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**Reciprocating internal combustion  
engines — Exhaust emission  
measurement —**

**Part 11:  
Test-bed measurement of gaseous and  
particulate exhaust emissions from  
engines used in nonroad mobile  
machinery under transient test conditions**

*Moteurs alternatifs à combustion interne — Mesurage des émissions de  
gaz d'échappement —*

*Partie 11: Mesurage au banc d'essai des émissions de gaz et de  
particules des gaz d'échappement de moteurs d'engins mobiles non  
routiers en régime transitoire*



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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8178-11 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

ISO 8178 consists of the following parts, under the general title *Reciprocating internal combustion engines — Exhaust gas emission measurement*:

- *Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*
- *Part 2: Measurement of gaseous and particulate exhaust emissions at site*
- *Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions*
- *Part 4: Test cycles for different engine applications*
- *Part 5: Test fuels*
- *Part 6: Report of measuring results and tests*
- *Part 7: Engine family determination*
- *Part 8: Engine group determination*
- *Part 9: Test cycles and test procedures for test bed measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*
- *Part 10: Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*
- *Part 11: Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions*

## Introduction

Today's measurement systems depend on the type of test cycle, steady state or transient, and the type of pollutant to be measured. On a steady state cycle, the mass of gaseous emissions can be calculated either from the concentration in the raw exhaust gas and the exhaust flow of the engine, which can easily be determined, or from the concentration in the diluted exhaust gas and the CVS (Constant Volume Sampling) flow of a full flow dilution system. Both equivalent systems are described in ISO 8178-1. For PM, full flow dilution or partial flow dilution systems, in which only a portion of the exhaust gas is diluted, can be used.

On a transient cycle as covered by this International Standard, real-time exhaust flow determination is more difficult. Therefore, the CVS principle has been used for many years due to the fact that exhaust mass flow measurement is not required with this system. The total exhaust gas is diluted, the total flow as the sum of dilution air and exhaust gas flow is kept virtually constant and the emissions (gaseous and PM) are measured in the diluted exhaust gas. The space and cost requirements of such a system are considerably higher than for the partial flow dilution systems used on steady state cycles. On the other hand, raw exhaust measurement and partial flow systems can only be applied to transients if sophisticated control systems and calculation algorithms are used.

For most nonroad applications and heavy-duty engines, the CVS system is large and costly. Therefore, ISO 16183 has been developed by ISO/TC 22/SC 5, which defines raw gaseous emissions measurement and partial flow dilution for heavy-duty engines under transient test conditions. Since many nonroad engines are similar to heavy-duty engines in engine size, displacement and power, it is believed that the contents of ISO 16183 can also be applied to nonroad engines.

For the purpose of this International Standard, both full flow dilution and partial flow dilution/raw exhaust methods are considered equivalent and are therefore covered herein.



# Reciprocating internal combustion engines — Exhaust emission measurement —

## Part 11:

# Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions

## 1 Scope

This part of ISO 8178 specifies the measurement and evaluation methods for gaseous and particulate exhaust emission from reciprocating internal combustion (RIC) engines under transient conditions on a test bed, necessary for determining one value for each exhaust gas pollutant.

The specific transient test cycle covered by this part of ISO 8178 is applicable to compression-ignition engines for mobile use with a power output between 37 kW and 560 kW, excluding engines for motor vehicles primarily designed for road use. This part of ISO 8178 may be applied to engines used in off-road vehicles and diesel powered off-road industrial equipment as described in 8.3.1.3 of ISO 8178-4. This includes e.g. engines for construction equipment including wheel loaders, bulldozers, crawler tractors, crawler loaders, truck-type loaders, off-highway trucks, hydraulic excavators, agricultural equipment, self propelled agricultural vehicles (including tractors), forestry equipment, fork lift trucks, road maintenance equipment and mobile cranes.

Many of the procedures described below are detailed accounts of laboratory methods, since determining an emissions value requires performing a complex set of individual measurements, rather than obtaining a single measured value. Thus, the results obtained depend as much on the process of performing the measurements as they depend on the engine and test method.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8178-1, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

ISO 8178-5, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 5: Test fuels*

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

ISO 5725-2:1994, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 14396:2002, *Reciprocating internal combustion engines — Determination and method for the measurement of engine power — Additional requirements for exhaust emission tests in accordance with ISO 8178*

ISO 15550, *Internal combustion engines — Determination and method for the measurement of engine power — General requirements*

ISO 16183:2002, *Heavy duty engines — Measurement of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions*

SAE J 1937:1995, *Engine testing with low-temperature charge air-cooler systems in a dynamometer test cell*

### 3 Terms and definitions

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

#### 3.1

##### **particulate matter**

any material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature of greater than 315 K (42 °C) and less than or equal to 325 K (52 °C), as measured at a point immediately upstream of the filter

NOTE This is primarily carbon, condensed hydrocarbons, and sulfates with associated water.

#### 3.2

##### **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

#### 3.3

##### **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

#### 3.4

##### **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

NOTE It is common in many full flow dilution systems to dilute this fraction of pre-diluted exhaust a second time to obtain appropriate sample temperatures at the particulate filter.

#### 3.5

##### **specific emissions**

mass emissions expressed in g/kWh

#### 3.6

##### **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

#### 3.7

##### **transient test cycle**

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

**3.8****rated speed**

engine speed at which, according to the statement of the engine manufacturer, the rated or prime power is delivered

NOTE For details see ISO 14396.

**3.9****low speed**

lowest engine speed where 50 % of the rated or prime power is delivered

**3.10****high speed**

highest engine speed where 70 % of the rated or prime power is delivered

**3.11****reference speed**

100 per cent speed value to be used for denormalizing the relative speed values of the NRTC test, as set out in 6.4.2

**3.12****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 1 The system response time ( $t_{90}$ ) consists of the delay time to the system and of the rise time of the system.

NOTE 2 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 analyser; in this International Standard, the sampling probe is defined as the reference point.

**3.13****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 1 For the gaseous components, this is basically the transport time of the measured component from the sampling probe to the detector.

NOTE 2 For the delay time, the sampling probe is defined as the reference point.

**3.14****rise time**

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

NOTE 1 This is the instrument response after the component to be measured has reached the instrument.

NOTE 2 For the rise time, the sampling probe is defined as the reference point.

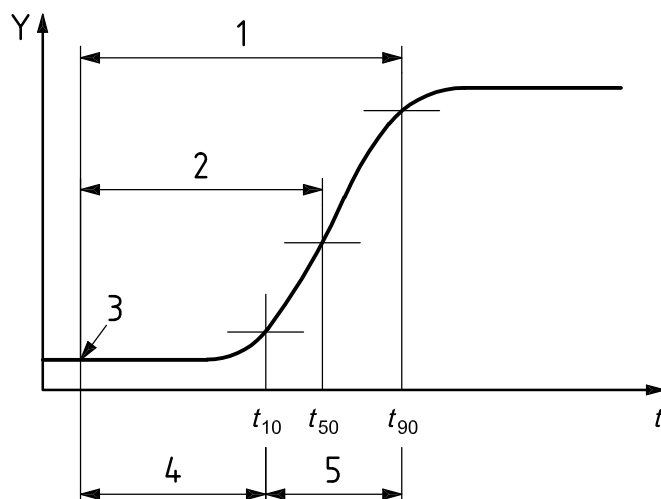
**3.15****transformation time**

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 1 For the transformation time, the sampling probe is defined as the reference point.

NOTE 2 The transformation time is used for the signal alignment of different measurement instruments.

NOTE 3 3.12 to 3.15 do not apply to full flow dilution systems covered by Clause 10.

**Key**

Y response

- 1 response time
- 2 transformation time
- 3 step input
- 4 delay time
- 5 rise time

**Figure 1 — Definitions of system response****4 Symbols and abbreviated terms****4.1 General symbols****Table 1 — List of 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> analyser |
| $E_E$      | %          | Ethane efficiency                                  |
| $E_{H_2O}$ | %          | Water quench of NO <sub>x</sub> analyser           |
| $E_M$      | %          | Methane efficiency                                 |
| $E_{NO_x}$ | %          | Efficiency of NO <sub>x</sub> converter            |
| $\eta$     | Pa*s       | Dynamic viscosity of exhaust gas                   |

Table 1 (continued)

| Symbol     | Unit                 | Term                                                                   |
|------------|----------------------|------------------------------------------------------------------------|
| $H_a$      | 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          |
| $k_w$      | —                    | 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                               |
| $q_{medf}$ | 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                                                    |
| $q_{vs}$   | l/min                | System flow rate of exhaust analyser 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                                    |

Table 1 (continued)

| Symbol      | Unit              | Term                                                     |
|-------------|-------------------|----------------------------------------------------------|
| $r_s$       | —                 | 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 analyser 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                       |

## 4.2 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  $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$

### 4.3 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        |

### 4.4 Abbreviations

|      |                                       |
|------|---------------------------------------|
| CLD  | Chemiluminescent Detector             |
| FID  | Flame Ionization Detector             |
| FTIR | Fourier Transform Infrared (Analyser) |
| GC   | Gas Chromatograph                     |
| HCLD | Heated Chemiluminescent Detector      |
| HFID | Heated Flame Ionization Detector      |
| HPLC | High Pressure Liquid Chromatograph    |
| MW   | Molecular Mass                        |
| NDIR | Non-Dispersive Infrared (Analyser)    |
| NMC  | Non-Methane Cutter                    |
| NRTC | Non Road Transient Cycle              |
| % FS | Percent of full scale                 |
| SIMS | Soft Ionization Mass Spectrometer     |
| Stk  | Stokes number                         |

## 5 Test conditions

### 5.1 Engine test conditions

#### 5.1.1 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.

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:

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

NOTE Equations (1) and (2) are identical with the exhaust emissions legislation from ECE, EEC and EPA, but different from the ISO power correction equations.

#### 5.1.2 Test validity

For a test to be recognized as valid, the parameter  $f_a$  shall be such that:  $0,93 \leq f_a \leq 1,07$ .

NOTE It is recommended that the test be conducted with the parameter  $f_a$  between 0,96 and 1,06.

### 5.2 Engines with charge air cooling

The charge air temperature shall be recorded and shall be, at the speed of rated 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.

Optionally, the setting of the charge air cooler may be done in accordance with SAE J 1937:1995.

### 5.3 Power

The basis of specific emissions measurement is uncorrected brake power as defined in ISO 14396. The engine shall be submitted for testing with the auxiliaries needed for operating the engine.

If it is impossible or inappropriate to install the auxiliaries on the test bench, the power absorbed by them shall be determined and subtracted from the measured engine power over the whole operating area of the test cycle.

Certain auxiliaries necessary only for the operation of the machine 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, and
- pumps for hydraulic actuators.

For further details see ISO 14396 and ISO 15550, Table 1.

Where auxiliaries have not been removed, the power absorbed by them shall be determined and added to the measured engine power over the whole operating area of the test cycle, except for engines where such auxiliaries form an integral part of the engine (e.g. cooling fans for air cooled engines).

The correction equation for converting the measured power or measured cycle work, as determined according to 6.6.2, to uncorrected brake power or uncorrected cycle work, shall be submitted by the engine manufacturer for the whole operating area of the cycle, and agreed by the parties involved.

#### 5.4 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.

If the engine is equipped with an integral air inlet system, it shall be used for testing.

#### 5.5 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 9.4.2 and 16.2 of ISO 8178-1.

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 four 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 catalyst support.

#### 5.6 Cooling system

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

#### 5.7 Lubricating oil

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

#### 5.8 Test fuel

Fuel characteristics influence the engine exhaust gas emission. Therefore, the characteristics of the fuel used for the test should be determined, recorded and presented with the results of the test. Where fuels designated in ISO 8178-5 as reference fuels are used, the reference code and the analysis of the fuel shall be provided. For all other fuels the characteristics to be recorded are those listed in the appropriate universal data sheets in ISO 8178-5.

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

The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the parties, the fuel shall be selected in accordance with Table 2. When a suitable reference fuel is not available, a fuel with properties very close to the reference fuel may be used. The characteristics of the fuel shall be declared.

**Table 2 — Selection of fuel**

| Test purpose                                                                                                                                                                              | Interested parties                                                                           | Fuel selection                                                                       |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Type approval<br>(Certification)                                                                                                                                                          | 1. Certification body<br>2. Manufacturer or supplier                                         | Reference fuel, if one is defined<br>Commercial fuel if no reference fuel is defined |
| Acceptance test                                                                                                                                                                           | 1. Manufacturer or supplier<br>2. Customer or inspector                                      | Commercial fuel as specified by the manufacturer <sup>a</sup>                        |
| Research/development                                                                                                                                                                      | One or more of:<br>Manufacturer, research organization,<br>fuel and lubricant supplier, etc. | To suit the purpose of the test                                                      |
| <sup>a</sup> Customers and inspectors should note that the emission tests carried out using commercial fuel will not necessarily comply with limits specified when using reference fuels. |                                                                                              |                                                                                      |

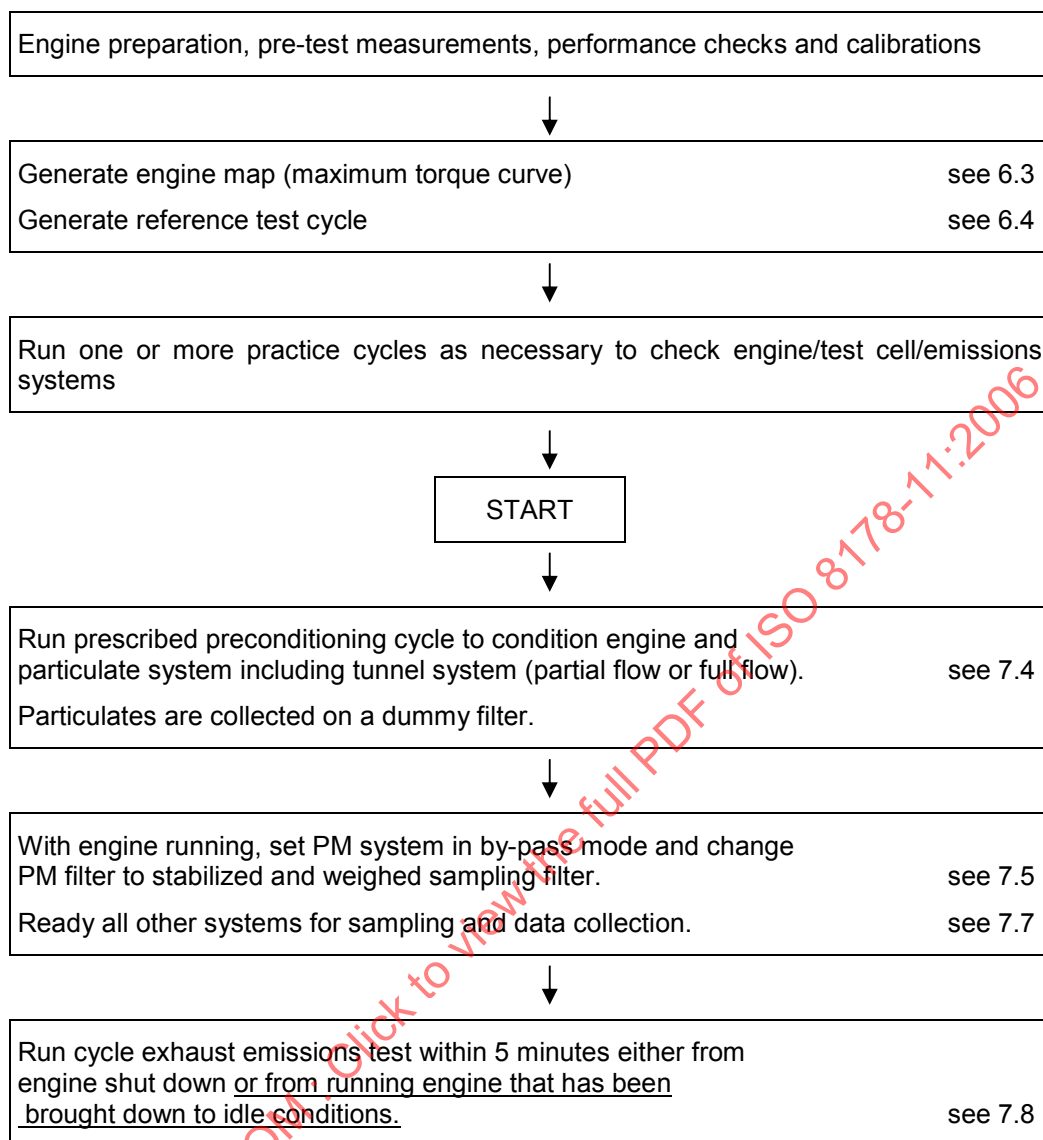
## 6 Test cycle

### 6.1 General

The nonroad transient cycle (NRTC) is listed in Annex A as a second-by-second sequence of normalized speed and torque values applicable to all engines covered by this International Standard. In order to perform the test on an engine test cell, the normalized values shall be converted to the reference 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 actual speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and actual 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).

### 6.2 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 clauses. Deviations from the guidance are permitted where appropriate, but the specific requirements of the relevant clauses are mandatory.



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

## 6.3 Engine mapping procedure

### 6.3.1 General

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

### 6.3.2 Determination of the mapping speed range

The minimum and maximum mapping speeds are defined as follows:

Minimum mapping speed = idle speed.

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

### 6.3.3 Engine mapping curve

The engine shall be warmed up 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 either of the following procedures.

#### 6.3.3.1 Transient map

- 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.

#### 6.3.3.2 Step map

- 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) While maintaining full load, the minimum mapping speed shall be maintained for at least 15 s, and the average torque during the last 5 s shall be recorded. The maximum torque curve from minimum to maximum mapping speed shall be determined in no greater than  $100 \pm 20$  /min speed increments. Each test point shall be held for at least 15 s, and the average torque during the last 5 s shall be recorded.

### 6.3.4 Mapping curve generation

All data points recorded under 6.3.3 shall be connected using linear interpolation between points. The resulting torque curve is the mapping curve and shall be used to convert the normalized torque values of the engine dynamometer schedule of Annex A into reference torque values for the test cycle, as described in 6.4.3.

### 6.3.5 Alternative mapping

If a manufacturer believes that the above mapping techniques are unsafe or unrepresentative for any given engine, alternative mapping techniques may be used. These alternative 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 section 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.

### 6.3.6 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.

## 6.4 Generation of the reference test cycle

### 6.4.1 Reference speed

The reference speed ( $n_{\text{ref}}$ ) corresponds to the 100 % normalized speed values specified in the engine dynamometer schedule of Annex A. The actual engine cycle resulting from denormalization to the reference speed depends on the selection of the reference speed. The reference speed shall be defined as follows:

$$n_{\text{ref}} = \text{low speed} + 0,95 \times (\text{high speed} - \text{low speed})$$

where

- high speed is the highest engine speed where 70 % of the rated power is delivered, and
- low speed is the lowest engine speed where 50 % of the rated power is delivered.

If the measured reference speed is within  $\pm 3$  % of the reference speed as declared by the manufacturer, the declared reference speed may be used for the emissions test. If the tolerance is exceeded, the measured reference speed shall be used for the emissions test.

### 6.4.2 Denormalization of engine speed

The speed shall be denormalized using the following equation:

$$\text{Reference speed} = \frac{\% \text{ speed} \times (\text{reference speed} - \text{idle speed})}{100} + \text{idle speed} \quad (3)$$

### 6.4.3 Denormalization of engine torque

The torque values in the engine dynamometer schedule of Annex A 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 6.3.3, as follows:

$$\text{Reference torque} = \frac{\% \text{ torque} \times \text{max. torque}}{100} \quad (4)$$

for the respective reference speed as determined in 6.4.2.

### 6.4.4 Example of denormalization procedure

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

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

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

Given the following values:

$$\text{reference speed} = 2\,200 \text{ /min}$$

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

results in

$$\text{actual speed} = \frac{43 \times (2\,200 - 600)}{100} + 600 = 1\,288 \text{ /min}$$

With the maximum torque of 700 Nm observed from the mapping curve at 1 288 /min:

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

## 6.5 Dynamometer

### 6.5.1 General

When using a load cell, the torque signal shall be transferred to the engine axis and the inertia of the dynamometer shall be considered. The actual engine torque is the torque read on the load cell plus the moment of inertia of the brake multiplied by the angular acceleration. The control system has to perform such a calculation in real time.

### 6.5.2 Eddy-current dynamometer

If the engine is tested with an eddy-current dynamometer, the dynamometer inertia must be adapted to the engine size. Therefore, it is recommended that the number of points, where the difference  $T_{sp} - 2 \cdot \pi \cdot \dot{n}_{sp} \cdot \Theta_D$  is smaller than 5 % of the engine's maximum negative torque, does not exceed 30

where

$T_{sp}$  is the demanded torque;

$\dot{n}_{sp}$  is the derivative of the engine speed;

$\Theta_D$  is the rotational inertia of the eddy-current dynamometer.

## 6.6 Verification of the test run

### 6.6.1 Data shift

To minimize the biasing effect of the time lag between the actual 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 actual signals are shifted, both speed and torque must be shifted the same amount in the same direction.

### 6.6.2 Calculation of the cycle work

The actual cycle work  $W_{act}$  (kWh) shall be calculated using each pair of engine feedback speed and torque values recorded. This shall be done after any actual data shift has occurred, if this option is selected. 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 9.3.7, 9.4.7, 10.3.7, 10.4.5). 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 Hz 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  $W_{ref}$ .

### 6.6.3 Validation statistics of the test cycle

Linear regressions of the actual values on the reference values shall be performed for speed, torque and power. This shall be done after any feedback data shift has occurred, if this option is selected. The method of least squares shall be used in accordance with the equations given in Annex G:

$$y = a_1 * x + a_0 \quad (5)$$

where

$y$  is the actual value of speed ( $\text{min}^{-1}$ ), torque (Nm), or power (kW);

$a_1$  is the slope of the regression line;

$x$  is the reference value of speed ( $\text{min}^{-1}$ ), torque (Nm), or power (kW);

$a_0$  is the  $y$  intercept of the regression line.

The standard error of estimate ( $S_{y,x}$ ) 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 3 must be met.

**Table 3 — Regression line tolerances**

|                                                        | Speed                     | Torque                                                                | Power                                                               |
|--------------------------------------------------------|---------------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------|
| Standard error of estimate ( $S_{y,x}$ ) 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, $a_1$                    | 0,95 to 1,03              | 0,83 - 1,03                                                           | 0,89 - 1,03                                                         |
| Coefficient of determination, $r^2$                    | min 0,9700                | min 0,880 0                                                           | min 0,910 0                                                         |
| $y$ intercept of the regression line, $a_0$            | $\pm 50 \text{ min}^{-1}$ | $\pm 20 \text{ Nm}$ 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 4 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 0,1 %. Point deletion may be applied to the whole or to any part of the cycle.

**Table 4 — Permitted point deletions from regression analysis**

| Condition                                                                                                                                                     | Points to be deleted |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| First $24 \pm 1$ seconds and last $25 \pm 1$ seconds                                                                                                          | 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, speed feedback > idle speed + $50 \text{ min}^{-1}$ , and torque feedback > 105 % torque reference                                                   | Torque and/or power  |
| No load, speed feedback $\leq$ idle speed + $50 \text{ min}^{-1}$ , and torque feedback = manufacturer defined/measured idle torque $\pm 2 \%$ of max. torque | Speed and/or power   |
| No load and speed feedback > 105 % speed reference                                                                                                            | Speed and/or power   |

## 7 Emissions test run

### 7.1 General

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. Good engineering practice recommends the general measurement of carbon dioxide as an excellent tool for the detection of measurement problems during the test run.

The above pollutants shall be examined during the prescribed transient cycle (NRTC) at warmed-up engine operating conditions. 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 analyser signal in accordance with 9.3.4, or in the diluted exhaust gas of a CVS full flow dilution system by integration or by bag sampling in accordance with 10.3.4. For particulates, a proportional sample shall be collected from the diluted exhaust gas on a specified filter by either partial flow dilution (see 9.4.2) or full flow dilution (see 10.4.3). 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.

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

### 7.2 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.

### 7.3 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.

### 7.4 Starting and preconditioning the dilution system and the engine

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 % torque for a minimum of 20 min 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 min. Flow rates shall be set at the approximate flow rates selected for transient testing. Torque shall be reduced from 100 % 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.

### 7.5 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.

## 7.6 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).

## 7.7 Checking the analysers

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

## 7.8 Engine starting procedure

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

## 7.9 Cycle run

### 7.9.1 Test sequence

The test sequence shall be started at the start of the engine or within 5 minutes after the engine has reached idle speed, when starting directly from the preconditioning phase. The test shall be performed according to the reference cycle as set out in 6.4. 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.

### 7.9.2 Analyser response

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, the measuring equipment shall be started, and simultaneously:

- start collecting or analysing dilution air, if a full flow dilution system is used;
- start collecting or analysing 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 analogue analysers, 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 analyser 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 analysing 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).

### 7.9.3 Particulate sampling

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, 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 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.

### 7.9.4 Engine stalling

If the engine stalls anywhere during the test cycle, the engine shall be preconditioned and restarted, and the test repeated. If a malfunction occurs in any of the required test equipment during the test cycle, the test shall be voided.

### 7.9.5 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 analyser system, sampling shall continue until system response times have elapsed.

The concentrations of the collecting bags, if used, shall be analysed as soon as possible and in any case not later than 20 min 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 analysers. 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 Principles of emissions measurement

### 8.1 General

In this International Standard, two measurement principles are described that are functionally equivalent, but can lead to slight differences in emissions results:

- 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; and
- 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.

## 8.2 Equivalence

The emission of gaseous and particulate components by the engine submitted for testing shall be measured by the methods described in Clauses 11 and 12. These clauses describe the recommended analytical systems for the gaseous emissions (Clause 11) and the recommended particulate dilution and sampling systems (Clause 12).

Other systems or analysers may be accepted if they yield equivalent results. The determination of system equivalency shall be based on a seven-sample pair (or larger) correlation study between the system under consideration and one of the accepted systems of this International Standard. 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 test cycle to be used shall be the appropriate cycle the engine will be run on. The equivalency of the sample pair averages shall be determined by *t*-test statistics as described in Annex B obtained under these laboratory, test cell and engine conditions. Outliers shall be determined in accordance with ISO 5725-2 and excluded from the database. The systems to be used for correlation testing shall be declared prior to the test and shall be agreed upon by the parties involved.

For introduction of a new system into the International Standard, the determination of equivalency shall be based upon the calculation of repeatability and reproducibility, as described in ISO 5725-2.

## 8.3 Accuracy

The equipment described in this document shall be used for emissions tests of engines. This document 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 clause. The instruments shall be calibrated as required by internal audit procedures or by the instrument manufacturer.

The calibration of all measuring instruments shall be traceable to national (or international) standards and comply with the requirements given in Table 5.

**Table 5 — Calibration accuracy of instruments**

| No. | Measurement instrument    | Accuracy                                                                          |
|-----|---------------------------|-----------------------------------------------------------------------------------|
| 1   | Engine speed              | $\pm 2\%$ of reading or $\pm 1\%$ of engine's max. value, whichever is larger     |
| 2   | Torque                    | $\pm 2\%$ of reading or $\pm 1\%$ of engine's max. value, whichever is larger     |
| 3   | Fuel consumption          | $\pm 2\%$ of engine's max. value                                                  |
| 4   | Air consumption           | $\pm 2\%$ of reading or $\pm 1\%$ of engine's max. value, whichever is larger     |
| 5   | Exhaust gas flow          | $\pm 2,5\%$ of reading or $\pm 1,5\%$ of engine's max. value, whichever is larger |
| 6   | Temperatures $\leq 600$ K | $\pm 2$ K absolute                                                                |
| 7   | Temperatures $> 600$ K    | $\pm 1\%$ of reading                                                              |
| 8   | Exhaust gas pressure      | $\pm 0,2$ kPa absolute                                                            |
| 9   | Intake air depression     | $\pm 0,05$ kPa absolute                                                           |
| 10  | Atmospheric pressure      | $\pm 0,1$ kPa absolute                                                            |
| 11  | Other pressures           | $\pm 0,1$ kPa absolute                                                            |
| 12  | Absolute humidity         | $\pm 5\%$ of reading                                                              |
| 13  | Dilution air flow         | $\pm 2\%$ of reading                                                              |
| 14  | Diluted exhaust gas flow  | $\pm 2\%$ of reading                                                              |

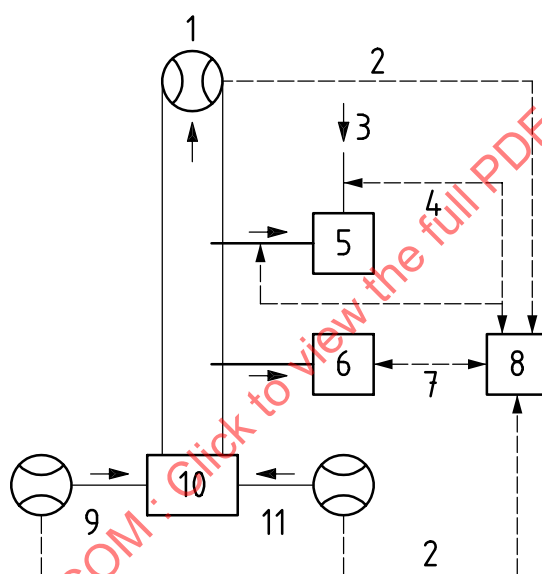
## 9 Determination of gaseous components in the raw exhaust gas and of the particulates with a partial flow dilution system

### 9.1 General

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 described in 9.2.4 (intake air and fuel flow measurement), 9.2.5 (tracer method) or 9.2.6 (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 as described in 9.3.3.

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 as described in 9.4.3.

The complete test set up is schematically shown in Figure 2.



#### Key

- exhaust sample
- flow measurement
- signal for system control and computation

- 1 exhaust flow
- 2 flow values
- 3 dilution air
- 4 flow control
- 5 partial flow dilution system
- 6 exhaust gas analyser
- 7 computation
- 8 control unit
- 9 fuel flow
- 10 engine
- 11 intake air flow

Figure 2 — Schematic of the raw/partial flow measurement system

## 9.2 Determination of exhaust gas mass flow

### 9.2.1 General

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 9.2.3 to 9.2.6 may be used.

### 9.2.2 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 analyser response time, as defined in 11.3.2.

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 9.4.3.

### 9.2.3 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, and
- 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 8.3.

### 9.2.4 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:

$$q_{mew,i} = q_{maw,i} + q_{mf,i} \text{ (for wet exhaust mass)} \quad (6)$$

The flowmeters shall meet the accuracy specifications of 8.3, but shall be accurate enough to also meet the accuracy specifications for the exhaust gas flow.

### 9.2.5 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 analyser.

The calculation of the exhaust gas flow is as follows:

$$q_{mew,i} = \frac{q_{vt} \times \rho_e}{60 \times (c_{mix,i} - c_a)} \quad (7)$$

where

- $q_{mew,i}$  is the instantaneous exhaust mass flow, kg/s;
- $q_{vt}$  is the tracer gas flow, cm<sup>3</sup>/min;
- $c_{mix,i}$  is the instantaneous concentration of the tracer gas after mixing, ppm;
- $\rho_e$  is the density of the exhaust gas, kg/m<sup>3</sup> (cf. Table 1); and
- $c_a$  is the 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 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 11.3.4.

### 9.2.6 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:

$$q_{mew,i} = q_{maw,i} \times \left( 1 + \frac{1}{A/F_{st} \times \lambda_i} \right) \quad (8)$$

with

$$A/F_{st} = \frac{138,0 \times \left( \beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right)}{12,011 \times \beta + 1,007\,94 \times \alpha + 15,999\,4 \times \varepsilon + 14,006\,7 \times \delta + 32,065 \times \gamma} \quad (9)$$

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

where

$A/F_{st}$  is the stoichiometric air to fuel ratio, kg/kg;

$\lambda$  is the excess air ratio;

$c_{CO_2}$  is the dry  $CO_2$  concentration, %;

$c_{CO}$  is the dry CO concentration, ppm; and

$c_{HC}$  is the HC concentration, ppm.

NOTE  $\beta$  can be 1 for fuels containing carbon and 0 for hydrogen fuel.

The air flowmeter shall meet the accuracy specifications of 8.3, the  $CO_2$  analyser used shall meet the specifications of 11.1, 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 11.2.9.

### 9.3 Determination of the gaseous components

#### 9.3.1 General

The gaseous components emitted by the engine submitted for testing shall be measured by the methods described in Clause 11. They shall be determined in the raw exhaust gas. Data evaluation and calculation procedures are described in 9.3.3 and 9.3.4.

#### 9.3.2 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 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  $CO_2$  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.

#### 9.3.3 Data evaluation

For the evaluation of the gaseous emissions, the raw emission concentrations (HC, CO and  $NO_x$ ) 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 analogue analysers, the response shall 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 Clause 3. Therefore, the response time of each gaseous emissions analyser and of the exhaust gas mass flow system shall be determined according to 11.3.2 and 9.2.2, respectively, and recorded.

### 9.3.4 Calculation of mass emission

#### 9.3.4.1 General

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 6 and the exhaust mass flow, aligned for the transformation time as determined in accordance with 9.3.3, and integrating the instantaneous values over the cycle in accordance with 9.3.4.2. Preferably, the concentrations should be measured on a wet basis. If measured on a dry basis, the dry/wet correction according to 9.3.5 shall be applied to the instantaneous concentration values before any further calculation is done.

Optionally, the mass emissions may be calculated using the exact equations of 9.3.4.3 with the prior agreement of the parties involved. The exact equations must be used if the fuel used for the test is not specified in Table 6, under multi-fuel operation or in case of dispute.

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

#### 9.3.4.2 Calculation method based on tabulated values

The following equation shall be applied:

$$m_{\text{gas}} = \sum_{i=1}^{i=n} u_{\text{gas}} \times c_{\text{gas},i} \times q_{\text{mew},i} \times \frac{1}{f} \quad (\text{in g/test}) \quad (11)$$

where

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

For the calculation of  $\text{NO}_x$ , the humidity correction factor  $k_{h,D}$  as applicable, as determined according to 9.3.6, shall be used.

The instantaneously measured concentration shall be converted to a wet basis according to 9.3.5, if not already measured on a wet basis.

Values for  $u$  are given in Table 6 for selected components based on ideal gas properties and a range of fuels.

Table 6 — Values of  $u$  in the raw exhaust gas and density for various exhaust components

| Gas                                      | NO <sub>x</sub>                         | CO        | HC        | CO <sub>2</sub>        | O <sub>2</sub> | CH <sub>4</sub> | HCHO      | CH <sub>3</sub> OH |
|------------------------------------------|-----------------------------------------|-----------|-----------|------------------------|----------------|-----------------|-----------|--------------------|
| $\rho_{\text{gas}}$ [kg/m <sup>3</sup> ] | 2,053                                   | 1,250     | a         | 1,963 6                | 1,427 7        | 0,716           | 1,340     | 1,430              |
| FUEL                                     | $\rho_e$ Coefficient $u_{\text{gas}}^b$ |           |           |                        |                |                 |           |                    |
| Diesel                                   | 1,294 3                                 | 0,001 586 | 0,000 966 | 0,000 479              | 0,001 517      | 0,001 103       | 0,000 553 | 0,001 035          |
| RME                                      | 1,295 0                                 | 0,001 585 | 0,000 965 | 0,000 536              | 0,001 516      | 0,001 102       | 0,000 553 | 0,001 035          |
| Methanol                                 | 1,261 0                                 | 0,001 628 | 0,000 991 | 0,001 133              | 0,001 557      | 0,001 132       | 0,000 568 | 0,001 062          |
| Ethanol                                  | 1,275 7                                 | 0,001 609 | 0,000 980 | 0,000 805              | 0,001 539      | 0,001 119       | 0,000 561 | 0,001 050          |
| Natural gas <sup>c</sup>                 | 1,266 1                                 | 0,001 621 | 0,000 987 | 0,000 558 <sup>d</sup> | 0,001 551      | 0,001 128       | 0,000 565 | 0,001 058          |
| Propane                                  | 1,280 5                                 | 0,001 603 | 0,000 976 | 0,000 512              | 0,001 533      | 0,001 115       | 0,000 559 | 0,001 046          |
| Butane                                   | 1,283 2                                 | 0,001 600 | 0,000 974 | 0,000 505              | 0,001 530      | 0,001 113       | 0,000 558 | 0,001 044          |
| Gasoline                                 | 1,297 7                                 | 0,001 582 | 0,000 963 | 0,000 481              | 0,001 513      | 0,001 100       | 0,000 552 | 0,001 032          |

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 CH<sub>2,93</sub> (for total HC the  $u_{\text{gas}}$  coefficient of CH<sub>4</sub> is used).

### 9.3.4.3 Calculation method based on exact equations

The mass emission shall be calculated using Equation (11). Instead of using the tabulated values, the following equations shall be applied for the calculation of  $u_{\text{gas}}$ . It is assumed in the following equations that the concentration  $c_{\text{gas}}$  in Equation (11) is measured in or converted to ppm.

$$u_{\text{gas},i} = \text{GAS} / (M_{r,e,i} \times 1\,000) \quad (12)$$

or

$$u_{\text{gas},i} = \rho_{\text{gas}} / (\rho_{e,i} \times 1\,000) \quad (13)$$

$$\text{where } \rho_{\text{gas}} = \text{GAS} / 22,41 \text{ is optionally taken from Table 6.} \quad (14)$$

The densities,  $\rho_{\text{gas}}$ , are given for a number of exhaust gas components in Table 6. The molecular mass of the exhaust,  $M_{r,e}$ , shall be derived for a general fuel composition  $\text{C}_\beta\text{H}_\alpha\text{O}_\varepsilon\text{N}_\delta\text{S}_\gamma$  under the assumption of complete combustion, as follows:

$$M_{r,e,i} = \frac{1 + \frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \times \frac{\frac{\alpha}{4} + \frac{\varepsilon}{2} + \frac{\delta}{2}}{12,011 \times \beta + 1,007\,94 \times \alpha + 15,999\,4 \times \varepsilon + 14,006\,7 \times \delta + 32,065 \times \gamma} + \frac{\frac{H_a \times 10^{-3}}{2 \times 1,007\,94 + 15,999\,4} + \frac{1}{M_{r,\text{air}}}}{1 + H_a \times 10^{-3}}} \quad (15)$$

The exhaust density  $\rho_e$  shall be derived, as follows:

$$\rho_{e,i} = \frac{1\,000 + H_a + 1\,000 \times (q_{mf,i} / q_{mad,i})}{773,4 + 1,243\,4 \times H_a + k_f \times 1\,000 \times (q_{mf,i} / q_{mad,i})} \quad (16)$$

where

$$k_f = 0,055\,584 \times w_{\text{ALF}} - 0,000\,108\,3 \times w_{\text{BET}} - 0,000\,156\,2 \times w_{\text{GAM}} + 0,007\,993\,6 \times w_{\text{DEL}} + 0,006\,997\,8 \times w_{\text{EPS}} \quad (17)$$

#### 9.3.4.4 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:

$$c_{\text{NMHC}} = \frac{c_{\text{HC(w/oCutter)}} \times (1 - E_{\text{M}}) - c_{\text{HC(w/Cutter)}}}{E_{\text{E}} - E_{\text{M}}} \quad (18)$$

$$c_{\text{CH}_4} = \frac{c_{\text{HC(w/Cutter)}} - c_{\text{HC(w/oCutter)}} \times (1 - E_{\text{E}})}{E_{\text{E}} - E_{\text{M}}} \quad (19)$$

where

$c_{\text{HC(w/Cutter)}}$  is the HC concentration with the sample gas flowing through the NMC;

$c_{\text{HC(w/oCutter)}}$  is the HC concentration with the sample gas bypassing the NMC;

$E_{\text{M}}$  is the methane efficiency as determined per ISO 8178-1, 8.8.4.2;

$E_{\text{E}}$  is the ethane efficiency as determined per ISO 8178-1, 8.8.4.3.

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

#### 9.3.5 Dry/wet correction

If the instantaneously measured concentration is measured on a dry basis, it shall be converted to a wet basis according to the following equations.

$$c_{\text{wet}} = k_{\text{W}} \times c_{\text{dry}} \quad (20)$$

$$k_{\text{W}} = \left( 1 - \frac{1,243\,4 \times H_{\text{a}} + 111,12 \times w_{\text{ALF}} \times \frac{q_{\text{mf},i}}{q_{\text{mad},i}}}{773,4 + 1,243\,4 \times H_{\text{a}} + \frac{q_{\text{mf},i}}{q_{\text{mad},i}} \times k_{\text{f}} \times 1\,000} \right) \times 1,008 \quad (21)$$

or

$$k_{\text{W}} = \left( 1 - \frac{1,243\,4 \times H_{\text{a}} + 111,12 \times w_{\text{ALF}} \times \frac{q_{\text{mf},i}}{q_{\text{mad},i}}}{773,4 + 1,243\,4 \times H_{\text{a}} + \frac{q_{\text{mf},i}}{q_{\text{mad},i}} \times k_{\text{f}} \times 1\,000} \right) \left/ \left( 1 - \frac{p_{\text{r}}}{p_{\text{b}}} \right) \right. \quad (22)$$

or

$$k_{\text{W}} = \frac{1}{1 + \alpha \times 0,005 \times (c_{\text{CO}_2} + c_{\text{CO}})} - k_{\text{W}2} \quad (23)$$

with

$$k_{\text{W}2} = \frac{1,608 \times H_{\text{a}}}{1\,000 + (1,608 \times H_{\text{a}})} \quad (24)$$

where

- $p_r$  is the water vapor pressure after cooling bath, kPa;
- $p_b$  is the total atmospheric pressure, kPa;
- $\alpha$  is the molar hydrogen ratio of the fuel;
- $c_{CO_2}$  is the dry  $CO_2$  concentration, %;
- $c_{CO}$  is the dry CO concentration, %;
- $H_a$  is the intake air humidity, g water per kg dry air;
- $k_f$  is the  $0,055\,584 \times w_{ALF} - 0,000\,108\,3 \times w_{BET} - 0,000\,156\,2 \times w_{GAM} + 0,007\,993\,6 \times w_{DEL} + 0,006\,997\,8 \times w_{EPS}$ .

NOTE Equations (21) and (22) are principally identical with the factor 1,008 in Equation (21) being an approximation for the more accurate denominator in Equation (22).

### 9.3.6 $NO_x$ correction for humidity and temperature

As the  $NO_x$  emission depends on ambient air conditions, the  $NO_x$  concentration shall be corrected for humidity and ambient air temperature with the factors given in either of the following equations.

a) for compression ignition engines:

$$k_{h,D} = \frac{1}{1 - 0,018\,2 \times (H_a - 10,71) + 0,004\,5 \times (T_a - 298)} \quad (25)$$

where

- $T_a$  is the temperature of the intake air, K;
- $H_a$  is the humidity of the intake air, g water per kg dry air.

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

b) For compression ignition engines with intermediate air cooler the following alternative equation may be used:

$$k_{h,D} = \frac{1}{1 - 0,012 \times (H_a - 10,71) - 0,002\,75 \times (T_a - 298) + 0,002\,85 \times (T_{SC} - T_{SCRef})} \quad (26)$$

where

- $T_{SC}$  is the temperature of the intercooled air;
- $T_{SCRef}$  is the intercooled air reference temperature, to be specified by the manufacturer.

NOTE For an explanation of the other variables, see under a).

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

### 9.3.7 Calculation of the specific emissions

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

$$M_{\text{gas}} = m_{\text{gas}}/W_{\text{act}} \quad (27)$$

where  $W_{\text{act}}$  is the actual cycle work as determined according to 6.6.2, kWh.

## 9.4 Particulate determination

### 9.4.1 General

The determination of the particulates requires a dilution system. In this clause, dilution shall be accomplished by a partial 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.

The partial flow dilution system shall 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  $r_{\text{dil}}$  or  $r_{\text{s}}$  be determined such that the accuracy limits of 9.4.2 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 Clause 12.

### 9.4.2 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 9.3.2 also apply to particulate sampling. The sampling line shall conform to the requirements of 16.2 of ISO 8178-1.

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.

### 9.4.3 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 12.3.3. If the combined transformation time of the exhaust flow measurement (see 9.2.2) 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 shall 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 so 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 12.3.3.

#### 9.4.4 Data evaluation

The tare weight of the filter, as determined according to 7.2, shall be subtracted from the gross weight of the filter, as determined according to 7.9.5, 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 7.5, in line with good engineering practice and the specific design features of the particulate measurement system used.

#### 9.4.5 Calculation of mass emission

The mass of particulates shall be calculated by either of the following methods. An example of the calculation procedures is given in Annex E.

a)

$$m_{PM} = \frac{m_f}{m_{sep}} \times \frac{m_{edf}}{1000} \quad (28)$$

where

$m_f$  is the particulate mass sampled over the cycle, mg;

$m_{sep}$  is the mass of diluted exhaust gas passing the particulate collection filters, kg;

$m_{edf}$  is the 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:

$$m_{edf} = \sum_{i=1}^{i=n} q_{medf,i} \times \frac{1}{f} \quad (29)$$

$$q_{medf,i} = q_{mew,i} \times r_{dil,i} \quad (30)$$

$$r_{\text{dil},i} = \frac{q_{m\text{dew},i}}{(q_{m\text{dew},i} - q_{m\text{dw},i})} \quad (31)$$

where

$q_{m\text{edf},i}$  is the instantaneous equivalent diluted exhaust mass flow rate, kg/s;

$q_{m\text{ew},i}$  is the instantaneous exhaust mass flow rate, kg/s;

$r_{\text{dil},i}$  is the instantaneous dilution ratio;

$q_{m\text{dew},i}$  is the instantaneous diluted exhaust mass flow rate through dilution tunnel, kg/s;

$q_{m\text{dw},i}$  is the instantaneous dilution air mass flow rate, kg/s;

$f$  is the data sampling rate, Hz; and

$n$  is the number of measurements.

b)

$$m_{\text{PM}} = m_{\text{f}} / (r_{\text{s}} \times 1\,000) \quad (32)$$

where

$m_{\text{f}}$  is the particulate mass sampled over the cycle, mg;

$r_{\text{s}}$  is the average sample ratio over the test cycle.

with

$$r_{\text{s}} = \frac{m_{\text{se}}}{m_{\text{ew}}} \times \frac{m_{\text{sep}}}{m_{\text{sed}}} \quad (33)$$

where

$m_{\text{se}}$  is the sample mass over the cycle, kg;

$m_{\text{ew}}$  is the total exhaust mass flow over the cycle, kg;

$m_{\text{sep}}$  is the mass of diluted exhaust gas passing the particulate collection filters, kg;

$m_{\text{sed}}$  is the mass of diluted exhaust gas passing the dilution tunnel, kg.

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

#### 9.4.6 Particulate correction factor for humidity

As the particulate emission of diesel engines depends on ambient air conditions, the particulate concentration shall be corrected for ambient air humidity with the factor  $K_{\text{p}}$  given in the following equations.

Reference values for humidity other than 10,71 g/kg may be used and shall be reported with the results by agreement of the parties involved.

Other correction equations may be used if they can be justified or validated.

$$k_p = \frac{1}{[1 + 0,0133 \times (H_a - 10,71)]} \quad (34)$$

where  $H_a$  is the humidity of the intake air in g water per kg dry air.

#### 9.4.7 Calculation of the specific emissions

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

$$M_{PM} = m_{PM} * k_p / W_{act} \quad (35)$$

where  $W_{act}$  is the actual cycle work as determined according to 6.6.2, kWh.

## 10 Determination of gaseous and particulate components with a full flow dilution system

### 10.1 General

The concentration signals, either by integration over the cycle or by bag sampling, of the gaseous components are 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 3.

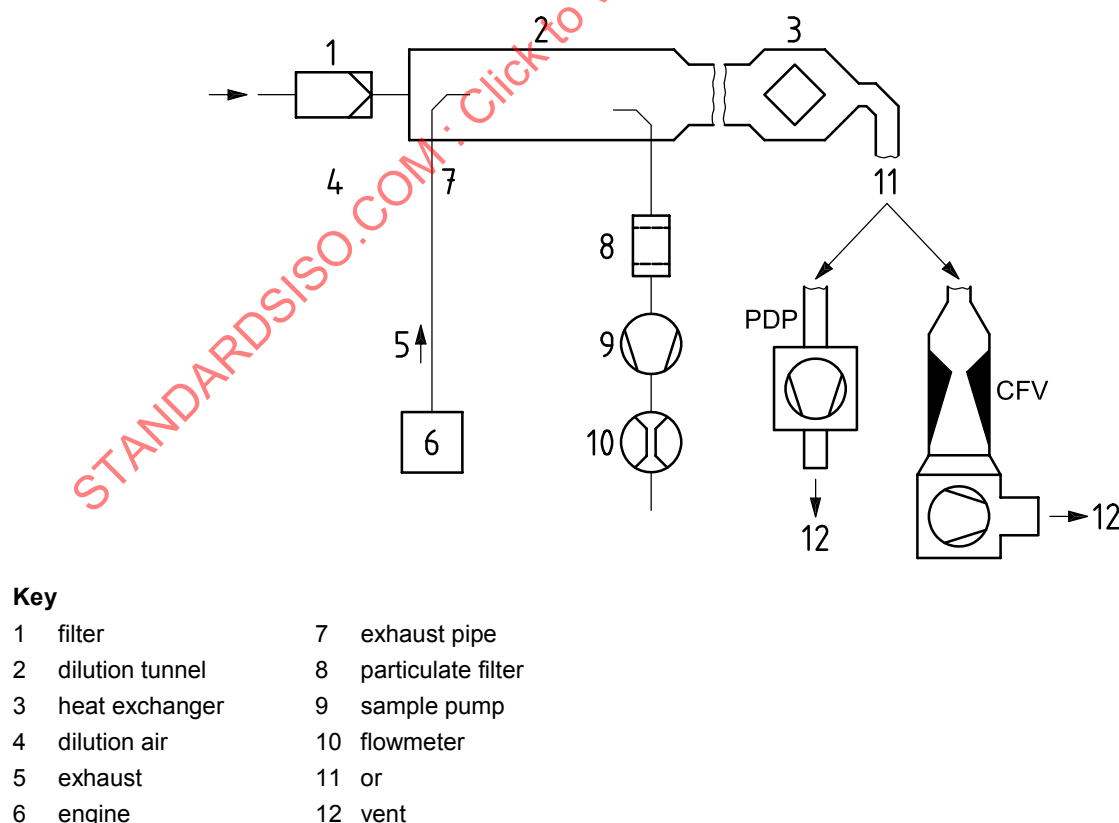


Figure 3 — Schematic of the CVS full flow dilution system

## 10.2 Determination of the diluted exhaust gas flow

### 10.2.1 General

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 10.2.2 to 10.2.4 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.

### 10.2.2 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.

$$m_{ed} = 1,293 * V_0 * N_P * (p_B - p_1) * 273 / (101,3 * T) \quad (36)$$

where

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

$N_P$  is the total revolutions of pump per test;

$p_B$  is the atmospheric pressure in the test cell, kPa;

$p_1$  is the pressure depression below atmospheric at pump inlet, kPa;

$T$  is the 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:

$$m_{ed,i} = 1,293 * V_0 * N_{P,i} * (p_B - p_1) * 273 / (101,3 * T) \quad (37)$$

where  $N_{P,i}$  is the total revolutions of pump per time interval.

### 10.2.3 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  $\pm 11$  K over the cycle by using a heat exchanger.

$$m_{ed} = 1,293 * t * K_V * p_A / T^{0,5} \quad (38)$$

where

$t$  is the cycle time, in s;

$K_V$  is the calibration coefficient of the critical flow venturi for standard conditions;

$p_A$  is the absolute pressure at venturi inlet, kPa;

$T$  is the 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:

$$m_{ed,i} = 1,293 * \Delta t_i * K_V * p_A / T^{0,5} \quad (39)$$

where  $\Delta t_i$  is the time interval, in s.

#### 10.2.4 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  $\pm 11$  K over the cycle by using a heat exchanger.

$$m_{ed} = 1,293 * Q_{SSV} \quad (40)$$

where

$$Q_{SSV} = A_0 d^2 C_d P_A \sqrt{\left[ \frac{1}{T} \left( r^{1,428\ 6} - r^{1,714\ 3} \right) \cdot \left( \frac{1}{1 - \beta^4 r^{1,428\ 6}} \right) \right]} \quad (41)$$

where

$A_0$  is the collection of constants and units conversions

$$= 0,006\ 111 \text{ in SI units of } \left( \frac{m^3}{\min} \right) \left( \frac{K^{\frac{1}{2}}}{kPa} \right) \left( \frac{1}{mm^2} \right)$$

$d$  is the diameter of the SSV throat, in m;

$C_d$  is the discharge coefficient of the SSV;

$P_A$  is the absolute pressure at venturi inlet, kPa;

$T$  is the 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 =  $\frac{d}{D}$ .

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:

$$m_{ed} = 1,293 * Q_{SSV} * \Delta t_i \quad (42)$$

where

$$Q_{SSV} = A_0 d^2 C_d P_A * \sqrt{\left[ \frac{1}{T} \left( r^{1,428\ 6} - r^{1,714\ 3} \right) \left( \frac{1}{1 - \beta^4 r^{1,428\ 6}} \right) \right]} \quad (43)$$

$\Delta t_i$  is the time interval, in 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 this clause.

### 10.3 Determination of the gaseous components

#### 10.3.1 General

The gaseous components emitted by the engine submitted for testing shall be measured by the methods described in 10.3.2. They shall be determined in the diluted exhaust gas. Data evaluation and calculation procedures are described in 10.3.3 and 10.3.4.

#### 10.3.2 Sampling for gaseous emissions

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements of ISO 8178-1. 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  $NO_x$ , the sample bag temperature must be above the dew point temperature;
- the pollutants are sampled continuously and integrated over the cycle; this method shall be used for HC and  $NO_x$ , unless the above conditions are fulfilled.

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 10.3.4.2.

#### 10.3.3 Data evaluation

For the evaluation of the gaseous emissions, the emission concentrations (HC, CO and  $NO_x$ ) 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 analogue analysers the response will be recorded, and the calibration data may be applied online or offline during the data evaluation.

#### 10.3.4 Calculation of mass emission

##### 10.3.4.1 Systems with constant mass flow

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

$$m_{\text{gas}} = u_{\text{gas}} \times c_{\text{gas}} \times m_{\text{ed}} \quad (44)$$

where

$u_{\text{gas}}$  is the ratio between density of exhaust component and density of air;

$c_{\text{gas}}$  is the average background corrected concentration of the respective component, ppm;

$m_{\text{ed}}$  is the total diluted exhaust mass over the cycle, kg.

For the calculation of  $\text{NO}_x$ , the humidity correction factor  $k_{h,D}$ , or  $k_{h,G}$ , as applicable, as determined according to 10.3.6, shall be used.

The measured concentration shall be converted to a wet basis according to 10.3.5, if not already measured on a wet basis.

Values for  $u$  are given in Table 7 below for selected components.

**Table 7 — Values of  $u$  in the diluted exhaust gas**

| Gas                                                                                                                                  | $\text{NO}_x$                                                                                          | CO        | HC                     | $\text{CO}_2$ | $\text{O}_2$ | $\text{CH}_4$ | HCHO      | $\text{CH}_3\text{OH}$ |
|--------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|-----------|------------------------|---------------|--------------|---------------|-----------|------------------------|
| $\rho_{\text{gas}}$ [kg/m <sup>3</sup> ]                                                                                             | 2,053                                                                                                  | 1,250     | <sup>a</sup>           | 1,963 6       | 1,427 7      | 0,716         | 1,340     | 1,430                  |
| <b>FUEL</b>                                                                                                                          | $\rho_{\text{air}} = 1,293 \text{ kg/m}^3$ <b>Coefficient <math>u_{\text{gas}}</math> <sup>b</sup></b> |           |                        |               |              |               |           |                        |
| Diesel                                                                                                                               | 0,001 588                                                                                              | 0,000 967 | 0,000 480              | 0,001 519     | 0,001 104    | 0,000 553     | 0,001 036 | 0,001 106              |
| RME                                                                                                                                  | 0,001 588                                                                                              | 0,000 967 | 0,000 537              | 0,001 519     | 0,001 104    | 0,000 553     | 0,001 036 | 0,001 106              |
| Methanol                                                                                                                             | 0,001 588                                                                                              | 0,000 967 | 0,001 105              | 0,001 519     | 0,001 104    | 0,000 553     | 0,001 036 | 0,001 106              |
| Ethanol                                                                                                                              | 0,001 588                                                                                              | 0,000 967 | 0,000 795              | 0,001 519     | 0,001 104    | 0,000 553     | 0,001 036 | 0,001 106              |
| Natural gas <sup>c</sup>                                                                                                             | 0,001 588                                                                                              | 0,000 967 | 0,000 584 <sup>d</sup> | 0,001 519     | 0,001 104    | 0,000 553     | 0,001 036 | 0,001 106              |
| Propane                                                                                                                              | 0,001 588                                                                                              | 0,000 967 | 0,000 507              | 0,001 519     | 0,001 104    | 0,000 553     | 0,001 036 | 0,001 106              |
| Butane                                                                                                                               | 0,001 588                                                                                              | 0,000 967 | 0,000 501              | 0,001 519     | 0,001 104    | 0,000 553     | 0,001 036 | 0,001 106              |
| Gasoline                                                                                                                             | 0,001 588                                                                                              | 0,000 967 | 0,000 483              | 0,001 519     | 0,001 104    | 0,000 553     | 0,001 036 | 0,001 106              |
| <sup>a</sup> Depending on fuel.                                                                                                      |                                                                                                        |           |                        |               |              |               |           |                        |
| <sup>b</sup> At $\lambda = 2$ , dry air, 273 K, 101,3 kPa.                                                                           |                                                                                                        |           |                        |               |              |               |           |                        |
| <sup>c</sup> $u$ accurate within 0,2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 %.                          |                                                                                                        |           |                        |               |              |               |           |                        |
| <sup>d</sup> NMHC on the basis of $\text{CH}_{2,93}$ (for total HC the $u_{\text{gas}}$ coefficient of $\text{CH}_4$ 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. It is not recommended to apply the exact calculation, as for the raw exhaust gas measurement, since dilution ratio and therefore the density of the diluted exhaust gas vary during the cycle.

#### 10.3.4.2 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 equation shall be used.

$$c = c_e - c_d \times (1 - (1/DF)) \quad (45)$$

where

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

$c_d$  is the concentration of the respective pollutant measured in the dilution air, ppm; and

$DF$  is the dilution factor.

The dilution factor shall be calculated as follows:

- a) for diesel and LPG fuelled gas engines

$$DF = \frac{F_S}{CO_{2\text{conce}} + (HC_{\text{conce}} + CO_{\text{conce}}) * 10^{-4}} \quad (46)$$

- b) for NG fuelled gas engines

$$DF = \frac{F_S}{CO_{2\text{conce}} + (NMHC_{\text{conce}} + CO_{\text{conce}}) * 10^{-4}} \quad (47)$$

where

$CO_{2,\text{conce}}$  is the concentration of  $CO_2$  in the diluted exhaust gas, % vol;

$HC_{\text{conce}}$  is the concentration of HC in the diluted exhaust gas, ppm C1;

$NMHC_{\text{conce}}$  is the concentration of NMHC in the diluted exhaust gas, ppm C1;

$CO_{\text{conce}}$  is the concentration of CO in the diluted exhaust gas, ppm; and

$F_S$  is the stoichiometric factor.

Concentrations measured on dry basis shall be converted to a wet basis in accordance with 10.3.5.

The stoichiometric factor shall be calculated as follows:

$$F_S = 100 \times \frac{x}{x + \frac{y}{2} + 3,76 \times \left( x + \frac{y}{4} \right)} \quad (48)$$

where  $x, y$  is the fuel composition  $C_xH_y$ .

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

—  $F_S$  (diesel) = 13,4;

—  $F_S$  (LPG) = 11,6;

—  $F_S$  (NG) = 9,5.

#### 10.3.4.3 Systems with flow compensation

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 equations shall be applied:

$$m_{\text{gas}} = \sum_{i=1}^n \left[ (m_{\text{ed},i} \times c_e \times u_{\text{gas}}) \right] - \left[ (m_{\text{ed}} \times c_d \times (1 - 1/DF) \times u_{\text{gas}}) \right] \quad (49)$$

where

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

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

$m_{ed,i}$  is the instantaneous mass of the diluted exhaust gas, kg;

$m_{ed}$  is the total mass of diluted exhaust gas over the cycle, kg;

$u_{gas}$  is the tabulated value from Table 7;

$DF$  is the dilution factor.

#### 10.3.4.4 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:

$$c_{NMHC} = \frac{c_{HC(w/oCutter)} \times (1 - E_M) - c_{HC(w/Cutter)}}{E_E - E_M} \quad (50)$$

$$c_{CH4} = \frac{c_{HC(w/Cutter)} - c_{HC(w/oCutter)} \times (1 - E_E)}{E_E - E_M} \quad (51)$$

where

$c_{HC(w/Cutter)}$  is the HC concentration with the sample gas flowing through the NMC;

$c_{HC(w/oCutter)}$  is the HC concentration with the sample gas bypassing the NMC;

$E_M$  is the methane efficiency as determined per ISO 8178-1, 8.8.4.2;

$E_E$  is the ethane efficiency as determined per ISO 8178-1, 8.8.4.3.

#### 10.3.5 Dry/wet correction

If the concentration is measured on a dry basis, it shall be converted to a wet basis according to the following equation.

$$c_{wet} = k_W \times c_{dry} \quad (21)$$

$$k_W = \left( 1 - \frac{\alpha \times \% \text{conc}_{CO2}(\text{wet})}{200} \right) - k_{w,1} \quad (52)$$

where

$$k_{w,1} = \frac{1,608 \times H_a}{1\,000 + (1,608 \times H_a)} \quad (53)$$

### 10.3.6 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 the following equations.

a) for compression-ignition engines:

$$k_{h,D} = \frac{1}{1 - 0,0182 \times (H_a - 10,71) + 0,0045 \times (T_a - 298)} \quad (54)$$

where

$T_a$  is the temperature of the intake air, K;

$H_a$  is the humidity of the intake air, g water per kg dry air.

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

b) For compression ignition engines with intermediate air cooler, the following alternative equation may be used:

$$k_{h,D} = \frac{1}{1 - 0,012 \times (H_a - 10,71) - 0,002\,75 \times (T_a - 298) + 0,002\,85 \times (T_{SC} - T_{SCRef})} \quad (55)$$

where

$T_{SC}$  is the temperature of the intercooled air;

$T_{SCRef}$  is the intercooled air reference temperature, to be specified by the manufacturer.

NOTE For an explanation of the other variables, see under a).

$H_a$  is the humidity of the intake air, g water per kg dry air, where  $H_a$  may be derived from relative humidity measurement, dewpoint measurement, vapor pressure measurement or dry/wet bulb measurement using the generally accepted equations.

### 10.3.7 Calculation of the specific emissions

The emissions (g/kWh) shall be calculated for all components, except NO<sub>x</sub>, in the following way:

$$M_{gas} = m_{gas} / W_{act} \quad (56)$$

for NO<sub>x</sub>

$$M_{gas} = m_{gas} * k_h / W_{act} \quad (57)$$

where  $W_{act}$  is the actual cycle work as determined according to 6.6.2, kWh.

## 10.4 Particulate determination

### 10.4.1 General

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 Clause 12.

#### 10.4.2 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 9.3.2 also apply to particulate sampling. The sampling line shall conform to the requirements of ISO 8178-1.

#### 10.4.3 Calculation of mass emission

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

$$m_{PM} = \frac{m_f}{m_{sep}} \times \frac{m_{ed}}{1000} \quad (58)$$

where

$m_f$  is the particulate mass sampled over the cycle, mg;

$m_{sep}$  is the mass of diluted exhaust gas passing the particulate collection filters, kg;

$m_{ed}$  is the 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.

$$m_{sep} = m_{set} - m_{ssd} \quad (59)$$

where

$m_{set}$  is the mass of double diluted exhaust gas through particulate filter, kg;

$m_{ssd}$  is the mass of secondary dilution air, kg.

If the particulate background level of the dilution air is determined in accordance with 7.5, the particulate mass may be background corrected. In this case, the particulate mass (g/test) shall be calculated as follows:

$$m_{PM} = \left[ \frac{m_f}{m_{sep}} - \left( \frac{m_b}{m_{sd}} \times \left( 1 - \frac{1}{DF} \right) \right) \right] \times \frac{m_{ed}}{1000} \quad (60)$$

where

$m_{PM}$ ,  $m_{sep}$ ,  $m_{ed}$  (see above);

$m_{sd}$  is the mass of primary dilution air sampled by background particulate sampler, kg;

$m_b$  is the mass of the collected background particulates of the primary dilution air, mg;

$DF$  is the dilution factor as determined in 10.3.4.2.

#### 10.4.4 Particulate correction factor for humidity

As the particulate emission of diesel engines depends on ambient air conditions, the particulate concentration shall be corrected for ambient air humidity with the factor  $K_p$  given in the following equation.

Reference values for humidity other than 10,71 g/kg may be used and shall be reported with the results by agreement of the parties involved.

Other correction equations may be used if they can be justified or validated.

$$k_p = \frac{1}{[1 + 0,0133 \times (H_a - 10,71)]} \quad (61)$$

where  $H_a$  is the humidity of the intake air in g water per kg dry air.

#### 10.4.5 Calculation of the specific emissions

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

$$M_{PM} = m_{PM} * k_p / W_{act} \quad (62)$$

where  $W_{act}$  is the actual cycle work as determined according to 6.6.2, in kWh.

### 11 Measurement equipment for the gaseous components

#### 11.1 General analyser specifications

##### 11.1.1 General

The analysers shall have a measuring range and response time appropriate for the accuracy required to measure the concentrations of the exhaust gas components under transient conditions. The analyser 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 analyser does not exceed  $\pm 2$  % 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 four non-zero nominally equally spaced points are to be made to ensure the accuracy of the calibration curves according to 8.5.5 of ISO 8178-1.

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

##### 11.1.2 Accuracy

The analyser 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 in ISO 8178-1, 8.5.

**NOTE** For the purpose of this International Standard, accuracy is defined as the deviation of the analyser reading from the nominal calibration values using a calibration gas (true value).

### 11.1.3 Precision

The precision, defined as 2,5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall 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).

### 11.1.4 Noise

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

### 11.1.5 Zero drift

Zero response is defined as the mean response, including noise, to a zero gas during a 30-second 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.

### 11.1.6 Span drift

Span response is defined as the mean response, including noise, to a span gas during a 30-second 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.

### 11.1.7 Rise time

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

**NOTE** Only evaluating the response time of the analyser alone will not clearly define the suitability of the total system for transient testing. Volumes, and especially dead volumes, throughout the system will not only affect the transportation time from the probe to the analyser, but also affect the rise time. Also, transport times inside of an analyser would be defined as analyser response time, like the converter or water traps inside of a NO<sub>x</sub> analysers. The determination of the total system response time is described in 11.3.2.

### 11.1.8 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.

## 11.2 Analysers

### 11.2.1 General

11.2.2 to 11.2.9 describe the measurement principles to be used. A detailed description of the measurement systems is given in ISO 8178-1, Clause 15. The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted.

### 11.2.2 Carbon monoxide (CO) analysis

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

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

The carbon dioxide analyser shall be of the NDIR absorption type.

#### 11.2.4 Hydrocarbon (HC) analysis

The hydrocarbon analyser shall be of the heated flame ionization detector (HFID) type with detector, valves, pipework, etc. heated so as to maintain a gas temperature of  $463\text{ K} \pm 10\text{ K}$  ( $190 \pm 10\text{ }^{\circ}\text{C}$ ).

#### 11.2.5 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 16.4.2 of ISO 8178-1, by subtraction of the methane from the hydrocarbons.

#### 11.2.6 Oxides of nitrogen ( $\text{NO}_x$ ) analysis

If measured on a dry basis, the oxides of nitrogen analyser shall be of the chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD) type with an  $\text{NO}_2/\text{NO}$  converter. If measured on a wet basis, a HCLD with converter maintained above  $328\text{ K}$  ( $55\text{ }^{\circ}\text{C}$ ) shall be used, provided the water quench check (see ISO 8178-1, 8.9.3.2) is satisfied. For both CLD and HCLD, the sampling path shall be maintained at a wall temperature of  $328\text{ K}$  to  $473\text{ K}$  ( $55\text{ }^{\circ}\text{C}$  to  $200\text{ }^{\circ}\text{C}$ ) up to the converter for dry measurement, and up to the analyser for wet measurement.

#### 11.2.7 Formaldehyde ( $\text{HCHO}$ ) analysis

For continuous measurement in the raw exhaust gas, an FTIR (Fourier transform infrared) or a SIMS (soft ionization mass spectrometric) analyser shall be used in accordance with the instrument suppliers' instructions.

The FTIR analyser shall be equipped with an algorithm to generate interference-free concentration values from an infrared spectrum. The FTIR analyser shall also be equipped with a dedicated spectral database for each instrument, in order to avoid interference caused by differences of the spectra between the instruments.

The SIMS analyser shall be equipped with a control library to generate interference decoupled values of the formaldehyde concentration. The internal energy of the ionizing ion shall be above  $11,6\text{ eV}$  (e.g.  $\text{Xe}^+$  with an internal energy of  $12,2\text{ eV}$ ). If measured on mass 30, the interference from  $\text{NO}_2$  shall be compensated with the help of the known ionization efficiency ratio of  $\text{NO}_2$  for masses 46 and 30. The interference decoupling shall be performed with a cycle time of at most  $300\text{ msec}$ . Measurement of formaldehyde on mass 29 is acceptable if the additional signal due to higher aldehydes is either desired, accepted or compensated (measurement on mass 29 gives an upper limit for the formaldehyde concentration).

If measured in the dilute exhaust gas of a partial flow dilution system, formaldehyde shall be determined by passing the diluted exhaust sample with a constant flow rate through an impinger containing an acetonitrile (ACN) solution of DNPH reagent or through a silica cartridge coated with 2,4-DNPH. The sample collected shall be analysed by a high pressure liquid chromatograph (HPLC) using UV detection at  $365\text{ nm}$  (for details see 16.6 of ISO 8178-1). The provisions for the accuracy of the flow measurement outlined in 12.1.4. must be met by the procedure given in 12.1.4.3, if the dilute gas is sampled from a total sampling type partial flow dilution system.

#### 11.2.8 Methanol ( $\text{CH}_3\text{OH}$ ) analysis

For continuous measurement in the raw exhaust gas, an FTIR (Fourier transform infrared) or a SIMS (soft ionization mass spectrometric) analyser shall be used in accordance with the instrument suppliers' instructions.

The FTIR analyser shall be equipped with an algorithm to generate interference-free concentration values from an infrared spectrum. The FTIR analyser shall also be equipped with a dedicated spectral data base for each instrument, in order to avoid interference caused by differences of the spectra between the instruments.

The SIMS analyser shall be equipped with a control library to generate interference decoupled values of the methanol concentration. The internal energy of the ionizing ion shall be above  $11,2\text{ eV}$  (e.g.  $\text{Xe}^+$  with an internal energy of  $12,2\text{ eV}$ ). This enables measurement of methanol on mass 31. The only substances interfering on this mass could be fragments of ethanol and propanol, substances which usually do not occur in

exhaust gases. For an accurate measurement of methanol, the interference decoupling shall nevertheless be performed with the help of the known ionization efficiency ratios of these substances on their unfragmented masses and mass 31.

Optionally, methanol may be determined with an HFID. In this case, the HFID calibrated on propane shall be operated at  $385\text{ K} \pm 10\text{ K}$  ( $112\text{ °C} \pm 10\text{ °C}$ ). The methanol response factor shall be determined at several concentrations in the range of concentrations in the sample, according to 8.8.5 of ISO 8178-1.

If measured in the dilute exhaust gas of partial flow dilution system, methanol shall be determined by passing the diluted exhaust sample with a constant flow rate through an impinger containing deionized water. The sample shall be analysed by a gas chromatograph (GC) with FID (for details see 16.5 of ISO 8178-1). The provisions for the accuracy of the flow measurement outlined in 12.1.4. must be met by the procedure given in 12.1.4.3, if the dilute gas is sampled from a total sampling type partial flow dilution system.

### 11.2.9 Air to fuel measurement

The air to fuel measurement equipment used to determine the exhaust gas flow as specified in 9.2.6 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:

- $\pm 3\%$  of reading  $\lambda < 2$ ;
- $\pm 5\%$  of reading  $2 \leq \lambda < 5$ ;
- $\pm 10\%$  of reading  $5 \leq \lambda$ .

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

## 11.3 Calibration

### 11.3.1 General

Each analyser shall be calibrated as often as necessary to fulfill the accuracy requirements of this International Standard. The calibration method that shall be used is described in detail in ISO 8178-1, Clause 8. Only calibration procedures specific to transient testing are described in this part of ISO 8178.

### 11.3.2 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 analysers 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 analyser and exhaust flow signals in the case of raw measurement, 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 11.1.7 for all limited components ( $\text{CO}$ ,  $\text{NO}_x$ ,  $\text{HC}$  or  $\text{NMHC}$ ) and all ranges used.

### 11.3.3 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 8.5 of ISO 8178-1.

### 11.3.4 Calibration of tracer gas analyser for exhaust flow measurement

The analyser for measurement of the tracer gas concentration, if used, 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 analyser'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 analyser 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 analyser full scale.

### 11.3.5 Calibration intervals

The analysers shall be calibrated according to 8.5 of ISO 8178-1 at least every 3 months or whenever a system repair or change is made that could influence calibration.

## 11.4 Analytical system

The analytical system is described in detail in ISO 8178-1, Clause 16.

## 12 Measurement equipment for particulates

### 12.1 General specifications

#### 12.1.1 General

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 raw or diluted exhaust flow, whatever is applicable, under transient engine operating conditions in accordance with 9.4.2.

### 12.1.2 Particulate sampling filters

The diluted exhaust shall be sampled by a filter that meets the requirements of 12.1.2.1 and 12.1.2.2 during the test sequence.

#### 12.1.2.1 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.

#### 12.1.2.2 Filter size

Particulate filters with a diameter of 47 mm are recommended. Larger diameter filters are acceptable (see 12.1.2.4), but smaller diameter filters are not permitted.

#### 12.1.2.3 Filter face velocity

A gas face velocity through the filter of 35 to 100 cm/s shall be achieved. The pressure drop increase between the beginning and the end of the test shall be no more than 25 kPa.

#### 12.1.2.4 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/1 000 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, 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 12.1.3.2, e.g. with a 0,1 µg balance.

### 12.1.3 Weighing chamber and analytical balance specifications

#### 12.1.3.1 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 282,5 K ± 3 K (9,5 °C ± 3 °C) and a relative humidity of 45 % ± 8 %.

#### 12.1.3.2 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 12.1.3.1 will be allowed if the duration of the disturbances does not exceed 30 min. 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 h 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 12.1.3.1 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.

### 12.1.3.3 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.

### 12.1.3.4 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.

## 12.1.4 Specifications for flow measurement

### 12.1.4.1 General requirements

Absolute accuracies of flow meter or flow measurement instrumentation shall be as specified in 8.3.

### 12.1.4.2 Special provisions for partial flow dilution systems

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:

$$q_{mp} = q_{mdew} - q_{mdw} \quad (63)$$

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 any 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 12.3.2.
- 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.

### 12.1.4.3 Correction for sample flow (partial flow dilution system only)

If measurement of methanol or formaldehyde 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 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 12.1.4.2 and 12.3.2.1, 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 9.4.5), the mass of  $q_{mex}$  extracted from the tunnel shall be taken into account by correcting the particulate mass  $m_f$ , as follows:

$$m_{f,corrected} = m_f \times \frac{q_{mdew}}{(q_{mdew} - q_{mex})} \quad (64)$$

### 12.1.5 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.

## 12.2 Dilution and sampling system

The dilution and sampling system is described in detail in ISO 8178-1, Clause 17.

## 12.3 Calibration

### 12.3.1 General

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 part of ISO 8178. The calibration method that shall be used is described in 12.3.2.

### 12.3.2 Flow measurement

#### 12.3.2.1 Periodical calibration

To fulfill the absolute accuracy of the flow measurements as specified in 8.3, 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 12.1.4:

- The flow meter for  $q_{mdw}$  is connected in series to the flow meter for  $q_{mdew}$ , the difference between the two flow meters is calibrated for at least five 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.
- A calibrated mass flow device is connected in series to the flowmeter for  $q_{mdew}$  and the accuracy is checked for the value used for the test. Then the calibrated mass flow device is connected in series to the flow meter for  $q_{mdw}$ , and the accuracy is checked for at least five settings corresponding to dilution ratio between 3 and 50, relative to  $q_{mdew}$  used during the test.
- The transfer tube TT is disconnected from the exhaust, and a calibrated flow measuring device with a suitable range to measure  $q_{mp}$  is connected to the transfer tube. Then  $q_{mdew}$  is set to the value used during the test, and  $q_{mdw}$  is sequentially set to at least five 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 is fed into the transfer tube TT. This tracer gas may be a component of the exhaust gas, like CO<sub>2</sub> or NO<sub>x</sub>. After dilution in the tunnel the tracer gas component is measured. This shall be carried out for five dilution ratios between 3 and 50. The accuracy of the sample flow is determined from the dilution ration  $r_{dil}$ :

$$q_{mp} = q_{mdew} / r_{dil} \quad (65)$$

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

#### 12.3.2.2 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 dilution 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 D shall be applied. The carbon flow rates shall be calculated according to equations D-1, D-2 and D-3. All carbon flow rates should agree to within 6 %.

#### 12.3.2.3 Pre-test check

A pre-test check shall be performed within 2 h 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 12.3.2.1) 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 12.3.2.1 that the flow meter calibration is stable over a longer period of time, the pre-test check may be omitted.

#### 12.3.3 Determination of the transformation time (partial flow dilution system only)

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 9.4.3).

The calculation shall be repeated for at least five 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 9.4.3., if the transformation time is greater than 0,3 s.

### 12.3.4 Calibration of the CVS system (full flow dilution system only)

#### 12.3.4.1 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 turbinemeter.

The CVS calibration is described in detail in ISO 8178-1, Clause 9.

#### 12.3.4.2 Total system verification

##### 12.3.4.2.1 General

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 10.3.4.1 except in the case of propane, where a factor of 0,000 472 is used in place of 0,000 479 for HC. Either of the following two techniques shall be used.

##### 12.3.4.2.2 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 min. 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.

##### 12.3.4.2.3 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 min, 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.

#### 12.3.5 Calibration intervals

The instruments shall be calibrated as required by internal audit procedures or by the instrument manufacturer.

## Annex A (normative)

### NRTC engine dynamometer schedule

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 1         | 0                   | 0                    |
| 2         | 0                   | 0                    |
| 3         | 0                   | 0                    |
| 4         | 0                   | 0                    |
| 5         | 0                   | 0                    |
| 6         | 0                   | 0                    |
| 7         | 0                   | 0                    |
| 8         | 0                   | 0                    |
| 9         | 0                   | 0                    |
| 10        | 0                   | 0                    |
| 11        | 0                   | 0                    |
| 12        | 0                   | 0                    |
| 13        | 0                   | 0                    |
| 14        | 0                   | 0                    |
| 15        | 0                   | 0                    |
| 16        | 0                   | 0                    |
| 17        | 0                   | 0                    |
| 18        | 0                   | 0                    |
| 19        | 0                   | 0                    |
| 20        | 0                   | 0                    |
| 21        | 0                   | 0                    |
| 22        | 0                   | 0                    |
| 23        | 0                   | 0                    |
| 24        | 1                   | 3                    |
| 25        | 1                   | 3                    |
| 26        | 1                   | 3                    |
| 27        | 1                   | 3                    |
| 28        | 1                   | 3                    |
| 29        | 1                   | 3                    |
| 30        | 1                   | 6                    |
| 31        | 1                   | 6                    |
| 32        | 2                   | 1                    |
| 33        | 4                   | 13                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 34        | 7                   | 18                   |
| 35        | 9                   | 21                   |
| 36        | 17                  | 20                   |
| 37        | 33                  | 42                   |
| 38        | 57                  | 46                   |
| 39        | 44                  | 33                   |
| 40        | 31                  | 0                    |
| 41        | 22                  | 27                   |
| 42        | 33                  | 43                   |
| 43        | 80                  | 49                   |
| 44        | 105                 | 47                   |
| 45        | 98                  | 70                   |
| 46        | 104                 | 36                   |
| 47        | 104                 | 65                   |
| 48        | 96                  | 71                   |
| 49        | 101                 | 62                   |
| 50        | 102                 | 51                   |
| 51        | 102                 | 50                   |
| 52        | 102                 | 46                   |
| 53        | 102                 | 41                   |
| 54        | 102                 | 31                   |
| 55        | 89                  | 2                    |
| 56        | 82                  | 0                    |
| 57        | 47                  | 1                    |
| 58        | 23                  | 1                    |
| 59        | 1                   | 3                    |
| 60        | 1                   | 8                    |
| 61        | 1                   | 3                    |
| 62        | 1                   | 5                    |
| 63        | 1                   | 6                    |
| 64        | 1                   | 4                    |
| 65        | 1                   | 4                    |
| 66        | 0                   | 6                    |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 67        | 1                   | 4                    |
| 68        | 9                   | 21                   |
| 69        | 25                  | 56                   |
| 70        | 64                  | 26                   |
| 71        | 60                  | 31                   |
| 72        | 63                  | 20                   |
| 73        | 62                  | 24                   |
| 74        | 64                  | 8                    |
| 75        | 58                  | 44                   |
| 76        | 65                  | 10                   |
| 77        | 65                  | 12                   |
| 78        | 68                  | 23                   |
| 79        | 69                  | 30                   |
| 80        | 71                  | 30                   |
| 81        | 74                  | 15                   |
| 82        | 71                  | 23                   |
| 83        | 73                  | 20                   |
| 84        | 73                  | 21                   |
| 85        | 73                  | 19                   |
| 86        | 70                  | 33                   |
| 87        | 70                  | 34                   |
| 88        | 65                  | 47                   |
| 89        | 66                  | 47                   |
| 90        | 64                  | 53                   |
| 91        | 65                  | 45                   |
| 92        | 66                  | 38                   |
| 93        | 67                  | 49                   |
| 94        | 69                  | 39                   |
| 95        | 69                  | 39                   |
| 96        | 66                  | 42                   |
| 97        | 71                  | 29                   |
| 98        | 75                  | 29                   |
| 99        | 72                  | 23                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 100       | 74                  | 22                   |
| 101       | 75                  | 24                   |
| 102       | 73                  | 30                   |
| 103       | 74                  | 24                   |
| 104       | 77                  | 6                    |
| 105       | 76                  | 12                   |
| 106       | 74                  | 39                   |
| 107       | 72                  | 30                   |
| 108       | 75                  | 22                   |
| 109       | 78                  | 64                   |
| 110       | 102                 | 34                   |
| 111       | 103                 | 28                   |
| 112       | 103                 | 28                   |
| 113       | 103                 | 19                   |
| 114       | 103                 | 32                   |
| 115       | 104                 | 25                   |
| 116       | 103                 | 38                   |
| 117       | 103                 | 39                   |
| 118       | 103                 | 34                   |
| 119       | 102                 | 44                   |
| 120       | 103                 | 38                   |
| 121       | 102                 | 43                   |
| 122       | 103                 | 34                   |
| 123       | 102                 | 41                   |
| 124       | 103                 | 44                   |
| 125       | 103                 | 37                   |
| 126       | 103                 | 27                   |
| 127       | 104                 | 13                   |
| 128       | 104                 | 30                   |
| 129       | 104                 | 19                   |
| 130       | 103                 | 28                   |
| 131       | 104                 | 40                   |
| 132       | 104                 | 32                   |
| 133       | 101                 | 63                   |
| 134       | 102                 | 54                   |
| 135       | 102                 | 52                   |
| 136       | 102                 | 51                   |
| 137       | 103                 | 40                   |
| 138       | 104                 | 34                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 139       | 102                 | 36                   |
| 140       | 104                 | 44                   |
| 141       | 103                 | 44                   |
| 142       | 104                 | 33                   |
| 143       | 102                 | 27                   |
| 144       | 103                 | 26                   |
| 145       | 79                  | 53                   |
| 146       | 51                  | 37                   |
| 147       | 24                  | 23                   |
| 148       | 13                  | 33                   |
| 149       | 19                  | 55                   |
| 150       | 45                  | 30                   |
| 151       | 34                  | 7                    |
| 152       | 14                  | 4                    |
| 153       | 8                   | 16                   |
| 154       | 15                  | 6                    |
| 155       | 39                  | 47                   |
| 156       | 39                  | 4                    |
| 157       | 35                  | 26                   |
| 158       | 27                  | 38                   |
| 159       | 43                  | 40                   |
| 160       | 14                  | 23                   |
| 161       | 10                  | 10                   |
| 162       | 15                  | 33                   |
| 163       | 35                  | 72                   |
| 164       | 60                  | 39                   |
| 165       | 55                  | 31                   |
| 166       | 47                  | 30                   |
| 167       | 16                  | 7                    |
| 168       | 0                   | 6                    |
| 169       | 0                   | 8                    |
| 170       | 0                   | 8                    |
| 171       | 0                   | 2                    |
| 172       | 2                   | 17                   |
| 173       | 10                  | 28                   |
| 174       | 28                  | 31                   |
| 175       | 33                  | 30                   |
| 176       | 36                  | 0                    |
| 177       | 19                  | 10                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 178       | 1                   | 18                   |
| 179       | 0                   | 16                   |
| 180       | 1                   | 3                    |
| 181       | 1                   | 4                    |
| 182       | 1                   | 5                    |
| 183       | 1                   | 6                    |
| 184       | 1                   | 5                    |
| 185       | 1                   | 3                    |
| 186       | 1                   | 4                    |
| 187       | 1                   | 4                    |
| 188       | 1                   | 6                    |
| 189       | 8                   | 18                   |
| 190       | 20                  | 51                   |
| 191       | 49                  | 19                   |
| 192       | 41                  | 13                   |
| 193       | 31                  | 16                   |
| 194       | 28                  | 21                   |
| 195       | 21                  | 17                   |
| 196       | 31                  | 21                   |
| 197       | 21                  | 8                    |
| 198       | 0                   | 14                   |
| 199       | 0                   | 12                   |
| 200       | 3                   | 8                    |
| 201       | 3                   | 22                   |
| 202       | 12                  | 20                   |
| 203       | 14                  | 20                   |
| 204       | 16                  | 17                   |
| 205       | 20                  | 18                   |
| 206       | 27                  | 34                   |
| 207       | 32                  | 33                   |
| 208       | 41                  | 31                   |
| 209       | 43                  | 31                   |
| 210       | 37                  | 33                   |
| 211       | 26                  | 18                   |
| 212       | 18                  | 29                   |
| 213       | 14                  | 51                   |
| 214       | 13                  | 11                   |
| 215       | 12                  | 9                    |
| 216       | 15                  | 33                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 217       | 20                  | 25                   |
| 218       | 25                  | 17                   |
| 219       | 31                  | 29                   |
| 220       | 36                  | 66                   |
| 221       | 66                  | 40                   |
| 222       | 50                  | 13                   |
| 223       | 16                  | 24                   |
| 224       | 26                  | 50                   |
| 225       | 64                  | 23                   |
| 226       | 81                  | 20                   |
| 227       | 83                  | 11                   |
| 228       | 79                  | 23                   |
| 229       | 76                  | 31                   |
| 230       | 68                  | 24                   |
| 231       | 59                  | 33                   |
| 232       | 59                  | 3                    |
| 233       | 25                  | 7                    |
| 234       | 21                  | 10                   |
| 235       | 20                  | 19                   |
| 236       | 4                   | 10                   |
| 237       | 5                   | 7                    |
| 238       | 4                   | 5                    |
| 239       | 4                   | 6                    |
| 240       | 4                   | 6                    |
| 241       | 4                   | 5                    |
| 242       | 7                   | 5                    |
| 243       | 16                  | 28                   |
| 244       | 28                  | 25                   |
| 245       | 52                  | 53                   |
| 246       | 50                  | 8                    |
| 247       | 26                  | 40                   |
| 248       | 48                  | 29                   |
| 249       | 54                  | 39                   |
| 250       | 60                  | 42                   |
| 251       | 48                  | 18                   |
| 252       | 54                  | 51                   |
| 253       | 88                  | 90                   |
| 254       | 103                 | 84                   |
| 255       | 103                 | 85                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 256       | 102                 | 84                   |
| 257       | 58                  | 66                   |
| 258       | 64                  | 97                   |
| 259       | 56                  | 80                   |
| 260       | 51                  | 67                   |
| 261       | 52                  | 96                   |
| 262       | 63                  | 62                   |
| 263       | 71                  | 6                    |
| 264       | 33                  | 16                   |
| 265       | 47                  | 45                   |
| 266       | 43                  | 56                   |
| 267       | 42                  | 27                   |
| 268       | 42                  | 64                   |
| 269       | 75                  | 74                   |
| 270       | 68                  | 96                   |
| 271       | 86                  | 61                   |
| 272       | 66                  | 0                    |
| 273       | 37                  | 0                    |
| 274       | 45                  | 37                   |
| 275       | 68                  | 96                   |
| 276       | 80                  | 97                   |
| 277       | 92                  | 96                   |
| 278       | 90                  | 97                   |
| 279       | 82                  | 96                   |
| 280       | 94                  | 81                   |
| 281       | 90                  | 85                   |
| 282       | 96                  | 65                   |
| 283       | 70                  | 96                   |
| 284       | 55                  | 95                   |
| 285       | 70                  | 96                   |
| 286       | 79                  | 96                   |
| 287       | 81                  | 71                   |
| 288       | 71                  | 60                   |
| 289       | 92                  | 65                   |
| 290       | 82                  | 63                   |
| 291       | 61                  | 47                   |
| 292       | 52                  | 37                   |
| 293       | 24                  | 0                    |
| 294       | 20                  | 7                    |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 295       | 39                  | 48                   |
| 296       | 39                  | 54                   |
| 297       | 63                  | 58                   |
| 298       | 53                  | 31                   |
| 299       | 51                  | 24                   |
| 300       | 48                  | 40                   |
| 301       | 39                  | 0                    |
| 302       | 35                  | 18                   |
| 303       | 36                  | 16                   |
| 304       | 29                  | 17                   |
| 305       | 28                  | 21                   |
| 306       | 31                  | 15                   |
| 307       | 31                  | 10                   |
| 308       | 43                  | 19                   |
| 309       | 49                  | 63                   |
| 310       | 78                  | 61                   |
| 311       | 78                  | 46                   |
| 312       | 66                  | 65                   |
| 313       | 78                  | 97                   |
| 314       | 84                  | 63                   |
| 315       | 57                  | 26                   |
| 316       | 36                  | 22                   |
| 317       | 20                  | 34                   |
| 318       | 19                  | 8                    |
| 319       | 9                   | 10                   |
| 320       | 5                   | 5                    |
| 321       | 7                   | 11                   |
| 322       | 15                  | 15                   |
| 323       | 12                  | 9                    |
| 324       | 13                  | 27                   |
| 325       | 15                  | 28                   |
| 326       | 16                  | 28                   |
| 327       | 16                  | 31                   |
| 328       | 15                  | 20                   |
| 329       | 17                  | 0                    |
| 330       | 20                  | 34                   |
| 331       | 21                  | 25                   |
| 332       | 20                  | 0                    |
| 333       | 23                  | 25                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 334       | 30                  | 58                   |
| 335       | 63                  | 96                   |
| 336       | 83                  | 60                   |
| 337       | 61                  | 0                    |
| 338       | 26                  | 0                    |
| 339       | 29                  | 44                   |
| 340       | 68                  | 97                   |
| 341       | 80                  | 97                   |
| 342       | 88                  | 97                   |
| 343       | 99                  | 88                   |
| 344       | 102                 | 86                   |
| 345       | 100                 | 82                   |
| 346       | 74                  | 79                   |
| 347       | 57                  | 79                   |
| 348       | 76                  | 97                   |
| 349       | 84                  | 97                   |
| 350       | 86                  | 97                   |
| 351       | 81                  | 98                   |
| 352       | 83                  | 83                   |
| 353       | 65                  | 96                   |
| 354       | 93                  | 72                   |
| 355       | 63                  | 60                   |
| 356       | 72                  | 49                   |
| 357       | 56                  | 27                   |
| 358       | 29                  | 0                    |
| 359       | 18                  | 13                   |
| 360       | 25                  | 11                   |
| 361       | 28                  | 24                   |
| 362       | 34                  | 53                   |
| 363       | 65                  | 83                   |
| 364       | 80                  | 44                   |
| 365       | 77                  | 46                   |
| 366       | 76                  | 50                   |
| 367       | 45                  | 52                   |
| 368       | 61                  | 98                   |
| 369       | 61                  | 69                   |
| 370       | 63                  | 49                   |
| 371       | 32                  | 0                    |
| 372       | 10                  | 8                    |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 373       | 17                  | 7                    |
| 374       | 16                  | 13                   |
| 375       | 11                  | 6                    |
| 376       | 9                   | 5                    |
| 377       | 9                   | 12                   |
| 378       | 12                  | 46                   |
| 379       | 15                  | 30                   |
| 380       | 26                  | 28                   |
| 381       | 13                  | 9                    |
| 382       | 16                  | 21                   |
| 383       | 24                  | 4                    |
| 384       | 36                  | 43                   |
| 385       | 65                  | 85                   |
| 386       | 78                  | 66                   |
| 387       | 63                  | 39                   |
| 388       | 32                  | 34                   |
| 389       | 46                  | 55                   |
| 390       | 47                  | 42                   |
| 391       | 42                  | 39                   |
| 392       | 27                  | 0                    |
| 393       | 14                  | 5                    |
| 394       | 14                  | 14                   |
| 395       | 24                  | 54                   |
| 396       | 60                  | 90                   |
| 397       | 53                  | 66                   |
| 398       | 70                  | 48                   |
| 399       | 77                  | 93                   |
| 400       | 79                  | 67                   |
| 401       | 46                  | 65                   |
| 402       | 69                  | 98                   |
| 403       | 80                  | 97                   |
| 404       | 74                  | 97                   |
| 405       | 75                  | 98                   |
| 406       | 56                  | 61                   |
| 407       | 42                  | 0                    |
| 408       | 36                  | 32                   |
| 409       | 34                  | 43                   |
| 410       | 68                  | 83                   |
| 411       | 102                 | 48                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 412       | 62                  | 0                    |
| 413       | 41                  | 39                   |
| 414       | 71                  | 86                   |
| 415       | 91                  | 52                   |
| 416       | 89                  | 55                   |
| 417       | 89                  | 56                   |
| 418       | 88                  | 58                   |
| 419       | 78                  | 69                   |
| 420       | 98                  | 39                   |
| 421       | 64                  | 61                   |
| 422       | 90                  | 34                   |
| 423       | 88                  | 38                   |
| 424       | 97                  | 62                   |
| 425       | 100                 | 53                   |
| 426       | 81                  | 58                   |
| 427       | 74                  | 51                   |
| 428       | 76                  | 57                   |
| 429       | 76                  | 72                   |
| 430       | 85                  | 72                   |
| 431       | 84                  | 60                   |
| 432       | 83                  | 72                   |
| 433       | 83                  | 72                   |
| 434       | 86                  | 72                   |
| 435       | 89                  | 72                   |
| 436       | 86                  | 72                   |
| 437       | 87                  | 72                   |
| 438       | 88                  | 72                   |
| 439       | 88                  | 71                   |
| 440       | 87                  | 72                   |
| 441       | 85                  | 71                   |
| 442       | 88                  | 72                   |
| 443       | 88                  | 72                   |
| 444       | 84                  | 72                   |
| 445       | 83                  | 73                   |
| 446       | 77                  | 73                   |
| 447       | 74                  | 73                   |
| 448       | 76                  | 72                   |
| 449       | 46                  | 77                   |
| 450       | 78                  | 62                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 451       | 79                  | 35                   |
| 452       | 82                  | 38                   |
| 453       | 81                  | 41                   |
| 454       | 79                  | 37                   |
| 455       | 78                  | 35                   |
| 456       | 78                  | 38                   |
| 457       | 78                  | 46                   |
| 458       | 75                  | 49                   |
| 459       | 73                  | 50                   |
| 460       | 79                  | 58                   |
| 461       | 79                  | 71                   |
| 462       | 83                  | 44                   |
| 463       | 53                  | 48                   |
| 464       | 40                  | 48                   |
| 465       | 51                  | 75                   |
| 466       | 75                  | 72                   |
| 467       | 89                  | 67                   |
| 468       | 93                  | 60                   |
| 469       | 89                  | 73                   |
| 470       | 86                  | 73                   |
| 471       | 81                  | 73                   |
| 472       | 78                  | 73                   |
| 473       | 78                  | 73                   |
| 474       | 76                  | 73                   |
| 475       | 79                  | 73                   |
| 476       | 82                  | 73                   |
| 477       | 86                  | 73                   |
| 478       | 88                  | 72                   |
| 479       | 92                  | 71                   |
| 480       | 97                  | 54                   |
| 481       | 73                  | 43                   |
| 482       | 36                  | 64                   |
| 483       | 63                  | 31                   |
| 484       | 78                  | 1                    |
| 485       | 69                  | 27                   |
| 486       | 67                  | 28                   |
| 487       | 72                  | 9                    |
| 488       | 71                  | 9                    |
| 489       | 78                  | 36                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 490       | 81                  | 56                   |
| 491       | 75                  | 53                   |
| 492       | 60                  | 45                   |
| 493       | 50                  | 37                   |
| 494       | 66                  | 41                   |
| 495       | 51                  | 61                   |
| 496       | 68                  | 47                   |
| 497       | 29                  | 42                   |
| 498       | 24                  | 73                   |
| 499       | 64                  | 71                   |
| 500       | 90                  | 71                   |
| 501       | 100                 | 61                   |
| 502       | 94                  | 73                   |
| 503       | 84                  | 73                   |
| 504       | 79                  | 73                   |
| 505       | 75                  | 72                   |
| 506       | 78                  | 73                   |
| 507       | 80                  | 73                   |
| 508       | 81                  | 73                   |
| 509       | 81                  | 73                   |
| 510       | 83                  | 73                   |
| 511       | 85                  | 73                   |
| 512       | 84                  | 73                   |
| 513       | 85                  | 73                   |
| 514       | 86                  | 73                   |
| 515       | 85                  | 73                   |
| 516       | 85                  | 73                   |
| 517       | 85                  | 72                   |
| 518       | 85                  | 73                   |
| 519       | 83                  | 73                   |
| 520       | 79                  | 73                   |
| 521       | 78                  | 73                   |
| 522       | 81                  | 73                   |
| 523       | 82                  | 72                   |
| 524       | 94                  | 56                   |
| 525       | 66                  | 48                   |
| 526       | 35                  | 71                   |
| 527       | 51                  | 44                   |
| 528       | 60                  | 23                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 529       | 64                  | 10                   |
| 530       | 63                  | 14                   |
| 531       | 70                  | 37                   |
| 532       | 76                  | 45                   |
| 533       | 78                  | 18                   |
| 534       | 76                  | 51                   |
| 535       | 75                  | 33                   |
| 536       | 81                  | 17                   |
| 537       | 76                  | 45                   |
| 538       | 76                  | 30                   |
| 539       | 80                  | 14                   |
| 540       | 71                  | 18                   |
| 541       | 71                  | 14                   |
| 542       | 71                  | 11                   |
| 543       | 65                  | 2                    |
| 544       | 31                  | 26                   |
| 545       | 24                  | 72                   |
| 546       | 64                  | 70                   |
| 547       | 77                  | 62                   |
| 548       | 80                  | 68                   |
| 549       | 83                  | 53                   |
| 550       | 83                  | 50                   |
| 551       | 83                  | 50                   |
| 552       | 85                  | 43                   |
| 553       | 86                  | 45                   |
| 554       | 89                  | 35                   |
| 555       | 82                  | 61                   |
| 556       | 87                  | 50                   |
| 557       | 85                  | 55                   |
| 558       | 89                  | 49                   |
| 559       | 87                  | 70                   |
| 560       | 91                  | 39                   |
| 561       | 72                  | 3                    |
| 562       | 43                  | 25                   |
| 563       | 30                  | 60                   |
| 564       | 40                  | 45                   |
| 565       | 37                  | 32                   |
| 566       | 37                  | 32                   |
| 567       | 43                  | 70                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 568       | 70                  | 54                   |
| 569       | 77                  | 47                   |
| 570       | 79                  | 66                   |
| 571       | 85                  | 53                   |
| 572       | 83                  | 57                   |
| 573       | 86                  | 52                   |
| 574       | 85                  | 51                   |
| 575       | 70                  | 39                   |
| 576       | 50                  | 5                    |
| 577       | 38                  | 36                   |
| 578       | 30                  | 71                   |
| 579       | 75                  | 53                   |
| 580       | 84                  | 40                   |
| 581       | 85                  | 42                   |
| 582       | 86                  | 49                   |
| 583       | 86                  | 57                   |
| 584       | 89                  | 68                   |
| 585       | 99                  | 61                   |
| 586       | 77                  | 29                   |
| 587       | 81                  | 72                   |
| 588       | 89                  | 69                   |
| 589       | 49                  | 56                   |
| 590       | 79                  | 70                   |
| 591       | 104                 | 59                   |
| 592       | 103                 | 54                   |
| 593       | 102                 | 56                   |
| 594       | 102                 | 56                   |
| 595       | 103                 | 61                   |
| 596       | 102                 | 64                   |
| 597       | 103                 | 60                   |
| 598       | 93                  | 72                   |
| 599       | 86                  | 73                   |
| 600       | 76                  | 73                   |
| 601       | 59                  | 49                   |
| 602       | 46                  | 22                   |
| 603       | 40                  | 65                   |
| 604       | 72                  | 31                   |
| 605       | 72                  | 27                   |
| 606       | 67                  | 44                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 607       | 68                  | 37                   |
| 608       | 67                  | 42                   |
| 609       | 68                  | 50                   |
| 610       | 77                  | 43                   |
| 611       | 58                  | 4                    |
| 612       | 22                  | 37                   |
| 613       | 57                  | 69                   |
| 614       | 68                  | 38                   |
| 615       | 73                  | 2                    |
| 616       | 40                  | 14                   |
| 617       | 42                  | 38                   |
| 618       | 64                  | 69                   |
| 619       | 64                  | 74                   |
| 620       | 67                  | 73                   |
| 621       | 65                  | 73                   |
| 622       | 68                  | 73                   |
| 623       | 65                  | 49                   |
| 624       | 81                  | 0                    |
| 625       | 37                  | 25                   |
| 626       | 24                  | 69                   |
| 627       | 68                  | 71                   |
| 628       | 70                  | 71                   |
| 629       | 76                  | 70                   |
| 630       | 71                  | 72                   |
| 631       | 73                  | 69                   |
| 632       | 76                  | 70                   |
| 633       | 77                  | 72                   |
| 634       | 77                  | 72                   |
| 635       | 77                  | 72                   |
| 636       | 77                  | 70                   |
| 637       | 76                  | 71                   |
| 638       | 76                  | 71                   |
| 639       | 77                  | 71                   |
| 640       | 77                  | 71                   |
| 641       | 78                  | 70                   |
| 642       | 77                  | 70                   |
| 643       | 77                  | 71                   |
| 644       | 79                  | 72                   |
| 645       | 78                  | 70                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 646       | 80                  | 70                   |
| 647       | 82                  | 71                   |
| 648       | 84                  | 71                   |
| 649       | 83                  | 71                   |
| 650       | 83                  | 73                   |
| 651       | 81                  | 70                   |
| 652       | 80                  | 71                   |
| 653       | 78                  | 71                   |
| 654       | 76                  | 70                   |
| 655       | 76                  | 70                   |
| 656       | 76                  | 71                   |
| 657       | 79                  | 71                   |
| 658       | 78                  | 71                   |
| 659       | 81                  | 70                   |
| 660       | 83                  | 72                   |
| 661       | 84                  | 71                   |
| 662       | 86                  | 71                   |
| 663       | 87                  | 71                   |
| 664       | 92                  | 72                   |
| 665       | 91                  | 72                   |
| 666       | 90                  | 71                   |
| 667       | 90                  | 71                   |
| 668       | 91                  | 71                   |
| 669       | 90                  | 70                   |
| 670       | 90                  | 72                   |
| 671       | 91                  | 71                   |
| 672       | 90                  | 71                   |
| 673       | 90                  | 71                   |
| 674       | 92                  | 72                   |
| 675       | 93                  | 69                   |
| 676       | 90                  | 70                   |
| 677       | 93                  | 72                   |
| 678       | 91                  | 70                   |
| 679       | 89                  | 71                   |
| 680       | 91                  | 71                   |
| 681       | 90                  | 71                   |
| 682       | 90                  | 71                   |
| 683       | 92                  | 71                   |
| 684       | 91                  | 71                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 685       | 93                  | 71                   |
| 686       | 93                  | 68                   |
| 687       | 98                  | 68                   |
| 688       | 98                  | 67                   |
| 689       | 100                 | 69                   |
| 690       | 99                  | 68                   |
| 691       | 100                 | 71                   |
| 692       | 99                  | 68                   |
| 693       | 100                 | 69                   |
| 694       | 102                 | 72                   |
| 695       | 101                 | 69                   |
| 696       | 100                 | 69                   |
| 697       | 102                 | 71                   |
| 698       | 102                 | 71                   |
| 699       | 102                 | 69                   |
| 700       | 102                 | 71                   |
| 701       | 102                 | 68                   |
| 702       | 100                 | 69                   |
| 703       | 102                 | 70                   |
| 704       | 102                 | 68                   |
| 705       | 102                 | 70                   |
| 706       | 102                 | 72                   |
| 707       | 102                 | 68                   |
| 708       | 102                 | 69                   |
| 709       | 100                 | 68                   |
| 710       | 102                 | 71                   |
| 711       | 101                 | 64                   |
| 712       | 102                 | 69                   |
| 713       | 102                 | 69                   |
| 714       | 101                 | 69                   |
| 715       | 102                 | 64                   |
| 716       | 102                 | 69                   |
| 717       | 102                 | 68                   |
| 718       | 102                 | 70                   |
| 719       | 102                 | 69                   |
| 720       | 102                 | 70                   |
| 721       | 102                 | 70                   |
| 722       | 102                 | 62                   |
| 723       | 104                 | 38                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 724       | 104                 | 15                   |
| 725       | 102                 | 24                   |
| 726       | 102                 | 45                   |
| 727       | 102                 | 47                   |
| 728       | 104                 | 40                   |
| 729       | 101                 | 52                   |
| 730       | 103                 | 32                   |
| 731       | 102                 | 50                   |
| 732       | 103                 | 30                   |
| 733       | 103                 | 44                   |
| 734       | 102                 | 40                   |
| 735       | 103                 | 43                   |
| 736       | 103                 | 41                   |
| 737       | 102                 | 46                   |
| 738       | 103                 | 39                   |
| 739       | 102                 | 41                   |
| 740       | 103                 | 41                   |
| 741       | 102                 | 38                   |
| 742       | 103                 | 39                   |
| 743       | 102                 | 46                   |
| 744       | 104                 | 46                   |
| 745       | 103                 | 49                   |
| 746       | 102                 | 45                   |
| 747       | 103                 | 42                   |
| 748       | 103                 | 46                   |
| 749       | 103                 | 38                   |
| 750       | 102                 | 48                   |
| 751       | 103                 | 35                   |
| 752       | 102                 | 48                   |
| 753       | 103                 | 49                   |
| 754       | 102                 | 48                   |
| 755       | 102                 | 46                   |
| 756       | 103                 | 47                   |
| 757       | 102                 | 49                   |
| 758       | 102                 | 42                   |
| 759       | 102                 | 52                   |
| 760       | 102                 | 57                   |
| 761       | 102                 | 55                   |
| 762       | 102                 | 61                   |

| Time<br>s | Norm.<br>speed<br>% | Norm.<br>torque<br>% |
|-----------|---------------------|----------------------|
| 763       | 102                 | 61                   |
| 764       | 102                 | 58                   |
| 765       | 103                 | 58                   |
| 766       | 102                 | 59                   |
| 767       | 102                 | 54                   |
| 768       | 102                 | 63                   |
| 769       | 102                 | 61                   |
| 770       | 103                 | 55                   |
| 771       | 102                 | 60                   |
| 772       | 102                 | 72                   |
| 773       | 103                 | 56                   |
| 774       | 102                 | 55                   |
| 775       | 102                 | 67                   |
| 776       | 103                 | 56                   |
| 777       | 84                  | 42                   |
| 778       | 48                  | 7                    |
| 779       | 48                  | 6                    |
| 780       | 48                  | 6                    |
| 781       | 48                  | 7                    |
| 782       | 48                  | 6                    |
| 783       | 48                  | 7                    |
| 784       | 67                  | 21                   |
| 785       | 105                 | 59                   |
| 786       | 105                 | 96                   |
| 787       | 105                 | 74                   |
| 788       | 105                 | 66                   |
| 789       | 105                 | 62                   |
| 790       | 105                 | 66                   |
| 791       | 89                  | 41                   |
| 792       | 52                  | 5                    |
| 793       | 48                  | 5                    |
| 794       | 48                  | 7                    |
| 795       | 48                  | 5                    |
| 796       | 48                  | 6                    |
| 797       | 48                  | 4                    |
| 798       | 52                  | 6                    |
| 799       | 51                  | 5                    |
| 800       | 51                  | 6                    |
| 801       | 51                  | 6                    |