow rates.

Alternatively, the system may be evacuated to a pressure of at least 20 kPa vacuum (80 kPa absolute). After an initial stabilisation period the pressure increase  $\Delta p$  (kPa/min) in the system should not exceed:

$$\Delta p = p / V_s \times 0,005 \times q_{v,s} \quad (60)$$

where:

$V_s$  = system volume, l

$q_{v,s}$  = system flow rate, l/min

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 is about 1 % low compared to the introduced concentration, this points to calibration or leakage problems.

### 9.3.3.5 Response time check of the analytical system

The system settings for the response time evaluation shall be exactly the same as during measurement of the test run (i.e. pressure, flow rates, filter settings on the analyzers and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0,1 second. The gases used for the test shall cause a concentration change of at least 60% FS.

The concentration trace of each single gas component shall be recorded. The response time is defined to be the difference in time between the gas switching and the appropriate change of the recorded concentration. The system response time ( $t_{90}$ ) consists of the delay time to the measuring detector and the rise time of the detector. The delay time is defined as the time from the change ( $t_0$ ) until the response is 10% of the final reading ( $t_{10}$ ). The rise time is defined as the time between 10% and 90% response of the final reading ( $t_{90} - t_{10}$ ).

For time alignment of the analyzer and exhaust flow signals, the transformation time is defined as the time from the change ( $t_0$ ) until the response is 50% of the final reading ( $t_{50}$ ).

The system response time shall be  $\leq 10$  seconds with a rise time  $\leq 2,5$  seconds in accordance with 9.3.1.7 for all limited components (CO, NO<sub>x</sub>, HC or NMHC) and all ranges used.

### 9.3.3.6 Calibration procedure

#### 9.3.3.6.1 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.

#### 9.3.3.6.2 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 analyzers.

#### 9.3.3.6.3 Establishment of the calibration curve

- a) Each normally used operating range shall be calibrated.
- b) Using purified synthetic air (or nitrogen), the CO, CO<sub>2</sub>, NO<sub>x</sub> and HC analyzers shall be set at zero.
- c) The appropriate calibration gases shall be introduced to the analyzers, the values recorded, and the calibration curve established.
- d) The calibration curve shall be established by at least 6 calibration points (excluding zero) approximately equally spaced over the operating range. The highest nominal concentration shall be equal to or higher than 90 % of full scale.
- e) The calibration curve shall be calculated by the method of least-squares. A best-fit linear or non-linear equation may be used.
- f) **The linearity of the calibration curve shall meet the requirements of paragraph 9.2, table 6.**
- g) The zero setting shall be rechecked and the calibration procedure repeated, if necessary.

#### 9.3.3.6.4 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.

### 9.3.3.7 Verification of the calibration curve

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

The calibration shall be 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  $\pm 4$  % of full scale from the declared reference value, the adjustment parameters may be modified. Should this not be the case, the span gas shall be verified or a new calibration curve shall be established in accordance with 9.3.3.6.3.

### 9.3.3.8 Calibration of tracer gas analyzer for exhaust flow measurement

The analyzer for measurement of the tracer gas concentration shall be calibrated using the standard gas.

The calibration curve shall be established by at least 10 calibration points (excluding zero) spaced so that a half of the calibration points are placed between 4% to 20% of analyzer's full scale and the rest are in between 20% to 100% of the full scale. The calibration curve is calculated by the method of least squares.

The calibration curve shall not differ by more than  $\pm 1$ % of the full scale from the nominal value of each calibration point, in the range from 20% to 100% of the full scale. It also shall not differ by more than  $\pm 2$ % of reading from the nominal value in the range from 4% to 20% of the full scale.

The analyzer shall be set at zero and spanned prior to the test run using a zero gas and a span gas whose nominal value is more than 80% of the analyzer full scale.

### 9.3.3.9 Efficiency test of NO<sub>x</sub> converter

The efficiency of the converter used for the conversion of NO<sub>2</sub> into NO is tested as given in 9.3.3.9.1 to 9.3.3.9.8 (see figure 5).

#### 9.3.3.9.1 Test setup

Using the test setup as schematically shown in figure 5 and the procedure below, the efficiency of converters shall be tested by means of an ozonator.

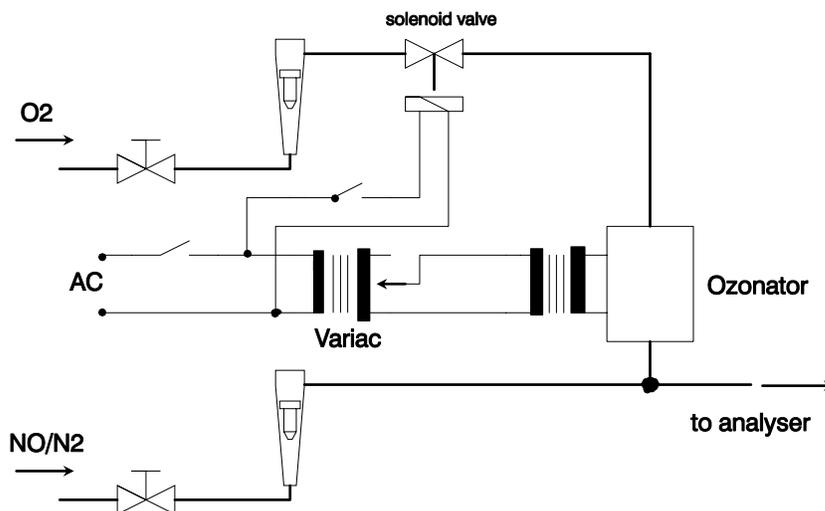


Figure 5 – Schematic of NO<sub>2</sub> converter efficiency device

#### 9.3.3.9.2 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 shall amount to about 80 % of the operating range and the NO<sub>2</sub> concentration of the gas mixture to less than 5 % of the NO concentration). The NO<sub>x</sub> analyzer shall be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

**9.3.3.9.3 Calculation**

The % efficiency of the NO<sub>x</sub> converter is calculated as follows:

$$E_{\text{NO}_x} = \left( 1 + \frac{a-b}{c-d} \right) \times 100 \quad (61)$$

where

*a* is the NO<sub>x</sub> concentration according to 9.3.3.9.6;

*b* is the NO<sub>x</sub> concentration according to 9.3.3.9.7;

*c* is the NO concentration according to 9.3.3.9.4;

*d* is the NO concentration according to 9.3.3.9.5;

**9.3.3.9.4 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 9.3.3.9.2. (The analyzer is in the NO mode).

The indicated concentration (*c*) shall be recorded. The ozonator is kept deactivated throughout the process.

**9.3.3.9.5 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 9.3.3.9.2. The indicated concentration (*d*) shall be recorded (The analyzer is in the NO mode).

**9.3.3.9.6 NO<sub>x</sub> mode**

The NO analyzer is then switched to the NO<sub>x</sub> mode so that the gas mixture (consisting of NO, NO<sub>2</sub>, O<sub>2</sub> and N<sub>2</sub>) now passes through the converter. The indicated concentration (*a*) shall be recorded. (The analyzer is in the NO<sub>x</sub> mode).

**9.3.3.9.7 Deactivation of the ozonator**

The ozonator is now deactivated. The mixture of gases described in 9.3.3.9.6 passes through the converter into the detector. The indicated concentration (*b*) shall be recorded. (The analyzer is in the NO<sub>x</sub> mode).

**9.3.3.9.8 NO mode**

Switched to NO mode with the ozonator deactivated, the flow of oxygen or synthetic air is also shut off. The NO<sub>x</sub> reading of the analyzer shall not deviate by more than ± 5 % from the value measured according to 9.3.3.9.2. (The analyzer is in the NO mode).

**9.3.3.9.9 Test interval**

The efficiency of the converter shall be tested prior to each calibration of the NO<sub>x</sub> analyzer.

**9.3.3.9.10 Efficiency requirement**

The efficiency of the converter  $E_{\text{NO}_x}$  shall not be less than 90 %, but a higher efficiency of 95 % is strongly recommended.

If, with the analyzer in the most common range, the ozonator cannot give a reduction from 80 % to 20 % according to 9.3.3.9.5, then the highest range which will give the reduction shall be used.

**9.3.3.10 Adjustment of the FID****9.3.3.10.1 Optimization of the detector response**

The FID shall 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 ppmC span gas shall be introduced to the analyzer. 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. This is the initial flow rate setting which may need further optimization depending on the results of the hydrocarbon response factors and the oxygen interference check according to clauses 9.3.3.10.2 and 9.3.3.10.3.

If the oxygen interference or the hydrocarbon response factors do not meet the following specifications, the air flow shall be incrementally adjusted above and below the manufacturer's specifications, repeating clause 9.3.3.10.2 and clause 9.3.3.10.3 for each flow.

The optimization may optionally be conducted using the procedures outlined in SAE paper n° 770141.

#### **9.3.3.10.2 Hydrocarbon response factors**

The analyzer shall be calibrated using propane in air and purified synthetic air, according to clause 9.3.3.6.

Response factors shall be determined when introducing an analyzer into service and after major service intervals. The response factor ( $r_h$ ) for a particular hydrocarbon species is the ratio of the FID C1 reading to the gas concentration in the cylinder expressed by ppmC1.

The concentration of the test gas shall be at a level to give a response of approximately 80 % of full scale. The concentration shall be known to an accuracy of  $\pm 2$  % in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder shall be preconditioned for 24 hours at a temperature of  $298 \text{ K} \pm 5 \text{ K}$  ( $25 \text{ }^\circ\text{C} \pm 5 \text{ }^\circ\text{C}$ ).

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

- Methane and purified synthetic air  $1,00 \leq r_h \leq 1,15$
- Propylene and purified synthetic air  $0,90 \leq r_h \leq 1,1$
- Toluene and purified synthetic air  $0,90 \leq r_h \leq 1,1$

These values are relative to a  $r_h$  of 1 for propane and purified synthetic air.

#### **9.3.3.10.3 Oxygen interference check**

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

NOTE The oxygen interference check need only be conducted if the measurement is done in the raw exhaust gas.

A range shall be chosen where the oxygen interference check gases (see 9.3.3.2.4) will fall in the upper 50 %. The test shall be conducted with the oven temperature set as required. Oxygen interference check gas specifications are found in 9.3.3.2.4.

- a) The analyzer shall be set at zero.
- b) The analyzer shall be spanned with the 0 % oxygen blend for gasoline-fueled engines. Diesel engine instruments shall be spanned with the 21 % oxygen blend.
- c) The zero response shall be rechecked. If it has changed by more than 0,5 % of full scale, steps a) and b) of this clause shall be repeated.
- d) The 5 % and 10 % oxygen interference check gases shall be introduced.
- e) The zero response shall be rechecked. If it has changed by more than  $\pm 1$  % of full scale, the test shall be repeated.
- f) The oxygen interference ( $\%O_2I$ ) shall be calculated for each mixture in step d) as follows:

$$\%O_2I = (B - \text{Analyzer Response}) \times 100 / B \quad (62)$$

$$\text{Analyzer response} = (A / \% \text{ FS at A}) \times (\% \text{ FS at B}) \quad (63)$$

where

$A$  = hydrocarbon concentration the span gas used in step b), ppmC

$B$  = hydrocarbon concentration of the oxygen interference check gases used in step d), ppm C

g) The oxygen interference ( $\%O_2I$ ) shall be less than  $\pm 3.0 \%$  for all required oxygen interference check gases prior to testing.

h) If the oxygen interference is greater than  $\pm 3.0 \%$ , the air flow above and below the manufacturer's specifications shall be incrementally adjusted, repeating 9.3.3.10.1 for each flow.

l) If the oxygen interference is greater than  $\pm 3.0 \%$  after adjusting the air flow, the fuel flow and thereafter the sample flow shall be varied, repeating 9.3.3.10.1 for each new setting.

k) If the oxygen interference is still greater than  $\pm 3.0 \%$ , the analyzer, FID fuel, or burner air shall be repaired or replaced prior to testing. This clause shall then be repeated with the repaired or replaced equipment or gases.

#### 9.3.3.10.4 Methanol response factor

When the FID analyzer is to be used for the analysis of hydrocarbons containing methanol, the methanol response factor ( $r_m$ ) of the analyzer shall be established.

A known volume of methanol ( $a$  in millilitres) is injected, using a microlitre syringe, into the heated mixing zone (395 K (122°C)) of a septum injector, vaporized and swept into a tedlar bag with a known volume of zero-grade air ( $b$  in  $m^3$ ). The air volume(s) shall be such that the methanol concentration in the bag is representative of the range of concentrations found in the exhaust sample.

The bag sample is analyzed using the FID, and the response factor  $r_m$  is calculated as follows:

$$r_m = \frac{FID}{SAM} \quad (64)$$

where

$FID$  = FID reading, ppmC

$SAM$  = Methanol concentration in the sample bag, as calculated from  $a$  and  $b$ :  $SAM = 594 \times a/b$ , ppmC

#### 9.3.3.11 Efficiency of the Non-Methane Cutter (NMC)

The NMC is used for the removal of the non-methane hydrocarbons from the sample gas by oxidizing all hydrocarbons except methane. Ideally, the conversion for methane is 0 %, and for the other hydrocarbons represented by ethane is 100 %. For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emission mass flow rate (see 8.3.2.5).

##### 9.3.3.11.1 Methane Efficiency

Methane calibration gas shall be flown through the FID with and without bypassing the NMC and the two concentrations recorded. The efficiency shall be determined as follows:

$$E_M = 1 - \frac{c_{HC(w/cutter)}}{c_{HC(w/o\ cutter)}} \quad (65)$$

where

$c_{HC(w/cutter)}$  = HC concentration with  $CH_4$  flowing through the NMC, ppmC

$c_{HC(w/o\ cutter)}$  = HC concentration with  $CH_4$  bypassing the NMC, ppmC

##### 9.3.3.11.2 Ethane Efficiency

Ethane calibration gas shall be flown through the FID with and without bypassing the NMC and the two concentrations recorded. The efficiency shall be determined as follows:

$$E_E = 1 - \frac{c_{HC(w/cutter)}}{c_{HC(w/o\ cutter)}} \quad (66)$$

where

$c_{HC(w/cutter)}$  = HC concentration with  $C_2H_6$  flowing through the NMC, ppmC

$c_{HC(w/o\ cutter)}$  = HC concentration with  $C_2H_6$  bypassing the NMC, ppmC

### 9.3.3.12 Interference effects

Other gases than the one being analyzed can interfere with the reading in several ways. Positive interference occurs in NDIR and PMD 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 reaction. The interference checks in 9.3.3.12.1 and 9.3.3.12.2 shall be performed prior to an analyzer's initial use and after major service intervals.

#### 9.3.3.12.1 CO analyzer interference check

Water and CO<sub>2</sub> can interfere with the CO analyzer performance. Therefore, a CO<sub>2</sub> 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 analyzer response recorded. The analyzer response shall 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.

#### 9.3.3.12.2 NO<sub>x</sub> analyzer quench checks

The two gases of concern for CLD (and HCLD) analyzers are CO<sub>2</sub> and water vapor. Quench responses to these gases are proportional to their concentrations, and therefore require test techniques to determine the quench at the highest expected concentrations experienced during testing.

##### 9.3.3.12.2.1 CO<sub>2</sub> quench check

A CO<sub>2</sub> span gas having a concentration of 80 to 100 % of full scale of the maximum operating range shall be passed through the NDIR analyzer and the CO<sub>2</sub> value recorded as *A*. It shall then be diluted approximately 50 % with NO span gas and passed through the NDIR and CLD, with the CO<sub>2</sub> and NO values recorded as *B* and *C*, respectively. The CO<sub>2</sub> shall then 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:

$$E_{\text{CO}_2} = \left[ 1 - \left( \frac{C \times A}{(D \times A) - (D \times B)} \right) \right] \times 100 \quad (67)$$

where

- A* = undiluted CO<sub>2</sub> concentration measured with NDIR, %
- B* = diluted CO<sub>2</sub> concentration measured with NDIR, %
- C* = diluted NO concentration measured with (H)CLD, ppm
- D* = undiluted NO concentration measured with (H)CLD, ppm

Alternative methods of diluting and quantifying of CO<sub>2</sub> and NO span gas values such as dynamic mixing/blending, can be used.

##### 9.3.3.12.2.2 Water quench check

This check applies to wet gas concentration measurements only. Calculation of water quench shall consider dilution of the NO span gas with water vapor and scaling of water vapor concentration of the mixture to that expected during testing.

A NO span gas having a concentration of 80 % to 100 % of full scale of the normal operating range shall be passed through the (H)CLD and the NO value recorded as *D*. The NO span gas shall then be bubbled through water at room temperature and passed through the (H)CLD and the NO value recorded as *C*. The water temperature shall be determined and recorded as *F*. The mixture's saturation vapor pressure that corresponds to the bubbler water temperature (*F*) shall be determined and recorded as *G*. The water vapor concentration (in %) of the mixture shall be calculated as follows:

$$H = 100 \times (G / p_b) \quad (68)$$

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

$$D_e = D \times (1 - H / 100) \quad (69)$$

and recorded as *D<sub>e</sub>*. For diesel exhaust, the maximum exhaust water vapor concentration (in %) expected during testing shall be estimated, under the assumption of a fuel H/C ratio of 1,8/1, from the maximum CO<sub>2</sub> concentration in the exhaust gas *A* as follows:

$$H_m = 0,9 \times A \quad (70)$$

and recorded as  $H_m$ .

The % water quench shall be calculated as follows:

$$E_{H_2O} = 100 \times ((D_e - C) / D_e) \times (H_m / H) \quad (71)$$

where

$D_e$  = expected diluted NO concentration, ppm  
 $C$  = measured diluted NO concentration, ppm  
 $H_m$  = maximum water vapour concentration, %  
 $H$  = actual water vapour concentration, %

NOTE It is important that the NO span gas contains minimal NO<sub>2</sub> concentration for this check, since absorption of NO<sub>2</sub> in water has not been accounted for in the quench calculations.

#### 9.3.3.12.2.3 *Maximum allowable quench*

The quench shall not be greater than:

- For all dry CLD analysers it must be demonstrated that for the highest expected water vapor concentration (i. e. "%H<sub>2</sub>Oexp" as calculated later in this paragraph), the water removal technique maintains CLD humidity at less or equal to 5 gwater/kgdry air (or about 0.008 percent H<sub>2</sub>O), which is 100 % RH at 3.9 °C and 101.3 kPa. This humidity specification is also equivalent to about 25 % RH at 25 °C and 101.3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD. Humidity of the CLD exhaust might also be measured as long as the only flow into the CLD is the flow of the dehumidifier.
- For raw measurement, CO<sub>2</sub>-quench according to 9.3.3.12.2.1: 2 % of full scale
- For raw measurement, water quench according to 9.3.3.12.2.2: 3 % of full scale
- For dilute measurement: 2 % combined CO<sub>2</sub> and water quench

#### 9.3.3.13 **Calibration intervals**

The analyzers shall be calibrated according to clause 9.3.3.6 at least every 3 months or whenever a system repair or change is made that could influence calibration.

### 9.3.4 **Analytical system**

#### 9.3.4.1 **Introduction**

Clause 9.3.4.2 and figures 6 and 7 contain general descriptions of the recommended sampling and analyzing systems. Since various configurations can produce equivalent results, exact conformance with figure 6 is not required. Components such as instruments, valves, solenoids, pumps, flow devices and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

#### 9.3.4.2 **Description of the analytical system**

Analytical system for the determination of the gaseous emissions in the raw exhaust gas (figure 6) or in the diluted exhaust gas (figure 7) are described based on the use of:

- HFID or FID analyzer for the measurement of hydrocarbons;
- NDIR analyzers for the measurement of carbon monoxide and carbon dioxide;
- HCLD or CLD analyzer for the measurement of the oxides of nitrogen;

The sample for all components should be taken with one sampling probe and internally split to the different analyzers. Optionally, two sampling probes located in close proximity may be used. Care must be taken that no unintended condensation of exhaust components (including water and sulfuric acid) occurs at any point of the analytical system.

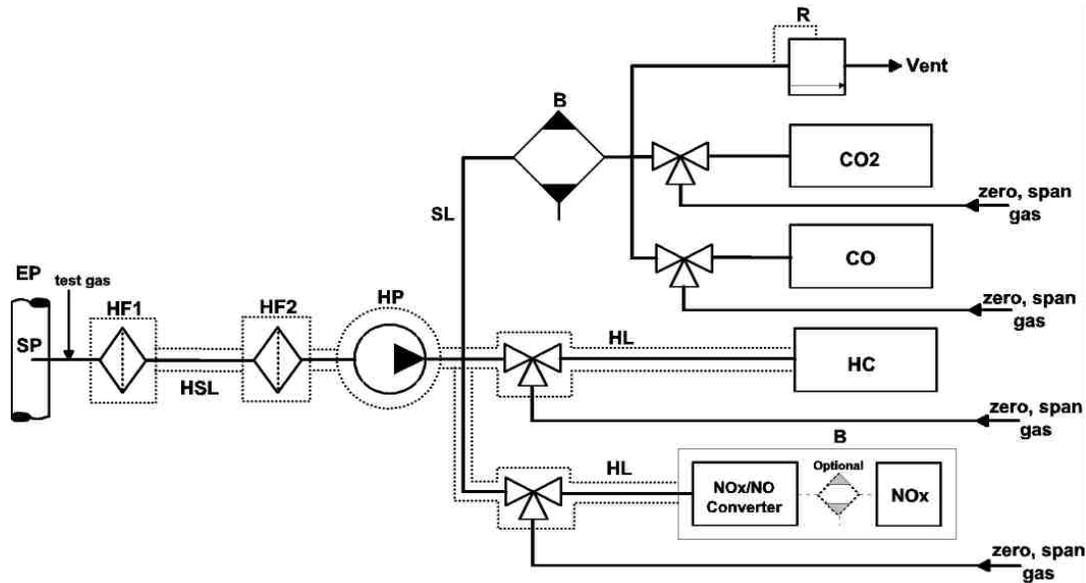
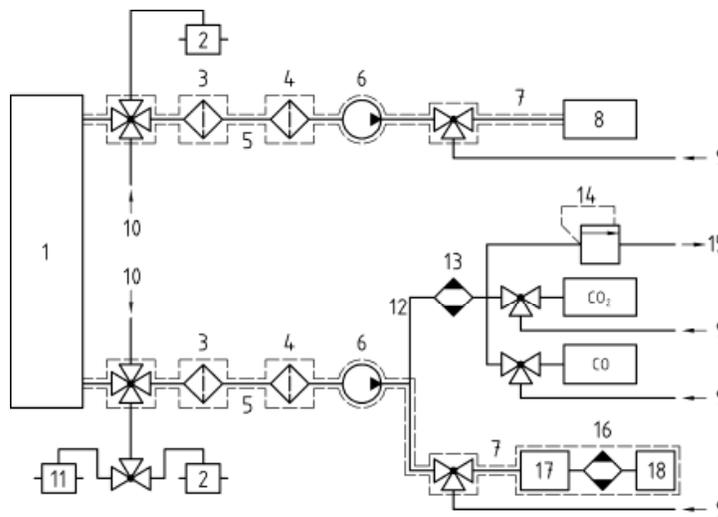


Figure 6 — Schematic flow diagram of raw exhaust gas analysis system for CO, CO<sub>2</sub>, NO<sub>x</sub>, HC



- |       |       |                  |             |         |                                  |
|-------|-------|------------------|-------------|---------|----------------------------------|
| 1 DT  | 4 HF2 | 7 HL             | 10 test gas | 13 B    | 16 B                             |
| 2 BK  | 5 HSL | 8 HC             | 11 BG       | 14 R    | 17 NO <sub>x</sub> /NO Converter |
| 3 HF1 | 6 HP  | 9 zero, span gas | 12 SL       | 15 vent | 18 NO <sub>x</sub>               |

Figure 7 — Schematic flow diagram of diluted exhaust gas analysis system for CO, CO<sub>2</sub>, NO<sub>x</sub>, HC

### **9.3.4.3 Components of figures 6 and 7**

#### **EP Exhaust pipe**

#### **SP Raw exhaust gas sampling probe (figure 6 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 3 holes in 3 different radial planes sized to sample approximately the same flow. The probe shall extend across at least 80 % of the diameter of the exhaust pipe. One or two sampling probes may be used.

#### **SP2 Dilute exhaust gas HC sampling probe (figure 7 only)**

The probe shall:

— be defined as the first 254 mm to 762 mm of the heated sampling line HSL1;

— have a 5 mm minimum inside diameter;

— be installed in the dilution tunnel DT (see 9.5.3, figure 20) 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  $463\text{ K} \pm 10\text{ K}$  ( $190\text{ °C} \pm 10\text{ °C}$ ) at the exit of the probe, or to  $385\text{ K} \pm 10\text{ K}$  ( $112\text{ °C} \pm 10\text{ °C}$ ) for methanol-fuelled engines;

— non-heated in case of FID measurement (cold).

#### **SP3 Dilute exhaust gas CO, CO<sub>2</sub>, NO<sub>x</sub> sampling probe (figure 7 only)**

The probe shall:

— be in the same plane as SP2;

— be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;

— be heated and insulated over its entire length to a minimum temperature of  $328\text{ K}$  ( $55\text{ °C}$ ) to prevent water condensation.

#### **HF1 Heated pre-filter (optional)**

The temperature shall be the same as HSL.

#### **HF2 Heated filter**

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

#### **HSL Heated sampling line**

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

The sampling line shall:

- have a 4 mm minimum and a 13,5 mm maximum inside diameter;

- be made of stainless steel or PTFE.

- maintain a wall temperature of  $463\text{ K} \pm 10\text{ K}$  ( $190\text{ °C} \pm 10\text{ °C}$ ) as measured at every separately controlled heated section, if the temperature of the exhaust gas at the sampling probe is equal to or below  $463\text{ K}$  ( $190\text{ °C}$ );

- maintain a wall temperature greater than  $453\text{ K}$  ( $180\text{ °C}$ ), if the temperature of the exhaust gas at the sampling probe is above  $463\text{ K}$  ( $190\text{ °C}$ );

- maintain a gas temperature of  $463\text{ K} \pm 10\text{ K}$  ( $190^\circ\text{C} \pm 10^\circ\text{C}$ ) immediately before the heated filter HF2 and the HFID;

**HL Heated NO<sub>x</sub> sampling line**

The sampling line shall:

- maintain a wall temperature of  $328\text{ K}$  to  $473\text{ K}$  ( $55^\circ\text{C}$  to  $200^\circ\text{C}$ ), up to the converter for dry measurement, and up to the analyzer for wet measurement.
- be made of stainless steel or PTFE.

**HP Heated sampling pump**

The pump shall be heated to the temperature of HSL.

**SL Sampling line for CO and CO<sub>2</sub>**

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

**HC HFID analyzer**

Heated flame ionization detector (HFID) or flame ionization detector (FID) for the determination of the hydrocarbons. The temperature of the HFID shall be kept at  $453\text{ K}$  to  $473\text{ K}$  ( $180^\circ\text{C}$  to  $200^\circ\text{C}$ ).

**CO, CO<sub>2</sub> NDIR analyzer**

NDIR analyzers for the determination of carbon monoxide and carbon dioxide (optional for the determination of the dilution ratio for PT measurement).

**NO<sub>x</sub> CLD analyzer**

CLD or HCLD analyzer for the determination of the oxides of nitrogen. If a HCLD is used it shall be kept at a temperature of  $328\text{ K}$  to  $473\text{ K}$  ( $55^\circ\text{C}$  to  $200^\circ\text{C}$ ).

**B Cooling bath (optional for NO measurement)**

To cool and condense water from the exhaust sample. It is optional if the analyzer is free from water vapor interference as determined in 9.3.3.12.2.2. If water is removed by condensation, the sample gas temperature or dew point shall be monitored either within the water trap or downstream. The sample gas temperature or dew point shall not exceed  $280\text{ K}$  ( $7^\circ\text{C}$ ). Chemical dryers are not allowed for removing water from the sample.

**BK Background bag (optional; figure 7 only)**

For the measurement of the background concentrations.

**BG Sample bag (optional; figure 7 only)**

For the measurement of the sample concentrations.

**R Pressure regulator**

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

**9.3.4.4 Non-methane cutter method (NMC)****9.3.4.4.1 General description**

The cutter oxidizes all hydrocarbons except CH<sub>4</sub> to CO<sub>2</sub> and H<sub>2</sub>O, so that by passing the sample through the NMC only CH<sub>4</sub> is detected by the HFID. In addition to the usual HC sampling train (see 9.3.4.2, figures 6 and 7), a second HC sampling train shall be installed equipped with a cutter as laid out in figure 8. This allows simultaneous measurement of total HC and NMHC.

The cutter shall be characterized at or above  $600\text{ K}$  ( $327^\circ\text{C}$ ) prior to test work with respect to its catalytic effect on CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> at H<sub>2</sub>O values representative of exhaust stream conditions. The dewpoint and O<sub>2</sub> level of the sampled exhaust stream must be known. The relative response of the FID to CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> shall be determined in accordance with 9.3.3.11.

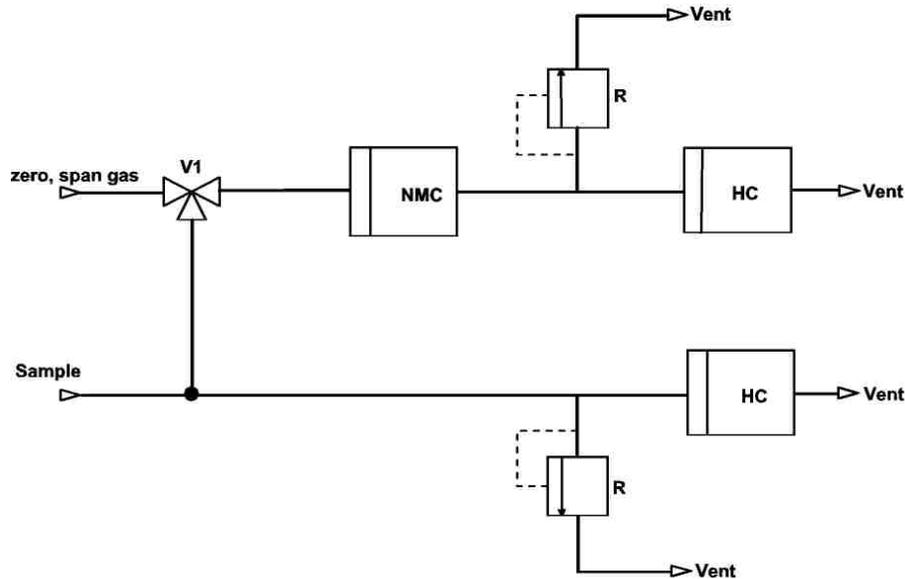


Figure 8 — Schematic flow diagram of methane analysis with the NMC

#### 9.3.4.4.2 Components of figure 8

##### NMC Non-methane cutter

To oxidize all hydrocarbons except methane.

##### HC

Heated flame ionization detector (HFID) or flame ionization detector (FID) to measure the HC and CH<sub>4</sub> concentrations. The temperature of the HFID shall be kept at 453 K to 473 K (180°C to 200°C).

##### V1 Selector valve

To select zero and span gas

##### R Pressure regulator

To control the pressure in the sampling line and the flow to the HFID

## 9.4 Particulate Measurement and Sampling System

### 9.4.1 General specifications

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. The particulate sampling system shall be designed to ensure a representative sample of the particulates proportional to the exhaust flow under transient engine operating conditions in accordance with 8.3.3.2.

### 9.4.2 Particulate sampling filters

The diluted exhaust shall be sampled by a filter that meets the requirements of 9.4.2.1 and 9.4.2.2 during the test sequence.

#### 9.4.2.1 Filter specification

Fluorocarbon coated glass fiber filters or fluorocarbon membrane filters are required. All filter types shall have a 0,3 µm DOP (di-octylphthalate) collection efficiency of at least 99 % at a gas face velocity between 35 and 100 cm/s.

#### 9.4.2.2 Filter size

Particulate filters with a diameter of 47 mm or 70 mm are recommended. Larger diameter filters are

acceptable (9.4.2.4), but smaller diameter filters are not permitted.

#### 9.4.2.3 Filter face velocity

A gas face velocity through the filter of 0,35 to 1 m/s shall be achieved. The pressure drop increase between the beginning and the end of the test shall be no more than 25 kPa.

#### 9.4.2.4 Filter loading

The required minimum filter loadings for the most common filter sizes are shown in table 8. For larger filter sizes, the minimum filter loading shall be 0,065 mg/1000 mm<sup>2</sup> filter area.

**Table 8 — Minimum filter loadings**

Filter Diameter (mm)	Minimum loading (mg)
47	0,11
70	0,25
90	0,41
110	0,62

If, based on previous testing, the required minimum filter loading is unlikely to be reached on a test cycle after optimization of flow rates and dilution ratio, the test cycle may be run repeatedly on the same filter without removing it from the filter holder with the agreement of the parties involved. Also, a lower filter loading may be acceptable, with the agreement of the parties involved, if it can be shown to meet the accuracy requirements of 9.4.3.2, e.g. with a balance of 0,1 µg resolution.

### 9.4.3 Weighing chamber and analytical balance specifications

#### 9.4.3.1 Weighing chamber conditions

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within 295 K ± 3 K (22°C ± 3°C) during all filter conditioning and weighing. The humidity shall be maintained to a dewpoint of 282,5K ± 3 K (9,5°C ± 3°C) and a relative humidity of 45% ± 8 %.

#### 9.4.3.2 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 stabilization. Disturbances to weighing room specifications as outlined in 9.4.3.1 will be allowed if the duration of the disturbances does not exceed 30 minutes. The weighing room should meet the required specifications prior to personal entrance into the weighing room. At least two unused reference filters shall be weighed within 4 hours of, but preferably at the same time as the sample filter weighings. They shall be the same size and material as the sample filters.

If the average weight of the reference filters changes between sample filter weighings by more than 10 µg, then all sample filters shall be discarded and the emissions test repeated.

If the weighing room stability criteria outlined in 9.4.3.1 is not met, but the reference filter 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 rerunning the test.

#### 9.4.3.3 Analytical balance

The analytical balance used to determine the filter weight shall have a precision (standard deviation) of at least 2 µg and a resolution of at least 1 µg (1 digit = 1 µg) specified by the balance manufacturer.

#### 9.4.3.4 Elimination of static electricity effects

If unstable or irreproducible filter weighings are observed due to the effects of static electricity, the filters shall be neutralized prior to weighing, e.g. by a Polonium neutralizer or a device of similar effect.

### 9.4.4 Specifications for flow measurement

Absolute accuracies of flow meter or flow measurement instrumentation shall be as specified in 9.2.

For partial flow dilution systems, the accuracy of the sample flow  $q_{mp}$  is of special concern, if not measured directly, but determined by differential flow measurement:

$$q_{mp} = q_{mdew} - q_{mdw} \quad (72)$$

In this case an accuracy of  $\pm 2\%$  for  $q_{mdew}$  and  $q_{mdw}$  is not sufficient to guarantee acceptable accuracies of  $q_{mp}$ . If the gas flow is determined by differential flow measurement, the maximum error of the difference shall be such that the accuracy of  $q_{mp}$  is within  $\pm 5\%$  when the dilution ratio is less than 15. It can be calculated by taking root-mean-square of the errors of each instrument.

Acceptable accuracies of  $q_{mp}$  can be obtained by either of the following methods:

- The absolute accuracies of  $q_{mdew}$  and  $q_{mdw}$  are  $\pm 0,2\%$  which guarantees an accuracy of  $q_{mp}$  of  $\leq 5\%$  at a dilution ratio of 15. However, greater errors will occur at higher dilution ratios.
- Calibration of  $q_{mdw}$  relative to  $q_{mdew}$  is carried out such that the same accuracies for  $q_{mp}$  as in a) are obtained. For the details of such a calibration see clause 9.6.2.
- The accuracy of  $q_{mp}$  is determined indirectly from the accuracy of the dilution ratio as determined by a tracer gas, e.g. CO<sub>2</sub>. Again, accuracies equivalent to method a) for  $q_{mp}$  are required.
- The absolute accuracy of  $q_{mdew}$  and  $q_{mdw}$  is within  $\pm 2\%$  of full scale, the maximum error of the difference between  $q_{mdew}$  and  $q_{mdw}$  is within  $0,2\%$ , and the linearity error is within  $\pm 0,2\%$  of the highest  $q_{mdew}$  observed during the test.

#### 9.4.4.1 Correction for sample flow

If measurement of gaseous emissions is done with a total sampling type partial flow dilution system, it is necessary to extract a sample flow  $q_{mex}$  from the tunnel, i.e. before the flow measuring device for  $q_{mdew}$ .  $q_{mex}$  shall be determined with the flow measurement device FM shown in figures 6 and 8, and will usually be much smaller than  $q_{mdew}$ , but not negligible ( $q_{mex} > 0,01 \times q_{mdew}$ ).

In order to guarantee an accuracy of  $q_{mp}$  as requested in 9.4.4 and 9.6.2.1, any of the methods outlined in these clauses may be used, but with  $q_{mdew}$  replaced by  $q_{mdew} + q_{mex}$ .

For the calculation of the PM mass emission (see 8.3.3.5), the mass of  $q_{mex}$  extracted from the tunnel shall be taken into account by correcting the particulate mass  $m_f$ , as follows:

$$m_{f,corrected} = m_f \times \frac{q_{mdew}}{(q_{mdew} - q_{mex})} \quad (73)$$

#### 9.4.5 Additional specifications

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, shall be designed to minimize deposition or alteration of the particulates. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

### 9.5 Dilution and sampling system

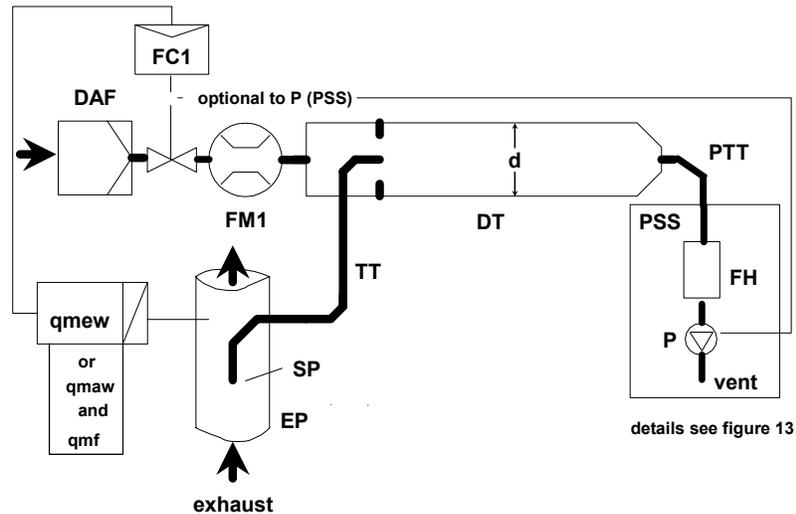
#### 9.5.1 Introduction

Clause 9.5.2 and figures 9 to 12 contain general 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, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgment.

#### 9.5.2 Description of partial flow system

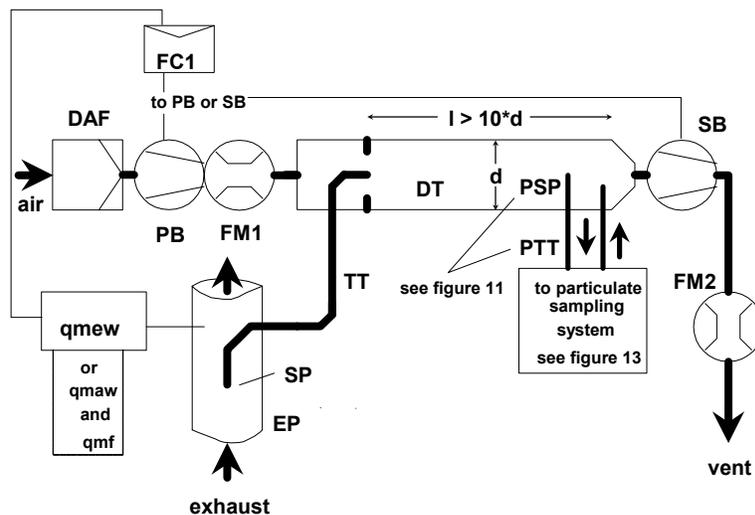
A dilution system is described based upon the dilution of a part of the exhaust stream. Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire dilute exhaust gas or only a portion of the dilute exhaust gas is passed to the particulate sampling system. 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.



**Figure 9 — Schematic of partial flow dilution system (total sampling type)**

With the total sampling system as shown in figure 9, 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 FC2 and the sampling pump P of the particulate sampling system (see figure 12). The dilution air flow is controlled by the flow controller FC1, which may use  $q_{mew}$  or  $q_{maw}$  and  $q_{mf}$  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 the flow measurement device FM1, the total flow rate with the flow measurement device FM3 of the particulate sampling system (see figure 12). The dilution ratio is calculated from these two flow rates.



**Figure 10 — Schematic of partial flow dilution system (fractional sampling type)**

With the fractional sampling system as shown in figure 10, 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 FC1 connected either to the dilution air flow or to the suction blower for the total tunnel flow. The flow controller FC1 may use  $q_{mew}$  or  $q_{maw}$  and  $q_{mf}$  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 the flow measurement device FM1, the total flow rate with the flow measurement device FM2. The dilution ratio is calculated from these two flow rates. From DT, a particulate sample is taken with the particulate sampling system

(see figure 13).

### 9.5.2.1 Components of figures 9 and 10

#### EP Exhaust pipe

The exhaust pipe may be insulated. To reduce the thermal inertia of the exhaust pipe a thickness to diameter ratio of 0,015 or less is recommended. The use of flexible sections shall be limited to a length to diameter ratio of 12 or less. Bends will be minimized to reduce inertial deposition. If the system includes a test bed silencer the silencer may also be insulated. It is recommended to have a straight pipe of 6 pipe diameters upstream and 3 pipe diameters downstream of the tip of the probe.

#### SP Sampling probe

The type of probe shall be either of the following

- open tube facing upstream on the exhaust pipe centerline
- open tube facing downstream on the exhaust pipe centerline
- multiple hole probe as described under SP in clause 9.3.4.3, figure 6
- hatted probe facing upstream on the exhaust pipe centerline as shown in figure 11

The minimum inside diameter of the probe tip shall be 4 mm. The minimum diameter ratio between exhaust pipe and probe shall be 4 for probes b) to d). For probe a), the exhaust pipe diameter, the probe diameter and the flow rates shall be set as to allow a maximum sampling error of  $0,98 \leq P \leq 1,02$  as determined in accordance with Annex B.

NOTE When using an open tube facing upstream on the exhaust pipe centerline, special caution should be applied with regard to the impact of large particles not related to combustion products from the cycle under test. Such particles may easily enter the probe which will result in an erroneous PM measurement. A typical example of such particles not related to the actual test are particles from the muffler or particles re-entrained from the exhaust pipe into the exhaust flow. Therefore, an inertial pre-classifier (cyclone or impactor) with at 50% cutpoint between 2.5 and 10 microns is recommended to be installed immediately upstream of the filter holder.

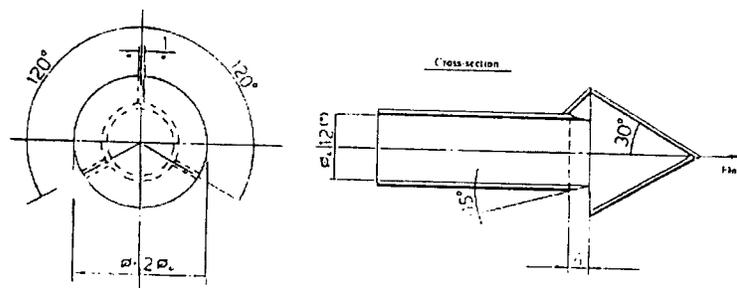


Figure 11 — Schematic of hatted probe

#### TT Exhaust transfer tube

The transfer tube shall be:

- as short as possible, but not more than 1 m in length.
- equal to or greater than the probe diameter, but not more than 25 mm in diameter.
- exiting on the centerline of the dilution tunnel and pointing downstream.

The tube shall be insulated with material with a maximum thermal conductivity of  $0,05 \text{ W/m} \times \text{K}$  with a radial insulation thickness corresponding to the diameter of the probe, or heated.

#### FC1 Flow controller

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 sensor signals specified in 8.3.1. The flow controller may

be installed upstream or downstream of the respective blower. When using a pressurized air supply, FC1 directly controls the air flow.

#### **FM1 Flow measurement device**

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

#### **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 higher than 288 K (15°C), and may be dehumidified. The dilution air may 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 (see clause 8.3.3.4).

#### **FM2 — Flow measurement device (fractional sampling type, figure 10, only)**

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 (fractional sampling type, figure 10, only)**

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 (fractional sampling type, figure 10, only)**

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

#### **DT Dilution tunnel**

The dilution tunnel:

- shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions for a fractional sampling system, i.e. complete mixing is not required for a total sampling system.
- shall be constructed of stainless steel
- 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 325 K (52°C) wall temperature.
- may be insulated.

#### **PSP — Particulate sampling probe (fractional sampling type, figure 10, only)**

The particulate sampling probe is the leading section of the particulate transfer tube 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 centerline approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;
- shall be 12 mm in minimum inside diameter;
- may be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust into the dilution tunnel;
- may be insulated.

#### **PTT Particulate transfer tube**

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

The dimensions are valid for:

- the *fractional sampling* type from the probe tip to the filter holder.

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

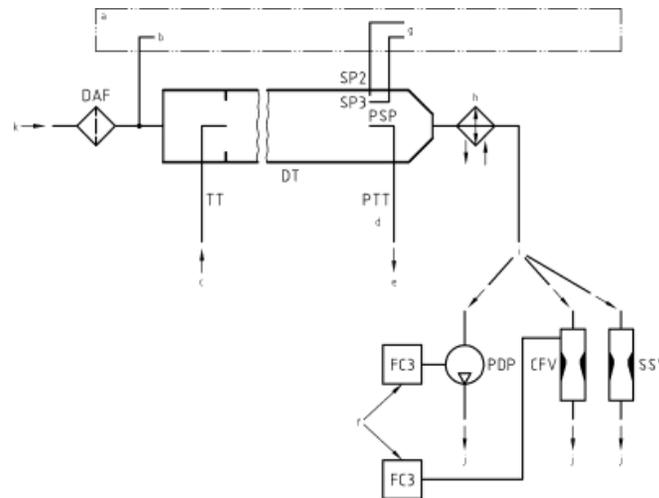
The transfer tube:

- may be heated to no greater than 325K (52°C) wall temperature.
- may be insulated.

### 9.5.3 Description of full flow dilution system

A dilution system is described based upon the dilution of the total exhaust using the CVS (constant volume sampling) concept and is shown in figure 12. The total volume of the mixture of exhaust and dilution air shall 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 (see 9.5.4, figure13). 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 9.5.4, figure 13, since it shares most of the parts with a typical particulate sampling system.



**Figure 12 — Schematic of full flow dilution system (CVS)**

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, with a critical flow venturi CFV or with a subsonic venturi SSV. 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 it is not necessary to calculate the dilution ratio.

#### 9.5.3.1 Components of figure 12

##### EP — exhaust pipe

The exhaust pipe length from the exit of the engine exhaust manifold, turbocharger outlet or after-treatment device to the dilution tunnel shall 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 shall be at least 25 mm. The thermal conductivity of the insulating material shall have a value no greater than 0,1 W/(m·K) measured at 673 K. 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.

#### **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 backpressure shall not be artificially lowered by the PDP or dilution air inlet system. Static exhaust backpressure measured with the PDP system operating shall remain within  $\pm 1,5$  kPa of the static pressure measured without connection to the PDP at identical engine speed and load. The gas mixture temperature immediately ahead of the PDP shall be within  $\pm 6$  K of the average operating temperature observed during the test, when no flow compensation is used. Flow compensation can only be used if the temperature at the inlet to the PDP does not exceed 323 K (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  $\pm 1,5$  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  $\pm 11$  K of the average operating temperature observed during the test, when no flow compensation is used.

#### **SSV — subsonic venturi**

SSV measures total diluted exhaust flow by using the gas flow function of a subsonic venturi in dependence of inlet pressure and temperature and pressure drop between venturi inlet and throat. Static exhaust backpressure measured with the SSV system operating shall remain within  $\pm 1,5$  kPa of the static pressure measured without connection to the SSV at identical engine speed and load. The gas mixture temperature immediately ahead of the SSV shall be within  $\pm 11$  K of the average operating temperature observed during the test, when no flow compensation is used.

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

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

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

If the temperature at the inlet to either the PDP, CFV **or** SSV is not kept within the limits stated above, a flow compensation system is required for continuous measurement of the flow rate and control of the proportional sampling in the particulate system. For that purpose, the continuously measured flow rate signals are used accordingly to correct the sample flow rate through the particulate filters of the particulate sampling system (see figure 13).

#### **DT — dilution tunnel**

The dilution tunnel

— shall be small enough in diameter to cause turbulent flow (Reynolds Number greater than 4000) 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 (see 9.5.4, figure 13). The flow capacity of the PDP, CFV **or** SSV shall be sufficient to maintain the diluted exhaust at a temperature between 315 K (42 °C) and 325 K (52 °C) immediately before the 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 (9.5.4, figure 22). The flow capacity of the PDP or CFV must be sufficient to maintain the diluted exhaust stream in the DT at a temperature of less than or equal to 464 K (191 °C) at the sampling zone. The secondary dilution

system shall provide sufficient secondary dilution air to maintain the doubly diluted exhaust stream at a temperature between 315 K (42 °C) and 325 K (52 °C) immediately before the 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 greater than 288 K (15 °C), and may be dehumidified. At the engine manufacturer's request the dilution air may 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 (see 8.3.3.4).

**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 gases are well mixed, i.e. on the dilution tunnel DT centreline of the dilution systems, approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;

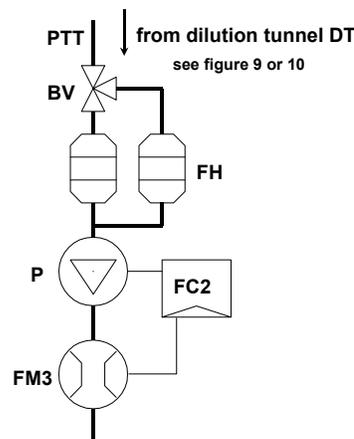
— shall be of 12 mm minimum inside diameter;

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

— may be insulated.

**9.5.4 Description of particulate sampling system**

The particulate sampling system is required for collecting the particulates on the particulate filter and is shown in figure 13. In the case of total sampling partial flow dilution, which consists of passing the entire diluted exhaust sample through the filters, the dilution (see 9.5.2, figure 9) and sampling systems 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 (see 9.5.2, figure 10, 9.5.3, figure 12) and sampling systems usually form different units.



**Figure 13 — Schematic of particulate sampling system**

**9.5.4.1 Components of figure 13**

**FH Filter holder**

The filter holder:

- may be heated to no greater than 325 K (52°C) wall temperature.

- may be insulated.

An inertial pre-classifier with a 50% cut point between 2,5  $\mu\text{m}$  and 10  $\mu\text{m}$  may be installed immediately upstream of the filter holder. The use of the pre-classifier is strongly recommended, if an open tube sampling probe facing upstream is used.

### **P Sampling pump**

#### **FC2 — Flow controller**

A flow controller shall be used for controlling the particulate sample flow rate.

#### **FM3 — Flow measurement device**

Gas meter or flow instrumentation to determine the particulate sample flow through the particulate filter. It may be installed upstream or downstream of the sampling pump, P.

#### **BV — Ball valve (optional)**

The ball valve shall have an inside diameter not less than the inside diameter of the particulate transfer tube PTT, and a switching time of less than 0,5 s.

NOTE If the ambient temperature in the vicinity of PSP, PTT, SDT and FH is below 293 K (20 °C), precautions should be taken to avoid particle losses on to the cool wall of these parts. Therefore, heating and/or insulating these parts within the limits given in the respective descriptions is recommended.

## **9.6 Calibration**

### **9.6.1 Introduction**

The calibration of the particulate measurement is limited to the flow meters used to determine sample flow and dilution ratio. Each flow meter shall be calibrated as often as necessary to fulfill the accuracy requirements of this standard. The calibration method that shall be used is described in 9.6.2.

### **9.6.2 Flow measurement**

#### **9.6.2.1 Periodical calibration**

To fulfill the absolute accuracy of the flow measurements as specified in 9.2, the flow meter or the flow measurement instrumentation shall be calibrated with an accurate flow meter traceable to international and/or national standards.

If the sample gas flow is determined by differential flow measurement the flow meter or the flow measurement instrumentation shall be calibrated in one of the following procedures, such that the probe flow  $q_{mp}$  into the tunnel shall fulfill the accuracy requirements of clause 9.4.4:

- a) The flow meter for  $q_{mdw}$  shall be connected in series to the flow meter for  $q_{mdew}$ , the difference between the two flow meters shall be calibrated for at least 5 set points with flow values equally spaced between the lowest  $q_{mdw}$  value used during the test and the value of  $q_{mdew}$  used during the test. The dilution tunnel may be bypassed.
- b) A calibrated flow device shall be connected in series to the flowmeter for  $q_{mdew}$  and the accuracy shall be checked for the value used for the test. Then the calibrated flow device shall be connected in series to the flow meter for  $q_{mdw}$ , and the accuracy shall be checked for at least 5 settings corresponding to dilution ratio between 3 and 50, relative to  $q_{mdew}$  used during the test.
- c) The transfer tube TT shall be disconnected from the exhaust, and a calibrated flow measuring device with a suitable range to measure  $q_{mp}$  shall be connected to the transfer tube. Then  $q_{mdew}$  shall be set to the value used during the test, and  $q_{mdw}$  shall be sequentially set to at least 5 values corresponding to dilution ratios  $q$  between 3 and 50. Alternatively, a special calibration flow path, may be provided, in which the tunnel is bypassed, but the total and dilution air flow through the corresponding meters as in the actual test.
- d) A tracer gas, shall be fed into the exhaust transfer tube TT. This tracer gas may be a component of the exhaust gas, like  $\text{CO}_2$  or  $\text{NO}_x$ . After dilution in the tunnel the tracer gas component shall be measured. This shall be carried out for 5 dilution ratios between 3 and 50. The accuracy of the sample flow shall be determined from the dilution ration  $r_d$ :

$$q_{mp} = q_{mdew} / r_d \quad (74)$$

The accuracies of the gas analyzers shall be taken into account to guarantee the accuracy of  $q_{mp}$ .

#### 9.6.2.2 Carbon flow check

A carbon flow check using actual exhaust is strongly recommended for detecting measurement and control problems and verifying the proper operation of the partial flow system. The carbon flow check should be run at least each time a new engine is installed, or something significant is changed in the test cell configuration.

The engine shall be operated at peak torque load and speed or any other steady state mode that produces 5% or more of CO<sub>2</sub>. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.

If a carbon flow check is conducted, the procedure given in Annex 10.5 shall be applied. The carbon flow rates shall be calculated according to equations 80 to 82. All carbon flow rates should agree to within 3 %.

#### 9.6.2.3 Pre-test check

A pre-test check shall be performed within 2 hours before the test run in the following way:

The accuracy of the flow meters shall be checked by the same method as used for calibration (see clause 9.6.2.1) for at least two points, including flow values of  $q_{mdw}$  that correspond to dilution ratios between 5 and 15 for the  $q_{mdew}$  value used during the test.

If it can be demonstrated by records of the calibration procedure under clause 9.6.2.1 that the flow meter calibration is stable over a longer period of time, the pre-test check may be omitted.

### 9.6.3 Determination of the transformation time

The system settings for the transformation time evaluation shall be exactly the same as during measurement of the test run. The transformation time shall be determined by the following method:

An independent reference flowmeter with a measurement range appropriate for the probe flow shall be put in series with and closely coupled to the probe. This flowmeter shall have a transformation time of less than 100 ms for the flow step size used in the response time measurement, with flow restriction sufficiently low as to not affect the dynamic performance of the partial flow dilution system, and consistent with good engineering practice.

A step change shall be introduced to the exhaust flow (or air flow if exhaust flow is calculated) input of the partial flow dilution system, from a low flow to at least 90% of full scale. The trigger for the step change should be the same one used to start the look-ahead control in actual testing. The exhaust flow step stimulus and the flowmeter response shall be recorded at a sample rate of at least 10 Hz.

From this data, the transformation time shall be determined for the partial flow dilution system, which is the time from the initiation of the step stimulus to the 50% point of the flowmeter response. In a similar manner, the transformation times of the  $q_{mp}$  signal of the partial flow dilution system and of the  $q_{mew,i}$  signal of the exhaust flow meter shall be determined. These signals are used in the regression checks performed after each test (see clause 8.3.3.3)

The calculation shall be repeated for at least 5 rise and fall stimuli, and the results shall be averaged. The internal transformation time (<100 msec) of the reference flowmeter shall be subtracted from this value. This is the "look-ahead" value of the partial flow dilution system, which shall be applied in accordance with clause 8.3.3.3.

### 9.6.4 Calibration of the CVS system

#### 9.6.4.1 General

The CVS system shall be calibrated by using an accurate flowmeter and a restricting device. The flow through the system shall be measured at different restriction settings, and the control parameters of the system shall be measured and related to the flow.

Various type of flowmeters may be used, e.g. calibrated venturi, calibrated laminar flowmeter, calibrated turbinometer.

### 9.6.4.2 Calibration of the Positive Displacement Pump (PDP)

All the parameters related to the pump shall be simultaneously measured along with the parameters related to a calibration venturi which is connected in series with the pump. The calculated flow rate (in m<sup>3</sup>/min at pump inlet, absolute pressure and temperature) shall be plotted versus a correlation function which is the value of a specific combination of pump parameters. The linear equation which relates the pump flow and the correlation function shall be determined. If a CVS has a multiple speed drive, the calibration shall be performed for each range used.

Temperature stability shall be maintained during calibration.

Leaks in all the connections and ducting between the calibration venturi and the CVS pump shall be maintained lower than 0.3% of the lowest flow point (highest restriction and lowest PDP speed point).

#### 9.6.4.2.1 Data analysis

The air flowrate ( $Q_s$ ) at each restriction setting (minimum 6 settings) shall be calculated in standard m<sup>3</sup>/min from the flowmeter data using the manufacturer's prescribed method. The air flow rate shall then be converted to pump flow ( $V_0$ ) in m<sup>3</sup>/rev at absolute pump inlet temperature and pressure as follows:

$$V_0 = \frac{Q_s}{n} * \frac{T}{273} * \frac{101.3}{p_A} \quad (75)$$

where,

$Q_s$  = air flow rate at standard conditions (101,3 kPa, 273 K), m<sup>3</sup>/s

T = temperature at pump inlet, K

$p_A$  = absolute pressure at pump inlet ( $p_B - p_1$ ), kPa

n = pump speed, rev/s

To account for the interaction of pressure variations at the pump and the pump slip rate, the correlation function ( $X_0$ ) between pump speed, pressure differential from pump inlet to pump outlet and absolute pump outlet pressure shall be calculated as follows:

$$X_0 = \frac{1}{n} * \sqrt{\frac{\Delta p_p}{p_A}} \quad (76)$$

where

$\Delta p_p$  = pressure differential from pump inlet to pump outlet, kPa

$p_A$  = absolute outlet pressure at pump outlet, kPa

A linear least-square fit shall be performed to generate the calibration equation as follows:

$$V_0 = D_0 - m * (X_0) \quad (77)$$

$D_0$  and  $m$  are the intercept and slope constants, respectively, describing the regression lines.

For a CVS system with multiple speeds, the calibration curves generated for the different pump flow ranges shall be approximately parallel, and the intercept values ( $D_0$ ) shall increase as the pump flow range decreases.

The calculated values from the equation shall be within  $\pm 0,5$  % of the measured value of  $V_0$ . Values of  $m$  will vary from one pump to another. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for  $m$ . Therefore, calibration shall be performed at pump start-up, after major maintenance, and if the total system verification indicates a change of the slip rate.

### 9.6.4.3 Calibration of the Critical Flow Venturi (CFV)

Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of inlet pressure and temperature, as shown below

$$Q_s = \frac{K_v * p_A}{\sqrt{T}} \quad (78)$$

where

$K_v$  = calibration coefficient

$p_A$  = absolute pressure at venturi inlet, kPa

$T$  = temperature at venturi inlet, K

#### 9.6.4.3.1 Data analysis

The air flowrate ( $Q_s$ ) at each restriction setting (minimum 8 settings) shall be calculated in standard  $m^3/min$  from the flowmeter data using the manufacturer's prescribed method. The calibration coefficient shall be calculated from the calibration data for each setting as follows:

$$K_v = \frac{Q_s * \sqrt{T}}{p_A} \quad (79)$$

where,

$Q_s$  = air flow rate at standard conditions (101,3 kPa, 273 K),  $m^3/s$

$T$  = temperature at the venturi inlet, K

$p_A$  = absolute pressure at venturi inlet, kPa

To determine the range of critical flow,  $K_v$  shall be plotted as a function of venturi inlet pressure. For critical (choked) flow,  $K_v$  will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and  $K_v$  decreases, which indicates that the CFV is operated outside the permissible range.

For a minimum of eight points in the region of critical flow, the average  $K_v$  and the standard deviation shall be calculated. The standard deviation shall not exceed  $\pm 0,3$  % of the average  $K_v$

#### 9.6.4.4 Calibration of the Subsonic Venturi (SSV)

Calibration of the SSV is based upon the flow equation for a subsonic venturi. Gas flow is a function of inlet pressure and temperature, pressure drop between the SSV inlet and throat, as shown below

$$Q_{SSV} = A_0 d^2 C_d P_A \sqrt{\left[ \frac{1}{T} \left( r_x^{1.4286} - r_x^{1.7143} \right) \left( \frac{1}{1 - r_y^4 r_x^{1.4286}} \right) \right]} \quad (80)$$

where

$A_0$  = collection of constants and units conversions

$$= 0,006111 \text{ in SI units of } \left( \frac{m^3}{min} \right) \left( \frac{K^{\frac{1}{2}}}{kPa} \right) \left( \frac{1}{mm^2} \right)$$

$d$  = diameter of the SSV throat, m

$C_d$  = discharge coefficient of the SSV

$P_A$  = absolute pressure at venturi inlet, kPa

$T$  = temperature at the venturi inlet, K

$r_x$  = ratio of the SSV throat to inlet absolute static pressure =  $1 - \frac{\Delta p}{p_a}$

$r_y$  = ratio of the SSV throat diameter,  $d$ , to the inlet pipe inner diameter  $D = d/D$

#### 9.6.4.4.1 Data analysis

The air flowrate ( $Q_{SSV}$ ) at each restriction setting (minimum 16 settings) shall be calculated in standard  $m^3/min$  from the flowmeter data using the manufacturer's prescribed method. The discharge coefficient

shall be calculated from the calibration data for each setting as follows:

$$C_d = \frac{Q_{SSV}}{d^2 P_A \sqrt{\frac{1}{T} \left( r_x^{1.4286} - r_x^{1.7143} \left( \frac{1}{1 - r_y^4 r_x^{1.4286}} \right) \right)}} \quad (81)$$

where

$Q_{SSV}$  = air flow rate at standard conditions (101,3 kPa, 273 K), m<sup>3</sup>/s

T = temperature at the venturi inlet, K

d = diameter of the SSV throat, m

$r_x$  = ratio of the SSV throat to inlet absolute static pressure =  $1 - \frac{\Delta p}{p_a}$

$r_y$  = ratio of the SSV throat diameter,  $d$ , to the inlet pipe inner diameter  $D = d/D$

To determine the range of subsonic flow,  $C_d$  shall be plotted as a function of Reynolds number, at the SSV throat. The Re at the SSV throat is calculated with the following formula:

$$Re = A_1 \frac{Q_{SSV}}{d \mu} \quad (82)$$

where

$A_1$  = a collection of constants and units conversions

$$= 25,55152 \left( \frac{1}{m^3} \right) \left( \frac{\min}{s} \right) \left( \frac{mm}{m} \right)$$

$Q_{SSV}$  = air flow rate at standard conditions (101,3 kPa, 273 K), m<sup>3</sup>/s

d = diameter of the SSV throat, m

$\mu$  = absolute or dynamic viscosity of the gas, calculated with the following formula:

$$\mu = \frac{bT^{3/2}}{S+T} = \frac{bT^{1/2}}{1+\frac{S}{T}} \text{ kg/m-s} \quad (83)$$

b = empirical constant =  $1,458 \times 10^6 \frac{kg}{msK^2}$

S = empirical constant = 110,4 K

Because  $Q_{SSV}$  is an input to the Re formula, the calculations must be started with an initial guess for  $Q_{SSV}$  or  $C_d$  of the calibration venturi, and repeated until  $Q_{SSV}$  converges. The convergence method must be accurate to 0.1% of point or better.

For a minimum of sixteen points in the region of subsonic flow, the calculated values of  $C_d$  from the resulting calibration curve fit equation must be within  $\pm 0.5\%$  of the measured  $C_d$  for each calibration point.

#### 9.6.4.5 Total system verification

The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of a pollutant gas into the system while it is being operated in the normal manner. The pollutant is analysed, and the mass calculated according to 8.4.2.4 except in the case of propane where a factor of 0,000472 is used in place of 0,000479 for HC. Either of the following two techniques shall be used.

##### 9.6.4.5.1 Metering with a critical flow orifice

A known quantity of pure gas (carbon monoxide or propane) shall be fed into the CVS system through a calibrated critical orifice. If the inlet pressure is high enough, the flow rate, which is adjusted by means of the critical flow orifice, is independent of the orifice outlet pressure (critical flow). The CVS system shall be operated as in a normal exhaust emission test for about 5 to 10 minutes. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined shall be within  $\pm 3\%$  of the known mass of the gas injected.

#### **9.6.4.5.2 Metering by means of a gravimetric technique**

The weight of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of  $\pm 0,01$  gram. For about 5 to 10 minutes, the CVS system shall be operated as in a normal exhaust emission test, while carbon monoxide or propane is injected into the system. The quantity of pure gas discharged shall be determined by means of differential weighing. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined shall be within  $\pm 3\%$  of the known mass of the gas injected.

#### **9.6.5 Calibration intervals**

The instruments shall be calibrated as required by internal audit procedures, by the instrument manufacturer or in accordance with ISO 9000 requirements.

## **10 Annexes**

### **10.1 [Essential Characteristics of the Engine and Information Concerning the Conduct of Tests]**

## 10.2 WHTC Engine Dynamometer Schedule

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	%	%	s	%	%	s	%	%
1	0,0	0,0	52	26,3	25,5	103	36,2	23,5
2	0,0	0,0	53	35,0	32,2	104	36,8	22,7
3	0,0	0,0	54	41,7	14,3	105	37,2	20,9
4	0,0	0,0	55	42,2	0,0	106	37,0	19,2
5	0,0	0,0	56	42,8	11,6	107	36,3	18,4
6	0,0	0,0	57	51,0	20,9	108	35,4	17,6
7	1,5	8,9	58	60,0	9,6	109	35,2	14,9
8	15,8	30,9	59	49,4	0,0	110	35,4	9,9
9	27,4	1,3	60	38,9	16,6	111	35,5	4,3
10	32,6	0,7	61	43,4	30,8	112	35,2	6,6
11	34,8	1,2	62	49,4	14,2	113	34,9	10,0
12	36,2	7,4	63	40,5	0,0	114	34,7	25,1
13	37,1	6,2	64	31,5	43,5	115	34,4	29,3
14	37,9	10,2	65	36,6	78,2	116	34,5	20,7
15	39,6	12,3	66	40,8	67,6	117	35,2	16,6
16	42,3	12,5	67	44,7	59,1	118	35,8	16,2
17	45,3	12,6	68	48,3	52,0	119	35,6	20,3
18	48,6	6,0	69	51,9	63,8	120	35,3	22,5
19	40,8	0,0	70	54,7	27,9	121	35,3	23,4
20	33,0	16,3	71	55,3	18,3	122	34,7	11,9
21	42,5	27,4	72	55,1	16,3	123	45,5	0,0
22	49,3	26,7	73	54,8	11,1	124	56,3	m
23	54,0	18,0	74	54,7	11,5	125	46,2	m
24	57,1	12,9	75	54,8	17,5	126	50,1	0,0
25	58,9	8,6	76	55,6	18,0	127	54,0	m
26	59,3	6,0	77	57,0	14,1	128	40,5	m
27	59,0	4,9	78	58,1	7,0	129	27,0	m
28	57,9	m	79	43,3	0,0	130	13,5	m
29	55,7	m	80	28,5	25,0	131	0,0	0,0
30	52,1	m	81	30,4	47,8	132	0,0	0,0
31	46,4	m	82	32,1	39,2	133	0,0	0,0
32	38,6	m	83	32,7	39,3	134	0,0	0,0
33	29,0	m	84	32,4	17,3	135	0,0	0,0
34	20,8	m	85	31,6	11,4	136	0,0	0,0
35	16,9	m	86	31,1	10,2	137	0,0	0,0
36	16,9	42,5	87	31,1	19,5	138	0,0	0,0
37	18,8	38,4	88	31,4	22,5	139	0,0	0,0
38	20,7	32,9	89	31,6	22,9	140	0,0	0,0
39	21,0	0,0	90	31,6	24,3	141	0,0	0,0
40	19,1	0,0	91	31,9	26,9	142	0,0	4,9
41	13,7	0,0	92	32,4	30,6	143	0,0	7,3
42	2,2	0,0	93	32,8	32,7	144	4,4	28,7
43	0,0	0,0	94	33,7	32,5	145	11,1	26,4
44	0,0	0,0	95	34,4	29,5	146	15,0	9,4
45	0,0	0,0	96	34,3	26,5	147	15,9	0,0
46	0,0	0,0	97	34,4	24,7	148	15,3	0,0
47	0,0	0,0	98	35,0	24,9	149	14,2	0,0
48	0,0	0,0	99	35,6	25,2	150	13,2	0,0
49	0,0	0,0	100	36,1	24,8	151	11,6	0,0
50	0,0	13,1	101	36,3	24,0	152	8,4	0,0
51	13,1	30,1	102	36,2	23,6	153	5,4	0,0

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	%	%	s	%	%	s	%	%
154	4,3	5,6	205	0,0	0,0	256	33,0	53,5
155	5,8	24,4	206	0,0	0,0	257	43,7	22,1
156	9,7	20,7	207	0,0	0,0	258	39,8	0,0
157	13,6	21,1	208	0,0	0,0	259	36,0	45,7
158	15,6	21,5	209	0,0	0,0	260	47,6	75,9
159	16,5	21,9	210	0,0	0,0	261	61,2	70,4
160	18,0	22,3	211	0,0	0,0	262	72,3	70,4
161	21,1	46,9	212	0,0	0,0	263	76,0	m
162	25,2	33,6	213	0,0	0,0	264	74,3	m
163	28,1	16,6	214	0,0	0,0	265	68,5	m
164	28,8	7,0	215	0,0	0,0	266	61,0	m
165	27,5	5,0	216	0,0	0,0	267	56,0	m
166	23,1	3,0	217	0,0	0,0	268	54,0	m
167	16,9	1,9	218	0,0	0,0	269	53,0	m
168	12,2	2,6	219	0,0	0,0	270	50,8	m
169	9,9	3,2	220	0,0	0,0	271	46,8	m
170	9,1	4,0	221	0,0	0,0	272	41,7	m
171	8,8	3,8	222	0,0	0,0	273	35,9	m
172	8,5	12,2	223	0,0	0,0	274	29,2	m
173	8,2	29,4	224	0,0	0,0	275	20,7	m
174	9,6	20,1	225	0,0	0,0	276	10,1	m
175	14,7	16,3	226	0,0	0,0	277	0,0	m
176	24,5	8,7	227	0,0	0,0	278	0,0	0,0
177	39,4	3,3	228	0,0	0,0	279	0,0	0,0
178	39,0	2,9	229	0,0	0,0	280	0,0	0,0
179	38,5	5,9	230	0,0	0,0	281	0,0	0,0
180	42,4	8,0	231	0,0	0,0	282	0,0	0,0
181	38,2	6,0	232	0,0	0,0	283	0,0	0,0
182	41,4	3,8	233	0,0	0,0	284	0,0	0,0
183	44,6	5,4	234	0,0	0,0	285	0,0	0,0
184	38,8	8,2	235	0,0	0,0	286	0,0	0,0
185	37,5	8,9	236	0,0	0,0	287	0,0	0,0
186	35,4	7,3	237	0,0	0,0	288	0,0	0,0
187	28,4	7,0	238	0,0	0,0	289	0,0	0,0
188	14,8	7,0	239	0,0	0,0	290	0,0	0,0
189	0,0	5,9	240	0,0	0,0	291	0,0	0,0
190	0,0	0,0	241	0,0	0,0	292	0,0	0,0
191	0,0	0,0	242	0,0	0,0	293	0,0	0,0
192	0,0	0,0	243	0,0	0,0	294	0,0	0,0
193	0,0	0,0	244	0,0	0,0	295	0,0	0,0
194	0,0	0,0	245	0,0	0,0	296	0,0	0,0
195	0,0	0,0	246	0,0	0,0	297	0,0	0,0
196	0,0	0,0	247	0,0	0,0	298	0,0	0,0
197	0,0	0,0	248	0,0	0,0	299	0,0	0,0
198	0,0	0,0	249	0,0	0,0	300	0,0	0,0
199	0,0	0,0	250	0,0	0,0	301	0,0	0,0
200	0,0	0,0	251	0,0	0,0	302	0,0	0,0
201	0,0	0,0	252	0,0	0,0	303	0,0	0,0
202	0,0	0,0	253	0,0	31,6	304	0,0	0,0
203	0,0	0,0	254	9,4	13,6	305	0,0	0,0
204	0,0	0,0	255	22,2	16,9	306	0,0	0,0

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	%	%	s	%	%	s	%	%
307	0,0	0,0	358	36,5	50,1	409	55,5	20,3
308	0,0	0,0	359	47,7	21,0	410	55,8	5,2
309	0,0	0,0	360	38,8	0,0	411	55,4	m
310	0,0	0,0	361	30,0	37,0	412	54,4	m
311	0,0	0,0	362	37,0	63,6	413	53,1	m
312	0,0	0,0	363	45,5	90,8	414	51,8	m
313	0,0	0,0	364	54,5	40,9	415	50,3	m
314	0,0	0,0	365	45,9	0,0	416	48,4	m
315	0,0	0,0	366	37,2	47,5	417	45,9	m
316	0,0	0,0	367	44,5	84,4	418	43,1	m
317	0,0	0,0	368	51,7	32,4	419	40,1	m
318	0,0	0,0	369	58,1	15,2	420	37,4	m
319	0,0	0,0	370	45,9	0,0	421	35,1	m
320	0,0	0,0	371	33,6	35,8	422	32,8	m
321	0,0	0,0	372	36,9	67,0	423	45,3	0,0
322	0,0	0,0	373	40,2	84,7	424	57,8	m
323	0,0	0,0	374	43,4	84,3	425	50,6	m
324	4,5	41,0	375	45,7	84,3	426	41,6	m
325	17,2	38,9	376	46,5	m	427	47,9	0,0
326	30,1	36,8	377	46,1	m	428	54,2	m
327	41,0	34,7	378	43,9	m	429	48,1	m
328	50,0	32,6	379	39,3	m	430	47,0	31,3
329	51,4	0,1	380	47,0	m	431	49,0	38,3
330	47,8	m	381	54,6	m	432	52,0	40,1
331	40,2	m	382	62,0	m	433	53,3	14,5
332	32,0	m	383	52,0	m	434	52,6	0,8
333	24,4	m	384	43,0	m	435	49,8	m
334	16,8	m	385	33,9	m	436	51,0	18,6
335	8,1	m	386	28,4	m	437	56,9	38,9
336	0,0	m	387	25,5	m	438	67,2	45,0
337	0,0	0,0	388	24,6	11,0	439	78,6	21,5
338	0,0	0,0	389	25,2	14,7	440	65,5	0,0
339	0,0	0,0	390	28,6	28,4	441	52,4	31,3
340	0,0	0,0	391	35,5	65,0	442	56,4	60,1
341	0,0	0,0	392	43,8	75,3	443	59,7	29,2
342	0,0	0,0	393	51,2	34,2	444	45,1	0,0
343	0,0	0,0	394	40,7	0,0	445	30,6	4,2
344	0,0	0,0	395	30,3	45,4	446	30,9	8,4
345	0,0	0,0	396	34,2	83,1	447	30,5	4,3
346	0,0	0,0	397	37,6	85,3	448	44,6	0,0
347	0,0	0,0	398	40,8	87,5	449	58,8	m
348	0,0	0,0	399	44,8	89,7	450	55,1	m
349	0,0	0,0	400	50,6	91,9	451	50,6	m
350	0,0	0,0	401	57,6	94,1	452	45,3	m
351	0,0	0,0	402	64,6	44,6	453	39,3	m
352	0,0	0,0	403	51,6	0,0	454	49,1	0,0
353	0,0	0,0	404	38,7	37,4	455	58,8	m
354	0,0	0,5	405	42,4	70,3	456	50,7	m
355	0,0	4,9	406	46,5	89,1	457	42,4	m
356	9,2	61,3	407	50,6	93,9	458	44,1	0,0
357	22,4	40,4	408	53,8	33,0	459	45,7	m

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	%	%		%	%		%	%
460	32,5	m	511	51,4	42,4	562	53,4	20,7
461	20,7	m	512	52,5	31,9	563	54,2	13,1
462	10,0	m	513	53,7	21,6	564	54,2	0,4
463	0,0	0,0	514	55,1	11,6	565	53,4	0,0
464	0,0	1,5	515	56,8	5,7	566	51,4	m
465	0,9	41,1	516	42,4	0,0	567	48,7	m
466	7,0	46,3	517	27,9	8,2	568	45,6	m
467	12,8	48,5	518	29,0	15,9	569	42,4	m
468	17,0	50,7	519	30,4	25,1	570	40,4	m
469	20,9	52,9	520	32,6	60,5	571	39,8	5,8
470	26,7	55,0	521	35,4	72,7	572	40,7	39,7
471	35,5	57,2	522	38,4	88,2	573	43,8	37,1
472	46,9	23,8	523	41,0	65,1	574	48,1	39,1
473	44,5	0,0	524	42,9	25,6	575	52,0	22,0
474	42,1	45,7	525	44,2	15,8	576	54,7	13,2
475	55,6	77,4	526	44,9	2,9	577	56,4	13,2
476	68,8	100,0	527	45,1	m	578	57,5	6,6
477	81,7	47,9	528	44,8	m	579	42,6	0,0
478	71,2	0,0	529	43,9	m	580	27,7	10,9
479	60,7	38,3	530	42,4	m	581	28,5	21,3
480	68,8	72,7	531	40,2	m	582	29,2	23,9
481	75,0	m	532	37,1	m	583	29,5	15,2
482	61,3	m	533	47,0	0,0	584	29,7	8,8
483	53,5	m	534	57,0	m	585	30,4	20,8
484	45,9	58,0	535	45,1	m	586	31,9	22,9
485	48,1	80,0	536	32,6	m	587	34,3	61,4
486	49,4	97,9	537	46,8	0,0	588	37,2	76,6
487	49,7	m	538	61,5	m	589	40,1	27,5
488	48,7	m	539	56,7	m	590	42,3	25,4
489	45,5	m	540	46,9	m	591	43,5	32,0
490	40,4	m	541	37,5	m	592	43,8	6,0
491	49,7	0,0	542	30,3	m	593	43,5	m
492	59,0	m	543	27,3	32,3	594	42,8	m
493	48,9	m	544	30,8	60,3	595	41,7	m
494	40,0	m	545	41,2	62,3	596	40,4	m
495	33,5	m	546	36,0	0,0	597	39,3	m
496	30,0	m	547	30,8	32,3	598	38,9	12,9
497	29,1	12,0	548	33,9	60,3	599	39,0	18,4
498	29,3	40,4	549	34,6	38,4	600	39,7	39,2
499	30,4	29,3	550	37,0	16,6	601	41,4	60,0
500	32,2	15,4	551	42,7	62,3	602	43,7	54,5
501	33,9	15,8	552	50,4	28,1	603	46,2	64,2
502	35,3	14,9	553	40,1	0,0	604	48,8	73,3
503	36,4	15,1	554	29,9	8,0	605	51,0	82,3
504	38,0	15,3	555	32,5	15,0	606	52,1	0,0
505	40,3	50,9	556	34,6	63,1	607	52,0	m
506	43,0	39,7	557	36,7	58,0	608	50,9	m
507	45,5	20,6	558	39,4	52,9	609	49,4	m
508	47,3	20,6	559	42,8	47,8	610	47,8	m
509	48,8	22,1	560	46,8	42,7	611	46,6	m
510	50,1	22,1	561	50,7	27,5	612	47,3	35,3

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	%	%	s	%	%	s	%	%
613	49,2	74,1	664	66,9	0,0	715	0,0	0,0
614	51,1	95,2	665	60,4	41,8	716	0,0	0,0
615	51,7	m	666	69,1	79,0	717	0,0	0,0
616	50,8	m	667	77,1	38,3	718	0,0	0,0
617	47,3	m	668	63,1	0,0	719	0,0	0,0
618	41,8	m	669	49,1	47,9	720	0,0	0,0
619	36,4	m	670	53,4	91,3	721	0,0	0,0
620	30,9	m	671	57,5	85,7	722	0,0	0,0
621	25,5	37,1	672	61,5	89,2	723	0,0	0,0
622	33,8	38,4	673	65,5	85,9	724	0,0	0,0
623	42,1	m	674	69,5	89,5	725	0,0	0,0
624	34,1	m	675	73,1	75,5	726	0,0	0,0
625	33,0	37,1	676	76,2	73,6	727	0,0	0,0
626	36,4	38,4	677	79,1	75,6	728	0,0	0,0
627	43,3	17,1	678	81,8	78,2	729	0,0	0,0
628	35,7	0,0	679	84,1	39,0	730	0,0	0,0
629	28,1	11,6	680	69,6	0,0	731	0,0	0,0
630	36,5	19,2	681	55,0	25,2	732	0,0	0,0
631	45,2	8,3	682	55,8	49,9	733	0,0	0,0
632	36,5	0,0	683	56,7	46,4	734	0,0	0,0
633	27,9	32,6	684	57,6	76,3	735	0,0	0,0
634	31,5	59,6	685	58,4	92,7	736	0,0	0,0
635	34,4	65,2	686	59,3	99,9	737	0,0	0,0
636	37,0	59,6	687	60,1	95,0	738	0,0	0,0
637	39,0	49,0	688	61,0	46,7	739	0,0	0,0
638	40,2	m	689	46,6	0,0	740	0,0	0,0
639	39,8	m	690	32,3	34,6	741	0,0	0,0
640	36,0	m	691	32,7	68,6	742	0,0	0,0
641	29,7	m	692	32,6	67,0	743	0,0	0,0
642	21,5	m	693	31,3	m	744	0,0	0,0
643	14,1	m	694	28,1	m	745	0,0	0,0
644	0,0	0,0	695	43,0	0,0	746	0,0	0,0
645	0,0	0,0	696	58,0	m	747	0,0	0,0
646	0,0	0,0	697	58,9	m	748	0,0	0,0
647	0,0	0,0	698	49,4	m	749	0,0	0,0
648	0,0	0,0	699	41,5	m	750	0,0	0,0
649	0,0	0,0	700	48,4	0,0	751	0,0	0,0
650	0,0	0,0	701	55,3	m	752	0,0	0,0
651	0,0	0,0	702	41,8	m	753	0,0	0,0
652	0,0	0,0	703	31,6	m	754	0,0	0,0
653	0,0	0,0	704	24,6	m	755	0,0	0,0
654	0,0	0,0	705	15,2	m	756	0,0	0,0
655	0,0	0,0	706	7,0	m	757	0,0	0,0
656	0,0	3,4	707	0,0	0,0	758	0,0	0,0
657	1,4	22,0	708	0,0	0,0	759	0,0	0,0
658	10,1	45,3	709	0,0	0,0	760	0,0	0,0
659	21,5	10,0	710	0,0	0,0	761	0,0	0,0
660	32,2	0,0	711	0,0	0,0	762	0,0	0,0
661	42,3	46,0	712	0,0	0,0	763	0,0	0,0
662	57,1	74,1	713	0,0	0,0	764	0,0	0,0
663	72,1	34,2	714	0,0	0,0	765	0,0	0,0

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	%	%		%	%		%	%
766	0,0	0,0	817	50,6	62,1	868	37,0	m
767	0,0	0,0	818	52,3	62,9	869	36,6	m
768	0,0	0,0	819	54,8	37,5	870	36,0	m
769	0,0	0,0	820	57,0	18,3	871	35,4	m
770	0,0	0,0	821	42,3	0,0	872	34,7	m
771	0,0	22,0	822	27,6	29,1	873	34,1	m
772	4,5	25,8	823	28,4	57,0	874	33,6	m
773	15,5	42,8	824	29,1	51,8	875	33,3	m
774	30,5	46,8	825	29,6	35,3	876	33,1	m
775	45,5	29,3	826	29,7	33,3	877	32,7	m
776	49,2	13,6	827	29,8	17,7	878	31,4	m
777	39,5	0,0	828	29,5	m	879	45,0	0,0
778	29,7	15,1	829	28,9	m	880	58,5	m
779	34,8	26,9	830	43,0	0,0	881	53,7	m
780	40,0	13,6	831	57,1	m	882	47,5	m
781	42,2	m	832	57,7	m	883	40,6	m
782	42,1	m	833	56,0	m	884	34,1	m
783	40,8	m	834	53,8	m	885	45,3	0,0
784	37,7	37,6	835	51,2	m	886	56,4	m
785	47,0	35,0	836	48,1	m	887	51,0	m
786	48,8	33,4	837	44,5	m	888	44,5	m
787	41,7	m	838	40,9	m	889	36,4	m
788	27,7	m	839	38,1	m	890	26,6	m
789	17,2	m	840	37,2	42,7	891	20,0	m
790	14,0	37,6	841	37,5	70,8	892	13,3	m
791	18,4	25,0	842	39,1	48,6	893	6,7	m
792	27,6	17,7	843	41,3	0,1	894	0,0	0,0
793	39,8	6,8	844	42,3	m	895	0,0	0,0
794	34,3	0,0	845	42,0	m	896	0,0	0,0
795	28,7	26,5	846	40,8	m	897	0,0	0,0
796	41,5	40,9	847	38,6	m	898	0,0	0,0
797	53,7	17,5	848	35,5	m	899	0,0	0,0
798	42,4	0,0	849	32,1	m	900	0,0	0,0
799	31,2	27,3	850	29,6	m	901	0,0	5,8
800	32,3	53,2	851	28,8	39,9	902	2,5	27,9
801	34,5	60,6	852	29,2	52,9	903	12,4	29,0
802	37,6	68,0	853	30,9	76,1	904	19,4	30,1
803	41,2	75,4	854	34,3	76,5	905	29,3	31,2
804	45,8	82,8	855	38,3	75,5	906	37,1	10,4
805	52,3	38,2	856	42,5	74,8	907	40,6	4,9
806	42,5	0,0	857	46,6	74,2	908	35,8	0,0
807	32,6	30,5	858	50,7	76,2	909	30,9	7,6
808	35,0	57,9	859	54,8	75,1	910	35,4	13,8
809	36,0	77,3	860	58,7	36,3	911	36,5	11,1
810	37,1	96,8	861	45,2	0,0	912	40,8	48,5
811	39,6	80,8	862	31,8	37,2	913	49,8	3,7
812	43,4	78,3	863	33,8	71,2	914	41,2	0,0
813	47,2	73,4	864	35,5	46,4	915	32,7	29,7
814	49,6	66,9	865	36,6	33,6	916	39,4	52,1
815	50,2	62,0	866	37,2	20,0	917	48,8	22,7
816	50,2	57,7	867	37,2	m	918	41,6	0,0

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	%	%	s	%	%	s	%	%
919	34,5	46,6	970	35,4	30,2	1021	52,5	13,1
920	39,7	84,4	971	36,6	55,6	1022	56,2	6,3
921	44,7	83,2	972	38,6	48,5	1023	44,0	0,0
922	49,5	78,9	973	39,9	41,8	1024	31,8	20,9
923	52,3	83,8	974	40,3	38,2	1025	38,7	36,3
924	53,4	77,7	975	40,8	35,0	1026	47,7	47,5
925	52,1	69,6	976	41,9	32,4	1027	54,5	22,0
926	47,9	63,6	977	43,2	26,4	1028	41,3	0,0
927	46,4	55,2	978	43,5	m	1029	28,1	26,8
928	46,5	53,6	979	42,9	m	1030	31,6	49,2
929	46,4	62,3	980	41,5	m	1031	34,5	39,5
930	46,1	58,2	981	40,9	m	1032	36,4	24,0
931	46,2	61,8	982	40,5	m	1033	36,7	m
932	47,3	62,3	983	39,5	m	1034	35,5	m
933	49,3	57,1	984	38,3	m	1035	33,8	m
934	52,6	58,1	985	36,9	m	1036	33,7	19,8
935	56,3	56,0	986	35,4	m	1037	35,3	35,1
936	59,9	27,2	987	34,5	m	1038	38,0	33,9
937	45,8	0,0	988	33,9	m	1039	40,1	34,5
938	31,8	28,8	989	32,6	m	1040	42,2	40,4
939	32,7	56,5	990	30,9	m	1041	45,2	44,0
940	33,4	62,8	991	29,9	m	1042	48,3	35,9
941	34,6	68,2	992	29,2	m	1043	50,1	29,6
942	35,8	68,6	993	44,1	0,0	1044	52,3	38,5
943	38,6	65,0	994	59,1	m	1045	55,3	57,7
944	42,3	61,9	995	56,8	m	1046	57,0	50,7
945	44,1	65,3	996	53,5	m	1047	57,7	25,2
946	45,3	63,2	997	47,8	m	1048	42,9	0,0
947	46,5	30,6	998	41,9	m	1049	28,2	15,7
948	46,7	11,1	999	35,9	m	1050	29,2	30,5
949	45,9	16,1	1000	44,3	0,0	1051	31,1	52,6
950	45,6	21,8	1001	52,6	m	1052	33,4	60,7
951	45,9	24,2	1002	43,4	m	1053	35,0	61,4
952	46,5	24,7	1003	50,6	0,0	1054	35,3	18,2
953	46,7	24,7	1004	57,8	m	1055	35,2	14,9
954	46,8	28,2	1005	51,6	m	1056	34,9	11,7
955	47,2	31,2	1006	44,8	m	1057	34,5	12,9
956	47,6	29,6	1007	48,6	0,0	1058	34,1	15,5
957	48,2	31,2	1008	52,4	m	1059	33,5	m
958	48,6	33,5	1009	45,4	m	1060	31,8	m
959	48,8	m	1010	37,2	m	1061	30,1	m
960	47,6	m	1011	26,3	m	1062	29,6	10,3
961	46,3	m	1012	17,9	m	1063	30,0	26,5
962	45,2	m	1013	16,2	1,9	1064	31,0	18,8
963	43,5	m	1014	17,8	7,5	1065	31,5	26,5
964	41,4	m	1015	25,2	18,0	1066	31,7	m
965	40,3	m	1016	39,7	6,5	1067	31,5	m
966	39,4	m	1017	38,6	0,0	1068	30,6	m
967	38,0	m	1018	37,4	5,4	1069	30,0	m
968	36,3	m	1019	43,4	9,7	1070	30,0	m
969	35,3	5,8	1020	46,9	15,7	1071	29,4	m

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	%	%		%	%		%	%
1072	44,3	0,0	1123	31,0	12,4	1174	0,0	0,0
1073	59,2	m	1124	30,1	18,5	1175	0,0	0,0
1074	58,3	m	1125	30,4	35,6	1176	0,0	0,0
1075	57,1	m	1126	31,2	30,1	1177	0,0	0,0
1076	55,4	m	1127	31,5	30,8	1178	0,0	0,0
1077	53,5	m	1128	31,5	26,9	1179	0,0	0,0
1078	51,5	m	1129	31,7	33,9	1180	0,0	0,0
1079	49,7	m	1130	32,0	29,9	1181	0,0	0,0
1080	47,9	m	1131	32,1	m	1182	0,0	0,0
1081	46,4	m	1132	31,4	m	1183	0,0	0,0
1082	45,5	m	1133	30,3	m	1184	0,0	0,0
1083	45,2	m	1134	29,8	m	1185	0,0	0,0
1084	44,3	m	1135	44,3	0,0	1186	0,0	0,0
1085	43,6	m	1136	58,9	m	1187	0,0	0,0
1086	43,1	m	1137	52,1	m	1188	0,0	0,0
1087	42,5	25,6	1138	44,1	m	1189	0,0	0,0
1088	43,3	25,7	1139	51,7	0,0	1190	0,0	0,0
1089	46,3	24,0	1140	59,2	m	1191	0,0	0,0
1090	47,8	20,6	1141	47,2	m	1192	0,0	0,0
1091	47,2	3,8	1142	35,1	0,0	1193	0,0	0,0
1092	45,6	4,4	1143	23,1	m	1194	0,0	0,0
1093	44,6	4,1	1144	13,1	m	1195	0,0	0,0
1094	44,1	m	1145	5,0	m	1196	0,0	20,4
1095	42,9	m	1146	0,0	0,0	1197	12,6	41,2
1096	40,9	m	1147	0,0	0,0	1198	27,3	20,4
1097	39,2	m	1148	0,0	0,0	1199	40,4	7,6
1098	37,0	m	1149	0,0	0,0	1200	46,1	m
1099	35,1	2,0	1150	0,0	0,0	1201	44,6	m
1100	35,6	43,3	1151	0,0	0,0	1202	42,7	14,7
1101	38,7	47,6	1152	0,0	0,0	1203	42,9	7,3
1102	41,3	40,4	1153	0,0	0,0	1204	36,1	0,0
1103	42,6	45,7	1154	0,0	0,0	1205	29,3	15,0
1104	43,9	43,3	1155	0,0	0,0	1206	43,8	22,6
1105	46,9	41,2	1156	0,0	0,0	1207	54,9	9,9
1106	52,4	40,1	1157	0,0	0,0	1208	44,9	0,0
1107	56,3	39,3	1158	0,0	0,0	1209	34,9	47,4
1108	57,4	25,5	1159	0,0	0,0	1210	42,7	82,7
1109	57,2	25,4	1160	0,0	0,0	1211	52,0	81,2
1110	57,0	25,4	1161	0,0	0,0	1212	61,8	82,7
1111	56,8	25,3	1162	0,0	0,0	1213	71,3	39,1
1112	56,3	25,3	1163	0,0	0,0	1214	58,1	0,0
1113	55,6	25,2	1164	0,0	0,0	1215	44,9	42,5
1114	56,2	25,2	1165	0,0	0,0	1216	46,3	83,3
1115	58,0	12,4	1166	0,0	0,0	1217	46,8	74,1
1116	43,4	0,0	1167	0,0	0,0	1218	48,1	75,7
1117	28,8	26,2	1168	0,0	0,0	1219	50,5	75,8
1118	30,9	49,9	1169	0,0	0,0	1220	53,6	76,7
1119	32,3	40,5	1170	0,0	0,0	1221	56,9	77,1
1120	32,5	12,4	1171	0,0	0,0	1222	60,2	78,7
1121	32,4	12,2	1172	0,0	0,0	1223	63,7	78,0
1122	32,1	6,4	1173	0,0	0,0	1224	67,2	79,6

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	%	%		%	%		%	%
1225	70,7	80,9	1276	42,3	m	1327	37,6	57,8
1226	74,1	81,1	1277	41,0	m	1328	37,3	73,2
1227	77,5	83,6	1278	39,6	m	1329	37,3	59,8
1228	80,8	85,6	1279	38,3	m	1330	37,4	52,2
1229	84,1	81,6	1280	37,1	m	1331	37,4	16,9
1230	87,4	88,3	1281	35,9	m	1332	37,1	34,3
1231	90,5	91,9	1282	34,6	m	1333	36,7	51,9
1232	93,5	94,1	1283	33,0	m	1334	36,2	25,3
1233	96,8	96,6	1284	31,1	m	1335	35,6	m
1234	100,0	m	1285	29,2	m	1336	34,6	m
1235	96,0	m	1286	43,3	0,0	1337	33,2	m
1236	81,9	m	1287	57,4	32,8	1338	31,6	m
1237	68,1	m	1288	59,9	65,4	1339	30,1	m
1238	58,1	84,7	1289	61,9	76,1	1340	28,8	m
1239	58,5	85,4	1290	65,6	73,7	1341	28,0	29,5
1240	59,5	85,6	1291	69,9	79,3	1342	28,6	100,0
1241	61,0	86,6	1292	74,1	81,3	1343	28,8	97,3
1242	62,6	86,8	1293	78,3	83,2	1344	28,8	73,4
1243	64,1	87,6	1294	82,6	86,0	1345	29,6	56,9
1244	65,4	87,5	1295	87,0	89,5	1346	30,3	91,7
1245	66,7	87,8	1296	91,2	90,8	1347	31,0	90,5
1246	68,1	43,5	1297	95,3	45,9	1348	31,8	81,7
1247	55,2	0,0	1298	81,0	0,0	1349	32,6	79,5
1248	42,3	37,2	1299	66,6	38,2	1350	33,5	86,9
1249	43,0	73,6	1300	67,9	75,5	1351	34,6	100,0
1250	43,5	65,1	1301	68,4	80,5	1352	35,6	78,7
1251	43,8	53,1	1302	69,0	85,5	1353	36,4	50,5
1252	43,9	54,6	1303	70,0	85,2	1354	37,0	57,0
1253	43,9	41,2	1304	71,6	85,9	1355	37,3	69,1
1254	43,8	34,8	1305	73,3	86,2	1356	37,6	49,5
1255	43,6	30,3	1306	74,8	86,5	1357	37,8	44,4
1256	43,3	21,9	1307	76,3	42,9	1358	37,8	43,4
1257	42,8	19,9	1308	63,3	0,0	1359	37,8	34,8
1258	42,3	m	1309	50,4	21,2	1360	37,6	24,0
1259	41,4	m	1310	50,6	42,3	1361	37,2	m
1260	40,2	m	1311	50,6	53,7	1362	36,3	m
1261	38,7	m	1312	50,4	90,1	1363	35,1	m
1262	37,1	m	1313	50,5	97,1	1364	33,7	m
1263	35,6	m	1314	51,0	100,0	1365	32,4	m
1264	34,2	m	1315	51,9	100,0	1366	31,1	m
1265	32,9	m	1316	52,6	100,0	1367	29,9	m
1266	31,8	m	1317	52,8	32,4	1368	28,7	m
1267	30,7	m	1318	47,7	0,0	1369	29,0	58,6
1268	29,6	m	1319	42,6	27,4	1370	29,7	88,5
1269	40,4	0,0	1320	42,1	53,5	1371	31,0	86,3
1270	51,2	m	1321	41,8	44,5	1372	31,8	43,4
1271	49,6	m	1322	41,4	41,1	1373	31,7	m
1272	48,0	m	1323	41,0	21,0	1374	29,9	m
1273	46,4	m	1324	40,3	0,0	1375	40,2	0,0
1274	45,0	m	1325	39,3	1,0	1376	50,4	m
1275	43,6	m	1326	38,3	15,2	1377	47,9	m

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	%	%		%	%		%	%
1378	45,0	m	1429	52,7	37,2	1480	56,1	94,9
1379	43,0	m	1430	41,6	0,0	1481	56,3	86,2
1380	40,6	m	1431	30,4	36,6	1482	56,2	64,1
1381	55,5	0,0	1432	30,5	73,2	1483	56,0	46,1
1382	70,4	41,7	1433	30,3	81,6	1484	56,2	33,4
1383	73,4	83,2	1434	30,4	89,3	1485	56,5	23,6
1384	74,0	83,7	1435	31,5	90,4	1486	56,3	18,6
1385	74,9	41,7	1436	32,7	88,5	1487	55,7	16,2
1386	60,0	0,0	1437	33,7	97,2	1488	56,0	15,9
1387	45,1	41,6	1438	35,2	99,7	1489	55,9	21,8
1388	47,7	84,2	1439	36,3	98,8	1490	55,8	20,9
1389	50,4	50,2	1440	37,7	100,0	1491	55,4	18,4
1390	53,0	26,1	1441	39,2	100,0	1492	55,7	25,1
1391	59,5	0,0	1442	40,9	100,0	1493	56,0	27,7
1392	66,2	38,4	1443	42,4	99,5	1494	55,8	22,4
1393	66,4	76,7	1444	43,8	98,7	1495	56,1	20,0
1394	67,6	100,0	1445	45,4	97,3	1496	55,7	17,4
1395	68,4	76,6	1446	47,0	96,6	1497	55,9	20,9
1396	68,2	47,2	1447	47,8	96,2	1498	56,0	22,9
1397	69,0	81,4	1448	48,8	96,3	1499	56,0	21,1
1398	69,7	40,6	1449	50,5	95,1	1500	55,1	19,2
1399	54,7	0,0	1450	51,0	95,9	1501	55,6	24,2
1400	39,8	19,9	1451	52,0	94,3	1502	55,4	25,6
1401	36,3	40,0	1452	52,6	94,6	1503	55,7	24,7
1402	36,7	59,4	1453	53,0	65,5	1504	55,9	24,0
1403	36,6	77,5	1454	53,2	0,0	1505	55,4	23,5
1404	36,8	94,3	1455	53,2	m	1506	55,7	30,9
1405	36,8	100,0	1456	52,6	m	1507	55,4	42,5
1406	36,4	100,0	1457	52,1	m	1508	55,3	25,8
1407	36,3	79,7	1458	51,8	m	1509	55,4	1,3
1408	36,7	49,5	1459	51,3	m	1510	55,0	m
1409	36,6	39,3	1460	50,7	m	1511	54,4	m
1410	37,3	62,8	1461	50,7	m	1512	54,2	m
1411	38,1	73,4	1462	49,8	m	1513	53,5	m
1412	39,0	72,9	1463	49,4	m	1514	52,4	m
1413	40,2	72,0	1464	49,3	m	1515	51,8	m
1414	41,5	71,2	1465	49,1	m	1516	50,7	m
1415	42,9	77,3	1466	49,1	m	1517	49,9	m
1416	44,4	76,6	1467	49,1	8,3	1518	49,1	m
1417	45,4	43,1	1468	48,9	16,8	1519	47,7	m
1418	45,3	53,9	1469	48,8	21,3	1520	47,3	m
1419	45,1	64,8	1470	49,1	22,1	1521	46,9	m
1420	46,5	74,2	1471	49,4	26,3	1522	46,9	m
1421	47,7	75,2	1472	49,8	39,2	1523	47,2	m
1422	48,1	75,5	1473	50,4	83,4	1524	47,8	m
1423	48,6	75,8	1474	51,4	90,6	1525	48,2	0,0
1424	48,9	76,3	1475	52,3	93,8	1526	48,8	23,0
1425	49,9	75,5	1476	53,3	94,0	1527	49,1	67,9
1426	50,4	75,2	1477	54,2	94,1	1528	49,4	73,7
1427	51,1	74,6	1478	54,9	94,3	1529	49,8	75,0
1428	51,9	75,0	1479	55,7	94,6	1530	50,4	75,8

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	%	%		%	%		%	%
1531	51,4	73,9	1582	56,4	48,9	1633	56,6	45,2
1532	52,3	72,2	1583	56,4	48,2	1634	56,8	46,0
1533	53,3	71,2	1584	56,5	48,3	1635	56,5	46,6
1534	54,6	71,2	1585	56,5	47,9	1636	56,6	48,3
1535	55,4	68,7	1586	56,6	46,8	1637	56,4	48,6
1536	56,7	67,0	1587	56,6	46,2	1638	56,6	50,3
1537	57,2	64,6	1588	56,5	44,4	1639	56,3	51,9
1538	57,3	61,9	1589	56,8	42,9	1640	56,5	54,1
1539	57,0	59,5	1590	56,5	42,8	1641	56,3	54,9
1540	56,7	57,0	1591	56,7	43,2	1642	56,4	55,0
1541	56,7	69,8	1592	56,5	42,8	1643	56,4	56,2
1542	56,8	58,5	1593	56,9	42,2	1644	56,2	58,6
1543	56,8	47,2	1594	56,5	43,1	1645	56,2	59,1
1544	57,0	38,5	1595	56,5	42,9	1646	56,2	62,5
1545	57,0	32,8	1596	56,7	42,7	1647	56,4	62,8
1546	56,8	30,2	1597	56,6	41,5	1648	56,0	64,7
1547	57,0	27,0	1598	56,9	41,8	1649	56,4	65,6
1548	56,9	26,2	1599	56,6	41,9	1650	56,2	67,7
1549	56,7	26,2	1600	56,7	42,6	1651	55,9	68,9
1550	57,0	26,6	1601	56,7	42,6	1652	56,1	68,9
1551	56,7	27,8	1602	56,7	41,5	1653	55,8	69,5
1552	56,7	29,7	1603	56,7	42,2	1654	56,0	69,8
1553	56,8	32,1	1604	56,5	42,2	1655	56,2	69,3
1554	56,5	34,9	1605	56,8	41,9	1656	56,2	69,8
1555	56,6	34,9	1606	56,5	42,0	1657	56,4	69,2
1556	56,3	35,8	1607	56,7	42,1	1658	56,3	68,7
1557	56,6	36,6	1608	56,4	41,9	1659	56,2	69,4
1558	56,2	37,6	1609	56,7	42,9	1660	56,2	69,5
1559	56,6	38,2	1610	56,7	41,8	1661	56,2	70,0
1560	56,2	37,9	1611	56,7	41,9	1662	56,4	69,7
1561	56,6	37,5	1612	56,8	42,0	1663	56,2	70,2
1562	56,4	36,7	1613	56,7	41,5	1664	56,4	70,5
1563	56,5	34,8	1614	56,6	41,9	1665	56,1	70,5
1564	56,5	35,8	1615	56,8	41,6	1666	56,5	69,7
1565	56,5	36,2	1616	56,6	41,6	1667	56,2	69,3
1566	56,5	36,7	1617	56,9	42,0	1668	56,5	70,9
1567	56,7	37,8	1618	56,7	40,7	1669	56,4	70,8
1568	56,7	37,8	1619	56,7	39,3	1670	56,3	71,1
1569	56,6	36,6	1620	56,5	41,4	1671	56,4	71,0
1570	56,8	36,1	1621	56,4	44,9	1672	56,7	68,6
1571	56,5	36,8	1622	56,8	45,2	1673	56,8	68,6
1572	56,9	35,9	1623	56,6	43,6	1674	56,6	68,0
1573	56,7	35,0	1624	56,8	42,2	1675	56,8	65,1
1574	56,5	36,0	1625	56,5	42,3	1676	56,9	60,9
1575	56,4	36,5	1626	56,5	44,4	1677	57,1	57,4
1576	56,5	38,0	1627	56,9	45,1	1678	57,1	54,3
1577	56,5	39,9	1628	56,4	45,0	1679	57,0	48,6
1578	56,4	42,1	1629	56,7	46,3	1680	57,4	44,1
1579	56,5	47,0	1630	56,7	45,5	1681	57,4	40,2
1580	56,4	48,0	1631	56,8	45,0	1682	57,6	36,9
1581	56,1	49,1	1632	56,7	44,9	1683	57,5	34,2

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	%	%		%	%		%	%
1684	57,4	31,1	1735	55,8	49,3	1786	31,6	m
1685	57,5	25,9	1736	55,9	47,7	1787	25,8	m
1686	57,5	20,7	1737	55,9	47,4	1788	19,9	m
1687	57,6	16,4	1738	55,8	46,9	1789	14,0	m
1688	57,6	12,4	1739	56,1	46,8	1790	8,1	m
1689	57,6	8,9	1740	56,1	45,8	1791	2,2	m
1690	57,5	8,0	1741	56,2	46,0	1792	0,0	0,0
1691	57,5	5,8	1742	56,3	45,9	1793	0,0	0,0
1692	57,3	5,8	1743	56,3	45,9	1794	0,0	0,0
1693	57,6	5,5	1744	56,2	44,6	1795	0,0	0,0
1694	57,3	4,5	1745	56,2	46,0	1796	0,0	0,0
1695	57,2	3,2	1746	56,4	46,2	1797	0,0	0,0
1696	57,2	3,1	1747	55,8	m	1798	0,0	0,0
1697	57,3	4,9	1748	55,5	m	1799	0,0	0,0
1698	57,3	4,2	1749	55,0	m	1800	0,0	0,0
1699	56,9	5,5	1750	54,1	m			
1700	57,1	5,1	1751	54,0	m			
1701	57,0	5,2	1752	53,3	m			
1702	56,9	5,5	1753	52,6	m			
1703	56,6	5,4	1754	51,8	m			
1704	57,1	6,1	1755	50,7	m			
1705	56,7	5,7	1756	49,9	m			
1706	56,8	5,8	1757	49,1	m			
1707	57,0	6,1	1758	47,7	m			
1708	56,7	5,9	1759	46,8	m			
1709	57,0	6,6	1760	45,7	m			
1710	56,9	6,4	1761	44,8	m			
1711	56,7	6,7	1762	43,9	m			
1712	56,9	6,9	1763	42,9	m			
1713	56,8	5,6	1764	41,5	m			
1714	56,6	5,1	1765	39,5	m			
1715	56,6	6,5	1766	36,7	m			
1716	56,5	10,0	1767	33,8	m			
1717	56,6	12,4	1768	31,0	m			
1718	56,5	14,5	1769	40,0	0,0			
1719	56,6	16,3	1770	49,1	m			
1720	56,3	18,1	1771	46,2	m			
1721	56,6	20,7	1772	43,1	m			
1722	56,1	22,6	1773	39,9	m			
1723	56,3	25,8	1774	36,6	m			
1724	56,4	27,7	1775	33,6	m			
1725	56,0	29,7	1776	30,5	m			
1726	56,1	32,6	1777	42,8	0,0			
1727	55,9	34,9	1778	55,2	m			
1728	55,9	36,4	1779	49,9	m			
1729	56,0	39,2	1780	44,0	m			
1730	55,9	41,4	1781	37,6	m			
1731	55,5	44,2	1782	47,2	0,0			
1732	55,9	46,4	1783	56,8	m			
1733	55,8	48,3	1784	47,5	m			
1734	55,6	49,1	1785	42,9	m			

m = motoring

### **10.3 Reference Fuels**

## 10.4 Determination of System Equivalence

The determination of system equivalency according to 5.1.1 shall be based on a 7 sample pair (or larger) correlation study between the candidate system and one of the accepted reference systems of this standard using the appropriate test cycle. **The equivalency criteria to be applied shall be the F-test and the two-sided Student t-test.**

This statistical method examines the hypothesis that the population mean value for an emission measured with the candidate system does not differ from the population mean value for that emission measured with the candidate system. The hypothesis shall be tested on the basis of a **5 % significance level of the F and t values. The critical F and t values for 7 to 10 sample pairs are given in table 9. If the F and t values calculated according to the formulae below are greater than the critical F and t values, the candidate system is not equivalent.**

The following procedure shall be applied. The indices R and C refer to the reference and candidate system, respectively.

- Conduct at least 7 tests with the candidate and reference systems preferably operated in parallel. The number of tests is referred to as  $n_R$  and  $n_C$ .
- Calculate the mean values  $x_R$  and  $x_C$  and the standard deviations  $s_R$  and  $s_C$ .
- Calculate the F value, as follows:**

$$F = \frac{s_{\text{major}}^2}{s_{\text{minor}}^2} \quad (83)$$

(the greater of the two standard deviations  $s_R$  or  $s_C$  must be in the numerator)

- Calculate the test value  $t$  as follows:

$$t = \frac{x_C - x_R}{\sqrt{(n_C - 1) \times s_C^2 + (n_R - 1) \times s_R^2}} \times \sqrt{\frac{n_C \times n_R \times (n_C + n_R - 2)}{n_C + n_R}} \quad (84)$$

- Compare the calculated  $F$  and  $t$  values with the critical  $F$  and  $t$  values corresponding to the respective number of tests indicated in table 9. **If larger sample sizes are selected, consult statistical tables for 5 % significance (95 % confidence) level.**

- Determine the degrees of freedom (df), as follows:**

**for the F-test: df =  $n_R - 1$  /  $n_C - 1$**

**for the t-test: df =  $n_C + n_R - 2$**

- Determine the equivalency, as follows:

- **if  $F < F_{\text{crit}}$  and  $t < t_{\text{crit}}$** , then candidate system is equivalent to reference system of this GTR
- **if  $F \geq F_{\text{crit}}$  and  $t \geq t_{\text{crit}}$** , then candidate system is different from reference system of this GTR

**Table 9 "t" values for selected sample sizes**

Sample Size	F-test		t-test	
	df	$F_{\text{crit}}$	df	$t_{\text{crit}}$
7	6/6	4,284	12	2,179
8	7/7	3,787	14	2,145
9	8/8	3,438	16	2,120
10	9/9	3,179	18	2,101

## 10.5 Carbon flow check

### 10.5.1 Introduction

All but a tiny part of the carbon in the exhaust comes from the fuel, and all but a minimal part of this is manifest in the exhaust gas as CO<sub>2</sub>. This is the basis for a system verification check based on CO<sub>2</sub> measurements.

The flow of carbon into the exhaust measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO<sub>2</sub> concentrations and gas flow rates at those points.

In this sense, the engine provides a known source of carbon flow, and observing the same carbon flow in the exhaust pipe and at the outlet of the partial flow PM sampling system verifies leak integrity and flow measurement accuracy. This check has the advantage that the components are operating under actual engine test conditions of temperature and flow.

Figure 14 shows the sampling points at which the carbon flows shall be checked. The specific equations for the carbon flows at each of the sample points are given below.

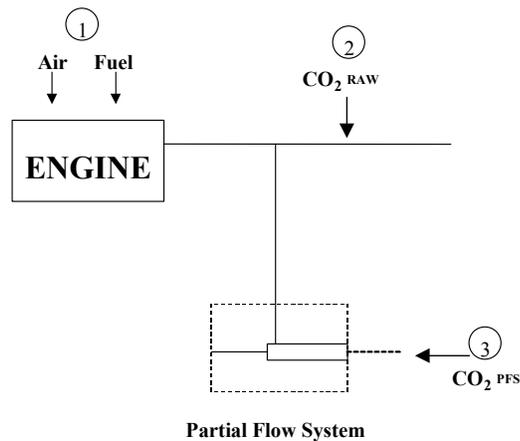


Figure 14 — Measuring points for carbon flow check

### 10.5.2 Carbon flow rate into the engine (location 1.)

The carbon mass flow rate into the engine for a fuel C<sub>β</sub>H<sub>α</sub>O<sub>ε</sub> is given by:

$$q_{mCf} = \frac{12\beta}{12\beta + \alpha + 16\varepsilon} \cdot q_{mf} \quad (80)$$

where

$q_{mf}$  = fuel mass flow rate, kg/s

### 10.5.3 Carbon flow rate in the raw exhaust (location 2.)

The carbon mass flow rate in the exhaust pipe of the engine shall be determined from the raw CO<sub>2</sub> concentration and the exhaust gas mass flow rate:

$$q_{mCe} = \left( \frac{c_{CO_2,r} - c_{CO_2,a}}{100} \right) \cdot q_{mew} \cdot \frac{12,011}{M_{re}} \quad (81)$$

where

$c_{CO_2,r}$	=	wet CO <sub>2</sub> concentration in the raw exhaust gas, %
$c_{CO_2,a}$	=	wet CO <sub>2</sub> concentration in the ambient air, % (around 0,04 %)
$q_{mew}$	=	exhaust gas mass flow rate on wet basis, kg/s
$M_{re}$	=	molecular mass of exhaust gas

If CO<sub>2</sub> is measured on a dry basis it shall be converted to a wet basis according to 8.1

#### 10.5.4 Carbon flow rate in the dilution system (location 3.)

For the partial flow dilution system, the splitting ratio also needs to be taken into account. The carbon flow rate shall be determined from the dilute CO<sub>2</sub> concentration, the exhaust gas mass flow rate and the sample flow rate:

$$q_{mCp} = \left( \frac{c_{CO_2,d} - c_{CO_2,a}}{100} \right) \cdot q_{mdew} \cdot \frac{12,011}{M_{re}} \cdot \frac{q_{mew}}{q_{mp}} \quad (82)$$

where

$c_{CO_2,d}$	=	wet CO <sub>2</sub> concentration in the dilute exhaust gas at the outlet of the dilution tunnel, %
$c_{CO_2,a}$	=	wet CO <sub>2</sub> concentration in the ambient air, % (around 0,04 %)
$q_{mew}$	=	exhaust gas mass flow rate on wet basis, kg/s
$q_{mp}$	=	sample flow of exhaust gas into partial flow dilution system, kg/s
$M_{re}$	=	molecular mass of exhaust gas

If CO<sub>2</sub> is measured on a dry basis, it shall be converted to wet basis according to paragraph 8.1

#### 10.5.5 Calculation of the molecular mass of the exhaust gas

The molecular mass ( $M_{re}$ ) of the exhaust gas shall be calculated as follows:

$$M_{re} = \frac{1 + \frac{q_{mf}}{q_{maw}}}{\frac{q_{mf}}{q_{maw}} \times \frac{\frac{\alpha}{4} + \frac{\varepsilon}{2} + \frac{\delta}{2}}{12,011 + 1,00794 \times \alpha + 15,9994 \times \varepsilon + 14,0067 \times \delta + 32,065 \times \gamma} + \frac{\frac{H_a \times 10^{-3}}{2 \times 1,00794 + 15,9994} + \frac{1}{M_{ra}}}{1 + H_a \times 10^{-3}}} \quad (83)$$

where

$q_{mf}$	=	fuel mass flow rate, kg/s
$q_{maw}$	=	intake air mass flow rate on wet basis, kg/s
$H_a$	=	humidity of intake air, g water per kg dry air
$M_{ra}$	=	molecular mass of dry intake air (= 28,9 g/mol)
$\alpha, \delta, \varepsilon, \gamma$	=	molar ratios referring to a fuel C H <sub><math>\alpha</math></sub> O <sub><math>\delta</math></sub> N <sub><math>\varepsilon</math></sub> S <sub><math>\gamma</math></sub>

Alternatively, the following molecular masses may be used:

$M_{re}$ (diesel)	=	28,9 g/mol
$M_{re}$ (LPG)	=	28,6 g/mol
$M_{re}$ (NG)	=	28,3 g/mol

## 10.6 Example of Calculation Procedure

### 10.6.1 Basic data for stoichiometric calculations

Atomic weight of hydrogen	1,00794	
Atomic weight of carbon	12,011	
Atomic weight of sulfur	32,065	
Atomic weight of nitrogen	14,0067	
Atomic weight of oxygen	15,9994	
Atomic weight of argon	39,9	
Molar weight of water	18,01534	g/mol
Molar weight of carbon dioxide	44,01	g/mol
Molar weight of carbon monoxide	28,011	g/mol
Molar weight of oxygen	31,9988	g/mol
Molar weight of nitrogen	28,011	g/mol
Molar weight of nitric oxide	30,008	g/mol
Molar weight of nitrogen dioxide	46,01	g/mol
Molar weight of sulfur dioxide	64,066	g/mol
Molar volume of water	22,401	l/mol
Molar volume of carbon dioxide	22,262	l/mol
Molar volume of oxygen	22,392	l/mol
Molar volume of nitrogen	22,390	l/mol
Molar volume of nitric oxide	22,391	l/mol
Molar volume of nitrogen dioxide	21,809	l/mol
Molar volume of sulfur dioxide	21,891	l/mol
Molar volume of argon	22,4	l/mol

### 10.6.2 Gaseous Emissions (Diesel Fuel)

The measurement data of an individual point of the test cycle (data sampling rate of 1 Hz) for the calculation of the instantaneous mass emission are shown below. In this example, CO and NO<sub>x</sub> are measured on a dry basis, HC on a wet basis. The HC concentration is given in propane equivalent (C3) and has to be multiplied by 3 to result in the C1 equivalent. The calculation procedure is identical for the other points of the cycle.

$T_{a,i}$ (K)	$H_{a,i}$ (g/kg)	$W_{act}$ kWh	$q_{mew,i}$ (kg/s)	$q_{maw,i}$ (kg/s)	$q_{mf,i}$ (kg/s)	$c_{HC,i}$ (ppm)	$c_{CO,i}$ (ppm)	$c_{NOx,i}$ (ppm)
295	8,0	40	0,155	0,150	0,005	10	40	500

The following fuel composition is considered:

Component	Molar ratio	% Mass
H	$\alpha = 1,8529$	$w_{ALF} = 13,45$
C	$\beta = 1,0000$	$w_{BET} = 86,50$
S	$\gamma = 0,0002$	$w_{GAM} = 0,050$
N	$\delta = 0,0000$	$w_{DEL} = 0,000$
O	$\varepsilon = 0,0000$	$w_{EPS} = 0,000$

**Step 1: Dry/wet correction (8.1):**

$$\text{Formula (14): } k_f = 0,055584 \times 13,45 - 0,0001083 \times 86,5 - 0,0001562 \times 0,05 = 0,7382$$

$$\text{Formula (8): } k_w = \left( 1 - \frac{1,2434 \times 8 + 111,12 \times 13,45 \times \frac{0,005}{0,148}}{773,4 + 1,2434 \times 8 + \frac{0,005}{0,148} \times 0,7382 \times 1000} \right) \times 1,0085 = 0,9331$$

$$\text{Formula (7): } c_{CO,i}(\text{wet}) = 40 \times 0,9331 = 37,3 \text{ ppm}$$

$$c_{NOx,i}(\text{wet}) = 500 \times 0,9331 = 466,6 \text{ ppm}$$

**Step 2: NO<sub>x</sub> correction for temperature and humidity (8.2):**

$$\text{Formula (15): } k_{h,D} = \frac{1}{1 - 0,0182 \times (8,00 - 10,71) + 0,0045 \times (295 - 298)} = 0,9654$$

**Step 3: Calculation of the instantaneous mass emission using u values from table 4 (8.3.2.4):**

$$\text{Formula (22): } m_{HC,i} = 0,000478 \times 10 \times 3 \times 0,155 = 0,00222 \text{ g/s}$$

$$m_{CO,i} = 0,000966 \times 37,3 \times 0,155 = 0,00558 \text{ g/s}$$

$$m_{NOx,i} = 0,001587 \times 466,6 \times 0,9654 \times 0,155 = 0,1108 \text{ g/s}$$

**Step 4: Integration of the instantaneous mass emission over the cycle (8.3.2.4):**

The following calculation is assumed for the WHTC cycle (1800 s) and the same emission in each point of the cycle.

$$\text{Formula (22): } m_{HC} = \sum_{i=1}^{1800} 0,00222 = 3,96 \text{ g/test}$$

$$m_{CO} = \sum_{i=1}^{1800} 0,00558 = 10,04 \text{ g/test}$$

$$m_{NOx} = \sum_{i=1}^{1800} 0,1108 = 199,44 \text{ g/test}$$

**Step 5: Calculation of the specific emissions (8.3.2.6):**

$$\text{Formula (26): } HC = 3,96 / 40 = 0,10 \text{ g/kWh}$$

$$CO = 10,04 / 40 = 0,25 \text{ g/kWh}$$

$$NO_x = 199,44 / 40 = 4,99 \text{ g/kWh}$$

### 10.6.3 Particulate Emission (Diesel Fuel)

Particulate measurement is based on the principle of sampling the particulates over the complete cycle, but determining the sample and flow rates ( $M_{SAM}$  and  $G_{EDF}$ ) during the individual points of the cycle. The calculation of  $G_{EDFW}$  depends on the system used. In the following example, a system with flow measurement according to 8.3.3.5, method a) is used.

The following measurement data are assumed in this example:

$W_{act}$ kWh	$q_{mew,i}$ (kg/s)	$q_{mf,i}$ (kg/s)	$q_{mdw,i}$ (kg/s)	$q_{mdew,i}$ (kg/s)	$m_f$ (mg)	$m_{se}$ (kg)
40	0,155	0,005	0,0015	0,0020	1,700	1,515

#### Step 1: Calculation of $m_{edf}$ (clause 8.3.3.5):

$$\text{Formula (31): } r_{dil,i} = \frac{0,002}{(0,002 - 0,0015)} = 4$$

$$\text{Formula (30): } q_{medf,i} = 0,155 \times 4 = 0,62 \text{ kg/s}$$

$$\text{Formula (29): } m_{edf} = \sum_{i=1}^{1800} 0,62 = 1116 \text{ kg/test}$$

#### Step 2: Calculation of the particulate mass emission (clause 8.3.3.5):

$$\text{Formula (28): } m_{PM} = \frac{1,7}{1,515} \times \frac{1116}{1000} = 1,252 \text{ g/test}$$

#### Step 3: Calculation of the specific emissions (8.3.3.6):

$$\text{Formula (34): } PM = 1,252 / 40 = 0,031 \text{ g/kWh}$$