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1958 AGREEMENT

Consideration of draft amendments to existing Regulations

Proposal for the 05 series of amendments to Regulation No. 49
(Emissions of C.I. and P.I. (NG and LPG) engines)

(Revision 4)

Submitted by the Working Party on Pollution and Energy

The text reproduced below was adopted by the Working Party on Pollution and Energy (GRPE) at its fifty-third session. It is a new consolidated version of Regulation No. 49 (Revision 4) and is based on ECE/TRANS/WP.29/GRPE/2007/5, as amended by Annex 2 to the report. The new Annexes 10 and 11 are based on documents ECE/TRANS/WP.29/2006/124 and Amend. 1 as well as ECE/TRANS/WP.29/2006/125. This proposal is submitted to WP.29 and AC.1 for consideration and vote (ECE/TRANS/WP.29/GRPE/53, para. 8).

**UNIFORM PROVISIONS CONCERNING THE MEASURES TO BE TAKEN AGAINST
THE EMISSION OF GASEOUS AND PARTICULATE POLLUTANTS FROM
COMPRESSION-IGNITION ENGINES FOR USE IN VEHICLES, AND THE
EMISSION OF GASEOUS POLLUTANTS FROM POSITIVE-IGNITION ENGINES
FUELLED WITH NATURAL GAS OR LIQUEFIED PETROLEUM GAS FOR USE IN
VEHICLES**

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1. SCOPE

- 1.1. This Regulation applies to vehicles of categories M and N 1/ and their engines, as shown in table A, with regard to the tests foreseen for these engines in table B.

Table A: APPLICABILITY

Vehicle category <u>1/</u>	Maximum mass	Positive-ignition engines			Compression-ignition engines	
		Petrol	NG ^(a)	LPG ^(b)	Diesel	Ethanol
M ₁	≤ 3.5 t	-	-	-	-	-
	> 3.5 t	-	R49	R49	R49	R49
M ₂	-	-	R49	R49	R49 or R83 ^(c)	R49
M ₃	-	-	R49	R49	R49	R49
N ₁	-	-	R49 or R83	R49 or R83	R49 or R83	R49
N ₂	-	-	R49	R49	R49 or R83 ^(c)	R49
N ₃	-	-	R49	R49	R49	R49

^(a) Natural Gas.

^(b) Liquefied Petroleum Gas.

^(c) Regulation No. 83 applies only for vehicles with a reference mass ≤ 2,840 kg as an extension of an approval given for an engine used in vehicles of categories M₁ or N₁. 1/ "R49 or R83" means that manufacturers can obtain type approval according to this Regulation or to Regulation No. 83, see paragraph 1.2.

Table B: REQUIREMENTS

	Positive-ignition engines			Compression-ignition engines	
	Petrol	NG	LPG	Diesel	Ethanol
Gaseous pollutants	-	Yes	Yes	Yes	Yes
Particulates	-	-	-	Yes	-
Durability	-	Yes	Yes	Yes	Yes
In-service-conformity	-	Yes	Yes	Yes	Yes
OBD	-	- ^(a)	- ^(b)	Yes	Yes

^(a) Foreseen for 2008 at the earliest.

^(b) Foreseen for 2008 at the earliest.

1.2. Equivalent approvals

The following do not need to be approved according to this Regulation, if they are part of a vehicle approved according to Regulation No. 83:

- (a) compression-ignition engines to be mounted in vehicles of categories N₁, N₂ and M₂ 1/ fuelled with diesel;
- (b) positive-ignition engines fuelled with natural gas (NG) or liquefied petroleum gas (LPG) to be mounted in vehicles of category N₁. 1/

2. DEFINITIONS

1/ As defined in Annex 7 to the Consolidated Resolution on the Construction of Vehicles (R.E.3), (document TRANS/WP.29/78/Rev.1/Amend.2 as last amended by Amend.4).

2.1. For the purposes of this Regulation, the following definitions shall apply:

"approval of an engine (engine family)" means the approval of an engine type (engine family) with regard to the level of the emission of gaseous and particulate pollutants;

"auxiliary emission control strategy (AECS)" means an emission control strategy that becomes active or that modifies the base emission control strategy for a specific purpose or purposes and in response to a specific set of ambient and/or operating conditions, e.g. vehicle speed, engine speed, gear used, intake temperature, or intake pressure;

"base emission control strategy (BECS)" means an emission control strategy that is active throughout the speed and load operating range of the engine unless an AECS is activated. Examples for BECS are, but are not limited to:

- (a) engine timing map;
- (b) EGR map;
- (c) SCR catalyst reagent dosing map;

"combined deNOx- particulate filter" means an exhaust aftertreatment system designed to concurrently reduce emissions of oxides of nitrogen (NOx) and particulate pollutants (PT);

"continuous regeneration" means the regeneration process of an exhaust aftertreatment system that occurs either permanently or at least once per ETC test. Such a regeneration process will not require a special test procedure;

"control area" means the area between the engine speeds A and C and between 25 to 100 per cent load;

"declared maximum power (P_{max})" means the maximum power in EC kW (net power) as declared by the manufacturer in his application for approval;

"defeat strategy" means:

- (a) an AECS that reduces the effectiveness of the emission control relative to the BECS under conditions that may reasonably be expected to be encountered in normal vehicle operation and use;
- (b) a BECS that discriminates between operation on a standardized approval test and other operations and provides a lesser level of emission control under conditions not substantially included in the applicable approval test procedures, or;
- (c) an OBD or an emission control monitoring strategy that discriminates between operation on a standardized approval test and other operations and provides a lower level of monitoring capability (timely and accurately) under conditions not substantially included in the applicable approval test procedures;

"deNOx system" means an exhaust aftertreatment system designed to reduce emissions of oxides of nitrogen (NOx) (e.g. there are presently passive and active lean NOx catalysts, NOx adsorbers and selective catalytic reduction (SCR) systems);

"delay time" means the time between the change of the component to be measured at the reference point and a system response of 10 per cent of the final reading (t_{10}). For the gaseous components, this is basically the transport time of the measured component from the sampling probe to the detector. For the delay time, the sampling probe is defined as the reference point;

"diesel engine" means an engine which works on the compression-ignition principle;

"ELR test" means a test cycle consisting of a sequence of load steps at constant engine speeds to be applied in accordance with paragraph 5.2.;

"ESC test" means a test cycle consisting of 13 steady state modes to be applied in accordance with paragraph 5.2.;

"ETC test" means a test cycle consisting of 1800 second-by-second transient modes to be applied in accordance with paragraph 5.2.;

"element of design" means in respect of a vehicle or engine,

- (a) any control system, including computer software, electronic control systems and computer logic;
- (b) any control system calibrations;
- (c) the result of systems interaction, or;
- (d) any hardware items;

"emissions-related defect" means a deficiency or deviation from normal production tolerances in design, materials or workmanship in a device, system or assembly that affects any parameter, specification or component belonging to the emission control system. A missing component may be considered to be an "emissions-related defect";

"emission control strategy (ECS)" means an element or set of elements of design that is incorporated into the overall design of an engine system or vehicle for the purposes of controlling exhaust emissions that includes one BECS and one set of AECS;

"emission control system" means the exhaust aftertreatment system, the electronic management controller(s) of the engine system and any emission-related component of the engine system in the exhaust which supplies an input to or receives an output from this(these) controller(s), and when applicable the communication interface (hardware and messages) between the engine system electronic control unit(s) (EECU) and any other power train or vehicle control unit with respect to emissions management;

"emission control monitoring system" means the system that ensures correct operation of the NOx control measures implemented in the engine system according to the requirements of paragraph 5.5.

"emission default mode" means an AECS activated in the case of a malfunction of the ECS detected by the OBD system that results in the MI being activated and that does not require an input from the failed component or system;

"engine-aftertreatment system family" means, for testing over a service accumulation schedule to establish deterioration factors according to Annex 7 to this Regulation and for checking the conformity of in-service vehicles/engines according to Annex 8 to this Regulation, a manufacturer's grouping of engines that comply with the definition of engine family but which are further grouped into engines utilising a similar exhaust after-treatment system;

"engine system" means the engine, the emission control system and the communication interface (hardware and messages) between the engine system electronic control unit(s) (EECU) and any other powertrain or vehicle control unit;

"engine family" means a manufacturer's grouping of engine systems which, through their design as defined in paragraph 7. of this Regulation, have similar exhaust emission characteristics; all members of the family shall comply with the applicable emission limit values;

"engine operating speed range" means the engine speed range, most frequently used during engine field operation, which lies between the low and high speeds, as set out in Appendix 1 to Annex 4A to this Regulation;

"engine speeds A, B and C" means the test speeds within the engine operating speed range to be used for the ESC test and the ELR test, as set out in Appendix 1 to Annex 4A to this Regulation;

"engine setting" means a specific engine/vehicle configuration that includes the emission control strategy (ECS), one single engine performance rating (the approved full-load curve) and, if used, one set of torque limiters;

"engine type" means a category of engines which do not differ in such essential respects as engine characteristics as described in Annex 1 to this Regulation;

"exhaust aftertreatment system" means a catalyst (oxidation or 3-way), particulate filter, deNO_x system, combined deNO_x-particulate filter or any other emission-reducing device that is installed downstream of the engine. This definition excludes exhaust gas recirculation, which, where fitted, is considered an integral part of the engine system;

"gas engine" means a positive-ignition engine which is fuelled with natural gas (NG) or liquefied petroleum gas (LPG);

"gaseous pollutants" means carbon monoxide, hydrocarbons (assuming a ratio of CH_{1.85} for diesel, CH_{2.525} for LPG and CH_{2.93} for NG (NMHC) and an assumed molecule CH_{3O_{0.5}} for ethanol-fuelled diesel engines), methane (assuming a ratio of CH₄ for NG)

and oxides of nitrogen, the last-named being expressed in nitrogen dioxide (NO₂) equivalent;

"high speed (n_{hi})" means the highest engine speed where 70 per cent of the declared maximum power occurs;

"low speed (n_{lo})" means the lowest engine speed where 50 per cent of the declared maximum power occurs;

"major functional failure" 2/ means a permanent or temporary malfunction of any exhaust aftertreatment system that is expected to result in an immediate or delayed increase of the gaseous or particulate emissions of the engine system and which cannot be properly estimated by the OBD system;

"malfunction" means:

- (a) any deterioration or failure, including electrical failures, of the emission control system, that would result in emissions exceeding the OBD threshold limits or, when applicable, in failing to reach the range of functional performance of the exhaust aftertreatment system where the emission of any regulated pollutant would exceed the OBD threshold limits;
- (b) any case where the OBD system is not able to fulfil the monitoring requirements of this Regulation.

A manufacturer may nevertheless consider a deterioration or failure that would result in emissions not exceeding the OBD threshold limits as a malfunction;

"malfunction indicator (MI)" means a visual indicator that clearly informs the driver of the vehicle in the event of a malfunction in the sense of this Regulation;

"multi-setting engine" means an engine containing more than one engine setting;

"NG gas range" means one of the H or L range as defined in European Standard EN 437, dated November 1993;

"net power" means the power in kW obtained on the test bench at the end of the crankshaft, or its equivalent, measured in accordance with the method of measuring power as set out in Regulation No. 85;

"OBD" means an on-board diagnostic system for emission control, which has the capability of detecting the occurrence of a malfunction and of identifying the likely area of malfunction by means of fault codes stored in computer memory;

2/ Paragraph 5.4.1. of this Regulation provides for the monitoring for major functional failure instead of monitoring for the degradation or the loss of catalytic/filtering efficiency of an exhaust aftertreatment system. Examples of major functional failure are given in paragraphs 3.2.3.2. and 3.2.3.3. of Annex 9A to this Regulation.

"OBD-engine family" means, for approval of the OBD system according to the requirements of Annex 9A to this Regulation, a manufacturer's grouping of engine systems having common OBD system design parameters according to paragraph 7.3. of this Regulation;

"opacimeter" means an instrument designed to measure the opacity of smoke particles by means of the light extinction principle;

"parent engine" means an engine selected from an engine family in such a way that its emissions characteristics will be representative for that engine family;

"particulate aftertreatment device" means an exhaust aftertreatment system designed to reduce emissions of particulate pollutants (PT) through a mechanical, aerodynamic, diffusional or inertial separation;

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

"per cent load" means the fraction of the maximum available torque at an engine speed;

"periodic regeneration" means the regeneration process of an emission control device that occurs periodically in less than 100 hours of normal engine operation. During cycles where regeneration occurs, emission standards can be exceeded.

"power take-off unit" means an engine-driven output device for the purposes of powering auxiliary, vehicle mounted, equipment;

"reagent" means any medium that is stored on-board the vehicle in a tank and provided to the exhaust aftertreatment system (if required) upon request of the emission control system;

"recalibration" means a fine tuning of an NG engine in order to provide the same performance (power, fuel consumption) in a different range of natural gas;

"reference speed (n_{ref})" means the 100 per cent speed value to be used for denormalizing the relative speed values of the ETC test, as set out in Appendix 2 to Annex 4A to this Regulation;

"response time" means the 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 per cent FS and takes place in less than 0.1 second. The system response time (t_{90}) consists of the delay time to the system and of the rise time of the system (see also ISO 16183);

"rise time" means the time between the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$). This is the instrument response after the component to be measured

has reached the instrument. For the rise time, the sampling probe is defined as the reference point;

"self adaptability" means any engine device allowing the air/fuel ratio to be kept constant;

"smoke" means particles suspended in the exhaust stream of a diesel engine which absorb, reflect, or refract light;

"test cycle" means a sequence of test points each with a defined speed and torque to be followed by the engine under steady state (ESC test) or transient operating conditions (ETC, ELR test);

"torque limiter" means a device that temporarily limits the maximum torque of the engine;

"transformation time" means the time between the change of the component to be measured at the sampling probe and a system response of 50 per cent of the final reading (t_{50}). The transformation time is used for the signal alignment of different measurement instruments;

"useful life" means, for vehicles and engines that are approved to either row B1, row B2 or row C of the table given in paragraph 5.2.1. of this Regulation, the relevant period of distance and/or time that is defined in paragraph 5.3. (durability of emission control systems) of this Regulation over which compliance with the relevant gaseous, particulate and smoke emission limits has to be assured as part of the approval;

"Wobbe index (lower Wl; or upper Wu)" means the ratio of the corresponding calorific value of a gas per unit volume and the square root of its relative density under the same reference conditions:

$$W = H_{\text{gas}} \times \sqrt{\rho_{\text{air}}/\rho_{\text{gas}}}$$

" λ -shift factor (S_λ)" means an expression that describes the required flexibility of the engine management system regarding a change of the excess-air ratio λ if the engine is fuelled with a gas composition different from pure methane (see Annex 7 for the calculation of S_λ).

2.2. Symbols, abbreviations and international standards

2.2.1. Symbols for test parameters:

Symbol	Unit	Term
A_p	m^2	Cross sectional area of the isokinetic sampling probe
A_e	m^2	Cross sectional area of the exhaust pipe
c	ppm/vol. per cent	Concentration

C_d	—	Discharge coefficient of SSV-CVS
C_1	—	Carbon 1 equivalent hydrocarbon
d	m	Diameter
D_0	m^3/s	Intercept of PDP calibration function
D	—	Dilution factor
D	—	Bessel function constant
E	—	Bessel function constant
E_E	—	Ethane efficiency
E_M	—	Methane efficiency
E_Z	g/kWh	Interpolated NO_x emission of the control point
f	1/s	Frequency
f_a	—	Laboratory atmospheric factor
f_c	s^{-1}	Bessel filter cut-off frequency
F_s	—	Stoichiometric factor
H	MJ/m^3	Calorific value
H_a	g/kg	Absolute humidity of the intake air
H_d	g/kg	Absolute humidity of the dilution air
i	—	Subscript denoting an individual mode or instantaneous measurement
K	—	Bessel constant
k	m^{-1}	Light absorption coefficient
k_f	—	Fuel specific factor for dry to wet correction
$k_{h,D}$	—	Humidity correction factor for NO_x for diesel engines
$k_{h,G}$	—	Humidity correction factor for NO_x for gas engines
K_V	—	CFV calibration function
$k_{w,a}$	—	Dry to wet correction factor for the intake air
$k_{w,d}$	—	Dry to wet correction factor for the dilution air
$k_{w,e}$	—	Dry to wet correction factor for the diluted exhaust gas
$k_{w,r}$	—	Dry to wet correction factor for the raw exhaust gas
L	per cent	Percent torque related to the maximum torque for the test engine
L_a	m	Effective optical path length
M_{ra}	g/mol	Molecular mass of the intake air
M_{re}	g/mol	Molecular mass of the exhaust
m_d	kg	Mass of the dilution air sample passed through the particulate sampling filters
m_{ed}	kg	Total diluted exhaust mass over the cycle
m_{edf}	kg	Mass of equivalent diluted exhaust over the cycle
m_{ew}	kg	Total exhaust mass over the cycle
m_f	mg	Particulate sample mass collected
$m_{f,d}$	mg	Particulate sample mass of the dilution air collected
m_{gas}	g/h or g	Gaseous emissions mass flow (rate)
m_{se}	kg	Sample mass over the cycle
m_{sep}	kg	Mass of the diluted exhaust sample passed through the particulate sampling filters
m_{set}	kg	Mass of the double diluted exhaust sample passed through the particulate sampling filters

m_{ssd}	kg	Mass of secondary dilution air
N	per cent	Opacity
N_p	—	Total revolutions of PDP over the cycle
$N_{p,i}$	—	Revolutions of PDP during a time interval
n	min^{-1}	Engine speed
n_p	s^{-1}	PDP speed
n_{hi}	min^{-1}	High engine speed
n_{lo}	min^{-1}	Low engine speed
n_{ref}	min^{-1}	Reference engine speed for ETC test
p_a	kPa	Saturation vapour pressure of the engine intake air
p_b	kPa	Total atmospheric pressure
p_d	kPa	Saturation vapour pressure of the dilution air
p_p	kPa	Absolute pressure
p_r	kPa	Water vapour pressure after cooling bath
p_s	kPa	Dry atmospheric pressure
p_i	kPa	Pressure depression at pump inlet
P(a)	kW	Power absorbed by auxiliaries to be fitted for test
P(b)	kW	Power absorbed by auxiliaries to be removed for test
P(n)	kW	Net power non-corrected
P(m)	kW	Power measured on test bed
q_{maw}	kg/h or kg/s	Intake air mass flow rate on wet basis
q_{mad}	kg/h or kg/s	Intake air mass flow rate on dry basis
q_{mdw}	kg/h or kg/s	Dilution air mass flow rate on wet basis
q_{mdew}	kg/h or kg/s	Diluted exhaust gas mass flow rate on wet basis
$q_{mdew,i}$	kg/s	Instantaneous CVS flow rate mass on wet basis
q_{medf}	kg/h or kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
q_{mew}	kg/h or kg/s	Exhaust gas mass flow rate on wet basis
q_{mf}	kg/h or kg/s	Fuel mass flow rate
q_{mp}	kg/h or kg/s	Particulate sample mass flow rate
q_{vs}	dm^3/min	Sample flow rate into analyzer bench
q_{vt}	cm^3/min	Tracer gas flow rate
Ω	—	Bessel constant
Q_s	m^3/s	PDP/CFV-CVS volume flow rate
Q_{SSV}	m^3/s	SSV-CVS volume flow rate
r_a	—	Ratio of cross sectional areas of isokinetic probe and exhaust pipe
r_d	—	Dilution ratio
r_D	—	Diameter ratio of SSV-CVS
r_p	—	Pressure ratio of SSV-CVS
r_s	—	Sample ratio
R_f	—	FID response factor
ρ	kg/m^3	density
S	kW	Dynamometer setting
S_i	m^{-1}	Instantaneous smoke value
S_λ	—	λ -shift factor
T	K	Absolute temperature

T_a	K	Absolute temperature of the intake air
t	s	Measuring time
t_e	s	Electrical response time
t_f	s	Filter response time for Bessel function
t_p	s	Physical response time
Δt	s	Time interval between successive smoke data (= 1/sampling rate)
Δt_i	s	Time interval for instantaneous CVS flow
τ	per cent	Smoke transmittance
u	-	Ratio between densities of gas component and exhaust gas
V_0	m^3/rev	PDP gas volume pumped per revolution
V_s	l	System volume of analyzer bench
W	—	Wobbe index
W_{act}	kWh	Actual cycle work of ETC
W_{ref}	kWh	Reference cycle work of ETC
W_f	—	Weighting factor
W_{fe}	—	Effective weighting factor
X_0	m^3/rev	Calibration function of PDP volume flow rate
Y_i	m^{-1}	1 s Bessel averaged smoke value

2.2.2. Symbols for chemical components

CH_4	Methane
C_2H_6	Ethane
C_2H_5OH	Ethanol
C_3H_8	Propane
CO	Carbon monoxide
DOP	Di-octylphtalate
CO_2	Carbon dioxide
HC	Hydrocarbons
NMHC	Non-methane hydrocarbons
NOx	Oxides of nitrogen
NO	Nitric oxide
NO_2	Nitrogen dioxide
PT	Particulates

2.2.3. Abbreviations

CFV	Critical flow venturi
CLD	Chemiluminescent detector
ELR	European load response test
ESC	European steady state cycle
ETC	European transient cycle
FID	Flame ionisation detector
GC	Gas chromatograph
HCLD	Heated chemiluminescent detector
HFID	Heated flame ionisation detector
LPG	Liquefied petroleum gas

NDIR	Non-dispersive infrared analyzer
NG	Natural gas
NMC	Non-methane cutter

2.2.4. Symbols for the fuel composition

W_{ALF}	hydrogen content of fuel, per cent mass
W_{BET}	carbon content of fuel, per cent mass
W_{GAM}	sulphur content of fuel, per cent mass
W_{DEL}	nitrogen content of fuel, per cent mass
W_{EPS}	oxygen content of fuel, per cent mass
α	molar hydrogen ratio (H/C)
β	molar carbon ratio (C/C)
γ	molar sulphur ratio (S/C)
δ	molar nitrogen ratio (N/C)
ε	molar oxygen ratio (O/C)

referring to a fuel $C_{\beta} H_{\alpha} O_{\varepsilon} N_{\delta} S_{\gamma}$
 $\beta = 1$ for carbon based fuels, $\beta = 0$ for hydrogen fuel

2.2.5. Standards referenced by this Regulation

ISO 15031-1	ISO 15031-1: 2001 Road vehicles - Communication between vehicle and external equipment for emissions related diagnostics - Part 1: General information.
ISO 15031-2	ISO/PRF TR 15031-2: 2004 Road vehicles - Communication between vehicle and external equipment for emissions related diagnostics - Part 2: Terms, definitions, abbreviations and acronyms.
ISO 15031-3	ISO 15031-3: 2004 Road vehicles - Communication between vehicle and external equipment for emissions related diagnostics - Part 3: Diagnostic connector and related electrical circuits, specification and use.
SAE J1939-13	SAE J1939-13: Off-Board Diagnostic Connector.
ISO 15031-4	ISO DIS 15031-4.3: 2004 Road vehicles - Communication between vehicle and external equipment for emissions related diagnostics - Part 4: External test equipment.
SAE J1939-73	SAE J1939-73: Application Layer – Diagnostics.
ISO 15031-5	ISO DIS 15031-5.4: 2004 Road vehicles - Communication between vehicle and external equipment for emissions related diagnostics - Part 5: Emissions-related diagnostic services.
ISO 15031-6	ISO DIS 15031-6.4: 2004 Road vehicles - Communication between vehicle and external equipment for emissions related diagnostics - Part 6: Diagnostic trouble code definitions.
SAE J2012	SAE J2012: Diagnostic Trouble Code Definitions Equivalent to ISO/DIS 15031-6, April 30, 2002.
ISO 15031-7	ISO 15031-7: 2001 Road vehicles - Communication between vehicle and external equipment for emissions related diagnostics - Part 7: Data link security.

SAE J2186	SAE J2186: E/E Data Link Security, dated October 1996.
ISO 15765-4	ISO 15765-4: 2001 Road vehicles - Diagnostics on Controller Area Network (CAN) - Part 4: Requirements for emissions-related systems.
SAE J1939	SAE J1939: Recommended Practice for a Serial Control and Communications Vehicle Network.
ISO 16185	ISO 16185: 2000 Road vehicles – engine family for homologation.
ISO 2575	ISO 2575: 2000 Road vehicles – Symbols for controls, indicators and tell-tales.
ISO 16183	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.

3. APPLICATION FOR APPROVAL

3.1. Application for approval for a type of engine or engine family as a separate technical unit

3.1.1. The application for approval of an engine type or engine family with regard to the level of the emission of gaseous and particulate pollutants for diesel engines and with regard to the level of the emission of gaseous pollutants for gas engines as well as the useful life and on-board diagnostic (OBD) system shall be submitted by the engine manufacturer or by a duly accredited representative.

Should the application concern an engine equipped with an on-board diagnostic (OBD) system, the requirements of paragraph 3.4. shall be fulfilled.

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

3.1.2.1. A description of the engine type or engine family, if applicable, comprising the particulars referred to in Annex 1 to this Regulation.

3.1.3. An engine conforming to the "engine type" or "parent engine" characteristics described in Annex 1 shall be submitted to the technical service responsible for conducting the approval tests defined in paragraph 5.

3.2. Application for approval for a vehicle type in respect of its engine

3.2.1. The application for approval of a vehicle with regard to emission of gaseous and particulate pollutants by its diesel engine or diesel engine family and with regard to the level of the emission of gaseous pollutants by its gas engine or gas engine family as well as the useful life and on-board diagnostic (OBD) system shall be submitted by the vehicle manufacturer or by a duly accredited representative.

Should the application concern an engine equipped with an on-board diagnostic (OBD) system, the requirements of paragraph 3.4. shall be fulfilled.

3.2.2. It shall be accompanied by the below-mentioned documents in triplicate and the following particulars:

3.2.2.1. A description of the vehicle type, of the engine-related vehicle parts and of the engine type or engine family, if applicable, comprising the particulars referred to in Annex 1 to this Regulation.

3.2.3. The manufacturer shall provide a description of the malfunction indicator (MI) used by the OBD system to signal the presence of a fault to a driver of the vehicle.

The manufacturer shall provide a description of the indicator and warning mode used to signal the lack of required reagent to a driver of the vehicle.

3.3. Application for approval for a vehicle type with an approved engine

3.3.1. The application for approval of a vehicle with regard to emission of gaseous and particulate pollutants by its approved diesel engine or diesel engine family and with regard to the level of the emission of gaseous pollutants by its approved gas engine or gas engine family as well as the useful life and on-board diagnostic (OBD) system shall be submitted by the vehicle manufacturer or by a duly accredited representative.

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

3.3.2.1. a description of the vehicle type and of engine-related vehicle parts comprising the particulars referred to in Annex 1, as applicable, and a copy of the approval communication form (Annex 2A) for the engine or engine family, if applicable, as a separate technical unit which is installed in the vehicle type.

3.3.3. The manufacturer shall provide a description of the malfunction indicator (MI) used by the OBD system to signal the presence of a fault to a driver of the vehicle.

The manufacturer shall provide a description of the indicator and warning mode used to signal the lack of required reagent to a driver of the vehicle.

3.4. On-board diagnostic systems

3.4.1. The application for approval of an engine equipped with an on-board diagnostic (OBD) system shall be accompanied by the information required in paragraph 9. of Annex 1 (description of the parent engine) and/or paragraph 6. of Appendix 2 to Annex 1 (description of an engine type within the family) together with:

3.4.1.1. Detailed written information fully describing the functional operation characteristics of the OBD system, including a listing of all relevant parts of the engine's emission control system, i.e. sensors, actuators and components, that are monitored by the OBD system;

- 3.4.1.2. Where applicable, a declaration by the manufacturer of the parameters that are used as a basis for major functional failure monitoring and, in addition:
 - 3.4.1.2.1. The manufacturer shall provide the technical service with a description of potential failures within the emission control system that will have an effect on emissions. This information shall be subject to discussion and agreement between the technical service and the vehicle manufacturer.
 - 3.4.1.3. Where applicable, a description of the communication interface (hardware and messages) between the engine electronic control unit (EECU) and any other powertrain or vehicle control unit when the exchanged information has an influence on the correct functioning of the emission control system.
 - 3.4.1.4. Where appropriate, copies of other approvals with the relevant data to enable extensions of approvals.
 - 3.4.1.5. If applicable, the particulars of the engine family as referred to in paragraph 7. of this Regulation.
 - 3.4.1.6. The manufacturer shall describe provisions taken to prevent tampering with and modification of the EECU or any interface parameter considered in paragraph 3.4.1.3.

4. APPROVAL

4.1. Granting of a universal fuel approval

A universal fuel approval is granted subject to the following requirements.

- 4.1.1. In the case of diesel or ethanol fuel the parent engine meets the requirements of this Regulation on the reference fuel specified in Annex 5.
- 4.1.2. In the case of natural gas the parent engine should demonstrate its capability to adapt to any fuel composition that may occur across the market. In the case of natural gas there are generally two types of fuel, high calorific fuel (H-gas) and low calorific fuel (L-gas), but with a significant spread within both ranges; they differ significantly in their energy content expressed by the Wobbe Index and in their λ -shift factor (S_λ). The formulae for the calculation of the Wobbe index and S_λ are given in paragraph. Natural gases with a λ -shift factor between 0.89 and 1.08 ($0.89 \leq S_\lambda \leq 1.08$) are considered to belong to H-range, while natural gases with a λ -shift factor between 1.08 and 1.19 ($1.08 \leq S_\lambda \leq 1.19$) are considered to belong to L-range. The composition of the reference fuels reflects the extreme variations of S_λ .

The parent engine shall meet the requirements of this Regulation on the reference fuels G_R (fuel 1) and G_{25} (fuel 2), as specified in Annex 5, without any readjustment to the fuelling between the two tests. However, one adaptation run over one ETC cycle without measurement is permitted after the change of the fuel. Before testing, the parent

engine shall be run-in using the procedure given in paragraph 3. of Appendix 2 to Annex 4A.

- 4.1.2.1. On the manufacturer's request the engine may be tested on a third fuel (fuel 3) if the λ -shift factor (S_λ) lies between 0.89 (i.e. the lower range of G_R) and 1.19 (i.e. the upper range of G_{25}), for example when fuel 3 is a market fuel. The results of this test may be used as a basis for the evaluation of the conformity of the production.
- 4.1.3. In the case of an engine fuelled with natural gas which is self-adaptive for the range of H-gases on the one hand and the range of L-gases on the other hand, and which switches between the H-range and the L-range by means of a switch, the parent engine shall be tested on the relevant reference fuel as specified in Annex 5 for each range, at each position of the switch. The fuels are G_R (fuel 1) and G_{23} (fuel 3) for the H-range of gases and G_{25} (fuel 2) and G_{23} (fuel 3) for the L-range of gases. The parent engine shall meet the requirements of this Regulation at both positions of the switch without any readjustment to the fuelling between the two tests at each position of the switch. However, one adaptation run over one ETC cycle without measurement is permitted after the change of the fuel. Before testing, the parent engine shall be run-in using the procedure given in paragraph 3. of Appendix 2 to Annex 4A.
- 4.1.3.1. At the manufacturer's request the engine may be tested on a third fuel instead of G_{23} (fuel 3) if the λ -shift factor (S_λ) lies between 0.89 (i.e. the lower range of G_R) and 1.19 (i.e. the upper range of G_{25}), for example when fuel 3 is a market fuel. The results of this test may be used as a basis for the evaluation of the conformity of the production.
- 4.1.4. In the case of natural gas engines, the ratio of the emission results "r" shall be determined for each pollutant as follows:

$$r = \frac{\text{emission result on reference fuel 2}}{\text{emission result on reference fuel 1}}$$

or,

$$r_a = \frac{\text{emission result on reference fuel 2}}{\text{emission result on reference fuel 3}}$$

and,

$$r_b = \frac{\text{emission result on reference fuel 1}}{\text{emission result on reference fuel 3}}$$

- 4.1.5. In the case of LPG the parent engine should demonstrate its capability to adapt to any fuel composition that may occur across the market. In the case of LPG there are variations in C_3/C_4 composition. These variations are reflected in the reference fuels. The parent engine should meet the emission requirements on the reference fuels A and B as specified in Annex 5 without any readjustment to the fuelling between the two tests. However, one adaptation run over one ETC cycle without measurement is permitted

after the change of the fuel. Before testing, the parent engine shall be run-in using the procedure defined in paragraph 3. of Appendix 2 to Annex 4A.

- 4.1.5.1. The ratio of emission results "r" shall be determined for each pollutant as follows:

$$r = \frac{\text{emission result on reference fuel B}}{\text{emission result on reference fuel A}}$$

4.2. Granting of a fuel range restricted approval

Fuel range restricted approval is granted subject to the following requirements.

- 4.2.1. Exhaust emissions approval of an engine running on natural gas and laid out for operation on either the range of H-gases or on the range of L-gases

The parent engine shall be tested on the relevant reference fuel, as specified in Annex 5, for the relevant range. The fuels are G_R (fuel 1) and G_{23} (fuel 3) for the H-range of gases and G_{25} (fuel 2) and G_{23} (fuel 3) for the L-range of gases. The parent engine shall meet the requirements of this Regulation without any readjustment to the fuelling between the two tests. However, one adaptation run over one ETC cycle without measurement is permitted after the change of the fuel. Before testing, the parent engine shall be run-in using the procedure defined in paragraph 3. of Appendix 2 to Annex 4A.

- 4.2.1.1. At the manufacturer's request the engine may be tested on a third fuel instead of G_{23} (fuel 3) if the λ -shift factor (S_λ) lies between 0.89 (i.e. the lower range of G_R) and 1.19 (i.e. the upper range of G_{25}), for example when fuel 3 is a market fuel. The results of this test may be used as a basis for the evaluation of the conformity of the production.

- 4.2.1.2. The ratio of emission results "r" shall be determined for each pollutant as follows:

$$r = \frac{\text{emission result on reference fuel 2}}{\text{emission result on reference fuel 1}}$$

or,

$$r_a = \frac{\text{emission result on reference fuel 2}}{\text{emission result on reference fuel 3}}$$

and,

$$r_b = \frac{\text{emission result on reference fuel 1}}{\text{emission result on reference fuel 3}}$$

- 4.2.1.3. On delivery to the customer the engine shall bear a label (see paragraph 4.11.) stating for which range of gases the engine is approved.

- 4.2.2. Exhaust emissions approval of an engine running on natural gas or LPG and laid out for operation on one specific fuel composition:

- 4.2.2.1. The parent engine shall meet the emission requirements on the reference fuels G_R and G_{25} in the case of natural gas, or the reference fuels A and B in the case of LPG, as specified in Annex 5. Between the tests fine-tuning of the fuelling system is allowed. This fine-tuning will consist of a recalibration of the fuelling database, without any alteration to either the basic control strategy or the basic structure of the database. If necessary the exchange of parts that are directly related to the amount of fuel flow (such as injector nozzles) is allowed.
- 4.2.2.2. At the manufacturer's request the engine may be tested on the reference fuels G_R and G_{23} , or on the reference fuels G_{25} and G_{23} , in which case the approval is only valid for the H-range or the L-range of gases respectively.
- 4.2.2.3. On delivery to the customer the engine shall bear a label (see paragraph 4.11.) stating for which fuel composition the engine has been calibrated.

APPROVAL OF NG-FUELLED ENGINES

	Paragraph 4.1.: Granting of a universal fuel approval	Number of test runs	Calculation of "r"	Paragraph 4.2.: Granting of a fuel restricted approval	Number of test runs	Calculation of "r"
Refer to para. 4.1.2. NG-engine adaptable to any fuel composition	GR (1) and G25 (2) at manufacturer's request engine may be tested on an additional market fuel (3), if $S_{\lambda} = 0.89 - 1.19$	2 (max. 3)	$r = \frac{\text{fuel 2 (G25)}}{\text{fuel 1 (GR)}}$ and, if tested with an additional fuel $ra = \frac{\text{fuel 2 (G25)}}{\text{fuel 3 (market fuel)}}$ and $rb = \frac{\text{fuel 1 (GR)}}{\text{fuel 3 (G23 or market fuel)}}$			
Refer to para. 4.1.3. NG-engine which is self adaptive by a switch	GR (1) and G23 (3) for H and G25 (2) and G23 (3) for L at manufacturer's request engine may be tested on a market fuel (3) instead of G23, if $S_{\lambda} = 0.89 - 1.19$	2 for the H-range, and 2 for the L-range; at respective position of switch 4	$rb = \frac{\text{fuel 1 (GR)}}{\text{fuel 3 (G23 or market fuel)}}$ and $ra = \frac{\text{fuel 2 (G25)}}{\text{fuel 3 (G23 or market fuel)}}$			
Refer to para. 4.2.1. NG-engine laid out for operation on either H-range gas or L-range gas				GR (1) and G23 (3) for H or G25 (2) and G23 (3) for L at manufacturer's request engine may be tested on a market fuel (3) instead of G23, if $S_{\lambda} = 0.89 - 1.19$	2 for the H-range or 2 for the L-range 2	$rb = \frac{\text{fuel 1 (GR)}}{\text{fuel 3 (G23 or market fuel)}}$ for the H-range or $ra = \frac{\text{fuel 2 (G25)}}{\text{fuel 3 (G23 or market fuel)}}$ for the L-range
Refer to para. 4.2.2. NG-engine laid out for operation on one specific fuel composition				GR (1) and G25 (2), fine-tuning between the tests allowed; at manufacturer's request engine may be tested on: GR (1) and G23 (3) for H or G25 (2) and G23 (3) for L	2 or 2 for the H-range or 2 for the L-range 2	

APPROVAL OF LPG-FUELLED ENGINES

	Paragraph 4.1.: Granting of a universal fuel approval	Number of test runs	Calculation of "r"	Paragraph 4.2.: Granting of a fuel restricted approval	Number of test runs	Calculation of "r"
refer to para. 4.1.5 LPG-engine adaptable to any fuel composition	fuel A and fuel B	2	$r = \frac{\text{fuel B}}{\text{fuel A}}$			
refer to para. 4.2.2 LPG-engine laid out for operation on one specific fuel composition				fuel A and fuel B, fine-tuning between the tests allowed	2	

4.3. Exhaust emissions approval of a member of a family

4.3.1. With the exception of the case mentioned in paragraph 4.3.2., the approval of a parent engine shall be extended to all family members without further testing, for any fuel composition within the range for which the parent engine has been approved (in the case of engines described in paragraph 4.2.2.) or the same range of fuels (in the case of engines described in either paragraphs 4.1. or 4.2.) for which the parent engine has been approved.

4.3.2. Secondary test engine

In case of an application for approval of an engine, or a vehicle in respect of its engine, that engine belonging to an engine family, if the technical service determines that, with regard to the selected parent engine the submitted application does not fully represent the engine family defined in Annex I, Appendix 1, an alternative and if necessary an additional reference test engine may be selected by the technical service and tested.

4.4. An approval number shall be assigned to each type approved. Its first two digits (at present 05, corresponding to 05 series of amendments) shall indicate the series of amendments incorporating the most recent major technical amendments made to the Regulation at the time of issue of the approval. The same Contracting Party shall not assign the same number to another engine type or vehicle type.

4.5. Notice of approval or of extension or of refusal of approval or production definitely discontinued of an engine type or vehicle type pursuant to this Regulation shall be communicated to the Parties to the 1958 Agreement which apply this Regulation, by means of a form conforming to the model in annexes 2A or 2B, as applicable, to this Regulation. Values measured during the type test shall also be shown.

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

4.6.1. a circle surrounding the letter "E" followed by the distinguishing number of the country which has granted approval 1/;

1/ 1 for Germany, 2 for France, 3 for Italy, 4 for the Netherlands, 5 for Sweden, 6 for Belgium, 7 for Hungary, 8 for the Czech Republic, 9 for Spain, 10 for Serbia, 11 for the United Kingdom, 12 for Austria, 13 for Luxembourg, 14 for Switzerland, 15 (vacant), 16 for Norway, 17 for Finland, 18 for Denmark, 19 for Romania, 20 for Poland, 21 for Portugal, 22 for the Russian Federation, 23 for Greece, 24 for Ireland, 25 for Croatia, 26 for Slovenia, 27 for Slovakia, 28 for Belarus, 29 for Estonia, 30 (vacant), 31 for Bosnia and Herzegovina, 32 for Latvia, 33 (vacant), 34 for Bulgaria, 35 (vacant), 36 for Lithuania, 37 for Turkey, 38 (vacant), 39 for Azerbaijan, 40 for The former Yugoslav Republic of Macedonia, 41 (vacant), 42 for the European Community (Approvals are granted by its Member States using their respective ECE symbol), 43 for Japan, 44 (vacant), 45 for Australia, 46 for Ukraine, 47 for South Africa, 48 for New Zealand, 49 for Cyprus, 50 for Malta, 51

- 4.6.2. the number of this Regulation, followed by the letter "R", a dash and the approval number to the right of the circle prescribed in paragraph 4.6.1.
- 4.6.3. However, the approval mark shall contain an additional character after the letter "R", the purpose of which is to distinguish the emission stages (emission limits, OBD, etc.) for which the approval has been granted according to the following table:

Character	Row ^(a)	OBD Stage I ^(b)	OBD Stage II	Durability and in-use	NOx control ^(c)
B	B1(2005)	YES	-	YES	-
C	B1(2005)	YES	-	YES	YES
D	B2(2008)	YES	-	YES	-
E	B2(2008)	YES	-	YES	YES
F	B2(2008)	-	YES	YES	-
G	B2(2008)	-	YES	YES	YES
H	C	YES	-	YES	-
I	C	YES	-	YES	YES
J	C	-	YES	YES	-
K	C	-	YES	YES	YES

^(a) In accordance with tables of paragraph 5.2.1. of this Regulation.

^(b) In accordance with paragraph 5.4. of this Regulation, gas engines are excluded from OBD stage I.

^(c) In accordance with paragraph 5.5. of this Regulation.

- 4.6.3.1. For NG fuelled engines the approval mark shall contain a suffix after the national symbol, the purpose of which is to distinguish which range of gases the approval has been granted. This mark will be as follows;
- 4.6.3.1.1. H in case of the engine being approved and calibrated for the H-range of gases;
- 4.6.3.1.2. L in case of the engine being approved and calibrated for the L-range of gases;
- 4.6.3.1.3. HL in case of the engine being approved and calibrated for both the H-range and L-range of gases;

for the Republic of Korea, 52 for Malaysia, 53 for Thailand and 56 for Montenegro. Subsequent numbers shall be assigned to other countries in the chronological order in which they ratify or accede to the Agreement Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions, and the numbers thus assigned shall be communicated by the Secretary-General of the United Nations to the Contracting Parties to the Agreement.

- 4.6.3.1.4. Ht in case of the engine being approved and calibrated for a specific gas composition in the H-range of gases and transformable to another specific gas in the H-range of gases by fine tuning of the engine fuelling;
- 4.6.3.1.5. Lt in case of the engine being approved and calibrated for a specific gas composition in the L-range of gases and transformable to another specific gas in the L-range of gases after fine tuning of the engine fuelling;
- 4.6.3.1.6. HLt in the case of the engine being approved and calibrated for a specific gas composition in either the H-range or the L-range of gases and transformable to another specific gas in either the H-range or the L-range of gases by fine tuning of the engine fuelling.
- 4.7. If the vehicle or engine conforms to an approved type under one or more other Regulations annexed to the Agreement, in the country which has granted approval under this Regulation, the symbol prescribed in paragraph 4.6.1. need not be repeated. In such a case, the Regulation and approval numbers and the additional symbols of all the Regulations under which approval has been granted under this Regulation shall be placed in vertical columns to the right of the symbol prescribed in paragraph 4.6.1.
- 4.8. The approval mark shall be placed close to or on the data plate affixed by the manufacturer to the approved type.
- 4.9. Annex 3 to this Regulation gives examples of arrangements of approval marks.
- 4.10. The engine approved as a technical unit shall bear, in addition to the approved mark:
 - 4.10.1. the trademark or trade name of the manufacturer of the engine;
 - 4.10.2. the manufacturer's commercial description.
- 4.11. Labels

In the case of NG and LPG fuelled engines with a fuel range restricted type approval, the following labels are applicable:

 - 4.11.1. Content

The following information shall be given:

In the case of paragraph 4.2.1.3., the label shall state "ONLY FOR USE WITH NATURAL GAS RANGE H". If applicable, "H" is replaced by "L".

In the case of paragraph 4.2.2.3., the label shall state "ONLY FOR USE WITH NATURAL GAS SPECIFICATION" or "ONLY FOR USE WITH LIQUEFIED PETROLEUM GAS SPECIFICATION", as applicable. All the information in the

relevant table(s) in Annex 5 shall be given with the individual constituents and limits specified by the engine manufacturer.

The letters and figures shall be at least 4 mm in height.

Note: If lack of space prevents such labelling, a simplified code may be used. In this event, explanatory notes containing all the above information shall be easily accessible to any person filling the fuel tank or performing maintenance or repair on the engine and its accessories, as well as to the authorities concerned. The site and content of these explanatory notes will be determined by agreement between the manufacturer and the approval authority.

4.11.2. Properties

Labels shall be durable for the useful life of the engine. Labels shall be clearly legible and their letters and figures shall be indelible. Additionally, labels shall be attached in such a manner that their fixing is durable for the useful life of the engine, and the labels cannot be removed without destroying or defacing them.

4.11.3. Placing

Labels shall be secured to an engine part necessary for normal engine operation and not normally requiring replacement during engine life. Additionally, these labels shall be located so as to be readily visible to the average person after the engine has been completed with all the auxiliaries necessary for engine operation.

4.12. In case of an application for approval for a vehicle type in respect of its engine, the marking specified in paragraph 4.11. shall also be placed close to fuel filling aperture.

4.13. In case of an application for approval for a vehicle type with an approved engine, the marking specified in paragraph 4.11. shall also be placed close to the fuel filling aperture.

5. SPECIFICATIONS AND TESTS

5.1. General

5.1.1. Emission control equipment

5.1.1.1. The components liable to affect, where appropriate, the emission of gaseous and particulate pollutants from diesel and gas engines shall be so designed, constructed, assembled and installed as to enable the engine, in normal use, to comply with the provisions of this Regulation.

5.1.2. The use of a defeat strategy is forbidden.

- 5.1.2.1. The use of a multi-setting engine is forbidden until appropriate and robust provisions for multi-setting engines are laid down in this Regulation.
- 5.1.3. Emission control strategy
- 5.1.3.1. Any element of design and emission control strategy (ECS) liable to affect the emission of gaseous and particulate pollutants from diesel engines and the emission of gaseous pollutants from gas engines shall be so designed, constructed, assembled and installed as to enable the engine, in normal use, to comply with the provisions of this Regulation. ECS consists of the base emission control strategy (BECS) and usually one or more auxiliary emission control strategies (AECS).
- 5.1.4. Requirements for base emission control strategy
- 5.1.4.1. The base emission control strategy (BECS) shall be so designed as to enable the engine, in normal use, to comply with the provisions of this Regulation. Normal use is not restricted to the conditions of use as specified in paragraph 5.1.5.4.
- 5.1.5. Requirements for auxiliary emission control strategy
- 5.1.5.1. An auxiliary emission control strategy (AECS) may be installed to an engine or on a vehicle provided that the AECS:
- (a) operates only outside the conditions of use specified in paragraph 5.1.5.4. for the purposes defined in paragraph 5.1.5.5. or,
 - (b) is activated only exceptionally within the conditions of use specified in paragraph 5.1.5.4. for the purposes defined in paragraph 5.1.5.6. and not longer than is needed for these purposes.
- 5.1.5.2. An auxiliary emission control strategy (AECS) that operates within the conditions of use specified in paragraph 5.1.5.4. and which results in the use of a different or modified emission control strategy (ECS) to that normally employed during the applicable emission test cycles will be permitted if, in complying with the requirements of paragraph 5.1.7., it is fully demonstrated that the measure does not permanently reduce the effectiveness of the emission control system. In all other cases, such strategy shall be considered to be a defeat strategy.
- 5.1.5.3. An auxiliary emission control strategy (AECS) that operates outside the conditions of use specified in paragraph 5.1.5.4. will be permitted if, in complying with the requirements of paragraph 5.1.7., it is fully demonstrated that the measure is the minimum strategy necessary for the purposes of paragraph 5.1.5.6. with respect to environmental protection and other technical aspects. In all other cases, such a strategy shall be considered to be a defeat strategy.
- 5.1.5.4. As provided for in paragraph 5.1.5.1., the following conditions of use apply under steady state and transient engine operations:
- (a) an altitude not exceeding 1,000 metres (or equivalent atmospheric pressure of 90 kPa), and;

- (b) an ambient temperature within the range 275 K to 303 K (2 °C to 30 °C) 2/ 3/ and;
 - (c) engine coolant temperature within the range 343 K to 373 K (70 °C to 100 °C).
- 5.1.5.5. An auxiliary emission control strategy (AECS) may be installed to an engine, or on a vehicle, provided that the operation of the AECS is included in the applicable approval test and is activated according to paragraph 5.1.5.6.
- 5.1.5.6. The AECS is activated:
- (a) only by on-board signals for the purpose of protecting the engine system (including air-handling device protection) and/or vehicle from damage, or;
 - (b) for purposes such as operational safety, emission default modes and limp-home strategies, or;
 - (c) for such purposes as excessive emissions prevention, cold start or warming-up, or;
 - (d) if it is used to trade-off the control of one regulated pollutant under specific ambient or operating conditions in order to maintain control of all other regulated pollutants within the emission limit values that are appropriate for the engine in question. The overall effects of such an AECS is to compensate for naturally occurring phenomena and do so in a manner that provides acceptable control of all emission constituents.
- 5.1.6. Requirements for torque limiters
- 5.1.6.1. A torque limiter will be permitted if it complies with the requirements of paragraph 5.1.6.2. or 5.5.5. In all other cases, a torque limiter shall be considered to be a defeat strategy.
- 5.1.6.2. A torque limiter may be installed to an engine, or on a vehicle, provided that:
- (a) the torque limiter is activated only by on-board signals for the purpose of protecting the powertrain or vehicle construction from damage and/or for the purpose of vehicle safety, or for power take-off activation when the vehicle is stationary, or for measures to ensure the correct functioning of the deNOx system, and;
 - (b) the torque limiter is active only temporarily, and;
 - (c) the torque limiter does not modify the emission control strategy (ECS), and;
 - (d) in case of power take-off or powertrain protection the torque is limited to a constant value, independent from the engine speed, while never exceeding the full-load torque, and;
 - (e) is activated in the same manner to limit the performance of a vehicle in order to encourage the driver to take the necessary measures in order to ensure the correct functioning of NOx control measures within the engine system.
- 5.1.7. Special requirements for electronic emission control systems

2/ Up to 1 October 2008, the following applies: "an ambient temperature within the range 279 K to 303 K (6 °C to 30 °C)".

3/ This temperature range will be reconsidered as part of the review of this Regulation with special emphasis on the appropriateness of the lower temperature boundary.

5.1.7.1. Documentation requirements

The manufacturer shall provide a documentation package that gives access to any element of design and emission control strategy (ECS), and torque limiter of the engine system and the means by which it controls its output variables, whether that control is direct or indirect. The documentation shall be made available in two parts:

- (a) the formal documentation package, which shall be supplied to the technical service at the time of submission of the approval application, shall include a full description of the ECS and, if applicable, the torque limiter. This documentation may be brief, provided that it exhibits evidence that all outputs permitted by a matrix obtained from the range of control of the individual unit inputs have been identified. This information shall be attached to the documentation required in paragraph 3. of this Regulation;
- (b) additional material that shows the parameters that are modified by any auxiliary emission control strategy (AECS) and the boundary conditions under which the AECS operates. The additional material shall include a description of the fuel system control logic, timing strategies and switch points during all modes of operation. It shall also include a description of the torque limiter described in paragraph 5.5.5. of this Regulation.

The additional material shall also contain a justification for the use of any AECS and include additional material and test data to demonstrate the effect on exhaust emissions of any AECS installed to the engine or on the vehicle. The justification for the use of an AECS may be based on test data and/or sound engineering analysis.

This additional material shall remain strictly confidential, and be made available to the approval authority on request. The approval authority will keep this material confidential.

5.1.8. Specifically for the approval of engines according to row A of the tables in paragraph 5.2.1. (engines not normally tested on ETC)

5.1.8.1. To verify whether any strategy or measure should be considered a defeat strategy according to the definitions given in paragraph 2., the approval authority and/or the technical service may additionally request a NO_x screening test using the ETC which may be carried out in combination with either the approval test or the procedures for checking the conformity of production.

5.1.8.2. In verifying whether any strategy or measure should be considered a defeat strategy according to the definitions given in paragraph 2., an additional margin of 10 per cent, related to the appropriate NO_x limit value, shall be accepted.

5.1.9. Provisions for electronic system security

- 5.1.9.1. Any vehicle with an Emission Control Unit shall include features to deter modification, except as authorized by the manufacturer. The manufacturer shall authorize modifications if these modifications are necessary for the diagnosis, servicing, inspection, retrofitting or repair of the vehicle. Any reprogrammable computer codes or operating parameters shall be resistant to tampering and afford a level of protection at least as good as the provisions in ISO 15031-7 (SAE J2186) provided that the security exchange is conducted using the protocols and diagnostic connector as prescribed in paragraph 6. of Annex 9A to this Regulation. Any removable calibration memory chips shall be plotted, encased in a sealed container or protected by electronic algorithms and shall not be changeable without the use of specialised tools and procedures.
- 5.1.9.2. Computer-coded engine operating parameters shall not be changeable without the use of specialised tools and procedures (e.g. soldered or potted computer components or sealed (or soldered) computer enclosures).
- 5.1.9.3. Manufacturers shall take adequate steps to protect the maximum fuel delivery setting from tampering while a vehicle is in-service.
- 5.1.9.4. Manufacturers may apply to the approval authority for an exemption from one of these requirements for those vehicles that are unlikely to require protection. The criteria that the approval authority will evaluate in considering an exemption will include, but are not limited to, the current availability of performance chips, the high-performance capability of the vehicle and the projected sales volume of the vehicle.
- 5.1.9.5. Manufacturers using programmable computer code systems (e.g. electrical erasable programmable read-only memory, EEPROM) shall deter unauthorized reprogramming. Manufacturers shall include enhanced tamper-protection strategies and write protect features requiring electronic access to an off-site computer maintained by the manufacturer. Alternative methods giving an equivalent level of tamper protection may be approved by the authority.

5.2. Specifications concerning the emission of gaseous and particulate pollutants and smoke

For type approval testing to either row B1 or B2 or row C of the tables in paragraph 5.2.1. the emissions shall be determined on the ESC, ELR and ETC tests.

For gas engines, the gaseous emissions shall be determined on the ETC test.

The ESC and ELR test procedures are described in Annex 4A, Appendix 1, the ETC test procedure in Annex 4A, Appendices 2 and 3.

The emissions of gaseous pollutants and particulate pollutants, if applicable, and smoke, if applicable, by the engine submitted for testing shall be measured by the methods described in Annex 4A, Appendix 4. Annex 4A, Appendix 7 describes the

recommended analytical systems for the gaseous pollutants, the recommended particulate sampling systems, and the recommended smoke measurement system.

Other systems or analyzers may be approved by the Technical Service if it is found that they yield equivalent results on the respective test cycle. The determination of system equivalency shall be based upon a 7-sample pair (or larger) correlation study between the system under consideration and one of the reference systems of this Regulation. For particulate emissions, only the full flow dilution system or the partial flow dilution system meeting the requirements of ISO 16183 are recognized as equivalent reference systems. "Results" refer to the specific cycle emissions value. The correlation testing shall be performed at the same laboratory, test cell, and on the same engine, and is preferred to be run concurrently. The equivalency of the sample pair averages shall be determined by F-test and t-test statistics as described in Appendix 4 to this Regulation obtained under these laboratory, test cell and engine conditions. Outliers shall be determined in accordance with ISO 5725 and excluded from the database. For introduction of a new system into this Regulation, determination of equivalency shall be based upon the calculation of repeatability and reproducibility, as described in ISO 5725.

5.2.1. Limit Values

The specific mass of the carbon monoxide, of the total hydrocarbons, of the oxides of nitrogen and of the particulates, as determined on the ESC test, and of the smoke opacity, as determined on the ELR test, shall not exceed the amounts shown in table 1.

Table 1
Limit values — ESC and ELR tests

Row	Mass of carbon monoxide (CO) g/kWh	Mass of hydrocarbons (HC) g/kWh	Mass of nitrogen oxides (NO _x) g/kWh	Mass of particulates (PT) g/kWh	Smoke m ⁻¹
A (2000)	2.1	0.66	5.0	0.10 // 0.13 ^(a)	0.8
B1 (2005)	1.5	0.46	3.5	0.02	0.5
B2 (2008)	1.5	0.46	2.0	0.02	0.5
C (EEV)	1.5	0.25	2.0	0.02	0.15

^(a) For engines having a swept volume of less than 0.75 dm³ per cylinder and a rated power speed of more than 3,000 min⁻¹

Table 2
Limit values — ETC tests

Row	Mass of carbon monoxide (CO) g/kWh	Mass of non-methane hydrocarbons (NMHC) g/kWh	Mass of (CH ₄) ^(a) g/kWh	Mass of nitrogen oxides (NO _x) g/kWh	Mass of particulates (PT) (PT) ^(b) g/kWh
A (2000)	5.45	0.78	1.6	5.0	0.16 // 0.21 ^(c)
B1 (2005)	4.0	0.55	1.1	3.5	0.03
B2 (2008)	4.0	0.55	1.1	2.0	0.03
C (EEV)	3.0	0.40	0.65	2.0	0.02

^(a) For NG engines only.

^(b) Not applicable for gas fuelled engines at stages B1 and B2.

^(c) For engines having a swept volume of less than 0.75 dm³ per cylinder and a rated power speed of more than 3,000 min⁻¹

5.2.2. Hydrocarbon measurement for diesel and gas fuelled engines

5.2.2.1. A manufacturer may choose to measure the mass of total hydrocarbons (THC) on the ETC test instead of measuring the mass of non-methane hydrocarbons. In this case, the limit for the mass of total hydrocarbons is the same as shown in table 2 for the mass of non-methane hydrocarbons.

5.2.3. Specific requirements for diesel engines

5.2.3.1. The specific mass of the oxides of nitrogen measured at the random check points within the control area of the ESC test shall not exceed by more than 10 per cent the values interpolated from the adjacent test modes (reference Annex 4A, Appendix 1, paragraphs 5.6.2. and 5.6.3.).

5.2.3.2. The smoke value on the random test speed of the ELR shall not exceed the highest smoke value of the two adjacent test speeds by more than 20 per cent, or by more than 5 per cent of the limit value, whichever is greater.

5.3. Durability and deterioration factors

5.3.1. The manufacturer shall demonstrate that a compression-ignition or gas engine approved by reference to the emission limits set out in row B1 or row B2 or row C of the tables in paragraph 5.2.1. will comply with those emission limits for a useful life of:

5.3.1.1. 100,000 km or five years, whichever is the sooner, in the case of engines to be fitted to vehicles of category N₁ and M₂;

5.3.1.2. 200,000 km or six years, whichever is the sooner, in the case of engines to be fitted to vehicles of category N₂, N₃ with a maximum technically permissible mass not

exceeding 16 tonnes and M₃ Class I, Class II and Class A, and Class B with a maximum technically permissible mass not exceeding 7.5 tonnes;

5.3.1.3. 500,000 km or seven years, whichever is the sooner, in the case of engines to be fitted to vehicles of category N₃ with a maximum technically permissible mass exceeding 16 tonnes and M₃, Class III and Class B with a maximum technically permissible mass exceeding 7.5 tonnes.

5.3.2. For the purposes of this Regulation, the manufacturer shall determine deterioration factors that will be used to demonstrate that the gaseous and particulate emissions of an engine family or engine-aftertreatment system family remain in conformity with the appropriate emission limits specified in the tables in paragraph 5.2.1. over the appropriate durability period laid down in paragraph 5.3.1.

5.3.3. The procedures for demonstrating the compliance of an engine or engine-aftertreatment system family with the relevant emission limits over the appropriate durability period are given in Annex 7 to this Regulation.

5.4. On-board diagnostic (OBD) system

5.4.1. A compression-ignition engine approved by reference to the emission limit values set out in row B1 or row C of the tables in paragraph 5.2.1. or a vehicle propelled by such an engine shall be fitted with an on-board diagnostic (OBD) system that signals the presence of a fault to the driver if the OBD threshold limits set out in row B1 or row C of the table in paragraph 5.4.4. are exceeded. The OBD system for emission control shall be in accordance with the requirements of Annex 9A to this Regulation.

5.4.1.1. In the case of exhaust after-treatment systems, the OBD system may monitor for major functional failure of any of the following:

- (a) a catalyst, where fitted as a separate unit, whether or not it is part of a deNO_x system or a diesel particulate filter;
- (b) a deNO_x system, where fitted;
- (c) a diesel particulate filter, where fitted;
- (d) a combined deNO_x-diesel particulate filter system.

5.4.2. From 1 October 2008 for new approvals and from 1 October 2009 for all approvals, a compression-ignition or a gas engine approved by reference to the emission limit values set out in row B2 or row C of the tables in paragraph 5.2.1., or a vehicle propelled by such an engine shall be fitted with an OBD system that signals the presence of a fault to the driver if the OBD threshold limits set out in row B2 or row C of the table in paragraph 5.4.4. are exceeded. The on-board diagnostic (OBD) system for emission control shall be in accordance with the requirements of Annex 9A to this Regulation.

5.4.3. The OBD system shall also include an interface between the engine electronic control unit (ECU) and any other engine or vehicle electrical or electronic systems that provide an input to or receive an output from the ECU and which affect the correct

functioning of the emission control system, such as the interface between the EECU and a transmission electronic control unit.

5.4.4. The OBD threshold limits shall be as follows:

Row	Compression-ignition engines	
	Mass of oxides of nitrogen (NO _x) g/kWh	Mass of particulate (PT) g/kWh
B1 (2005)	7.0	0.1
B2 (2008)	7.0	0.1
C (EEV)	7.0	0.1

5.4.5. Full and uniform access to OBD information shall be provided for the purposes of testing, diagnosis, servicing and repair in keeping with the relevant provisions of ECE Regulation No. 83 and provisions regarding replacement components ensuring compatibility with OBD systems.

5.4.6. Small batch engine production

As an alternative to the requirements of this paragraph, engine manufacturers whose world-wide annual production of a type of engine, belonging to an OBD engine family:

- (a) is less than 500 units per year, may obtain approval on the basis of the requirements of the present Regulation where the engine is monitored only for circuit continuity and the after-treatment system is monitored for major functional failure;
- (b) is less than 50 units per year, may obtain approval on the basis of the requirements of the present Regulation where the complete emission control system (i.e. the engine and after-treatment system) are monitored only for circuit continuity.

The approval authority shall inform the other Contracting Parties of the circumstances of each approval granted under this provision.

5.5. Requirements to ensure correct operation of NO_x control measures

5.5.1. General

5.5.1.1. This paragraph is applicable to compression-ignition engine systems irrespective of the technology used to comply with the emission limit values provided in the tables in paragraph 5.2.1.

5.5.1.2. Application dates

The application dates shall be in accordance with paragraph 13. of this Regulation.

- 5.5.1.3. Any engine system covered by this paragraph shall be designed, constructed and installed so as to be capable of meeting these requirements over the useful life of the engine.
- 5.5.1.4. Information that fully describes the functional operational characteristics of an engine system covered by this paragraph shall be provided by the manufacturer in Annex 1.
- 5.5.1.5. In its application for approval, if the engine system requires a reagent, the manufacturer shall specify the characteristics of all reagent(s) consumed by any exhaust aftertreatment system, e.g. type and concentrations, operational temperature conditions, reference to international standards etc.
- 5.5.1.6. Subject to requirements set out in paragraph 5.1., any engine system covered by this paragraph shall retain its emission control function during all conditions regularly pertaining in the territory of the Community, especially at low ambient temperatures.
- 5.5.1.7. For the purpose of approval, the manufacturer shall demonstrate to the Technical Service that for engine systems that require a reagent, any emission of ammonia does not exceed, over the applicable emissions test cycle, a mean value of 25 ppm.
- 5.5.1.8. For engine systems requiring a reagent, each separate reagent tank installed on a vehicle shall include means for taking a sample of any fluid inside the tank. The sampling point shall be easily accessible without the use of any specialised tool or device.
- 5.5.2. Maintenance requirements
 - 5.5.2.1. The manufacturer shall furnish or cause to be furnished to all owners of new heavy-duty vehicles or new heavy-duty engines written instructions that shall state that if the vehicle emission control system is not functioning correctly, the driver shall be informed of a problem by the malfunction indicator (MI) and the engine shall consequentially operate with a reduced performance.
 - 5.5.2.2. The instructions will indicate requirements for the proper use and maintenance of vehicles, including where relevant the use of consumable reagents.
 - 5.5.2.3. The instructions shall be written in clear and non-technical language and in the language of the country in which a new heavy-duty vehicle or new heavy-duty engine is sold or registered.
 - 5.5.2.4. The instructions shall specify if consumable reagents have to be refilled by the vehicle operator between normal maintenance intervals and shall indicate a likely rate of reagent consumption according to the type of new heavy-duty vehicle.
 - 5.5.2.5. The instructions shall specify that use of and refilling of a required reagent of the correct specifications when indicated is mandatory for the vehicle to comply with the certificate of conformity issued for that vehicle or engine type.

5.5.2.6. The instructions shall state that it may be a criminal offence to use a vehicle that does not consume any reagent if it is required for the reduction of pollutant emissions and that, in consequence, any favourable conditions for the purchase or operation of the vehicle obtained in the country of registration or other country in which the vehicle is used may become invalid.

5.5.3. Engine system NOx control

5.5.3.1. Incorrect operation of the engine system with respect to NOx emissions control (for example due to lack of any required reagent, incorrect EGR flow or deactivation of EGR) shall be determined through monitoring of the NOx level by sensors positioned in the exhaust stream.

5.5.3.2. Any deviation in NOx level more than 1.5 g/kWh above the applicable limit value given in table 1 of paragraph 5.2.1., shall result in the driver being informed by activation of the MI as referred to in paragraph 3.6.5. of Annex 9A to this Regulation.

5.5.3.3. In addition, a non-erasable fault code identifying the reason why NOx exceeds the levels specified in paragraph 5.5.3.2. shall be stored in accordance with paragraph 3.9.2. of Annex 9A to this Regulation for at least 400 days or 9,600 hours of engine operation.

The reasons for the NOx exceedance shall, at a minimum, and where applicable, be identified in the cases of empty reagent tank, interruption of reagent dosing activity, insufficient reagent quality, too low reagent consumption, incorrect EGR flow or deactivation of the EGR. In all other cases, the manufacturer is permitted to refer to a non-erasable fault code "high NOx - root cause unknown".

5.5.3.4. If the NOx level exceeds the OBD threshold limit values given in the table in Paragraph 5.4.4., a torque limiter shall reduce the performance of the engine according to the requirements of paragraph 5.5.5. in a manner that is clearly perceived by the driver of the vehicle. When the torque limiter is activated the driver shall continue to be alerted according to the requirements of paragraph 5.5.3.2. and a non-erasable fault code shall be stored in accordance with paragraph 5.5.3.3.

5.5.3.5. In the case of engine systems that rely on the use of EGR and no other aftertreatment system for NOx emissions control, the manufacturer may utilise an alternative method to the requirements of paragraph 5.5.3.1. for the determination of the NOx level. At the time of type approval the manufacturer shall demonstrate that the alternative method is equally timely and accurate in determining the NOx level compared to the requirements of paragraph 5.5.3.1. and that it triggers the same consequences as those referred to in paragraphs 5.5.3.2., 5.5.3.3. and 5.5.3.4.

5.5.4. Reagent control

- 5.5.4.1. For vehicles that require the use of a reagent to fulfil the requirements of this paragraph, the driver shall be informed of the level of reagent in the on-vehicle reagent storage tank through a specific mechanical or electronic indication on the vehicle's dashboard. This shall include a warning when the level of reagent goes:
- (a) below 10 per cent of the tank or a higher percentage at the choice of the manufacturer, or;
 - (b) below the level corresponding to the driving distance possible with the fuel reserve level specified by the manufacturer.

The reagent indicator shall be placed in close proximity to the fuel level indicator.

- 5.5.4.2. The driver shall be informed, according to the requirements of paragraph 3.6.5. of Annex 9A to this Regulation, if the reagent tank becomes empty.

- 5.5.4.3. As soon as the reagent tank becomes empty, the requirements of paragraph 5.5.5. shall apply in addition to the requirements of paragraph 5.5.4.2.

- 5.5.4.4. A manufacturer may choose to comply with the paragraphs 5.5.4.5. to 5.5.4.12. as an alternative to complying with the requirements of paragraph 5.5.3.

- 5.5.4.5. Engine systems shall include a means of determining that a fluid corresponding to the reagent characteristics declared by the manufacturer and recorded in Annex 1 to this Regulation is present on the vehicle.

- 5.5.4.6. If the fluid in the reagent tank does not correspond to the minimum requirements declared by the manufacturer as recorded in Annex 1 to this Regulation the additional requirements of paragraph 5.5.4.12. shall apply.

- 5.5.4.7. Engine systems shall include a means for determining reagent consumption and providing off-board access to consumption information.

- 5.5.4.8. Average reagent consumption and average demanded reagent consumption by the engine system either over the previous complete 48 hour period of engine operation or the period needed for a demanded reagent consumption of at least 15 litres, whichever is longer, shall be available via the serial port of the standard diagnostic connector as referred to in paragraph 6.8.3. of Annex 9A to this Regulation.

- 5.5.4.9. In order to monitor reagent consumption, at least the following parameters within the engine shall be monitored:
- (a) level of reagent in on-vehicle storage tank;
 - (b) flow of reagent or injection of reagent as close as technically possible to the point of injection into an exhaust aftertreatment system.

- 5.5.4.10. Any deviation more than 50 per cent in average reagent consumption and average demanded reagent consumption by the engine system over the period defined in

- paragraph 5.5.4.8. shall result in application of the measures laid down in paragraph 5.5.4.12.
- 5.5.4.11. In the case of interruption in reagent dosing activity the measures laid down in paragraph 5.5.4.12. shall apply. This is not required where such interruption is demanded by the engine ECU because engine operating conditions are such that the engine's emission performance does not require reagent dosing, provided that the manufacturer has clearly informed the approval authority when such operating conditions apply.
- 5.5.4.12. Any failure detected with respect to paragraphs 5.5.4.6., 5.5.4.10. or 5.5.4.11. shall trigger the same consequences in the same order as those referred to in paragraphs 5.5.3.2., 5.5.3.3. or 5.5.3.4.
- 5.5.5. Measures to discourage tampering of exhaust aftertreatment systems
- 5.5.5.1. Any engine system covered by this paragraph shall include a torque limiter that will alert the driver that the engine system is operating incorrectly or the vehicle is being operated in an incorrect manner and thereby encourage the prompt rectification of any fault(s).
- 5.5.5.2. The torque limiter shall be activated when the vehicle becomes stationary for the first time after the conditions of either paragraphs 5.5.3.4., 5.5.4.3., 5.5.4.6., 5.5.4.10. or 5.5.4.11. have occurred.
- 5.5.5.3. Where the torque limiter comes into effect, the engine torque shall not, in any case, exceed a constant value of:
- (a) 60 per cent of the engine maximum torque for vehicles of category $N_3 > 16$ tons, $M_1 > 7.5$ tons, M_3/III and $M_3/B > 7.5$ tons ^{4/};
 - (b) 75 per cent of the engine maximum torque for vehicles of category N_1 , N_2 , $N_3 \leq 16$ tons, $3.5 < M_1 \leq 7.5$ tons, M_2 , M_3/I , M_3/II , M_3/A and $M_3/B \leq 7.5$ tons.
- 5.5.5.4. Requirements for documentation and the torque limiter are set out in paragraphs 5.5.5.5. to 5.5.5.8.
- 5.5.5.5. Detailed written information fully describing the functional operation characteristics of the emission control monitoring system and the torque limiter shall be specified according to the documentation requirements of paragraph 5.1.7.1.(b). Specifically, the manufacturer shall provide information on the algorithms used by the ECU for relating the NO_x concentration to the specific NO_x emission (in g/kWh) on the ETC in accordance with paragraph 5.5.6.5.
- 5.5.5.6. The torque limiter shall be deactivated when the engine speed is at idle if the conditions for its activation have ceased to exist. The torque limiter shall not be automatically deactivated without the reason for its activation being remedied.

^{4/} As defined in the Consolidated Resolution on the Construction of Vehicles (R.E.3).

5.5.5.7. Deactivation of the torque limiter shall not be feasible by means of a switch or a maintenance tool.

5.5.5.8. The torque limiter shall not apply to engines or vehicles for use by the armed services, by rescue services and by fire-services and ambulances. Permanent deactivation shall only be done by the engine or vehicle manufacturer, and a special engine type within the engine family shall be designated for proper identification.

5.5.6. Operating conditions of the emission control monitoring system

5.5.6.1. The emission control monitoring system shall be operational,

(a) at all ambient temperatures between 266 K and 308 K (-7 °C and 35 °C);

(b) at all altitudes below 1600 m;

(c) at engine coolant temperatures above 343 K (70 °C).

This paragraph does not apply in the case of monitoring for reagent level in the storage tank where monitoring shall be conducted under all conditions of use.

5.5.6.2. The emission control monitoring system may be deactivated when a limp-home strategy is active and which results in a torque reduction greater than the levels indicated in paragraph 5.5.5.3. for the appropriate vehicle category.

5.5.6.3. If an emission default mode is active, the emission control monitoring system shall remain operational and comply with the provisions of paragraph 5.5.

5.5.6.4. The incorrect operation of NO_x control measures shall be detected within four OBD test cycles as referred to in the definition given in paragraph 6.1. of Appendix 1 of Annex 9A to this Regulation.

5.5.6.5. Algorithms used by the ECU for relating the actual NO_x concentration to the specific NO_x emission (in g/kWh) on the ETC shall not be considered to be a defeat strategy.

5.5.6.6. If an AECS that has been approved by the approval authority in accordance with paragraph 5.1.5. becomes operational, any increase in NO_x due to the operation of the AECS may be applied to the appropriate NO_x level referred to in paragraph 5.5.3.2. In all such cases, the influence of the AECS on the NO_x threshold shall be described in accordance with paragraph 5.5.5.5.

5.5.7. Failure of the emission control monitoring system

5.5.7.1. The emission control monitoring system shall be monitored for electrical failures and for removal or deactivation of any sensor that prevents it from diagnosing an emission increase as required by paragraphs 5.5.3.2. and 5.5.3.4.

Examples of sensors that affect the diagnostic capability are those directly measuring NOx concentration, urea quality sensors, and sensors used for monitoring reagent dosing activity, reagent level, reagent consumption or EGR rate.

5.5.7.2. If a failure of the emission control monitoring system is confirmed, the driver shall be immediately alerted by the activation of the warning signal according to paragraph 3.6.5. of Annex 9A to this Regulation.

5.5.7.3. The torque limiter shall be activated in accordance with paragraph 5.5.5. if the failure is not remedied within 50 hours of engine operation.

The period laid down in the first subparagraph shall be reduced to 36 hours from the dates specified in paragraph 14.2.3.

5.5.7.4. When the emission control monitoring system has determined that the failure has ceased to exist, the fault code(s) associated with that failure may be cleared from the system memory, except in the cases referred to in paragraph 5.5.7.5., and the torque limiter, if applicable, shall be deactivated according to paragraph 5.5.5.6.

Fault code(s) associated with a failure of the emission control monitoring system shall not be capable of being cleared from the system memory by any scan tool.

5.5.7.5. In the case of the removal or deactivation of elements of the emission control monitoring system, in accordance with paragraph 5.5.7.1., a non-erasable fault code shall be stored in accordance with paragraph 3.9.2. of Annex 9A to this Regulation for a minimum of 400 days or 9,600 hours of engine operation.

5.5.8. Demonstration of the emission control monitoring system

5.5.8.1. As part of the application for approval provided for in paragraph 3., the manufacturer shall demonstrate the conformity of the provisions of this paragraph by tests on an engine dynamometer in accordance with paragraphs 5.5.8.2. to 5.5.8.7.

5.5.8.2. The compliance of an engine family or an OBD engine family to the requirements of this paragraph may be demonstrated by testing the emission control monitoring system of one of the members of the family (the parent engine), provided the manufacturer demonstrates to the type approval authority that the emission control monitoring systems are similar within the family.

This demonstration may be performed by presenting to the approval authorities such elements as algorithms, functional analyses, etc.

The parent engine is selected by the manufacturer in agreement with the type approval authority.

5.5.8.3. The testing of the emission control monitoring system consists of the following three phases:

- (a) Selection:
An incorrect operation of the NO_x control measures or a failure of the emission control monitoring system is selected by the authority within a list of incorrect operations provided by the manufacturer.
- (b) Qualification:
The influence of the incorrect operation is validated by measuring the NO_x level over the ETC on an engine test bed.
- (c) Demonstration:
The reaction of the system (torque reduction, warning signal, etc.) shall be demonstrated by running the engine on four OBD test cycles.

5.5.8.3.1. For the selection phase, the manufacturer shall provide the type approval authority with a description of the monitoring strategies used to determine potential incorrect operation of any NO_x control measure and potential failures in the emission control monitoring system that would lead either to activation of the torque limiter or to activation of the warning signal only.

Typical examples of incorrect operations for this list are an empty reagent tank, an incorrect operation leading to an interruption of reagent dosing activity, an insufficient reagent quality, an incorrect operation leading to low reagent consumption, an incorrect EGR flow or a deactivation of the EGR.

A minimum of two and a maximum of three incorrect operations of the NO_x control system or failures of the emission control monitoring system shall be selected by the type approval authority from this list.

5.5.8.3.2. For the qualification phase, the NO_x emissions shall be measured over the ETC test cycle, according to the provisions of Appendix 2 to Annex 4A. The result of the ETC test shall be used to determine in which way the NO_x control monitoring system is expected to react during the demonstration process (torque reduction and/or warning signal). The failure shall be simulated in a way that the NO_x level does not exceed by more than 1 g/kWh any of the threshold levels given in paragraphs 5.5.3.2. or 5.5.3.4.

Emissions qualification is not required in case of an empty reagent tank or for demonstrating a failure of the emission control monitoring system.

The torque limiter shall be deactivated during the qualification phase.

5.5.8.3.3. For the demonstration phase, the engine shall be run over a maximum of four OBD test cycles.

No failure other than the ones which are being considered for demonstration purposes shall be present.

5.5.8.3.4. Prior to starting the test sequence of paragraph 5.5.8.3.3., the emission control monitoring system shall be set to a "no failure" status.

- 5.5.8.3.5. Depending on the NO_x level selected, the system shall activate a warning signal and in addition, if applicable, the torque limiter at any time before the end of the detection sequence. The detection sequence may be stopped once the NO_x control monitoring system has properly reacted.
- 5.5.8.4. In the case of an emission control monitoring system principally based on monitoring the NO_x level by sensors positioned in the exhaust stream, the manufacturer may choose to directly monitor certain system functionalities (e.g. interruption of dosing activity, closed EGR valve) for the determination of compliance. In that case, the selected system functionality shall be demonstrated.
- 5.5.8.5. The level of torque reduction required in paragraph 5.5.5.3. by the torque limiter shall be approved together with the general engine performance approval in accordance with Regulation No. 85. For the demonstration process, the manufacturer shall demonstrate to the approval authority the inclusion of the correct torque limiter into the engine ECU. Separate torque measurement during the demonstration is not required.
- 5.5.8.6. As an alternative to paragraphs 5.5.8.3.3. to 5.5.8.3.5., the demonstration of the emission control monitoring system and the torque limiter may be performed by testing a vehicle. The vehicle shall be driven on the road or on a test track with the selected incorrect operations or failures of the emission control monitoring system to demonstrate that the warning signal and activation of the torque limiter will operate in accordance with the requirements of paragraph 5.5., and, in particular, those in paragraphs 5.5.5.2. and 5.5.5.3.
- 5.5.8.7. If the storage in the computer memory of a non-erasable fault code is required for complying with the requirements of paragraph 5.5., the following three conditions shall be met by the end of demonstration sequence:
- (a) that it is possible to confirm via the OBD scan tool the presence in the OBD computer memory of the appropriate non-erasable fault code described in paragraph 5.5.3.3. and that it can be shown to the satisfaction of the type approval authority that the scan tool cannot erase it, and;
 - (b) that it is possible to confirm the time spent during the detection sequence with the warning signal activated by reading the non-erasable counter referred to in paragraph 3.9.2. of Annex 9A to this Regulation, and that it can be shown to the satisfaction of the type approval authority that the scan tool cannot erase it, and;
 - (c) that the approval authority has approved the elements of design showing that this non-erasable information is stored in accordance with paragraph 3.9.2. of Annex 9A to this Regulation for a minimum of 400 days or 9,600 hours of engine operation.

6. INSTALLATION ON THE VEHICLE

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

6.1.1. intake depression shall not exceed that specified for the approved engine in Annex 2A;

6.1.2. exhaust back pressure shall not exceed that specified for the approved engine in Annex 2A;

6.1.3. power absorbed by the auxiliaries needed for operating the engine shall not exceed that specified for the approved engine in Annex 2A.

7. ENGINE FAMILY

7.1. Parameters defining the engine family

The engine family, as determined by the engine manufacturer shall comply with the provisions of ISO 16185.

7.1.1. Combustion cycle:

- (a) 2 cycle
- (b) 4 cycle

7.1.2. Cooling medium:

- (a) air
- (b) water
- (c) oil

7.1.3. For gas engines and engines with aftertreatment

- (a) Number of cylinders (other diesel engines with fewer cylinders than the parent engine may be considered to belong to the same engine family provided the fuelling system meters fuel for each individual cylinder).

7.1.4. Individual cylinder displacement:

- (a) engines to be within a total spread of 15 per cent

7.1.5. Method of air aspiration:

- (a) naturally aspirated
- (b) pressure charged
- (c) pressure charged with charge air cooler

7.1.6. Combustion chamber type/design:

- (a) pre-chamber
- (b) swirl chamber
- (c) open chamber

7.1.7. Valve and porting — configuration, size and number:

- (a) cylinder head
- (b) cylinder wall
- (c) crankcase

7.1.8. Fuel injection system (diesel engines):

- (a) pump-line-injector
 - (b) in-line pump
 - (c) distributor pump
 - (d) single element
 - (e) unit injector
- 7.1.9. Fuelling system (gas engines):
- (a) mixing unit
 - (b) gas induction/injection (single point, multi-point)
 - (c) liquid injection (single point, multi-point).
- 7.1.10. Ignition system (gas engines)
- 7.1.11. Miscellaneous features:
- (a) exhaust gas recirculation
 - (b) water injection/emulsion
 - (c) secondary air injection
 - (d) charge cooling system
- 7.1.12. Exhaust aftertreatment:
- (a) 3-way-catalyst
 - (b) oxidation catalyst
 - (c) reduction catalyst
 - (d) thermal reactor
 - (e) particulate trap

7.2. Choice of the parent engine

7.2.1. Diesel engines

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

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

7.2.2. Gas engines

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

- (a) the highest fuel delivery per stroke at the speed of declared rated power;
- (b) the most advanced spark timing;
- (c) the lowest EGR rate;
- (d) no air pump or lowest actual air flow pump.

Under certain circumstances, the approval authority may conclude that the worst case emission rate of the family can best be characterized by testing a second engine. Thus, the approval authority may select an additional engine for test based upon features which indicate that it may have the highest emission level of the engines within that family.

7.3. Parameters for defining an OBD-engine family

The OBD-engine family may be defined by basic design parameters that shall be common to engine systems within the family.

In order that engine systems may be considered to belong to the same OBD-engine family, the following list of basic parameters shall be common:

- (a) the methods of OBD monitoring;
 - (b) the methods of malfunction detection;
- unless these methods have been shown as equivalent by the manufacturer by means of relevant engineering demonstration or other appropriate procedures.

Note: engines that do not belong to the same engine family may still belong to the same OBD-engine family provided the above-mentioned criteria are satisfied.

8. CONFORMITY OF PRODUCTION

The conformity of production procedures shall comply with those set out in the Agreement, Appendix 2 (E/ECE/324-E/ECE/TRANS/505/Rev.2), with the following requirements:

- 8.1. Every engine or vehicle bearing an approval mark as prescribed under this Regulation shall be so manufactured as to conform, with regard to the description as given in the approval form and its annexes, to the approved type.
- 8.2. As a general rule, conformity of production with regard to limitation of emissions is checked based on the description given in the communication form and its annexes.
- 8.3. If emissions of pollutants are to be measured and an engine approval has had one or several extensions, the tests will be carried out on the engine(s) described in the information package relating to the relevant extension.
 - 8.3.1. Conformity of the engine subjected to a pollutant test:

After submission of the engine to the authorities, the manufacturer shall not carry out any adjustment to the engines selected.

8.3.1.1. Three engines are randomly taken in the series. Engines that are subject to testing only on the ESC and ELR tests or only on the ETC test for type approval to row A of the tables in paragraph 5.2.1. are subject to those applicable tests for the checking of production conformity. With the agreement of the authority, all other engines type approved to row A, B1 or B2, or C of the tables in paragraph 5.2.1. are subjected to testing either on the ESC and ELR cycles or on the ETC cycle for the checking of the production conformity. The limit values are given in paragraph 5.2.1. of this Regulation.

8.3.1.2. The tests are carried out according to Appendix 1 to this Regulation where the competent authority is satisfied with the production standard deviation given by the manufacturer.

The tests are carried out according to Appendix 2 to this Regulation, where the competent authority is not satisfied with the production standard deviation given by the manufacturer.

At the manufacturer's request, the tests may be carried out in accordance with Appendix 3 to this Regulation.

8.3.1.3. On the basis of a test of the engine by sampling, the production of a series is regarded as conforming where a pass decision is reached for all the pollutants and non conforming where a fail decision is reached for one pollutant, in accordance with the test criteria applied in the appropriate Appendix.

When a pass decision has been reached for one pollutant, this decision may not be changed by any additional tests made in order to reach a decision for the other pollutants.

If no pass decision is reached for all the pollutants and if no fail decision is reached for one pollutant, a test is carried out on another engine (see figure 2).

If no decision is reached, the manufacturer may at any time decide to stop testing. In that case a fail decision is recorded.

8.3.2. The tests will be carried out on newly manufactured engines. Gas fuelled engines shall be run-in using the procedure defined in paragraph 3. of Appendix 2 to Annex 4A.

8.3.2.1. However, at the request of the manufacturer, the tests may be carried out on diesel or gas engines which have been run-in more than the period referred to in paragraph 8.3.2., up to a maximum of 100 hours. In this case, the running-in procedure will be conducted by the manufacturer who shall undertake not to make any adjustments to those engines.

- 8.3.2.2. When the manufacturer asks to conduct a running-in procedure in accordance with paragraph 8.3.2.1., it may be carried out on:
- (a) all the engines that are tested, or;
 - (b) the first engine tested, with the determination of an evolution coefficient as follows:
 - (i) the pollutant emissions will be measured at zero and at "x" hours on the first engine tested,
 - (ii) the evolution coefficient of the emissions between zero and "x" hours will be calculated for each pollutant:
 - a. Emissions "x" hours/Emissions zero hours
 - b. It may be less than one.

The subsequent test engines will not be subjected to the running-in procedure, but their zero hour emissions will be modified by the evolution coefficient.

In this case, the values to be taken will be:

- (a) the values at "x" hours for the first engine;
- (b) the values at zero hour multiplied by the evolution coefficient for the other engines.

8.3.2.3. For diesel and LPG fuelled engines, all these tests may be conducted with commercial fuel. However, at the manufacturer's request, the reference fuels described in Annex 5 may be used. This implies tests, as described in paragraph 4. of this Regulation, with at least two of the reference fuels for each gas engine.

8.3.2.4. For NG fuelled engines, all these tests may be conducted with commercial fuel in the following way:

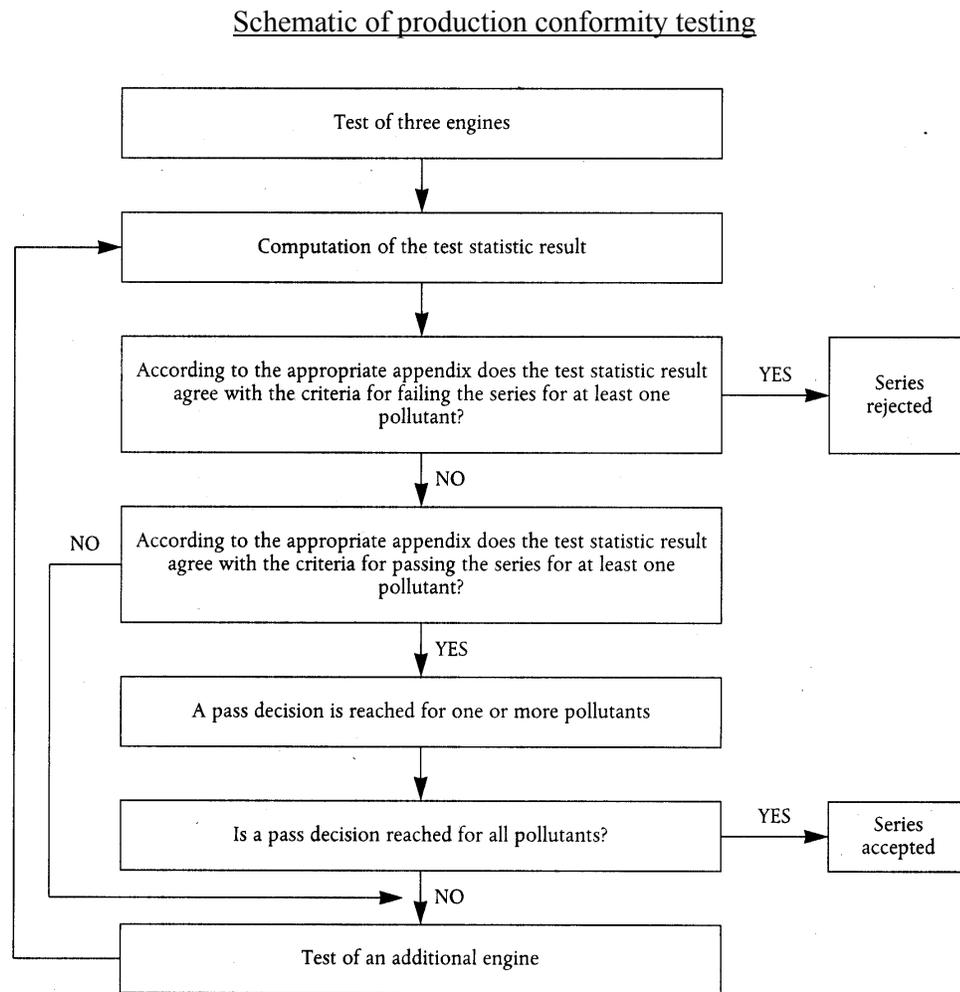
- (a) for H marked engines with a commercial fuel within the H-range ($0.89 \leq S\lambda \leq 1.00$),
- (b) for L marked engines with a commercial fuel within the L-range ($1.00 \leq S\lambda \leq 1.19$),
- (c) for HL marked engines with a commercial fuel within the extreme range of the λ -shift factor ($0.89 \leq S\lambda \leq 1.19$).

However, at the manufacturer's request, the reference fuels described in Annex 5 may be used. This implies tests, as described in paragraph 4. of this Regulation.

8.3.2.5. In the case of dispute caused by the non-compliance of gas fuelled engines when using a commercial fuel, the tests shall be performed with a reference fuel on which the parent engine has been tested, or with the possible additional fuel 3 as referred to in paragraphs 4.1.3.1. and 4.2.1.1. on which the parent engine may have been tested. Then, the result has to be converted by a calculation applying the relevant factor(s) "r", "ra" or "rb" as described in paragraphs 4.1.4., 4.1.5.1. and 4.2.1.2. If "r", "ra" or "rb" are less than 1 no correction shall take place. The measured results and the calculated results shall demonstrate that the engine meets the limit values with all relevant fuels (fuels 1, 2 and, if applicable, fuel 3 in the case of natural gas engines and fuels A and B in the case of LPG engines).

8.3.2.6. Tests for conformity of production of a gas fuelled engine laid out for operation on one specific fuel composition shall be performed on the fuel for which the engine has been calibrated.

Figure 2



8.4. On-board diagnostics (OBD)

8.4.1. If a verification of the conformity of production of the OBD system is to be carried out, it shall be conducted in accordance with the following:

8.4.2. When the approval authority determines that the quality of production seems unsatisfactory an engine is randomly taken from the series and subjected to the tests described in Appendix 1 to Annex 9A to this Regulation. The tests may be carried out on an engine that has been run-in up to a maximum of 100 hours.

8.4.3. The production is deemed to conform if this engine meets the requirements of the tests described in Appendix 1 to Annex 9A to this Regulation.

8.4.4. If the engine taken from the series does not satisfy the requirements of paragraph 8.4.2., a further random sample of four engines shall be taken from the series and subjected to the tests described in Appendix 1 to Annex 9A to this Regulation. The tests may be carried out on engines that have been run-in up to a maximum of 100 hours.

8.4.5. The production is deemed to conform if at least three engines out of the further random sample of four engines meet the requirements of the tests described in Appendix 1 to Annex 9A to this Regulation.

9. CONFORMITY OF IN-SERVICE VEHICLES/ENGINES

9.1. For the purpose of this Regulation, the conformity of in-service vehicles/engines shall be checked periodically over the useful life period of an engine installed in a vehicle.

9.2. With reference to approvals granted for emissions, additional measures are appropriate for confirming the functionality of the emission control devices during the useful life of an engine installed in a vehicle under normal conditions of use.

9.3. The procedures to be followed regarding the conformity of in-service vehicles/engines are given in Annex 8 to this Regulation.

10. PENALTIES FOR NON-CONFORMITY OF PRODUCTION

10.1. The approval granted in respect of an engine or vehicle type pursuant to this Regulation may be withdrawn if the requirements laid down in paragraph 8.1. are not complied with, or if the engine(s) or vehicle(s) taken fail to pass the tests prescribed in paragraph 8.3.

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

11. MODIFICATION AND EXTENSION OF APPROVAL OF THE APPROVED TYPE

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

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

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

11.2. Confirmation or refusal of approval, specifying the alterations, shall be communicated by the procedure specified in paragraph 4.5. to the Contracting Parties to the Agreement applying this Regulation.

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

12. PRODUCTION DEFINITELY DISCONTINUED

If the holder of the approval completely ceases to manufacture the type approved in accordance with this Regulation, he shall so inform the authority which granted the approval. Upon receiving the relevant communication that authority shall inform thereof the other Parties to the 1958 Agreement which apply this Regulation by means of a communication form conforming to the model in Annexes 2A or 2B to this Regulation.

13. TRANSITIONAL PROVISIONS

13.1. General

13.1.1. As from the official date of entry into force of the 05 series of amendments, no Contracting Party applying this Regulation may refuse to grant ECE approval under this Regulation as amended by the 05 series of amendments.

13.1.2. As from the date of entry into force of the 05 series of amendments, Contracting Parties applying this Regulation shall grant ECE approvals only if the engine meets the requirements of this Regulation as amended by the 05 series of amendments.

The engine shall be subject to the relevant tests set out in paragraph 5. and shall comply with paragraphs 13.2.1., 13.2.2. and 13.2.3.

13.2. New type approvals

13.2.1. Notwithstanding the provisions of paragraphs 13.4. and 13.5., Contracting Parties applying this Regulation shall, from the date of entry into force of the 05 series of amendments to this Regulation, grant an ECE approval to an engine only if that engine satisfies:

- (a) the relevant emission limits of Rows B1, B2 or C in the tables to paragraph 5.2.1. of this Regulation;
- (b) the durability requirements set out in paragraph 5.3.;
- (c) the OBD requirements set out in paragraph 5.4.;
- (d) the additional provisions set out in paragraph 5.5.

Character	Date New types - all types	Row ^(a)	OBD Stage I ^(b)	OBD Stage II	Durability and in-use	NOx control ^(c)
B	01/10/05 01/10/06	B1(2005)	YES	-	YES	-
C	09/11/06 01/10/07	B1(2005)	YES	-	YES	YES
D		B2(2008)	YES	-	YES	-
E		B2(2008)	YES	-	YES	YES
F		B2(2008)	-	YES	YES	-
G		B2(2008)	-	YES	YES	YES
H		C	YES	-	YES	-
I		C	YES	-	YES	YES
J		C	-	YES	YES	-
K		C	-	YES	YES	YES

^(a) In accordance with tables of paragraph 5.2.1. of this Regulation.

^(b) In accordance with paragraph 5.4. of this Regulation, gas engines are excluded from OBD stage I.

^(c) In accordance with paragraph 5.5. of this Regulation.

13.2.2. Notwithstanding the provisions of paragraphs 13.4. and 13.5., Contracting Parties applying this Regulation shall, from 9 November 2006, grant an ECE approval to an engine only if that engine satisfies all conditions set out in paragraph 13.2.1. and the additional provisions set out in paragraph 5.5. of this Regulation.

13.2.3. Notwithstanding the provisions of paragraphs 13.4.1. and 13.5., Contracting Parties applying this Regulation shall, from 1 October 2008, grant an ECE approval to an engine only if that engine satisfies:

- (a) the relevant emission limits of rows B2 or C in the tables to paragraph 5.2.1.
- (b) the durability requirements set out in paragraph 5.3.
- (c) the OBD requirements set out in paragraph 5.4. (OBD stage 2)
- (d) the additional provisions set out in paragraph 5.5.

13.3. Limit of validity of old type approvals

13.3.1. As from the official date of entry into force of the 05 series of amendments, type approvals granted to this Regulation as amended by the 04 series of amendments shall cease to be valid.

13.3.2. As from 01 October 2007, type approvals granted to this Regulation as amended by the 05 series of amendments, which do not comply with the requirement of paragraph 13.2.2., shall cease to be valid.

13.3.3. As from 01 October 2009, type approvals granted to this Regulation as amended by the 05 series of amendments, which do not comply with the requirements of paragraph 13.2.3., shall cease to be valid.

13.4. Gas engines

13.4.1. Gas engines do not need to comply with provisions set out in paragraphs 5.5.

13.4.2. Gas engines do not need to comply with the provisions set out in paragraph 5.4.1. (OBD stage 1).

13.5. Replacement engines for vehicles in use

13.5.1. Contracting Parties applying this Regulation may continue to grant approvals to those engines which comply with the requirements of this Regulation as amended by any previous series of amendments, or to any level of the Regulation as amended by the 05 series of amendments, provided that the engine is intended as a replacement for a vehicle in-use and for which that earlier standard was applicable at the date of that vehicle's entry into service.

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

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

Appendix 1PROCEDURE FOR PRODUCTION CONFORMITY TESTING
WHEN STANDARD DEVIATION IS SATISFACTORY

1. This appendix describes the procedure to be used to verify production conformity for the emissions of pollutants when the manufacturer's production standard deviation is satisfactory.
2. With a minimum sample size of three engines the sampling procedure is set so that the probability of a lot passing a test with 40 per cent of the engines defective is 0.95 (producer's risk = 5 per cent) while the probability of a lot being accepted with 65 per cent of the engines defective is 0.10 (consumer's risk = 10 per cent).
3. The following procedure is used for each of the pollutants given in paragraph 5.2.1. of this Regulation (see figure 2):

Let:

- L = the natural logarithm of the limit value for the pollutant;
- x_i = the natural logarithm of the measurement (after having applied the relevant DF) for the i-th engine of the sample;
- s = an estimate of the production standard deviation (after taking the natural logarithm of the measurements);
- n = the current sample number.

4. For each sample the sum of the standardized deviations to the limit is calculated using the following formula:

$$\frac{1}{s} \sum_{i=1}^n (L - x_i)$$

5. Then:
 - (a) if the test statistic result is greater than the pass decision number for the sample size given in table 3, a pass decision is reached for the pollutant;
 - (b) if the test statistic result is less than the fail decision number for the sample size given in table 3, a fail decision is reached for the pollutant;
 - (c) otherwise, an additional engine is tested according to paragraph 8.3.1. and the calculation procedure is applied to the sample increased by one more unit.

Table 3: Pass and Fail Decision Numbers of Appendix 1 Sampling Plan
Minimum sample size: 3

Cumulative number of engines tested (sample size)	Pass decision number A_n	Fail decision number B_n
3	3.327	- 4.724
4	3.261	- 4.790
5	3.195	- 4.856
6	3.129	- 4.922
7	3.063	- 4.988
8	2.997	- 5.054
9	2.931	- 5.120
10	2.865	- 5.185
11	2.799	- 5.251
12	2.733	- 5.317
13	2.667	- 5.383
14	2.601	- 5.449
15	2.535	- 5.515
16	2.469	- 5.581
17	2.403	- 5.647
18	2.337	- 5.713
19	2.271	- 5.779
20	2.205	- 5.845
21	2.139	- 5.911
22	2.073	- 5.977
23	2.007	- 6.043
24	1.941	- 6.109
25	1.875	- 6.175
26	1.809	- 6.241
27	1.743	- 6.307
28	1.677	- 6.373
29	1.611	- 6.439
30	1.545	- 6.505
31	1.479	- 6.571
32	- 2.112	- 2.112

Appendix 2PROCEDURE FOR PRODUCTION CONFORMITY TESTING
WHEN STANDARD DEVIATION IS UNSATISFACTORY OR UNAVAILABLE

1. This appendix describes the procedure to be used to verify production conformity for the emissions of pollutants when the manufacturer's production standard deviation is either unsatisfactory or unavailable.
2. With a minimum sample size of three engines the sampling procedure is set so that the probability of a lot passing a test with 40 per cent of the engines defective is 0.95 (producer's risk = 5 per cent) while the probability of a lot being accepted with 65 per cent of the engines defective is 0.10 (consumer's risk = 10 per cent).
3. The values of the pollutants given in paragraph 5.2.1. of this Regulation, after having applied the relevant DF, are considered to be log normally distributed and should be transformed by taking their natural logarithms. Let m_0 and m denote the minimum and maximum sample size respectively ($m_0 = 3$ and $m = 32$) and let n denote the current sample number.
4. If the natural logarithms of the measured values (after having applied the relevant DF) in the series are x_1, x_2, \dots, x_i and L is the natural logarithm of the limit value for the pollutant, then, define:

$$d_i = x_i - L$$

$$\bar{d}_n = \frac{1}{n} \sum_{i=1}^n d_i$$

$$v_n^2 = \frac{1}{n} \sum_{i=1}^n (d_i - \bar{d}_n)^2$$

5. Table 4 shows values of the pass (A_n) and fail (B_n) decision numbers against current sample number. The test statistic result is the ratio \bar{d}_n/v_n and shall be used to determine whether the series has passed or failed as follows:

For $m_0 \leq n \leq m$:

- (a) pass the series if $\bar{d}_n/v_n \leq A_n$,
- (b) fail the series if $\bar{d}_n/v_n \geq B_n$,
- (c) take another measurement if $A_n < \bar{d}_n/v_n < B_n$.

6. Remarks

The following recursive formulae are useful for calculating successive values of the test statistic:

$$\bar{d}_n = \left(1 - \frac{1}{n}\right) \bar{d}_{n-1} + \frac{1}{n} d_n$$

$$v_n^2 = \left(1 - \frac{1}{n}\right) v_{n-1}^2 + \frac{(\bar{d}_n - d_n)^2}{n-1}$$

$$(n = 2, 3, \dots; \bar{d}_1 = d_1; v_1 = 0)$$

Table 4: Pass and fail decision numbers of Appendix 2 sampling plan
Minimum sample size: 3

Cumulative number of engines tested (sample size)	Pass decision number A_n	Fail decision number B_n
3	- 0.80381	16.64743
4	- 0.76339	7.68627
5	- 0.72982	4.67136
6	- 0.69962	3.25573
7	- 0.67129	2.45431
8	- 0.64406	1.94369
9	- 0.61750	1.59105
10	- 0.59135	1.33295
11	- 0.56542	1.13566
12	- 0.53960	0.97970
13	- 0.51379	0.85307
14	- 0.48791	0.74801
15	- 0.46191	0.65928
16	- 0.43573	0.58321
17	- 0.40933	0.51718
18	- 0.38266	0.45922
19	- 0.35570	0.40788
20	- 0.32840	0.36203
21	- 0.30072	0.32078
22	- 0.27263	0.28343
23	- 0.24410	0.24943
24	- 0.21509	0.21831
25	- 0.18557	0.18970
26	- 0.15550	0.16328
27	- 0.12483	0.13880
28	- 0.09354	0.11603
29	- 0.06159	0.09480
30	- 0.02892	0.07493
31	- 0.00449	0.05629
32	0.03876	0.03876

Appendix 3

PROCEDURE FOR PRODUCTION CONFORMITY TESTING
AT MANUFACTURER'S REQUEST

1. This appendix describes the procedure to be used to verify, at the manufacturer's request, production conformity for the emissions of pollutants.
2. With a minimum sample size of three engines the sampling procedure is set so that the probability of a lot passing a test with 30 per cent of the engines defective is 0.90 (producer's risk = 10 per cent) while the probability of a lot being accepted with 65 per cent of the engines defective is 0.10 (consumer's risk = 10 per cent).
3. The following procedure is used for each of the pollutants given in paragraph 5.2.1. of this Regulation (see figure 2):

Let:

- L = the natural logarithm of the limit value for the pollutant;
- x_i = the natural logarithm of the measurement (after having applied the relevant DF) for the i-th engine of the sample;
- s = an estimate of the production standard deviation (after taking the natural logarithm of the measurements);
- n = the current sample number.

4. Calculate for the sample the test statistic quantifying the number of non-conforming engines, i.e. $x_i \geq L$.
5. Then:
 - (a) if the test statistic is less than or equal to the pass decision number for the sample size given in table 5, a pass decision is reached for the pollutant;
 - (b) if the test statistic is greater than or equal to the fail decision number for the sample size given in table 5, a fail decision is reached for the pollutant;
 - (c) otherwise, an additional engine is tested according to paragraph 8.3.1. of this Regulation and the calculation procedure is applied to the sample increased by one more unit.

In table 5 the pass and fail decision numbers are calculated by means of the International Standard ISO 8422/1991.

Table 5: Pass and fail decision numbers of Appendix 3 sampling plan
Minimum sample size: 3

Cumulative number of engines tested (sample size)	Pass decision number	Fail decision number
3	—	3
4	0	4
5	0	4
6	1	5
7	1	5
8	2	6
9	2	6
10	3	7
11	3	7
12	4	8
13	4	8
14	5	9
15	5	9
16	6	10
17	6	10
18	7	11
19	8	9

Appendix 4

DETERMINATION OF SYSTEM EQUIVALENCE

The determination of system equivalency according to paragraph 5.2. of this Regulation shall be based on a 7-sample pair (or larger) correlation study between the candidate system and one of the accepted reference systems of this Regulation using the appropriate test cycle(s). The equivalency criteria to be applied shall be the F-test and the two-sided student t-test.

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

The following procedure shall be followed. The subscripts R and C refer to the reference and candidate system, respectively:

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

$$F = \frac{s_{\text{major}}^2}{s_{\text{minor}}^2}$$

(the greater of the two standard deviations s_R or s_C shall be in the numerator)

- (d) Calculate the t value, as follows:

$$t = \frac{|x_C - x_R|}{\sqrt{(n_C - 1) \times s_C^2 + (n_R - 1) \times s_R^2}} \times \sqrt{\frac{n_C \times n_R \times (n_C + n_R - 2)}{n_C + n_R}}$$

- (e) Compare the calculated F and t values with the critical F and t values corresponding to the respective number of tests indicated in table below. If larger sample sizes are selected, consult statistical tables for 5 per cent significance (95 per cent confidence) level.

- (f) Determine the degrees of freedom (df), as follows:
 for the F-test: $df = n_R - 1 / n_C - 1$
 for the t-test: $df = n_C + n_R - 2$

F and t values for selected sample sizes:

Sample Size	F-test		t-test	
	df	F _{crit}	df	t _{crit}
7	6/6	4.284	12	2.179
8	7/7	3.787	14	2.145
9	8/8	3.438	16	2.120
10	9/9	3.179	18	2.101

- (g) Determine the equivalency, as follows:
- (i) if $F < F_{crit}$ and $t < t_{crit}$, then the candidate system is equivalent to the reference system of this Regulation;
 - (ii) if $F \geq F_{crit}$ and $t \geq t_{crit}$, then the candidate system is different from the reference system of this Regulation.

Annex 1

INFORMATION DOCUMENT

This information document is related to the approval according to Regulation No. 49. It is referring to measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive-ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles.

Vehicle type/parent engine/engine type 1/

0. GENERAL

- 0.1. Make (name of undertaking):
- 0.2. Type and commercial description (mention any variants):
- 0.3. Means and location of identification of type, if marked on the vehicle:
- 0.4. Category of vehicle (if applicable):
- 0.5. Category of engine: diesel/NG fuelled/LPG fuelled/ethanol fuelled 1/
- 0.6. Name and address of manufacturer:
- 0.7. Location of statutory plates and inscriptions and method of affixing:
- 0.8. In the case of components and separate technical units, location and method of affixing of the ECE approval mark:
- 0.9. Address(es) of assembly plant(s):

Attachments:

- 1. Essential characteristics of the (parent) engine and information concerning the conduct of test (see Appendix 1).
- 2. Essential characteristics of the engine family (see Appendix 2).
- 3. Essential characteristics of the engine types within the family (see Appendix 3).
- 4. Characteristics of the engine-related vehicle parts, if applicable (see Appendix 4).
- 5. Photographs and/or drawings of the parent engine type and, if applicable, of the engine compartment.
- 6. List further attachments, if any.

Date and place

1/ Delete as appropriate.

Annex 1 – Appendix 1ESSENTIAL CHARACTERISTICS OF THE (PARENT) ENGINE AND
INFORMATION CONCERNING THE CONDUCT OF TEST 1/

1. Description of engine
- 1.1. Manufacturer:.....
- 1.2. Manufacturer's engine code:.....
- 1.3. Cycle: four stroke / two stroke 2/:
- 1.4. Number and arrangement of cylinders:
- 1.4.1. Bore:..... mm
- 1.4.2. Stroke:..... mm
- 1.4.3. Firing order:.....
- 1.5. Engine capacity:..... cm³
- 1.6. Volumetric compression ratio 3/:.....
- 1.7. Drawing(s) of combustion chamber and piston crown:.....
- 1.8. Minimum cross-sectional area of inlet and outlet ports: cm²
- 1.9. Idling speed:..... min⁻¹
- 1.10. Maximum net power:..... kW at min⁻¹
- 1.11. Maximum permitted engine speed:..... min⁻¹
- 1.12. Maximum net torque:..... Nm at min⁻¹
- 1.13. Combustion system: compression ignition/positive ignition 2/
- 1.14. Fuel: Diesel/LPG/NG-H/NG-L/NG-HL/ethanol 2/
- 1.15. Cooling system
- 1.15.1. Liquid
- 1.15.1.1. Nature of liquid:.....
- 1.15.1.2. Circulating pump(s): yes/no 2/
- 1.15.1.3. Characteristics or make(s) and type(s) (if applicable):.....
- 1.15.1.4. Drive ratio(s) (if applicable):.....
- 1.15.2. Air
- 1.15.2.1. Blower: yes/no 2/
- 1.15.2.2. Characteristics or make(s) and type(s) (if applicable):.....
- 1.15.2.3. Drive ratio(s) (if applicable):.....
- 1.16. Temperature permitted by the manufacturer
- 1.16.1. Liquid cooling: Maximum temperature at outlet:..... K
- 1.16.2. Air cooling: reference point:.....
Maximum temperature at reference point:..... K
- 1.16.3. Maximum temperature of the air at the outlet of the intake intercooler (if applicable):
.....
- 1.16.4. Maximum exhaust temperature at the point in the exhaust pipe(s) adjacent to the
outer flange(s) of the exhaust manifold(s) or turbocharger(s):
..... K

1/ In the case of non-conventional engines and systems, particulars equivalent to those referred to here shall be supplied by the manufacturer.

2/ Strike out what does not apply

3/ Specify the tolerance

- 1.16.5. Fuel temperature: min..... K, max..... K
for diesel engines at injection pump inlet, for gas fuelled engines at pressure regulator
final stage
- 1.16.6. Fuel pressure: min..... kPa, max..... kPa
at pressure regulator final stage, NG fuelled gas engines only
- 1.16.7. Lubricant temperature: min..... K, max..... K
- 1.17. Pressure charger: yes/no 2/
- 1.17.1. Make:
- 1.17.2. Type:
- 1.17.3. Description of the system (e.g. max. charge pressure, waste gate, if applicable):
.....
- 1.17.4. Intercooler: yes/no 2/
- 1.18. Intake system
Maximum allowable intake depression at rated engine speed and at 100 per cent load
as specified in and under the operating conditions of Regulation No. 24, 02 series of
amendments:
..... kPa
- 1.19. Exhaust system
Maximum allowable exhaust back pressure at rated engine speed and at 100 per cent
load as specified in and under the operating conditions of Regulation No. 24, 02
series of amendments.
..... kPa
Exhaust system volume: dm³
- 1.20. Engine Electronic Control Unit (ECU) (all engine types):
- 1.20.1. Make:
- 1.20.2. Type:
- 1.20.3. Software calibration number(s):
2. Measures taken against air pollution
- 2.1. Device for recycling crankcase gases (description and drawings):
- 2.2. Additional anti-pollution devices
(if any, and if not covered by another heading).....
- 2.2.1. Catalytic converter: yes/no 2/
- 2.2.1.1. Make(s):
- 2.2.1.2. Type(s):
- 2.2.1.3. Number of catalytic converters and elements:
- 2.2.1.4. Dimensions, shape and volume of the catalytic converter(s):
- 2.2.1.5. Type of catalytic action:
- 2.2.1.6. Total charge of precious metals:
- 2.2.1.7. Relative concentration:
- 2.2.1.8. Substrate (structure and material):
- 2.2.1.9. Cell density:
- 2.2.1.10. Type of casing for the catalytic converter(s):
- 2.2.1.11. Location of the catalytic converter(s) (place and reference distance in the exhaust line):
.....
- 2.2.1.12. Normal operating temperature range (K):
- 2.2.1.13. Consumable reagents (where appropriate):

- 2.2.1.13.1. Type and concentration of reagent needed for catalytic action:
- 2.2.1.13.2. Normal operational temperature range of reagent:
- 2.2.1.13.3. International standard (where appropriate):.....
- 2.2.1.13.4. Frequency of reagent refill: continuous/maintenance 1/:
- 2.2.2. Oxygen sensor: yes/no 2/
- 2.2.2.1. Make(s):
- 2.2.2.2. Type:
- 2.2.2.3. Location:
- 2.2.3. Air injection: yes/no 2/
- 2.2.3.1. Type (pulse air, air pump, etc.):.....
- 2.2.4. EGR: yes/no 2/
- 2.2.4.1. Characteristics (make, type, flow etc):
- 2.2.5. Particulate trap: yes/no 2/:
- 2.2.5.1. Dimensions, shape and capacity of the particulate trap:.....
- 2.2.5.2. Type and design of the particulate trap:
- 2.2.5.3. Location (reference distance in the exhaust line):
- 2.2.5.4. Method or system of regeneration, description and/or drawing:
- 2.2.5.5. Normal operating temperature (K) and pressure (kPa) range:..... "
- 2.2.5.6. In case of periodic regeneration:
 - (a) Number of ETC test cycles between 2 regenerations (n1):
 - (b) Number of ETC test cycles during regeneration (n2):
- 2.2.6. Other systems: yes/no 2/
- 2.2.6.1. Description and operation:.....

3. Fuel feed

- 3.1. Diesel engines
- 3.1.1. Feed pump
 - Pressure 3/:..... kPa or characteristic diagram 2/:.....
- 3.1.2. Injection system
 - 3.1.2.1. Pump
 - 3.1.2.1.1. Make(s):
 - 3.1.2.1.2. Type(s):.....
 - 3.1.2.1.3. Delivery: mm³ 3/ per stroke at engine speed of min⁻¹
 at full injection, or characteristic diagram 2/ 3/.....
 Mention the method used: On engine/on pump bench 2/
 If boost control is supplied, state the characteristic fuel delivery and boost pressure
 versus engine speed.
 - 3.1.2.1.4. Injection advance
 - 3.1.2.1.4.1. Injection advance curve 3/:
 - 3.1.2.1.4.2. Static injection timing 3/:.....
- 3.1.2.2. Injection piping
 - 3.1.2.2.1. Length: mm
 - 3.1.2.2.2. Internal diameter: mm
 - 3.1.2.2.3. Common rail, make and type:.....
- 3.1.2.3. Injector(s)
 - 3.1.2.3.1. Make(s):
 - 3.1.2.3.2. Type(s):.....

3.1.2.3.3.	"Opening pressure":.....	kPa <u>3/</u>
	or characteristic diagram <u>2/ 3/</u> :	
3.1.2.4.	Governor	
3.1.2.4.1.	Make(s):.....	
3.1.2.4.2.	Type(s):.....	
3.1.2.4.3.	Speed at which cut-off starts under full load:.....	min ⁻¹
3.1.2.4.4.	Maximum no-load speed:	min ⁻¹
3.1.2.4.5.	Idling speed:	min ⁻¹
3.1.3.	Cold start system	
3.1.3.1.	Make(s):.....	
3.1.3.2.	Type(s):.....	
3.1.3.3.	Description:	
3.1.3.4.	Auxiliary starting aid:.....	
3.1.3.4.1.	Make:	
3.1.3.4.2.	Type:.....	
3.2.	Gas fuelled engines <u>2/</u>	
3.2.1.	Fuel: Natural gas/LPG <u>2/</u>	
3.2.2.	Pressure regulator(s) or vaporiser/pressure regulator(s) <u>3/</u>	
3.2.2.1.	Make(s):.....	
3.2.2.2.	Type(s):.....	
3.2.2.3.	Number of pressure reduction stages:	
3.2.2.4.	Pressure in final stage: min..... kPa, max.....	kPa
3.2.2.5.	Number of main adjustment points:	
3.2.2.6.	Number of idle adjustment points:	
3.2.2.7.	Certification number:.....	
3.2.3.	Fuelling system: mixing unit / gas injection / liquid injection / direct injection <u>2/</u>	
3.2.3.1.	Mixture strength regulation:	
3.2.3.2.	System description and/or diagram and drawings:.....	
3.2.3.3.	Certification number:.....	
3.2.4.	Mixing unit	
3.2.4.1.	Number:	
3.2.4.2.	Make(s):.....	
3.2.4.3.	Type(s):.....	
3.2.4.4.	Location:.....	
3.2.4.5.	Adjustment possibilities:	
3.2.4.6.	Certification number:.....	
3.2.5.	Inlet manifold injection	
3.2.5.1.	Injection: single point/multipoint <u>2/</u>	
3.2.5.2.	Injection: continuous/simultaneously timed/sequentially timed <u>2/</u>	
3.2.5.3.	Injection equipment	
3.2.5.3.1.	Make(s):.....	
3.2.5.3.2.	Type(s):.....	
3.2.5.3.3.	Adjustment possibilities:	
3.2.5.3.4.	Certification number:.....	
3.2.5.4.	Supply pump (if applicable):	
3.2.5.4.1.	Make(s):.....	
3.2.5.4.2.	Type(s):.....	

- 3.2.5.4.3 Certification number:
- 3.2.5.5. Injector(s):
 - 3.2.5.5.1. Make(s):
 - 3.2.5.5.2. Type(s):
 - 3.2.5.5.3. Certification number:
- 3.2.6. Direct injection
 - 3.2.6.1. Injection pump / pressure regulator 2/
 - 3.2.6.1.1. Make(s):
 - 3.2.6.1.2. Type(s):
 - 3.2.6.1.3. Injection timing:
 - 3.2.6.1.4. Certification number:
 - 3.2.6.2. Injector(s)
 - 3.2.6.2.1. Make(s):
 - 3.2.6.2.2. Type(s):
 - 3.2.6.2.3. Opening pressure or characteristic diagram 3/:
 - 3.2.6.2.4. Certification number:
- 3.2.7. Electronic control unit (ECU)
 - 3.2.7.1. Make(s):
 - 3.2.7.2. Type(s):
 - 3.2.7.3. Adjustment possibilities:
- 3.2.8. NG fuel-specific equipment
 - 3.2.8.1. Variant 1
(only in the case of approvals of engines for several specific fuel compositions)
 - 3.2.8.1.1. Fuel composition:

methane (CH ₄):	basis:	%mole	min.	%mole	max.....	%mole
ethane (C ₂ H ₆):	basis:	%mole	min.	%mole	max.....	%mole
propane (C ₃ H ₈):	basis:	%mole	min.	%mole	max.....	%mole
butane (C ₄ H ₁₀):	basis:	%mole	min.	%mole	max.....	%mole
C5/C5+:	basis:	%mole	min.	%mole	max.....	%mole
oxygen (O ₂):	basis:	%mole	min.	%mole	max.....	%mole
inert (N ₂ , He etc):	basis:	%mole	min.	%mole	max.....	%mole
 - 3.2.8.1.2. Injector(s)
 - 3.2.8.1.2.1. Make(s):
 - 3.2.8.1.2.2. Type(s):
 - 3.2.8.1.3. Others (if applicable)
 - 3.2.8.2. Variant 2
(only in the case of approvals for several specific fuel compositions)
- 4. Valve timing
 - 4.1. Maximum lift of valves and angles of opening and closing in relation to dead centres of equivalent data:
 - 4.2. Reference and/or setting ranges 2/:
- 5. Ignition system (spark ignition engines only)
 - 5.1. Ignition system type: common coil and plugs/individual coil and plugs/coil on plug/other (specify) 2/
 - 5.2. Ignition control unit

- 5.2.1. Make(s):
- 5.2.2. Type(s):
- 5.3. Ignition advance curve / advance map) 2/ 3/:
- 5.4. Ignition timing 3/: degrees before TDC at a speed of min⁻¹
and a MAP of Pa
- 5.5. Spark plugs
- 5.5.1. Make(s):
- 5.5.2. Type(s):
- 5.5.3. Gap setting: mm
- 5.6. Ignition coil(s)
- 5.6.1. Make(s):
- 5.6.2. Type(s):

6. Engine-driven equipment

The engine shall be submitted for testing with the auxiliaries needed for operating the engine (e.g. fan, water pump etc.), as specified in and under the operating conditions of Regulation No. 24, 02 series of amendments, Annex 10, paragraph 5.1.1.

6.1. Auxiliaries to be fitted for the test

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(s).

6.2. Auxiliaries to be removed for the test

Auxiliaries needed only for the operation of the vehicle (e.g. air compressor, air-conditioning system etc.) shall be removed for the test. Where the auxiliaries cannot be removed, the power absorbed by them may be determined and added to the measured engine power over the whole operating area of the test cycle(s).

7. Additional information on test conditions

7.1. Lubricant used

7.1.1. Make:

7.1.2. Type:

(State percentage of oil in mixture if lubricant and fuel are mixed):

7.2. Engine-driven equipment (if applicable)

The power absorbed by the auxiliaries needs only be determined,

(a) if auxiliaries needed for operating the engine, are not fitted to the engine and/or

(b) if auxiliaries not needed for operating the engine, are fitted to the engine.

7.2.1. Enumeration and identifying details:

7.2.2. Power absorbed at various indicated engine speeds:

Equipment	Power absorbed (kW) at various engine speeds						
	Idle	Low Speed	High Speed	Speed A ^(a)	Speed B ^(a)	Speed C ^(a)	Ref. Speed ^(b)
P(a) Auxiliaries needed for operating the engine (to be							

subtracted from measured engine power) see paragraph 5.1.1. of Regulation No. 24/02, Annex 10							
P(b) Auxiliaries not needed for operating the engine (to be added to measured engine power) see paragraph 5.1.2. of Regulation No. 24/02, Annex 10							
(a) ESC test. (b) ETC test only.							

8. Engine performance

8.1. Engine speeds 3/

Low speed (n_{lo}): min⁻¹

High speed (n_{hi}): min⁻¹

for ESC and ELR Cycles

Idle: min⁻¹

Speed A: min⁻¹

Speed B: min⁻¹

Speed C: min⁻¹

for ETC cycle

Reference speed: min⁻¹

8.2. Engine power (measured in accordance with the provisions of Regulation No. 24, 02 series of amendments) in kW

	Engine Speed				
	Idle	Speed A ^(a)	Speed B ^(a)	Speed C ^(a)	Ref. Speed ^(b)
P(m) Power measured on test bed					
P(a) Power absorbed by auxiliaries to be fitted for test (paragraph 5.1.1. of Regulation No. 24/02, Annex 10) (a) if fitted (b) if not fitted	0	0	0	0	0
P(b) Power absorbed by auxiliaries to be removed for test (paragraph 5.1.2. of Regulation No. 24/02, Annex 10) (a) if fitted (b) if not fitted	0	0	0	0	0
P(n) Net engine power = P(m)-P(a)+P(b)					
^(a) ESC test.					
^(b) ETC test only.					

8.3. Dynamometer settings (kW)

The dynamometer settings for the ESC and ELR tests and for the reference cycle of the ETC test shall be based upon the net engine power P(n) of paragraph 8.2. It is recommended to install the engine on the test bed in the net condition. In this case, P(m) and P(n) are identical. If it is impossible or inappropriate to operate the engine under net conditions, the dynamometer settings shall be corrected to net conditions using the above formula.

8.3.1. ESC and ELR Tests

The dynamometer settings shall be calculated according to the formula in Annex III, Appendix 1, paragraph 1.2.

Percent Load	Engine Speed			
	Idle	Speed A	Speed B	Speed C
10	---			
25	---			
50	---			
75	---			
100				

8.3.2. ETC Test

If the engine is not tested under net conditions, the correction formula for converting the measured power or measured cycle work, as determined according to Annex 4A, Appendix 2, paragraph 2., to net power or net cycle work shall be submitted by the engine manufacturer for the whole operating area of the cycle, and approved by the Technical Service.

9. On-board diagnostic (OBD) system

- 9.1. Written description and/or drawing of the MI 4:.....
- 9.2. List and purpose of all components monitored by the OBD system:
- 9.3. Written description (general OBD working principles) for:
 - 9.3.1. Diesel/gas engines
 - 9.3.1.1. Catalyst monitoring.....
 - 9.3.1.2. deNOx system monitoring.....
 - 9.3.1.3. Diesel particulate filter monitoring.....
 - 9.3.1.4. Electronic fuelling system monitoring.....
 - 9.3.1.5. Other components monitored by the OBD system
- 9.4. Criteria for MI activation (fixed number of driving cycles or statistical method): ...
- 9.5. List of all OBD output codes and formats used (with explanation of each):

10. Torque limiter

- 10.1. Description of the torque limiter activation
- 10.2. Description of the full load curve limitation

1/ Delete where inapplicable

2/ In the case of systems laid-out in a different manner, supply equivalent information (for paragraph 3.2.).

3/ Specify the tolerance; to be within ± 3 per cent of the values declared by the manufacturer.

Annex 1 - Appendix 2

ESSENTIAL CHARACTERISTICS OF THE ENGINE FAMILY

1. Common parameters
 - 1.1. Combustion cycle:
 - 1.2. Cooling medium:
 - 1.3. Number of cylinders 1/:
 - 1.4. Individual cylinder displacement:
 - 1.5. Method of air aspiration:
 - 1.6. Combustion chamber type/design:
 - 1.7. Valve and porting - configuration, size and number:
 - 1.8. Fuel system:
 - 1.9. Ignition system (gas engines):
 - 1.10. Miscellaneous features:
 - (a) charge cooling system 1/:
 - (b) exhaust gas recirculation 1/:
 - (c) water injection/emulsion 1/:
 - (d) air injection 1/:
 - 1.11. Exhaust aftertreatment 1/:

Proof of identical (or lowest for the parent engine) ratio: system capacity/fuel delivery per stroke, pursuant to diagram number(s):
2. Engine family listing
 - 2.1. Name of diesel engine family:
 - 2.1.1. Specification of engines within this family:

	Parent Engine				
Engine Type					
No. of cylinders					
Rated Speed (min^{-1})					
Fuel flow per stroke (mm^3)					
Rated net power (kW)					
Maximum torque speed (min^{-1})					
Fuel delivery per stroke (mm^3)					
Maximum torque (Nm)					
Low idle speed (min^{-1})					
Cylinder displacement (in per cent of parent engine)					100

2.2. Name of gas engine family:

2.2.1. Specification of engines within this family:

					Parent Engine
Engine Type					
No. of cylinders					
Rated Speed (min ⁻¹)					
Fuel delivery per stroke (mm ³)					
Rated net power (kW)					
Maximum torque speed (min ⁻¹)					
Fuel delivery per stroke (mm ³)					
Maximum torque (Nm)					
Low idle speed (min ⁻¹)					
Cylinder displacement (in per cent of parent engine)					100
Spark timing					
EGR flow					
Air pump yes/no					
Air pump actual flow					

1/ If not applicable, mark n.a.

Annex 1 - Appendix 3ESSENTIAL CHARACTERISTICS OF THE ENGINE TYPE WITHIN THE FAMILY 1/

1. Description of engine
- 1.1. Manufacturer:
- 1.2. Manufacturer's engine code:.....
- 1.3. Cycle: four stroke / two stroke 2/:
- 1.4. Number and arrangement of cylinders:
- 1.4.1. Bore: mm
- 1.4.2. Stroke:..... mm
- 1.4.3. Firing order:
- 1.5. Engine capacity: cm³
- 1.6. Volumetric compression ratio 3/:
- 1.7. Drawing(s) of combustion chamber and piston crown:.....
- 1.8. Minimum cross-sectional area of inlet and outlet ports: cm²
- 1.9. Idling speed: min⁻¹
- 1.10. Maximum net power:..... kW at min⁻¹
- 1.11. Maximum permitted engine speed: min⁻¹
- 1.12. Maximum net torque: Nm at min⁻¹
- 1.13. Combustion system: compression ignition/positive ignition 2/
- 1.14. Fuel: Diesel/LPG/NG-H/NG-L/NG-HL/ethanol 2/
- 1.15. Cooling system
- 1.15.1. Liquid
- 1.15.1.1. Nature of liquid:.....
- 1.15.1.2. Circulating pump(s): yes/no 2/
- 1.15.1.3. Characteristics or make(s) and type(s) (if applicable):.....
- 1.15.1.4. Drive ratio(s) (if applicable):.....
- 1.15.2. Air
- 1.15.2.1. Blower: yes/no 2/
- 1.15.2.2. Characteristics or make(s) and type(s) (if applicable):.....
- 1.15.2.3. Drive ratio(s) (if applicable):.....
- 1.16. Temperature permitted by the manufacturer
- 1.16.1. Liquid cooling: Maximum temperature at outlet:..... K
- 1.16.2. Air cooling: reference point:.....
Maximum temperature at reference point: K
- 1.16.3. Maximum temperature of the air at the outlet of the intake intercooler (if applicable):
..... K
- 1.16.4. Maximum exhaust temperature at the point in the exhaust pipe(s) adjacent to the outer
flange(s) of the exhaust manifold(s) or turbocharger(s):..... K
- 1.16.5. Fuel temperature: min. K, max. K
for diesel engines at injection pump inlet, for gas fuelled engines at pressure regulator
final stage
- 1.16.6. Fuel pressure: min. kPa,
max. kPa
at pressure regulator final stage, NG fuelled gas engines only
- 1.16.7. Lubricant temperature: min. K, max. K

- 1.17. Pressure charger: yes/no 2/
- 1.17.1. Make:
- 1.17.2. Type:
- 1.17.3. Description of the system (e.g. max. charge pressure, waste gate, if applicable):
.....
- 1.17.4. Intercooler: yes/no 2/
- 1.18. Intake system
Maximum allowable intake depression at rated engine speed and at 100 per cent load as specified in and under the operating conditions of Regulation No. 24, 02 series of amendments: kPa
- 1.19. Exhaust system
Maximum allowable exhaust back pressure at rated engine speed and at 100 per cent load as specified in and under the operating conditions of Regulation No. 24, 02 series of amendments: kPa
Exhaust system volume: dm³
- 1.20. Engine Electronic Control Unit (EECU) (all engine types):
- 1.20.1. Make:
- 1.20.2. Type:
- 1.20.3. Software calibration number(s):
2. Measures taken against air pollution
- 2.1. Device for recycling crankcase gases (description and drawings):
- 2.2. Additional anti-pollution devices (if any, and if not covered by another heading)
.....
- 2.2.1. Catalytic converter: yes/no 2/
- 2.2.1.1. Make(s):
- 2.2.1.2. Type(s):
- 2.2.1.3. Number of catalytic converters and elements:
- 2.2.1.4. Dimensions, shape and volume of the catalytic converter(s):
- 2.2.1.5. Type of catalytic action:
- 2.2.1.6. Total charge of precious metals:
- 2.2.1.7. Relative concentration:
- 2.2.1.8. Substrate (structure and material):
- 2.2.1.9. Cell density:
- 2.2.1.10. Type of casing for the catalytic converter(s):
- 2.2.1.11. Location of the catalytic converter(s) (place and reference distance in the exhaust line):
- 2.2.1.12. Normal operating temperature range (K):
- 2.2.1.13. Consumable reagents (where appropriate):
- 2.2.1.13.1. Type and concentration of reagent needed for catalytic action:
- 2.2.1.13.2. Normal operational temperature range of reagent:
- 2.2.1.13.3. International standard (where appropriate):
- 2.2.1.13.4. Frequency of reagent refill: continuous/maintenance 4/:
- 2.2.2. Oxygen sensor: yes/no 2/
- 2.2.2.1. Make(s):
- 2.2.2.2. Type:
- 2.2.2.3. Location:

- 2.2.3. Air injection: yes/no 2/
- 2.2.3.1. Type (pulse air, air pump, etc.):.....
- 2.2.4. EGR: yes/no 2/
- 2.2.4.1. Characteristics (make, type, flow etc):.....
- 2.2.5. Particulate trap: yes/no 2/:.....
- 2.2.5.1. Dimensions, shape and capacity of the particulate trap:.....
- 2.2.5.2. Type and design of the particulate trap:.....
- 2.2.5.3. Location (reference distance in the exhaust line):.....
- 2.2.5.4. Method or system of regeneration, description and/or drawing:.....
- 2.2.5.5. Normal operating temperature (K) and pressure (kPa) range:.....
- 2.2.5.6. In case of periodic regeneration:
- (a) Number of ETC test cycles between 2 regenerations (n1)
- (b) Number of ETC test cycles during regeneration (n2)
- 2.2.6. Other systems: yes/no 2/
- 2.2.6.1. Description and operation:.....
3. Fuel feed
- 3.1. Diesel engines
- 3.1.1. Feed pump
- Pressure 3/: kPa or characteristic diagram 2/:.....
- 3.1.2. Injection system
- 3.1.2.1. Pump
- 3.1.2.1.1. Make(s):.....
- 3.1.2.1.2. Type(s):.....
- 3.1.2.1.3. Delivery: mm³ 3/ per stroke at engine speed of min⁻¹
at full injection, or characteristic diagram 2/ 3/:.....
Mention the method used: On engine/on pump bench 2/
If boost control is supplied, state the characteristic fuel delivery and boost pressure
versus engine speed.
- 3.1.2.1.4. Injection advance
- 3.1.2.1.4.1. Injection advance curve 3/ :.....
- 3.1.2.1.4.2. Static injection timing 3/:.....
- 3.1.2.2. Injection piping
- 3.1.2.2.1. Length:..... mm
- 3.1.2.2.2. Internal diameter:..... mm
- 3.1.2.2.3. Common rail, make and type:.....
- 3.1.2.3. Injector(s)
- 3.1.2.3.1. Make(s):.....
- 3.1.2.3.2. Type(s):.....
- 3.1.2.3.3. "Opening pressure":..... kPa 3/ or characteristic diagram 2/ 3/:
- 3.1.2.4. Governor
- 3.1.2.4.1. Make(s):.....
- 3.1.2.4.2. Type(s):.....
- 3.1.2.4.3. Speed at which cut-off starts under full load:..... min⁻¹
- 3.1.2.4.4. Maximum no-load speed:..... min⁻¹
- 3.1.2.4.5. Idling speed:..... min⁻¹
- 3.1.3. Cold start system

- 3.1.3.1. Make(s):
- 3.1.3.2. Type(s):
- 3.1.3.3. Description:
- 3.1.3.4. Auxiliary starting aid:
- 3.1.3.4.1. Make:
- 3.1.3.4.2. Type:
- 3.2. Gas fuelled engines 5/
- 3.2.1. Fuel: Natural gas/LPG 2/
- 3.2.2. Pressure regulator(s) or vaporiser/pressure regulator(s) 3/
- 3.2.2.1. Make(s):
- 3.2.2.2. Type(s):
- 3.2.2.3. Number of pressure reduction stages:
- 3.2.2.4. Pressure in final stage: min. kPa, max. kPa
- 3.2.2.5. Number of main adjustment points:
- 3.2.2.6. Number of idle adjustment points:
- 3.2.2.7. Certification number:
- 3.2.3. Fuelling system: mixing unit / gas injection / liquid injection / direct injection 2/
- 3.2.3.1. Mixture strength regulation:
- 3.2.3.2. System description and/or diagram and drawings:
- 3.2.3.3. Certification number:
- 3.2.4. Mixing unit
- 3.2.4.1. Number:
- 3.2.4.2. Make(s):
- 3.2.4.3. Type(s):
- 3.2.4.4. Location:
- 3.2.4.5. Adjustment possibilities:
- 3.2.4.6. Certification number:
- 3.2.5. Inlet manifold injection
- 3.2.5.1. Injection: single point/multipoint 2/
- 3.2.5.2. Injection: continuous/simultaneously timed/sequentially timed 2/
- 3.2.5.3. Injection equipment
- 3.2.5.3.1. Make(s):
- 3.2.5.3.2. Type(s):
- 3.2.5.3.3. Adjustment possibilities:
- 3.2.5.3.4. Certification number:
- 3.2.5.4. Supply pump (if applicable):
- 3.2.5.4.1. Make(s):
- 3.2.5.4.2. Type(s):
- 3.2.5.4.3. Certification number:
- 3.2.5.5. Injector(s):
- 3.2.5.5.1. Make(s):
- 3.2.5.5.2. Type(s):
- 3.2.5.5.3. Certification number:
- 3.2.6. Direct injection
- 3.2.6.1. Injection pump / pressure regulator 2/
- 3.2.6.1.1. Make(s):
- 3.2.6.1.2. Type(s):

- 3.2.6.1.3. Injection timing:
- 3.2.6.1.4. Certification number:.....
- 3.2.6.2. Injector(s)
- 3.2.6.2.1. Make(s):.....
- 3.2.6.2.2. Type(s):.....
- 3.2.6.2.3. Opening pressure or characteristic diagram 3/:
- 3.2.6.2.4. Certification number:.....
- 3.2.7. Electronic control unit (ECU)
- 3.2.7.1. Make(s):.....
- 3.2.7.2. Type(s):.....
- 3.2.7.3. Adjustment possibilities:
- 3.2.8. NG fuel-specific equipment
- 3.2.8.1. Variant 1
(only in the case of approvals of engines for several specific fuel compositions)
- 3.2.8.1.1. Fuel composition:
- | | | | | | | |
|---|--------------|-------|-----------|-------|-----------|-------|
| methane (CH ₄): | basis: | %mole | min. | %mole | max. | %mole |
| ethane (C ₂ H ₆): | basis: | %mole | min. | %mole | max. | %mole |
| propane (C ₃ H ₈): | basis: | %mole | min. | %mole | max. | %mole |
| butane (C ₄ H ₁₀): | basis: | %mole | min. | %mole | max. | %mole |
| C5/C5+: | basis: | %mole | min. | %mole | max. | %mole |
| oxygen (O ₂): | basis: | %mole | min. | %mole | max. | %mole |
| inert (N ₂ , He etc): | basis: | %mole | min. | %mole | max. | %mole |
- 3.2.8.1.2. Injector(s)
- 3.2.8.1.2.1. Make(s):.....
- 3.2.8.1.2.2. Type(s):.....
- 3.2.8.1.3. Others (if applicable)
- 3.2.8.2. Variant 2
(only in the case of approvals for several specific fuel compositions)
4. Valve timing
- 4.1. Maximum lift of valves and angles of opening and closing in relation to dead centres of equivalent data:.....
- 4.2. Reference and/or setting ranges 2/:
5. Ignition system (spark ignition engines only)
- 5.1. Ignition system type: common coil and plugs/individual coil and plugs/coil on plug/other (specify) 2/
- 5.2. Ignition control unit
- 5.2.1. Make(s):.....
- 5.2.2. Type(s):.....
- 5.3. Ignition advance curve / advance map 2/ 3/:
- 5.4. Ignition timing 3/: degrees before TDC at a speed of..... min⁻¹
and a MAP of..... kPa
- 5.5. Spark plugs
- 5.5.1. Make(s):.....
- 5.5.2. Type(s):.....
- 5.5.3. Gap setting:..... mm

- 5.6. Ignition coil(s)
- 5.6.1. Make(s):
- 5.6.2. Type(s):

- 6. On-board diagnostic (OBD) system
- 6.1. Written description and/or drawing of the MI 4/:
- 6.2. List and purpose of all components monitored by the OBD system:
- 6.3. Written description (general OBD working principles) for:
 - 6.3.1. Diesel/gas engines 4/:
 - 6.3.1.1. Catalyst monitoring 4/:
 - 6.3.1.2. deNOx system monitoring 4/:
 - 6.3.1.3. Diesel particulate filter monitoring 4/:
 - 6.3.1.4. Electronic fuelling system monitoring 4/:
 - 6.3.1.5. Other components monitored by the OBD system 4/:
- 6.4. Criteria for MI activation (fixed number of driving cycles or statistical method):
.....
- 6.5. List of all OBD output codes and formats used (with explanation of each):

- 7. Torque limiter
- 7.1. Description of the torque limiter activation
- 7.2. Description of the full load curve limitation

1/ To be submitted for each engine of the family.
2/ Strike out what does not apply.
3/ Specify the tolerance.
4/ Delete where inapplicable.
5/ In the case of systems laid-out in a different manner, supply equivalent information (for paragraph 3.2.).

Annex 1 - Appendix 4

CHARACTERISTICS OF THE ENGINE-RELATED VEHICLE PARTS

1. Intake system depression at rated engine speed and at 100 per cent load: kPa
2. Exhaust system back pressure at rated engine speed and at 100 per cent load:..... kPa
3. Volume of exhaust system: cm³
4. Power absorbed by the auxiliaries needed for operating the engine as specified in and under the operation conditions of Regulation No. 24, 02 series of amendments, Annex 10, paragraph 5.1.1.

Equipment	Power absorbed (kW) at various engine speeds						
	Idle	Low Speed	High Speed	Speed A ^(a)	Speed B ^(a)	Speed C ^(a)	Ref. Speed ^(b)
P(a) Auxiliaries needed for operating the engine (to be subtracted from measured engine power) See paragraph 5.1.1. of Regulation No. 24/02, Annex 10.							

^(a) ESC test.

^(b) ETC test only.

Annex 1 - Appendix 5

OBD-RELATED INFORMATION

1. In accordance with the provisions of paragraph 5. of Annex 9A to this Regulation, the following additional information shall be provided by the vehicle manufacturer for the purposes of enabling the manufacture of OBD-compatible replacement or service parts and diagnostic tools and test equipment, unless such information is covered by intellectual property rights or constitutes specific know-how of the manufacturer or the OEM supplier(s). The information given in this paragraph shall be repeated in Annex 2A to this Regulation:
 - 1.1. A description of the type and number of the pre-conditioning cycles used for the original type approval of the vehicle.
 - 1.2. A description of the type of the OBD demonstration cycle used for the original approval of the vehicle for the component monitored by the OBD system.
 - 1.3. A comprehensive document describing all sensed components with the strategy for fault detection and MI activation (fixed number of driving cycles or statistical method), including a list of relevant secondary sensed parameters for each component monitored by the OBD system. A list of all OBD output codes and format used (with an explanation of each) associated with individual emission related powertrain components and individual non-emission related components, where monitoring of the component is used to determine MI activation.
 - 1.3.1. The information required by this paragraph may, for example, be defined by completing a table as follows, which shall be attached to this annex:

Component	Fault code	Monitoring strategy	Fault detection criteria	MI activation criteria	Secondary parameters	Preconditioning	Demonstration test
SCR catalyst	Pxxxx	NOx sensor 1 and 2 signals	Difference between sensor 1 and sensor 2 signals	3 rd cycle	Engine speed, engine load, catalyst temperature, reagent activity	Three OBD test cycles (3 short ESC cycles)	OBD test cycle (short ESC cycle)

- 1.3.2. The information required by this appendix may be limited to the complete list of the fault codes recorded by the OBD system where paragraph 5.1.2.1. of Annex 9A to this Regulation is not applicable as in the case of replacement or service components. This information may, for example, be defined by completing the two first columns of the table of paragraph 1.3.1. above.

The complete information package should be made available to the approval authority as part of the additional material requested in paragraph 5.1.7.1. "documentation requirements" of this Regulation.

- 1.3.3. The information required by this paragraph shall be repeated in Annex 2A to this Regulation.

Where paragraph 5.1.2.1. of Annex 9A to this Regulation is not applicable in the case of replacement or service components, the information provided in Annex 2A can be limited to the one mentioned in paragraph 1.3.2.

8. Maximum permissible power absorbed by the engine-driven equipment:
 Idle:..... kW; Low Speed:..... kW; High Speed: kW
 Speed A: kW; Speed B:..... kW; Speed C: kW;
 Reference Speed: kW

9. Restrictions of use (if any):

10. Emission levels of the engine/parent engine

10.1. Emission stage (according to table in paragraph 4.6.3.)

10.2. ESC test (if applicable):

Deterioration factor (DF): calculated/fixed 2/

Specify the DF values and the emissions on the ESC test in the table below:

ESC test				
DF:	CO	THC	NO _x	PT
Emissions	CO (g/kWh)	THC (g/kWh)	NO _x (g/kWh)	PT (g/kWh)
Measured:				
Calculated with DF:				

10.3. ELR test (if applicable):
 smoke value: m⁻¹

10.4. ETC test:
 Deterioration factor (DF): calculated/fixed 2/

ETC test					
DF:	CO	NMHC	CH ₄	NO _x	PT
Emissions	CO (g/kWh)	NMHC (g/kWh) <u>2/</u>	CH ₄ (g/kWh) <u>2/</u>	NO _x (g/kWh)	PT (g/kWh) <u>2/</u>
Measured with regeneration:					
Measured without regeneration:					
Measured/weighted:					
Calculated with DF:					

11. Engine submitted for tests on:

- 12. Technical service responsible for conducting the approval tests:
.....
- 13. Date of test report issued by that service:
- 14. Number of the test report issued by that service:
- 15. Site of approval mark on the engine:
- 16. Place:
- 17. Date:
- 18. Signature:
- 19. The following documents, bearing the approval number shown above, are annexed to this communication:

One copy of Annex 1 to this Regulation completed and with the drawings and diagrams referred to attached.

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

2/ Strike out what does not apply.

Appendix 1

OBD-RELATED INFORMATION

As noted in Appendix 4 of Annex 1 to this Regulation, the information in this appendix is provided by the engine/vehicle manufacturer for the purposes of enabling the manufacture of OBD-compatible replacement or service parts and diagnostic tools and test equipment. Such information need not be supplied by the engine/vehicle manufacturer if it is covered by intellectual property rights or constitutes specific know-how of the manufacturer or the OEM supplier(s).

Upon request, this appendix will be made available to any interested component, diagnostic tools or test equipment manufacturer, on a non-discriminatory basis.

In compliance with the provisions of paragraph 1.3.3. of Appendix 4 to Annex 1, the information required by this paragraph shall be identical to that provided in that Appendix.

1. A description of the type and number of the pre-conditioning cycles used for the original type approval of the vehicle.
2. A description of the type of the OBD demonstration cycle used for the original type approval of the vehicle for the component monitored by the OBD system.
3. A comprehensive document describing all sensed components with the strategy for fault detection and MI activation (fixed number of driving cycles or statistical method), including a list of relevant secondary sensed parameters for each component monitored by the OBD system. A list of all OBD output codes and format used (with an explanation of each) associated with individual emission related powertrain components and individual non-emission related components, where monitoring of the component is used to determine MI activation.

9.1. Emission stage (according to table in paragraph 4.6.3.)

9.2. ESC test (if applicable):

Deterioration factor (DF): calculated/fixed 2/

Specify the DF values and the emissions on the ESC test in the table below:

ESC test				
DF:	CO	THC	NOx	PT
Emissions	CO (g/kWh)	THC (g/kWh)	NOx (g/kWh)	PT (g/kWh)
Measured:				
Calculated with DF:				

9.3. ELR test (if applicable):
smoke value: m⁻¹

9.4. ETC test:
Deterioration factor (DF): calculated/fixed 2/

ETC test					
DF:	CO	NMHC	CH ₄	NOx	PT
Emissions	CO (g/kWh)	NMHC (g/kWh) <u>2</u> /	CH ₄ (g/kWh) <u>2</u> /	NOx (g/kWh)	PT (g/kWh) <u>2</u> /
Measured with regeneration:					
Measured without regeneration:					
Measured/weighted:					
Calculated with DF:					

10. Engine submitted for tests on:

11. Technical service responsible for conducting the approval tests:

12. Date of test report issued by that service:

13. Number of test report issued by that service:

- 14. Approval number of the engine/engine family, if approved as a separate technical unit:
.....
- 15. Site of approval mark on the vehicle/engine 2/:
- 16. Place:
- 17. Date:.....
- 18. Signature:.....

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

2/ Strike out what does not apply.

Annex 3

ARRANGEMENTS OF APPROVAL MARKS
(See table in paragraph 4.6.3. of this Regulation)

I. APPROVAL "B" (Row B1, OBD stage 1, without NOx control).

Example 1

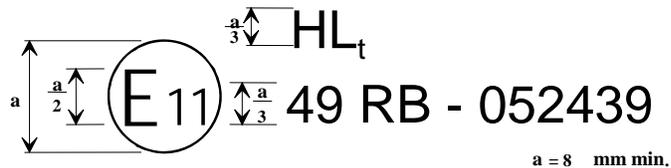
Diesel engines:



Example 2

Natural gas (NG) engines:

The suffix after the national symbol indicates the fuel qualification determined in accordance with paragraph 4.6.3.1. of this Regulation.



The above approval marks affixed to an engine/vehicle show that the engine/vehicle type concerned has been approved in the United Kingdom (E11) pursuant to Regulation No 49 and under approval number 052439. This approval indicates that the approval was given in accordance with the requirements of Regulation No. 49 with the 05 series of amendments incorporated and satisfying the relevant emission stages detailed in paragraph 4.6.3. of this Regulation.

II. APPROVAL "C" (Row B1, OBD stage 1, with NOx control).

Example 3

Diesel engines:



The above approval mark affixed to an engine/vehicle shows that the engine/vehicle type concerned has been approved in the United Kingdom (E11) pursuant to Regulation No. 49 and

under approval number 052439. This approval indicates that the approval was given in accordance with the requirements of Regulation No. 49 with the 05 series of amendments incorporated and satisfying the relevant emission stages detailed in paragraph 4.6.3. of this Regulation.

III. APPROVAL "F" (Row B2, OBD stage 2, without NOx control).

Example 4

LPG engines:



The above approval mark affixed to an engine/vehicle shows that the engine/vehicle type concerned has been approved in the United Kingdom (E11) pursuant to Regulation No. 49 and under approval number 052439. This approval indicates that the approval was given in accordance with the requirements of Regulation No. 49 with the 05 series of amendments incorporated and satisfying the relevant emission stages detailed in paragraph 4.6.3. of this Regulation.

IV. APPROVAL "G" (Row B2, OBD stage 2, with NOx control).

Example 5

Diesel engine:



The above approval mark affixed to an engine/vehicle shows that the engine/vehicle type concerned has been approved in the United Kingdom (E11) pursuant to Regulation No. 49 and under approval number 052439. This approval indicates that the approval was given in accordance with the requirements of Regulation No. 49 with the 05 series of amendments incorporated and satisfying the relevant emission stages detailed in paragraph 4.6.3. of this Regulation.

V. APPROVAL "J" (Row C, OBD stage 2, without NOx control).

Example 6

LPG engine:



The above approval mark affixed to an engine/vehicle shows that the engine/vehicle type concerned has been approved in the United Kingdom (E11) pursuant to Regulation No. 49 and under approval number 052439. This approval indicates that the approval was given in accordance with the requirements of Regulation No. 49 with the 05 series of amendments incorporated and satisfying the relevant emission stages detailed in paragraph 4.6.3. of this Regulation.

VI. ENGINE/VEHICLE APPROVED TO ONE OR MORE REGULATIONS
(See paragraph 4.7. of this Regulation)

Example 7



The above approval mark affixed to a HL natural gas engine/vehicle shows that the engine/vehicle type concerned has been approved in the United Kingdom (E11) pursuant to Regulation No. 49 (emission stage G) and Regulation No. 24 1/. The first two digits of the approval numbers indicate that, at the dates when the respective approvals were given, Regulation No. 49 included the 05 series of amendments, and Regulation No. 24 the 03 series of amendments.

1/ The second Regulation number is given merely as an example.

Annex 4A

TEST PROCEDURE

1. INTRODUCTION

- 1.1. This annex describes the methods of determining emissions of gaseous components, particulates and smoke from the engines to be tested. Three test cycles are described that shall be applied according to the provisions of paragraph 5.2.:
- the ESC which consists of a steady state 13-mode cycle,
 - the ELR which consists of transient load steps at different speeds, which are integral parts of one test procedure, and are run concurrently,
 - the ETC which consists of a second-by-second sequence of transient modes.

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

1.3. Measurement principle

The emissions to be measured from the exhaust of the engine include the gaseous components (carbon monoxide, total hydrocarbons for diesel engines on the ESC test only; non-methane hydrocarbons for diesel and gas engines on the ETC test only; methane for gas engines on the ETC test only and oxides of nitrogen), the particulates (diesel engines only) and smoke (diesel engines on the ELR test only). 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.

1.3.1. ESC Test

During a prescribed sequence of warmed-up engine operating conditions the amounts of the above exhaust emissions shall be examined continuously by taking a sample from the raw or diluted exhaust gas. The test cycle consists of a number of speed and power modes which cover the typical operating range of diesel engines. During each mode the concentration of each gaseous pollutant, exhaust flow and power output shall be determined, and the measured values weighted. For particulate measurement, the exhaust gas shall be diluted with conditioned ambient air using either a partial flow or full flow dilution system. The particulates shall be collected on a single suitable filter in proportion to the weighting factors of each mode. The grams of each pollutant emitted per kilowatt hour shall be calculated as described in Appendix 1 to this annex. Additionally, NO_x shall be measured at three test points within the control area selected by the Technical Service and the measured values compared to the values calculated from those modes of the test cycle enveloping the selected test points. The NO_x control check ensures the effectiveness of the emission control of the engine within the typical engine operating range.

1.3.2. ELR Test

During a prescribed load response test, the smoke of a warmed-up engine shall be determined by means of an opacimeter. The test consists of loading the engine at constant speed from 10 per cent to 100 per cent load at three different engine speeds. Additionally, a fourth load step selected by the Technical Service 1/ shall be run, and the value compared to the values of the previous load steps. The smoke peak shall be determined using an averaging algorithm, as described in Appendix 1 to this annex.

1.3.3. ETC Test

During a prescribed transient cycle of warmed-up engine operating conditions, which is based closely on road-type-specific driving patterns of heavy-duty engines installed in trucks and buses, the above pollutants shall be examined either after diluting the total exhaust gas with conditioned ambient air (CVS system with double dilution for particulates) or by determining the gaseous components in the raw exhaust gas and the particulates with a partial flow dilution system. 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. For a CVS system, the concentration of NO_x and HC shall be determined over the cycle by integration of the analyzer signal, whereas the concentration of CO, CO₂, and NMHC may be determined by integration of the analyzer signal or by bag sampling. If measured in the raw exhaust gas, all gaseous components shall be determined over the cycle by integration of the analyzer signal. For particulates, a proportional sample shall be collected on a suitable filter. The raw or diluted 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, as described in Appendix 2 to this annex.

2. TEST CONDITIONS

2.1. Engine test conditions

2.1.1. 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, for example, in a "V" engine configuration, the average temperature of the distinct groups shall be taken.

(a) for compression-ignition engines:

Naturally aspirated and mechanically supercharged engines:

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

Turbocharged engines with or without cooling of the intake air:

1/ The test points shall be selected using approved statistical methods of randomisation.

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

(b) for spark-ignition engines:

$$f_a = \left(\frac{99}{p_s}\right)^{1.2} \cdot \left(\frac{T_a}{298}\right)^{0.6}$$

2.1.2. Test validity

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

$$0.96 \leq f_a \leq 1.06$$

2.2. Engines with charge air cooling

The charge air temperature shall be recorded and shall be, at the speed of the declared maximum power and full load, within ± 5 K of the maximum charge air temperature specified in Annex 1, Appendix 1, paragraph 1.16.3. 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 within ± 5 K of the maximum charge air temperature specified in Annex 1, Appendix 1, paragraph 1.16.3. at the speed of the declared maximum power and full load. The setting of the charge air cooler for meeting the above conditions shall be used for the whole test cycle.

2.3. Engine air intake system

An engine air intake system shall be used presenting an air intake restriction within ± 100 Pa of the upper limit of the engine operating at the speed at the declared maximum power and full load.

2.4. Engine exhaust system

An exhaust system shall be used presenting an exhaust back pressure within $\pm 1,000$ Pa of the upper limit of the engine operating at the speed of declared maximum power and full load and a volume within ± 40 per cent of that specified by the manufacturer. A test shop system may be used, provided it represents actual engine operating conditions. The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in paragraph 3.4. of Appendix 4 to this annex, and in Appendix 7, paragraph 2.2.1., EP and paragraph 2.3.1., EP.

If the engine is equipped with an exhaust aftertreatment device, the exhaust pipe shall have the same diameter as found in-use for at least 4 pipe diameters upstream to the inlet of the beginning of the expansion section containing the aftertreatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust aftertreatment device shall be the same as in the vehicle configuration or within the distance specifications of the manufacturer. The exhaust backpressure or restriction shall follow the same criteria as above,

and may be set with a valve. The aftertreatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

2.5. Cooling system

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

2.6. Lubricating oil

Specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test, as specified in Annex 1, paragraph 7.1.

2.7. Fuel

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

The fuel temperature and measuring point shall be specified by the manufacturer within the limits given in Annex 1, paragraph 1.16.5. The fuel temperature shall not be lower than 306 K (33 °C). If not specified, it shall be $311 \text{ K} \pm 5 \text{ K}$ ($38 \text{ °C} \pm 5 \text{ °C}$) at the inlet to the fuel supply.

For NG and LPG fuelled engines, the fuel temperature and measuring point shall be within the limits given in Annex 1, paragraph 1.16.5. or in Annex 1, Appendix 3, paragraph 1.16.5. in cases where the engine is not a parent engine.

2.8 If the engine is equipped with an exhaust aftertreatment system, the emissions measured on the test cycle shall be representative of the emissions in the field. In the case of an engine equipped with a exhaust aftertreatment system that requires the consumption of a reagent, the reagent used for all tests shall comply with Annex 1, paragraph 2.2.1.13.

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

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

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

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

The final test result shall be the arithmetic mean of the different ETC test results.

If the exhaust aftertreatment has a security mode that shifts to a periodic regeneration mode it should be checked following paragraph 2.8.2. of this annex. For that specific case the emission limits in table 2 of paragraph 5.2. could be exceeded and would not be weighted.

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

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

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

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

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

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

During the regeneration process, the emission limits in table 2 of paragraph 5.2. can be exceeded.

The measured emissions shall be weighted according to paragraphs 5.5. and 6.3. of Appendix 2 to this annex and the final result shall not exceed the limits in table 2 of paragraph 5.2.

Appendix 1

ESC AND ELR TEST CYCLES

1. ENGINE AND DYNAMOMETER SETTINGS

1.1 Determination of engine speeds A, B and C

The engine speeds A, B and C shall be declared by the manufacturer in accordance with the following provisions:

The high speed n_{hi} shall be determined by calculating 70 per cent of the declared maximum net power $P(n)$, as determined in Annex 1, paragraph 8.2. The highest engine speed where this power value occurs on the power curve is defined as n_{hi} .

The low speed n_{lo} shall be determined by calculating 50 per cent of the declared maximum net power $P(n)$, as determined in Annex 1, paragraph 8.2. The lowest engine speed where this power value occurs on the power curve is defined as n_{lo} .

The engine speeds A, B and C shall be calculated as follows:

$$\text{Speed A} = n_{lo} + 25 \text{ per cent } (n_{hi} - n_{lo})$$

$$\text{Speed B} = n_{lo} + 50 \text{ per cent } (n_{hi} - n_{lo})$$

$$\text{Speed C} = n_{lo} + 75 \text{ per cent } (n_{hi} - n_{lo})$$

The engine speeds A, B and C may be verified by either of the following methods:

- (a) Additional test points shall be measured during engine power approval according to Regulation 85 for an accurate determination of n_{hi} and n_{lo} . The maximum power, n_{hi} and n_{lo} shall be determined from the power curve, and engine speeds A, B and C shall be calculated according to the above provisions.
- (b) The engine shall be mapped along the full load curve, from maximum no load speed to idle speed, using at least 5 measurement points per $1,000 \text{ min}^{-1}$ intervals and measurement points within $\pm 50 \text{ min}^{-1}$ of the speed at declared maximum power. The maximum power, n_{hi} and n_{lo} shall be determined from this mapping curve, and engine speeds A, B and C shall be calculated according to the above provisions.

If the measured engine speeds A, B and C are within ± 3 per cent of the engine speeds as declared by the manufacturer, the declared engine speeds shall be used for the emissions test. If the tolerance is exceeded for any of the engine speeds, the measured engine speeds shall be used for the emissions test.

1.2. Determination of dynamometer settings

The torque curve at full load shall be determined by experimentation to calculate the torque values for the specified test modes under net conditions, as specified in Annex 1, paragraph 8.2. The power absorbed by engine-driven equipment, if applicable, shall be taken into account. The dynamometer setting for each test mode shall be calculated using the formula:

$s = P(n) * (L/100)$ if tested under net conditions

$s = P(n) * (L/100) + (P(a) - P(b))$ if not tested under net conditions

where:

s = dynamometer setting, kW

P(n) = net engine power as indicated in Annex 1, paragraph 8.2., kW

L = per cent load as indicated in paragraph 2.7.1., per cent

P(a) = power absorbed by auxiliaries to be fitted as indicated in Annex 1, paragraph 6.1.

P(b) = power absorbed by auxiliaries to be removed as indicated in Annex 1, paragraph 6.2.

2. ESC TEST RUN

At the manufacturers request, a dummy test may be run for conditioning of the engine and exhaust system before the measurement cycle.

2.1. Preparation of the sampling filter

At least one hour before the test, each filter shall be placed in a partially covered petri dish which is protected against dust contamination, and placed in a weighing chamber for stabilisation. At the end of the stabilisation 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. The tare weight shall be recorded.

2.2. Installation of the measuring equipment

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

2.3. Starting the dilution system and the engine

The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilised at maximum power according to the recommendation of the manufacturer and good engineering practice.

2.4. 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 passing dilution air through the particulate filters. 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.

2.5. Adjustment of the dilution ratio

The dilution air shall be set such that the temperature of the diluted exhaust gas measured immediately prior to the filter shall not exceed 325 K (52 °C) at any mode. The dilution ratio (q) shall not be less than 4.

For systems that use CO₂ or NO_x concentration measurement for dilution ratio control, the CO₂ or NO_x content of the dilution air shall be measured at the beginning and at the end of each test. The pre- and post test background CO₂ or NO_x concentration measurements of the dilution air shall be within 100 ppm or 5 ppm of each other, respectively.

2.6. Checking the analyzers

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

2.7. Test cycle

2.7.1. The following 13-mode cycle shall be followed in dynamometer operation on the test engine

Mode Number	Engine Speed	Percent Load	Weighting Factor	Mode Length
1	idle	—	0.15	4 minutes
2	A	100	0.08	2 minutes
3	B	50	0.10	2 minutes
4	B	75	0.10	2 minutes
5	A	50	0.05	2 minutes
6	A	75	0.05	2 minutes
7	A	25	0.05	2 minutes
8	B	100	0.09	2 minutes
9	B	25	0.10	2 minutes
10	C	100	0.08	2 minutes
11	C	25	0.05	2 minutes
12	C	75	0.05	2 minutes
13	C	50	0.05	2 minutes

2.7.2. Test sequence

The test sequence shall be started. The test shall be performed in the order of the mode numbers as set out in paragraph 2.7.1.

The engine shall be operated for the prescribed time in each mode, completing engine speed and load changes in the first 20 seconds. The specified speed shall be held to within $\pm 50 \text{ min}^{-1}$ and the specified torque shall be held to within ± 2 per cent of the maximum torque at the test speed.

At the manufacturer's request, the test sequence may be repeated a sufficient number of times for sampling more particulate mass on the filter. The manufacturer shall supply a detailed description of the data evaluation and calculation procedures. The gaseous emissions shall only be determined on the first cycle.

2.7.3. Analyzer response

The output of the analyzers shall be recorded on a strip chart recorder or measured with an equivalent data acquisition system with the exhaust gas flowing through the analyzers throughout the test cycle.

2.7.4. Particulate sampling

A single filter shall be used for the complete test procedure. The modal weighting factors specified in the test cycle procedure shall be taken into account by taking a sample proportional to the exhaust mass flow during each individual mode of the cycle. This can be achieved by adjusting sample flow rate, sampling time, and/or dilution ratio, accordingly, so that the criterion for the effective weighting factors in paragraph 6.6. is met.

The sampling time per mode shall be at least 4 seconds per 0.01 weighting factor. Sampling shall be conducted as late as possible within each mode. Particulate sampling shall be completed no earlier than 5 seconds before the end of each mode.

2.7.5. Engine conditions

The engine speed and load, intake air temperature and depression, exhaust temperature and backpressure, fuel flow and air or exhaust flow, charge air temperature, fuel temperature and humidity shall be recorded during each mode, with the speed and load requirements (see paragraph 2.7.2.) being met during the time of particulate sampling, but in any case during the last minute of each mode.

Any additional data required for calculation shall be recorded (see paragraphs 4. and 5.).

2.7.6. NO_x check within the control area

The NO_x check within the control area shall be performed immediately upon completion of mode 13.

The engine shall be conditioned at mode 13 for a period of three minutes before the start of the measurements. Three measurements shall be made at different locations within the control area, selected by the Technical Service 2/. The time for each measurement shall be 2 minutes.

The measurement procedure is identical to the NO_x measurement on the 13-mode cycle, and shall be carried out in accordance with paragraphs 2.7.3., 2.7.5., and 4.1. of this appendix, and Appendix 4, paragraph 3.

2/ The test points shall be selected using approved statistical methods of randomisation.

The calculation shall be carried out in accordance with paragraph 4.

2.7.7. Rechecking the analyzers

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

3. ELR TEST RUN

3.1. Installation of the measuring equipment

The opacimeter and sample probes, if applicable, shall be installed after the exhaust silencer or any aftertreatment device, if fitted, according to the general installation procedures specified by the instrument manufacturer. Additionally, the requirements of paragraph 10. of ISO 11614 shall be observed.

Prior to any zero and full-scale checks, the opacimeter shall be warmed up and stabilised according to the instrument manufacturer's recommendations. If the opacimeter is equipped with a purge air system to prevent sooting of the meter optics, this system shall also be activated and adjusted according to the manufacturer's recommendations.

3.2. Checking of the opacimeter

The zero and full scale checks shall be made in the opacity readout mode, since the opacity scale offers two truly definable calibration points, namely 0 per cent opacity and 100 per cent opacity. The light absorption coefficient is then correctly calculated based upon the measured opacity and the L_A , as submitted by the opacimeter manufacturer, when the instrument is returned to the k readout mode for testing.

With no blockage of the opacimeter light beam, the readout shall be adjusted to 0.0 per cent \pm 1.0 per cent opacity. With the light being prevented from reaching the receiver, the readout shall be adjusted to 100.0 per cent \pm 1.0 per cent opacity.

3.3. Test cycle

3.3.1. Conditioning of the engine

Warming up of the engine and the system shall be at maximum power in order to stabilise the engine parameters according to the recommendation of the manufacturer. The preconditioning phase should also protect the actual measurement against the influence of deposits in the exhaust system from a former test.

When the engine is stabilised, the cycle shall be started within 20 ± 2 s after the preconditioning phase. At the manufacturers request, a dummy test may be run for additional conditioning before the measurement cycle.

- (h) Upon completion of the third load step, the engine shall be adjusted to the selected engine speed and any load above 10 per cent within 20 ± 2 s.
- (i) The sequence (a) to (c) shall be run with the engine operating at the selected engine speed.

3.4. Cycle validation

The relative standard deviations of the mean smoke values at each test speed (SV_A , SV_B , SV_C , as calculated in accordance with paragraph 6.3.3. of this appendix from the three successive load steps at each test speed) shall be lower than 15 per cent of the mean value, or 10 per cent of the limit value shown in table 1 of paragraph 5.2., whichever is greater. If the difference is greater, the sequence shall be repeated until 3 successive load steps meet the validation criteria.

3.5. Rechecking of the opacimeter

The post-test opacimeter zero drift value shall not exceed $\pm 5,0$ per cent of the limit value shown in table 1 of paragraph 5.2.

4. CALCULATION OF THE EXHAUST GAS FLOW

4.1. Determination of raw exhaust gas mass flow

For calculation of the emissions in the raw exhaust, it is necessary to know the exhaust gas flow. The exhaust gas mass flow rate shall be determined in accordance with paragraph 4.1.1. or 4.1.2. The accuracy of exhaust flow determination shall be $\pm 2,5$ per cent of reading or ± 1.5 per cent of the engine's maximum value whichever is the greater. Equivalent methods (e.g. those described in paragraph 4.2. of Appendix 2 to this annex) may be used.

4.1.1. Direct measurement method

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

- (a) pressure differential devices, like flow nozzle;
- (b) ultrasonic flowmeter;
- (c) 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 shall not be affected by the installation of the device.

4.1.2. Air and fuel measurement method

This involves measurement of the air flow and the fuel flow. Air flowmeters and fuel flowmeters shall be used that meet the total accuracy requirement of paragraph 4.1. The calculation of the exhaust gas flow is as follows:

$$q_{mew} = q_{maw} + q_{mf}$$

4.2. Determination of diluted exhaust gas mass flow

For calculation of the emissions in the diluted exhaust using a full flow dilution system it is necessary to know the diluted exhaust gas flow. The flow rate of the diluted exhaust (q_{medw}) shall be measured over each mode with a PDP-CVS, CFV-CVS or SSV-CVS in line with the general formulae given in paragraph 4.1. of Appendix 2 to this annex. The accuracy shall be ± 2 per cent of reading or better, and shall be determined according to the provisions of paragraph 2.4. of Appendix 5 to this annex.

5. CALCULATION OF THE GASEOUS EMISSIONS

5.1. Data evaluation

For the evaluation of the gaseous emissions, the chart reading of the last 30 seconds of each mode shall be averaged and the average concentrations (conc) of HC, CO and NO_x during each mode shall be determined from the average chart readings and the corresponding calibration data. A different type of recording can be used if it ensures an equivalent data acquisition.

For the NO_x check within the control area, the above requirements apply for NO_x only.

The exhaust gas flow q_{mew} or the diluted exhaust gas flow q_{mdew} , if used optionally, shall be determined in accordance with paragraph 2.3. of Appendix 4 to this annex.

5.2. Dry / wet correction

The measured concentration shall be converted to a wet basis according to the following formulae, if not already measured on a wet basis. The conversion shall be done for each individual mode.

$$c_{wet} = k_W \times c_{dry}$$

For the raw exhaust gas:

$$k_{w,r} = \left(1 - \frac{1.2442 \times H_a + 111.19 \times w_{ALF} \times \frac{q_{mf}}{q_{mad}}}{773.4 + 1.2442 \times H_a + \frac{q_{mf}}{q_{mad}} \times k_f \times 1000} \right) \times 1.008$$

or

$$k_{w,r} = \left(1 - \frac{1.2442 \times H_a + 111.19 \times w_{ALF} \times \frac{q_{mf}}{q_{mad}}}{773.4 + 1.2442 \times H_a + \frac{q_{mf}}{q_{mad}} \times k_f \times 1000} \right) / \left(1 - \frac{p_r}{p_b} \right)$$

or

$$k_{w,a} = \left(\frac{1}{1 + \alpha \times 0.005 \times (c_{CO_2} + c_{CO})} - k_{w1} \right) \times 1.008$$

with

$$k_f = 0.055594 \times w_{ALF} + 0.0080021 \times w_{DEL} + 0.0070046 \times w_{EPS}$$

and

$$k_{w1} = \frac{1.608 \times H_a}{1,000 + (1.608 \times H_a)}$$

where:

- H_a = intake air humidity, g water per kg dry air
- w_{ALF} = hydrogen content of the fuel, per cent mass
- $q_{mf,i}$ = instantaneous fuel mass flow rate, kg/s
- $q_{mad,i}$ = instantaneous dry intake air mass flow rate, kg/s
- p_r = water vapour pressure after cooling bath, kPa
- p_b = total atmospheric pressure, kPa
- w_{DEL} = nitrogen content of the fuel, per cent mass
- w_{EPS} = oxygen content of the fuel, per cent mass
- α = molar hydrogen ratio of the fuel
- c_{CO_2} = dry CO₂ concentration, per cent
- c_{CO} = dry CO concentration, per cent

For the diluted exhaust gas:

$$K_{we1} = \left(1 - \frac{\alpha \times \% c_{wCO_2}}{200} \right) - K_{w1}$$

or,

$$K_{we2} = \left(\frac{(1 - K_{w1})}{1 + \frac{\alpha \times \% c_{dCO2}}{200}} \right)$$

For the dilution air:

$$K_{wd} = 1 - K_{w1}$$

$$K_{w1} = \frac{1.608 \times \left[H_d \times \left(1 - \frac{1}{D} \right) + H_a \times \left(\frac{1}{D} \right) \right]}{1000 + \left\{ 1.608 \times \left[H_d \times \left(1 - \frac{1}{D} \right) + H_a \times \left(\frac{1}{D} \right) \right] \right\}}$$

For the intake air:

$$K_{wa} = 1 - K_{w2}$$

$$K_{w2} = \frac{1.608 \times H_a}{1000 + (1.608 \times H_a)}$$

where:

H_a = intake air humidity, g water per kg dry air

H_d = dilution air humidity, g water per kg dry air

and may be derived from relative humidity measurement, dewpoint measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

5.3. 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 ambient air temperature and humidity with the factors given in the following formulae. The factors are valid in the range between 0 and 25 g/kg dry air.

(a) for compression ignition engines:

$$k_{h,D} = \frac{1}{1 - 0.0182 \times (H_a - 10.71) + 0.0045 \times (T_a - 298)}$$

with:

T_a = temperature of the intake air, K

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

where:

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

(b) for spark ignition engines

$$k_{h,G} = 0.6272 + 44.030 \times 10^{-3} \times H_a - 0.862 \times 10^{-3} \times H_a^2$$

where:

H_a may be derived from relative humidity measurement, dew point measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

5.4. Calculation of the emission mass flow rates

The emission mass flow rate (g/h) for each mode shall be calculated as follows. For the calculation of NO_x , the humidity correction factor $k_{h,D}$, or $k_{h,G}$, as applicable, as determined according to paragraph 5.3., shall be used.

The measured concentration shall be converted to a wet basis according to paragraph 5.2. if not already measured on a wet basis. Values for u_{gas} are given in table 6 for selected components based on ideal gas properties and the fuels relevant for this Regulation.

(a) for the raw exhaust gas

$$m_{gas} = u_{gas} \times c_{gas} \times q_{mew}$$

where:

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

(b) for the diluted gas

$$m_{gas} = u_{gas} \times c_{gas,c} \times q_{mdew}$$

where:

u_{gas} = ratio between density of exhaust component and density of air
 $c_{gas,c}$ = background corrected concentration of the respective component in the diluted exhaust gas, ppm
 q_{mdew} = diluted exhaust mass flow rate, kg/h

where:

$$c_{gas,c} = c - c_d \times \left[1 - \frac{1}{D} \right]$$

The dilution factor D shall be calculated according to paragraph 5.4.1. of Appendix 2 to this annex.

5.5. Calculation of the specific emissions

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

$$GAS_x = \frac{\sum_{i=1}^{i=n} (m_{GASi} \times W_{Fi})}{\sum_{i=1}^{i=n} (P(n)_i \times W_{Fi})}$$

where:

m_{gas} is the mass of individual gas

P_n is the net power determined according to paragraph 8.2. in Annex 1.

The weighting factors used in the above calculation are according to paragraph 2.7.1.

Table 6
Values of u_{gas} in the raw and dilute exhaust gas for various exhaust components

Fuel		NO _x	CO	THC/NMHC	CO ₂	CH ₄	Density
Diesel	Exhaust raw	0.001587	0.000966	0.000479	0.001518	0.000553	1.2943
	Exhaust dilute	0.001588	0.000967	0.000480	0.001519	0.000553	1.293
Ethanol	Exhaust raw	0.001609	0.000980	0.000805	0.001539	0.000561	1.2757
	Exhaust dilute	0.001588	0.000967	0.000795	0.001519	0.000553	1.293
CNG	Exhaust raw	0.001622	0.000987	0.000523	0.001552	0.000565	1.2661
	Exhaust dilute	0.001588	0.000967	0.000584	0.001519	0.000553	1.293
Propane	Exhaust raw	0.001603	0.000976	0.000511	0.001533	0.000559	1.2805
	Exhaust dilute	0.001588	0.000967	0.000507	0.001519	0.000553	1.293
Butane	Exhaust raw	0.001600	0.000974	0.000505	0.001530	0.000558	1.2832
	Exhaust dilute	0.001588	0.000967	0.000501	0.001519	0.000553	1.293

Notes: - u values of raw exhaust based on ideal gas properties at $\lambda = 2$. dry air, 273 K, 101.3 kPa
- u values of dilute exhaust based on ideal gas properties and density of air
- u values of CNG accurate within 0.2 per cent for mass composition of: C = 66 to 76 per cent; H = 22 to 25 per cent; N = 0 to 12 per cent
- u value of CNG for HC corresponds to CH_{2,93} (for total HC use u value of CH₄)

5.6. Calculation of the area control values

For the three control points selected according to paragraph 2.7.6., the NO_x emission shall be measured and calculated according to paragraph 5.6.1. and also determined by interpolation from the modes of the test cycle closest to the respective control point according to paragraph 5.6.2. The measured values are then compared to the interpolated values according to paragraph 5.6.3.

5.6.1. Calculation of the specific emission

The NO_x emission for each of the control points (Z) shall be calculated as follows:

$$m_{NO_{x,Z}} = 0.001587 \times C_{NO_{x,Z}} \times k_{h,D} \times q_{mew}$$

$$NOx_Z = \frac{m_{NOx,Z}}{P(n)_Z}$$

5.6.2. Determination of the emission value from the test cycle

The NO_x emission for each of the control points shall be interpolated from the four closest modes of the test cycle that envelop the selected control point Z as shown in figure 4. For these modes (R, S, T, U), the following definitions apply:

Speed(R) = Speed(T) = n_{RT}

Speed(S) = Speed(U) = n_{SU}

Per cent load(R) = Per cent load(S)

Per cent load(T) = Per cent load(U).

The NO_x emission of the selected control point Z shall be calculated as follows:

$$E_Z = \frac{E_{RS} + (E_{TU} - E_{RS}) \times (M_Z - M_{RS})}{M_{TU} - M_{RS}}$$

and:

$$E_{TU} = \frac{E_T + (E_{TU} - E_T) \times (n_Z - n_{RT})}{n_{SU} - n_{RT}}$$

$$E_{RS} = \frac{E_R + (E_S - E_R) \times (n_Z - n_{RT})}{n_{SU} - n_{RT}}$$

$$M_{TU} = \frac{M_T + (M_U - M_T) \times (n_Z - n_{RT})}{n_{SU} - n_{RT}}$$

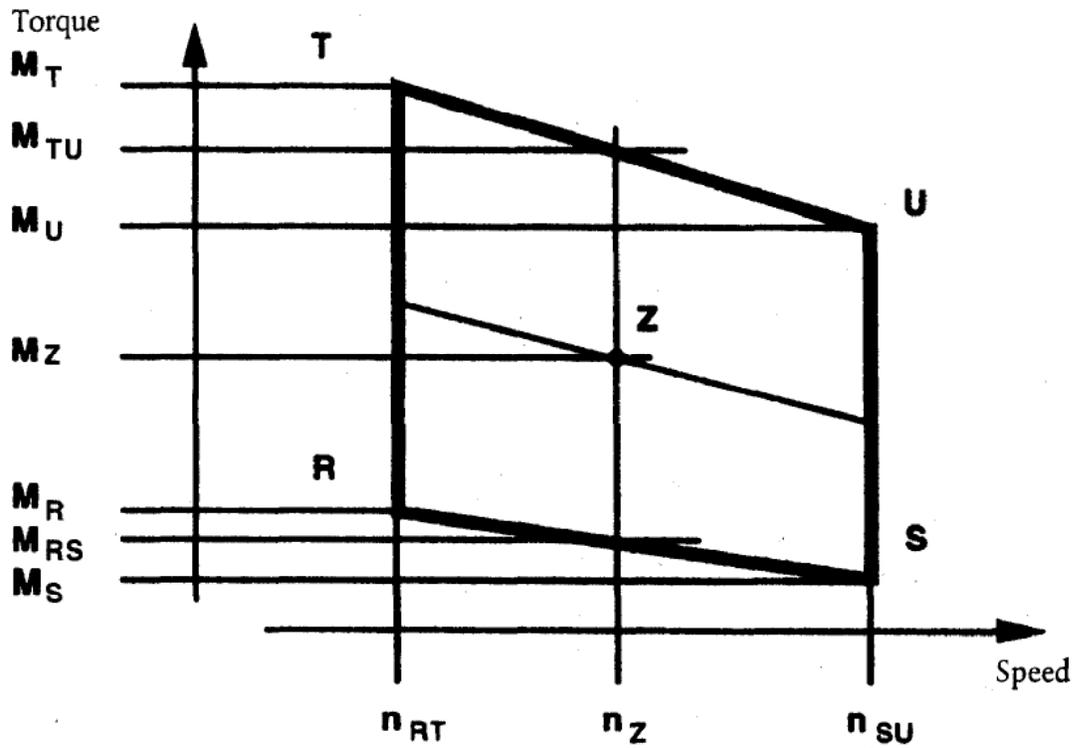
$$M_{RS} = \frac{M_R + (M_S - M_R) \times (n_Z - n_{RT})}{n_{SU} - n_{RT}}$$

where:

E_R, E_S, E_T, E_U = specific NO_x emission of the enveloping modes calculated in accordance with paragraph 5.6.1.

M_R, M_S, M_T, M_U = engine torque of the enveloping modes

Figure 4
Interpolation of NO_x Control Point



5.6.3. Comparison of NO_x emission values

The measured specific NO_x emission of the control point Z ($NO_{x,Z}$) is compared to the interpolated value (E_Z) as follows:

$$NOx_{diff} = 100 \times \frac{NOx_Z - E_Z}{E_Z}$$

6. CALCULATION OF THE PARTICULATE EMISSIONS

6.1. Data evaluation

For the evaluation of the particulates, the total sample masses (m_{sep}) through the filter shall be recorded for each mode.

The filter shall be returned to the weighing chamber and conditioned for at least one hour, but not more than 80 hours, and then weighed. The gross weight of the filters shall be recorded and the tare weight (see paragraph 2.1.) subtracted, which results in the particulate sample mass m_f .

If background correction is to be applied, the dilution air mass (m_d) through the filter and the particulate mass ($m_{f,d}$) shall be recorded. If more than one measurement was made, the quotient $m_{f,d}/m_d$ shall be calculated for each single measurement and the values averaged.

6.2. Partial flow dilution system

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

6.2.1. Isokinetic systems

$$q_{medf} = q_{mew} \times r_d$$

$$r_d = \frac{q_{mdw} + (q_{mew} \times r_a)}{q_{mew} \times r_a}$$

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

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

6.2.2. Systems with measurement of CO₂ or NO_x concentration

$$q_{medf} = q_{mew} \times r_d$$

$$r_d = \frac{c_{wE} - c_{wA}}{c_{wD} - c_{wA}}$$

where:

- c_{wE} = wet concentration of the tracer gas in the raw exhaust
- c_{wD} = wet concentration of the tracer gas in the diluted exhaust
- c_{wA} = wet concentration of the tracer gas in the dilution air

Concentrations measured on a dry basis shall be converted to a wet basis according to paragraph 5.2. of this appendix.

6.2.3. Systems with CO₂ measurement and carbon balance method 4/

$$q_{medf} = \frac{206.5 \times q_{mf}}{c_{(CO_2)D} - c_{(CO_2)A}}$$

4/ The value is only valid for the reference fuel specified in Annex IV.

where:

$c_{(CO_2)D}$ = CO₂ concentration of the diluted exhaust

$c_{(CO_2)A}$ = CO₂ concentration of the dilution air

(concentrations in vol per cent on wet basis)

This equation is based upon the carbon balance assumption (carbon atoms supplied to the engine are emitted as CO₂) and determined through the following steps:

$$q_{medf} = q_{mew} \times r_d$$

and

$$r_d = \frac{206.5 \times q_{mf}}{q_{mew} \times [c_{(CO_2)D} - c_{(CO_2)A}]}$$

6.2.4. Systems with flow measurement

$$q_{medf} = q_{mew} \times r_d$$

$$r_d = \frac{q_{mdew}}{q_{mdew} - q_{mdw}}$$

6.3. Full flow dilution system

All calculations shall be based upon the average values of the individual modes during the sampling period. The diluted exhaust gas flow q_{mdew} shall be determined in accordance with paragraph 4.1. of Appendix 2 to this annex. The total sample mass m_{sep} shall be calculated in accordance with paragraph 6.2.1. of Appendix 2 to this annex.

6.4. Calculation of the particulate mass flow rate

The particulate mass flow rate shall be calculated as follows. If a full flow dilution system is used, q_{medf} as determined according to paragraph 6.2. shall be replaced with q_{mdew} as determined according to paragraph 6.3.

$$PT_{mass} = \frac{m_f}{m_{sep}} \times \frac{q_{medf}}{1000}$$

$$\overline{q_{medf}} = \sum_{i=1}^{i=n} q_{medfi} \times W_{fi}$$

$$m_{sep} = \sum_{i=1}^{i=n} m_{sepi}$$

$$i = 1, \dots, n$$

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

$$PT_{mass} = \left\{ \frac{m_f}{m_{sep}} - \left[\frac{m_{f,d}}{m_d} \times \sum_{i=1}^{i=n} \left(1 - \frac{1}{Di} \right) \times W_{fi} \right] \right\} \times \frac{\overline{q_{medf}}}{1000}$$

where D shall be calculated in accordance with paragraph 5.4.1. of Appendix 2 to this annex.

6.5. Calculation of the specific emission

The particulate emission shall be calculated in the following way:

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

6.6. Effective weighting factor

The effective weighting factor W_{fei} for each mode shall be calculated in the following way:

$$W_{fei} = \frac{m_{sepi} \times q_{medf}}{m_{sep} \times q_{medfi}}$$

The value of the effective weighting factors shall be within ± 0.003 (0.005 for the idle mode) of the weighting factors listed in paragraph 2.7.1. of this appendix.

7. CALCULATION OF THE SMOKE VALUES

7.1. Bessel algorithm

The Bessel algorithm shall be used to compute the 1 s average values from the instantaneous smoke readings, converted in accordance with paragraph 6.3.1. The algorithm emulates a low pass second order filter, and its use requires iterative calculations to determine the coefficients. These coefficients are a function of the response time of the opacimeter system and the sampling rate. Therefore, paragraph 6.1.1. shall be repeated whenever the system response time and/or sampling rate changes.

7.1.1. Calculation of filter response time and Bessel constants

The required Bessel response time (t_F) is a function of the physical and electrical response times of the opacimeter system, as specified in Appendix 4 to this annex and shall be calculated by the following equation:

$$t_F = \sqrt{1 - (t_p^2 + t_e^2)}$$

where:

- t_p = physical response time, s
- t_e = electrical response time, s

The calculations for estimating the filter cut-off frequency (f_c) are based on a step input 0 to 1 in ≤ 0.01 s (see Annex 6). The response time is defined as the time between when the Bessel output reaches 10 per cent (t_{10}) and when it reaches 90 per cent (t_{90}) of this step function. This shall be obtained by iterating on f_c until $t_{90}-t_{10} \approx t_F$. The first iteration for f_c is given by the following formula:

$$f_c = \frac{\pi}{10 \times t_F}$$

The Bessel constants E and K shall be calculated by the following equations:

$$E = \frac{1}{(1 + \Omega \times \sqrt{(3 \times D) + D \times \Omega^2})}$$

$$K = 2 \times E \times (D \times \Omega^2 - 1) - 1$$

where:

$$D = 0.618034$$

$$\Delta t = \frac{1}{\text{sampling rate}}$$

$$\Omega = \frac{1}{[\tan(\pi \times \Delta t \times f_c)]}$$

7.1.2. Calculation of the Bessel algorithm

Using the values of E and K, the 1 s Bessel averaged response to a step input S_i shall be calculated as follows:

$$Y_i = Y_{i-1} + E \times (S_i + 2 \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + K \times (Y_{i-1} - Y_{i-2})$$

where:

$$S_{i-2} = S_{i-1} = 0$$

$$S_i = 1$$

$$Y_{i-2} = Y_{i-1} = 0$$

The times t_{10} and t_{90} shall be interpolated. The difference in time between t_{90} and t_{10} defines the response time t_F for that value of f_c . If this response time is not close enough to the required response time, iteration shall be continued until the actual response time is within 1 per cent of the required response as follows:

$$((t_{90} - t_{10}) - t_F) \leq 0.01 \times t_F$$

7.2. Data evaluation

The smoke measurement values shall be sampled with a minimum rate of 20 Hz.

7.3. Determination of smoke

7.3.1. Data Conversion

Since the basic measurement unit of all opacimeters is transmittance, the smoke values shall be converted from transmittance (τ) to the light absorption coefficient (k) as follows:

$$k = -\frac{1}{L_A} \times \ln\left(1 - \frac{N}{100}\right)$$

and

$$N = 100 - \tau$$

where:

- k = light absorption coefficient, m^{-1}
- L_A = effective optical path length, as submitted by instrument manufacturer, m
- N = opacity, per cent
- τ = transmittance, per cent

The conversion shall be applied, before any further data processing is made.

7.3.2. Calculation of Bessel averaged smoke

The proper cut-off frequency f_c is the one that produces the required filter response time t_f . Once this frequency has been determined through the iterative process of paragraph 6.1.1., the proper Bessel algorithm constants E and K shall be calculated. The Bessel algorithm shall then be applied to the instantaneous smoke trace (k -value), as described in paragraph 6.1.2.:

$$Y_i = Y_{i-1} + E \times (S_i + 2 \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + K \times (Y_{i-1} - Y_{i-2})$$

The Bessel algorithm is recursive in nature. Thus, it needs some initial input values of S_{i-1} and S_{i-2} and initial output values Y_{i-1} and Y_{i-2} to get the algorithm started. These may be assumed to be 0.

For each load step of the three speeds A, B and C, the maximum 1s value Y_{\max} shall be selected from the individual Y_i values of each smoke trace.

7.3.3. Final result

The mean smoke values (SV) from each cycle (test speed) shall be calculated as follows:

$$\begin{aligned} \text{For test speed A:} & \quad SV_A = (Y_{\max 1,A} + Y_{\max 2,A} + Y_{\max 3,A}) / 3 \\ \text{For test speed B:} & \quad SV_B = (Y_{\max 1,B} + Y_{\max 2,B} + Y_{\max 3,B}) / 3 \\ \text{For test speed C:} & \quad SV_C = (Y_{\max 1,C} + Y_{\max 2,C} + Y_{\max 3,C}) / 3 \end{aligned}$$

where:

$$Y_{\max 1}, Y_{\max 2}, Y_{\max 3} = \text{highest 1 s Bessel averaged smoke value at each of the three load steps}$$

The final value shall be calculated as follows:

$$SV = (0.43 \cdot SV_A) + (0.56 \cdot SV_B) + (0.01 \cdot SV_C)$$

Appendix 2

ETC TEST CYCLE

1. ENGINE MAPPING PROCEDURE

1.1. Determination of the Mapping Speed Range

For generating the ETC on the test cell, the engine needs to be mapped prior to the test cycle for determining the speed vs. torque curve. 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 lower

1.2. Performing the Engine Power Map

The engine shall be warmed up at maximum power in order to stabilise the engine parameters according to the recommendation of the manufacturer and good engineering practice. When the engine is stabilised, the engine map shall be performed as follows:

- (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 $8 \pm 1 \text{ min}^{-1} / \text{s}$ from minimum to maximum mapping speed. Engine speed and torque points shall be recorded at a sample rate of a least one point per second.

1.3. Mapping Curve Generation

All data points recorded under paragraph 1.2. of this appendix 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 cycle into actual torque values for the test cycle, as described in paragraph 2. of this appendix.

1.4. Alternate Mapping

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

1.5. 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:

- (a) an unreasonable amount of time has transpired since the last map, as determined by engineering judgement,
- or,
- (b) physical changes or recalibrations have been made to the engine which may potentially affect engine performance.

2. GENERATION OF THE REFERENCE TEST CYCLE

The transient test cycle is described in Appendix 3 to this annex. The normalized values for torque and speed shall be changed to the actual values, as follows, resulting in the reference cycle.

2.1. Actual Speed

The speed shall be unnormalized using the following equation:

$$\text{Actual speed} = \frac{\% \text{speed (reference speed} - \text{idle speed)}}{100} + \text{idle speed}$$

The reference speed (n_{ref}) corresponds to the 100 per cent speed values specified in the engine dynamometer schedule of Appendix 3. It is defined as follows (see figure 1 of paragraph 2.):

$$n_{\text{ref}} = n_{\text{lo}} + 95 \text{ per cent} \cdot (n_{\text{hi}} - n_{\text{lo}})$$

where n_{hi} and n_{lo} are either specified according to paragraph 2. or determined according to paragraph 1.1. of Appendix 1 to this annex.

2.2. Actual torque

The torque is normalized to the maximum torque at the respective speed. The torque values of the reference cycle shall be unnormalized, using the mapping curve determined according to paragraph 1.3. of this appendix, as follows:

$$\text{Actual torque} = (\text{per cent torque} \cdot \text{max. torque}/100)$$

for the respective actual speed as determined in paragraph 2.1. of this appendix.

The negative torque values of the motoring points ("m") shall take on, for purposes of reference cycle generation, unnormalized values determined in either of the following ways:

- (a) negative 40 per cent of the positive torque available at the associated speed point,
- (b) mapping of the negative torque required to motor the engine from minimum to maximum mapping speed,
- (c) determination of the negative torque required to motor the engine at idle and reference speeds and linear interpolation between these two points.

2.3. Example of the unnormalization procedure

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

per cent speed = 43

per cent torque = 82

Given the following values:

reference speed = 2,200 min⁻¹

idle speed = 600 min⁻¹

results in,

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

$$\text{actual torque} = (82 \times 700/100) = 574 \text{ Nm}$$

where the maximum torque observed from the mapping curve at 1,288 min⁻¹ is 700 Nm.

3. EMISSIONS TEST RUN

At the manufacturers request, a dummy test may be run for conditioning of the engine and exhaust system before the measurement cycle.

NG and LPG fuelled engines shall be run-in using the ETC test. The engine shall be run over a minimum of two ETC cycles and until the CO emission measured over one ETC cycle does not exceed by more than 10 per cent the CO emission measured over the previous ETC cycle.

3.1. Preparation of the sampling filters (if applicable)

At least one hour before the test, each filter shall be placed in a partially covered petri dish, which is protected against dust contamination, and placed in a weighing chamber for stabilisation. At the end of the stabilisation 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. The tare weight shall be recorded.

3.2. 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.

3.3. Starting the dilution system and the engine

The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilised at maximum power according to the recommendation of the manufacturer and good engineering practice.

3.4. Starting the particulate sampling system (diesel engines only)

The particulate sampling system shall be started and running on by-pass. The particulate background level of the dilution air may be determined by passing dilution air through the particulate filters. If filtered dilution air is used, one measurement may be done 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.

The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilised according to the recommendation of the manufacturer and good engineering practice.

In case of periodic regeneration aftertreatment, the regeneration shall not occur during the warm-up of the engine.

3.5. Adjustment of the dilution system

The flow rates of the dilution system (full flow or partial flow) shall be set to eliminate water condensation in the system, and to obtain a filter face temperature of maximum 325 K (52°C) or less (see paragraph 2.3.1. of Appendix 7, DT).

3.6. Checking the analyzers

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

3.7. Engine starting procedure

The stabilized engine shall be started 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, when the engine has reached the idle speed.

3.8. Test cycle

3.8.1. Test sequence

The test sequence shall be started, if the engine has reached idle speed. The test shall be performed according to the reference cycle as set out in paragraph 2. of this appendix. Engine speed and torque command set points shall be issued at 5 Hz (10 Hz

recommended) or greater. Feedback engine speed and torque shall be recorded at least once every second during the test cycle, and the signals may be electronically filtered.

3.8.2. Gaseous emissions measurement

3.8.2.1. Full flow dilution system

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

- (a) start collecting or analysing dilution air;
- (b) start collecting or analysing diluted exhaust gas;
- (c) start measuring the amount of diluted exhaust gas (CVS) and the required temperatures and pressures;
- (d) start recording the feedback data of speed and torque of the dynamometer.

HC and NO_x shall be measured continuously in the dilution tunnel with a frequency of 2 Hz. The average concentrations shall be determined by integrating the analyzer signals over the test cycle. The system response time shall be no greater than 20 s, and shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary. CO, CO₂, NMHC and CH₄ 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 values shall be recorded with a minimum of one measurement per second (1 Hz).

3.8.2.2 Raw exhaust measurement

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

- (a) start analysing the raw exhaust gas concentrations;
- (b) start measuring the exhaust gas or intake air and fuel flow rate;
- (c) start recording the feedback data of speed and torque of the dynamometer.

For the evaluation of the gaseous emissions, the 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. The system response time shall be no greater than 10 s. All other data may be recorded with a sample rate of at least 1 Hz. For analogue analyzers 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 paragraph 2. of this Regulation. Therefore, the response time of each gaseous emissions analyzer and of the exhaust gas mass flow system shall be determined according to the provisions of paragraph 4.2.1. and paragraph 1.5. of Appendix 5 to this annex and recorded.

3.8.3. Particulate sampling (if applicable)

3.8.3.1. Full flow dilution system

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 no flow compensation 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 ± 5 per cent of the set flow rate. If flow compensation (i.e., proportional control of sample flow) is used, it shall be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ± 5 per cent of its set value (except for the first 10 seconds of sampling).

For double dilution operation, sample flow is the net difference between the flow rate through the sample filters and the secondary dilution air flow rate.

The average temperature and pressure at the gas meter(s) or flow instrumentation inlet shall be recorded. If the set flow rate cannot be maintained over the complete cycle (within ± 5 per cent) 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.

3.8.3.2. Partial flow dilution system

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.

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 paragraph 3.3. of Appendix 5 to this annex. If the combined transformation time of the exhaust flow measurement (see paragraph 4.2.1. of this appendix) and the partial flow system is ≤ 0.3 s, online control may be used. If the transformation time exceeds 0.3 s, look ahead control based on a pre-recorded test run shall be used. In this case, the rise time shall be ≤ 1 s and the delay time of the combination ≤ 10 s.

The total system response shall be designed as to ensure a representative sample of the particulates, $q_{mp,i}$, proportional to the exhaust mass flow. To determine the proportionality, a regression analysis of $q_{mp,i}$ versus $q_{mew,i}$ shall be conducted on a minimum 1 Hz data acquisition rate, and the following criteria shall be met:

- (a) The correlation coefficient R^2 of the linear regression between $q_{mp,i}$ and $q_{mew,i}$ shall not be less than 0.95;
- (b) The standard error of estimate of $q_{mp,i}$ on $q_{mew,i}$ shall not exceed 5 per cent of q_{mp} maximum;
- (c) q_{mp} intercept of the regression line shall not exceed ± 2 per cent 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 the transformation time of the exhaust mass flow signal, $t_{50,F}$, or both, are > 0.3 s. 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 paragraph 3.3. of Appendix 5 to this annex.

3.8.4. 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.

3.8.5. Operations after test

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

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

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

3.9. Verification of the test run

3.9.1. Data shift

To minimize the biasing effect of the time lag between the feedback and reference cycle values, the entire engine speed and torque feedback signal sequence may be advanced or delayed in time with respect to the reference speed and torque sequence. If the feedback signals are shifted, both speed and torque shall be shifted the same amount in the same direction.

3.9.2. 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 feedback 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 paragraphs 5.5. and 6.3. of this appendix). 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 reference and actual cycle work, all 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 per cent and $+5$ per cent of W_{ref}

3.9.3. Validation statistics of the test cycle

Linear regressions of the feedback 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, with the best-fit equation having the form:

$$y = mx + b$$

where:

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

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

It is recommended that this analysis be performed at 1 Hz. All negative reference torque values and the associated feedback values shall be deleted from the calculation of cycle torque and power validation statistics. For a test to be considered valid, the criteria of table 7 shall be met.

Table 7
Regression line tolerances

	Speed	Torque	Power
Standard error of estimate (SE) of Y on X	Max 100 min ⁻¹	Max 13 per cent of power map maximum engine torque	Max 8 per cent of power map maximum engine power
Slope of the regression line, m	0.95 to 1.03	0.83-1.03	0.89-1.03
Coefficient of determination, r ²	min 0.9700	min 0.8800	min 0.9100
Y intercept of the regression line, b	± 50 min ⁻¹	± 20 Nm or ± 2 per cent of max torque whichever is greater	± 4 kW or ± 2 per cent of max power whichever is greater

Point deletions from the regression analyses are permitted where noted in table 8.

Table 8
Permitted point deletions from regression analysis

Conditions	Points to be deleted
Full load demand and torque feedback < 95 per cent torque reference	Torque and/or power
Full load demand and speed feedback < 95 per cent speed reference	Speed and/or power
No load, not an idle point, and torque feedback > torque reference	Torque and/or power
No load, speed feedback ≤ idle speed + 50 min ⁻¹ and torque feedback = manufacturer defined/measured idle torque ± 2 per cent of max. torque	Speed and/or power
No load, speed feedback > idle speed + 50 min ⁻¹ and torque feedback > 105 per cent torque reference	Torque and/or power
No load and speed feedback > 105 per cent speed reference	Speed and/or power

4. CALCULATION OF THE EXHAUST GAS FLOW

4.1. Determination of the diluted exhaust gas flow

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 for SSV), as determined in paragraph 2. of Appendix 5 to this annex). The following formulae shall be applied, if the temperature of the diluted exhaust is kept constant over the cycle by using a heat

exchanger (± 6 K for a PDP-CVS, ± 11 K for a CFV-CVS or ± 11 K for a SSV-CVS), see paragraph 2.3. of Annex V).

For the PDP-CVS system:

$$m_{ed} = 1.293 \cdot V_0 \cdot N_p \cdot (p_b - p_1) \cdot 273 / (101.3 \cdot T)$$

where:

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

N_p = total revolutions of pump per test

p_b = atmospheric pressure in the test cell, kPa

p_1 = pressure depression below atmospheric at pump inlet, kPa

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

For the CFV-CVS system:

$$m_{ed} = 1.293 \cdot t \cdot K_v \cdot p_p / T^{0.5}$$

where:

t = cycle time, s

K_v = calibration coefficient of the critical flow venturi for standard conditions,

p_p = absolute pressure at venturi inlet, kPa

T = absolute temperature at venturi inlet, K

For the SSV-CVS system

$$m_{ed} = 1.293 \cdot Q_{SSV}$$

where:

$$Q_{SSV} = A_0 d^2 C_d p_p \sqrt{\left[\frac{1}{T} (r_p^{1.4286} - r_p^{1.7143}) \cdot \left(\frac{1}{1 - r_D^4 r_p^{1.4286}} \right) \right]}$$

with:

A_0 = collection of constants and units conversions

$$= 0.006111 \text{ in SI units of } \left(\frac{m^3}{\text{min}} \right) \left(\frac{K^{1/2}}{kPa} \right) \left(\frac{1}{mm^2} \right)$$

d = diameter of the SSV throat, m

C_d = discharge coefficient of the SSV

p_p = absolute pressure at venturi inlet, kPa

T = temperature at the venturi inlet, K

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

r_D = ratio of the SSV throat diameter, d , to the inlet pipe inner diameter 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.

For the PDP-CVS system:

$$m_{ed,i} = 1.293 \cdot V_0 \cdot N_{p,i} \cdot (p_b - p_1) \cdot 273 / (101.3 \cdot T)$$

where:

$$N_{p,i} = \text{total revolutions of pump per time interval}$$

For the CFV-CVS system:

$$m_{ed,i} = 1.293 \cdot \Delta t_i \cdot K_V \cdot p_p / T^{0,5}$$

where:

$$\Delta t_i = \text{time interval, s}$$

For the SSV-CVS system:

$$m_{ed,i} = 1.293 \cdot Q_{SSV} \cdot \Delta t_i$$

where:

$$\Delta t_i = \text{time interval, s}$$

The real time calculation shall be initialised with either a reasonable value for C_d , such as 0.98, or a reasonable value of Q_{SSV} . If the calculation is initialised 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 shall be in the range of Reynolds numbers used to derive the calibration curve developed in paragraph 2.4. of Appendix 5 to this annex.

4.2. Determination of raw exhaust gas mass flow

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 paragraphs 4.2.2. to 4.2.5. of this appendix may be used.

4.2.1. Response time

For the purpose of emissions calculation, the response time of either method described below shall be equal to or less than the requirement for the analyzer response time, as defined in paragraph 1.5. of Appendix 5 to this annex.

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 ≤ 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 ≤ 5 seconds with a rise time of ≤ 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 paragraph 3.8.3.2.

4.2.2. Direct measurement method

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

- (a) pressure differential devices, like flow nozzle;
- (b) ultrasonic flowmeter;
- (c) 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. Engine performance and emissions shall especially not be affected by the installation of the device.

The accuracy of exhaust flow determination shall be at least ± 2.5 per cent of reading or ± 1.5 per cent of engine's maximum value, whichever is the greater.

4.2.3. Air and fuel measurement method

This involves measurement of the air flow and the fuel flow. Air flowmeters and fuel flowmeters shall be used that meet the total exhaust flow accuracy requirement of paragraph 4.2.2. of this appendix. The calculation of the exhaust gas flow is as follows:

$$q_{mew} = q_{maw} + q_{mf}$$

4.2.4. Tracer measurement method

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

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

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

The calculation of the exhaust gas flow is as follows:

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

where:

$q_{mew,i}$	=	instantaneous exhaust mass flow, kg/s
q_{vt}	=	tracer gas flow, cm ³ /min
$c_{mix,i}$	=	instantaneous concentration of the tracer gas after mixing, ppm
ρ_e	=	density of the exhaust gas, kg/m ³ (cf. table 6)
c_b	=	background concentration of the tracer gas in the intake air, ppm

When the background concentration is less than 1 per cent 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 paragraph 1.7. of Appendix 5 to this annex.

4.2.5. 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:

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

with:

$$A/F_{st} = \frac{138.0 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right)}{12.011 + 1.00794 \times \alpha + 15.9994 \times \varepsilon + 14.0067 \times \delta + 32.065 \times \gamma}$$

$$\lambda_i = \frac{\left(100 - \frac{c_{COd} \times 10^{-4}}{2} - c_{HCw} \times 10^{-4} \right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{COd} \times 10^{-4}}{3.5 \times c_{CO2d}} - \frac{\varepsilon}{2} - \frac{\delta}{2}}{1 + \frac{c_{CO} \times 10^{-4}}{3.5 \times c_{CO2d}}} \right) \times (c_{CO2d} + c_{COd} \times 10^{-4})}{4.764 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right) \times (c_{CO2d} + c_{COd} \times 10^{-4} + c_{HCw} \times 10^{-4})}$$

where:

A/F_{st}	=	stoichiometric air to fuel ratio, kg/kg
λ	=	excess air ratio
c_{CO2}	=	dry CO ₂ concentration, per cent
c_{CO}	=	dry CO concentration, ppm
c_{HC}	=	HC concentration, ppm

The air flowmeter shall meet the accuracy specifications of paragraph 2.2. of Appendix 4 to this annex, the CO₂ analyzer used shall meet the specifications of paragraph 3.3.2. of Appendix 4 to this annex 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 paragraph 3.3.6. of Appendix 4 to this annex.

5. CALCULATION OF THE GASEOUS EMISSIONS

5.1. Data evaluation

For the evaluation of the gaseous emissions in the diluted exhaust gas, the emission concentrations (HC, CO and NO_x) and the diluted exhaust gas mass flow rate shall be recorded according to paragraph 3.8.2.1. of this appendix and stored on a computer system. For analogue analyzers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

For the evaluation of the gaseous emissions in the raw exhaust gas, the emission concentrations (HC, CO and NO_x) and the exhaust gas mass flow rate shall be recorded according to paragraph 3.8.2.2. of this appendix and stored on a computer system. For analogue analyzers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

5.2. Dry / wet correction

If the concentration is measured on a dry basis, it shall be converted to a wet basis according to the following formula. For continuous measurement, the conversion shall be applied to each instantaneous measurement before any further calculation.

$$c_w = k_w \times c_d$$

The conversion equations of paragraph 5.2. of Appendix 1 to this annex shall apply.

5.3. 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 ambient air temperature and humidity with the factors given in paragraph 5.3. of Appendix 1 to this annex. The factors are valid in the range between 0 and 25 g/kg dry air.

5.4. Calculation of the emission mass flow rates

The emission mass over the cycle (g/test) shall be calculated as follows depending on the measurement method applied. The measured concentration shall be converted to a wet basis according to paragraph 5.2. of Appendix 1 to this annex, if not already

measured on a wet basis. The respective values for u_{gas} shall be applied that are given in table 6 of Appendix 1 to this annex for selected components based on ideal gas properties and the fuels relevant for this Regulation.

(a) for the raw exhaust gas:

$$m_{\text{gas}} = u_{\text{gas}} \times \sum_{i=1}^{i=n} c_{\text{gas},i} \times q_{\text{mew},i} \times \frac{1}{f}$$

where:

- u_{gas} = ratio between density of exhaust component and density of exhaust gas from table 6
- $c_{\text{gas},i}$ = instantaneous concentration of the respective component in the raw exhaust gas, ppm
- $q_{\text{mew},i}$ = instantaneous exhaust mass flow rate, kg/s
- f = data sampling rate, Hz
- n = number of measurements

(b) for the diluted exhaust gas without flow compensation:

$$m_{\text{gas}} = u_{\text{gas}} \times c_{\text{gas}} \times m_{\text{ed}}$$

where:

- u_{gas} = ratio between density of exhaust component and density of air from table 6
- c_{gas} = average background corrected concentration of the respective component, ppm
- m_{ed} = total diluted exhaust mass over the cycle, kg

(c) for the diluted exhaust gas with flow compensation:

$$m_{\text{gas}} = \left[u_{\text{gas}} \times \sum_{i=1}^{i=n} \left(c_{\text{e},i} \times q_{\text{mdew},i} \times \frac{1}{f} \right) \right] - \left[(m_{\text{ed}} \times c_{\text{d}} \times (1 - 1/D)) \times u_{\text{gas}} \right]$$

where:

- $c_{\text{e},i}$ = instantaneous concentration of the respective component measured in the diluted exhaust gas, ppm
- c_{d} = concentration of the respective component measured in the dilution air, ppm
- $q_{\text{mdew},i}$ = instantaneous diluted exhaust gas mass flow rate, kg/s
- m_{ed} = total mass of diluted exhaust gas over the cycle, kg
- u_{gas} = ratio between density of exhaust component and density of air from table 6
- D = dilution factor (see paragraph 5.4.1.)

If applicable, the concentration of NMHC and CH₄ shall be calculated by either of the methods shown in paragraph 3.3.4. of Appendix 4 to this annex, as follows:

- (a) GC method (full flow dilution system, only):

$$c_{\text{NMHC}} = c_{\text{HC}} - c_{\text{CH}_4}$$

- (b) NMC method:

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

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

where:

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

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

5.4.1. Determination of the background corrected concentrations (full flow dilution system, only)

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

$$c = c_e - c_d \times (1 - (1/D))$$

where:

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

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

D = dilution factor

The dilution factor shall be calculated as follows:

- (a) for diesel and LPG fueled gas engines

$$D = \frac{F_s}{c_{\text{CO}_2} + (c_{\text{HC}} + c_{\text{CO}}) \times 10^{-4}}$$

- (b) for NG fueled gas engines

$$D = \frac{F_s}{c_{\text{CO}_2,e} + (c_{\text{NMHC,e}} + c_{\text{CO,e}}) \times 10^{-4}}$$

where:

c_{CO_2} = concentration of CO_2 in the diluted exhaust gas, per cent vol

c_{HC} = concentration of HC in the diluted exhaust gas, ppm C1

c_{NMHC} = concentration of NMHC in the diluted exhaust gas, ppm C1

c_{CO} = concentration of CO in the diluted exhaust gas, ppm
 F_S = stoichiometric factor

Concentrations measured on dry basis shall be converted to a wet basis in accordance with paragraph 5.2. of Appendix 1 to this annex.

The stoichiometric factor shall be calculated as follows:

$$F_S = \frac{100 \times \frac{1}{1 + \frac{\alpha}{2} + 3.76 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2}\right)}}{1}$$

where:

α, ε are the molar ratios referring to a fuel $C H_\alpha O_\varepsilon$

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

5.5. Calculation of the specific emissions

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

(a) all components, except NO_x :

$$M_{gas} = \frac{m_{gas}}{W_{act}}$$

(b) NO_x :

$$M_{gas} = \frac{m_{gas} \times k_h}{W_{act}}$$

where:

W_{act} = actual cycle work as determined according to paragraph 3.9.2.

5.5.1. In case of a periodic exhaust aftertreatment system, the emissions shall be weighted as follows:

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

where:

$n1$ = number of ETC tests between two regenerations;
 $n2$ = number of ETC during a regeneration (minimum of one ETC test);
 $\overline{M}_{gas, n2}$ = emissions during a regeneration;
 $\overline{M}_{gas, n1}$ = emissions after a regeneration.

6. CALCULATION OF THE PARTICULATE EMISSION (IF APPLICABLE)

6.1. Data evaluation

The particulate filter shall be returned to the weighing chamber no later than one hour after completion of the test. It shall be conditioned in a partially covered petri dish, which is protected against dust contamination, for at least one hour, but not more than 80 hours, and then weighed. The gross weight of the filters shall be recorded and the tare weight subtracted, 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.

If background correction is to be applied, the dilution air mass (m_d) through the filter and the particulate mass ($m_{f,d}$) shall be recorded.

6.2. Calculation of the mass flow

6.2.1. Full flow dilution system

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

$$m_{PT} = \frac{m_f}{m_{sep}} \times \frac{m_{ed}}{1000}$$

where:

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

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

$$m_{sep} = m_{set} - m_{ssd}$$

where:

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

If the particulate background level of the dilution air is determined in accordance with paragraph 3.4., the particulate mass may be background corrected. In this case, the particulate mass (g/test) shall be calculated as follows:

$$m_{PT} = \left[\frac{m_f}{m_{sep}} - \left(\frac{m_d}{m_{f,d}} \times \left(1 - \frac{1}{D} \right) \right) \right] \times \frac{m_{ed}}{1,000}$$

where:

m_{PT} , m_{sep} , m_{ed} = see above

- m_d = mass of primary dilution air sampled by background particulate sampler, kg
 $m_{f,d}$ = mass of the collected background particulates of the primary dilution air, mg
 D = dilution factor as determined in paragraph 5.4.1.

6.2.2. Partial flow dilution system

The mass of particulates (g/test) shall be calculated by either of the following methods:

(a)

$$m_{PT} = \frac{m_f}{m_{sep}} \times \frac{m_{edf}}{1,000}$$

where:

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

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

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

$$q_{medf,i} = q_{mew,i} \times r_{d,i}$$

$$r_{d,i} = \frac{q_{mdew,i}}{(q_{mdew,i} - q_{mdw,i})}$$

where:

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

(b)

$$m_{PT} = m_f / (r_s \times 1,000)$$

where:

- m_f = particulate mass sampled over the cycle, mg

r_s = average sample ratio over the test cycle

with:

$$r_s = \frac{m_{se}}{m_{ew}} \times \frac{m_{sep}}{m_{sed}}$$

where:

m_{se} = sample mass over the cycle, kg

m_{ew} = total exhaust mass flow over the cycle, kg

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

m_{sed} = mass of diluted exhaust gas passing the dilution tunnel, kg

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

6.3. Calculation of the Specific Emission

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

$$M_{PT} = \frac{m_{PT}}{W_{act}}$$

where:

W_{act} = actual cycle work as determined according to paragraph 3.9.2., kWh.

6.3.1 In case of a periodic regeneration aftertreatment system, the emissions shall be weighted as follows:

$$\overline{PT} = (n1 \times \overline{PT}_{n1} + n2 \times \overline{PT}_{n2}) / (n1 + n2)$$

where:

$n1$ = number of ETC tests between two regeneration events;

$n2$ = number of ETC tests during a regeneration (minimum of one ETC);

\overline{PT}_{n2} = emissions during a regeneration;

\overline{PT}_{n1} = emissions outside a regeneration.

Appendix 3

ETC ENGINE DYNAMOMETER SCHEDULE

Time (s)	Norm. speed (per cent)	Norm. torque (per cent)
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	0.1	1.5
17	23.1	21.5
18	12.6	28.5
19	21.8	71
20	19.7	76.8
21	54.6	80.9
22	71.3	4.9
23	55.9	18.1
24	72	85.4
25	86.7	61.8
26	51.7	0
27	53.4	48.9
28	34.2	87.6
29	45.5	92.7
30	54.6	99.5
31	64.5	96.8
32	71.7	85.4
33	79.4	54.8
34	89.7	99.4
35	57.4	0
36	59.7	30.6
37	90.1	"m"
38	82.9	"m"
39	51.3	"m"
40	28.5	"m"
41	29.3	"m"
42	26.7	"m"
43	20.4	"m"
44	14.1	0

45	6.5	0
46	0	0
47	0	0
48	0	0
49	0	0
50	0	0
51	0	0
52	0	0
53	0	0
54	0	0
55	0	0
56	0	0
57	0	0
58	0	0
59	0	0
60	0	0
61	0	0
62	25.5	11.1
63	28.5	20.9
64	32	73.9
65	4	82.3
66	34.5	80.4
67	64.1	86
68	58	0
69	50.3	83.4
70	66.4	99.1
71	81.4	99.6
72	88.7	73.4
73	52.5	0
74	46.4	58.5
75	48.6	90.9
76	55.2	99.4
77	62.3	99
78	68.4	91.5
79	74.5	73.7
80	38	0
81	41.8	89.6
82	47.1	99.2
83	52.5	99.8
84	56.9	80.8
85	58.3	11.8
86	56.2	"m"
87	52	"m"
88	43.3	"m"
89	36.1	"m"
90	27.6	"m"
91	21.1	"m"
92	8	0
93	0	0
94	0	0

95	0	0
96	0	0
97	0	0
98	0	0
99	0	0
100	0	0
101	0	0
102	0	0
103	0	0
104	0	0
105	0	0
106	0	0
107	0	0
108	11.6	14.8
109	0	0
110	27.2	74.8
111	17	76.9
112	36	78
113	59.7	86
114	80.8	17.9
115	49.7	0
116	65.6	86
117	78.6	72.2
118	64.9	"m"
119	44.3	"m"
120	51.4	83.4
121	58.1	97
122	69.3	99.3
123	72	20.8
124	72.1	"m"
125	65.3	"m"
126	64	"m"
127	59.7	"m"
128	52.8	"m"
129	45.9	"m"
130	38.7	"m"
131	32.4	"m"
132	27	"m"
133	21.7	"m"
134	19.1	0.4
135	34.7	14
136	16.4	48.6
137	0	11.2
138	1.2	2.1
139	30.1	19.3
140	30	73.9
141	54.4	74.4
142	77.2	55.6
143	58.1	0
144	45	82.1

145	68.7	98.1
146	85.7	67.2
147	60.2	0
148	59.4	98
149	72.7	99.6
150	79.9	45
151	44.3	0
152	41.5	84.4
153	56.2	98.2
154	65.7	99.1
155	74.4	84.7
156	54.4	0
157	47.9	89.7
158	54.5	99.5
159	62.7	96.8
160	62.3	0
161	46.2	54.2
162	44.3	83.2
163	48.2	13.3
164	51	"m"
165	50	"m"
166	49.2	"m"
167	49.3	"m"
168	49.9	"m"
169	51.6	"m"
170	49.7	"m"
171	48.5	"m"
172	50.3	72.5
173	51.1	84.5
174	54.6	64.8
175	56.6	76.5
176	58	"m"
177	53.6	"m"
178	40.8	"m"
179	32.9	"m"
180	26.3	"m"
181	20.9	"m"
182	10	0
183	0	0
184	0	0
185	0	0
186	0	0
187	0	0
188	0	0
189	0	0
190	0	0
191	0	0
192	0	0
193	0	0
194	0	0

195	0	0
196	0	0
197	0	0
198	0	0
199	0	0
200	0	0
201	0	0
202	0	0
203	0	0
204	0	0
205	0	0
206	0	0
207	0	0
208	0	0
209	0	0
210	0	0
211	0	0
212	0	0
213	0	0
214	0	0
215	0	0
216	0	0
217	0	0
218	0	0
219	0	0
220	0	0
221	0	0
222	0	0
223	0	0
224	0	0
225	21.2	62.7
226	30.8	75.1
227	5.9	82.7
228	34.6	80.3
229	59.9	87
230	84.3	86.2
231	68.7	"m"
232	43.6	"m"
233	41.5	85.4
234	49.9	94.3
235	60.8	99
236	70.2	99.4
237	81.1	92.4
238	49.2	0
239	56	86.2
240	56.2	99.3
241	61.7	99
242	69.2	99.3
243	74.1	99.8
244	72.4	8.4

245	71.3	0
246	71.2	9.1
247	67.1	"m"
248	65.5	"m"
249	64.4	"m"
250	62.9	25.6
251	62.2	35.6
252	62.9	24.4
253	58.8	"m"
254	56.9	"m"
255	54.5	"m"
256	51.7	17
257	56.2	78.7
258	59.5	94.7
259	65.5	99.1
260	71.2	99.5
261	76.6	99.9
262	79	0
263	52.9	97.5
264	53.1	99.7
265	59	99.1
266	62.2	99
267	65	99.1
268	69	83.1
269	69.9	28.4
270	70.6	12.5
271	68.9	8.4
272	69.8	9.1
273	69.6	7
274	65.7	"m"
275	67.1	"m"
276	66.7	"m"
277	65.6	"m"
278	64.5	"m"
279	62.9	"m"
280	59.3	"m"
281	54.1	"m"
282	51.3	"m"
283	47.9	"m"
284	43.6	"m"
285	39.4	"m"
286	34.7	"m"
287	29.8	"m"
288	20.9	73.4
289	36.9	"m"
290	35.5	"m"
291	20.9	"m"
292	49.7	11.9
293	42.5	"m"
294	32	"m"

295	23.6	"m"
296	19.1	0
297	15.7	73.5
298	25.1	76.8
299	34.5	81.4
300	44.1	87.4
301	52.8	98.6
302	63.6	99
303	73.6	99.7
304	62.2	"m"
305	29.2	"m"
306	46.4	22
307	47.3	13.8
308	47.2	12.5
309	47.9	11.5
310	47.8	35.5
311	49.2	83.3
312	52.7	96.4
313	57.4	99.2
314	61.8	99
315	66.4	60.9
316	65.8	"m"
317	59	"m"
318	50.7	"m"
319	41.8	"m"
320	34.7	"m"
321	28.7	"m"
322	25.2	"m"
323	43	24.8
324	38.7	0
325	48.1	31.9
326	40.3	61
327	42.4	52.1
328	46.4	47.7
329	46.9	30.7
330	46.1	23.1
331	45.7	23.2
332	45.5	31.9
333	46.4	73.6
334	51.3	60.7
335	51.3	51.1
336	53.2	46.8
337	53.9	50
338	53.4	52.1
339	53.8	45.7
340	50.6	22.1
341	47.8	26
342	41.6	17.8
343	38.7	29.8
344	35.9	71.6

345	34.6	47.3
346	34.8	80.3
347	35.9	87.2
348	38.8	90.8
349	41.5	94.7
350	47.1	99.2
351	53.1	99.7
352	46.4	0
353	42.5	0.7
354	43.6	58.6
355	47.1	87.5
356	54.1	99.5
357	62.9	99
358	72.6	99.6
359	82.4	99.5
360	88	99.4
361	46.4	0
362	53.4	95.2
363	58.4	99.2
364	61.5	99
365	64.8	99
366	68.1	99.2
367	73.4	99.7
368	73.3	29.8
369	73.5	14.6
370	68.3	0
371	45.4	49.9
372	47.2	75.7
373	44.5	9
374	47.8	10.3
375	46.8	15.9
376	46.9	12.7
377	46.8	8.9
378	46.1	6.2
379	46.1	"m"
380	45.5	"m"
381	44.7	"m"
382	43.8	"m"
383	41	"m"
384	41.1	6.4
385	38	6.3
386	35.9	0.3
387	33.5	0
388	53.1	48.9
389	48.3	"m"
390	49.9	"m"
391	48	"m"
392	45.3	"m"
393	41.6	3.1
394	44.3	79

395	44.3	89.5
396	43.4	98.8
397	44.3	98.9
398	43	98.8
399	42.2	98.8
400	42.7	98.8
401	45	99
402	43.6	98.9
403	42.2	98.8
404	44.8	99
405	43.4	98.8
406	45	99
407	42.2	54.3
408	61.2	31.9
409	56.3	72.3
410	59.7	99.1
411	62.3	99
412	67.9	99.2
413	69.5	99.3
414	73.1	99.7
415	77.7	99.8
416	79.7	99.7
417	82.5	99.5
418	85.3	99.4
419	86.6	99.4
420	89.4	99.4
421	62.2	0
422	52.7	96.4
423	50.2	99.8
424	49.3	99.6
425	52.2	99.8
426	51.3	100
427	51.3	100
428	51.1	100
429	51.1	100
430	51.8	99.9
431	51.3	100
432	51.1	100
433	51.3	100
434	52.3	99.8
435	52.9	99.7
436	53.8	99.6
437	51.7	99.9
438	53.5	99.6
439	52	99.8
440	51.7	99.9
441	53.2	99.7
442	54.2	99.5
443	55.2	99.4
444	53.8	99.6

445	53.1	99.7
446	55	99.4
447	57	99.2
448	61.5	99
449	59.4	5.7
450	59	0
451	57.3	59.8
452	64.1	99
453	70.9	90.5
454	58	0
455	41.5	59.8
456	44.1	92.6
457	46.8	99.2
458	47.2	99.3
459	51	100
460	53.2	99.7
461	53.1	99.7
462	55.9	53.1
463	53.9	13.9
464	52.5	"m"
465	51.7	"m"
466	51.5	52.2
467	52.8	80
468	54.9	95
469	57.3	99.2
470	60.7	99.1
471	62.4	"m"
472	60.1	"m"
473	53.2	"m"
474	44	"m"
475	35.2	"m"
476	30.5	"m"
477	26.5	"m"
478	22.5	"m"
479	20.4	"m"
480	19.1	"m"
481	19.1	"m"
482	13.4	"m"
483	6.7	"m"
484	3.2	"m"
485	14.3	63.8
486	34.1	0
487	23.9	75.7
488	31.7	79.2
489	32.1	19.4
490	35.9	5.8
491	36.6	0.8
492	38.7	"m"
493	38.4	"m"
494	39.4	"m"

495	39.7	"m"
496	40.5	"m"
497	40.8	"m"
498	39.7	"m"
499	39.2	"m"
500	38.7	"m"
501	32.7	"m"
502	30.1	"m"
503	21.9	"m"
504	12.8	0
505	0	0
506	0	0
507	0	0
508	0	0
509	0	0
510	0	0
511	0	0
512	0	0
513	0	0
514	30.5	25.6
515	19.7	56.9
516	16.3	45.1
517	27.2	4.6
518	21.7	1.3
519	29.7	28.6
520	36.6	73.7
521	61.3	59.5
522	40.8	0
523	36.6	27.8
524	39.4	80.4
525	51.3	88.9
526	58.5	11.1
527	60.7	"m"
528	54.5	"m"
529	51.3	"m"
530	45.5	"m"
531	40.8	"m"
532	38.9	"m"
533	36.6	"m"
534	36.1	72.7
535	44.8	78.9
536	51.6	91.1
537	59.1	99.1
538	66	99.1
539	75.1	99.9
540	81	8
541	39.1	0
542	53.8	89.7
543	59.7	99.1
544	64.8	99

545	70.6	96.1
546	72.6	19.6
547	72	6.3
548	68.9	0.1
549	67.7	"m"
550	66.8	"m"
551	64.3	16.9
552	64.9	7
553	63.6	12.5
554	63	7.7
555	64.4	38.2
556	63	11.8
557	63.6	0
558	63.3	5
559	60.1	9.1
560	61	8.4
561	59.7	0.9
562	58.7	"m"
563	56	"m"
564	53.9	"m"
565	52.1	"m"
566	49.9	"m"
567	46.4	"m"
568	43.6	"m"
569	40.8	"m"
570	37.5	"m"
571	27.8	"m"
572	17.1	0.6
573	12.2	0.9
574	11.5	1.1
575	8.7	0.5
576	8	0.9
577	5.3	0.2
578	4	0
579	3.9	0
580	0	0
581	0	0
582	0	0
583	0	0
584	0	0
585	0	0
586	0	0
587	8.7	22.8
588	16.2	49.4
589	23.6	56
590	21.1	56.1
591	23.6	56
592	46.2	68.8
593	68.4	61.2
594	58.7	"m"

595	31.6	"m"
596	19.9	8.8
597	32.9	70.2
598	43	79
599	57.4	98.9
600	72.1	73.8
601	53	0
602	48.1	86
603	56.2	99
604	65.4	98.9
605	72.9	99.7
606	67.5	"m"
607	39	"m"
608	41.9	38.1
609	44.1	80.4
610	46.8	99.4
611	48.7	99.9
612	50.5	99.7
613	52.5	90.3
614	51	1.8
615	50	"m"
616	49.1	"m"
617	47	"m"
618	43.1	"m"
619	39.2	"m"
620	40.6	0.5
621	41.8	53.4
622	44.4	65.1
623	48.1	67.8
624	53.8	99.2
625	58.6	98.9
626	63.6	98.8
627	68.5	99.2
628	72.2	89.4
629	77.1	0
630	57.8	79.1
631	60.3	98.8
632	61.9	98.8
633	63.8	98.8
634	64.7	98.9
635	65.4	46.5
636	65.7	44.5
637	65.6	3.5
638	49.1	0
639	50.4	73.1
640	50.5	"m"
641	51	"m"
642	49.4	"m"
643	49.2	"m"
644	48.6	"m"

645	47.5	"m"
646	46.5	"m"
647	46	11.3
648	45.6	42.8
649	47.1	83
650	46.2	99.3
651	47.9	99.7
652	49.5	99.9
653	50.6	99.7
654	51	99.6
655	53	99.3
656	54.9	99.1
657	55.7	99
658	56	99
659	56.1	9.3
660	55.6	"m"
661	55.4	"m"
662	54.9	51.3
663	54.9	59.8
664	54	39.3
665	53.8	"m"
666	52	"m"
667	50.4	"m"
668	50.6	0
669	49.3	41.7
670	50	73.2
671	50.4	99.7
672	51.9	99.5
673	53.6	99.3
674	54.6	99.1
675	56	99
676	55.8	99
677	58.4	98.9
678	59.9	98.8
679	60.9	98.8
680	63	98.8
681	64.3	98.9
682	64.8	64
683	65.9	46.5
684	66.2	28.7
685	65.2	1.8
686	65	6.8
687	63.6	53.6
688	62.4	82.5
689	61.8	98.8
690	59.8	98.8
691	59.2	98.8
692	59.7	98.8
693	61.2	98.8
694	62.2	49.4

695	62.8	37.2
696	63.5	46.3
697	64.7	72.3
698	64.7	72.3
699	65.4	77.4
700	66.1	69.3
701	64.3	"m"
702	64.3	"m"
703	63	"m"
704	62.2	"m"
705	61.6	"m"
706	62.4	"m"
707	62.2	"m"
708	61	"m"
709	58.7	"m"
710	55.5	"m"
711	51.7	"m"
712	49.2	"m"
713	48.8	40.4
714	47.9	"m"
715	46.2	"m"
716	45.6	9.8
717	45.6	34.5
718	45.5	37.1
719	43.8	"m"
720	41.9	"m"
721	41.3	"m"
722	41.4	"m"
723	41.2	"m"
724	41.8	"m"
725	41.8	"m"
726	43.2	17.4
727	45	29
728	44.2	"m"
729	43.9	"m"
730	38	10.7
731	56.8	"m"
732	57.1	"m"
733	52	"m"
734	44.4	"m"
735	40.2	"m"
736	39.2	16.5
737	38.9	73.2
738	39.9	89.8
739	42.3	98.6
740	43.7	98.8
741	45.5	99.1
742	45.6	99.2
743	48.1	99.7
744	49	100

745	49.8	99.9
746	49.8	99.9
747	51.9	99.5
748	52.3	99.4
749	53.3	99.3
750	52.9	99.3
751	54.3	99.2
752	55.5	99.1
753	56.7	99
754	61.7	98.8
755	64.3	47.4
756	64.7	1.8
757	66.2	"m"
758	49.1	"m"
759	52.1	46
760	52.6	61
761	52.9	0
762	52.3	20.4
763	54.2	56.7
764	55.4	59.8
765	56.1	49.2
766	56.8	33.7
767	57.2	96
768	58.6	98.9
769	59.5	98.8
770	61.2	98.8
771	62.1	98.8
772	62.7	98.8
773	62.8	98.8
774	64	98.9
775	63.2	46.3
776	62.4	"m"
777	60.3	"m"
778	58.7	"m"
779	57.2	"m"
780	56.1	"m"
781	56	9.3
782	55.2	26.3
783	54.8	42.8
784	55.7	47.1
785	56.6	52.4
786	58	50.3
787	58.6	20.6
788	58.7	"m"
789	59.3	"m"
790	58.6	"m"
791	60.5	9.7
792	59.2	9.6
793	59.9	9.6
794	59.6	9.6

795	59.9	6.2
796	59.9	9.6
797	60.5	13.1
798	60.3	20.7
799	59.9	31
800	60.5	42
801	61.5	52.5
802	60.9	51.4
803	61.2	57.7
804	62.8	98.8
805	63.4	96.1
806	64.6	45.4
807	64.1	5
808	63	3.2
809	62.7	14.9
810	63.5	35.8
811	64.1	73.3
812	64.3	37.4
813	64.1	21
814	63.7	21
815	62.9	18
816	62.4	32.7
817	61.7	46.2
818	59.8	45.1
819	57.4	43.9
820	54.8	42.8
821	54.3	65.2
822	52.9	62.1
823	52.4	30.6
824	50.4	"m"
825	48.6	"m"
826	47.9	"m"
827	46.8	"m"
828	46.9	9.4
829	49.5	41.7
830	50.5	37.8
831	52.3	20.4
832	54.1	30.7
833	56.3	41.8
834	58.7	26.5
835	57.3	"m"
836	59	"m"
837	59.8	"m"
838	60.3	"m"
839	61.2	"m"
840	61.8	"m"
841	62.5	"m"
842	62.4	"m"
843	61.5	"m"
844	63.7	"m"

845	61.9	"m"
846	61.6	29.7
847	60.3	"m"
848	59.2	"m"
849	57.3	"m"
850	52.3	"m"
851	49.3	"m"
852	47.3	"m"
853	46.3	38.8
854	46.8	35.1
855	46.6	"m"
856	44.3	"m"
857	43.1	"m"
858	42.4	2.1
859	41.8	2.4
860	43.8	68.8
861	44.6	89.2
862	46	99.2
863	46.9	99.4
864	47.9	99.7
865	50.2	99.8
866	51.2	99.6
867	52.3	99.4
868	53	99.3
869	54.2	99.2
870	55.5	99.1
871	56.7	99
872	57.3	98.9
873	58	98.9
874	60.5	31.1
875	60.2	"m"
876	60.3	"m"
877	60.5	6.3
878	61.4	19.3
879	60.3	1.2
880	60.5	2.9
881	61.2	34.1
882	61.6	13.2
883	61.5	16.4
884	61.2	16.4
885	61.3	"m"
886	63.1	"m"
887	63.2	4.8
888	62.3	22.3
889	62	38.5
890	61.6	29.6
891	61.6	26.6
892	61.8	28.1
893	62	29.6
894	62	16.3

895	61.1	"m"
896	61.2	"m"
897	60.7	19.2
898	60.7	32.5
899	60.9	17.8
900	60.1	19.2
901	59.3	38.2
902	59.9	45
903	59.4	32.4
904	59.2	23.5
905	59.5	40.8
906	58.3	"m"
907	58.2	"m"
908	57.6	"m"
909	57.1	"m"
910	57	0.6
911	57	26.3
912	56.5	29.2
913	56.3	20.5
914	56.1	"m"
915	55.2	"m"
916	54.7	17.5
917	55.2	29.2
918	55.2	29.2
919	55.9	16
920	55.9	26.3
921	56.1	36.5
922	55.8	19
923	55.9	9.2
924	55.8	21.9
925	56.4	42.8
926	56.4	38
927	56.4	11
928	56.4	35.1
929	54	7.3
930	53.4	5.4
931	52.3	27.6
932	52.1	32
933	52.3	33.4
934	52.2	34.9
935	52.8	60.1
936	53.7	69.7
937	54	70.7
938	55.1	71.7
939	55.2	46
940	54.7	12.6
941	52.5	0
942	51.8	24.7
943	51.4	43.9
944	50.9	71.1

945	51.2	76.8
946	50.3	87.5
947	50.2	99.8
948	50.9	100
949	49.9	99.7
950	50.9	100
951	49.8	99.7
952	50.4	99.8
953	50.4	99.8
954	49.7	99.7
955	51	100
956	50.3	99.8
957	50.2	99.8
958	49.9	99.7
959	50.9	100
960	50	99.7
961	50.2	99.8
962	50.2	99.8
963	49.9	99.7
964	50.4	99.8
965	50.2	99.8
966	50.3	99.8
967	49.9	99.7
968	51.1	100
969	50.6	99.9
970	49.9	99.7
971	49.6	99.6
972	49.4	99.6
973	49	99.5
974	49.8	99.7
975	50.9	100
976	50.4	99.8
977	49.8	99.7
978	49.1	99.5
979	50.4	99.8
980	49.8	99.7
981	49.3	99.5
982	49.1	99.5
983	49.9	99.7
984	49.1	99.5
985	50.4	99.8
986	50.9	100
987	51.4	99.9
988	51.5	99.9
989	52.2	99.7
990	52.8	74.1
991	53.3	46
992	53.6	36.4
993	53.4	33.5
994	53.9	58.9

995	55.2	73.8
996	55.8	52.4
997	55.7	9.2
998	55.8	2.2
999	56.4	33.6
1000	55.4	"m"
1001	55.2	"m"
1002	55.8	26.3
1003	55.8	23.3
1004	56.4	50.2
1005	57.6	68.3
1006	58.8	90.2
1007	59.9	98.9
1008	62.3	98.8
1009	63.1	74.4
1010	63.7	49.4
1011	63.3	9.8
1012	48	0
1013	47.9	73.5
1014	49.9	99.7
1015	49.9	48.8
1016	49.6	2.3
1017	49.9	"m"
1018	49.3	"m"
1019	49.7	47.5
1020	49.1	"m"
1021	49.4	"m"
1022	48.3	"m"
1023	49.4	"m"
1024	48.5	"m"
1025	48.7	"m"
1026	48.7	"m"
1027	49.1	"m"
1028	49	"m"
1029	49.8	"m"
1030	48.7	"m"
1031	48.5	"m"
1032	49.3	31.3
1033	49.7	45.3
1034	48.3	44.5
1035	49.8	61
1036	49.4	64.3
1037	49.8	64.4
1038	50.5	65.6
1039	50.3	64.5
1040	51.2	82.9
1041	50.5	86
1042	50.6	89
1043	50.4	81.4
1044	49.9	49.9

1045	49.1	20.1
1046	47.9	24
1047	48.1	36.2
1048	47.5	34.5
1049	46.9	30.3
1050	47.7	53.5
1051	46.9	61.6
1052	46.5	73.6
1053	48	84.6
1054	47.2	87.7
1055	48.7	80
1056	48.7	50.4
1057	47.8	38.6
1058	48.8	63.1
1059	47.4	5
1060	47.3	47.4
1061	47.3	49.8
1062	46.9	23.9
1063	46.7	44.6
1064	46.8	65.2
1065	46.9	60.4
1066	46.7	61.5
1067	45.5	"m"
1068	45.5	"m"
1069	44.2	"m"
1070	43	"m"
1071	42.5	"m"
1072	41	"m"
1073	39.9	"m"
1074	39.9	38.2
1075	40.1	48.1
1076	39.9	48
1077	39.4	59.3
1078	43.8	19.8
1079	52.9	0
1080	52.8	88.9
1081	53.4	99.5
1082	54.7	99.3
1083	56.3	99.1
1084	57.5	99
1085	59	98.9
1086	59.8	98.9
1087	60.1	98.9
1088	61.8	48.3
1089	61.8	55.6
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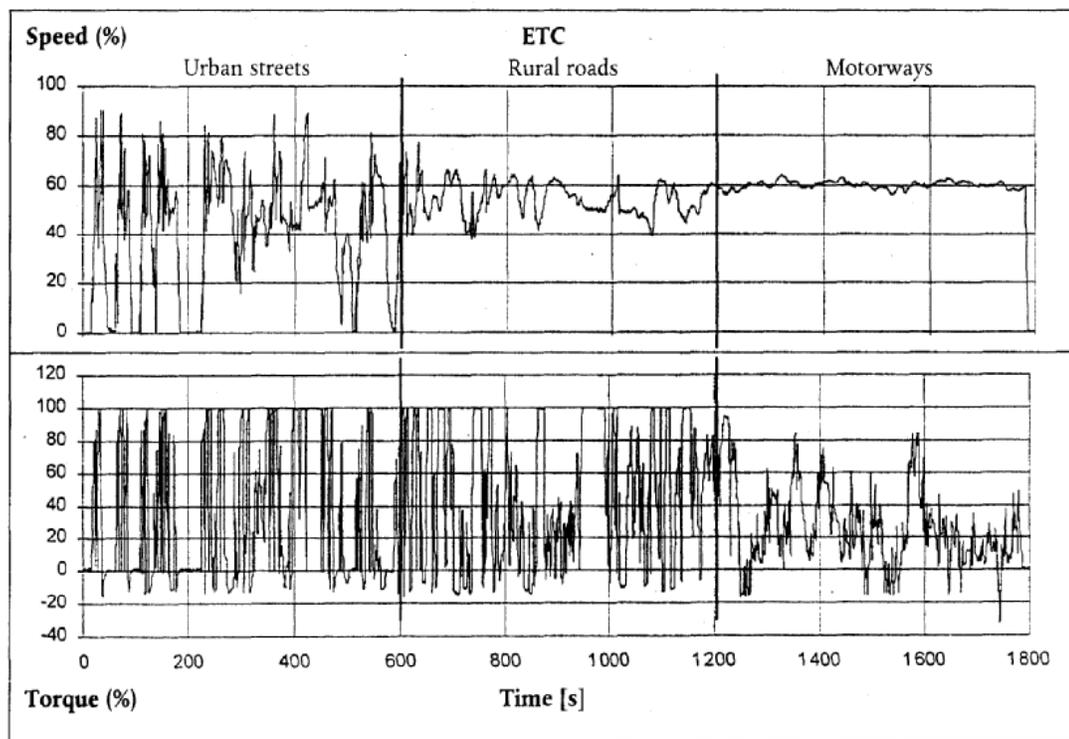
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1789	0	0
1790	0	0
1791	0	0
1792	0	0
1793	0	0
1794	0	0

1795	0	0
1796	0	0
1797	0	0
1798	0	0
1799	0	0
1800	0	0
"m" = motoring		

A graphical display of the ETC dynamometer schedule is shown in figure 5.

Figure 5
ETC dynamometer schedule



Appendix 4

MEASUREMENT AND SAMPLING PROCEDURES

1. INTRODUCTION

Gaseous components, particulates, and smoke emitted by the engine submitted for testing shall be measured by the methods described in Appendix 7. The respective paragraphs of Appendix 7 describe the recommended analytical systems for the gaseous emissions (paragraph 1.), the recommended particulate dilution and sampling systems (paragraph 2.), and the recommended opacimeters for smoke measurement (paragraph 3.).

For the ESC, the gaseous components shall be determined in the raw exhaust gas. Optionally, they may be determined in the diluted exhaust gas, if a full flow dilution system is used for particulate determination. Particulates shall be determined with either a partial flow or a full flow dilution system.

For the ETC, the following systems may be used:

- (a) a CVS full flow dilution system for determining gaseous and particulate emissions (double dilution systems are permissible), or,
- (b) a combination of raw exhaust measurement for the gaseous emissions and a partial flow dilution system for particulate emissions, or,
- (c) any combination of the two principles (e.g. raw gaseous measurement and full flow particulate measurement).

2. DYNAMOMETER AND TEST CELL EQUIPMENT

The following equipment shall be used for emission tests of engines on engine dynamometers.

2.1. Engine dynamometer

An engine dynamometer shall be used with adequate characteristics to perform the test cycles described in Appendices 1 and 2 to this annex. The speed measuring system shall have an accuracy of ± 2 per cent of reading. The torque measuring system shall have an accuracy of ± 3 per cent of reading in the range > 20 per cent of full scale, and an accuracy of $\pm 0,6$ per cent of full scale in the range ≤ 20 per cent of full scale.

2.2. Other instruments

Measuring instruments for fuel consumption, air consumption, temperature of coolant and lubricant, exhaust gas pressure and intake manifold depression, exhaust gas temperature, air intake temperature, atmospheric pressure, humidity and fuel temperature shall be used, as required. These instruments shall satisfy the requirements given in table 9:

Table 9
Accuracy of measuring instruments

Measuring instrument	Accuracy
Fuel consumption	± 2 per cent of engine's maximum value
Air consumption	± 2 per cent of reading or ± 1 per cent of engine's maximum value whichever is greater
Exhaust gas flow	± 2.5 per cent of reading or ± 1.5 per cent of engine's maximum value whichever is greater
Temperatures ≤ 600 K (327 °C)	± 2 K absolute
Temperatures ≥ 600 K (327 °C)	± 1 per cent of reading
Atmospheric pressure	± 0.1 kPa absolute
Exhaust gas pressure	± 0.2 kPa absolute
Intake depression	± 0.05 kPa absolute
Other pressures	± 0.1 kPa absolute
Relative humidity	± 3 per cent absolute
Absolute humidity	± 5 per cent of reading
Dilution air flow	± 2 per cent of reading
Diluted exhaust gas flow	± 2 per cent of reading

3. DETERMINATION OF THE GASEOUS COMPONENTS

3.1. General analyzer specifications

The analyzers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (paragraph 3.1.1.). It is recommended that the analyzers be operated such that the measured concentration falls between 15 per cent and 100 per cent of full scale.

If read-out systems (computers, data loggers) can provide sufficient accuracy and resolution below 15 per cent of full scale, measurements below 15 per cent of full scale are also acceptable. In this case, additional calibrations of at least 4 non-zero nominally equally spaced points are to be made to ensure the accuracy of the calibration curves according to paragraph 1.6.4. of Appendix 5 to this annex.

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

3.1.1. Accuracy

The analyzer shall not deviate from the nominal calibration point by more than ± 2 per cent of the reading over the whole measurement range except zero, or ± 0,3 per cent of full scale whichever is larger. The accuracy shall be determined according to the calibration requirements laid down in paragraph 1.6. of Appendix 5 to this annex.

NOTE: For the purpose of this Regulation, accuracy is defined as the deviation of the analyzer reading from the nominal calibration values using a calibration gas (= true value).

3.1.2. Precision

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, has to be not greater than ± 1 per cent of full scale concentration for each range used above 155 ppm (or ppmC) or ± 2 per cent of each range used below 155 ppm (or ppmC).

3.1.3. Noise

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

3.1.4. Zero drift

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

3.1.5. Span drift

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

3.1.6. Rise time

The rise time of the analyzer installed in the measurement system shall not exceed 3.5 s.

NOTE: Only evaluating the response time of the analyzer alone will not clearly define the suitability of the total system for transient testing. Volumes and especially dead volumes through out the system will not only effect the transportation time from the probe to the analyzer, but also effect the rise time. Also transport times inside of an analyzer would be defined as analyzer response time, like the converter or water traps inside NO_x analyzers. The determination of the total system response time is described in paragraph 1.5. of Appendix 5 to this annex.

3.2. Gas drying

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

3.3. Analyzers

Paragraphs 3.3.1 to 3.3.4 describe the measurement principles to be used. A detailed description of the measurement systems is given in Appendix 7. The gases to be measured shall be analysed with the following instruments. For non-linear analyzers, the use of linearizing circuits is permitted.

3.3.1. Carbon monoxide (CO) analysis

The carbon monoxide analyzer shall be of the Non-Dispersive InfraRed (NDIR) absorption type.

3.3.2. Carbon dioxide (CO₂) analysis

The carbon dioxide analyzer shall be of the Non-Dispersive InfraRed (NDIR) absorption type.

3.3.3. Hydrocarbon (HC) analysis

For diesel and LPG fuelled gas engines, the hydrocarbon analyzer shall be of the Heated Flame Ionisation Detector (HFID) type with detector, valves, pipework, etc. heated so as to maintain a gas temperature of $463\text{ K} \pm 10\text{ K}$ ($190 \pm 10\text{ }^\circ\text{C}$). For NG fuelled gas engines, the hydrocarbon analyzer may be of the non heated Flame Ionisation Detector (FID) type depending upon the method used (see paragraph 1.3. of Appendix 7).

3.3.4. Non-Methane Hydrocarbon (NMHC) analysis (NG fuelled gas engines only)

Non-methane hydrocarbons shall be determined by either of the following methods:

3.3.4.1. Gas chromatographic (GC) method

Non-methane hydrocarbons shall be determined by subtraction of the methane analysed with a Gas Chromatograph (GC) conditioned at 423 K ($150\text{ }^\circ\text{C}$) from the hydrocarbons measured according to paragraph 3.3.3.

3.3.4.2. Non-Methane Cutter (NMC) method

The determination of the non-methane fraction shall be performed with a heated NMC operated in line with an FID as per paragraph 3.3.3. by subtraction of the methane from the hydrocarbons.

3.3.5. Oxides of nitrogen (NO_x) analysis

The oxides of nitrogen analyzer shall be of the ChemiLuminescent Detector (CLD) or Heated ChemiLuminescent Detector (HCLD) type with a NO₂/NO converter, if measured on a dry basis. If measured on a wet basis, a HCLD with converter maintained above 328 K (55 °C) shall be used, provided the water quench check (see paragraph 1.9.2.2. of Appendix 5 to this annex) is satisfied.

3.3.6. Air-to-fuel measurement

The air to fuel measurement equipment used to determine the exhaust gas flow as specified in paragraph 4.2.5. of Appendix 2 to this annex shall be a wide range air to fuel ratio sensor or lambda sensor of Zirconia type. The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.

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

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

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

3.4. Sampling of gaseous emissions

3.4.1. Raw exhaust gas

The gaseous emissions sampling probes shall be fitted at least 0.5 m or 3 times the diameter of the exhaust pipe - whichever is the larger - upstream of the exit of the exhaust gas system but sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70°C) at the probe.

In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest CO₂ 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.

3.4.2. Diluted exhaust gas

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements of paragraph 2.3.1. of Appendix 7 (EP).

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:

- (a) the pollutants are sampled into a sampling bag over the cycle and measured after completion of the test;
- (b) the pollutants are sampled continuously and integrated over the cycle; this method is mandatory for HC and NO_x.

4. DETERMINATION OF THE PARTICULATES

The determination of the particulates requires a dilution system. Dilution may be accomplished by a partial flow dilution system or a full flow double dilution system. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems. The temperature of the diluted exhaust gas shall be below 325 K (52 °C) immediately upstream of the filter holders. Humidity control of the dilution air before entering the dilution system is permitted, and especially dehumidifying is useful if dilution air humidity is high. The temperature of the dilution air shall be higher than 288 K (15 °C) in close proximity to the entrance into the dilution tunnel.

The partial flow dilution system has to be designed to extract a proportional raw exhaust sample from the engine exhaust stream, thus responding to excursions in the exhaust stream flow rate, and introduce dilution air to this sample to achieve a temperature of below 325 K (52 °C) at the test filter. For this it is essential that the dilution ratio or the sampling ratio r_{dil} or r_s be determined such that the accuracy limits of paragraph 3.2.1. of Appendix 5 to this annex 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 (paragraph 2.2. of Appendix 7).

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 paragraph 3.4.1. also apply to particulate sampling. The sampling line shall conform to the requirements of paragraph 2. of Appendix 7.

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.

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

For particulate sampling, the single filter method shall be applied which uses one filter (see paragraph 4.1.3. of this appendix) for the whole test cycle. For the ESC, considerable attention shall be paid to sampling times and flows during the sampling phase of the test.

4.1 Particulate sampling filters

The diluted exhaust shall be sampled by a filter that meets the requirements of paragraphs 4.1.1. and 4.1.2. during the test sequence.

4.1.1. Filter specification

Fluorocarbon coated glass fiber filters are required. All filter types shall have a 0.3 μm DOP (di-octylphthalate) collection efficiency of at least 99 per cent at a gas face velocity between 35 and 100 cm/s.

4.1.2. Filter size

Particulate filters with a diameter of 47 mm or 70 mm are recommended. Larger diameter filters are acceptable (paragraph 4.1.4.), but smaller diameter filters are not permitted.

4.1.3. 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.

4.1.4. Filter loading

The required minimum filter loadings for the most common filter sizes are shown in table 10. For larger filter sizes, the minimum filter loading shall be 0.065 mg/1,000 mm² filter area.

Table 10
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 optimisation of flow rates and dilution ratio, a lower filter loading may be acceptable, with the agreement of the parties involved (manufacturer and approval authority), if it can be shown to meet the accuracy requirements of paragraph 4.2., e.g. with a 0.1 µg balance.

4.1.5. Filter holder

For the emissions test, the filters shall be placed in a filter holder assembly meeting the requirements of paragraph 2.2. of Appendix 7. The filter holder assembly shall be of a design that provides an even flow distribution across the filter stain area. Quick acting valves shall be located either upstream or downstream of the filter holder. An inertial pre-classifier with a 50 per cent cut point between 2.5 µm and 10 µm may be installed immediately upstream of the filter holder. The use of the pre-classifier is strongly recommended if an open tube sampling probe facing upstream into the exhaust flow is used.

4.2 Weighing chamber and analytical balance specifications

4.2.1. 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 per cent ± 8 per cent.

4.2.2. Reference filter weighing

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilisation. Disturbances to weighing room specifications as outlined in paragraph 4.2.1. will be allowed if the duration of the disturbances does not exceed 30 minutes. The weighing room should meet the required specifications prior to personal entrance into the weighing room. At least two unused reference filters shall be weighed within 4 hours of, but preferably at

the same time as the sample filter weightings. They shall be the same size and material as the sample filters.

If the average weight of the reference filters changes between sample filter weightings 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 paragraph 4.2.1. is not met, but the reference filter weightings meet the above criteria, the engine manufacturer has the option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system and re-running the test.

4.2.3. 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.

4.2.4. Elimination of static electricity effects

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

4.2.5. Specifications for flow measurement

4.2.5.1. General requirements

Absolute accuracies of flow meter or flow measurement instrumentation shall be as specified in paragraph 2.2.

4.2.5.2. 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:

$$q_{mp} = q_{mdew} - q_{mdw}$$

In this case an accuracy of ± 2 per cent 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 ± 5 per cent when the dilution ratio is less than 15. It can be calculated by taking root-mean-square of the errors of each instrument.

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

The absolute accuracies of q_{mdew} and q_{mdw} are ± 0.2 per cent which guarantees an accuracy of q_{mp} of ≤ 5 per cent 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 paragraph 3.2.1. of Appendix 5 to this annex;

The accuracy of q_{mp} is determined indirectly from the accuracy of the dilution ratio as determined by a tracer gas, e.g. CO_2 . Again, accuracies equivalent to method a) for q_{mp} are required;

The absolute accuracy of q_{mdew} and q_{mdw} is within ± 2 per cent of full scale, the maximum error of the difference between q_{mdew} and q_{mdw} is within 0.2 per cent, and the linearity error is within ± 0.2 per cent of the highest q_{mdew} observed during the test.

5. DETERMINATION OF SMOKE

This paragraph provides specifications for the required and optional test equipment to be used for the ELR test. The smoke shall be measured with an opacimeter having an opacity and a light absorption coefficient readout mode. The opacity readout mode shall only be used for calibration and checking of the opacimeter. The smoke values of the test cycle shall be measured in the light absorption coefficient readout mode.

5.1. General requirements

The ELR requires the use of a smoke measurement and data processing system which includes three functional units. These units may be integrated into a single component or provided as a system of interconnected components. The three functional units are:

- (a) An opacimeter meeting the specifications of Appendix 7, paragraph 3.
- (b) A data processing unit capable of performing the functions described in paragraph 6. of Appendix 1 to this Annex
- (c) A printer and/or electronic storage medium to record and output the required smoke values specified in paragraph 6.3 of Appendix 1 to this Annex.

5.2. Specific requirements

5.2.1 Linearity

The linearity shall be within ± 2 per cent opacity.

5.2.2 Zero Drift

The zero drift during a one hour period shall not exceed ± 1 per cent opacity.

5.2.3. Opacimeter Display and Range

For display in opacity, the range shall be 0-100 per cent opacity, and the readability 0.1 per cent opacity. For display in light absorption coefficient, the range shall be 0-30 m^{-1} light absorption coefficient, and the readability 0.01 m^{-1} light absorption coefficient.

5.2.4. Instrument response time

The physical response time of the opacimeter shall not exceed 0.2 s. The physical response time is the difference between the times when the output of a rapid response receiver reaches 10 and 90 per cent of the full deviation when the opacity of the gas being measured is changed in less than 0.1 s.

The electrical response time of the opacimeter shall not exceed 0.05 s. The electrical response time is the difference between the times when the opacimeter output reaches 10 and 90 per cent of the full scale when the light source is interrupted or completely extinguished in less than 0.01 s.

5.2.5. Neutral density filters

Any neutral density filter used in conjunction with opacimeter calibration, linearity measurements, or setting span shall have its value known to within 1.0 per cent opacity. The filter's nominal value shall be checked for accuracy at least yearly using a reference traceable to a national or international standard.

Neutral density filters are precision devices and can easily be damaged during use. Handling should be minimized and, when required, should be done with care to avoid scratching or soiling of the filter.

Appendix 5

CALIBRATION PROCEDURE

1. CALIBRATION OF THE ANALYTICAL INSTRUMENTS

1.1. Introduction

Each analyzer shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method that shall be used is described in this paragraph for the analyzers indicated in Appendix 4, paragraph 3. and Appendix 7, paragraph 1.

1.2. Calibration Gases

The shelf life of all calibration gases shall be respected.

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

1.2.1. Pure Gases

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

Purified nitrogen

(Contamination ≤ 1 ppm C1, ≤ 1 ppm CO, ≤ 400 ppm CO₂, ≤ 0.1 ppm NO)

Purified oxygen

(Purity > 99.5 per cent vol O₂)

Hydrogen-helium mixture

(40 ± 2 per cent hydrogen, balance helium)

(Contamination ≤ 1 ppm C1, ≤ 400 ppm CO₂)

Purified synthetic air

(Contamination ≤ 1 ppm C1, ≤ 1 ppm CO, ≤ 400 ppm CO₂, ≤ 0.1 ppm NO)

(Oxygen content between 18-21 per cent vol.)

Purified propane or CO for the CVS verification

1.2.2. Calibration and Span Gases

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

C₃H₈ and purified synthetic air (see paragraph 1.2.1.);

CO and purified nitrogen;

NO_x and purified nitrogen (the amount of NO₂ contained in this calibration gas shall not exceed 5 per cent of the NO content);

CO₂ and purified nitrogen

CH₄ and purified synthetic air

C₂H₆ and purified synthetic air

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

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

The gases used for calibration and span may also be obtained by means of a gas divider, diluting with purified N₂ or with purified synthetic air. The accuracy of the mixing device shall be such that the concentration of the diluted calibration gases may be determined to within ± 2 per cent.

1.2.3. Use of precision blending devices

The gases used for calibration and span may also be obtained by means of precision blending devices (gas dividers), diluting with purified N₂ or with purified synthetic air. The accuracy of the mixing device shall be such that the concentration of the blended calibration gases is accurate to within ± 2 per cent. This accuracy implies that primary gases used for blending shall be known to an accuracy of at least ± 1 per cent, traceable to national or international gas standards. The verification shall be performed at between 15 and 50 per cent of full scale for each calibration incorporating a blending device.

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

1.3. Operating Procedure for Analyzers and Sampling System

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

1.4. Leakage test

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

The maximum allowable leakage rate on the vacuum side shall be 0.5 per cent of the in-use flow rate for the portion of the system being checked. The analyzer flows and bypass flows may be used to estimate the in-use flow rates.

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

$$\Delta p = p / V_s \times 0.005 \times q_{vs}$$

where:

V_s = system volume, l

q_{vs} = system flow rate, l/min

Another method is the introduction of a concentration step change at the beginning of the sampling line by switching from zero to span gas. If after an adequate period of time the reading is about 1 per cent low compared to the introduced concentration, these points to calibration or leakage problems.

1.5. Response time check of analytical system

The system settings for the response time evaluation shall be exactly the same as during measurement of the test run (i.e. pressure, flow rates, filter settings on the analyzers and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0.1 second. The gases used for the test shall cause a concentration change of at least 60 per cent 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 per cent of the final reading (t_{10}). The rise time is defined as the time between 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$).

For time alignment of the analyzer 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 per cent of the final reading (t_{50}).

The system response time shall be ≤ 10 seconds with a rise time ≤ 3.5 seconds for all limited components (CO, NO_x, HC or NMHC) and all ranges used.

1.6. Calibration

1.6.1. Instrument assembly

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

1.6.2. Warming-up time

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

1.6.3. NDIR and HFID analyzer

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

1.6.4. Establishment of the calibration curve

- (a) Each normally used operating range shall be calibrated;
- (b) Using purified synthetic air (or nitrogen), the CO, CO₂, NO_x and HC analyzers shall be set at zero;
- (c) The appropriate calibration gases shall be introduced to the analyzers, the values recorded, and the calibration curve established;
- (d) The calibration curve shall be established by at least 6 calibration points (excluding zero) approximately equally spaced over the operating range. The highest nominal concentration shall be equal to or higher than 90 per cent of full scale;
- (e) The calibration curve shall be calculated by the method of least-squares. A best-fit linear or non-linear equation may be used;
- (f) The calibration points shall not differ from the least-squares best-fit line by more than ± 2 per cent of reading or ± 0.3 per cent of full scale whichever is larger;
- (g) The zero setting shall be rechecked and the calibration procedure repeated, if necessary.

1.6.5. Alternative methods

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

1.6.6. Calibration of tracer gas analyzer for exhaust flow measurement

The calibration curve shall be established by at least 6 calibration points (excluding zero) approximately equally spaced over the operating range. The highest nominal concentration shall be equal to or higher than 90 per cent of full scale. The calibration curve is calculated by the method of least squares.

The calibration points shall not differ from the least-squares best-fit line by more than ± 2 per cent of reading or ± 0.3 per cent of full scale whichever is larger.

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

1.6.7. Verification of the calibration

Each normally used operating range shall be checked prior to each analysis 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 per cent of full scale of the measuring range.

If, for the two points considered, the value found does not differ by more than ± 4 per cent of full scale from the declared reference value, the adjustment parameters may be modified. Should this not be the case, a new calibration curve shall be established in accordance with paragraph 1.5.5.

1.7. Efficiency test of the NO_x converter

The efficiency of the converter used for the conversion of NO₂ into NO shall be tested as given in paragraphs 1.7.1. to 1.7.8. (figure 6).

1.7.1. Test set-up

Using the test set-up as shown in figure 6 (see also Appendix 4, paragraph 3.3.5. to this annex) and the procedure below, the efficiency of converters can be tested by means of an ozonator.

1.7.2. Calibration

The CLD and the HCLD shall be calibrated in the most common operating range following the manufacturer's specifications using zero and span gas (the NO content of which shall amount to about 80 per cent of the operating range and the NO₂ concentration of the gas mixture to less than 5 per cent of the NO concentration). The NO_x analyzer shall be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

1.7.3. Calculation

The efficiency of the NO_x converter is calculated as follows:

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

where,

- a is the NO_x concentration according to paragraph 1.7.6.
- b is the NO_x concentration according to paragraph 1.7.7.
- c is the NO concentration according to paragraph 1.7.4.
- d is the NO concentration according to paragraph 1.7.5.

1.7.4. Adding of oxygen

Via a T-fitting, oxygen or zero air is added continuously to the gas flow until the concentration indicated is about 20 per cent less than the indicated calibration concentration given in paragraph 1.7.2. (the analyzer is in the NO mode). The indicated concentration c shall be recorded. The ozonator is kept deactivated throughout the process.

1.7.5. Activation of the ozonator

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

1.7.6. NO_x mode

The NO analyzer is then switched to the NO_x mode so that the gas mixture (consisting of NO, NO₂, O₂ and N₂) now passes through the converter. The indicated concentration "a" shall be recorded (the analyzer is in the NO_x mode).

1.7.7. Deactivation of the ozonator

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

1.7.8. NO mode

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

1.7.9. Test interval

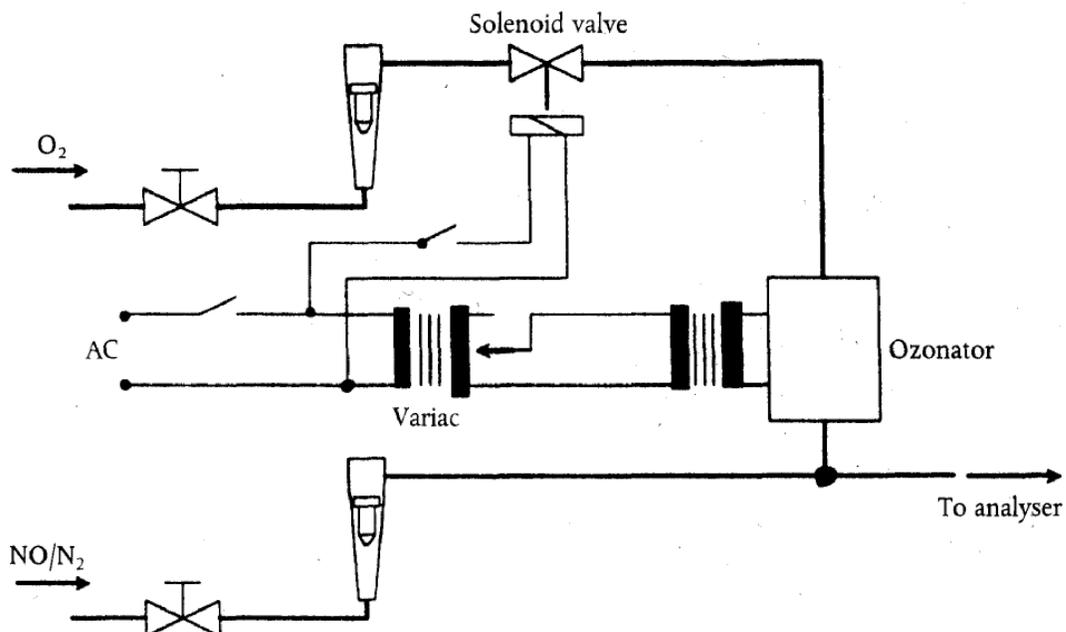
The efficiency of the converter shall be tested prior to each calibration of the NO_x analyzer.

1.7.10. Efficiency requirement

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

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

Figure 6
Schematic of NO_x converter efficiency device



1.8. Adjustment of the FID

1.8.1. Optimisation of the detector response

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

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

1.8.2. Hydrocarbon response factors

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

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

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

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

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

Propylene and purified synthetic air $0.90 \leq R_f \leq 1.10$

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

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

1.8.3. Oxygen interference check

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

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

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

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

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

1.8.4. Efficiency of the non-methane cutter (NMC, for NG fuelled gas engines only)

The NMC is used for the removal of the non-methane hydrocarbons from the sample gas by oxidizing all hydrocarbons except methane. Ideally, the conversion for methane is 0 per cent, and for the other hydrocarbons represented by ethane is 100 per cent. For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emission mass flow rate (see Annex III, Appendix 2, paragraph 4.3.).

1.8.4.1. Methane efficiency

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

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

where,

c_w = HC concentration with CH₄ flowing through the NMC
 $c_{w/o}$ = HC concentration with CH₄ bypassing the NMC

1.8.4.2. Ethane efficiency

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

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

where,

c_w = HC concentration with C₂H₆ flowing through the NMC
 $c_{w/o}$ = HC concentration with C₂H₆ bypassing the NMC

1.9. Interference effects with CO, CO₂, and NO_x analyzers

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

1.9.1. CO analyzer interference check

Water and CO₂ can interfere with the CO analyzer performance. Therefore, a CO₂ span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyzer response recorded. The analyzer response shall not be more than 1 per cent of full scale for ranges equal to or above 300 ppm or more than 3 ppm for ranges below 300 ppm.

1.9.2. NO_x analyzer quench checks

The two gases of concern for CLD (and HCLD) analyzers are CO₂ and water vapour. Quench responses to these gases are proportional to their concentrations, and therefore require test techniques to determine the quench at the highest expected concentrations experienced during testing.

1.9.2.1. CO₂ quench check

A CO₂ span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range shall be passed through the NDIR analyzer and the CO₂ value recorded as A. It shall then be diluted approximately 50 per cent with NO span gas and passed through the NDIR and (H)CLD, with the CO₂ and NO values recorded as B and C, respectively. The CO₂ shall then be shut off and only the NO span gas be passed through the (H)CLD and the NO value recorded as D.

The quench, which shall not be greater than 3 per cent of full scale, shall be calculated as follows:

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

with:

- A is the undiluted CO₂ concentration measured with NDIR in per cent
- B is the diluted CO₂ concentration measured with NDIR in per cent
- C is the diluted NO concentration measured with (H)CLD in ppm
- D is the undiluted NO concentration measured with (H)CLD in ppm

Alternative methods of diluting and quantifying of CO₂ and NO span gas values such as dynamic mixing/blending can be used.

1.9.2.2. Water quench check

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

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

$$H = 100 \times (G/E)$$

The expected diluted NO span gas (in water vapour) concentration (D_e) shall be calculated as follows:

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

For diesel exhaust, the maximum exhaust water vapour concentration (H_m , in per cent) expected during testing shall be estimated, under the assumption of a fuel atom H/C ratio of 1.8:1, from the undiluted CO₂ span gas concentration (A , as measured in paragraph 1.9.2.1.) as follows:

$$H_m = 0.9 \times A$$

The water quench, which shall not be greater than 3 per cent, shall be calculated as follows:

$$\text{per cent quench} = 100 \times ((D_e - C)/D_e) \times (H_m/H)$$

where

D_e = is the expected diluted NO concentration in ppm

C = is the diluted NO concentration in ppm

H_m = is the maximum water vapour concentration in per cent

H = is the actual water vapour concentration in per cent

Note: It is important that the NO span gas contains minimal NO₂ concentration for this check, since absorption of NO₂ in water has not been accounted for in the quench calculations.

1.10. Calibration intervals

The analyzers shall be calibrated according to paragraph 1.5. at least every 3 months or whenever a system repair or change is made that could influence calibration.

2. CALIBRATION OF THE CVS-SYSTEM

2.1. General

The CVS system shall be calibrated by using an accurate flowmeter traceable to national or international standards 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 types of flowmeters may be used, e.g. calibrated venturi, calibrated laminar flowmeter, calibrated turbinometer.

2.2. Calibration of the positive displacement pump (PDP)

All parameters related to the pump shall be simultaneously measured with the parameters related to the flowmeter which is connected in series with the pump. The calculated flow rate (in m³/min at pump inlet, absolute pressure and temperature) shall be plotted versus a correlation function which is the value of a specific combination of pump parameters. The linear equation which relates the pump flow and the correlation function shall then be determined. If a CVS has a multiple speed drive, the calibration shall be performed for each range used. Temperature stability shall be maintained during calibration.

2.2.1. Data analysis

The air flowrate (Q_s) at each restriction setting (minimum 6 settings) shall be calculated in standard m³/min from the flowmeter data using the manufacturer's prescribed method. The air flow rate shall then be converted to pump flow (V_0) in m³/rev at absolute pump inlet temperature and pressure as follows:

$$V_0 = \frac{q_{vCVS}}{n} \times \frac{T}{273} \times \frac{101.3}{p_p}$$

where,

- q_{vCVS} = air flow rate at standard conditions (101.3 kPa, 273 K),
m³/s
- T = temperature at pump inlet, K
- p_p = absolute pressure at pump inlet ($p_B - p_1$), kPa
- n = pump speed, rev/s

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

$$X_0 = \frac{1}{n} \times \sqrt{\frac{\Delta p_p}{p_p}}$$

where,

- Δp_p = pressure differential from pump inlet to pump outlet, kPa
- p_p = absolute outlet pressure at pump outlet, kPa

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

$$V_0 = D_0 - m \times X_0$$

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

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

The calculated values from the equation shall be within $\pm 0,5$ per cent of the measured value of V_0 . Values of m will vary from one pump to another. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for m . Therefore, calibration shall be performed at pump start-up, after major maintenance, and if the total system verification (paragraph 2.4.) indicates a change of the slip rate.

2.3. Calibration of the critical flow venturi (CFV)

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

2.3.1. Data analysis

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

$$K_v = \frac{q_{v, CVS} \times \sqrt{T}}{p_p}$$

where,

$q_{v, CVS}$	= air flow rate at standard conditions (101.3 kPa, 273 K), m^3/s
T	= temperature at the venturi inlet, K
p_p	= absolute pressure at venturi inlet, kPa

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

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

2.4. Calibration of the subsonic venturi (SSV)

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

2.4.1. Data analysis

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

$$Q_{SSV} = A_0 d^2 C_d P_p \sqrt{\left[\frac{1}{T} (r_p^{1.4286} - r_p^{1.7143}) \cdot \left(\frac{1}{1 - r_D^4 r_p^{1.4286}} \right) \right]}$$

where:

- Q_{SSV} = air flow rate at standard conditions (101.3 kPa, 273 K), m^3/s
 T = temperature at the venturi inlet, K
 d = diameter of the SSV throat, m
 r_p = ratio of the SSV throat to inlet absolute, static pressure = $1 - \frac{\Delta p}{P_p}$
 r_D = ratio of the SSV throat diameter, d , to the inlet pipe inner diameter D

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

$$Re = A_1 \frac{Q_{SSV}}{d\mu}$$

where:

- A_1 = a collection of constants and units conversions
 $= 25.55152 \left(\frac{1}{m^3} \right) \left(\frac{min}{s} \right) \left(\frac{mm}{m} \right)$
 Q_{SSV} = air flow rate at standard conditions (101.3 kPa, 273 K), m^3/s
 d = diameter of the SSV throat, m
 μ = absolute or dynamic viscosity of the gas, calculated with the following formula:

$$\mu = \frac{b \times T^{1.5}}{S + T} \text{ kg/m-s}$$

 b = empirical constant = 1.458×10^6 , $kg/ms K^{0.5}$
 S = empirical constant = 110.4 K

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

For a minimum of sixteen points in the region of subsonic flow, the calculated values of C_d from the resulting calibration curve fit equation shall be within ± 0.5 per cent of the measured C_d for each calibration point.

2.5. Total system verification

The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of a pollutant gas into the system while it is being operated in the normal manner. The pollutant is analysed, and the mass calculated according to Annex 4A, Appendix 2, paragraph 4.3. except in the case of propane where a factor of 0.000472 is used in place of 0.000479 for HC. Either of the following two techniques shall be used.

2.5.1. Metering with a critical flow orifice

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

2.5.2. Metering by means of a gravimetric technique

The weight of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ± 0.01 gram. For about 5 to 10 minutes, the CVS system shall be operated as in a normal exhaust emission test, while carbon monoxide or propane is injected into the system. The quantity of pure gas discharged shall be determined by means of differential weighing. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined shall be within ± 3 per cent of the known mass of the gas injected.

3. CALIBRATION OF THE PARTICULATE MEASURING SYSTEM

3.1. Introduction

The calibration of the particulate measurement is limited to the flow meters used to determine sample flow and dilution ratio. Each flow meter shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method that shall be used is described in paragraph 3.2.

3.2. Flow measurement

3.2.1. Periodical calibration

- (a) To fulfil the absolute accuracy of the flow measurements as specified in paragraph 2.2. of Appendix 4 to this annex, the flow meter or the flow measurement instrumentation shall be calibrated with an accurate flow meter traceable to international and/or national standards.
- (b) 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 fulfil the accuracy requirements of paragraph 4.2.5.2. of Appendix 4 to this annex:
 - (i) The flow meter for q_{mdw} shall be connected in series to the flow meter for q_{mdew} , the difference between the two flow meters shall be calibrated for at least 5 set points with flow values equally spaced between the lowest q_{mdw} value used during the test and the value of q_{mdew} used during the test. The dilution tunnel may be bypassed.
 - (ii) A calibrated mass flow device shall be connected in series to the flowmeter for q_{mdew} and the accuracy shall be checked for the value used for the test. Then the calibrated mass flow device shall be connected in series to the flow meter for q_{mdw} , and the accuracy shall be checked for at least 5 settings corresponding to dilution ratio between 3 and 50, relative to q_{mdew} used during the test.
 - (iii) The transfer tube TT shall be disconnected from the exhaust, and a calibrated flow measuring device with a suitable range to measure q_{mp} shall be connected to the transfer tube. Then q_{mdew} shall be set to the value used during the test, and q_{mdw} shall be sequentially set to at least 5 values corresponding to dilution ratios q between 3 and 50. Alternatively, a special calibration flow path, may be provided, in which the tunnel is bypassed, but the total and dilution air flow through the corresponding meters as in the actual test.
 - (iv) A tracer gas, shall be fed into the exhaust transfer tube TT. This tracer gas may be a component of the exhaust gas, like CO_2 or NO_x . After dilution in the tunnel the tracer gas component shall be measured. This shall be carried out for 5 dilution ratios between 3 and 50. The accuracy of the sample flow shall be determined from the dilution ratio r_d :

$$q_{mp} = \frac{q_{mdew}}{r_d}$$

- (c) The accuracies of the gas analyzers shall be taken into account to guarantee the accuracy of q_{mp} .

3.2.2. Carbon flow check

- (a) A carbon flow check using actual exhaust is recommended for detecting measurement and control problems and verifying the proper operation of the partial flow system. The carbon flow check should be run at least each time a new

engine is installed, or something significant is changed in the test cell configuration.

- (b) The engine shall be operated at peak torque load and speed or any other steady state mode that produces 5 per cent or more of CO₂. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.
- (c) If a carbon flow check is conducted, the procedure given in Appendix 6 to this annex shall be applied. The carbon flow rates shall be calculated according to paragraphs 2.1. to 2.3. of Appendix 6 to this annex. All carbon flow rates should agree to within 6 per cent of each other.

3.2.3. Pre-test check

- (a) A pre-test check shall be performed within 2 hours before the test run in the following way:
- (b) The accuracy of the flow meters shall be checked by the same method as used for calibration (see paragraph 3.2.1. of this appendix) 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.
- (c) If it can be demonstrated by records of the calibration procedure under paragraph 3.2.1. that the flow meter calibration is stable over a longer period of time, the pre-test check may be omitted.

3.3. Determination of transformation time (for partial flow dilution systems on ETC only)

- (a) 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:
- (b) 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.
- (c) 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 per cent 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.
- (d) 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 per cent 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 paragraph 3.8.3.2. of Appendix 2 to this annex).

- (e) The calculation shall be repeated for at least 5 rise and fall stimuli, and the results shall be averaged. The internal transformation time (< 100 msec) of the reference flowmeter shall be subtracted from this value. This is the "look-ahead" value of the partial flow dilution system, which shall be applied in accordance with paragraph 3.8.3.2. of Appendix 2 to this annex.

3.4. Checking the partial flow conditions

The range of the exhaust gas velocity and the pressure oscillations shall be checked and adjusted according to the requirements of paragraph 2.2.1. of Appendix 7 (EP), if applicable.

3.5. Calibration intervals

The flow measurement instrumentation shall be calibrated at least every 3 months or whenever a system repair or change is made that could influence calibration.

4. CALIBRATION OF THE SMOKE MEASUREMENT EQUIPMENT

4.1. Introduction

The opacimeter shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method to be used is described in this paragraph for the components indicated in Appendix 4, paragraph 5 and Appendix 7, paragraph 3. to this annex.

4.2. Calibration procedure

4.2.1. Warming-up time

The opacimeter shall be warmed up and stabilised according to the manufacturer's recommendations. If the opacimeter is equipped with a purge air system to prevent sooting of the instrument optics, this system should also be activated and adjusted according to the manufacturer's recommendations.

4.2.2. Establishment of the linearity response

The linearity of the opacimeter shall be checked in the opacity readout mode as per the manufacturer's recommendations. Three neutral density filters of known transmittance, which shall meet the requirements of Appendix 4, paragraph 5.2.5. to this annex, shall be introduced to the opacimeter and the value recorded. The neutral density filters shall have nominal opacities of approximately 10 per cent, 20 per cent and 40 per cent.

The linearity shall not differ by more than ± 2 per cent opacity from the nominal value of the neutral density filter. Any non-linearity exceeding the above value shall be corrected prior to the test.

4.3. Calibration intervals

The opacimeter shall be calibrated according to paragraph 4.2.2. at least every 3 months or whenever a system repair or change is made that could influence calibration.

Appendix 6

CARBON FLOW CHECK

1. INTRODUCTION

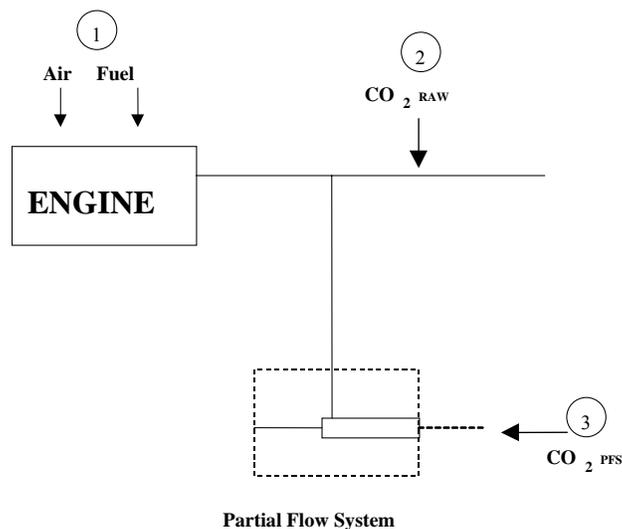
All but a tiny part of the carbon in the exhaust comes from the fuel, and all but a minimal part of this is manifest in the exhaust gas as CO₂. This is the basis for a system verification check based on CO₂ measurements.

The flow of carbon into the exhaust measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO₂ concentrations and gas flow rates at those points.

In this sense, the engine provides a known source of carbon flow, and observing the same carbon flow in the exhaust pipe and at the outlet of the partial flow PM sampling system verifies leak integrity and flow measurement accuracy. This check has the advantage that the components are operating under actual engine test conditions of temperature and flow.

The following diagram shows the sampling points at which the carbon flows shall be checked. The specific equations for the carbon flows at each of the sample points are given below.

Figure 7
Measuring points for carbon flow check



2. CALCULATIONS

2.1. Carbon flow rate into the engine (location 1)

The carbon mass flow rate into the engine for a fuel $\text{CH}_\alpha\text{O}_\varepsilon$ is given by:

$$q_{mCf} = \frac{12.011}{12.011 + \alpha + 15.999 \times \varepsilon} \times q_{mf}$$

where:

q_{mf} = fuel mass flow rate, kg/s

2.2. Carbon flow rate in the raw exhaust (location 2)

The carbon mass flow rate in the exhaust pipe of the engine shall be determined from the raw CO_2 concentration and the exhaust gas mass flow rate:

$$q_{mCe} = \left(\frac{c_{\text{CO}_2r} - c_{\text{CO}_2a}}{100} \right) \times q_{mew} \times \frac{12.011}{M_{re}}$$

where:

$c_{\text{CO}_2,r}$ = wet CO_2 concentration in the raw exhaust gas, per cent

$c_{\text{CO}_2,a}$ = wet CO_2 concentration in the ambient air, per cent (around 0.04 per cent)

q_{mew} = exhaust gas mass flow rate on wet basis, kg/s

M_{re} = molecular mass of exhaust gas

If CO_2 is measured on a dry basis it shall be converted to a wet basis according to paragraph 5.2. of Appendix 1 to this annex.

2.3. Carbon flow rate in the dilution system (location 3)

The carbon flow rate shall be determined from the dilute CO_2 concentration, the exhaust gas mass flow rate and the sample flow rate:

$$q_{mCp} = \left(\frac{c_{\text{CO}_2d} - c_{\text{CO}_2a}}{100} \right) \times q_{mdew} \times \frac{12.011}{M_{re}} \times \frac{q_{mew}}{q_{mp}}$$

where:

$c_{\text{CO}_2,d}$ = wet CO_2 concentration in the dilute exhaust gas at the outlet of the dilution tunnel, per cent

$c_{\text{CO}_2,a}$ = wet CO_2 concentration in the ambient air, per cent (around 0.04 per cent)

q_{mdew} = diluted exhaust gas mass flow rate on wet basis, kg/s

q_{mew} = exhaust gas mass flow rate on wet basis, kg/s (partial flow system only)

q_{mp} = sample flow of exhaust gas into partial flow dilution system, kg/s (partial flow system only)

M_{re} = molecular mass of exhaust gas

If CO₂ is measured on a dry basis, it shall be converted to wet basis according to paragraph 5.2. of Appendix 1 to this annex.

2.4. The molecular mass (M_{re}) of the exhaust gas shall be calculated as follows:

$$M_{re} = \frac{1 + \frac{q_{mf}}{q_{maw}}}{\frac{q_{mf}}{q_{maw}} \times \frac{\frac{\alpha}{4} + \frac{\varepsilon}{2} + \frac{\delta}{2}}{12.01 + 1.0079 \times \alpha + 15.999 \times \varepsilon + 14.006 \times \delta + 32.06 \times \gamma} + \frac{H_a \times 10^{-3}}{2 \times 1.0079 + 15.999} + \frac{1}{M_{ra}} + \frac{1}{1 + H_a \times 10^{-3}}}$$

where:

- q_{mf} = fuel mass flow rate, kg/s
- q_{maw} = intake air mass flow rate on wet basis, kg/s
- H_a = humidity of intake air, g water per kg dry air
- M_{ra} = molecular mass of dry intake air (= 28.9 g/mol)
- α, δ, ε, γ = molar ratios referring to a fuel C_{H_α} O_δ N_ε S_γ

Alternatively, the following molecular masses may be used:

- M_{re} (diesel) = 28.9 g/mol
- M_{re} (LPG) = 28.6 g/mol
- M_{re} (NG) = 28.3 g/mol

Appendix 7

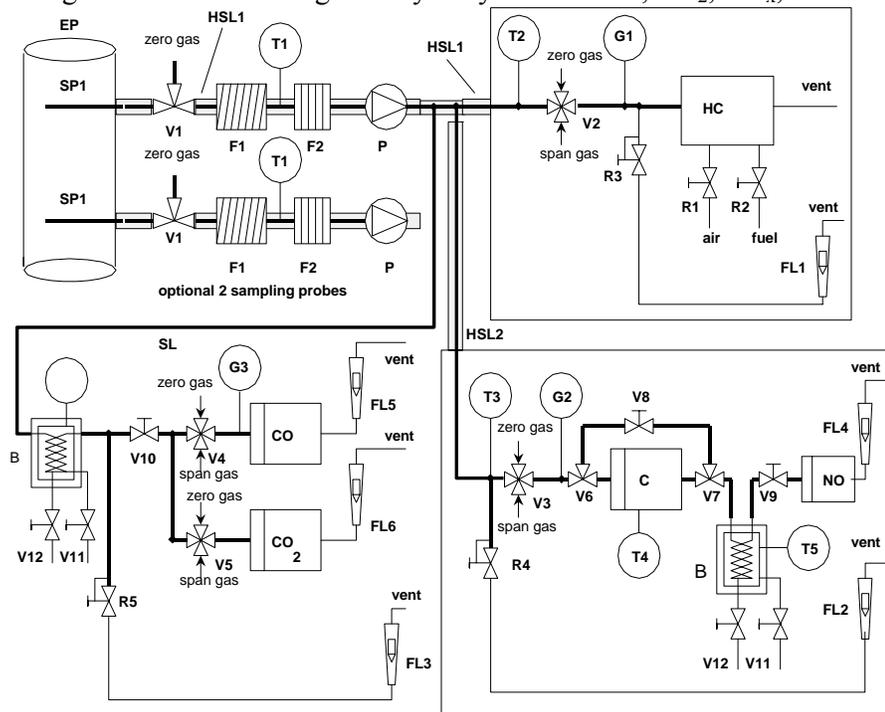
ANALYTICAL AND SAMPLING SYSTEMS

1. DETERMINATION OF THE GASEOUS EMISSIONS

1.1. Introduction

Paragraph 1.2. and figures 7 and 8 contain detailed descriptions of the recommended sampling and analysing systems. Since various configurations can produce equivalent results, exact conformance with figures 7 and 8 is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and co-ordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

Figure 7
Flow diagram of raw exhaust gas analysis system for CO, CO₂, NO_x, HC ESC only



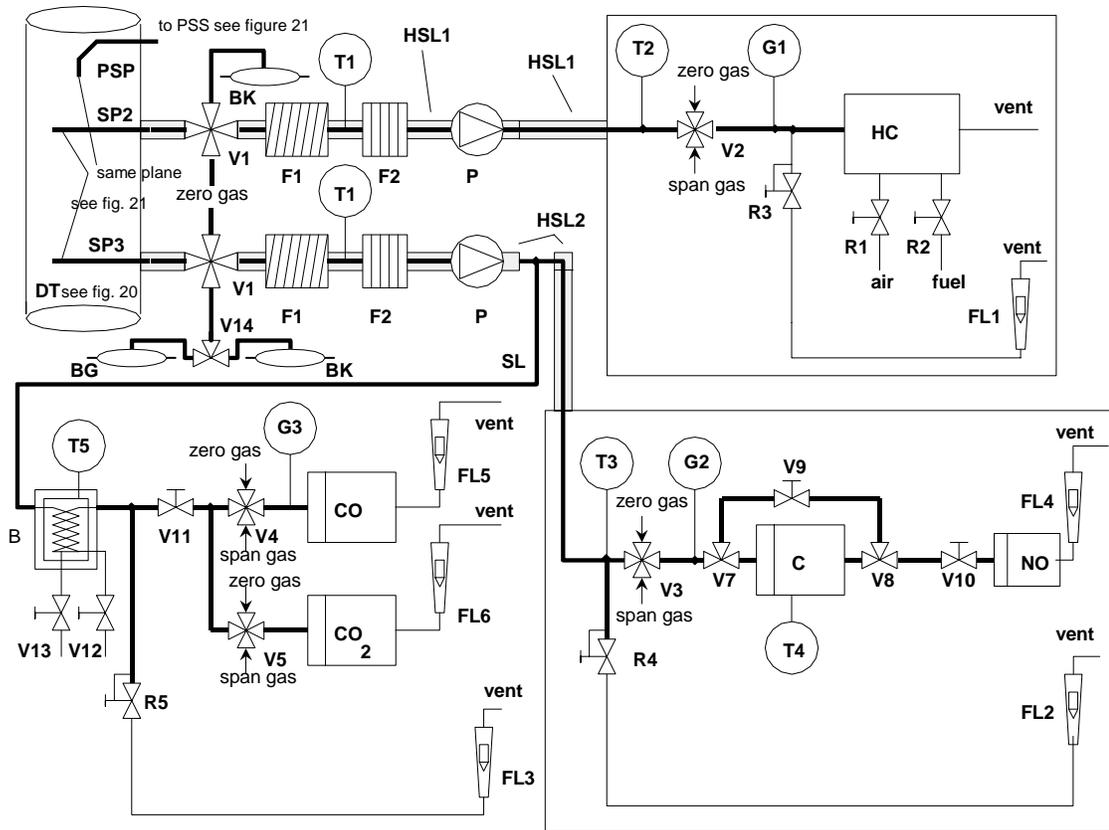
1.2. Description of the analytical system

An analytical system for the determination of the gaseous emissions in the raw (figure 7, ESC only) or diluted (figure 8, ETC and ESC) exhaust gas is described based on the use of:

- (a) HFID analyzer for the measurement of hydrocarbons;
- (b) NDIR analyzers for the measurement of carbon monoxide and carbon dioxide;
- (c) HCLD or equivalent analyzer for the measurement of the oxides of nitrogen;

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

Figure 8
Flow diagram of diluted exhaust gas analysis system for
CO, CO₂, NO_x, HC ETC, optional for ESC



1.2.1. Components of figures 7 and 8

EP exhaust pipe
Exhaust gas sampling probe (figure 7 only)

A stainless steel straight closed end multi-hole probe is recommended. The inside diameter shall not be greater than the inside diameter of the sampling line. The wall thickness of the probe shall not be greater than 1 mm. There shall be a minimum of 3 holes in 3 different radial planes sized to sample approximately the same flow. The probe shall extend across at least 80 per cent of the diameter of the exhaust pipe. One or two sampling probes may be used.

SP2 diluted exhaust gas HC sampling probe (figure 8 only)

The probe shall:

- (a) be defined as the first 254 mm to 762 mm of the heated sampling line HSL1;
- (b) have a 5 mm minimum inside diameter;
- (c) be installed in the dilution tunnel DT (see paragraph 2.3., figure 20) at a point where the dilution air and exhaust gas are well mixed (i.e. approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel);
- (d) be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
- (e) be heated so as to increase the gas stream temperature to $463\text{ K} \pm 10\text{ K}$ ($190\text{ °C} \pm 10\text{ °C}$) at the exit of the probe.

SP3 diluted exhaust gas CO, CO₂, NO_x sampling probe (figure 8 only)

The probe shall:

- (a) be in the same plane as SP 2;
- (b) be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
- (c) be heated and insulated over its entire length to a minimum temperature of 328 K (55 °C) to prevent water condensation.

HSL1 heated sampling line

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

The sampling line shall:

- (a) have a 5 mm minimum and a 13,5 mm maximum inside diameter;
- (b) be made of stainless steel or PTFE;
- (c) maintain a wall temperature of $463\text{ K} \pm 10\text{ K}$ ($190\text{ °C} \pm 10\text{ °C}$) as measured at every separately controlled heated section, if the temperature of the exhaust gas at the sampling probe is equal to or below 463 K (190 °C);
- (d) maintain a wall temperature greater than 453 K (180 °C), if the temperature of the exhaust gas at the sampling probe is above 463 K (190 °C);
- (e) maintain a gas temperature of $463\text{ K} \pm 10\text{ K}$ ($190\text{ °C} \pm 10\text{ °C}$) immediately before the heated filter F2 and the HFID.

HSL2 heated NO_x sampling line

The sampling line shall:

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

SL sampling line for CO and CO₂

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

BK background bag (optional; figure 8 only)

For the sampling of the background concentrations.

BG sample bag (optional; figure 8 CO and CO₂ only)

For the sampling of the sample concentrations.

F1 heated pre-filter (optional)

The temperature shall be the same as HSL1.

F2 Heated filter

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

P heated sampling pump

The pump shall be heated to the temperature of HSL1.

HC

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

CO, CO₂

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

NO

CLD or HCLD analyzer for the determination of the oxides of nitrogen. If a HCLD is used it shall be kept at a temperature of 328 K to 473 K (55 °C to 200 °C).

C converter

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

B cooling bath (optional)

To cool and condense water from the exhaust sample. The bath shall be maintained at a temperature of 273 K to 277 K (0 °C to 4 °C) by ice or refrigeration. It is optional if the

analyzer is free from water vapour interference as determined in paragraphs 1.9.1. and 1.9.2. of Appendix 5 to this annex. If water is removed by condensation, the sample gas temperature or dew point shall be monitored either within the water trap or downstream. The sample gas temperature or dew point shall not exceed 280 K (7 °C). Chemical dryers are not allowed for removing water from the sample.

T1, T2, T3 temperature sensor

To monitor the temperature of the gas stream.

T4 temperature sensor

To monitor the temperature of the NO₂-NO converter.

T5 temperature sensor

To monitor the temperature of the cooling bath.

G1, G2, G3 pressure gauge

To measure the pressure in the sampling lines.

R1, R2 pressure regulator

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

R3, R4, R5 pressure regulator

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

FL1, FL2, FL3 flowmeter

To monitor the sample by-pass flow rate.

FL4 to FL6 flowmeter (optional)

To monitor the flow rate through the analyzers.

V1 to V5 selector valve

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

V6, V7 solenoid valve

To by-pass the NO₂-NO converter.

V8 needle valve

To balance the flow through the NO₂-NO converter C and the by-pass.

V9, V10 needle valve

To regulate the flows to the analyzers.

V11, V12 Toggle valve (optional)

To drain the condensate from the bath B.

1.3. NMHC analysis (NG fuelled gas engines only)

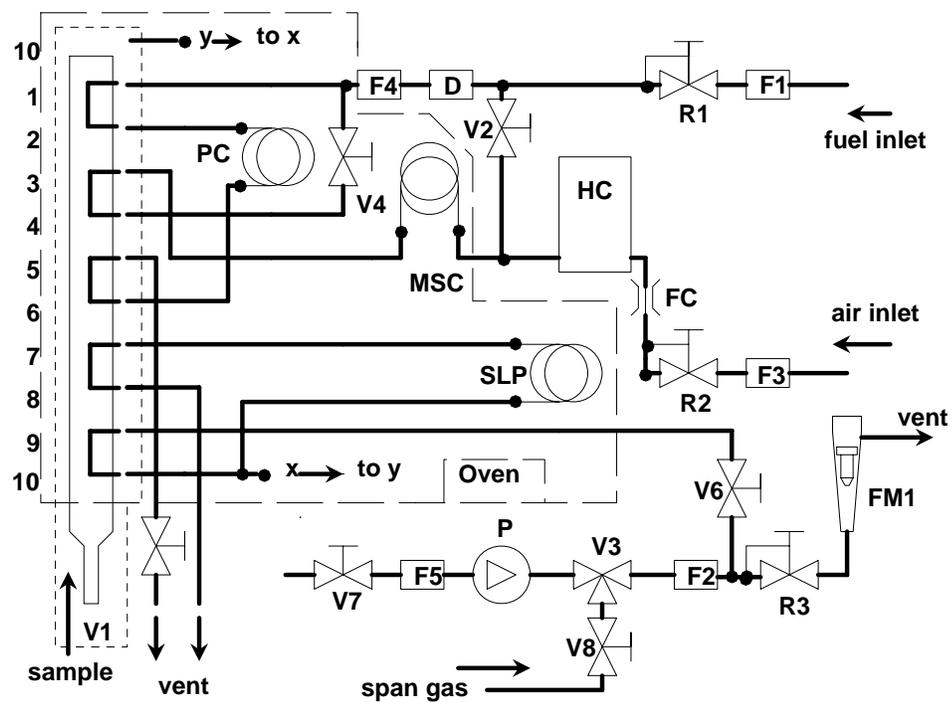
1.3.1. Gas chromatographic method (GC, figure 9)

When using the GC method, a small measured volume of a sample is injected onto an analytical column through which it is swept by an inert carrier gas. The column separates various components according to their boiling points so that they elute from the column at different times. They then pass through a detector which gives an electrical signal that depends on their concentration. Since it is not a continuous analysis technique, it can only be used in conjunction with the bag sampling method as described in paragraph 3.4.2. of Appendix 4 to this annex.

For NMHC an automated GC with a FID shall be used. The exhaust gas shall be sampled into a sampling bag from which a part shall be taken and injected into the GC. The sample is separated into two parts (CH₄/Air/CO and NMHC/CO₂/H₂O) on the Porapak column. The molecular sieve column separates CH₄ from the air and CO before passing it to the FID where its concentration is measured. A complete cycle from injection of one sample to injection of a second can be made in 30 s. To determine NMHC, the CH₄ concentration shall be subtracted from the total HC concentration (see paragraph 4.3.1. of Appendix 2 to this annex).

Figure 9 shows a typical GC assembled to routinely determine CH₄. Other GC methods can also be used based on good engineering judgement.

Figure 9
Flow diagram for methane analysis (GC method)



Components of figure 9

PC Porapak column

Porapak N, 180/300 μm (50/80 mesh), 610 mm length \times 2.16 mm ID shall be used and conditioned at least 12 h at 423 K (150 $^{\circ}\text{C}$) with carrier gas prior to initial use.

MSC Molecular sieve column

Type 13X, 250/350 μm (45/60 mesh), 1220 mm length \times 2.16 mm ID shall be used and conditioned at least 12 h at 423 K (150 $^{\circ}\text{C}$) with carrier gas prior to initial use.

OV Oven

To maintain columns and valves at stable temperature for analyzer operation, and to condition the columns at 423 K (150 $^{\circ}\text{C}$).

SLP Sample loop

A sufficient length of stainless steel tubing to obtain approximately 1 cm^3 volume.

P Pump

To bring the sample to the gas chromatograph.

D Dryer

A dryer containing a molecular sieve shall be used to remove water and other contaminants which might be present in the carrier gas.

HC

Flame ionisation detector (FID) to measure the concentration of methane.

V1 Sample injection valve

To inject the sample taken from the sampling bag via SL of figure 8. It shall be low dead volume, gas tight, and heatable to 423 K (150 °C).

V3 Selector valve

To select span gas, sample, or no flow.

V2, V4, V5, V6, V7, V8 Needle valve

To set the flows in the system.

R1, R2, R3 Pressure regulator

To control the flows of the fuel (= carrier gas), the sample, and the air, respectively.

FC Flow capillary

To control the rate of air flow to the FID

G1, G2, G3 Pressure gauge

To control the flows of the fuel (= carrier gas), the sample, and the air, respectively.

F1, F2, F3, F4, F5 Filter

Sintered metal filters to prevent grit from entering the pump or the instrument.

FL1

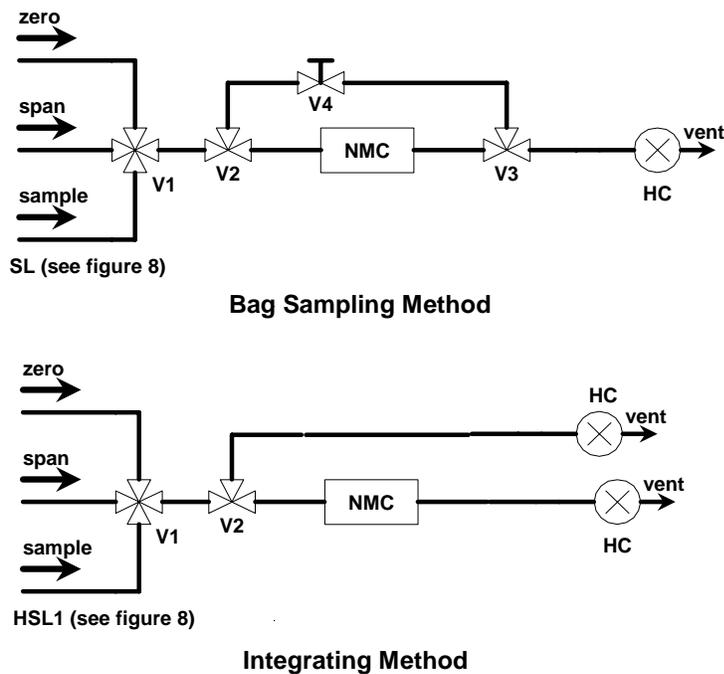
To measure the sample by-pass flow rate.

1.3.2. Non-Methane Cutter Method (NMC, figure 10)

The cutter oxidizes all hydrocarbons except CH₄ to CO₂ and H₂O, so that by passing the sample through the NMC only CH₄ is detected by the FID. If bag sampling is used, a flow diverter system shall be installed at SL (see paragraph 1.2., figure 8) with which the flow can be alternatively passed through or around the cutter according to the upper part of figure 10. For NMHC measurement, both values (HC and CH₄) shall be observed on the FID and recorded. If the integration method is used, an NMC in line with a second FID shall be installed parallel to the regular FID into HSL1 (see paragraph 1.2., figure 8) according to the lower part of figure 10. For NMHC measurement, the values of the two FID's (HC and CH₄) shall be observed and recorded.

The cutter shall be characterized at or above 600 K (327 °C) prior to test work with respect to its catalytic effect on CH₄ and C₂H₆ at H₂O values representative of exhaust stream conditions. The dewpoint and O₂ level of the sampled exhaust stream shall be known. The relative response of the FID to CH₄ shall be recorded (see paragraph 1.8.2. of Appendix 5 to this annex).

Figure 10
 Flow diagram for methane analysis with the non-methane cutter (NMC)



Components of figure 10

NMC Non-methane cutter

To oxidize all hydrocarbons except methane.

HC

Heated flame ionisation detector (HFID) to measure the HC and CH₄ concentrations. The temperature shall be kept at 453 K to 473 K (180 °C to 200 °C).

V1 Selector valve

To select sample, zero and span gas. V1 is identical with V2 of figure 8.

V2, V3 Solenoid valve

To by-pass the NMC.

V4 Needle valve

To balance the flow through the NMC and the by-pass.

R1 Pressure regulator

To control the pressure in the sampling line and the flow to the HFID. R1 is identical with R3 of figure 8.

FL1 Flowmeter

To measure the sample by-pass flow rate. FL1 is identical with FL1 of figure 8.

2. EXHAUST GAS DILUTION AND DETERMINATION OF THE PARTICULATES

2.1. Introduction

Paragraphs 2.2., 2.3. and 2.4. and figures 11 to 22 contain detailed descriptions of the recommended dilution and sampling systems. Since various configurations can produce equivalent results, exact conformance with these figures is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

2.2. Partial Flow Dilution System

A dilution system is described in figures 11 to 19 based upon the dilution of a part of the exhaust stream. Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire dilute exhaust gas or only a portion of the dilute exhaust gas is passed to the particulate sampling system (paragraph 2.4., figure 21). The first method is referred to as total sampling type, the second method as fractional sampling type.

The calculation of the dilution ratio depends upon the type of system used. The following types are recommended:

Isokinetic systems (figures 11, 12)

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

Flow controlled systems with concentration measurement (figures 13 to 17)

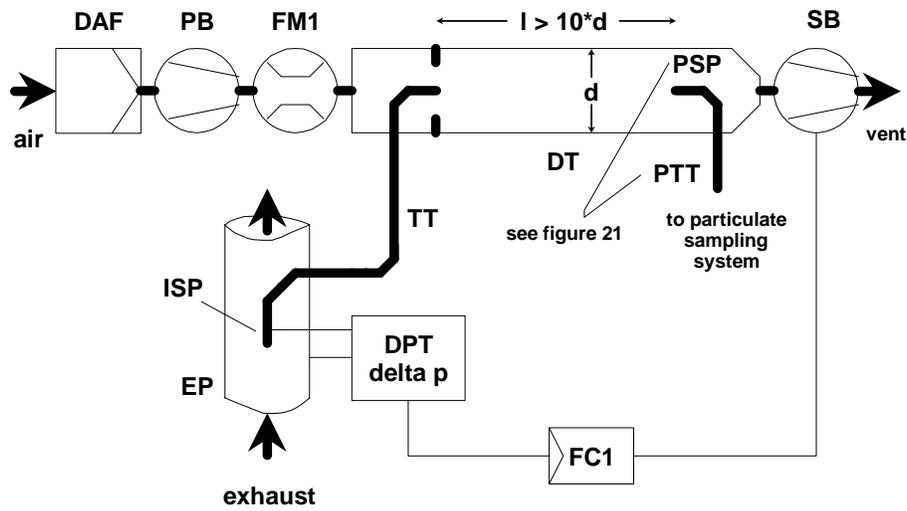
With these systems, a sample is taken from the bulk exhaust stream by adjusting the dilution air flow and the total dilute exhaust flow. The dilution ratio is determined from the concentrations of tracer gases, such as CO₂ or NO_x naturally occurring in the engine exhaust. The concentrations in the dilute exhaust gas and in the dilution air are measured, whereas the concentration in the raw exhaust gas can be either measured directly or determined from fuel flow and the carbon balance equation, if the fuel composition is known. The systems may be controlled by the calculated dilution ratio (figures 13 and 14) or by the flow into the transfer tube (figures 12, 13 and 14).

Flow controlled systems with flow measurement (figures 18 and 19)

With these systems, a sample is taken from the bulk exhaust stream by setting the dilution air flow and the total dilute exhaust flow. The dilution ratio is determined from the difference of the two flows rates. Accurate calibration of the flow meters relative to one another is required, since the relative magnitude of the two flow rates can lead to significant errors at higher dilution ratios (of 15 and above). Flow control is very straight forward by keeping the dilute exhaust flow rate constant and varying the dilution air flow rate, if needed.

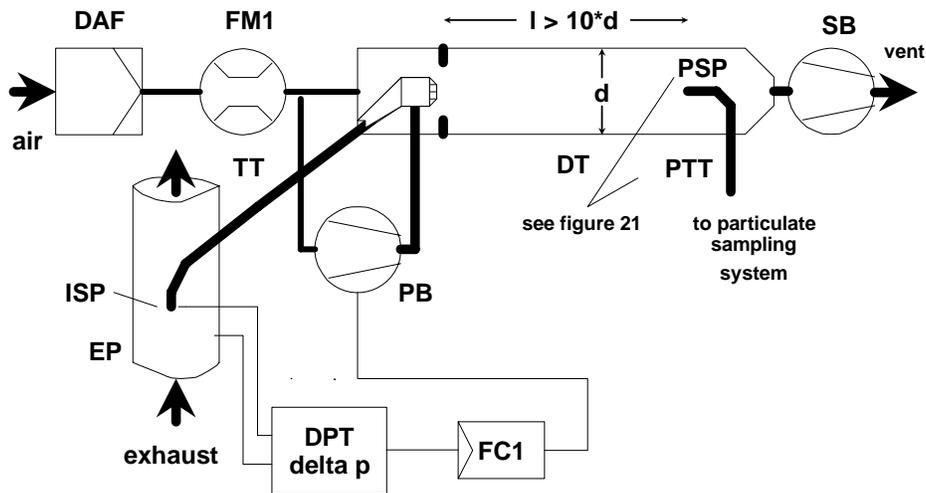
When using partial flow dilution systems, attention shall be paid to avoiding the potential problems of loss of particulates in the transfer tube, ensuring that a representative sample is taken from the engine exhaust, and determination of the split ratio. The systems described pay attention to these critical areas.

Figure 11
 Partial flow dilution system with isokinetic probe and fractional sampling (SB control)



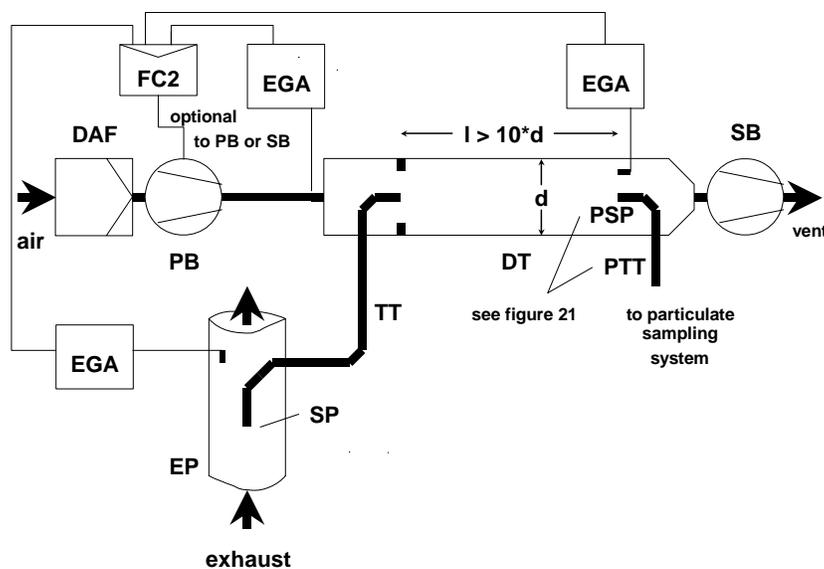
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the transfer tube TT by the isokinetic sampling probe ISP. The differential pressure of the exhaust gas between exhaust pipe and inlet to the probe is measured with the pressure transducer DPT. This signal is transmitted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

Figure 12
 Partial flow dilution system with isokinetic probe and fractional sampling (PB control)



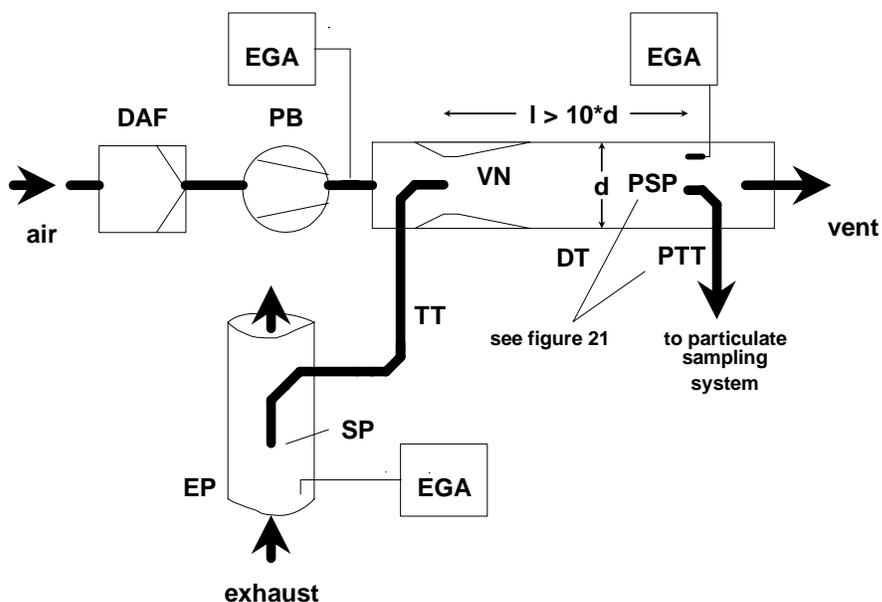
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the transfer tube TT by the isokinetic sampling probe ISP. The differential pressure of the exhaust gas between exhaust pipe and inlet to the probe is measured with the pressure transducer DPT. This signal is transmitted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

Figure 13
Partial flow dilution system with CO₂ or NO_x concentration measurement
and fractional sampling



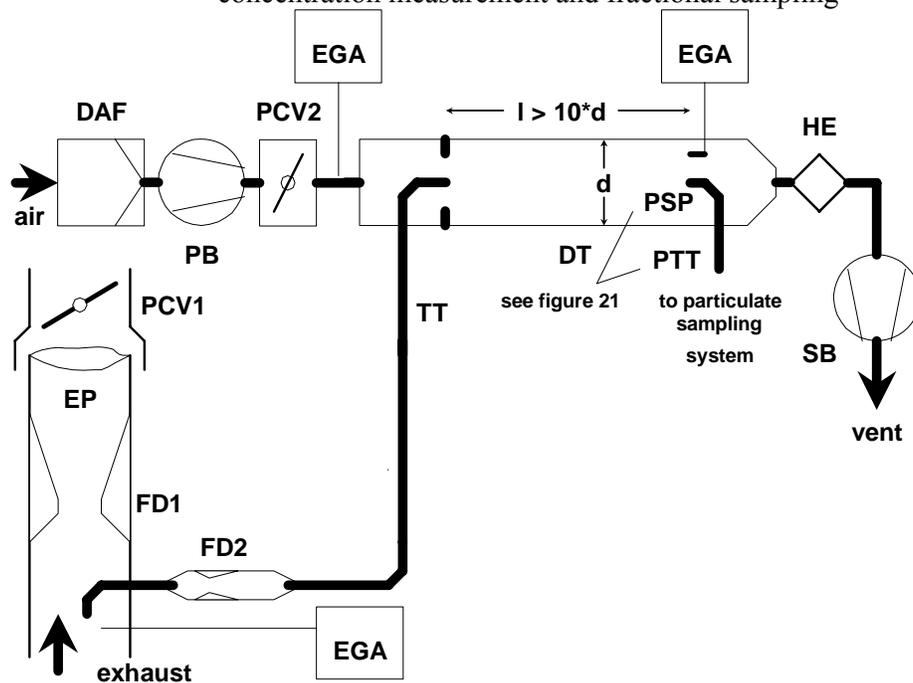
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The concentrations of a tracer gas (CO₂ or NO_x) are measured in the raw and diluted exhaust gas as well as in the dilution air with the exhaust gas analyzer(s) EGA. These signals are transmitted to the flow controller FC2 that controls either the pressure blower PB or the suction blower SB to maintain the desired exhaust split and dilution ratio in DT. The dilution ratio is calculated from the tracer gas concentrations in the raw exhaust gas, the diluted exhaust gas, and the dilution air.

Figure 15
Partial flow dilution system with single venturi,
concentration measurement and fractional sampling



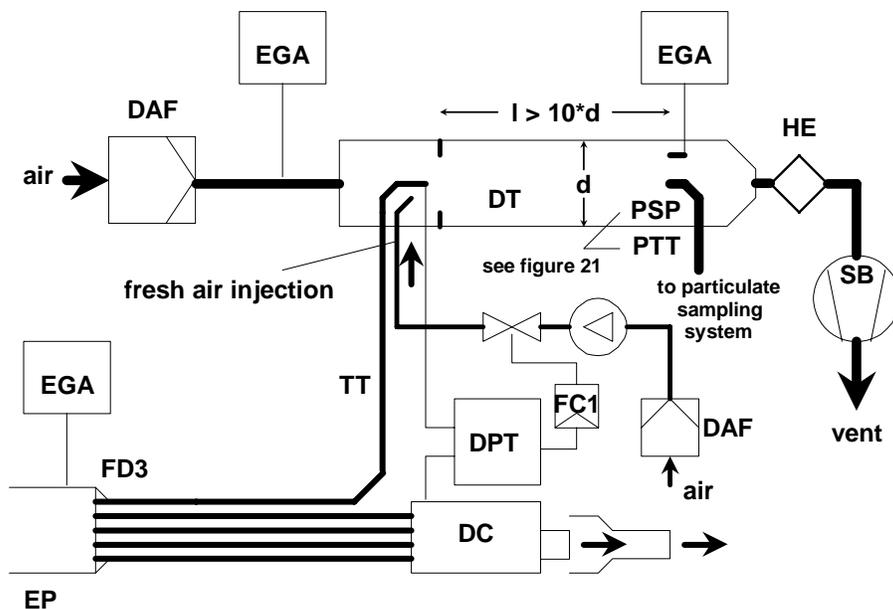
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT due to the negative pressure created by the venturi VN in DT. The gas flow rate through TT depends on the momentum exchange at the venturi zone, and is therefore affected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

Figure 16
Partial flow dilution system with twin venturi or twin orifice,
concentration measurement and fractional sampling



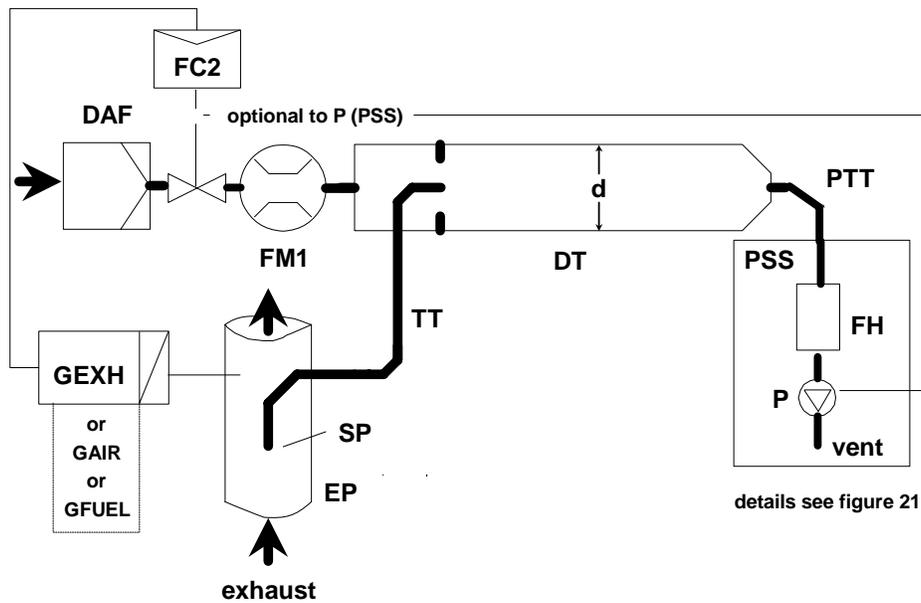
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT by a flow divider that contains a set of orifices or venturis. The first one (FD1) is located in EP, the second one (FD2) in TT. Additionally, two pressure control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

Figure 17
Partial flow dilution system with multiple tube splitting,
concentration measurement and fractional sampling



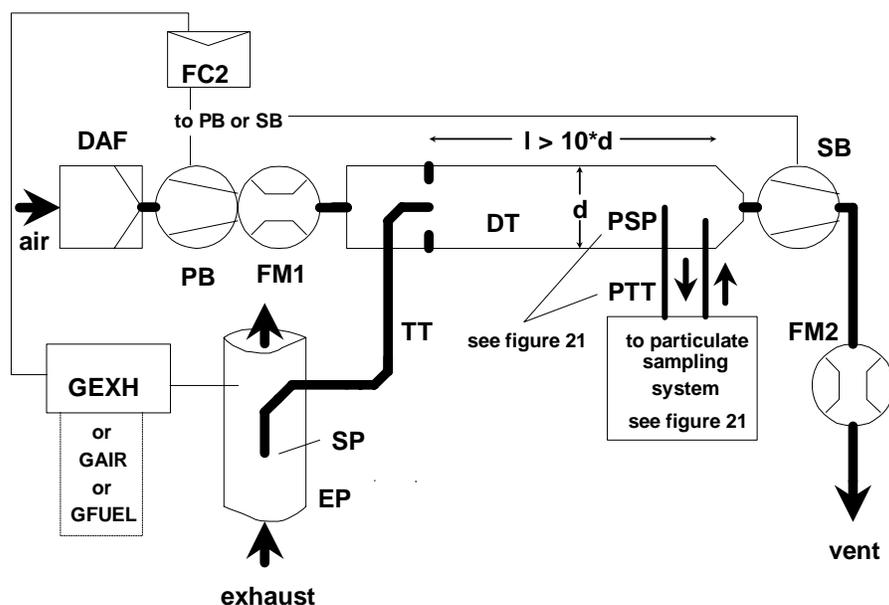
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the transfer tube TT by the flow divider FD3 that consists of a number of tubes of the same dimensions (same diameter, length and bend radius) installed in EP. The exhaust gas through one of these tubes is lead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

Figure 18
Partial flow dilution system with flow control and total sampling



Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The total flow through the tunnel is adjusted with the flow controller FC3 and the sampling pump P of the particulate sampling system (see figure 18). The dilution air flow is controlled by the flow controller FC2, which may use G_{EXHW} , G_{AIRW} , or G_{FUEL} as command signals, for the desired exhaust split. The sample flow into DT is the difference of the total flow and the dilution air flow. The dilution air flow rate is measured with the flow measurement device FM1, the total flow rate with the flow measurement device FM3 of the particulate sampling system (see figure 21). The dilution ratio is calculated from these two flow rates.

Figure 19
Partial flow dilution system with flow control and fractional sampling



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

2.2.1. Components of figures 11 to 19

EP exhaust pipe

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

For an isokinetic system, the exhaust pipe shall be free of elbows, bends and sudden diameter changes for at least 6-pipe diameters upstream and 33-pipe diameters downstream of the tip of the probe. The gas velocity at the sampling zone shall be higher than 10 m/s except at idle mode. Pressure oscillations of the exhaust gas shall not exceed ± 500 Pa on the average. Any steps to reduce pressure oscillations beyond using a chassis-type exhaust

system (including silencer and aftertreatment devices) shall not alter engine performance nor cause the deposition of particulates.

For systems without isokinetic probe, it is recommended to have a straight pipe of 6-pipe diameters upstream and 3-pipe diameters downstream of the tip of the probe.

SP sampling probe (figures 10, 14, 15, 16, 18 and 19)

The minimum inside diameter shall be 4 mm. The minimum diameter ratio between exhaust pipe and probe shall be 4. The probe shall be an open tube facing upstream on the exhaust pipe centreline, or a multiple hole probe as described under SP1 in paragraph 1.2.1., figure 5.

ISP isokinetic sampling probe (figures 11 and 12)

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

A control system is necessary for isokinetic exhaust splitting by maintaining a differential pressure of zero between EP and ISP. Under these conditions exhaust gas velocities in EP and ISP are identical and the mass flow through ISP is a constant fraction of the exhaust gas flow. ISP has to be connected to a differential pressure transducer DPT. The control to provide a differential pressure of zero between EP and ISP is done with the flow controller FC1.

FD1, FD2 flow divider (figure 16)

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

FD3 flow divider (figure 17)

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

EGA exhaust gas analyzer (figures 13, 14, 15, 16 and 17)

CO₂ or NO_x analyzers may be used (with carbon balance method CO₂ only). The analyzers shall be calibrated like the analyzers for the measurement of the gaseous emissions. One or several analyzers may be used to determine the concentration differences. The accuracy of the measuring systems has to be such that the accuracy of G_{EDFW,i} is within ± 4 per cent.

TT transfer tube (figures 11 to 19)

The transfer tube shall be:

- (a) As short as possible, but not more than 5 m in length.
- (b) Equal to or greater than the probe diameter, but not more than 25 mm in diameter.
- (c) Exiting on the centreline of the dilution tunnel and pointing downstream.

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

DPT differential pressure transducer (figures 11, 12 and 17)

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

FC1 flow controller (figures 11, 12 and 17)

For isokinetic systems (figures 11 and 12), a flow controller is necessary to maintain a differential pressure of zero between EP and ISP. The adjustment can be done by:

- (a) controlling the speed or flow of the suction blower SB and keeping the speed or flow of the pressure blower PB constant during each mode (figure 11) or;
- (b) adjusting the suction blower SB to a constant mass flow of the diluted exhaust gas and controlling the flow of the pressure blower PB, and therefore the exhaust sample flow in a region at the end of the transfer tube TT (figure 12).

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

For a multi tube system (figure 17), a flow controller is necessary for proportional exhaust splitting to maintain a differential pressure of zero between the exit of the multi tube unit and the exit of TT. The adjustment is done by controlling the injection air flow rate into DT at the exit of TT.

PCV1, PCV2 pressure control valve (figure 16)

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

DC damping chamber (figure 17)

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

VN venturi (figure 15)

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

FC2 flow controller (figures 13, 14, 18 and 19, optional)

A flow controller may be used to control the flow of the pressure blower PB and/or the suction blower SB. It may be connected to the exhaust, intake air, or fuel flow signals and/or to the CO₂ or NO_x differential signals. When using a pressurised air supply (figure 18), FC2 directly controls the air flow.

FM1 flow measurement device (figures 11, 12, 18 and 19)

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

FM2 flow measurement device (figure 19)

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

PB pressure blower (figures 11, 12, 13, 14, 15, 16 and 19)

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

SB suction blower (figures 11, 12, 13, 16, 17, 19)

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

DAF dilution air filter (figures 11 to 19)

It is recommended that the dilution air be filtered and charcoal scrubbed to eliminate background hydrocarbons. At the engine manufacturers request the dilution air shall be

sampled according to good engineering practice to determine the background particulate levels, which can then be subtracted from the values measured in the diluted exhaust.

DT Dilution tunnel (figures 11 to 19)

The dilution tunnel:

- (a) shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions;
- (b) shall be constructed of stainless steel with:
 - (i) thickness/diameter ratio of 0.025 or less for dilution tunnels with inside diameters greater than 75 mm;
 - (ii) a nominal thickness of no less than 1.5 mm for dilution tunnels with inside diameters of equal to or less than 75 mm;
- (c) shall be at least 75 mm in diameter for the fractional sampling type;
- (d) is recommended to be at least 25 mm in diameter for the total sampling type;
- (e) may be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel;
- (f) may be insulated.

The engine exhaust shall be thoroughly mixed with the dilution air. For fractional sampling systems, the mixing quality shall be checked after introduction into service by means of a CO₂-profile of the tunnel with the engine running (at least four equally spaced measuring points). If necessary, a mixing orifice may be used.

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

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

HE heat exchanger (figures 16 and 17)

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

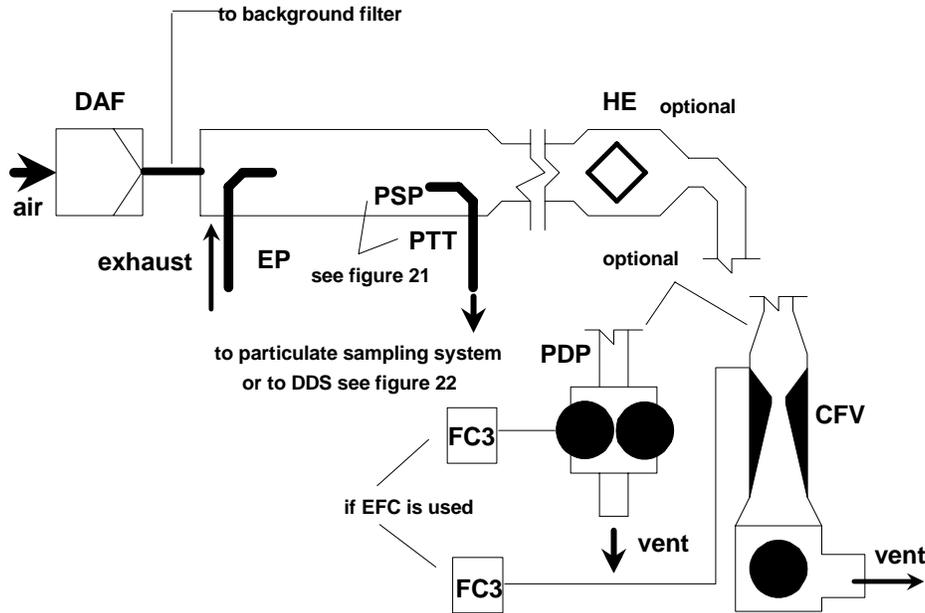
2.3. Full flow dilution system

A dilution system is described in figure 20 based upon the dilution of the total exhaust using the CVS (constant volume sampling) concept. The total volume of the mixture of exhaust and dilution air shall be measured. Either a PDP or a CFV system may be used.

For subsequent collection of the particulates, a sample of the dilute exhaust gas is passed to the particulate sampling system (paragraph 2.4., figures 21 and 22). If this is done directly,

it is referred to as single dilution. If the sample is diluted once more in the secondary dilution tunnel, it is referred to as double dilution. This is useful, if the filter face temperature requirement cannot be met with single dilution. Although partly a dilution system, the double dilution system is described as a modification of a particulate sampling system in paragraph 2.4., figure 22, since it shares most of the parts with a typical particulate sampling system.

Figure 20
Full flow dilution system to background filter



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

2.3.1. Components of figure 20

EP exhaust pipe

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

PDP positive displacement pump

The PDP meters total diluted exhaust flow from the number of the pump revolutions and the pump displacement. The exhaust system backpressure shall not be artificially lowered by the PDP or dilution air inlet system. Static exhaust backpressure measured with the PDP system operating shall remain within ± 1.5 kPa of the static pressure measured without connection to the PDP at identical engine speed and load. The gas mixture temperature immediately ahead of the PDP shall be within ± 6 K of the average operating temperature observed during the test, when no flow compensation is used. Flow compensation may only be used if the temperature at the inlet to the PDP does not exceed 323 K (50 °C).

CFV critical flow venturi

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

HE heat exchanger (optional, if EFC is used)

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

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

If the temperature at the inlet to either the PDP or CFV is not kept within the limits stated above, a flow compensation system is required for continuous measurement of the flow rate and control of the proportional sampling in the particulate system. To that purpose, the continuously measured flow rate signals are used to correct the sample flow rate through the particulate filters of the particulate sampling system (see paragraph 2.4., figures 21 and 22), accordingly.

DT dilution tunnel

The dilution tunnel:

- (a) shall be small enough in diameter to cause turbulent flow (Reynolds number greater than 4,000) and of sufficient length to cause complete mixing of the exhaust and dilution air; a mixing orifice may be used;
- (b) shall be at least 460 mm in diameter with a single dilution system;
- (c) shall be at least 210 mm in diameter with a double dilution system;
- (d) may be insulated.

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

When using single dilution, a sample from the dilution tunnel is transferred to the particulate sampling system (paragraph 2.4., figure 21). The flow capacity of the PDP or CFV shall be sufficient to maintain the diluted exhaust at a temperature of less than or equal to 325 K (52°C) immediately before the primary particulate filter.

When using double dilution, a sample from the dilution tunnel is transferred to the secondary dilution tunnel where it is further diluted, and then passed through the sampling filters (paragraph 2.4., figure 22). The flow capacity of the PDP or CFV shall be sufficient to maintain the diluted exhaust stream in the DT at a temperature of less than or equal to 464 K (191 °C) at the sampling zone. The secondary dilution system shall provide sufficient secondary dilution air to maintain the doubly-diluted exhaust stream at a temperature of less than or equal to 325 K (52 °C) immediately before the primary particulate filter.

DAF dilution air filter

It is recommended that the dilution air be filtered and charcoal scrubbed to eliminate background hydrocarbons. At the engine manufacturers request the dilution air shall be sampled according to good engineering practice to determine the background particulate levels, which can then be subtracted from the values measured in the diluted exhaust.

PSP particulate sampling probe

The probe is the leading section of PTT and:

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

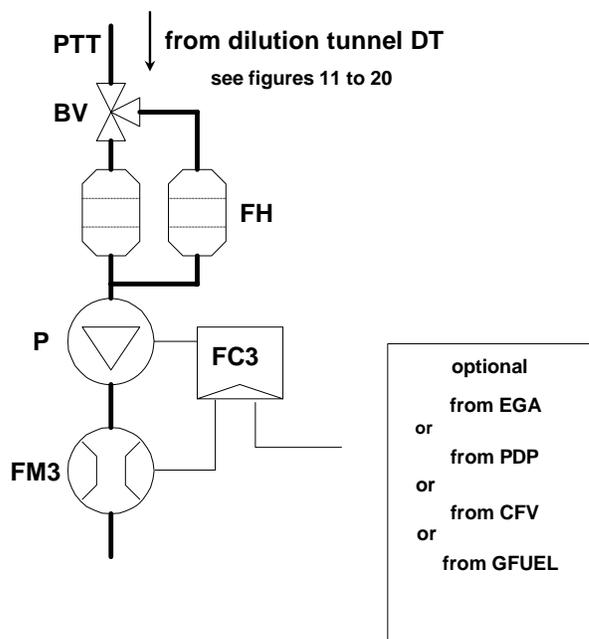
2.4. Particulate sampling system

The particulate sampling system is required for collecting the particulates on the particulate filter. In the case of total sampling partial flow dilution, which consists of passing the entire diluted exhaust sample through the filters, dilution (paragraph 2.2., figures 14 and 18) and sampling system usually form an integral unit. In the case of fractional sampling partial flow dilution or full flow dilution, which consists of passing through the filters only a portion of the diluted exhaust, the dilution (paragraph 2.2., figures 11, 12, 13, 15, 16, 17, 19; paragraph 2.3., figure 20) and sampling systems usually form different units.

In this Regulation, the double dilution system (figure 22) of a full flow dilution system is considered as a specific modification of a typical particulate sampling system as shown in figure 21. The double dilution system includes all important parts of the particulate sampling system, like filter holders and sampling pump, and additionally.

In order to avoid any impact on the control loops, it is recommended that the sample pump be running throughout the complete test procedure. For the single filter method, a bypass system shall be used for passing the sample through the sampling filters at the desired times. Interference of the switching procedure on the control loops shall be minimized.

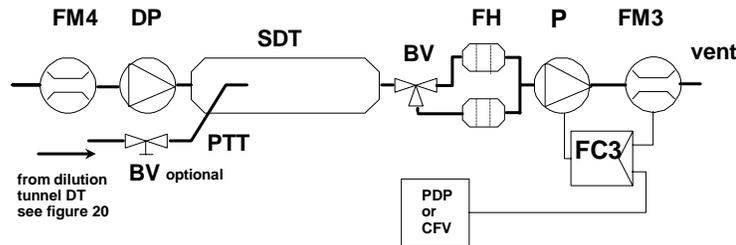
Figure 21
Particulate sampling system



A sample of the diluted exhaust gas is taken from the dilution tunnel DT of a partial flow or full flow dilution system through the particulate sampling probe PSP and the particulate transfer tube PTT by means of the sampling pump P. The sample is passed through the filter holder(s) FH that contain the particulate sampling filters. The sample flow rate is

controlled by the flow controller FC3. If electronic flow compensation EFC (see figure 20) is used, the diluted exhaust gas flow is used as command signal for FC3.

Figure 22
Double dilution system (full flow system only)



A sample of the diluted exhaust gas is transferred from the dilution tunnel DT of a full flow dilution system through the particulate sampling probe PSP and the particulate transfer tube PTT to the secondary dilution tunnel SDT, where it is diluted once more. The sample is then passed through the filter holder(s) FH that contain the particulate sampling filters. The dilution air flow rate is usually constant whereas the sample flow rate is controlled by the flow controller FC3. If electronic flow compensation EFC (see figure 20) is used, the total diluted exhaust gas flow is used as command signal for FC3.

2.4.1. Components of figures 21 and 22

PTT Particulate transfer tube (figures 21 and 22)

The particulate transfer tube shall not exceed 1,020 mm in length, and shall be minimized in length whenever possible. As indicated below (i.e. for partial flow dilution fractional sampling systems and for full flow dilution systems), the length of the sampling probes (SP, ISP, PSP, respectively, see paragraphs 2.2. and 2.3.) shall be included.

The dimensions are valid for:

- the partial flow dilution fractional sampling type and the full flow single dilution system from the tip of the probe (SP, ISP, PSP, respectively) to the filter holder;
- the partial flow dilution total sampling type from the end of the dilution tunnel to the filter holder;
- the full flow double dilution system from the tip of the probe (PSP) to the secondary dilution tunnel.

The transfer tube:

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

SDT secondary dilution tunnel (figure 22)

The secondary dilution tunnel should have a minimum diameter of 75 mm, and should be of sufficient length so as to provide a residence time of at least 0,25 seconds for the doubly-diluted sample. The primary filter holder FH shall be located within 300 mm of the exit of the SDT.

The secondary dilution tunnel:

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

FH Filter holder(s) (figures 21 and 22)

The filter holder shall meet the requirements of paragraph 4.1.3. of Appendix 4 to this annex.

The filter holder:

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

P sampling pump (figures 21 and 22)

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

DP dilution air pump (figure 22)

The dilution air pump shall be located so that the secondary dilution air is supplied at a temperature of $298 \text{ K} \pm 5 \text{ K}$ ($25^\circ\text{C} \pm 5^\circ\text{C}$), if the dilution air is not preheated.

FC3 Flow controller (figures 21 and 22)

A flow controller shall be used to compensate the particulate sample flow rate for temperature and backpressure variations in the sample path, if no other means are available. The flow controller is required if electronic flow compensation EFC (see figure 20) is used.

FM3 Flow measurement device (figures 21 and 22)

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

FM4 flow measurement device (figure 22)

The gas meter or flow instrumentation for the dilution air flow shall be located so that the inlet gas temperature remains at $298 \text{ K} \pm 5 \text{ K}$ ($25 \text{ }^\circ\text{C} \pm 5 \text{ }^\circ\text{C}$).

BV ball valve (optional)

The ball valve shall have an inside diameter not less than the inside diameter of the particulate transfer tube PTT, and a switching time of less than 0.5 seconds.

Note: If the ambient temperature in the vicinity of PSP, PTT, SDT, and FH is below 293 K ($20 \text{ }^\circ\text{C}$), precautions should be taken to avoid particle losses onto the cool wall of these parts. Therefore, heating and/or insulating these parts within the limits given in the respective descriptions is recommended. It is also recommended that the filter face temperature during sampling be not below 293 K ($20 \text{ }^\circ\text{C}$).

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

3. DETERMINATION OF SMOKE

3.1. Introduction

Paragraphs 3.2. and 3.3. and figures 23 and 24 contain detailed descriptions of the recommended opacimeter systems. Since various configurations can produce equivalent results, exact conformance with figures 23 and 24 is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

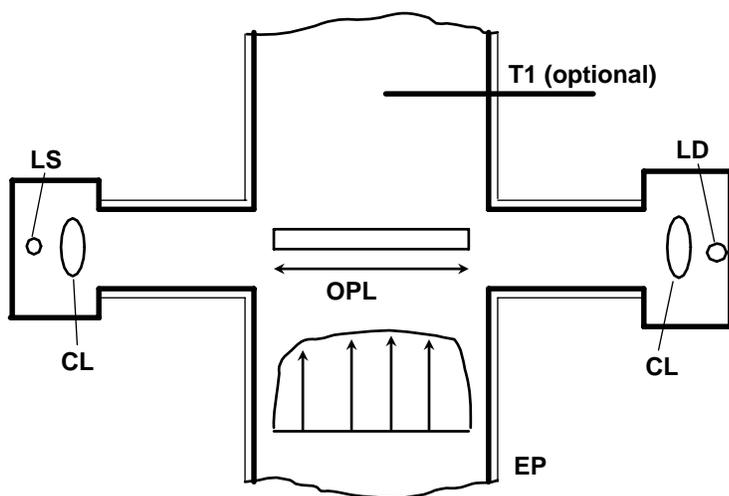
The principle of measurement is that light is transmitted through a specific length of the smoke to be measured and that proportion of the incident light which reaches a receiver is used to assess the light obscuration properties of the medium. The smoke measurement depends upon the design of the apparatus, and may be done in the exhaust pipe (full flow in-line opacimeter), at the end of the exhaust pipe (full flow end-of-line opacimeter) or by taking a sample from the exhaust pipe (partial flow opacimeter). For the determination of the light absorption coefficient from the opacity signal, the optical path length of the instrument shall be supplied by the instrument manufacturer.

3.2. Full flow opacimeter

Two general types of full flow opacimeters may be used (figure 23). With the in-line opacimeter, the opacity of the full exhaust plume within the exhaust pipe is measured. With this type of opacimeter, the effective optical path length is a function of the opacimeter design.

With the end-of-line opacimeter, the opacity of the full exhaust plume is measured as it exits the exhaust pipe. With this type of opacimeter, the effective optical path length is a function of the exhaust pipe design and the distance between the end of the exhaust pipe and the opacimeter.

Figure 23
Full flow opacimeter



3.2.1. Components of figure 23

EP exhaust pipe

With an in-line opacimeter, there shall be no change in the exhaust pipe diameter within 3 exhaust pipe diameters before or after the measuring zone. If the diameter of the measuring zone is greater than the diameter of the exhaust pipe, a pipe gradually convergent before the measuring zone is recommended.

With an end-of-line opacimeter, the terminal 0.6 m of the exhaust pipe shall be of circular cross section and be free from elbows and bends. The end of the exhaust pipe shall be cut off squarely. The opacimeter shall be mounted centrally to the plume within 25 ± 5 mm of the end of the exhaust pipe.

OPL optical path length

The length of the smoke obscured optical path between the opacimeter light source and the receiver, corrected as necessary for non-uniformity due to density gradients and fringe effect. The optical path length shall be submitted by the instrument manufacturer taking into account any measures against sooting (e.g. purge air). If the optical path length is not available, it shall be determined in accordance with ISO 11614, paragraph 11.6.5. For the correct determination of the optical path length, a minimum exhaust gas velocity of 20 m/s is required.

LS light source

The light source shall be an incandescent lamp with a colour temperature in the range of 2,800 to 3,250 K or a green light emitting diode (LED) with a spectral peak between 550 and 570 nm. The light source shall be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

LD light detector

The detector shall be a photocell or a photodiode (with a filter, if necessary). In the case of an incandescent light source, the receiver shall have a peak spectral response similar to the photopic curve of the human eye (maximum response) in the range of 550 to 570 nm, to less than 4 per cent of that maximum response below 430 nm and above 680 nm. The light detector shall be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

CL collimating lens

The light output shall be collimated to a beam with a maximum diameter of 30 mm. The rays of the light beam shall be parallel within a tolerance of 3° of the optical axis.

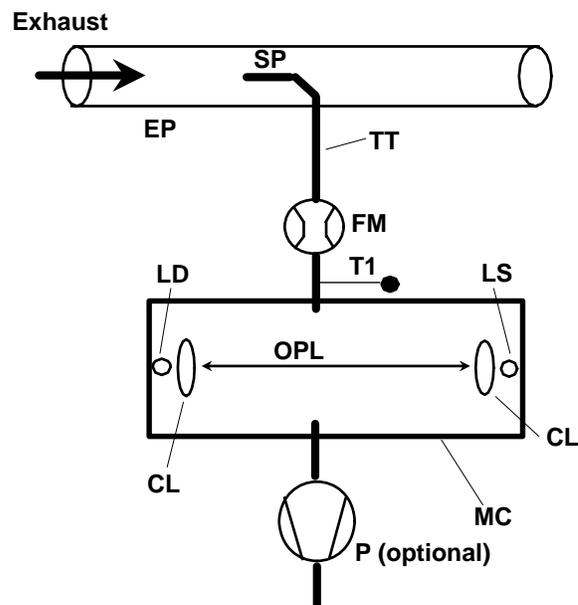
T1 temperature sensor (optional)

The exhaust gas temperature may be monitored over the test.

3.3. Partial flow opacimeter

With the partial flow opacimeter (figure 24), a representative exhaust sample is taken from the exhaust pipe and passed through a transfer line to the measuring chamber. With this type of opacimeter, the effective optical path length is a function of the opacimeter design. The response times referred to in the following paragraph apply to the minimum flow rate of the opacimeter, as specified by the instrument manufacturer.

Figure 24
Partial flow opacimeter



3.3.1. Components of figure 24

EP exhaust pipe

The exhaust pipe shall be a straight pipe of at least 6-pipe diameters upstream and 3-pipe diameters downstream of the tip of the probe.

SP sampling probe

The sampling probe shall be an open tube facing upstream on or about the exhaust pipe centreline. The clearance with the wall of the tailpipe shall be at least 5 mm. The probe diameter shall ensure a representative sampling and a sufficient flow through the opacimeter.

TT transfer tube

The transfer tube shall:

- Be as short as possible and ensure an exhaust gas temperature of 373 ± 30 K ($100 \text{ °C} \pm 30 \text{ °C}$) at the entrance to the measuring chamber.
- Have a wall temperature sufficiently above the dew point of the exhaust gas to prevent condensation.
- Be equal to the diameter of the sampling probe over the entire length.
- Have a response time of less than 0.05 s at minimum instrument flow, as determined according to paragraph 5.2.4. of Appendix 4 to this annex.
- Have no significant effect on the smoke peak.

FM flow measurement device

Flow instrumentation to detect the correct flow into the measuring chamber. The minimum and maximum flow rates shall be specified by the instrument manufacturer, and shall be such that the response time requirement of TT and the optical path length specifications are met. The flow measurement device may be close to the sampling pump, P, if used.

MC measuring chamber

The measuring chamber shall have a non-reflective internal surface, or equivalent optical environment. The impingement of stray light on the detector due to internal reflections of diffusion effects shall be reduced to a minimum.

The pressure of the gas in the measuring chamber shall not differ from the atmospheric pressure by more than 0.75 kPa. Where this is not possible by design, the opacimeter reading shall be converted to atmospheric pressure.

The wall temperature of the measuring chamber shall be set to within ± 5 K between 343 K (70 °C) and 373 K (100 °C), but in any case sufficiently above the dew point of the exhaust gas to prevent condensation. The measuring chamber shall be equipped with appropriate devices for measuring the temperature.

OPL optical path length

The length of the smoke obscured optical path between the opacimeter light source and the receiver, corrected as necessary for non-uniformity due to density gradients and fringe effect. The optical path length shall be submitted by the instrument manufacturer taking into account any measures against sooting (e.g. purge air). If the optical path length is not available, it shall be determined in accordance with ISO 11614, paragraph 11.6.5.

LS light source

The light source shall be an incandescent lamp with a colour temperature in the range of 2,800 to 3,250 K or a green light emitting diode (LED) with a spectral peak between 550 and 570 nm. The light source shall be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

LD light detector

The detector shall be a photocell or a photodiode (with a filter, if necessary). In the case of an incandescent light source, the receiver shall have a peak spectral response similar to the photopic curve of the human eye (maximum response) in the range of 550 to 570 nm, to less than 4 per cent of that maximum response below 430 nm and above 680 nm. The light detector shall be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

CL collimating lens

The light output shall be collimated to a beam with a maximum diameter of 30 mm. The rays of the light beam shall be parallel within a tolerance of 3° of the optical axis.

T1 temperature sensor

To monitor the exhaust gas temperature at the entrance to the measuring chamber.

P sampling pump (optional)

A sampling pump downstream of the measuring chamber may be used to transfer the sample gas through the measuring chamber.

Annex 5

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

1.1. DIESEL REFERENCE FUEL FOR TESTING ENGINES TO THE EMISSION LIMITS GIVEN IN ROW A OF THE TABLES IN PARAGRAPH 5.2.1. OF THIS REGULATION ^(a)

Parameter	Unit	Limits ^(b)		Test Method	Publication
		Minimum	Maximum		
Cetane number ^(c)		52	54	EN-ISO 5165	1998 ^(d)
Density at 15 °C	kg/m ³	833	837	EN-ISO 3675	1995
Distillation:					
— 50 per cent point	°C	245	—	EN-ISO 3405	1998
— 95 per cent point	°C	345	350	EN-ISO 3405	1998
— final boiling point	°C	—	370	EN-ISO 3405	1998
Flash point	°C	55	—	EN 27719	1993
CFPP	°C	—	- 5	EN 116	1981
Viscosity at 40 °C	mm ² /s	2.5	3.5	EN-ISO 3104	1996
Polycyclic aromatic hydrocarbons	per cent m/m	3.0	6.0	IP 391 (*)	1995
Sulphur content ^(e)	mg/kg	—	300	pr. EN-ISO/DIS 14596	1998 ^(d)
Copper corrosion		—	1	EN-ISO 2160	1995
Conradson carbon residue (10 per cent DR)	per cent m/m	—	0.2	EN-ISO 10370	
Ash content	per cent m/m	—	0.01	EN-ISO 6245	1995
Water content	per cent m/m	—	0.05	EN-ISO 12937	1995
Neutralisation (strong acid) number	mg KOH/g	—	0.02	ASTM D 974-95	1998 ^(d)
Oxidation stability ^(f)	mg/ml	—	0.025	EN-ISO 12205	1996
(*) New and better method for polycyclic aromatics under development	per cent m/m	—	—	EN 12916	[1997] ^(d)

-
- (a) If it is required to calculate the thermal efficiency of an engine or vehicle, the calorific value of the fuel can be calculated from:
Specific energy (calorific value)(net) in MJ/kg = $(46.423 - 8.792d^2 + 3.170d)(1 - (x + y + s)) + 9.420s - 2.499x$
where.
d = the density at 15 °C
x = the proportion by mass of water (per cent divided by 100)
y = the proportion by mass of ash (per cent divided by 100)
s = the proportion by mass of sulphur (per cent divided by 100).
- (b) The values quoted in the specification are "true values". In establishment of their limit values the terms of ISO 4259, Petroleum products - Determination and application of precision data in relation to methods of test, have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for statistical reasons, the manufacturer of a fuel should nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify the question as to whether a fuel meets the requirements of the specification, the terms of ISO 4259 should be applied.
- (c) The range for cetane number is not in accordance with the requirement of a minimum range of 4R. However, in the case of dispute between fuel supplier and fuel user. the terms in ISO 4259 can be used to resolve such disputes provided replicate measurements, of sufficient number to achieve the necessary precision, are made in preference to single determinations.
- (d) The month of publication will be completed in due course.
- (e) The actual sulphur content of the fuel used for the test shall be reported.
- (f) Even though oxidation stability is controlled, it is likely that shelf life will be limited. Advice should be sought from the supplier as to storage conditions and life.
-

1.2. DIESEL REFERENCE FUEL FOR TESTING ENGINES TO THE EMISSION LIMITS GIVEN IN ROWS B1, B2 OR C OF THE TABLES IN PARAGRAPH 5.2.1. OF THIS REGULATION

Parameter	Unit	Limits ^(a)		Test Method
		minimum	maximum	
Cetane number ^(b)		52.0	54.0	EN-ISO 5165
Density at 15°C	kg/m ³	833	837	EN-ISO 3675
Distillation:				
50 per cent point	°C	245	-	EN-ISO 3405
95 per cent point	°C	345	350	EN-ISO 3405
- Final boiling point	°C	-	370	EN-ISO 3405
Flash point	°C	55	-	EN 22719
CFPP	°C	-	-5	EN 116
Viscosity at 40°C	mm ² /s	2.3	3.3	EN-ISO 3104
Polycyclic aromatic hydrocarbons	per cent m/m	2.0	6.0	IP 391
Sulphur content ^(c)	mg/kg	-	10	ASTM D 5453
Copper corrosion		-	class 1	EN-ISO 2160
Conradson carbon residue (10 per cent DR)	per cent m/m	-	0.2	EN-ISO 10370
Ash content	per cent m/m	-	0.01	EN-ISO 6245
Water content	per cent m/m	-	0.02	EN-ISO 12937
Neutralisation (strong acid) number	Mg KOH/g	-	0.02	ASTM D 974
Oxidation stability ^(d)	mg/ml	-	0.025	EN-ISO 12205
Lubricity (HFRR wear scan diameter at 60°C)	Mm	-	400	CEC F-06-A-96
FAME	prohibited			
<p>^(a) The values quoted in the specifications are "true values". In establishment of their limit values the terms of ISO 4259 "Petroleum products – Determination and application of precision data in relation to methods of test" have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels should nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify the questions as to whether a fuel meets the requirements of the specifications, the terms of ISO 4259 should be applied.</p> <p>^(b) The range for cetane number is not in accordance with the requirements of a minimum range of 4R. However, in the case of a dispute between fuel supplier and fuel user, the terms of ISO 4259 may be used to resolve such disputes provided replicate measurements, of sufficient number to archive the necessary precision, are made in preference to single determinations.</p> <p>^(c) The actual sulphur content of the fuel used for the Type I test shall be reported.</p> <p>^(d) Even though oxidation stability is controlled, it is likely that shelf life will be limited. Advice should be sought from the supplier as to storage conditions and life.</p>				

1.3. ETHANOL FOR DIESEL ENGINES ^(a)

Parameter	Unit	Limits ^(b)		Test method ^(c)
		Minimum	Maximum	
Alcohol, mass	per cent m/m	92.4	—	ASTM D 5501
Other alcohol than ethanol contained in total alcohol, mass	per cent m/m	—	2	ADTM D 5501
Density at 15 °C	kg/m ³	795	815	ASTM D 4052
Ash content	per cent m/m		0.001	ISO 6245
Flash point	°C	10		ISO 2719
Acidity, calculated as acetic acid	per cent m/m	—	0.0025	ISO 1388-2
Neutralisation (strong acid) number	KOH mg/l	—	1	
Colour	According to scale	—	10	ASTM D 1209
Dry residue at 100 °C	mg/kg		15	ISO 759
Water content	per cent m/m		6.5	ISO 760
Aldehydes calculated as acetic acid	per cent m/m		0.0025	ISO 1388-4
Sulphur content	mg/kg	—	10	ASTM D 5453
Esters, calculated as ethylacetate	per cent m/m	—	0.1	ASSTM D 1617

^(a) Cetane improver, as specified by the engine manufacturer, may be added to the ethanol fuel. The maximum allowed amount is 10 per cent m/m.

^(b) The values quoted in the specification are "true values". In establishment of their limit values the terms of ISO 4259, Petroleum products - Determination and application of precision data in relation to methods of test, have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R - reproducibility). Notwithstanding this measure, which is necessary for statistical reasons, the manufacturer of a fuel should nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify the question as to whether a fuel meets the requirements of the specification, the terms of ISO 4259 should be applied.

^(c) Equivalent ISO methods will be adopted when issued for all properties listed above

2. NATURAL GAS (NG)

European market fuels are available in two ranges:

- (a) the H range, whose extreme reference fuels are G_R and G₂₃;
- (b) the L range, whose extreme reference fuels are G₂₃ and G₂₅.

The characteristics of G_R, G₂₃ and G₂₅ reference fuels are summarized below:

Reference fuel G _R					
Characteristics	Units	Basis	Limits		Test Method
			Minimum	Maximum	
Composition:					
Methane		87	84	89	
Ethane		13	11	15	
Balance ^(a)	per cent-	-	-	1	ISO 6974
Sulphur content	mg/m ³ ^(b)	-	-	10	ISO 6326-5
^(a) Inerts +C ₂₊					
^(b) Value to be determined at standard conditions (293.2 K (20 °C) and 101.3 kPa).					
Reference fuel G ₂₃					
Characteristics	Units	Basis	Limits		Test Method
			Minimum	Maximum	
Composition:					
Methane		92.5	91.5	93.5	
Balance ^(a)	per cent-	-	-	1	ISO 6974
N ₂		7.5	6.5	8.5	
Sulphur content	mg/m ³ ^(b)	-	-	10	ISO 6326-5
^(a) Inerts (different from N ₂) +C ₂₊ +C ₂₊					
^(b) Value to be determined at standard conditions (293.2 K (20 °C) and 101.3 kPa).					
Reference fuel G ₂₅					
Characteristics	Units	Basis	Limits		Test Method
			Minimum	Maximum	
Composition:					
Methane		86	84	88	
Balance ^(a)	per cent-	-	-	1	ISO 6974
N ₂		14	12	16	
Sulphur content	mg/m ³ ^(b)	-	-	10	ISO 6326-5
^(a) Inerts (different from N ₂) +C ₂₊ +C ₂₊					
^(b) Value to be determined at standard conditions (293.2 K (20 °C) and 101.3 kPa).					

3. TECHNICAL DATA OF THE LPG REFERENCE FUELS

A. TECHNICAL DATA OF THE LPG REFERENCE FUELS USED FOR TESTING VEHICLES TO THE EMISSION LIMITS GIVEN IN ROW A OF THE TABLES IN PARAGRAPH 5.2.1. OF THIS REGULATION

Parameter	Unit	Fuel A	Fuel B	Test method
Composition:				ISO 7941
C ₃ -content	per cent vol	50 ± 2	85 ± 2	
C ₄ -content	per cent vol	balance	balance	
< C ₃ , >C ₄	per cent vol	Max. 2	max. 2	
Olefins	per cent vol	max. 12	max. 14	
Evaporation residue	mg/kg	max. 50	max. 50	ISO 13757
Water at 0°C		free	free	visual inspection
Total sulphur content	mg/kg	max. 50	max. 50	EN 24260
Hydrogen sulphide		none	none	ISO 8819
Copper strip corrosion	rating	Class 1	class 1	ISO 6251 ^(a)
Odour		characteristic	characteristic	
Motor octane number		min. 92.5	min. 92.5	EN 589 Annex B

^(a) This method may not accurately determine the presence of corrosive materials if the sample contains corrosion inhibitors or other chemicals which diminish the corrosivity of the sample to the copper strip. Therefore, the addition of such compounds for the sole purpose of biasing the test method is prohibited.

B. TECHNICAL DATA OF THE LPG REFERENCE FUELS USED FOR TESTING VEHICLES TO THE EMISSION LIMITS GIVEN IN ROW B1, B2 OR C OF THE TABLES IN PARAGRAPH 5.2.1. OF THIS REGULATION

Parameter	Unit	Fuel A	Fuel B	Test method
Composition:				ISO 7941
C ₃ -content	per cent vol	50 ± 2	85 ± 2	
C ₄ -content	per cent vol	balance	balance	
< C ₃ , >C ₄	per cent vol	max. 2	max. 2	
Olefins	per cent vol	max. 12	max. 14	
Evaporation residue	mg/kg	max. 50	max. 50	ISO 13757
Water at 0°C		free	free	Visual inspection
Total sulphur content	mg/kg	max. 10	max. 10	EN 24260
Hydrogen sulphide		none	none	ISO 8819
Copper strip corrosion	Rating	class 1	class 1	ISO 6251 ^(a)
Odour		characteristic	characteristic	
Motor octane number		min. 92.5	min. 92.5	EN 589 Annex B

^(a) This method may not accurately determine the presence of corrosive materials if the sample contains corrosion inhibitors or other chemicals which diminish the corrosivity of the sample to the copper strip. Therefore, the addition of such compounds for the sole purpose of biasing the test method is prohibited.

Annex 6

EXAMPLE OF CALCULATION PROCEDURE

1. ESC TEST

1.1. Gaseous emissions

The measurement data for the calculation of the individual mode results are shown below. In this example, CO and NO_x are measured on a dry basis, HC on a wet basis. The HC concentration is given in propane equivalent (C3) and has to be multiplied by 3 to result in the C1 equivalent. The calculation procedure is identical for the other modes.

P (kW)	T _a (K)	H _a (g/kg)	G _{EXH} (kg)	G _{AIRW} (kg)	G _{FUEL} (kg)	HC (ppm)	CO (ppm)	NO _x (ppm)
82.9	294.8	7.81	563.38	545.29	18.09	6.3	41.2	495

Calculation of the dry to wet correction factor K_{w,r} (Annex 4A, Appendix 1, paragraph 45.2):

$$F_{FH} = \frac{1.969}{1 + \frac{18.09}{545.29}} = 1.9058$$

$$K_{w2} = \frac{1.608 \times 7.81}{1000 + (1.608 \times 7.81)} = 0.0124$$

and

$$K_{w,r} = \left(1 - 1.9058 \times \frac{18.09}{541.06} \right) - 0.0124 = 0.9239$$

Calculation of the wet concentrations:

$$CO = 41.2 \times 0.9239 = 38.1 \text{ ppm}$$

$$NO_x = 495 \times 0.9239 = 457 \text{ ppm}$$

Calculation of the NO_x humidity correction factor K_{H,D} (Annex 4A, Appendix 1, paragraph 54.3):

$$A = 0.309 \times 18.09/541.06 - 0.0266 = -0.0163$$

$$B = -0.209 \times 18.09/541.06 + 0.00954 = 0.0026$$

$$K_{H,D} = \frac{1}{1 - 0.0163 \times (7.81 - 10.71) + 0.0026 \times (294.8 - 298)} = 0.9625$$

Calculation of the emission mass flow rates (Annex 4A, Appendix 1, paragraph 54.4.):

$$\text{NO}_x = 0.001587 \times 457 \times 0.9625 \times 563.38 = 393.27 \text{ g/h}$$

$$\text{CO} = 0.000966 \times 38.1 \times 563.38 = 20.735 \text{ g/h}$$

$$\text{HC} = 0.000479 \times 6.3 \times 3 \times 563.38 = 5.100 \text{ g/h}$$

Calculation of the specific emissions (Annex 4A, Appendix 1, paragraph 54.5.):

The following example calculation is given for CO; the calculation procedure is identical for the other components.

The emission mass flow rates of the individual modes are multiplied by the respective weighting factors, as indicated in Annex 4A, Appendix 1, paragraph 2.7.1., and summed up to result in the mean emission mass flow rate over the cycle:

$$\begin{aligned} \text{CO} &= (6.7 \times 0.15) + (24.6 \times 0.08) + (20.5 \times 0.10) + (20.7 \times 0.10) + (20.6 \times 0.05) + (15.0 \times \\ &0.05) + (19.7 \times 0.05) + (74.5 \times 0.09) + (31.5 \times 0.10) + (81.9 \times 0.08) + (34.8 \times 0.05) + (30.8 \\ &\times 0.05) + (27.3 \times 0.05) \\ &= 30.91 \text{ g/h} \end{aligned}$$

The engine power of the individual modes is multiplied by the respective weighting factors, as indicated in Annex 4A, Appendix 1, paragraph 2.7.1., and summed up to result in the mean cycle power:

$$\begin{aligned} \text{P(n)} &= (0.1 \times 0.15) + (96.8 \times 0.08) + (55.2 \times 0.10) + (82.9 \times 0.10) + (46.8 \times 0.05) + (70.1 \times \\ &0.05) + (23.0 \times 0.05) + (114.3 \times 0.09) + (27.0 \times 0.10) + (122.0 \times 0.08) + (28.6 \times 0.05) + \\ &(87.4 \times 0.05) + (57.9 \times 0.05) \\ &= 60.006 \text{ kW} \end{aligned}$$

$$\overline{\text{CO}} = \frac{30.91}{60.006} = 0.0515 \text{ g/kWh}$$

Calculation of the specific NO_x emission of the random point (Annex 4A, Appendix 1, paragraph 54.6.1):

Assume the following values have been determined on the random point:

n_Z	1 600 min ⁻¹
M_Z	495 Nm
$\text{NO}_{x \text{ mass},Z}$	487.9 g/h (calculated according to the previous formulae)
P(n)_Z	83 kW
$\text{NO}_{x,Z}$	487.9/83 = 5.878 g/kWh

Determination of the emission value from the test cycle (Annex 4A, Appendix 1, paragraph 45.6.2.):

Assume the values of the four enveloping modes on the ESC to be as follows:

n_{RT}	n_{SU}	E_R	E_S	E_T	E_U	M_R	M_S	M_T	M_U
1368	1785	5.943	5.565	5.889	4.973	515	460	681	610

$$E_{TU} = 5.889 + (4.973 - 5.889) \times (1\,600 - 1\,368) / (1\,785 - 1\,368) = 5.377 \text{ g/kWh}$$

$$E_{RS} = 5.943 + (5.565 - 5.943) \times (1\,600 - 1\,368) / (1\,785 - 1\,368) = 5.732 \text{ g/kWh}$$

$$M_{TU} = 681 + (601 - 681) \times (1\,600 - 1\,368) / (1\,785 - 1\,368) = 641.3 \text{ Nm}$$

$$M_{RS} = 515 + (460 - 515) \times (1\,600 - 1\,368) / (1\,785 - 1\,368) = 484.3 \text{ Nm}$$

$$E_Z = 5.732 + (5.377 - 5.732) \times (495 - 484.3) / (641.3 - 484.3) = 5.708 \text{ g/kWh}$$

Comparison of the NO_x emission values (Annex 4A, Appendix 1, paragraph 45.6.3.):

$$NO_{x \text{ diff}} = 100 \times (5.878 - 5.708) / 5.708 = 2.98 \text{ per cent}$$

1.2. Particulate emissions

Particulate measurement is based on the principle of sampling the particulates over the complete cycle, but determining the sample and flow rates (M_{SAM} and G_{EDF}) during the individual modes. The calculation of G_{EDF} depends on the system used. In the following examples, a system with CO₂ measurement and carbon balance method and a system with flow measurement are used. When using a full flow dilution system, G_{EDF} is directly measured by the CVS equipment.

Calculation of G_{EDF} (Annex 4A, Appendix 1, paragraphs 6.2.3. and 6.2.4.):

Assume the following measurement data of mode 4. The calculation procedure is identical for the other modes.

G_{EXH} (kg/h)	G_{FUEL} (kg/h)	G_{DILW} (kg/h)	G_{TOTW} (kg/h)	CO _{2D} (per cent)	CO _{2A} (per cent)
334.02	10.76	5.4435	6.0	0.657	0.040

(a) carbon balance method

$$G_{EDFW} = \frac{206.5 \times 10.76}{0.657 - 0.040} = 3\,601.2 \text{ kg/h}$$

(b) flow measurement method

$$q = \frac{6.0}{6.0 - 5.4435} = 10.78$$

$$G_{EDFW} = 334.02 \times 10.78 = 3\,600.7 \text{ kg/h}$$

Calculation of the mass flow rate (Annex 4A, Appendix 1, paragraph 6.4.):

The G_{EDFW} flow rates of the individual modes are multiplied by the respective weighting factors, as indicated in Annex 4A, Appendix 1, paragraph 2.7.1., and summed up to result

in the mean G_{EDF} over the cycle. The total sample rate M_{SAM} is summed up from the sample rates of the individual modes.

$$\begin{aligned}\overline{G}_{EDF W} &= (3\,567 \times 0.15) + (3\,592 \times 0.08) + (3\,611 \times 0.10) + (3\,600 \times 0.10) + (3\,618 \times 0.05) \\ &\quad + (3\,600 \times 0.05) + (3\,640 \times 0.05) + (3\,614 \times 0.09) + (3\,620 \times 0.10) + \\ &\quad (3\,601 \times 0.08) + (3\,639 \times 0.05) + (3\,582 \times 0.05) + (3\,635 \times 0.05) \\ &= 3\,604.6 \text{ kg/h}\end{aligned}$$

$$\begin{aligned}M_{SAM} &= 0.226 + 0.122 + 0.151 + 0.152 + 0.076 + 0.076 + 0.076 + 0.136 + 0.151 + \\ &\quad 0.121 + 0.076 + 0.076 + 0.075 \\ &= 1.515 \text{ kg}\end{aligned}$$

Assume the particulate mass on the filters to be 2.5 mg, then

$$PT_{mass} = \frac{2.5}{1.515} \times \frac{360.4}{1000} = 5.948 \text{ g/h}$$

Background correction (optional)

Assume one background measurement with the following values. The calculation of the dilution factor DF is identical to paragraph 3.1. of this annex and not shown here.

$$M_d = 0.1 \text{ mg}; M_{DIL} = 1.5 \text{ kg}$$

$$\begin{aligned}\text{Sum of DF} &= [(1-1/119.15) \times 0.15] + [(1-1/8.89) \times 0.08] + [(1-1/14.75) \times 0.10] + \\ &\quad [(1-1/10.10) \times 0.10] + [(1-1/18.02) \times 0.05] + [(1-1/12.33) \times 0.05] + \\ &\quad [(1-1/32.18) \times 0.05] + [(1-1/6.94) \times 0.09] + [(1-1/25.19) \times 0.10] + \\ &\quad [(1-1/6.12) \times 0.08] + [(1-1/20.87) \times 0.05] + [(1-1/8.77) \times 0.05] + \\ &\quad [(1-1/12.59) \times 0.05] \\ &= 0.923\end{aligned}$$

$$PT_{mass} = \frac{2.5}{1.515} - \left(\frac{0.1}{1.5} \times 0.923 \right) \times \frac{3\,604.6}{1000} = 5.726 \text{ g/h}$$

Calculation of the specific emission (Annex 4A, Appendix 1, paragraph 6.5.):

$$\begin{aligned}P(n) &= (0.1 \times 0.15) + (96.8 \times 0.08) + (55.2 \times 0.10) + (82.9 \times 0.10) + (46.8 \times 0.05) + \\ &\quad (70.1 \times 0.05) + (23.0 \times 0.05) + (114.3 \times 0.09) + (27.0 \times 0.10) + (122.0 \times 0.08) + \\ &\quad (28.6 \times 0.05) + (87.4 \times 0.05) + (57.9 \times 0.05)\end{aligned}$$

$$= 60.006 \text{ kW}$$

$$\overline{PT} = \frac{5.948}{60.006} = 0.099 \text{ g/kWh}$$

if background corrected $\overline{PT} = (5.726/60.006) = 0.095 \text{ g/kWh}$,

Calculation of the specific weighting factor (Annex 4A, Appendix 1, paragraph 6.6.):

Assume the values calculated for mode 4 above, then $W_{fei} = (0.152 \times 360 \times 4.6 / 1.515 \times 360 \times 0.7) = 0.1004$

This value is within the required value of 0.10 ± 0.003 .

2. ELR TEST

Since Bessel filtering is a completely new averaging procedure in European exhaust legislation, an explanation of the Bessel filter, an example of the design of a Bessel algorithm, and an example of the calculation of the final smoke value is given below. The constants of the Bessel algorithm only depend on the design of the opacimeter and the sampling rate of the data acquisition system. It is recommended that the opacimeter manufacturer provide the final Bessel filter constants for different sampling rates and that the customer use these constants for designing the Bessel algorithm and for calculating the smoke values.

2.1. General remarks on the Bessel filter

Due to high frequency distortions, the raw opacity signal usually shows a highly scattered trace. To remove these high frequency distortions a Bessel filter is required for the ELR-Test. The Bessel filter itself is a recursive, second-order low-pass filter which guarantees the fastest signal rise without overshoot.

Assuming a real time raw exhaust plume in the exhaust tube, each opacimeter shows a delayed and differently measured opacity trace. The delay and the magnitude of the measured opacity trace is primarily dependent on the geometry of the measuring chamber of the opacimeter, including the exhaust sample lines, and on the time needed for processing the signal in the electronics of the opacimeter. The values that characterize these two effects are called the physical and the electrical response time which represent an individual filter for each type of opacimeter.

The goal of applying a Bessel filter is to guarantee a uniform overall filter characteristic of the whole opacimeter system, consisting of:

- (a) physical response time of the opacimeter (t_p)
- (b) electrical response time of the opacimeter (t_e)
- (c) filter response time of the applied Bessel filter (t_f)

The resulting overall response time of the system t_{Aver} is given by:

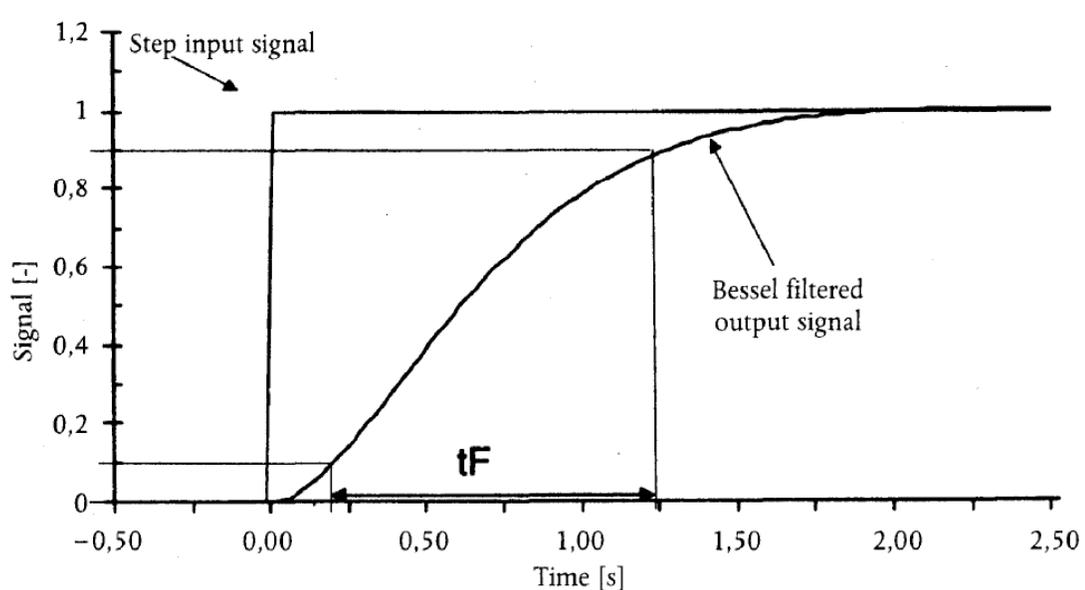
$$t_{Aver} = \sqrt{t_f^2 + t_p^2 + t_e^2}$$

and shall be equal for all kinds of opacimeters in order to give the same smoke value. Therefore, a Bessel filter has to be created in such a way, that the filter response time (t_F) together with the physical (t_p) and electrical response time (t_e) of the individual opacimeter shall result in the required overall response time (t_{Aver}). Since t_p and t_e are given values for each individual opacimeter, and t_{Aver} is defined to be 1.0 s in this Regulation, t_F can be calculated as follows:

$$t_F = \sqrt{t_{Aver}^2 + t_p^2 + t_e^2}$$

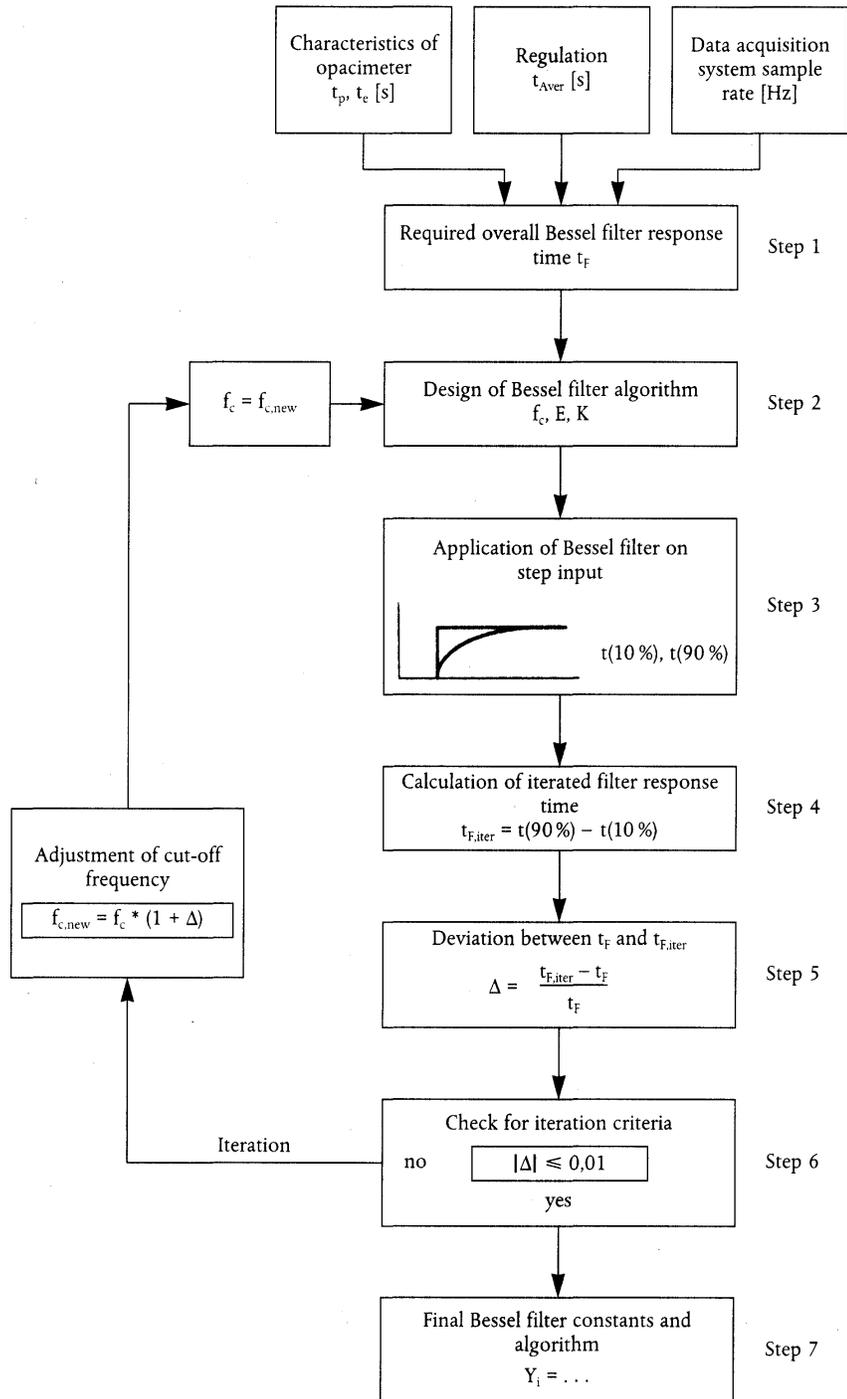
By definition, the filter response time t_F is the rise time of a filtered output signal between 10 per cent and 90 per cent on a step input signal. Therefore the cut-off frequency of the Bessel filter has to be iterated in such a way, that the response time of the Bessel filter fits into the required rise time.

Figure a
Traces of a step input signal and the filtered output signal



In figure a, the traces of a step input signal and Bessel filtered output signal as well as the response time of the Bessel filter (t_F) are shown.

Designing the final Bessel filter algorithm is a multi step process which requires several iteration cycles. The scheme of the iteration procedure is presented below.



2.2. Calculation of the Bessel algorithm

In this example a Bessel algorithm is designed in several steps according to the above iteration procedure which is based upon Annex 4A, Appendix 1, paragraph 7.1.

For the opacimeter and the data acquisition system, the following characteristics are assumed:

- (a) physical response time t_p 0.15 s
- (b) electrical response time t_e 0.05 s
- (c) overall response time t_{Aver} 1.00 s (by definition in this Regulation)
- (d) sampling rate 150 Hz

Step 1: Required Bessel filter response time t_F :

$$t_F = \sqrt{1^2 - (0.15^2 + 0.05^2)} = 0.987421 \text{ s}$$

Step 2: Estimation of cut-off frequency and calculation of Bessel constants E, K for first iteration:

$$f_c = \frac{3.1415}{10 \times 0.987421} = 0.318152 \text{ Hz}$$

$$\Delta t = 1/150 = 0.006667 \text{ s}$$

$$\Omega = \frac{1}{\tan[3.1415 \times 0.006667 \times 0.318152]} = 150.07664$$

$$E = \frac{1}{1 + 150.076644 \times \sqrt{3 \times 0.618034} + 0.618034 \times 150.076644^2} = 7.07948 \times 10^{-5}$$

$$K = 2 \times 7.07948 \times 10^{-5} \times (0.618034 \times 150.076644^2 - 1) - 1 = 0.970783$$

This gives the Bessel algorithm:

$$Y_i = Y_{i-1} + 7.07948 E - 5 \times (S_i + 2 \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + 0.970783 \times (Y_{i-1} - Y_{i-2})$$

where S_i represents the values of the step input signal (either "0" or "1") and Y_i represents the filtered values of the output signal.

Step 3: Application of Bessel filter on step input:

The Bessel filter response time t_F is defined as the rise time of the filtered output signal between 10 per cent and 90 per cent on a step input signal. For determining the times of 10 per cent (t_{10}) and 90 per cent (t_{90}) of the output signal, a Bessel filter has to be applied to a step input using the above values of f_c , E and K.

The index numbers, the time and the values of a step input signal and the resulting values of the filtered output signal for the first and the second iteration are shown in table B. The points adjacent to t_{10} and t_{90} are marked in bold numbers.

In table B, first iteration, the 10 per cent value occurs between index number 30 and 31 and the 90 per cent value occurs between index number 191 and 192. For the calculation of

$t_{F,iter}$ the exact t_{10} and t_{90} values are determined by linear interpolation between the adjacent measuring points, as follows:

$$t_{10} = t_{lower} + \Delta t \times (0.1 - out_{lower}) / (out_{upper} - out_{lower})$$

$$t_{90} = t_{lower} + \Delta t \times (0.9 - out_{lower}) / (out_{upper} - out_{lower})$$

where out_{upper} and out_{lower} , respectively, are the adjacent points of the Bessel filtered output signal, and t_{lower} is the time of the adjacent time point, as indicated in table B.

$$t_{10} = 0.200000 + 0.006667 \times (0.1 - 0.099208) / (0.104794 - 0.099208) = 0.200945 \text{ s}$$

$$t_{90} = 0.273333 + 0.006667 \times (0.9 - 0.899147) / (0.901168 - 0.899147) = 1.276147 \text{ s}$$

Step 4: Filter response time of first iteration cycle:

$$t_{F,iter} = 1.276147 - 0.200945 = 1.075202 \text{ s}$$

Step 5: Deviation between required and obtained filter response time of first iteration cycle:

$$\Delta = (1.075202 - 0.987421) / 0.987421 = 0.081641$$

Step 6: Checking the iteration criteria:

$|\Delta| \leq 0.01$ is required. Since $0.081641 > 0.01$, the iteration criteria is not met and a further iteration cycle has to be started. For this iteration cycle, a new cut-off frequency is calculated from f_c and Δ as follows: $f_{c,new} = 0.318152 \times (1 + 0.081641) = 0.344126 \text{ Hz}$

This new cut-off frequency is used in the second iteration cycle, starting at step 2 again. The iteration has to be repeated until the iteration criterion is met. The resulting values of the first and second iteration are summarized in table A.

Table A
Values of the first and second iteration

Parameter		1. Iteration	2. Iteration
f_c	(Hz)	0.318152	0.344126
E	(-)	7.07948 E-5	8.272777 E-5
K	(-)	0.970783	0.968410
t_{10}	(s)	0.200945	0.185523
t_{90}	(s)	1.276147	1.179562
$t_{F,iter}$	(s)	1.075202	0.994039
Δ	(-)	0.081641	0.006657
$f_{c,new}$	(Hz)	0.344126	0.346417

Step 7: Final Bessel algorithm:

As soon as the iteration criterion has been met, the final Bessel filter constants and the final Bessel algorithm are calculated according to step 2. In this example, the iteration criterion has been met after the second iteration ($\Delta = 0.006657 \leq 0.01$). The final algorithm is then used for determining the averaged smoke values (see next paragraph 2.3.).

$$Y_i = Y_{i-1} + 8.272777 \times 10^{-5} \times (S_i + 2 \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + 0.968410 \times (Y_{i-1} - Y_{i-2})$$

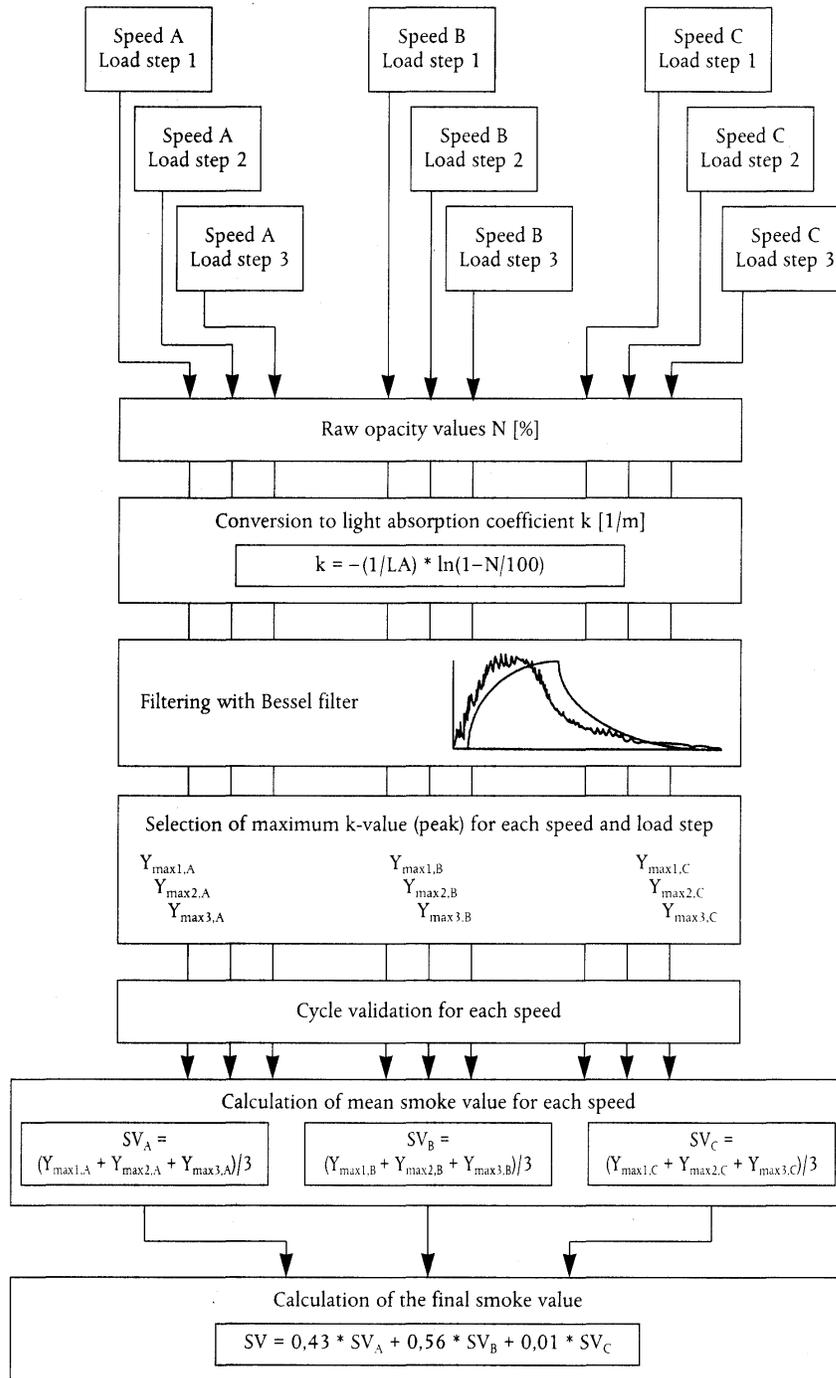
Table B

Values of step input signal and Bessel filtered output signal for the first and second iteration cycle

Index i [-]	Time [s]	Step Input Signal S_i [-]	Filtered Output Signal Y_i [-]	
			1. Iteration	2. Iteration
-2	-0.013333	0	0.000000	0.000000
-1	-0.006667	0	0.000000	0.000000
0	0.000000	1	0.000071	0.000083
1	0.006667	1	0.000352	0.000411
2	0.013333	1	0.000908	0.001060
3	0.020000	1	0.001731	0.002019
4	0.026667	1	0.002813	0.003278
5	0.033333	1	0.004145	0.004828
□	□	□	□	□
24	0.160000	1	0.067877	0.077876
25	0.166667	1	0.072816	0.083476
26	0.173333	1	0.077874	0.089205
27	0.180000	1	0.083047	0.095056
28	0.186667	1	0.088331	0.101024
29	0.193333	1	0.093719	0.107102
30	0.200000	1	0.099208	0.113286
31	0.206667	1	0.104794	0.119570
32	0.213333	1	0.110471	0.125949
33	0.220000	1	0.116236	0.132418
34	0.226667	1	0.122085	0.138972
35	0.233333	1	0.128013	0.145605
36	0.240000	1	0.134016	0.152314
37	0.246667	1	0.140091	0.159094
□	□	□	□	□
175	1.166667	1	0.862416	0.895701
176	1.173333	1	0.864968	0.897941
177	1.180000	1	0.867484	0.900145
178	1.186667	1	0.869964	0.902312
179	1.193333	1	0.872410	0.904445
180	1.200000	1	0.874821	0.906542
181	1.206667	1	0.877197	0.908605
182	1.213333	1	0.879540	0.910633
183	1.220000	1	0.881849	0.912628
184	1.226667	1	0.884125	0.914589
185	1.233333	1	0.886367	0.916517
186	1.240000	1	0.888577	0.918412
187	1.246667	1	0.890755	0.920276
188	1.253333	1	0.892900	0.922107
189	1.260000	1	0.895014	0.923907
190	1.266667	1	0.897096	0.925676
191	1.273333	1	0.899147	0.927414
192	1.280000	1	0.901168	0.929121
193	1.286667	1	0.903158	0.930799
194	1.293333	1	0.905117	0.932448
195	1.300000	1	0.907047	0.934067
□	□	□	□	□

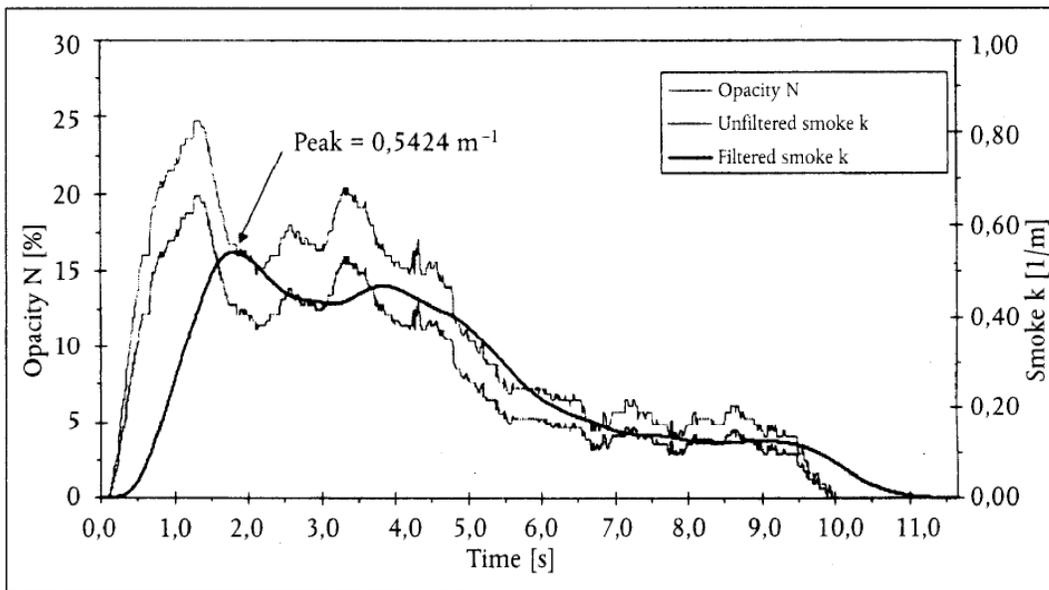
2.3. Calculation of the smoke values

In the scheme below the general procedure of determining the final smoke value is presented.



In figure b, the traces of the measured raw opacity signal, and of the unfiltered and filtered light absorption coefficients (k-value) of the first load step of an ELR-Test are shown, and the maximum value $Y_{\max 1,A}$ (peak) of the filtered k trace is indicated. Correspondingly, table C contains the numerical values of index i, time (sampling rate of 150 Hz), raw opacity, unfiltered k and filtered k. Filtering was conducted using the constants of the Bessel algorithm designed in paragraph 2.2. of this annex. Due to the large amount of data, only those sections of the smoke trace around the beginning and the peak are tabled.

Figure b
Traces of measured opacity N, of unfiltered smoke k and of filtered smoke k



The peak value ($i = 272$) is calculated assuming the following data of table C. All other individual smoke values are calculated in the same way. For starting the algorithm, S_{-1} , S_{-2} , Y_{-1} and Y_{-2} are set to zero.

L_A (m)	0.430
Index i	272
N (per cent)	16.783
S_{271} (m^{-1})	0.427392
S_{270} (m^{-1})	0.427532
Y_{271} (m^{-1})	0.542383
Y_{270} (m^{-1})	0.542337

Calculation of the k-value (Annex 4A, Appendix 1, paragraph 7.3.1.):

$$k = -(1/0,430) \times \ln(1 - (16,783/100)) = 0,427252 \text{ m}^{-1}$$

This value corresponds to S_{272} in the following equation.

Calculation of Bessel averaged smoke (Annex 4A, Appendix 1, paragraph 7.3.2.):

In the following equation, the Bessel constants of the previous paragraph 2.2. are used. The actual unfiltered k-value, as calculated above, corresponds to S_{272} (S_i). S_{271} (S_{i-1}) and S_{270} (S_{i-2}) are the two preceding unfiltered k-values, Y_{271} (Y_{i-1}) and Y_{270} (Y_{i-2}) are the two preceding filtered k-values.

$$\begin{aligned}
 Y_{272} &= 0.542383 + 8.272777 \times 10^{-5} \times (0.427252 + 2 \times 0.427392 + 0.427532 - 4 \times 0.542337) \\
 &\quad + 0.968410 \times (0.542383 - 0.542337) \\
 &= 0.542389 \text{ m}^{-1}
 \end{aligned}$$

This value corresponds to $Y_{\max 1, A}$ in the following equation.

Calculation of the final smoke value (Annex 4A, Appendix 1, paragraph 7.3.3.):

From each smoke trace, the maximum filtered k-value is taken for the further calculation. Assume the following values

Speed	$Y_{\max} \text{ (m}^{-1}\text{)}$		
	Cycle 1	Cycle 2	Cycle 3
A	0.5424	0.5435	0.5587
B	0.5596	0.5400	0.5389
C	0.4912	0.5207	0.5177

$$\begin{aligned}
 SV_A &= (0.5424 + 0.5435 + 0.5587) / 3 = 0.5482 \text{ m}^{-1} \\
 SV_B &= (0.5596 + 0.5400 + 0.5389) / 3 = 0.5462 \text{ m}^{-1} \\
 SV_C &= (0.4912 + 0.5207 + 0.5177) / 3 = 0.5099 \text{ m}^{-1} \\
 SV &= (0.43 \times 0.5482) + (0.56 \times 0.5462) + (0.01 \times 0.5099) = 0.5467 \text{ m}^{-1}
 \end{aligned}$$

Cycle validation (Annex 4A, Appendix 1, paragraph 3.4.)

Before calculating SV, the cycle shall be validated by calculating the relative standard deviations of the smoke of the three cycles for each speed.

Speed	Mean SV (m^{-1})	absolute standard deviation (m^{-1})	relative standard deviation (per cent)
A	0.5482	0.0091	1.7
B	0.5462	0.0116	2.1
C	0.5099	0.0162	3.2

In this example, the validation criteria of 15 per cent are met for each speed.

Table C
Values of opacity N, unfiltered and filtered k-value at beginning of load step

Index i [-]	Time [s]	Opacity N [per cent]	unfiltered k-value [m ⁻¹]	filtered k-value [m ⁻¹]
- 2	0.000000	0.000000	0.000000	0.000000
- 1	0.000000	0.000000	0.000000	0.000000
0	0.000000	0.000000	0.000000	0.000000
1	0.006667	0.020000	0.000465	0.000000
2	0.013333	0.020000	0.000465	0.000000
3	0.020000	0.020000	0.000465	0.000000
4	0.026667	0.020000	0.000465	0.000001
5	0.033333	0.020000	0.000465	0.000002
6	0.040000	0.020000	0.000465	0.000002
7	0.046667	0.020000	0.000465	0.000003
8	0.053333	0.020000	0.000465	0.000004
9	0.060000	0.020000	0.000465	0.000005
10	0.066667	0.020000	0.000465	0.000006
11	0.073333	0.020000	0.000465	0.000008
12	0.080000	0.020000	0.000465	0.000009
13	0.086667	0.020000	0.000465	0.000011
14	0.093333	0.020000	0.000465	0.000012
15	0.100000	0.192000	0.004469	0.000014
16	0.106667	0.212000	0.004935	0.000018
17	0.113333	0.212000	0.004935	0.000022
18	0.120000	0.212000	0.004935	0.000028
19	0.126667	0.343000	0.007990	0.000036
20	0.133333	0.566000	0.013200	0.000047
21	0.140000	0.889000	0.020767	0.000061
22	0.146667	0.929000	0.021706	0.000082
23	0.153333	0.929000	0.021706	0.000109
24	0.160000	1.263000	0.029559	0.000143
25	0.166667	1.455000	0.034086	0.000185
26	0.173333	1.697000	0.039804	0.000237
27	0.180000	2.030000	0.047695	0.000301
28	0.186667	2.081000	0.048906	0.000378
29	0.193333	2.081000	0.048906	0.000469
30	0.200000	2.424000	0.057067	0.000573
31	0.206667	2.475000	0.058282	0.000693
32	0.213333	2.475000	0.058282	0.000827
33	0.220000	2.808000	0.066237	0.000977
34	0.226667	3.010000	0.071075	0.001144
35	0.233333	3.253000	0.076909	0.001328
36	0.240000	3.606000	0.085410	0.001533
37	0.246667	3.960000	0.093966	0.001758
38	0.253333	4.455000	0.105983	0.002007
39	0.260000	4.818000	0.114836	0.002283
40	0.266667	5.020000	0.119776	0.002587
□	□	□	□	□

Values of opacity N, unfiltered and filtered k-value around $Y_{\max 1,A}$ (peak value, indicated in bold number)

Index i [-]	Time [s]	Opacity N [per cent]	unfiltered k-value [m ⁻¹]	filtered k-value [m ⁻¹]
□	□	□	□	□
259	1.726667	17.182000	0.438429	0.538856
260	1.733333	16.949000	0.431896	0.539423
261	1.740000	16.788000	0.427392	0.539936
262	1.746667	16.798000	0.427671	0.540396
263	1.753333	16.788000	0.427392	0.540805
264	1.760000	16.798000	0.427671	0.541163
265	1.766667	16.798000	0.427671	0.541473
266	1.773333	16.788000	0.427392	0.541735
267	1.780000	16.788000	0.427392	0.541951
268	1.786667	16.798000	0.427671	0.542123
269	1.793333	16.798000	0.427671	0.542251
270	1.800000	16.793000	0.427532	0.542337
271	1.806667	16.788000	0.427392	0.542383
272	1.813333	16.783000	0.427252	0.542389
273	1.820000	16.780000	0.427168	0.542357
274	1.826667	16.798000	0.427671	0.542288
275	1.833333	16.778000	0.427112	0.542183
276	1.840000	16.808000	0.427951	0.542043
277	1.846667	16.768000	0.426833	0.541870
278	1.853333	16.010000	0.405750	0.541662
279	1.860000	16.010000	0.405750	0.541418
280	1.866667	16.000000	0.405473	0.541136
281	1.873333	16.010000	0.405750	0.540819
282	1.880000	16.000000	0.405473	0.540466
283	1.886667	16.010000	0.405750	0.540080
284	1.893333	16.394000	0.416406	0.539663
285	1.900000	16.394000	0.416406	0.539216
286	1.906667	16.404000	0.416685	0.538744
287	1.913333	16.394000	0.416406	0.538245
288	1.920000	16.394000	0.416406	0.537722
289	1.926667	16.384000	0.416128	0.537175
290	1.933333	16.010000	0.405750	0.536604
291	1.940000	16.010000	0.405750	0.536009
292	1.946667	16.000000	0.405473	0.535389
293	1.953333	16.010000	0.405750	0.534745
294	1.960000	16.212000	0.411349	0.534079
295	1.966667	16.394000	0.416406	0.533394
296	1.973333	16.394000	0.416406	0.532691
297	1.980000	16.192000	0.410794	0.531971
298	1.986667	16.000000	0.405473	0.531233
299	1.993333	16.000000	0.405473	0.530477
300	2.000000	16.000000	0.405473	0.529704
□	□	□	□	□

3. ETC TEST

3.1. Gaseous emissions (diesel engine)

Assume the following test results for a PDP-CVS system

V_0 (m ³ /rev)	0.1776
N_p (rev)	23073
p_B (kPa)	98.0
p_1 (kPa)	2.3
T (K)	322.5
H_a (g/kg)	12.8
NO_x conce (ppm)	53.7
NO_x concd (ppm)	0.4
CO_{conce} (ppm)	38.9
CO_{concd} (ppm)	1.0
HC_{conce} (ppm)	9.00
HC_{concd} (ppm)	3.02
$CO_{2,conce}$ (per cent)	0.723
W_{act} (kWh)	62.72

Calculation of the diluted exhaust gas flow (Annex 4A, Appendix 2, paragraph 4.1.):

$$M_{TOTW} = 1.293 \times 0.1776 \times 23\,073 \times (98.0 - 2.3) \times 273 / (101.3 \times 322.5) \\ = 423\,7.2 \text{ kg}$$

Calculation of the NO_x correction factor (Annex 4A, Appendix 2, paragraph 4.2.):

$$K_{H,D} = \frac{1}{1 - 0.0182 \times (12.8 - 10.71)} = 1.039$$

Calculation of the background corrected concentrations (Annex 4A, Appendix 2, paragraph 4.3.1.1.):

Assuming a diesel fuel of the composition $C_{12}H_{18}$

$$F_S = 100 \times \frac{1}{1 + \frac{1.8}{2} + \left[3.76 \times \left(1 + \frac{1.8}{4} \right) \right]} = 13.6$$

$$DF = \frac{13.6}{0.723 + (9.00 + 38.9) \times 10^{-4}} = 18.69$$

$$NO_{x\,conc} = 53.7 - 0.4 \times (1 - (1/18.69)) = 53.3 \text{ ppm}$$

$$CO_{conc} = 38.9 - 1.0 \times (1 - (1/18.69)) = 37.9 \text{ ppm}$$

$$HC_{conc} = 9.00 - 3.02 \times (1 - (1/18.69)) = 6.14 \text{ ppm}$$

Calculation of the emissions mass flow (Annex 4A, Appendix 2, paragraph 4.3.1.):

$$NO_{x\ mass} = 0.001587 \times 53.3 \times 1.039 \times 423\ 7.2 = 372.391 \text{ g}$$

$$CO_{mass} = 0.000966 \times 37.9 \times 423\ 7.2 = 155.129 \text{ g}$$

$$HC_{mass} = 0.000479 \times 6.14 \times 423\ 7.2 = 12.462 \text{ g}$$

Calculation of the specific emissions (Annex 4A, Appendix 2, paragraph 4.4.):

$$\overline{NO}_x = 372.391/62.72 = 5.94 \text{ g/kWh}$$

$$\overline{CO} = 155.129/62.72 = 2.47 \text{ g/kWh}$$

$$\overline{HC} = 12.462/62.72 = 0.199 \text{ g/kWh}$$

3.2. Particulate emissions (diesel engine)

Assume the following test results for a PDP-CVS system with double dilution

M_{TOTW} (kg)	4237.2
$M_{f,p}$ (mg)	3.030
$M_{f,b}$ (mg)	0.044
M_{TOT} (kg)	2.159
M_{SEC} (kg)	0.909
M_d (mg)	0.341
M_{DIL} (kg)	1.245
DF	18.69
W_{act} (kWh)	62.72

Calculation of the mass emission (Annex 4A, Appendix 2, paragraph 5.1.):

$$M_f = 3.030 + 0.044 = 3.074 \text{ mg}$$

$$M_{SAM} = 2.159 - 0.909 = 1.250 \text{ kg}$$

$$PT_{mass} = \frac{3.074}{1.250} \times \frac{4\ 237.2}{1000} = 10.42 \text{ g}$$

Calculation of the background corrected mass emission (Annex 4A, Appendix 2, paragraph 5.1.):

$$PT_{mass} = \left[\frac{3.074}{1.250} - \left(\frac{0.341}{1.245} \times \left(1 + \frac{1}{18.69} \right) \right) \right] \times \frac{4\ 237.2}{1000} = 9.32 \text{ g}$$

Calculation of the specific emission (Annex 4A, Appendix 2, paragraph 5.2.):

$$\overline{PT} = 10.42/62.72 = 0.166 \text{ g/kWh}$$

$$\overline{PT} = 9.32/62.72 = 0.149 \text{ g/kWh, if background corrected}$$

3.3. Gaseous emissions (CNG engine)

Assume the following test results for a PDP-CVS system with double dilution

M_{TOTW} (kg)	4237.2
H_a (g/kg)	12.8
NO_x conce (ppm)	17.2
NO_x concd (ppm)	0.4
CO conce (ppm)	44.3
CO concd (ppm)	1.0
HC conce (ppm)	27.0
HC concd (ppm)	3.02
CH_4 conce (ppm)	18.0
CH_4 concd (ppm)	1.7
CO_2 conce (per cent)	0.723
W_{act} (kWh)	62.72

Calculation of the NO_x correction factor (Annex 4A, Appendix 2, paragraph 4.2.):

$$K_{H,G} = \frac{1}{1 - 0.0329 \times (12.8 - 10.71)} = 1.074$$

Calculation of the NMHC concentration (Annex 4A, Appendix 2, paragraph 4.3.1.):

(a) GC method

$$NMHC_{conce} = 27.0 - 18.0 = 9.0 \text{ ppm}$$

(b) NMC method

Assuming a methane efficiency of 0.04 and an ethane efficiency of 0.98 (see Annex III, Appendix 5, paragraph 1.8.4.)

$$NMHC_{conce} = \frac{27.0 \times (1 - 0.04) - 18.0}{0.98 - 0.04} = 8.4 \text{ ppm}$$

Calculation of the background corrected concentrations (Annex 4A, Appendix 2, paragraph 4.3.1.1.):

Assuming a G_{20} reference fuel (100 per cent methane) of the composition C_1H_4 :

$$F_S = 100 \times \frac{1}{1 + \frac{4}{2} + \left(3.76 \times \left(1 + \frac{4}{4} \right) \right)} = 9.5$$

$$DF = \frac{9.5}{0.723 + (27.0 + 44.3) \times 10^{-4}} = 13.01$$

For NMHC, the background concentration is the difference between HC_{concd} and CH_{4concd}

$$\text{NO}_{x \text{ conc}} = 17.2 - 0.4 \times (1 - (1/13.01)) = 16.8 \text{ ppm}$$

$$\text{CO}_{\text{conc}} = 44.3 - 1.0 \times (1 - (1/13.01)) = 43.4 \text{ ppm}$$

$$\text{NMHC}_{\text{conc}} = 8.4 - 1.32 \times (1 - (1/13.01)) = 7.2 \text{ ppm}$$

$$\text{CH}_{4 \text{ conc}} = 18.0 - 1.7 \times (1 - (1/13.01)) = 16.4 \text{ ppm}$$

Calculation of the emissions mass flow (Annex 4A, Appendix 2, paragraph 4.3.1.):

$$\text{NO}_{x \text{ mass}} = 0.001587 \times 16.8 \times 1.074 \times 423 \text{ 7.2} = 121.330 \text{ g}$$

$$\text{CO}_{\text{mass}} = 0.000966 \times 43.4 \times 423 \text{ 7.2} = 177.642 \text{ g}$$

$$\text{NMHC}_{\text{mass}} = 0.000502 \times 7.2 \times 423 \text{ 7.2} = 15.315 \text{ g}$$

$$\text{CH}_{4 \text{ mass}} = 0.000554 \times 16.4 \times 423 \text{ 7.2} = 38.498 \text{ g}$$

Calculation of the specific emissions (Annex 4A, Appendix 2, paragraph 4.4.):

$$\overline{\text{NO}}_x = 121.330/62.72 = 1.93 \text{ g/kWh}$$

$$\overline{\text{CO}} = 177.642/62.72 = 2.83 \text{ g/kWh}$$

$$\overline{\text{NMHC}} = 15.315/62.72 = 0.244 \text{ g/kWh}$$

$$\overline{\text{CH}}_4 = 38.498/62.72 = 0.614 \text{ g/kWh}$$

4. Λ -SHIFT FACTOR (S_λ)

4.1. Calculation of the λ -shift factor (S_λ) ^{1/}

$$S_\lambda = \frac{2}{\left(1 - \frac{\text{inert}\%}{100}\right) \left(n + \frac{m}{4}\right) - \frac{\text{O}_2^*}{100}}$$

where:

S_λ = λ -shift factor;

inert per cent = per cent by volume of inert gases in the fuel (i.e. N₂, CO₂, He, etc.);

O_2^* = per cent by volume of original oxygen in the fuel;

N and m = refer to average C_nH_m representing the fuel hydrocarbons, i.e:

$$n = \frac{1 \times \left[\frac{\text{CH}_4\%}{100}\right] + 2 \times \left[\frac{\text{C}_2\%}{100}\right] + 3 \times \left[\frac{\text{C}_3\%}{100}\right] + 4 \times \left[\frac{\text{C}_4\%}{100}\right] + 5 \times \left[\frac{\text{C}_5\%}{100}\right] + \dots}{1 - \frac{\text{diluent}\%}{100}}$$

^{1/} Stoichiometric Air/Fuel ratios of automotive fuels - SAE J1829, June 1987. John B. Heywood, Internal combustion engine fundamentals, McGraw-Hill, 1988, Chapter 3.4 "Combustion stoichiometry" (pp. 68 to 72)

$$m = \frac{4 \times \left[\frac{\text{CH}_4 \%}{100} \right] + 4 \times \left[\frac{\text{C}_2\text{H}_4 \%}{100} \right] + 6 \times \left[\frac{\text{C}_2\text{H}_6 \%}{100} \right] + \dots + 8 \times \left[\frac{\text{C}_3\text{H}_8 \%}{100} \right] + \dots}{\frac{1 - \text{diluent \%}}{100}}$$

where:

- CH₄ = per cent by volume of methane in the fuel;
- C₂ = per cent by volume of all C₂ hydrocarbons (e.g.: C₂H₆, C₂H₄, etc.) in the fuel;
- C₃ = per cent by volume of all C₃ hydrocarbons (e.g.: C₃H₈, C₃H₆, etc.) in the fuel;
- C₄ = per cent by volume of all C₄ hydrocarbons (e.g.: C₄H₁₀, C₄H₈, etc.) in the fuel;
- C₅ = per cent by volume of all C₅ hydrocarbons (e.g.: C₅H₁₂, C₅H₁₀, etc.) in the fuel;
- diluent = per cent by volume of dilution gases in the fuel (i.e.: O₂*, N₂, CO₂, He, etc.).

4.2. Examples for the calculation of the λ-shift factor S_λ:

Example 1: G₂₅: CH₄ = 86 per cent, N₂ = 14 per cent (by volume)

$$n = \frac{1 \times \left[\frac{\text{CH}_4 \%}{100} \right] + 2 \times \left[\frac{\text{C}_2 \%}{100} \right] + \dots}{\frac{1 - \text{diluent \%}}{100}} = \frac{1 \times 0.86}{1 - \frac{14}{100}} = \frac{0.86}{0.86} = 1$$

$$m = \frac{4 \times \left[\frac{\text{CH}_4 \%}{100} \right] + 4 \times \left[\frac{\text{C}_2\text{H}_4 \%}{100} \right] + \dots}{\frac{1 - \text{diluent \%}}{100}} = \frac{4 \times 0.86}{0.86} = 4$$

$$S_\lambda = \frac{2}{\left(1 - \frac{\text{inert}\%}{100}\right) \left(n + \frac{m}{4}\right) - \frac{\text{O}_2^*}{100}} = \frac{2}{\left(1 - \frac{14}{100}\right) \times \left(1 + \frac{4}{4}\right)} = 1.16$$

Example 2: G_R: CH₄ = 87 per cent, C₂H₆ = 13 per cent (by vol)

$$n = \frac{1 \times \left[\frac{\text{CH}_4 \%}{100} \right] + 2 \times \left[\frac{\text{C}_2 \%}{100} \right] + \dots}{\frac{1 - \text{diluent \%}}{100}} = \frac{1 \times 0.87 + 2 \times 0.13}{1 - \frac{0}{100}} = \frac{1.13}{1} = 1.13$$

$$m = \frac{4 \times \left[\frac{\text{CH}_4 \%}{100} \right] + 4 \times \left[\frac{\text{C}_2\text{H}_4 \%}{100} \right] + \dots}{\frac{1 - \text{diluent \%}}{100}} = \frac{4 \times 0.87 + 6 \times 0.13}{1} = 4.26$$

$$S_{\lambda} = \frac{2}{\left(1 - \frac{\text{inert}\%}{100}\right)\left(n + \frac{m}{4}\right) - \frac{O_2^*}{100}} = \frac{2}{\left(1 - \frac{0}{100}\right) \times \left(1.13 + \frac{4.26}{4}\right)} = 0.911$$

Example 3: USA: CH₄ = 89 per cent, C₂H₆ = 4.5 per cent, C₃H₈ = 2.3 per cent, C₆H₁₄ = 0.2 per cent, O₂ = 0.6 per cent, N₂ = 4 per cent

$$n = \frac{1 \times \left[\frac{\text{CH}_4\%}{100}\right] + 2 \times \left[\frac{\text{C}_2\%}{100}\right] + \dots}{\frac{1 - \text{diluent}\%}{100}} = \frac{1 \times 0.89 + 2 \times 0.045 + 3 \times 0.023 + 4 \times 0.002}{1 - \frac{0.64 + 4}{100}} = 1.11$$

$$m = \frac{4 \times \left[\frac{\text{CH}_4\%}{100}\right] + 4 \times \left[\frac{\text{C}_2\text{H}_4\%}{100}\right] + 6 \times \left[\frac{\text{C}_2\text{H}_6\%}{100}\right] + \dots + 8 \times \left[\frac{\text{C}_3\text{H}_8\%}{100}\right]}{\frac{1 - \text{diluent}\%}{100}} = \frac{4 \times 0.89 + 4 \times 0.045 + 8 \times 0.023 + 14 \times 0.002}{1 - \frac{0.6 + 4}{100}} = 4.24$$

$$S_{\lambda} = \frac{2}{\left(1 - \frac{\text{inert}\%}{100}\right)\left(n + \frac{m}{4}\right) - \frac{O_2^*}{100}} = \frac{2}{\left(1 - \frac{4}{100}\right) \times \left(1.11 + \frac{4.24}{4}\right) - \frac{0.6}{100}} = 0.96$$

Annex 7

PROCEDURES FOR CONDUCTING THE TEST FOR DURABILITY
OF EMISSION CONTROL SYSTEMS

1. INTRODUCTION

This annex details the procedures for selecting a family of engines to be tested over a service accumulation schedule for the purpose of determining deterioration factors. Such deterioration factors will be applied to the measured emissions from engines undergoing a periodical audit to ensure that in-service engine emissions remain in conformity with the applicable emission limits, as given in the tables in paragraph 5.2.1. to this Regulation, over the durability period applicable to the vehicle in which the engine is installed.

This annex also details the emission and non-emission-related maintenance that will be carried out on engines undergoing a service accumulation schedule. Such maintenance will be performed on in-service engines and communicated to owners of new heavy-duty engines.

2. SELECTION OF ENGINES FOR ESTABLISHING USEFUL LIFE DETERIORATION FACTORS

- 2.1. Engines will be selected from the engine family defined in paragraph 7.1. to this Regulation for emission testing to establish useful life deterioration factors.
- 2.2. Engines from different engine families may be further combined into families based on the type of exhaust aftertreatment system utilised. In order to place engines with different numbers of cylinders and different cylinder configuration but having the same technical specifications and installation for the exhaust aftertreatment systems into the same engine-aftertreatment system family, the manufacturer shall provide data to the approval authority that demonstrates that the emissions of such engines are equivalent.
- 2.3. One engine representing the engine-aftertreatment system family shall be selected by the engine manufacturer for testing over the service accumulation schedule defined in paragraph 3.2. of this annex, according to the criteria for selecting engines given in paragraph 7.2. to this Regulation and shall be reported to the approval authority before any testing commences.
 - 2.3.1. If the approval authority decides that the worst case emission rate of the engine-aftertreatment system family can be characterized better by another engine then the test engine shall be selected by the approval authority after consultation with the engine manufacturer.

3. ESTABLISHING USEFUL LIFE DETERIORATION FACTORS

3.1. General

Deterioration factors applicable to an engine-aftertreatment system family are developed from the selected engines based on a distance and service accumulation procedure that includes periodic testing for gaseous and particulate emissions over the ESC and ETC tests.

3.2. Service accumulation schedule

Service accumulation schedules may be carried out at the choice of the manufacturer by running a vehicle equipped with the selected parent engine over an "in-service accumulation" schedule or by running the selected parent engine over a "dynamometer service accumulation" schedule.

3.2.1. In-service and dynamometer service accumulation

3.2.1.1. The manufacturer shall determine the form and extent of the distance and service accumulation for engines, consistent with good engineering practice.

3.2.1.2. The manufacturer will determine when the engine will be tested for gaseous and particulate emissions over the ESC and ETC tests.

3.2.1.3. A single engine-operating schedule shall be used for all engines in an engine-aftertreatment system family.

3.2.1.4. At the request of the manufacturer and with the agreement of the approval authority, only one test cycle (either the ESC or ETC test) need be run at each test point with the other test cycle run only at the beginning and at the end of the service accumulation schedule.

3.2.1.5. Operating schedules may be different for different engine-aftertreatment system families.

3.2.1.6. Operating schedules may be shorter than the useful life period provided that the number of test points allows for a proper extrapolation of the test results, according to paragraph 3.5.2. In any case, the service accumulation shall not be shorter than shown in the table in paragraph 3.2.1.8.

3.2.1.7. The manufacturer has to provide the applicable correlation between minimum service accumulation period (driving distance) and engine dynamometer hours, for example, fuel consumption correlation, vehicle speed versus engine revolutions correlation etc.

3.2.1.8. Minimum service accumulation

Category of vehicle in which engine will be installed	Minimum service accumulation period	Useful life (paragraph of this Regulation)
Category N ₁ vehicles	100,000 km	Paragraph 5.3.1.1.
Category N ₂ vehicles	125,000 km	Paragraph 5.3.1.2.
Category N ₃ vehicles with a maximum technically permissible mass not exceeding 16 tonnes	125,000 km	Paragraph 5.3.1.2.
Category N ₃ vehicles with a maximum technically permissible mass exceeding 16 tonnes	167,000 km	Paragraph 5.3.1.3.
Category M ₂ vehicles	100,000 km	Paragraph 5.3.1.1.
Category M ₃ vehicles of classes I, II, A and B, with a maximum technically permissible mass not exceeding 7.5 tonnes	125,000 km	Paragraph 5.3.1.2.
Category M ₃ vehicles of classes III and B, with a maximum technically permissible mass exceeding 7.5 tonnes	167,000 km	Paragraph 5.3.1.3.

3.2.1.9. The in-service accumulation schedule shall be fully described in the application for approval and reported to the approval authority before the start of any testing.

3.2.2. If the approval authority decides that additional measurements need to be carried out on the ESC and ETC tests between the points selected by the manufacturer it shall notify the manufacturer. The revised in-service accumulation schedule or dynamometer service accumulation schedule shall be prepared by the manufacturer and agreed by the approval authority.

3.3. Engine testing

3.3.1. Start of the service accumulation schedule

3.3.1.1. For each engine-aftertreatment system family, the manufacturer shall determine the number of hours of engine running after which the operation of the engine-after-treatment system has stabilised. If requested by the approval authority the manufacturer shall make available the data and analysis used to make this determination. As an alternative, the manufacturer may elect to run the engine for 125 hours to stabilise the engine-aftertreatment system.

3.3.1.2. The stabilisation period determined in paragraph 3.3.1.1. will be deemed to be the start of the service accumulation schedule.

3.3.2. Service accumulation testing

3.3.2.1. After stabilisation, the engine will be run over the service accumulation schedule selected by the manufacturer, as described in paragraph 3.2. above. At the periodic intervals in the

service accumulation schedule determined by the manufacturer, and, where appropriate, also stipulated by the approval authority according to paragraph 3.2.2., the engine shall be tested for gaseous and particulate emissions over the ESC and ETC tests. In accordance with paragraph 3.2., if it has been agreed that only one test cycle (ESC or ETC) be run at each test point, the other test cycle (ESC or ETC) shall be run at the beginning and end of the service accumulation schedule.

3.3.2.2. During the service accumulation schedule, maintenance will be carried out on the engine according to paragraph 4.

3.3.2.3. During the service accumulation schedule, unscheduled maintenance on the engine or vehicle may be performed, for example if the OBD system has specifically detected a problem that has resulted in the malfunction indicator (MI) being activated.

3.4. Reporting

3.4.1. The results of all emission tests (ESC and ETC) conducted during the service accumulation schedule shall be made available to the approval authority. If any emission test is declared to be void, the manufacturer shall provide an explanation of why the test has been declared void. In such a case, another series of emission tests over the ESC and ETC tests shall be carried out within a further 100 hours of service accumulation.

3.4.2. Whenever a manufacturer tests an engine over a service accumulation schedule for the establishment of deterioration factors, the manufacturer shall retain in its records all information concerning all the emission tests and maintenance carried out on the engine during the service accumulation schedule. This information shall be submitted to the approval authority along with the results of the emission tests conducted over the service accumulation schedule.

3.5. Determination of deterioration factors

3.5.1. For each pollutant measured on the ESC and ETC tests and at each test point during the service accumulation schedule, a "best fit" regression analysis shall be made on the basis of all test results. The results of each test for each pollutant shall be expressed to the same number of decimal places as the limit value for that pollutant, as shown in the tables in paragraph 5.2.1. to this Regulation, plus one additional decimal place. In accordance with paragraph 3.2., if it has been agreed that only one test cycle (ESC or ETC) be run at each test point and the other test cycle (ESC or ETC) run only at the beginning and end of the service accumulation schedule, the regression analysis shall be made only on the basis of the test results from the test cycle run at each test point.

3.5.2. On the basis of the regression analysis, the manufacturer shall calculate the projected emission values for each pollutant at the start of the service accumulation schedule and at the useful life that is applicable for the engine under test by extrapolation of the regression equation as determined in paragraph 3.5.1.

- 3.5.3. For engines not equipped with an exhaust aftertreatment system, the deterioration factor for each pollutant is the difference between the projected emission values at the useful life period and at the start of the service accumulation schedule.

For engines equipped with an exhaust aftertreatment system, the deterioration factor for each pollutant is the ratio of the projected emission values at the useful life period and at the start of the service accumulation schedule.

In accordance with paragraph 3.2., if it has been agreed that only one test cycle (ESC or ETC) be run at each test point and the other test cycle (ESC or ETC) run only at the beginning and end of the service accumulation schedule, the deterioration factor calculated for the test cycle that has been run at each test point shall be applicable also for the other test cycle, provided that for both test cycles, the relationship between the measured values run at the beginning and at the end of the service accumulation schedule are similar.

- 3.5.4. The deterioration factors for each pollutant on the appropriate test cycles shall be recorded in paragraph 1.4. of Appendix 1 to Annex 6 to this Regulation.
- 3.6. As an alternative to using a service accumulation schedule to determine deterioration factors, engine manufacturers may choose to use the following deterioration factors:

Engine type	Test cycle	CO	HC	NMHC	CH ₄	NO _x	PM
Diesel engine	ESC	1.1	1.05	-	-	1.05	1.1
	ETC	1.1	1.05	-	-	1.05	1.1
Gas engine	ETC	1.1	1.05	1.05	1.2	1.05	-

- 3.6.1. The manufacturer may select to carry across the DF's determined for an engine or engine/aftertreatment combination to engines or engine/aftertreatment combinations that do not fall into the same engine family category as determined according to paragraph 2.1. In such cases, the manufacturer shall demonstrate to the approval authority that the base engine or engine/aftertreatment combination and the engine or engine/aftertreatment combination for which the DF's are being carried over have the same technical specifications and installation requirements on the vehicle and that the emissions of such engine or engine/aftertreatment combinations are similar.

3.7. Checking of conformity of production

- 3.7.1. Conformity of production for emissions compliance is checked on the basis of paragraph 8. to this Regulation.

- 3.7.2. At the time of approval, the manufacturer may choose to measure at the same time the pollutant emissions before any exhaust aftertreatment system. In so doing, the manufacturer may develop an informal deterioration factor separately for the engine and the aftertreatment system that may be used by the manufacturer as an aid to end of production line auditing.

- 3.7.3. For the purposes of approval, only the deterioration factors adopted by the manufacturer from paragraph 3.6.1. or the deterioration factors developed according to paragraph 3.5. shall be recorded in paragraph 1.4. of Appendix 1 to Annex 6 to this Regulation.

4. MAINTENANCE

During the service accumulation schedule, maintenance performed on engines and proper consumption of any required reagent used to determine deterioration factors are classified as either emission-related or non-emission-related and each of these can be classified as scheduled and unscheduled. Some emission-related maintenance is also classified as critical emission-related maintenance.

4.1. Emission-related scheduled maintenance

- 4.1.1. This paragraph specifies emission-related scheduled maintenance for the purpose of conducting a service accumulation schedule and for inclusion in the maintenance instructions furnished to owners of new heavy-duty vehicles and heavy-duty engines.
- 4.1.2. All emission-related scheduled maintenance for purposes of conducting a service accumulation schedule shall occur at the same or equivalent distance intervals that will be specified in the manufacturer's maintenance instructions to the owner of the heavy-duty vehicle or heavy-duty engine. This maintenance schedule may be updated as necessary throughout the service accumulation schedule provided that no maintenance operation is deleted from the maintenance schedule after the operation has been performed on the test engine.
- 4.1.3. Any emission-related maintenance performed on engines shall be necessary to assure in-use conformity with the relevant emission standards. The manufacturer shall submit data to the approval authority to demonstrate that all of the emission-related scheduled maintenance is technically necessary.
- 4.1.4. The engine manufacturer shall specify the adjustment, cleaning and maintenance (where necessary) of the following items:
- (a) Filters and coolers in the exhaust gas re-circulation system ;
 - (b) Positive crankcase ventilation valve;
 - (c) Fuel injector tips (cleaning only);
 - (d) Fuel injectors;
 - (e) Turbocharger;
 - (f) Electronic engine control unit and its associated sensors and actuators;
 - (g) Particulate filter system (including related components);
 - (h) Exhaust gas re-circulation system, including all related control valves and tubing;
 - (i) Any exhaust aftertreatment system.
- 4.1.5. For the purposes of maintenance, the following components are defined as critical emission-related items:
- (a) Any exhaust aftertreatment system;
 - (b) Electronic engine control unit and its associated sensors and actuators;

- (c) Exhaust gas re-circulation system including all related filters, coolers, control valves and tubing;
 - (d) Positive crankcase ventilation valve.
- 4.1.6. All critical emission-related scheduled maintenance shall have a reasonable likelihood of being performed in-use. The manufacturer shall demonstrate to the approval authority the reasonable likelihood of such maintenance being performed in-use and such demonstration shall be made prior to the performance of the maintenance during the service accumulation schedule.
- 4.1.7. Critical emission-related scheduled maintenance items that satisfy any of the conditions defined in paragraphs 4.1.7.1. to 4.1.7.4. will be accepted as having a reasonable likelihood of the maintenance item being performed in-use.
- 4.1.7.1. Data is submitted which establishes a connection between emissions and vehicle performance such that as emissions increase due to lack of maintenance, vehicle performance will simultaneously deteriorate to a point unacceptable for typical driving.
- 4.1.7.2. Survey data is submitted which demonstrates that, at an 80 per cent confidence level, 80 per cent of such engines already have this critical maintenance item performed in-use at the recommended interval(s).
- 4.1.7.3. In association with the requirements of paragraph [3.6....] of Annex 9A to this Regulation, a clearly visible indicator shall be installed on the dashboard of the vehicle to alert the driver that maintenance is due. The indicator shall be actuated at the appropriate distance or by component failure. The indicator shall remain activated while the engine is in operation and shall not be erased without the required maintenance being carried out. Re-setting of the signal shall be a required step in the maintenance schedule. The system shall not be designed to deactivate upon the end of the appropriate useful life period of the engine or thereafter.
- 4.1.7.4. Any other method which the approval authority determines as establishing a reasonable likelihood that the critical maintenance will be performed in-use.
- 4.2. Changes to scheduled maintenance
- 4.2.1. The manufacturer shall submit a request to the approval authority for approval of any new scheduled maintenance that it wishes to perform during the service accumulation schedule and thereby recommend to owners of heavy-duty vehicles and engines. The manufacturer shall also include its recommendation as to the category (i.e. emission-related, non-emission-related, critical or non-critical) of the new scheduled maintenance being proposed and, for emission-related maintenance, the maximum feasible maintenance interval. The request shall be accompanied by data supporting the need for the new scheduled maintenance and the maintenance interval.
- 4.3. Non-emission-related scheduled maintenance

- 4.3.1. Non-emission-related scheduled maintenance which is reasonable and technically necessary (e.g. oil change, oil filter change, fuel filter change, air filter change, cooling system maintenance, idle speed adjustment, governor, engine bolt torque, valve lash, injector lash, timing, adjustment of the tension of any drive-belt, etc) may be performed on engines or vehicles selected for the service accumulation schedule at the least frequent intervals recommended by the manufacturer to the owner (e.g. not at the intervals recommended for severe service).
- 4.4. Maintenance on engines selected for testing over a service accumulation schedule
 - 4.4.1. Repairs to the components of an engine selected for testing over a service accumulation schedule other than the engine, emission control system or fuel system shall be performed only as a result of part failure or engine system malfunction.
 - 4.4.2. Equipment, instruments or tools may not be used to identify malfunctioning, maladjusted or defective engine components unless the same or equivalent equipment, instruments or tools will be available to dealerships and other service outlets and,
 - (a) Are used in conjunction with scheduled maintenance on such components, and;
 - (b) Are used subsequent to the identification of an engine malfunction.
- 4.5. Critical emission-related unscheduled maintenance
 - 4.5.1. The consumption of a required reagent is defined as critical emission-related unscheduled maintenance for the purpose of conducting a service accumulation schedule and for inclusion in the maintenance instructions furnished by manufacturers to owners of new heavy-duty vehicles or heavy-duty engines.

Annex 8

CONFORMITY OF IN-SERVICE VEHICLES/ENGINES

1. GENERAL

- 1.1. With reference to approvals granted for emissions, measures are appropriate for confirming the functionality of the emission control devices during the useful life of an engine installed in a vehicle under normal conditions of use (conformity of in-service vehicles/engines properly maintained and used).
- 1.2. For the purpose of this Regulation these measures shall be checked over a period corresponding to the appropriate useful life period defined in paragraph 5.3. of this Regulation for vehicles or engines which are approved to either row B1, row B2 or row C of the tables in paragraph 5.2.1. of this Regulation.
- 1.3. The checking of conformity of in-service vehicles/engines is done on the basis of information provided by the manufacturer to the approval authority conducting an audit of the emissions-performance of a range of representative vehicles or engines of which the manufacturer holds the approval.

Figure 1 in this annex illustrates the procedure for in-service conformity checking.

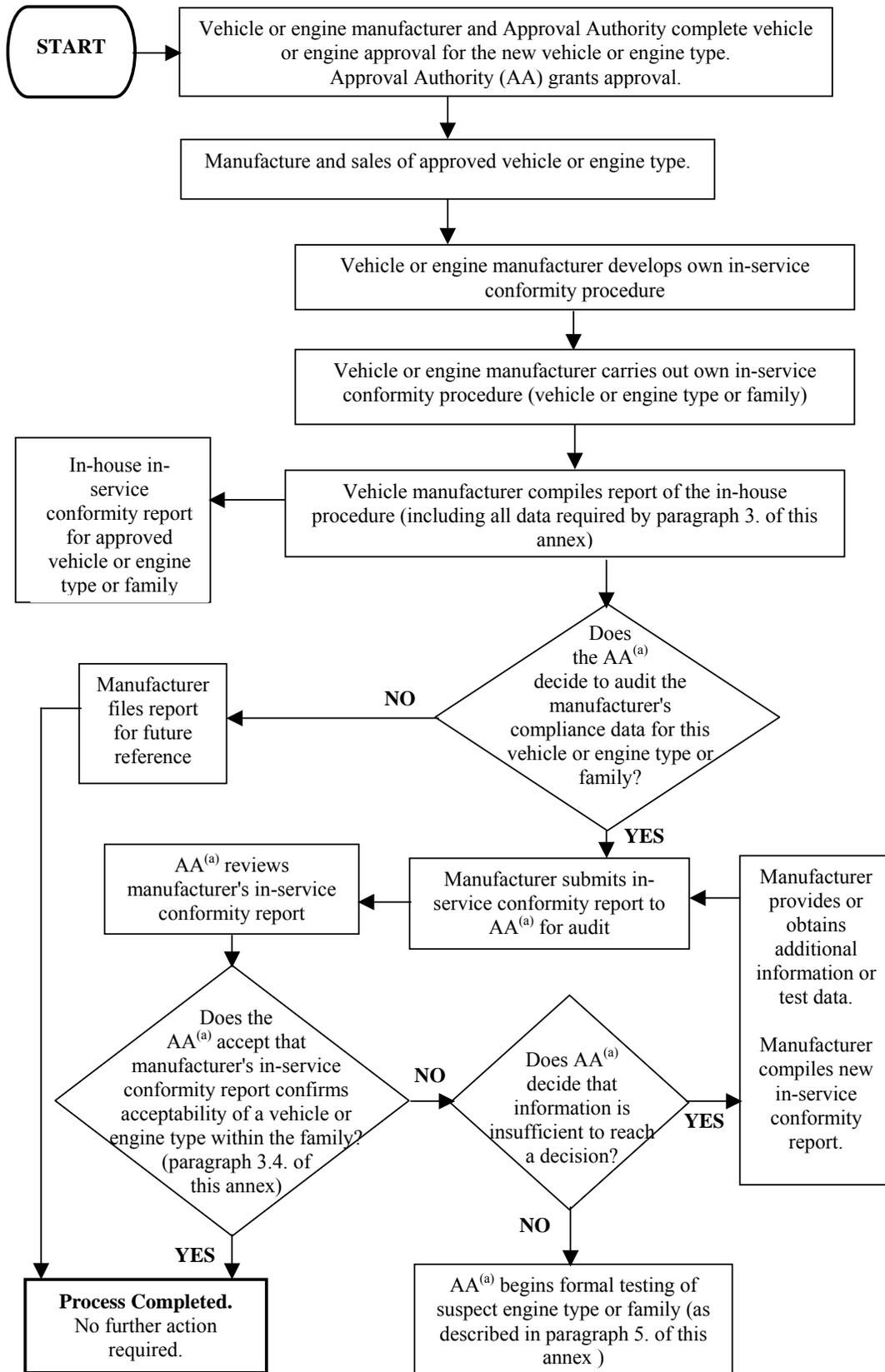
2. PROCEDURES FOR AUDIT

- 2.1. Audit of in-service conformity by the administrative department is conducted on the basis of any relevant information that the manufacturer has, under procedures similar to those defined in Appendix 2 of the 1958 Agreement (E/ECE/324-E/ECE/TRANS/505/Rev.2). Alternatives are in-service monitoring reports supplied by the manufacturer, approval authority surveillance testing and/or information on surveillance testing performed by a Contracting Party. The procedures to be used are given in paragraph 3.

3. AUDIT PROCEDURES

- 3.1. An audit of in-service conformity will be conducted by the approval authority on the basis of information supplied by the manufacturer. The manufacturer's in-service monitoring (ISM) report should be based on in-use testing of engines or vehicles using proven and relevant testing protocols. Such information (the ISM report) shall include, but is not limited to, the following (see paragraphs 3.1.1. to 3.1.13.):
 - 3.1.1. The name and address of the manufacturer.
 - 3.1.2. The name, address, telephone and fax numbers and e-mail address of his authorized representative within the areas covered by the manufacturer's information.

Figure 1. In-service conformity checking – audit procedure



^(a) In this case, AA means the Approval Authority that granted the approval.

- 3.1.3. The model name(s) of the engines included in the manufacturer's information.
- 3.1.4. The list of engine types covered within the manufacturer's information, i.e. the engine-after-treatment system family.
- 3.1.5. The vehicle identification number (VIN) codes applicable to the vehicles equipped with an engine that is part of the audit.
- 3.1.6. The numbers of the type approvals applicable to the engine types within the in-service family, including, where applicable, the numbers of all extensions and field fixes/recalls (re-works):
- 3.1.7. Details of extensions, field fixes/recalls to those type approvals for the engines covered within the manufacturer's information (if requested by the approval authority).
- 3.1.8. The period of time over which the manufacturer's information was collected.
- 3.1.9. The engine build period covered within the manufacturer's information (e.g. "vehicles or engines manufactured during the 2005 calendar year").
- 3.1.10. The manufacturer's in-service conformity checking procedure, including:
 - 3.1.10.1. Vehicle or engine location method;
 - 3.1.10.2. Selection and rejection criteria for vehicle or engine;
 - 3.1.10.3. Test types and procedures used for the programme;
 - 3.1.10.4. The manufacturer's acceptance/rejection criteria for the in-service family group;
 - 3.1.10.5. Geographical area(s) within which the manufacturer has collected information;
 - 3.1.10.6. Sample size and sampling plan used.
- 3.1.11. The results from the manufacturer's in-service conformity procedure, including:
 - 3.1.11.1. Identification of the engines included in the programme (whether tested or not). The identification will include:
 - (a) model name;
 - (b) vehicle identification number (VIN);
 - (c) engine identification number;
 - (d) vehicle registration number equipped with an engine that is part of the audit;
 - (e) date of manufacture;
 - (f) region of use (where known);
 - (g) type of use of the vehicle (where known), i.e. urban delivery, long haul etc.

- 3.1.11.2. The reason(s) for rejecting a vehicle or engine from a sample (e.g., vehicle being in-use for less than one year, improper emission-related maintenance, evidence of using a fuel having a higher sulphur content than required for normal vehicle use, emission control equipment not in conformity with approval). The reason for rejection shall be substantiated (e.g., the nature of non-fulfilment of maintenance instructions, etc.). A vehicle should not be excluded solely on the ground that the AECS may have been excessively in operation.
- 3.1.11.3. Emission-related servicing and maintenance history for each engine in the sample (including any re-works).
- 3.1.11.4. Repair history for each engine in the sample (where known).
- 3.1.11.5. Test data, including:
- (a) date of test;
 - (b) location of test;
 - (c) distance indicated odometer of vehicle equipped with an engine that is covered by the audit;
 - (d) test fuel specifications (e.g. test reference fuel or market fuel);
 - (e) test conditions (temperature, humidity, dynamometer inertia weight);
 - (f) dynamometer settings (e.g. power setting);
 - (g) emission test results conducted on the ESC, ETC and ELR tests according to paragraph 4. of this annex. A minimum of five engines shall be tested;
 - (h) alternative to item (g) above, tests may be conducted using another protocol. The relevance for monitoring in-service functionality with such a test shall be stated and substantiated by manufacturer in conjunction with the approval process (paragraphs 3. and 4. in to this Regulation).
- 3.1.12. Records of indication from the OBD system.
- 3.1.13. Record of experiences of the use of consumable reagent. Reports should detail, but not be limited to, operator experiences with the handling of filling, refilling and consumption of the reagent, and the conduct of the filling installations, and, specifically, the frequency of activation in-use of the temporary performance limiter and events of other defect instances, activation of the MI and the registering of a fault code relating to a lack of the consumable reagent.
- 3.1.13.1. The manufacturer shall supply in-use and defect reports. The manufacturer shall report on warranty claims and their nature, and in-field indications of activation/ deactivation of the MI and the registering of a fault code relating to a lack of the consumable reagent and the activation/deactivation of the engine performance limiter (see paragraph 5.5.5. of this Regulation).
- 3.2 The information gathered by the manufacturer shall be sufficiently comprehensive to ensure that in-service performance can be assessed for normal conditions over the appropriate durability/useful life period defined in paragraph 6.3. of this Regulation and in a way representative of the manufacturer's geographic penetration.

- 3.3 The manufacturer may wish to run in-service monitoring comprising fewer engines/vehicles than the number given in paragraph 3.1.11.5., item (g), and using a procedure defined under paragraph 3.1.11.5., item (h). The reason could be that the engines in the engine family(-ies) covered by the report are in a small number. The conditions should have been agreed on beforehand by the approval authority.
- 3.4 On the basis of the monitoring report referred to in this paragraph, the approval authority shall either:
- (a) decide that the in-service conformity of an engine type or an engine family is satisfactory and not to take any further action;
 - (b) decide that the data provided by the manufacturer is insufficient to reach a decision and request additional information and/or test data from the manufacturer. Where requested, and depending on the approval of the engine, such additional test data shall include ESC, ELR, and ETC test results, or from other proven procedures according to paragraph 3.1.11.5., item (h);
 - (c) decide that the in-service conformity of an engine family is unsatisfactory and proceed to have confirmatory testing carried out on a sample of engines from the engine family, according to paragraph 5. of this annex.
- 3.5 A Contracting Party may conduct and report its surveillance testing, based on the audit procedure spelled out in this paragraph. Information on the procurement, maintenance, and manufacturer's participation in the activities may be recorded. Likewise, the Contracting Party may use alternative emission test protocols, according to paragraph 3.1.11.5., item (h).
- 3.6 The approval authority may take up surveillance testing conducted and reported by a Contracting Party as a basis for the decisions according to paragraph 3.4.
- 3.7 The manufacturer should report to the approval authority and the Contracting Party(s) where the subject engines/vehicles are kept in service when planning to conduct a voluntary remedial action. The reporting shall be supplied by the manufacturer in conjunction with taking the decision to take action, specifying the particulars of the action, describe the groups of engines/vehicles to be included in the action, and regularly thereafter on the commencement of the campaign. The applicable particulars of paragraph 7. to this annex may be used.

4. EMISSION TESTS

- 4.1 An engine selected from the engine family shall be tested over the ESC and ETC test cycles for gaseous and particulate emissions and over the ELR test cycle for smoke emission. The engine shall be representative of the type of use expected for this type of engine, and come from a vehicle in normal use. The procurement, inspection, and restorative maintenance of the engine/vehicle shall be conducted using a protocol such as is specified in paragraph 3., and shall be documented.

The appropriate maintenance schedule, referred to in paragraph 4. of Annex II, shall have been carried out on the engine.

4.2 The emission values determined from the ESC, ETC and ELR tests shall be expressed to the same number of decimal places as the limit value for that pollutant, as shown in the tables in paragraph 5.2.1. of this Regulation, plus one additional decimal place.

5. CONFIRMATORY TESTING

5.1 Confirmatory testing is done for the purpose of confirmation of the in-service emission functionality of an engine family.

5.1.1. If the approval authority is not satisfied with the manufacturers' ISM according to paragraph 3.4. or on a reported evidence of unsatisfactory in-service conformity, e.g., according to paragraph 3.5., may order the manufacturer to run test for confirmatory purposes. The approval authority will examine the confirmatory test report supplied by the manufacturer.

5.1.2. The approval authority may conduct confirmatory testing.

5.2 The confirmatory test should be applicable engine ESC, ETC and ELR tests, as specified in paragraph 4. Representative engines to be tested should be dismantled from vehicles used under normal conditions and be tested. Alternatively, after prior agreement with the approval authority, the manufacturer may test emission control components from vehicles in use, after being dismantled, transferred and mounted on properly used and representative engine(s). For each series of tests, the same package of emission control components shall be selected. The reason for the selection shall be stated.

5.3 A test result may be regarded as non-satisfactory when, from tests of two or more engines representing the same engine family, for any regulated pollutant component, the limit value as shown in paragraph 5.2.1. of this Regulation is exceeded significantly.

6. ACTIONS TO BE TAKEN

6.1 Where the approval authority is not satisfied with the information or test data supplied by the manufacturer, and, having carried out confirmatory engine testing according to paragraph 5., or based on confirmatory testing conducted by a Contracting Party (paragraph 5.3.), and it is certain that an engine type is not in conformity with the requirements of these provisions, the approval authority shall request the manufacturer to submit a plan of remedial measure to remedy the non-conformity.

6.2 In this case, the remedial measures referred to in Appendix 2 of the 1958 Agreement (E/ECE/324-E/ECE/TRANS/505/Rev.2) are extended to engines in service belonging to the same vehicle type which are likely to be affected with the same defects, in accordance with paragraph 8.

To be valid the plan of remedial measures presented by the manufacturer shall be approved by the approval authority. The manufacturer is responsible for the execution of the remedial plan as approved.

The approval authority shall notify its decision to all Contracting Parties within 30 days. The Contracting Parties may require that the same plan of remedial measures be applied to all engines of the same type registered in their territory.

- 6.3 If a Party to the Agreement has established that a vehicle type does not conform to the applicable requirements of this annex, it shall notify without delay the Party to the Agreement which granted the original type approval in accordance with the requirements of the Agreement.

Then, subject to the provision of the Agreement, the competent authority of the Party to the Agreement which granted the original type approval shall inform the manufacturer that a vehicle type fails to satisfy the requirements of these provisions and that certain measures are expected from the manufacturer. The manufacturer shall submit to the authority, within two months after this notification, a plan of measures to overcome the defects, the substance of which should correspond with the requirements of paragraph 7. The competent authority which granted the original approval shall, within two months, consult the manufacturer in order to secure agreement on a plan of measures and on carrying out the plan. If the competent authority which granted the original type approval establishes that no agreement can be reached, the relevant procedures to the Agreement shall be initiated.

7. PLAN OF REMEDIAL MEASURES

- 7.1. The plan of remedial measures, requested according to paragraph 6.1, shall be filed with the approval authority not later than 60 working days from the date of the notification referred to in paragraph 6.1. The approval authority shall within 30 working days declare its approval or disapproval of the plan of remedial measures. However, where the manufacturer can demonstrate to the satisfaction of the competent approval authority, that further time is required to investigate the non-compliance in order to submit a plan of remedial measures, an extension is granted.
- 7.2. The remedial measures shall apply to all engines likely to be affected by the same defect. The need to amend the approval documents shall be assessed.
- 7.3. The manufacturer shall provide a copy of all communications related to the plan of remedial measures, shall also maintain a record of the recall campaign, and supply regular status reports to the approval authority.
- 7.4. The plan of remedial measures shall include the requirements specified in paragraphs 7.4.1. to 7.4.11. The manufacturer shall assign a unique identifying name or number to the plan of remedial measures.
- 7.4.1. A description of each engine type included in the plan of remedial measures.
- 7.4.2. A description of the specific modifications, alterations, repairs, corrections, adjustments, or other changes to be made to bring the engines into conformity including a brief summary of

the data and technical studies which support the manufacturer's decision as to the particular measures to be taken to correct the non-conformity.

- 7.4.3. A description of the method by which the manufacturer informs the engine or vehicle owners about the remedial measures.
- 7.4.4. A description of the proper maintenance or use, if any, which the manufacturer stipulates as a conditions of eligibility for repair under the plan of remedial measures, and an explanation of the manufacturer's reasons for imposing any such condition. No maintenance or use conditions may be imposed unless it is demonstrably related to the non-conformity and the remedial measures.
- 7.4.5. A description of the procedure to be followed by engine owners to obtain correction of the non-conformity. This shall include a date after which the remedial measures may be taken, the estimated time for the workshop to perform the repairs and where they can be done. The repair shall be done expediently, within a reasonable time after delivery of the vehicle.
- 7.4.6. A copy of the information transmitted to the vehicle owner.
- 7.4.7. A brief description of the system which the manufacturer uses to assure an adequate supply of component or systems for fulfilling the remedial action. It shall be indicated when there will be an adequate supply of components or systems to initiate the campaign.
- 7.4.8. A copy of all instructions to be sent to those persons who are to perform the repair.
- 7.4.9. A description of the impact of the proposed remedial measures on the emissions, fuel consumption, driveability, and safety of each engine type, covered by the plan of remedial measures with data, technical studies, etc. which support these conclusions.
- 7.4.10. Any other information, reports or data the approval authority may reasonably determine is necessary to evaluate the plan of remedial measures.
- 7.4.11. Where the plan of remedial measures includes a recall, a description of the method for recording the repair shall be submitted to the approval authority. If a label is used, an example of it shall be submitted.
- 7.5. The manufacturer may be required to conduct reasonably designed and necessary tests on components and engines incorporating a proposed change, repair, or modification to demonstrate the effectiveness of the change, repair, or modification.
- 7.6. The manufacturer is responsible for keeping a record of every engine or vehicle recalled and repaired and the workshop which performed the repair. The approval authority shall have access to the record on request for a period of 5 years from the implementation of the plan of remedial measures.
- 7.7. The repair and/or modification or addition of new equipment shall be recorded in a certificate supplied by the manufacturer to the owner of the engine.

Annex 9A

ON-BOARD DIAGNOSTIC SYSTEMS (OBD)

1. INTRODUCTION

This annex describes the provisions specific to the on-board diagnostic (OBD) system for the emission control systems of motor vehicles.

2. DEFINITIONS

For the purposes of this annex, the following definitions, in addition to the definitions contained in paragraph 2. of this Regulation, apply:

"warm-up cycle" means sufficient engine operation such that the coolant temperature has risen by at least 22 K from engine starting and reaches a minimum temperature of 343 K (70 °C);

"access" means the availability of all emission-related OBD data including all fault codes required for the inspection, diagnosis, servicing or repair of emissions related parts of the vehicle, via the serial interface of the standard diagnostic connector;

"deficiency" means, in respect of engine OBD systems, that up to two separate components or systems that are monitored contain temporary or permanent operating characteristics that impair the otherwise efficient OBD monitoring of those components or systems or do not meet all the other detailed requirements for OBD. Engines or vehicles in respect of their engine may be approved, registered and sold with such deficiencies according to the requirements of paragraph 4.3. of this annex;

"deteriorated component/system" means an engine or exhaust aftertreatment component/system that has been intentionally deteriorated in a controlled manner by the manufacturer for the purpose of conducting a approval test on the OBD system;

"OBD test cycle" means a driving cycle which is a version of the ESC test cycle having the same running-order of the 13 individual modes as described in paragraph 2.7.1. of Appendix 1 to Annex 4A to this Regulation but where the length of each mode is reduced to 60 seconds;

"operating sequence" means the sequence used for determining the conditions for extinguishing the MI. It consists of an engine start-up, an operating period, an engine shut-off, and the time until the next start-up, where the OBD monitoring is running and a malfunction would be detected if present;

"preconditioning cycle" means the running of at least three consecutive OBD test cycles or emission test cycles for the purpose of achieving stability of the engine operation, the emission control system and OBD monitoring readiness;

"repair information" means all information required for diagnosis, servicing, inspection, periodic monitoring or repair of the engine and which the manufacturers provide for their authorized dealers/repair shops. Where necessary, such information shall include service handbooks, technical manuals, diagnosis information (e.g. minimum and maximum theoretical values for measurements), wiring diagrams, the software calibration identification number applicable to an engine type, information enabling the update of the software of the electronic systems in accordance with the specifications of the vehicle manufacturer, instructions for individual and special cases, information provided

concerning tools and equipment, data record information and two-directional monitoring and test data. The manufacturer shall not be obliged to make available that information which is covered by intellectual property rights or constitutes specific know-how of manufacturers and/or OEM suppliers; in this case the necessary technical information shall not be improperly withheld;

"standardized" means that all emission related OBD data (i.e. stream information in the case a scanning tool is used), including all fault codes used, shall be produced only in accordance with industry standards which, by virtue of the fact that their format and the permitted options are clearly defined, provide for a maximum level of harmonisation in the motor vehicle industry, and whose use is expressly permitted in this Regulation;

"unrestricted" means:

- (a) access not dependent on an access code obtainable only from the manufacturer, or a similar device, or,
- (b) access allowing evaluation of the data produced without the need for any unique decoding information, unless that information itself is standardized.

3. REQUIREMENTS AND TESTS

3.1. General requirements

- 3.1.1. OBD systems shall be designed, constructed and installed in a vehicle so as to enable it to identify types of malfunction over the entire life of the engine. In achieving this objective the approval authority shall accept that engines which have been used in excess of the appropriate durability period defined in paragraph 5.3. of this Regulation may show some deterioration in OBD system performance such that the OBD thresholds given in the table in paragraph 5.4.4. of this Regulation may be exceeded before the OBD system signals a failure to the driver of the vehicle.
- 3.1.2. A sequence of diagnostic checks shall be initiated at each engine start and completed at least once provided that the correct test conditions are met. The test conditions shall be selected in such a way that they all occur under the driving conditions as represented by the test defined in paragraph 2. of Appendix 1 to this annex.
 - 3.1.2.1. Manufacturers are not required to activate a component/system exclusively for the purpose of OBD functional monitoring under vehicle operating conditions when it would not normally be active (e.g. activation of a reagent tank heater of a deNOx system or combined deNOx-particulate filter when such a system would not normally be active).
- 3.1.3. OBD may involve devices, which measure, senses or responds to operating variables (e.g. vehicle speed, engine speed, gear used, temperature, intake pressure or any other parameter) for the purpose of detecting malfunctions and of minimizing the risk of indicating false malfunction. These devices are not defeat devices.
- 3.1.4. Access to the OBD system required for the inspection, diagnosis, servicing or repair of the engine shall be unrestricted and standardized. All emission related fault codes shall be consistent with those described in paragraph 6.8.5. of this annex.

3.2. OBD Stage 1 requirements

3.2.1. From the dates given in paragraph 5.4.1. of this Regulation, the OBD system of all diesel engines and of vehicles equipped with a diesel engine shall indicate the failure of an emission-related component or system when that failure results in an increase in emissions above the appropriate OBD thresholds given in the table in paragraph 5.4.4. of this Regulation.

3.2.2. In satisfying the Stage 1 requirements, the OBD system shall monitor for:

3.2.2.1. complete removal of a catalyst, where fitted in a separate housing, that may or may not be part of a deNOx system or particulate filter.

3.2.2.2. reduction in the efficiency of the deNOx system, where fitted, with respect to the emissions of NOx only.

3.2.2.3. reduction in the efficiency of the particulate filter, where fitted, with respect to the emissions of particulate only.

3.2.2.4. reduction in the efficiency of a combined deNOx-particulate filter system, where fitted, with respect to both the emissions of NOx and particulate.

3.2.3. Major functional failure

3.2.3.1. As an alternative to monitoring against the appropriate OBD threshold limits with respect to paragraphs 3.2.2.1. to 3.2.2.4., OBD systems of diesel engines may in accordance with paragraph 5.4.1.1. of this Regulation monitor for major functional failure of the following components:

- (a) a catalyst, where fitted as a separate unit, that may or may not be part of a deNOx system or particulate filter;
- (b) a deNOx system, where fitted;
- (c) a particulate filter, where fitted;
- (d) a combined deNOx-particulate filter system.

3.2.3.2. In the case of an engine equipped with a deNOx system, examples of monitoring for major functional failure are for complete removal of the system or replacement of the system by a bogus system (both intentional major functional failure), lack of required reagent for a deNOx system, failure of any SCR electrical component, any electrical failure of a component (e.g. sensors and actuators, dosing control unit) of a deNOx system including, when applicable, the reagent heating system, failure of the reagent dosing system (e.g. missing air supply, clogged nozzle, dosing pump failure).

3.2.3.3. In the case of an engine equipped with a particulate filter, examples of monitoring for major functional failure are for major melting of the trap substrate or a clogged trap resulting in a differential pressure out of the range declared by the manufacturer, any electrical failure of a component (e.g. sensors and actuators, dosing control unit) of a

particulate filter, any failure, when applicable, of a reagent dosing system (e.g. clogged nozzle, dosing pump failure).

- 3.2.4. Manufacturers may demonstrate to the approval authority that certain components or systems need not be monitored if, in the event of their total failure or removal, emissions do not exceed the applicable thresholds limits for OBD Stage 1 given in the table in paragraph 5.4.4. of this Regulation when measured over the cycles shown in paragraph 1.1. of Appendix 1 to this annex. This provision shall not apply to an exhaust gas recirculation (EGR) device, a deNOx system, a particulate filter or a combined deNOx-particulate filter system nor shall it apply to a component or system that is monitored for major functional failure.

3.3. OBD Stage 2 requirements

- 3.3.1. From the dates given in paragraph 5.4.2. of this Regulation the OBD system of all diesel or gas engines and of vehicles equipped with a diesel or a gas engine shall indicate the failure of an emission-related component or system of the engine system when that failure results in an increase in emissions above the appropriate OBD thresholds given in the table in paragraph 5.4.4. of this Regulation.

The OBD system shall consider the communication interface (hardware and messages) between the engine system electronic control unit(s) (EECU) and any other power train or vehicle control unit when the exchanged information has an influence on the correct functioning of the emission control. The OBD system shall diagnose the integrity of the connection between the EECU and the medium that provides the link with these other vehicle components (e.g. the communication bus).

- 3.3.2. In satisfying the Stage 2 requirements, the OBD system shall monitor for:

- 3.3.2.1. reduction in the efficiency of the catalyst, where fitted in a separate housing, that may or may not be part of a deNOx system or particulate filter.
- 3.3.2.2. reduction in the efficiency of the deNOx system, where fitted, with respect to the emissions of NOx only.
- 3.3.2.3. reduction in the efficiency of the particulate filter, where fitted, with respect to the emissions of particulate only.
- 3.3.2.4. reduction in the efficiency of a combined deNOx-particulate filter system, where fitted, with respect to both the emissions of NOx and particulate.
- 3.3.2.5. the interface between the engine electronic control unit (EECU) and any other powertrain or vehicle electrical or electronic system (e.g. the transmission control unit (TECU)) for electrical disconnection.
- 3.3.3. Manufacturers may demonstrate to the approval authority that certain components or systems need not be monitored if, in the event of their total failure or removal, emissions do not exceed the applicable thresholds limits for OBD Stage 2 given in the table in

paragraph 5.4.4. of this Regulation when measured over the cycles shown in paragraph 1.1. of Appendix 1 to this annex. This provision shall not apply to an exhaust gas recirculation (EGR) device, a deNO_x system, a particulate filter or a combined deNO_x-particulate filter system.

3.4. Stage 1 and Stage 2 requirements

3.4.1. In satisfying both the Stage 1 or Stage 2 requirements the OBD system shall monitor:

3.4.1.1. The fuel-injection system electronic, fuel quantity and timing actuator(s) for circuit continuity (i.e. open circuit or short circuit) and total functional failure.

3.4.1.2. All other engine or exhaust aftertreatment emission-related components or systems, which are connected to a computer, the failure of which would result in tailpipe emissions exceeding the OBD threshold limits given in the table in paragraph 5.4.4. of this Regulation. At a minimum, examples include the exhaust gas recirculation (EGR) system, systems or components for monitoring and control of air mass-flow, air volumetric flow (and temperature), boost pressure and inlet manifold pressure (and relevant sensors to enable these functions to be carried out), sensors and actuators of a deNO_x system, sensors and actuators of an electronically activated active particulate filter.

3.4.1.3. Any other emission-related engine or exhaust aftertreatment component or system connected to an electronic control unit shall be monitored for electrical disconnection unless otherwise monitored.

3.4.1.4. In the case of engines equipped with an aftertreatment system using a consumable reagent, the OBD system shall monitor for:

- (a) lack of any required reagent;
 - (b) the quality of the required reagent being within the specifications declared by the manufacturer in Annex 1 to this Regulation;
 - (c) reagent consumption and dosing activity;
- according to paragraph 5.5.4. of this Regulation.

3.5. OBD operation and temporary disablement of certain OBD monitoring capabilities

3.5.1. The OBD system shall be so designed, constructed and installed in a vehicle as to enable it to comply with the requirements of this annex during the conditions of use defined in paragraph 5.1.5.4. of this Regulation.

Outside these normal operating conditions the emission control system may show some degradation in OBD system performance such that the thresholds given in the table in paragraph 5.4.4. of this Regulation may be exceeded before the OBD system signals a failure to the driver of the vehicle.

The OBD system shall not be disabled unless one or more of the following conditions for disablement are met:

- 3.5.1.1. The affected OBD monitoring systems may be disabled if its ability to monitor is affected by low fuel levels. For this reason, disablement is permitted when the fuel tank level falls below 20 per cent of the nominal capacity of the fuel tank.
- 3.5.1.2. The affected OBD monitoring systems may be temporarily disabled during the operation of an auxiliary emission control strategy as described in paragraph 5.1.5.1. of this Regulation.
- 3.5.1.3. The affected OBD monitoring systems may be temporarily disabled when operational safety or limp-home strategies are activated.
- 3.5.1.4. For vehicles designed to accommodate the installation of power take-off units, disablement of affected OBD monitoring systems is permitted provided disablement takes place only when the power take-off unit is active and the vehicle is not being driven.
- 3.5.1.5. The affected OBD monitoring systems may be disabled temporarily during the periodic regeneration of an emission control system downstream of the engine (i.e. a particulate filter, deNOx system or combined deNOx-particulate filter).
- 3.5.1.6. The affected OBD monitoring systems may be disabled temporarily outside the conditions of use defined in paragraph 5.1.5.4. of this Regulation when this disablement can be justified by a limitation of the OBD monitoring (including modelling) capability.
- 3.5.2. The OBD monitoring system is not required to evaluate components during malfunction if such evaluation would result in a risk to safety or component failure.
- 3.6. Activation of malfunction indicator (MI)
 - 3.6.1. The OBD system shall incorporate a malfunction indicator readily visible to the vehicle operator. Except in the case of paragraph 3.6.2. of this annex, the MI (e.g. symbol or lamp) shall not be used for any purpose other than emission related malfunction except to indicate emergency start-up or limp-home routines to the driver. Safety related messages can be given the highest priority. The MI shall be visible in all reasonable lighting conditions. When activated, it shall display a symbol in conformity with ISO 2575 1/ (as a dashboard telltale lamp or a symbol on a dashboard display). A vehicle shall not be equipped with more than one general purpose MI for emission-related problems. Displaying separate specific information is permitted (e.g. such as information dealing with brake system, fasten seat belt, oil pressure, servicing requirements, or indicating the lack of necessary reagent for the deNOx system). The use of red for the MI is prohibited.
 - 3.6.2. The MI may be used to indicate to the driver that an urgent service task needs to be carried out. Such an indication may also be accompanied by an appropriate message on a dashboard display that an urgent servicing requirement needs to be carried out.

1/ Symbol numbers F01 or F22.

- 3.6.3. For strategies requiring more than a preconditioning cycle for MI activation, the manufacturer shall provide data and/or an engineering evaluation which adequately demonstrates that the monitoring system is equally effective and timely in detecting component deterioration. Strategies requiring on average more than ten OBD or emission test cycles for MI activation are not accepted.
- 3.6.4. The MI shall also activate whenever the engine control enters a emission default mode of operation. The MI shall also activate if the OBD system is unable to fulfil the basic monitoring requirements specified in this Regulation.
- 3.6.5. Where reference is made to this paragraph, the MI shall be activated and, in addition, a distinct warning mode should also be activated, e.g. flashing MI or activation of a symbol in conformity with ISO 2575 2/ in addition to MI activation.
- 3.6.6. The MI shall activate when the vehicle's ignition is in the "key-on" position before engine starting or cranking and de-activate within 10 seconds after engine starting if no malfunction has previously been detected.

3.7. Fault code storage

The OBD system shall record fault code(s) indicating the status of the emission-control system. A fault code shall be stored for any detected and verified malfunction causing MI activation and shall identify the malfunctioning system or component as uniquely as possible. A separate code should be stored indicating the expected MI activation status (e.g. MI commanded "ON", MI commanded "OFF").

Separate status codes shall be used to identify correctly functioning emission control systems and those emission control systems that need further engine operation to be fully evaluated. If the MI is activated due to malfunction or emission default modes of operation, a fault code shall be stored that identifies the likely area of malfunction. A fault code shall also be stored in the cases referred to in paragraphs 3.4.1.1. and 3.4.1.3. of this annex.

- 3.7.1. If monitoring has been disabled for 10 driving cycles due to the continued operation of the vehicle under conditions conforming to those specified in paragraph 3.5.1.2. of this annex, readiness for the subject monitoring system may be set to "ready" status without monitoring having been completed.
- 3.7.2. The hours run by the engine while the MI is activated shall be available upon request at any instant through the serial port on the standard link connector, according to the specifications given in paragraph 6.8. of this annex.

3.8. Extinguishing the MI

2/ Symbol number F24.

- 3.8.1. The MI may be de-activated after three subsequent sequential operating sequences or 24 engine running hours during which the monitoring system responsible for activating the MI ceases to detect the malfunction and if no other malfunction has been identified that would independently activate the MI.
- 3.8.2. In the case of MI activation due to lack of reagent for the deNOx system, or combined deNOx-particulate after-treatment device or use of a reagent outside the specifications declared by the manufacturer, the MI may be switched back to the previous state of activation after filling or replacement of the storage medium with a reagent having the correct specifications.
- 3.8.3. In the case of MI activation due to incorrect operation of the engine system with respect to NOx control measures, or incorrect reagent consumption and dosing activity, the MI may be switched back to the previous state of activation if the conditions given in paragraphs 5.5.3., 5.5.4 and 5.5.7. of this Regulation no longer apply.

3.9. Erasing a fault code

- 3.9.1 The OBD system may erase a fault code and the hours run by the engine and freeze-frame information if the same fault is not re-registered in at least 40 engine warm-up cycles or 100 engine running hours, whichever occurs first, with the exception of the cases referred to in paragraph 3.9.2.
- 3.9.2 From 9 November 2006 for new type approvals and from 1 October 2007 for all registrations, in the case of a non-erasable fault code being generated according to paragraph 5.5.3. or 5.5.4. of this Regulation, the OBD system shall retain a record of the fault code and the hours run by the engine during the MI activation for at least 400 days or 9,600 hours of engine operation.

Any such fault code and the corresponding hours run by the engine during MI activation shall not be erased through use of any external diagnostic or other tool as referred to in paragraph 6.8.3. of this annex.

4. REQUIREMENTS RELATING TO THE APPROVAL OF OBD SYSTEMS

- 4.1. For the purpose of approval, the OBD system shall be tested according to the procedures given in Appendix 1 to this annex.

An engine representative of its engine family (see paragraph 7. of this Regulation) shall be used for the OBD demonstration tests or the test report of the parent OBD system of the OBD engine family will be provided to the approval authority as an alternative to carrying out the OBD demonstration test.

- 4.1.1. In the case of OBD stage 1 referred to in paragraph 3.2., the OBD system shall:

- 4.1.1.1. indicate the failure of an emission-related component or system when that failure results in an increase in emissions above the OBD thresholds given in the table in paragraph 5.4.4. of this Regulation, or;
- 4.1.1.2. where appropriate, indicate any major functional failure of an exhaust aftertreatment system.
- 4.1.2. In the case of OBD stage 2 referred to in paragraph 3.3., the OBD system shall indicate the failure of an emission-related component or system when that failure results in an increase in emissions above the OBD thresholds given in the table in paragraph 5.4.4. of this Regulation.
- 4.1.3. In the case of both OBD 1 and OBD 2, the OBD system shall indicate the lack of any required reagent necessary for the operation of an exhaust aftertreatment system.

4.2. Installation requirements

- 4.2.1. The installation on the vehicle of an engine equipped with an OBD system shall comply with the following provisions of this annex with respect to the vehicle equipment:
 - (a) the provisions of paragraphs 3.6.1., 3.6.2. and 3.6.5. concerning the MI and, where appropriate, additional warning modes;
 - (b) when applicable, the provisions of paragraph 6.8.3.1. concerning the use of an on-board diagnostic facility;
 - (c) the provisions of paragraph 6.8.6. concerning the connection interface.

4.3. Approval of an OBD system containing deficiencies

- 4.3.1. A manufacturer may request to the authority that an OBD system be accepted for approval even though the system contains one or more deficiencies such that the specific requirements of this annex are not fully met.
- 4.3.2. In considering the request, the authority shall determine whether compliance with the requirements of this annex is feasible or unreasonable.

The authority shall take into consideration data from the manufacturer that details such factors as, but not limited to, technical feasibility, lead time and production cycles including phase-in or phase-out of engines designs and programmed upgrades of computers, the extend to which the resultant OBD system will be effective in complying with the requirements of this Regulation and that the manufacturer has demonstrated an acceptable level of effort toward the requirements of this Regulation.

- 4.3.3. The authority will not accept any deficiency request that includes the complete lack of a required diagnostic monitor.
- 4.3.4. The authority shall not accept any deficiency request that does not respect the OBD threshold limits given in the table in paragraph 5.4.4. of this Regulation.

- 4.3.5. In determining the identified order of deficiencies, deficiencies relating to OBD Stage 1 in respect of paragraphs 3.2.2.1., 3.2.2.2., 3.2.2.3., 3.2.2.4. and 3.4.1.1. and OBD Stage 2 in respect of paragraphs 3.3.2.1., 3.3.2.2., 3.3.2.3., 3.3.2.4. and 3.4.1.1. of this annex shall be identified first.
- 4.3.6. Prior to or at the time of approval, no deficiency shall be granted in respect of the requirements of paragraph 3.2.3. and paragraph 6., except sub-paragraph 6.8.5. of this annex.
- 4.3.7. Deficiency period
- 4.3.7.1. A deficiency may be carried-over for a period of two years after the date of approval of the engine type or vehicle in respect of its engine type, unless it can be adequately demonstrated that substantial engine modifications and additional lead-time beyond two years would be necessary to correct the deficiency. In such a case, the deficiency may be carried-out for a period not exceeding three years.
- 4.3.7.2. A manufacturer may request that the original approval authority grant a deficiency retrospectively when such a deficiency is discovered after the original approval. In this case, the deficiency may be carried-over for a period of two years after the date of notification to the approval authority unless it can be adequately demonstrated that substantial engine modifications and additional lead-time beyond two years would be necessary to correct the deficiency. In such a case, the deficiency may be carried-out for a period not exceeding three years.
- 4.3.7.3. The authority shall notify its decision in granting a deficiency request to all Contracting Parties.

5. ACCESS TO OBD INFORMATION

5.1. Replacement parts, diagnostic tools and test equipment

- 5.1.1. Applications for approval or amendment of an approval shall be accompanied by the relevant information concerning the OBD system. This relevant information shall enable manufacturers of replacement or retrofit components to make the parts they manufacture compatible with the OBD system with a view to fault-free operation assuring the vehicle user against malfunctions. Similarly, such relevant information shall enable the manufacturers of diagnostic tools and test equipment to make tools and equipment that provide for effective and accurate diagnosis of emission control systems.
- 5.1.2. Upon request, the approval authorities shall make Appendix 1 to Annex 2A, containing the relevant information on the OBD system as specified in Appendix 2 to Annex 6 to this Regulation, available to any interested components, diagnostic tools or test equipment manufacturer on a non-discriminatory basis.

- 5.1.2.1. In the case of replacement or service components, information can only be requested for such components that are subject to approval, or for components that form part of a system that is subject to approval.
- 5.1.2.2. The request for information shall identify the exact specification of the engine model type/engine model type within an engine family for which the information is required. It shall confirm that the information is required for the development of replacement or retrofit parts or components or diagnostic tools or test equipment.

5.2 Repair information

- 5.2.1. No later than three months after the manufacturer has provided any authorized dealer or repair shop within the Community with repair information, the manufacturer shall make that information (including all subsequent amendments and supplements) available upon reasonable and non-discriminatory payment.
- 5.2.2. The manufacturer shall also make accessible, where appropriate upon payment the technical information required for the repair or maintenance of motor vehicles unless that information is covered by an intellectual property right or constitutes essential, secret know-how which is identified in an appropriate form; in such case, the necessary technical information shall not be withheld improperly.

Entitled to such information is any person engaged in commercially servicing or repairing, road-side rescuing, inspecting or testing of vehicles or in manufacturing or selling replacement or retro-fit components, diagnostic tools and test equipment.

- 5.2.3. In the event of failure to comply with these provisions the approval authority shall take appropriate measures to ensure that repair information is available, in accordance with the procedures laid down for approval and in-service surveys.

6. DIAGNOSTIC SIGNALS

- 6.1. Upon determination of the first malfunction of any component or system, "freeze-frame" engine conditions present at the time shall be stored in computer memory. Stored engine conditions shall include, but are not limited to calculated load value, engine speed, coolant temperature, intake manifold pressure (if available), and the fault code which caused the data to be stored. For freeze-frame storage, the manufacturer shall choose the most appropriate set of conditions facilitating effective repairs.
- 6.2. Only one frame of data is required. Manufacturers may choose to store additional frames provided that at least the required frame can be read by a generic scan tool meeting the specifications of paragraphs 6.8.3. and 6.8.4. If the fault code causing the conditions to be stored is erased in accordance with paragraph 3.9. of this annex, the stored engine conditions may also be erased.
- 6.3. If available, the following signals in addition to the required freeze-frame information shall be made available on demand through the serial port on the standardized data link

connector, if the information is available to the on-board computer or can be determined using information available to the on-board computer: diagnostic trouble codes, engine coolant temperature, injection timing, intake air temperature, manifold air pressure, air flow rate, engine speed, pedal position sensor output value, calculated load value, vehicle speed and fuel pressure.

The signals shall be provided in standard units based on the specifications given in paragraph 6.8. Actual signals shall be clearly identified separately from default value or limp-home signals.

- 6.4. For all emission control systems for which specific on-board evaluation tests are conducted, separate status codes, or readiness codes, shall be stored in computer memory to identify correctly functioning emission control systems and those emission control systems which require further vehicle operation to complete a proper diagnostic evaluation. A readiness code need not be stored for those monitors that can be considered continuously operating monitors. Readiness codes should never be set to "not ready" status upon "key-on" or "key-off". The intentional setting of readiness codes to "not ready" status via service procedures shall apply to all such codes, rather than applying to individual codes.
- 6.5. The OBD requirements to which the vehicle is certified (i.e. stage 1 OBD or stage 2 OBD) and the major emission control systems monitored by the OBD system consistent with paragraph 6.8.4. shall be available through the serial data port on the standardized data link connector according to the specifications given in paragraph 6.8.
- 6.6. The software calibration identification number as declared in Annexes 1 and 2A to this Regulation shall be made available through the serial port of the standardized diagnostic connector. The software calibration identification number shall be provided in a standardized format.
- 6.7. The vehicle identification number (VIN) number shall be made available through the serial port of the standardized diagnostic connector. The VIN number shall be provided in a standardized format.
- 6.8. The emission control diagnostic system shall provide for standardized or unrestricted access and conform to either ISO 15765 or SAE J1939, as specified in the following paragraphs 3/.
- 6.8.1. The use of either ISO 15765 or SAE J1939 shall be consistent throughout paragraphs 6.8.2. to 6.8.5.
- 6.8.2. The on-board to off-board communications link shall conform to ISO 15765-4 or to the similar clauses within the SAE J1939 series of standards.

3/ The use of the ISO single protocol standard (ISO/PAS 27145) developed for a world-wide global technical regulation on heavy-duty OBD will be considered to satisfy the appropriate requirements of paragraph 6.

6.8.3. Test equipment and diagnostic tools needed to communicate with OBD systems shall meet or exceed the functional specification given in ISO 15031-4 or SAE J1939-73 paragraph 5.2.2.1.

6.8.3.1. The use of an on-board diagnostic facility such as a dashboard mounted video display device for enabling access to OBD information is permitted but this is in addition to enabling access to OBD information by means of the standard diagnostic connector.

6.8.4. Diagnostic data, (as specified in this paragraph) and bi-directional control information shall be provided using the format and units described in ISO 15031-5 or SAE J1939-73 paragraph 5.2.2.1. and shall be available using a diagnostic tool meeting the requirements of ISO 15031-4 or SAE J1939-73 paragraph 5.2.2.1.

The manufacturer shall provide a national standardization body with emission-related diagnostic data, e.g. PID's, OBD monitor Id's, Test Id's not specified in ISO 15031-5 but related to this Regulation.

6.8.5. When a fault is registered, the manufacturer shall identify the fault using the most appropriate fault code consistent with those given in paragraph 6.3. of ISO 15031-6 relating to emission-related system diagnostic trouble codes. If such identification is not possible, the manufacturer may use diagnostic trouble codes according to paragraphs 5.3. and 5.6. of ISO 15031-6. The fault codes shall be fully accessible by standardized diagnostic equipment complying with the provisions of paragraph 6.8.3. of this annex.

The manufacturer shall provide a national standardization body with emission-related diagnostic data, e.g. PID's, OBD monitor Id's, Test Id's not specified in ISO 15031-5 but related to this Regulation.

As an alternative, the manufacturer may identify the fault using the most appropriate fault code consistent with those given in SAE J2012 or in SAE J1939-73.

6.8.6. The connection interface between the vehicle and the diagnostic tester shall be standardized and shall meet all the requirements of ISO 15031-3 or SAE J1939-13.

In the case of category N₂, N₃, M₂, and M₃ vehicles, as an alternative to the connector location described in the above standards and provided all other requirements of ISO 15031-3 are met, the connector may be located in a suitable position by the side of the driver's seat, including on the floor of the cabin. In this case the connector should be accessible by a person standing outside the vehicle and not restrict access to the driver's seat.

The installation position shall be subject to agreement of the approval authority such that it is readily accessible by service personnel but protected from accidental damage during normal conditions of use.

Appendix 1

ON-BOARD DIAGNOSTIC (OBD) SYSTEM APPROVAL TESTS

1. INTRODUCTION

This appendix describes the procedure for checking the function of the on-board diagnostic (OBD) system installed on the engine by failure simulation of relevant emission-related systems in the engine management or emission control system. It also sets procedures for determining the durability of OBD systems.

1.1. Deteriorated components/systems

In order to demonstrate the efficient monitoring of an emission control system or component, the failure of which may result in tailpipe emissions exceeding the appropriate OBD threshold limits, the manufacturer shall make available the deteriorated components and/or electrical devices which would be used to simulate failures.

Such deteriorated components or devices shall not cause emissions to exceed the OBD threshold limits referred to in the table in paragraph 5.4.4. of this Regulation by more than 20 per cent.

In the case of approval of an OBD system according to paragraph 5.4.1. of this Regulation, the emissions shall be measured over the ESC test cycle (see Appendix 1 to Annex 4A to this Regulation). In the case of approval of an OBD system according to paragraph 5.4.2. of this Regulation, the emissions shall be measured over the ETC test cycle (see Appendix 2 to Annex 4A to this Regulation).

- 1.1.1. If it is determined that the installation of a deteriorated component or device on an engine means that a comparison with the OBD threshold limits is not possible (e.g. because the statistical conditions for validating the ETC test cycle are not met), the failure of that component or device may be considered as qualified upon the agreement of the approval authority based on technical argumentation provided by the manufacturer.
- 1.1.2. In the case that the installation of a deteriorated component or device on an engine means that the full load curve (as determined with a correctly operating engine) cannot (even partially) be attained during the test, the deteriorated component or device is considered as qualified upon the agreement of the approval authority based on technical argumentation provided by the manufacturer.
- 1.1.3. The use of deteriorated components or devices that cause engine emissions to exceed the OBD threshold limits referred to in the table in paragraph 5.4.4. of this Regulation by no more than 20 per cent may not be required in some very specific cases (for example, if a limp home strategy is activated, if the engine cannot run any test, or in case of EGR sticking valves, etc). This exception shall be documented by the manufacturer. It is subject to the agreement of the technical service.

1.2. Test principle

When the engine is tested with the deteriorated component or device fitted, the OBD system is approved if the MI is activated. The OBD system is also approved if the MI is activated below the OBD threshold limits.

The use of deteriorated components or devices that cause the engine emissions to exceed the OBD threshold limits referred to in the table in paragraph 5.4.4. of this Regulation by no more than 20 per cent are not required in the specific case of the failure modes described in paragraphs 6.3.1.6. and 6.3.1.7. of this appendix and also with respect to monitoring for major functional failure.

- 1.2.1. The use of deteriorated components or devices that cause engine emissions to exceed the OBD threshold limits referred to in the table in paragraph 5.4.4. of this Regulation by no more than 20 per cent may not be required in some very specific cases (for example, if a limp home strategy is activated, if the engine cannot run any test, or in case of EGR sticking valves, etc). This exception shall be documented by the manufacturer. It is subject to the agreement of the technical service.

2. DESCRIPTION OF TEST

- 2.1. The testing of OBD systems consists of the following phases:
- (a) simulating the malfunction of a component of the engine management or emission control system as described in paragraph 1.1. of this appendix;
 - (b) preconditioning of the OBD system with a simulated malfunction over the preconditioning cycle specified in paragraph 6.2.;
 - (c) operating the engine with a simulated malfunction over the OBD test cycle referred to in paragraph 6.1.;
 - (d) determining whether the OBD system reacts to the simulated malfunction and indicates malfunction in an appropriate manner.
- 2.1.1. Should the performance (e.g. power curve) of the engine be affected by the malfunction, the OBD test-cycle remains the shortened version of the ESC test-cycle used for the assessing the exhaust emissions of the engine without that malfunction.
- 2.2. Alternatively, at the request of the manufacturer, malfunction of one or more components may be electronically simulated according to the requirements of paragraph 6.
- 2.3. Manufacturers may request that monitoring take place outside the OBD test cycle referred to in paragraph 6.1. if it can be demonstrated to the authority that monitoring during conditions encountered during this OBD test cycle would impose restrictive monitoring conditions when the vehicle is used in service.

3. TEST ENGINE AND FUEL

3.1. Engine

The test engine shall comply with the specifications laid down in Annex 1 to this Regulation.

3.2. Fuel

The appropriate reference fuel as described in Annex 5 to this Regulation shall be used for testing.

4. TEST CONDITIONS

The test conditions shall satisfy the requirements of the emission test described in the present Regulation.

5. TEST EQUIPMENT

The engine dynamometer shall meet the requirements of Annex 4A to this Regulation.

6. OBD TEST CYCLE

6.1. The OBD test cycle is a single shortened ESC test cycle. The individual modes shall be performed in the same order as the ESC test cycle, as defined in paragraph 2.7.1. of Appendix 1 to Annex 4A to this Regulation .

The engine shall be operated for a maximum of 60 seconds in each mode, completing engine speed and load changes in the first 20 seconds. The specified speed shall be held to within $\pm 50 \text{ min}^{-1}$ and the specified torque shall be held to within ± 2 per cent of the maximum torque at each speed.

Exhaust emissions are not required to be measured during the OBD test cycle.

6.2. Preconditioning cycle

6.2.1. After introduction of one of the failure modes given in paragraph 6.3., the engine and its OBD system shall be preconditioned by performing a preconditioning cycle.

6.2.2. At the request of the manufacturer and with the agreement of the approval authority, an alternative number of a maximum of nine consecutive OBD test cycles may be used.

6.3. OBD system test

6.3.1. Diesel engines and vehicles equipped with a diesel engine

6.3.1.1. After preconditioning according to paragraph 6.2., the test engine is operated over the OBD test cycle described in paragraph 6.1. of this appendix. The MI shall activate before the end of this test under any of the conditions given in 6.3.1.2. to 6.3.1.7. The technical service may substitute those conditions by others in accordance with paragraph 6.3.1.7. For the purposes of approval, the total number of failures subject to testing, in the case of different systems or components, shall not exceed four.

If the test is being carried out to type-approve an OBD-engine family consisting of engines that do not belong to the same engine family, the type approval authority will increase the number of failures subject to testing up to a maximum of four times the number of engine families present in the OBD-engine family. The approval authority may decide to curtail the test at any time before this maximum number of failure tests has been reached.

6.3.1.2. Where fitted in a separate housing that may or may not be part of a deNOx system or diesel particulate filter, replacement of any catalyst with a deteriorated or defective catalyst or electronic simulation of such a failure.

6.3.1.3. Where fitted, replacement of a deNOx system (including any sensors that are an integral part of the system) with a deteriorated or defective deNOx system or electronic simulation of a deteriorated or defective deNOx system that results in emissions exceeding the OBD NOx threshold limit referred to in the table given in paragraph 5.4.4. of this Regulation.

In the case that the engine is being approved according to paragraph 5.4.1. of this Regulation in relation to monitoring for major functional failure, the test of the deNOx system shall determine that the MI illuminates under any of the following conditions:

- (a) complete removal of the system or replacement of the system by a bogus system;
- (b) lack of any required reagent for a deNOx system;
- (c) any electrical failure of a component (e.g. sensors and actuators, dosing control unit) of a deNOx system, including, when applicable, the reagent heating system;
- (d) failure of a reagent dosing system (e.g. missing air supply, clogged nozzle, dosing pump failure) of a deNOx system;
- (e) major breakdown of the system.

6.3.1.4. Where fitted, total removal of the particulate filter or replacement of the particulate filter with a defective particulate filter that results in emissions exceeding the OBD particulate threshold limit given in the table in paragraph 5.4.4. of this Regulation.

In the case that the engine is being approved according to paragraph 5.4.1. of this Regulation in relation to monitoring for major functional failure, the test of the particulate filter shall determine that the MI illuminates under any of the following conditions:

- (a) complete removal of the particulate filter or replacement of the system by a bogus system;
- (b) major melting of the particulate filter substrate;

- (c) major cracking of the particulate filter substrate;
- (d) any electrical failure of a component (e.g. sensors and actuators, dosing control unit) of a particulate filter;
- (e) failure, when applicable, of the reagent dosing system (e.g. clogged nozzle, dosing pump failure) of a particulate filter;
- (f) a clogged particulate filter resulting in a differential pressure out of the range declared by the manufacturer.

6.3.1.5. Where fitted, replacement of a combined deNOx-particulate filter system (including any sensors that are an integral part of the device) with a deteriorated or defective system or electronic simulation of a deteriorated or defective system that results in emissions exceeding the OBD NOx and particulate threshold limits given in the table in paragraph 5.4.4. of this Regulation.

In the case that the engine is being approved according to paragraph 5.4.1. of this Regulation in relation to monitoring for major functional failure, the test of the combined deNOx-particulate filter system shall determine that the MI illuminates under any of the following conditions:

- (a) complete removal of the system or replacement of the system by a bogus system;
- (b) lack of any required reagent for a combined deNOx-particulate filter system;
- (c) any electrical failure of a component (e.g. sensors and actuators, dosing control unit) of a combined deNOx-particulate filter system, including, when applicable, the reagent heating system;
- (d) failure of a reagent dosing system (e.g. missing air supply, clogged nozzle, dosing pump failure) of a combined deNOx-particulate filter system;
- (e) major breakdown of a NOx trap system;
- (f) major melting of the particulate filter substrate;
- (g) major cracking of the particulate filter substrate;
- (h) a clogged particulate filter resulting in a differential pressure out of the range declared by the manufacturer.

6.3.1.6. Disconnection of any fuelling system electronic fuel quantity and timing actuator that results in emissions exceeding any of the OBD thresholds referred to in the table given in paragraph 5.4.4. of this Regulation.

6.3.1.7. Disconnection of any other emission-related engine component connected to a computer that results in emissions exceeding any of the thresholds referred to in the table given in paragraph 5.4.4. of this Regulation.

6.3.1.8. In demonstrating compliance with the requirements of paragraphs 6.3.1.6. and 6.3.1.7. and with the agreement of the approval authority, the manufacturer may take appropriate steps to demonstrate that the OBD system will indicate a fault when disconnection occurs.

Annex 10

TEST PROCEDURE FOR COMPRESSION-IGNITION (C.I.) ENGINES AND POSITIVE-IGNITION (P.I.) ENGINES FUELLED WITH NATURAL GAS (NG) OR LIQUEFIED PETROLEUM GAS (LPG) INCORPORATING THE WORLD-WIDE HARMONIZED HEAVY-DUTY CERTIFICATION (WHDC, global technical regulation (gtr) No. 4)

1. APPLICABILITY

This annex is not applicable for the purpose of type approval according to this Regulation for the time being. It will be made applicable in the future.

2. Reserved 1/.

3. DEFINITIONS, SYMBOLS AND ABBREVIATIONS

3.1. Definitions

For the purpose of this Regulation,

3.1.1. "continuous regeneration" means the regeneration process of an exhaust after-treatment system that occurs either permanently or at least once per WHTC hot start test. Such a regeneration process will not require a special test procedure.

3.1.2. "delay time" means the difference in time between the change of the component to be measured at the reference point and a system response of 10 per cent of the final reading (t_{10}) with the sampling probe being defined as the reference point. For the gaseous components, this is the transport time of the measured component from the sampling probe to the detector with the sampling probe being defined as the reference point.

3.1.3. "deNO_x system" means an exhaust after-treatment system designed to reduce emissions of oxides of nitrogen (NO_x) (e.g. passive and active lean NO_x catalysts, NO_x adsorbers and selective catalytic reduction (SCR) systems).

3.1.4. "diesel engine" means an engine which works on the compression-ignition principle.

3.1.5. "engine family" means a manufacturers grouping of engines which, through their design as defined in paragraph 5.2. of this annex, have similar exhaust emission characteristics; all members of the family must comply with the applicable emission limit values.

3.1.6. "engine system" means the engine, the emission control system and the communication interface (hardware and messages) between the engine system electronic control unit(s) (ECU) and any other powertrain or vehicle control unit.

1/ The numbering of this annex is consistent with the numbering of the WHDC gtr. However, some sections of the WHDC gtr are not needed in this annex.

- 3.1.7. "engine type" means a category of engines which do not differ in essential engine characteristics.
- 3.1.8. "exhaust after-treatment system" means a catalyst (oxidation or 3-way), particulate filter, deNO_x system, combined deNO_x particulate filter or any other emission-reducing device that is installed downstream of the engine. This definition excludes exhaust gas recirculation (EGR), which is considered an integral part of the engine.
- 3.1.9. "full flow dilution method" means the process of mixing the total exhaust flow with dilution air prior to separating a fraction of the diluted exhaust stream for analysis.
- 3.1.10. "gas engine" means an engine which is fuelled with natural gas (NG) or liquefied petroleum gas (LPG).
- 3.1.11. "gaseous pollutants" means carbon monoxide, hydrocarbons and/or non-methane hydrocarbons (assuming a ratio of CH_{1.85} for diesel, CH_{2.525} for LPG and CH_{2.93} for NG, and an assumed molecule CH₃O_{0.5} for ethanol fuelled diesel engines), methane (assuming a ratio of CH₄ for NG) and oxides of nitrogen (expressed in nitrogen dioxide (NO₂) equivalent).
- 3.1.12. "high speed (n_{hi})" means the highest engine speed where 70 per cent of the declared maximum power occurs.
- 3.1.13. "low speed (n_{lo})" means the lowest engine speed where 55 per cent of the declared maximum power occurs.
- 3.1.14. "maximum power (P_{max})" means the maximum power in kW as specified by the manufacturer.
- 3.1.15. "maximum torque speed" means the engine speed at which the maximum torque is obtained from the engine, as specified by the manufacturer.
- 3.1.16. "parent engine" means an engine selected from an engine family in such a way that its emissions characteristics are representative for that engine family.
- 3.1.17. "particulate after-treatment device" means an exhaust after-treatment system designed to reduce emissions of particulate pollutants (PM) through a mechanical, aerodynamic, diffusional or inertial separation.
- 3.1.18. "partial flow dilution method" means the process of separating a part from the total exhaust flow, then mixing it with an appropriate amount of dilution air prior to the particulate sampling filter.
- 3.1.19. "particulate matter (PM)" means any material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature between 315 K (42 °C) and 325 K (52 °C), as measured at a point immediately upstream of the filter; this is primarily carbon, condensed hydrocarbons, and sulphates with associated water.

- 3.1.20. "per cent load" means the fraction of the maximum available torque at an engine speed.
- 3.1.21. "periodic regeneration" means the regeneration process of an exhaust after-treatment system that occurs periodically in typically less than 100 hours of normal engine operation. During cycles where regeneration occurs, emission standards may be exceeded.
- 3.1.22. "ramped steady state test cycle" means a test cycle with a sequence of steady state engine test modes with defined speed and torque criteria at each mode and defined ramps between these modes (WHSC).
- 3.1.23. "rated speed" means the maximum full load speed allowed by the governor as specified by the manufacturer in his sales and service literature, or, if such a governor is not present, the speed at which the maximum power is obtained from the engine, as specified by the manufacturer in his sales and service literature.
- 3.1.24. "response time" means the difference in time between the change of the component to be measured at the reference point and a system response of 90 per cent of the final reading (t_{90}) with the sampling probe being defined as the reference point, whereby the change of the measured component is at least 60 per cent full scale (FS) and takes place in less than 0.1 second. The system response time consists of the delay time to the system and of the rise time of the system.
- 3.1.25. "rise time" means the difference in time between the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$).
- 3.1.26. "specific emissions" means the mass emissions expressed in g/kWh.
- 3.1.27. "test cycle" means a sequence of test points each with a defined speed and torque to be followed by the engine under steady state (WHSC test) or transient operating conditions (WHTC).
- 3.1.28. "transformation time" means the difference in time between the change of the component to be measured at the reference point and a system response of 50 per cent of the final reading (t_{50}) with the sampling probe being defined as the reference point. The transformation time is used for the signal alignment of different measurement instruments.
- 3.1.29. "transient test cycle" means a test cycle with a sequence of normalized speed and torque values that vary relatively quickly with time (WHTC).
- 3.1.30. "useful life" means the relevant period of distance and/or time over which compliance with the relevant gaseous and particulate emission limits has to be assured.

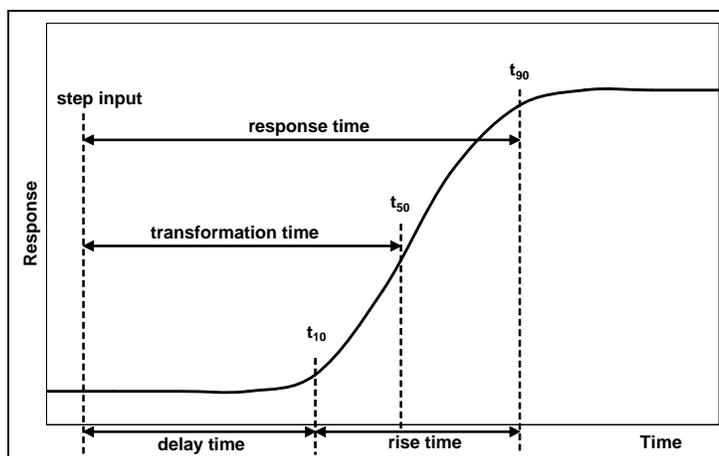


Figure 1: Definitions of system response

3.2. General symbols

Symbol	Unit	Term
A/F_{st}	-	Stoichiometric air to fuel ratio
c	ppm/Vol per cent	Concentration
c_d	ppm/Vol per cent	Concentration on dry basis
c_w	ppm/Vol per cent	Concentration on wet basis
c_b	ppm/Vol per cent	Background concentration
C_d	-	Discharge coefficient of SSV
d	m	Diameter
d_v	m	Throat diameter of venturi
D_0	m^3/s	PDP calibration intercept
D	-	Dilution factor
Δt	s	Time interval
e_{gas}	g/kWh	Specific emission of gaseous components
e_{PM}	g/kWh	Specific emission of particulates
e_p	g/kWh	Specific emission during regeneration
e_w	g/kWh	Weighted specific emission
E_{CO2}	per cent	CO ₂ quench of NO _x analyzer
E_E	per cent	Ethane efficiency
E_{H2O}	per cent	Water quench of NO _x analyzer
E_M	per cent	Methane efficiency
E_{NOx}	per cent	Efficiency of NO _x converter
f	Hz	Data sampling rate
f_a	-	Laboratory atmospheric factor
F_s	-	Stoichiometric factor
H_a	g/kg	Absolute humidity of the intake air
H_d	g/kg	Absolute humidity of the dilution air
i	-	Subscript denoting an instantaneous measurement (e.g. 1 Hz)

Symbol	Unit	Term
k_f	-	Fuel specific factor
$k_{h,D}$	-	Humidity correction factor for NO _x for CI engines
$k_{h,G}$	-	Humidity correction factor for NO _x for PI engines
k_r	-	Regeneration factor
$k_{w,a}$	-	Dry to wet correction factor for the intake air
$k_{w,d}$	-	Dry to wet correction factor for the dilution air
$k_{w,e}$	-	Dry to wet correction factor for the diluted exhaust gas
$k_{w,r}$	-	Dry to wet correction factor for the raw exhaust gas
K_V	-	CFV calibration function
λ	-	Excess air ratio
m_d	kg	Mass of the dilution air sample passed through the particulate sampling filters
m_{ed}	kg	Total diluted exhaust mass over the cycle
m_{edf}	kg	Mass of equivalent diluted exhaust gas over the test cycle
m_{ew}	kg	Total exhaust mass over the cycle
m_f	mg	Particulate sample mass collected
$m_{f,d}$	mg	Particulate sample mass of the dilution air 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 test 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_{ssd}	kg	Mass of secondary dilution air
M_a	g/mol	Molar mass of the intake air
M_e	g/mol	Molar mass of the exhaust
M_{gas}	g/mol	Molar mass of gaseous components
n	-	Number of measurements
n_r	-	Number of measurements during regeneration
n	min ⁻¹	Engine rotational speed
n_{hi}	min ⁻¹	High engine speed
n_{lo}	min ⁻¹	Low engine speed
n_{pref}	min ⁻¹	Preferred engine speed
n_p	r/s	PDP pump speed
p_a	kPa	Saturation vapour pressure of engine intake air
p_b	kPa	Total atmospheric pressure
p_d	kPa	Saturation vapour pressure of the dilution air
p_p	kPa	Absolute pressure
p_r	kPa	Water vapour pressure after cooling bath
p_s	kPa	Dry atmospheric pressure
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

Symbol	Unit	Term
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_{mp}	kg/s	Sample flow of exhaust gas into partial flow dilution system
q_{vCVS}	m ³ /s	CVS volume rate
q_{vs}	dm ³ /min	System flow rate of exhaust analyzer system
q_{vt}	cm ³ /min	Tracer gas flow rate
r_d	-	Dilution ratio
r_D	-	Diameter ratio of SSV
r_h	-	Hydrocarbon response factor of the FID
r_m	-	Methanol response factor of the FID
r_p	-	Pressure ratio of SSV
r_s	-	Average sample ratio
ρ	kg/m ³	Density
ρ_e	kg/m ³	Exhaust gas density
σ		Standard deviation
T	K	Absolute temperature
T_a	K	Absolute temperature of the intake air
t	s	Time
t_{10}	s	Time between step input and 10 per cent of final reading
t_{50}	s	Time between step input and 50 per cent of final reading
t_{90}	s	Time between step input and 90 per cent of final reading
u	-	Ratio between densities of gas component and exhaust gas
V_0	m ³ /r	PDP gas volume pumped per revolution
V_s	dm ³	System volume of exhaust analyzer bench
W_{act}	kWh	Actual cycle work of the test cycle
W_{ref}	kWh	Reference cycle work of the test cycle
X_0	m ³ /r	PDP calibration function

3.3. Symbols and abbreviations for the fuel composition

w_{ALF}	hydrogen content of fuel, per cent mass
w_{BET}	carbon content of fuel, per cent mass
w_{GAM}	sulphur content of fuel, per cent mass
w_{DEL}	nitrogen content of fuel, per cent mass
w_{EPS}	oxygen content of fuel, per cent mass
α	molar hydrogen ratio (H/C)
γ	molar sulphur ratio (S/C)
δ	molar nitrogen ratio (N/C)
ε	molar oxygen ratio (O/C)

referring to a fuel $CH_{\alpha}O_{\varepsilon}N_{\delta}S_{\gamma}$

3.4. Symbols and abbreviations for the chemical components

C1	Carbon 1 equivalent hydrocarbon
CH ₄	Methane
C ₂ H ₆	Ethane
C ₃ H ₈	Propane
CO	Carbon monoxide
CO ₂	Carbon dioxide
DOP	Di-octylphthalate
HC	Hydrocarbons
H ₂ O	Water
NMHC	Non-methane hydrocarbons
NO _x	Oxides of nitrogen
NO	Nitric oxide
NO ₂	Nitrogen dioxide
PM	Particulate matter

3.5. Abbreviations

CFV	Critical Flow Venturi
CLD	Chemiluminescent Detector
CVS	Constant Volume Sampling
deNO _x	NO _x after-treatment system
EGR	Exhaust gas recirculation
FID	Flame Ionization Detector
GC	Gas Chromatograph
HCLD	Heated Chemiluminescent Detector
HFID	Heated Flame Ionization Detector
LPG	Liquefied Petroleum Gas
NDIR	Non-Dispersive Infrared (Analyzer)
NG	Natural Gas
NMC	Non-Methane Cutter
PDP	Positive Displacement Pump

Per cent FS	Per cent of full scale
PFS	Partial Flow System
SSV	Subsonic Venturi
VGT	Variable Geometry Turbine

4. GENERAL REQUIREMENTS

The engine system shall be so designed, constructed and assembled as to enable the engine in normal use to comply with the provisions of this annex during its useful life, as defined in this Regulation.

5. PERFORMANCE REQUIREMENTS

5.1. Emission of gaseous and particulate pollutants

The emissions of gaseous and particulate pollutants by the engine shall be determined on the WHTC and WHSC test cycles, as described in paragraph 7. The measurement systems shall meet the linearity requirements in paragraph 9.2. and the specifications in paragraph 9.3. (gaseous emissions measurement), paragraph 9.4. (particulate measurement) and in Appendix 3 to this annex.

Other systems or analyzers may be approved by the type approval authority, if it is found that they yield equivalent results in accordance with paragraph 5.1.1.

5.1.1. Equivalency

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 systems of this annex.

"Results" refer to the specific cycle weighted emissions value. The correlation testing is to be performed at the same laboratory, test cell, and on the same engine, and is preferred to be run concurrently. The equivalency of the sample pair averages shall be determined by *F*-test and *t*-test statistics as described in Appendix 4 obtained under the laboratory test cell and the engine conditions described above. Outliers shall be determined in accordance with ISO 5725 and excluded from the database. The systems to be used for correlation testing shall be subject to the approval by the type approval authority.

5.2. Engine family

5.2.1. General

An engine family is characterized by design parameters. These shall be common to all engines within the family. The engine manufacturer may decide, which engines belong to an engine family, as long as the membership criteria listed in paragraph 5.2.3. are respected. The engine family shall be approved by the type approval authority. The manufacturer shall provide to the type approval authority the appropriate information relating to the emission levels of the members of the engine family.

5.2.2. Special cases

In some cases there may be interaction between parameters. This shall be taken into consideration to ensure that only engines with similar exhaust emission characteristics are included within the same engine family. These cases shall be identified by the manufacturer and notified to the type approval authority. It shall then be taken into account as a criterion for creating a new engine family.

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

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

5.2.3. Parameters defining the engine family

5.2.3.1. Combustion cycle

- (a) 2-stroke cycle
- (b) 4-stroke cycle
- (c) Rotary engine
- (d) Others

5.2.3.2. Configuration of the cylinders

5.2.3.2.1. Position of the cylinders in the block

- (a) V
- (b) In line
- (c) Radial
- (d) Others (F, W, etc.)

5.2.3.2.2. Relative position of the cylinders

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

5.2.3.3. Main cooling medium

- (a) air
- (b) water
- (c) oil

5.2.3.4. Individual cylinder displacement

5.2.3.4.1. Engine with a unit cylinder displacement $\geq 0.75 \text{ dm}^3$

In order for engines with a unit cylinder displacement of $\geq 0.75 \text{ dm}^3$ to be considered to belong to the same engine family, the spread of their individual cylinder displacements shall not exceed 15 per cent of the largest individual cylinder displacement within the family.

5.2.3.4.2. Engine with a unit cylinder displacement $< 0.75 \text{ dm}^3$

In order for engines with a unit cylinder displacement of $< 0.75 \text{ dm}^3$ to be considered to belong to the same engine family, the spread of their individual cylinder displacements shall not exceed 30 per cent of the largest individual cylinder displacement within the family.

5.2.3.4.3. Engine with other unit cylinder displacement limits

Engines with an individual cylinder displacement that exceeds the limits defined in paragraphs 5.2.3.4.1. and 5.2.3.4.2. may be considered to belong to the same family with the approval of the type approval authority. The approval shall be based on technical elements (calculations, simulations, experimental results etc.) showing that exceeding the limits does not have a significant influence on the exhaust emissions.

5.2.3.5. Method of air aspiration

- (a) naturally aspirated
- (b) pressure charged
- (c) pressure charged with charge cooler

5.2.3.6. Fuel type

- (a) Diesel
- (b) Natural gas (NG)
- (c) Liquefied petroleum gas (LPG)
- (d) Ethanol

- 5.2.3.7. Combustion chamber type
 - (a) Open chamber
 - (b) Divided chamber
 - (c) Other types

- 5.2.3.8. Ignition Type
 - (a) Positive ignition
 - (b) Compression ignition

- 5.2.3.9. Valves and porting
 - (a) Configuration
 - (b) Number of valves per cylinder

- 5.2.3.10. Fuel supply type
 - (a) Liquid fuel supply type
 - (i) Pump and (high pressure) line and injector
 - (ii) In-line or distributor pump
 - (iii) Unit pump or unit injector
 - (iv) Common rail
 - (v) Carburettor(s)
 - (vi) Others
 - (b) Gas fuel supply type
 - (i) Gaseous
 - (ii) Liquid
 - (iii) Mixing units
 - (iv) Others
 - (c) Other types

- 5.2.3.11. Miscellaneous devices
 - (a) Exhaust gas recirculation (EGR)
 - (b) Water injection
 - (c) Air injection
 - (d) Others

- 5.2.3.12. Electronic control strategy

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

In the case of electronically controlled engines, the manufacturer shall present the technical elements explaining the grouping of these engines in the same family, i.e. the reasons why these engines can be expected to satisfy the same emission requirements. These elements can be calculations, simulations, estimations, description of injection parameters, experimental results, etc.

Examples of controlled features are:

- (a) Timing
- (b) Injection pressure
- (c) Multiple injections
- (d) Boost pressure
- (e) VGT
- (f) EGR

5.2.3.13. Exhaust after-treatment systems

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

- (a) Oxidation catalyst
- (b) Three-way catalyst
- (c) DeNO_x system with selective reduction of NO_x (addition of reducing agent)
- (d) Other DeNO_x systems
- (e) Particulate trap with passive regeneration
- (f) Particulate trap with active regeneration
- (g) Other particulate traps
- (h) Other devices

When an engine has been certified without after-treatment system, whether as parent engine or as member of the family, then this engine, when equipped with an oxidation catalyst, may be included in the same engine family, if it does not require different fuel characteristics.

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

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

5.2.4. Choice of the parent engine

5.2.4.1. Compression ignition engines

Once the engine family has been agreed by the type approval authority, the parent engine of the family shall be selected using the primary criterion of the highest fuel delivery per stroke at the declared maximum torque speed. In the event that two or more engines share this primary criterion, the parent engine shall be selected using the secondary criterion of highest fuel delivery per stroke at rated speed.

5.2.4.2. Positive ignition engines

Once the engine family has been agreed by the type approval authority, the parent engine of the family shall be selected using the primary criterion of the largest displacement. In the event that two or more engines share this primary criterion, the parent engine shall be selected using the secondary criterion in the following order of priority:

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

5.2.4.3. Remarks on the choice of the parent engine

The type approval or certification authority may conclude that the worst-case emission of the family can best be characterized by testing additional engines. In this case, the engine manufacturer shall submit the appropriate information to determine the engines within the family likely to have the highest emissions level.

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

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

6. TEST CONDITIONS

6.1. Laboratory test conditions

The absolute temperature (T_a) of the intake 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. The parameter f_a shall be reported with the test results. For better repeatability and reproducibility of the test results, it is recommended that the parameter f_a be such that: $0.93 \leq f_a \leq 1.07$.

- (a) Compression-ignition engines:

Naturally aspirated and mechanically supercharged engines:

$$f_a = \left(\frac{99}{p_s} \right) \times \left(\frac{T_a}{298} \right)^{0.7} \quad (1)$$

Turbocharged engines with or without cooling of the intake air:

$$f_a = \left(\frac{99}{p_s}\right)^{0.7} \times \left(\frac{T_a}{298}\right)^{1.5} \quad (2)$$

(b) Positive ignition engines:

$$f_a = \left(\frac{99}{p_s}\right)^{1.2} \times \left(\frac{T_a}{298}\right)^{0.6} \quad (3)$$

6.2. Engines with charge air-cooling

The charge air temperature shall be recorded and shall be, at the rated speed and full load, within ± 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 laboratory system or external blower is used, the charge air temperature shall be set to within ± 5 K of the maximum charge air temperature specified by the manufacturer at the rated speed 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, unless this results in unrepresentative overcooling of the charge air. The charge air cooler volume shall be based upon good engineering practice and shall be representative of the production engine's in-use installation.

6.3. Engine power

The basis of specific emissions measurement is uncorrected power as defined in ECE Regulation No. 85.

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

- (a) air compressor for brakes
- (b) power steering compressor
- (c) air conditioning compressor
- (d) pumps for hydraulic actuators

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

6.4. Engine air intake system

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

6.5. Engine exhaust system

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

6.6. Engine with exhaust after-treatment system

If the engine is equipped with an exhaust after-treatment system, 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 after-treatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust after-treatment 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 after-treatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

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

For engines equipped with exhaust after-treatment systems that are regenerated on a periodic basis, as described in paragraph 6.6.2., emission results shall be adjusted to account for regeneration events. In this case, the average emission depends on the frequency of the regeneration event in terms of fraction of tests during which the regeneration occurs.

After-treatment systems with continuous regeneration according to paragraph 6.6.1. do not require a special test procedure.

6.6.1. Continuous regeneration

For an exhaust after-treatment system based on a continuous regeneration process the emissions shall be measured on an after-treatment system that has been stabilized so as to result in repeatable emissions behaviour.

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

In order to demonstrate that the regeneration process is continuous, at least three WHTC hot start tests shall be conducted. During the tests, exhaust temperatures and pressures shall be recorded (temperature before and after the after-treatment system, exhaust back pressure, etc.).

The after-treatment system is considered to be satisfactory if the conditions declared by the manufacturer occur during the test during a sufficient time and the emission results do not scatter by more than ± 15 per cent.

If the exhaust after-treatment system has a security mode that shifts to a periodic regeneration mode, it shall be checked according to paragraph 6.6.2. For that specific case, the applicable emission limits may be exceeded and would not be weighted.

6.6.2. Periodic regeneration

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

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

The manufacturer shall declare the normal parameter conditions under which the regeneration process occurs (soot load, temperature, exhaust back-pressure, etc.) and its duration based on the number of cycles (n_r). The manufacturer shall also provide all the data to determine the number of cycles between two regenerations (n). The exact procedure to determine this time shall be agreed by the type approval authority based upon good engineering judgement.

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

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

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

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

The measured emissions shall be weighted according to paragraph 8.5.2.2., and the final weighted result shall not exceed the applicable emission limits. The test procedure is schematically shown in figure 2.

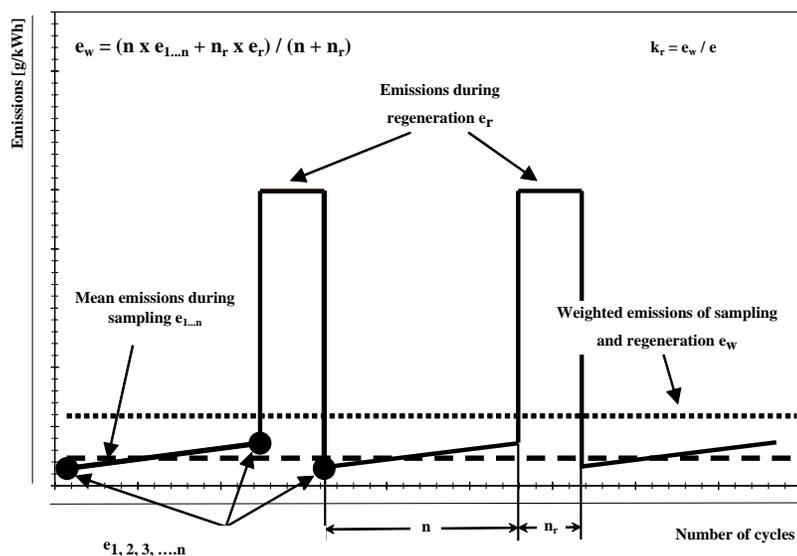


Figure 2:
Scheme of periodic regeneration

6.7. Cooling system

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

6.8. Lubricating oil

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

6.9. Specification of the reference fuel

The reference fuel is specified in Appendix 2 of this annex for C.I. engines and in Annexes 6 and 7 for CNG and LPG fuelled engines.

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

7. TEST PROCEDURES

7.1. Principles of emissions measurement

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

- (a) 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;
- (b) the gaseous components and the particulates are determined using a full flow dilution system (CVS system);
- (c) any combination of the two principles (e.g. raw gaseous measurement and full flow particulate measurement) is permitted.

The engine shall be subjected to the test cycles specified below.

7.2. Transient test cycle WHTC

The transient test cycle WHTC is listed in Appendix 1 as a second-by-second sequence of normalized speed and torque values applicable to all engines covered by this annex. In order to perform the test on an engine test cell, the normalized values shall be converted to the actual values for the individual engine under test based on the engine-mapping curve. The conversion is referred to as denormalization, and the test cycle so developed as the reference cycle of the engine to be tested. With those reference speed and torque values, the cycle shall be run on the test cell, and the 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).

The gaseous pollutants may be recorded continuously or sampled into a sampling bag. The particulate sample shall be diluted with conditioned ambient air, and collected on a single suitable filter. The WHTC is shown schematically in figure 3.

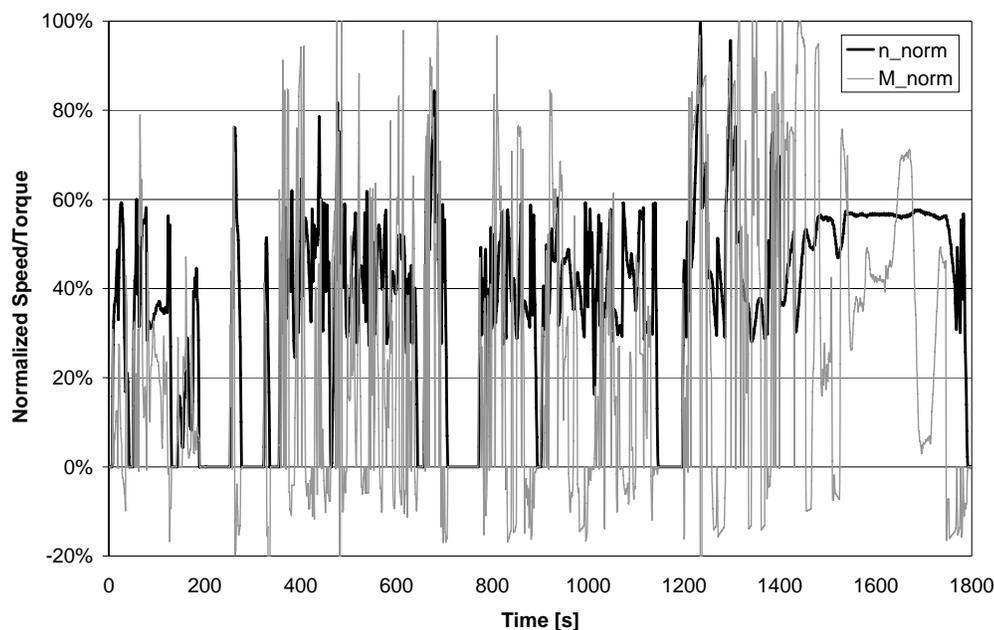


Figure 3:
WHTC test cycle

7.3. Ramped steady state test cycle WHSC

The ramped steady state test cycle WHSC consists of a number of normalized speed and load modes which cover the typical operating range of heavy duty engines. Mode 0 is not run, but is only accounted for mathematically by a weighting factor (WF) of 0.24 and zero emissions and power. The engine shall be operated for the prescribed time in each mode, whereby engine speed and load shall be changed linearly within 20 seconds. 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.

During each mode and the ramps between the modes the concentration of each gaseous pollutant, exhaust flow and power output shall be determined, and the measured values averaged over the test cycle. The gaseous pollutants may be recorded continuously or sampled into a sampling bag. The particulate sample shall be diluted with conditioned ambient air. One sample over the complete test procedure shall be taken, and collected on a single suitable filter.

For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle.

The WHSC is shown in table 1. The weighting factors (WF) are given for reference only. The idle mode is separated in two modes, mode 1 at the beginning and mode 13 at the end of the test cycle.

Mode	Normalized Speed (per cent)	Normalized Load (per cent)	WF for reference	Mode length (s) incl. 20 s ramp
0	Motoring	-	0.24	-
1	0	0	0.17/2	210
2	55	100	0.02	50
3	55	25	0.10	250
4	55	70	0.03	75
5	35	100	0.02	50
6	25	25	0.08	200
7	45	70	0.03	75
8	45	25	0.06	150
9	55	50	0.05	125
10	75	100	0.02	50
11	35	50	0.08	200
12	35	25	0.10	250
13	0	0	0.17/2	210
Sum			1.00	1895

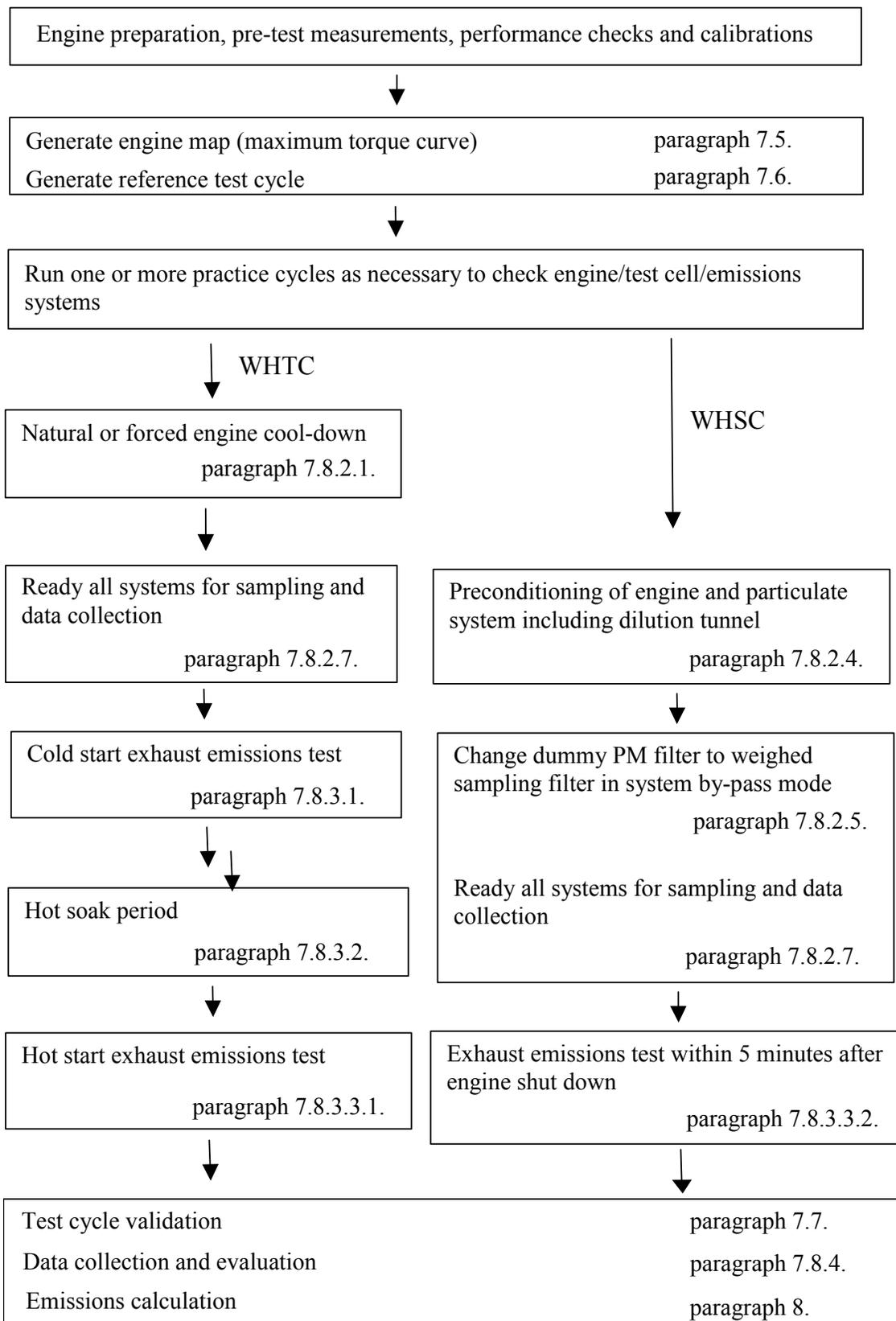
Table 1:
WHSC test cycle

7.4. General test sequence

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

For the WHTC, the test procedure consists of a cold start test following either natural or forced cool-down of the engine, a 5 minutes hot soak period and a hot start test.

For the WHSC, the test procedure consists of a hot start test following engine preconditioning at WHSC mode 9.



7.5. Engine mapping procedure

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

7.5.1. Determination of the mapping speed range

The minimum and maximum mapping speeds are defined as follows:

Minimum mapping speed = idle speed
Maximum mapping speed = $n_{hi} \times 1.02$ or speed where full load torque drops off to zero, whichever is smaller.

7.5.2. Engine mapping curve

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

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

7.5.3. Alternate mapping

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

7.5.4. Replicate tests

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

- (a) an unreasonable amount of time has transpired since the last map, as determined by engineering judgement, or
- (b) physical changes or recalibrations have been made to the engine which potentially affect engine performance.

7.6. Generation of the reference test cycle

7.6.1. Denormalization of engine speed

The speed shall be denormalized using the following equation:

$$\text{Actual speed} = n_{\text{norm}} \times (0.45 \times n_{\text{lo}} + 0.45 \times n_{\text{pref}} + 0.1 \times n_{\text{hi}} - n_{\text{idle}}) \times 2.0327 + n_{\text{idle}} \quad (4)$$

where:

n_{lo} is the lowest speed where the power is 55 per cent of maximum power

n_{pref} is the engine speed where the max. torque integral is 51 per cent of the whole integral

n_{hi} is the highest speed where the power is 70 per cent of maximum power.

n_{idle} is the idle speed

as shown in figure 4.

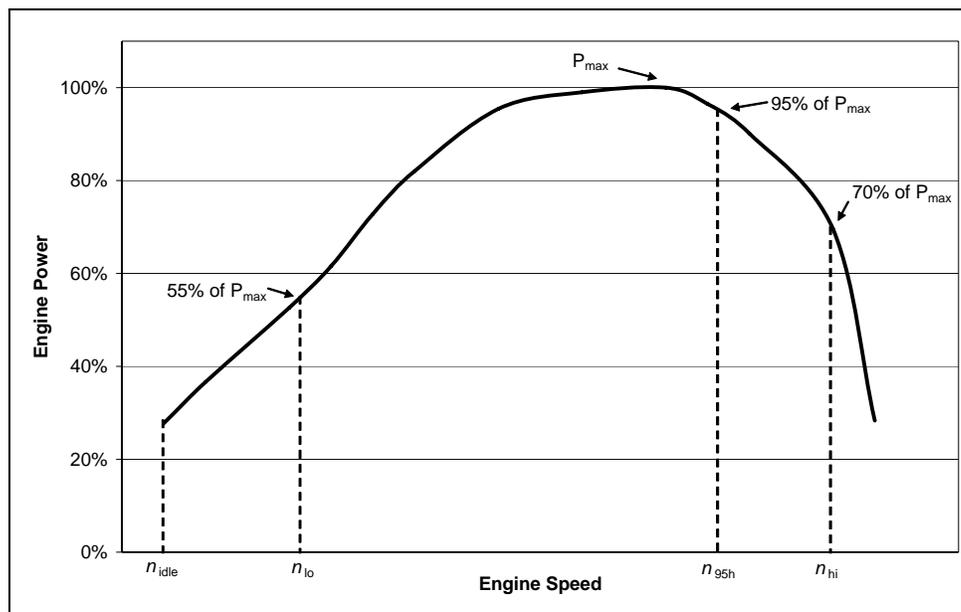


Figure 4:
Definition of test speeds

7.6.1.1. Determination of preferred speed

From the engine mapping curve as determined in accordance with paragraph 7.5.2., the integral of the maximum torque shall be calculated from n_{idle} to n_{95h} . n_{95h} is the highest speed where the power is 95 per cent of maximum power. n_{pref} is then defined as the speed that corresponds to 51 per cent of the whole integral, as shown in figure 5.

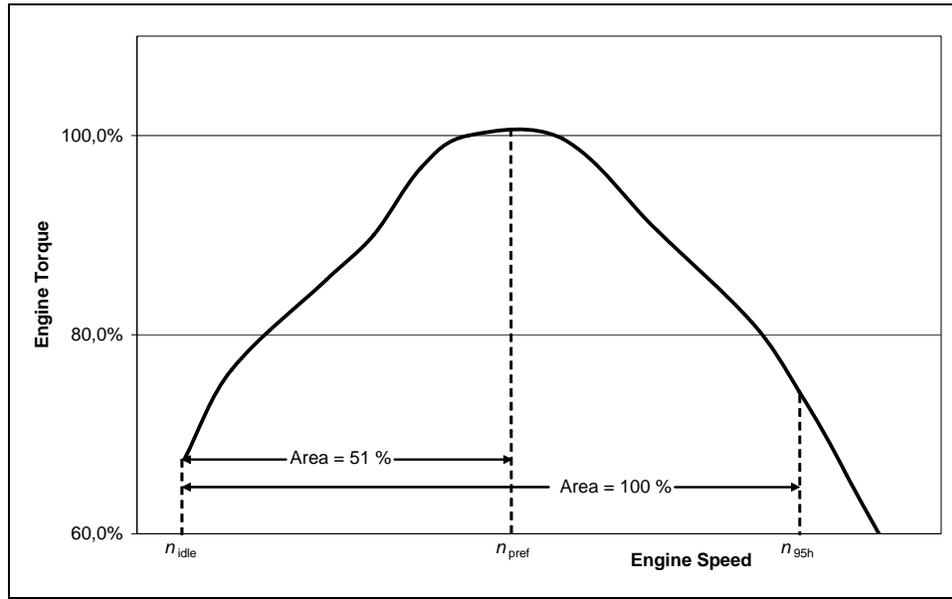


Figure 5:
Definition of n_{pref}

7.6.2. Denormalization of engine torque

The torque values in the engine dynamometer schedule of Appendix 1 are normalized to the maximum torque at the respective speed. The torque values of the reference cycle shall be denormalized, using the mapping curve determined according to paragraph 7.5.2., as follows:

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

for the respective actual speed as determined in paragraph 7.6.1.

7.6.3. Example of denormalization procedure

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

$$\begin{aligned} \text{per cent speed} &= 43 \text{ per cent} \\ \text{per cent torque} &= 82 \text{ per cent} \end{aligned}$$

Given the following values:

$$\begin{aligned}n_{lo} &= 1,015 \text{ min}^{-1} \\n_{hi} &= 2,200 \text{ min}^{-1} \\n_{pref} &= 1,300 \text{ min}^{-1} \\n_{idle} &= 600 \text{ min}^{-1}\end{aligned}$$

results in:

$$\begin{aligned}\text{actual speed} &= \frac{43 \times (0.45 \times 1,015 + 0.45 \times 1,300 + 0.1 \times 2,200 - 600) \times 2.0327}{100} + 600 \\&= 1,178 \text{ min}^{-1}\end{aligned}$$

With the maximum torque of 700 Nm observed from the mapping curve at $1,178 \text{ min}^{-1}$

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

7.7. Validation of the test run

7.7.1. Calculation of the cycle work

Before calculating the cycle work, any points recorded during engine starting shall be omitted. The cycle work W_{act} (kWh) shall be calculated based on engine feedback speed and torque values. The reference cycle work W_{ref} (kWh) shall be calculated based on engine reference speed and torque values. The actual cycle work W_{act} is used for comparison to the reference cycle work W_{ref} and for calculating the brake specific emissions (see paragraph 8.5.2.1.).

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 85 per cent and 105 per cent of W_{ref} .

7.7.2. Validation statistics of the test cycle

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

To minimize the biasing effect of the time lag between the actual and reference cycle values, the entire engine speed and torque actual 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.

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

$$y = mx + b \quad (6)$$

where:

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

The standard error of estimate (SEE) 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 Hz. For a test to be considered valid, the criteria of table 2 shall be met.

	Speed	Torque	Power
Standard error of estimate (SEE) of y on x	max. 100 min^{-1}	max. 13 per cent of maximum engine torque	max. 8 per cent of maximum engine power
Slope of the regression line, m	0.95 to 1.03	0.83 - 1.03	0.89 - 1.03
Coefficient of determination, r^2	min. 0.970	min. 0.850	min. 0.910
y intercept of the regression line, b	$\pm 50 \text{ min}^{-1}$	$\pm 20 \text{ Nm}$ or ± 2 per cent of max. torque whichever is greater	$\pm 4 \text{ kW}$ or ± 2 per cent of max. power whichever is greater

Table 2:
Regression line tolerances

For regression purposes only, point deletions are permitted where noted in table 3 before doing the regression calculation. However, those points shall 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 per cent and a normalized reference speed of 0 per cent. Point deletion may be applied to the whole or to any part of the cycle.

Condition	Points to be deleted
First 6 ± 1 seconds	Speed, torque, power
Full load demand and actual torque < 95 per cent reference torque	Torque and/or power
Full load demand and actual speed < 95 per cent reference speed	Speed and/or power
No load demand and actual torque > reference torque	Torque and/or power
No load demand and actual torque > ± 2 per cent of max. torque (idle point)	Speed and/or power
No load demand and reference torque < 0 per cent (motoring point)	Torque and/or power

Table 3:
Permitted point deletions from regression analysis

7.8. Emissions Test Run

7.8.1. Introduction

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

The above pollutants shall be examined during the prescribed test cycles. The concentrations of the gaseous components shall be determined over the cycle either in the raw exhaust gas by integration of the analyzer signal, or in the diluted exhaust gas of a CVS full flow dilution system by integration or by bag sampling. For particulates, a proportional sample shall be collected from the diluted exhaust gas on a specified filter by either partial flow dilution or full flow dilution. Depending on the method used, the diluted or undiluted exhaust gas flow rate shall be determined over the cycle to calculate the mass emission values of the pollutants. The mass emission values shall be related to the engine work, as calculated in accordance with paragraph 7.7.1., to get the grams of each pollutant emitted per kilowatt hour.

7.8.2. Pre-test procedures

Pre-test engine measurements, pre-test engine performance checks and pre-test system calibrations shall be made prior to the engine mapping procedure in line with general sequence shown in paragraph 7.4.

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

A natural or forced cool-down procedure may be applied. For forced cool-down, good engineering judgment shall be used to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to remove heat from the

coolant through the engine cooling system, and to remove heat from an exhaust after-treatment system. In the case of a forced after-treatment system cool down, cooling air shall not be applied until the after-treatment system has cooled below its catalytic activation temperature. Any cooling procedure that results in unrepresentative emissions is not permitted.

7.8.2.2. Preparation of the particulate sampling filter

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

7.8.2.3. Installation of the measuring equipment

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

7.8.2.4. Preconditioning the dilution system and the engine (WHSC only)

The dilution system and the engine shall be started and warmed up. After warm-up, the engine and sampling system shall be preconditioned by operating the engine at mode 9 for a minimum of 10 minutes while simultaneously operating either the partial flow dilution system or the full flow dilution and secondary dilution system. Dummy particulate emissions samples may be collected. Those sample filters need not be stabilized or weighed, and may be discarded. Flow rates shall be set at the approximate flow rates selected for testing.

7.8.2.5. Starting the particulate sampling system

The particulate sampling system shall be started and operated 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. The measurement may be done prior to or after the test. If the measurement is done both at the beginning and at the end of the cycle, the values may be averaged. If a different sampling system is used for background measurement, the measurement shall be done in parallel to the test run.

7.8.2.6. Adjustment of the dilution system

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

7.8.2.7. Checking the analyzers

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

7.8.3. Engine starting procedure

7.8.3.1. Cold start test (WHTC only)

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

- (a) The engine shall be started as recommended in the owners manual using a production starter motor and adequately charged battery or a suitable power supply; or
- (b) The engine shall be started by using the dynamometer. The engine shall be motored within ± 25 per cent of its typical in-use cranking speed. Cranking shall be stopped within 1 second of starting the engine. If the engine does not start after 15 seconds of cranking, cranking shall be stopped and the reason for the failure to start determined, unless the owners manual or the service-repair manual describes the longer cranking time as normal.

7.8.3.2. Hot soak period (WHTC only)

Immediately upon completion of the cold start test, the engine shall be soaked for 5 ± 1 minutes.

7.8.3.3. Hot start test

7.8.3.3.1. WHTC

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

7.8.3.3.2. WHSC

Five minutes after completion of preconditioning at mode 9 as described in paragraph 7.8.2.4., the engine shall be started according to the manufacturer's recommended starting procedure in the owner's manual, using either a production starter motor or the dynamometer in accordance with paragraph 7.8.3.1.

7.8.4. Cycle run

The general requirements laid down in this paragraph apply to both, the cold start test referred to in paragraph 7.8.3.1. and to the hot start test referred to in paragraph 7.8.3.3.

7.8.4.1. Test sequence

The test sequence shall commence at the start of the engine.

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

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

7.8.4.2. Analyzer response

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

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

If raw exhaust measurement is used, the emission concentrations ((NM)HC, CO and NO_x) 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 analyzers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

If a full flow dilution system is used, HC and NO_x shall be measured continuously in the dilution tunnel with a frequency of at least 2 Hz. The average concentrations shall be determined by integrating the analyzer signals over the test cycle. The system response time shall be no greater than 20 s, and shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary. CO, CO₂, and NMHC may be determined by integration of continuous measurement signals or by analyzing the concentrations in the sample bag, collected over the cycle. The concentrations of the gaseous pollutants in the dilution air shall be determined by integration or by collecting into the background bag. All other parameters that need to be measured shall be recorded with a minimum of one measurement per second (1 Hz).

7.8.4.3. Particulate sampling

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

If a partial flow dilution system is used, the sample pump(s) shall be controlled, so that the flow rate through the particulate sample probe or transfer tube is maintained proportional to the exhaust mass flow rate as determined in accordance with paragraph 8.3.3.3.

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 ± 2.5 per cent 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 ± 2.5 per cent of its set value (except for the first 10 seconds of sampling). The average temperature and pressure at the gas meter(s) or flow instrumentation inlet shall be recorded. If the set flow rate cannot be maintained over the complete cycle within ± 2.5 per cent because of high particulate loading on the filter, the test shall be voided. The test shall be rerun using a lower sample flow rate.

7.8.4.4. Engine stalling and equipment malfunction

If the engine stalls anywhere during the cold start test of the WHTC or during the WHSC, the test shall be voided. The engine shall be preconditioned and restarted according to the starting methods of paragraph 7.8.3.1., and the test repeated.

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

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

7.8.4.5. Operations after test

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

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

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

The particulate filter shall be returned to the weighing chamber no later than one hour after completion of the test. It 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 filter shall be recorded.

8. EMISSION MEASUREMENT AND CALCULATION

The final test result shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure, in accordance with ASTM E 29-04. No rounding of intermediate values leading to the final break-specific emission result is permitted.

8.1. Dry/wet correction

If the emissions are measured on a dry basis, the measured concentration shall be converted to a wet basis according to the following equation:

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

where:

c_w is the wet concentration in ppm or per cent volume

c_d is the dry concentration in ppm or per cent volume

k_w is the dry/wet correction factor

8.1.1. Raw exhaust gas

$$k_{w,a} = \left(1 - \frac{1.2442 \times H_a + 111.19 \times w_{ALF} \times \frac{q_{mf,i}}{q_{mad,i}}}{773.4 + 1.2442 \times H_a + \frac{q_{mf,i}}{q_{mad,i}} \times k_f \times 1,000} \right) \times 1.008 \quad (8)$$

or

$$k_{w,a} = \left(1 - \frac{1.2442 \times H_a + 111.19 \times w_{ALF} \times \frac{q_{mf,i}}{q_{mad,i}}}{773.4 + 1.2442 \times H_a + \frac{q_{mf,i}}{q_{mad,i}} \times k_f \times 1,000} \right) / \left(1 - \frac{p_r}{p_b} \right) \quad (9)$$

or

$$k_{w,a} = \left(\frac{1}{1 + \alpha \times 0.005 \times (c_{CO_2} + c_{CO})} - k_{w1} \right) \times 1.008 \quad (10)$$

with

$$k_f = 0.055594 \times w_{ALF} + 0.0080021 \times w_{DEL} + 0.0070046 \times w_{EPS} \quad (11)$$

and

$$k_{w1} = \frac{1.608 \times H_a}{1,000 + (1.608 \times H_a)} \quad (12)$$

where:

- H_a is the intake air humidity, g water per kg dry air
- w_{ALF} is the hydrogen content of the fuel, per cent mass
- $q_{mf,i}$ is the instantaneous fuel mass flow rate, kg/s
- $q_{mad,i}$ is the instantaneous dry intake air mass flow rate, kg/s
- p_r is the water vapour pressure after cooling bath, kPa
- p_b is the total atmospheric pressure, kPa
- w_{DEL} is the nitrogen content of the fuel, per cent mass
- w_{EPS} is the oxygen content of the fuel, per cent mass
- α is the molar hydrogen ratio of the fuel
- c_{CO2} is the dry CO₂ concentration, per cent
- c_{CO} is the dry CO concentration, per cent

Equations (8) and (9) are principally identical with the factor 1.008 in equations (8) and (10) being an approximation for the more accurate denominator in equation (9).

8.1.2. Diluted exhaust gas

$$k_{w,e} = \left[\left(1 - \frac{\alpha \times c_{CO2w}}{200} \right) - k_{w2} \right] \times 1.008 \quad (13)$$

or

$$k_{w,e} = \left[\left(\frac{(1 - k_{w2})}{1 + \frac{\alpha \times c_{CO2d}}{200}} \right) \right] \times 1.008 \quad (14)$$

with

$$k_{w2} = \frac{1.608 \times \left[H_d \times \left(1 - \frac{1}{D} \right) + H_a \times \left(\frac{1}{D} \right) \right]}{1,000 + \left\{ 1.608 \times \left[H_d \times \left(1 - \frac{1}{D} \right) + H_a \times \left(\frac{1}{D} \right) \right] \right\}} \quad (15)$$

where:

- α is the molar hydrogen ratio of the fuel
- c_{CO2w} is the wet CO₂ concentration, per cent

$c_{\text{CO}_2\text{d}}$ is the dry CO_2 concentration, per cent
 H_{d} is the dilution air humidity, g water per kg dry air
 H_{a} is the intake air humidity, g water per kg dry air
 D is the dilution factor (see paragraph 8.4.2.4.2.)

8.1.3. Dilution air

$$k_{w,d} = (1 - k_{w3}) \times 1.008 \quad (16)$$

with

$$k_{w3} = \frac{1.608 \times H_{\text{d}}}{1,000 + (1.608 \times H_{\text{d}})} \quad (17)$$

where:

H_{d} is the dilution air humidity, g water per kg dry air

8.2. NO_x correction for humidity

As the NO_x emission depends on ambient air conditions, the NO_x concentration shall be corrected for humidity with the factors given in paragraph 8.2.1. or 8.2.2. The intake air humidity H_{a} may be derived from relative humidity measurement, dew point measurement, vapour pressure measurement or dry/wet bulb measurement using generally accepted equation.

8.2.1. Compression-ignition engines

$$k_{h,D} = \frac{15.698 \times H_{\text{a}}}{1,000} + 0.832 \quad (18)$$

where:

H_{a} is the intake air humidity, g water per kg dry air

8.2.2. Positive ignition engines

$$k_{h,G} = 0.6272 + 44.030 \times 10^{-3} \times H_{\text{a}} - 0.862 \times 10^{-3} \times H_{\text{a}}^2 \quad (19)$$

where:

H_{a} is the intake air humidity, g water per kg dry air

8.3. Partial flow dilution (PFS) and raw gaseous measurement

The instantaneous concentration signals of the gaseous components are used for the calculation of the mass emissions by multiplication with the instantaneous exhaust mass flow rate. The exhaust mass flow rate may be measured directly, or calculated using the

methods of intake air and fuel flow measurement, tracer method or intake air and air/fuel ratio measurement. Special attention shall be paid to the response times of the different instruments. These differences shall be accounted for by time aligning the signals. For particulates, the exhaust mass flow rate signals are used for controlling the partial flow dilution system to take a sample proportional to the exhaust mass flow rate. The quality of proportionality shall be checked by applying a regression analysis between sample and exhaust flow in accordance with paragraph 8.3.3.3. The complete test set up is schematically shown in figure 6.

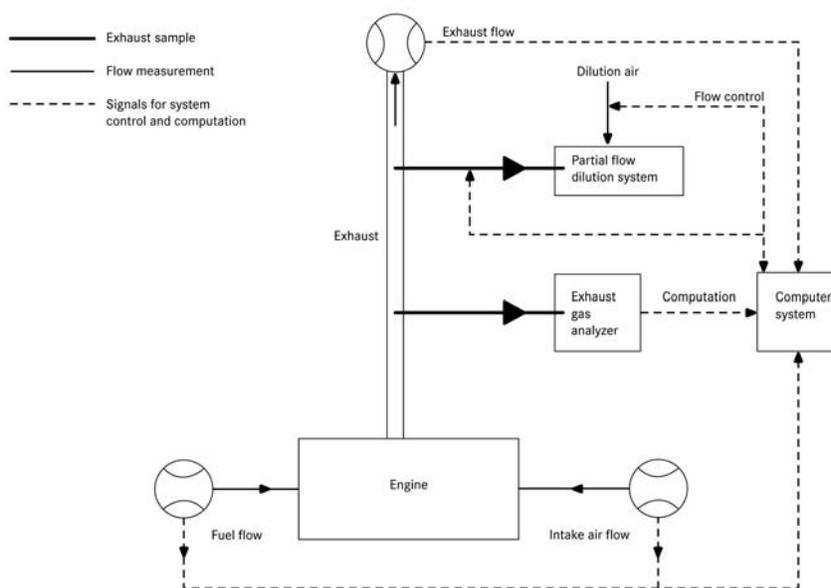


Figure 6:
Scheme of raw/partial flow measurement system

8.3.1. Determination of exhaust gas mass flow

8.3.1.1. Introduction

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

8.3.1.2. Response time

For the purpose of emissions calculation, the response time of either method described in paragraphs 8.3.1.3 to 8.3.1.6 shall be equal to or less than the analyzer response time of ≤ 10 s, as required in paragraph 9.3.5.

For the purpose of controlling of a partial flow dilution system, a faster response is required. For partial flow dilution systems with online control, the response time shall be ≤ 0.3 s. For partial flow dilution systems with look ahead control based on a pre-recorded test run, the response time of the exhaust flow measurement system shall be ≤ 5 s with a rise time of ≤ 1 s. The system response time shall be specified by the instrument manufacturer. The combined response time requirements for the exhaust gas flow and partial flow dilution system are indicated in paragraph 8.3.3.3.

8.3.1.3. Direct measurement method

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

- (a) pressure differential devices, like flow nozzle, (details see ISO 5167)
- (b) ultrasonic flowmeter
- (c) 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 shall not be affected by the installation of the device.

The flow meters shall meet the linearity requirements of paragraph 9.2.

8.3.1.4. Air and fuel measurement method

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

$$q_{mew,i} = q_{maw,i} + q_{mf,i} \quad (20)$$

where:

- $q_{mew,i}$ is the instantaneous exhaust mass flow rate, kg/s
- $q_{maw,i}$ is the instantaneous intake air mass flow rate, kg/s
- $q_{mf,i}$ is the instantaneous fuel mass flow rate, kg/s

The flow meters shall meet the linearity requirements of paragraph 9.2., but shall be accurate enough to also meet the linearity requirements for the exhaust gas flow.

8.3.1.5. Tracer measurement method

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

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

the exhaust pipe. The concentration of the gas shall then be measured in the exhaust gas sample.

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

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

The calculation of the exhaust gas flow shall be as follows:

$$q_{mew,i} = \frac{q_{vt} \times \rho_e}{60 \times (c_{mix,i} - c_b)} \quad (21)$$

where:

$q_{mew,i}$ is the instantaneous exhaust mass flow rate, kg/s

q_{vt} is tracer gas flow rate, cm³/min

$c_{mix,i}$ is the instantaneous concentration of the tracer gas after mixing, ppm

ρ_e is the density of the exhaust gas, kg/m³ (cf. table 4)

c_b is the background concentration of the tracer gas in the intake air, ppm

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

When the background concentration is less than 1 per cent 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 linearity requirements for the exhaust gas flow of paragraph 9.2.

8.3.1.6. Airflow and air to fuel ratio measurement method

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

$$q_{mew,i} = q_{maw,i} \times \left(1 + \frac{1}{A/F_{st} \times \lambda_i} \right) \quad (22)$$

with

$$A/F_{st} = \frac{138.0 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right)}{12.011 + 1.00794 \times \alpha + 15.9994 \times \varepsilon + 14.0067 \times \delta + 32.065 \times \gamma} \quad (23)$$

$$\lambda_i = \frac{\left(100 - \frac{c_{COd} \times 10^{-4}}{2} - c_{HCw} \times 10^{-4}\right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{COd} \times 10^{-4}}{3.5 \times c_{CO2d}} - \frac{\varepsilon}{2} - \frac{\delta}{2}}{1 + \frac{c_{CO} \times 10^{-4}}{3.5 \times c_{CO2d}}}\right) \times (c_{CO2d} + c_{COd} \times 10^{-4})}{4.764 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \times (c_{CO2d} + c_{COd} \times 10^{-4} + c_{HCw} \times 10^{-4})} \quad (24)$$

where:

$q_{mew,i}$ is the instantaneous exhaust mass flow rate, kg/s

$q_{maw,i}$ is the instantaneous intake air mass flow rate, kg/s

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

λ_i is the instantaneous excess air ratio

c_{CO2d} is the dry CO₂ concentration, per cent

c_{COd} is the dry CO concentration, ppm

c_{HCw} is the wet HC concentration, ppm

Air flowmeter and analyzers shall meet the linearity requirements of paragraph 9.2., and the total system shall meet the linearity requirements for the exhaust gas flow of paragraph 9.2.

If an air to fuel ratio measurement equipment such as a zirconia type sensor is used for the measurement of the excess air ratio, it shall meet the specifications of paragraph 9.3.2.7.

8.3.2. Determination of the gaseous components

8.3.2.1. Introduction

The gaseous components in the raw exhaust gas emitted by the engine submitted for testing shall be measured with the measurement and sampling systems described in paragraph 9.3. and Appendix 3. The data evaluation is described in paragraph 8.3.2.3.

Two calculation procedures are described in paragraphs 8.3.2.4. and 8.3.2.5., which are equivalent for the reference fuels of Appendix 2. The procedure in paragraph 8.3.2.4. is more straightforward, since it uses tabulated u values for the ratio between component and exhaust gas density. The procedure in paragraph 8.3.2.5. is more accurate for fuel qualities that deviate from the specifications in Appendix 2, but requires elementary analysis of the fuel composition.

8.3.2.2. Sampling for gaseous emissions

The gaseous emissions sampling probes shall be fitted at least 0.5 m or 3 times the diameter of the exhaust pipe - whichever is the larger - upstream of the exit of the exhaust gas system but sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe.

In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest CO₂ emission. For exhaust emission calculation the total exhaust mass flow shall be used.

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

8.3.2.3. 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 shall be recorded with a sample rate of at least 1 Hz. For analogue analyzers, 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 paragraph 3.1.28. Therefore, the response time of each gaseous emissions analyzer and of the exhaust gas mass flow system shall be determined according to paragraphs 8.3.1.2 and 9.3.5., respectively, and recorded.

8.3.2.4. Calculation of mass emission based on tabulated values

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

For the calculation of NO_x, the mass emission shall be multiplied with the humidity correction factor $k_{h,D}$, or $k_{h,G}$, as determined according to paragraph 8.2.

An example of the calculation procedures is given in Appendix 6.

The following equation shall be applied:

$$m_{\text{gas}} = u_{\text{gas}} \times \sum_{i=1}^{i=n} c_{\text{gas},i} \times q_{\text{mew},i} \times \frac{1}{f} \quad (\text{in g/test}) \quad (25)$$

where:

u_{gas} is the ratio between density of exhaust component and density of exhaust gas

$c_{\text{gas},i}$ is the instantaneous concentration of the component in the exhaust gas, ppm

$q_{\text{mew},i}$ is the instantaneous exhaust mass flow, kg/s

f is the data sampling rate, Hz

n is the number of measurements

Fuel	ρ_e	Gas					
		NO _x	CO	HC	CO ₂	O ₂	CH ₄
		ρ_{gas} [kg/m ³]					
		2.053	1.250	^{a)}	1.9636	1.4277	0.716
u_{gas} ^{b)}							
Diesel	1.2943	0.001586	0.000966	0.000479	0.001517	0.001103	0.000553
Ethanol	1.2757	0.001609	0.000980	0.000805	0.001539	0.001119	0.000561
CNG ^{c)}	1.2661	0.001621	0.000987	0.000558 ^{d)}	0.001551	0.001128	0.000565
Propane	1.2805	0.001603	0.000976	0.000512	0.001533	0.001115	0.000559
Butane	1.2832	0.001600	0.000974	0.000505	0.001530	0.001113	0.000558
LPG ^{e)}	1.2811	0.001602	0.000976	0.000510	0.001533	0.001115	0.000559
a) depending on fuel b) at $\lambda = 2$, dry air, 273 K, 101.3 kPa c) u accurate within 0.2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 % d) NMHC on the basis of CH _{2.93} (for total HC the u_{gas} coefficient of CH ₄ shall be used) e) u accurate within 0.2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %							

Table 4:
Raw exhaust gas u values and component densities

8.3.2.5. Calculation of mass emission based on exact equations

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

For the calculation of NO_x , the mass emission shall be multiplied with the humidity correction factor $k_{h,D}$, or $k_{h,G}$, as determined according to paragraph 8.2.

The following equation shall be applied:

$$m_{\text{gas}} = \sum_{i=1}^{i=n} u_{\text{gas},i} \times c_{\text{gas},i} \times q_{\text{mew},i} \times \frac{1}{f} \quad (\text{in g/test}) \quad (26)$$

where:

$u_{\text{gas},i}$ is the instantaneous density ratio of exhaust component and exhaust gas

$c_{\text{gas},i}$ is the instantaneous concentration of the component in the exhaust gas, ppm

$q_{\text{mew},i}$ is the instantaneous exhaust mass flow, kg/s

f is the data sampling rate, Hz

n is the number of measurements

The instantaneous u values shall be calculated as follows:

$$u_{\text{gas},i} = M_{\text{gas}} / (M_{e,i} \times 1,000) \quad (27)$$

or

$$u_{\text{gas},i} = \rho_{\text{gas}} / (\rho_{e,i} \times 1,000) \quad (28)$$

with

$$\rho_{\text{gas}} = M_{\text{gas}} / 22.414 \quad (29)$$

where:

M_{gas} is the molar mass of the gas component, g/mol (cf. Appendix 6)

$M_{e,i}$ is the instantaneous molar mass of the exhaust gas, g/mol

ρ_{gas} is the density of the gas component, kg/m³

$\rho_{e,i}$ is the instantaneous density of the exhaust gas, kg/m³

The molar mass of the exhaust, M_e , shall be derived for a general fuel composition $CH_\alpha O_\varepsilon N_\delta S_\gamma$ under the assumption of complete combustion, as follows:

$$M_{e,i} = \frac{1 + \frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \times \frac{\frac{\alpha}{4} + \frac{\varepsilon}{2} + \frac{\delta}{2}}{12.011 + 1.00794 \times \alpha + 15.9994 \times \varepsilon + 14.0067 \times \delta + 32.065 \times \gamma} + \frac{\frac{H_a \times 10^{-3}}{2 \times 1.00794 + 15.9994} + \frac{1}{M_a}}{1 + H_a \times 10^{-3}}} \quad (30)$$

where:

$q_{maw,i}$ is the instantaneous intake air mass flow rate on wet basis, kg/s

$q_{mf,i}$ is the instantaneous fuel mass flow rate, kg/s

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

M_a is the molar mass of the dry intake air = 28.965 g/mol

The exhaust density ρ_e shall be derived, as follows:

$$\rho_{e,i} = \frac{1,000 + H_a + 1,000 \times (q_{mf,i}/q_{mad,i})}{773.4 + 1.2434 \times H_a + k_f \times 1,000 \times (q_{mf,i}/q_{mad,i})} \quad (31)$$

where:

$q_{mad,i}$ is the instantaneous intake air mass flow rate on dry basis, kg/s

$q_{mf,i}$ is the instantaneous fuel mass flow rate, kg/s

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

k_f is the fuel specific factor according to equation 11 in paragraph 8.1.1.

8.3.3. Particulate determination

8.3.3.1. Introduction

The determination of the particulates requires dilution of the sample with filtered ambient air, synthetic air or nitrogen. The partial flow dilution system shall be set to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas between 315 K (42 °C) and 325 K (52 °C) immediately upstream of the filter holders. Dehumidifying the dilution air before entering the dilution system is permitted, and especially useful if dilution air humidity is high. The temperature of the dilution air shall be > 288 K (15 °C) in close proximity to the entrance into the dilution tunnel.

The partial flow dilution system has to be designed to extract a proportional raw exhaust sample from the engine exhaust stream, thus responding to excursions in the exhaust stream flow rate, and introduce dilution air to this sample to achieve a temperature between 315 K (42 °C) and 325 K (52 °C) at the test filter. For this it is essential that

the dilution ratio or the sampling ratio r_d or r_s be determined such that the accuracy requirements of paragraph 9.4.4. are fulfilled.

To determine the mass of the particulates, a particulate sampling system, a particulate sampling filter, a microgram balance, and a temperature and humidity controlled weighing chamber, are required. The details of the system are described in paragraph 9.4.

8.3.3.2. Particulate sampling

In general, the particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, but sufficiently distant as to not cause interference. Therefore, the installation provisions of paragraph 8.3.2.2. also apply to particulate sampling. The sampling line shall conform to the requirements laid down in Appendix 3.

In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest particulate emission. For exhaust emission calculation the total exhaust mass flow of the manifold shall be used.

8.3.3.3. System response time

For the control of a partial flow dilution system, a fast system response is required. The transformation time for the system shall be determined by the procedure in paragraph 9.4.7.3. If the combined transformation time of the exhaust flow measurement (see paragraph 8.3.1.2.) and the partial flow system is < 0.3 s, online control shall be used. If the transformation time exceeds 0.3 s, look ahead control based on a pre-recorded test run shall be used. In this case, the combined rise time shall be ≤ 1 s and the combined delay time ≤ 10 s.

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

- (a) The coefficient of determination r^2 of the linear regression between $q_{mp,i}$ and $q_{mew,i}$ shall not be less than 0.95
- (b) The standard error of estimate of $q_{mp,i}$ on $q_{mew,i}$ shall not exceed 5 per cent of q_{mp} maximum.
- (c) q_{mp} intercept of the regression line shall not exceed ± 2 per cent of q_{mp} maximum.

Look-ahead control is required if the combined transformation times of the particulate system, $t_{50,P}$ and of the exhaust mass flow signal, $t_{50,F}$ are > 0.3 s. In this case, a pre-test shall be run, and the exhaust mass flow signal of the pre-test be used for controlling the sample flow into the particulate system. A correct control of the partial dilution system is obtained, if the time trace of $q_{mew,pre}$ of the pre-test, 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 paragraph 9.4.7.3.

8.3.3.4. Data evaluation

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

With the prior approval of the type approval authority, the particulate mass may be corrected for the particulate level of the dilution air, as determined in paragraph 7.8.2.5., in line with good engineering practice and the specific design features of the particulate measurement system used.

8.3.3.5. Calculation of mass emission

Depending on system design, the mass of particulates (g/test) shall be calculated by either of the methods in paragraphs 8.3.3.5.1. or 8.3.3.5.2 after buoyancy correction of the particulate sample mass according to paragraph 9.4.3.5. An example of the calculation procedures is given in Appendix 6.

8.3.3.5.1. Calculation based on sample ratio

$$m_{PM} = m_f / (r_s \times 1,000) \quad (32)$$

where:

m_f is the particulate mass sampled over the cycle, mg

r_s is the average sample ratio over the test cycle

with

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

where:

m_{se} is the sample mass over the cycle, kg

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

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

8.3.3.5.2. Calculation based on dilution ratio

$$m_{PM} = \frac{m_f}{m_{sep}} \times \frac{m_{edf}}{1,000} \quad (34)$$

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:

$$m_{edf} = \sum_{i=1}^{i=n} q_{medf,i} \times \frac{1}{f} \quad (35)$$

$$q_{medf,i} = q_{mew,i} \times r_{d,i} \quad (36)$$

$$r_{d,i} = \frac{q_{mdew,i}}{(q_{mdew,i} - q_{mdw,i})} \quad (37)$$

where:

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

8.4. Full flow dilution measurement (CVS)

The concentration signals, either by integration over the cycle or by bag sampling, of the gaseous components shall be used for the calculation of the mass emissions by multiplication with the diluted exhaust mass flow rate. The exhaust mass flow rate shall be measured with a constant volume sampling (CVS) system, which may use a positive displacement pump (PDP), a critical flow venturi (CFV) or a subsonic venturi (SSV) with or without flow compensation.

For bag sampling and particulate sampling, a proportional sample shall be taken from the diluted exhaust gas of the CVS system. For a system without flow compensation, the ratio of sample flow to CVS flow must not vary by more than ± 2.5 per cent from the set point of the test. For a system with flow compensation, each individual flow rate shall be constant within ± 2.5 per cent of its respective target flow rate.

The complete test set up is schematically shown in figure 7.

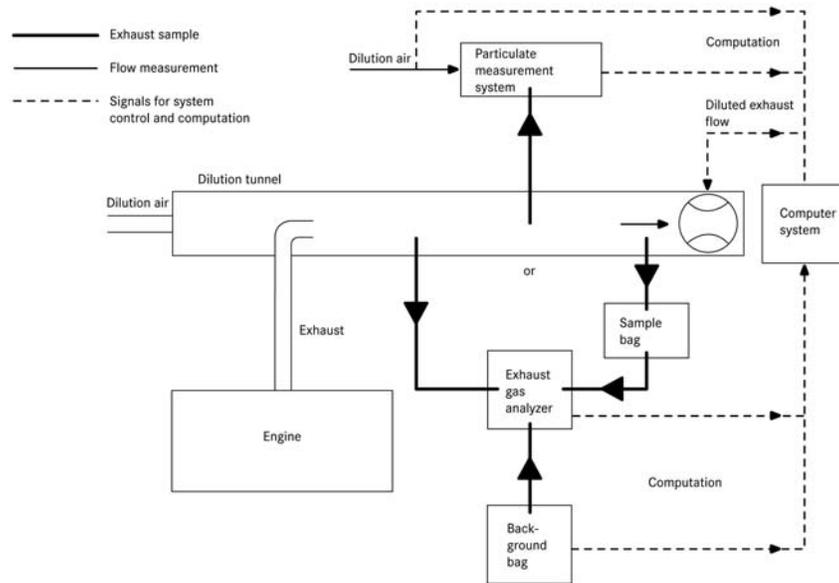


Figure 7:
Scheme of full flow measurement system

8.4.1. Determination of the diluted exhaust gas flow

8.4.1.1. Introduction

For calculation of the emissions in the diluted exhaust gas, it is necessary to know the diluted exhaust gas mass flow rate. The total diluted exhaust gas flow over the cycle (kg/test) shall be calculated from the measurement values over the cycle and the corresponding calibration data of the flow measurement device (V_0 for PDP, K_V for CFV, C_d for SSV) by either of the methods described in paragraphs 8.4.1.2. to 8.4.1.4. If the total sample flow of particulates (m_{sep}) exceeds 0.5 per cent of the total CVS flow (m_{ed}), the CVS flow shall be corrected for m_{sep} or the particulate sample flow shall be returned to the CVS prior to the flow measuring device.

8.4.1.2. PDP-CVS system

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

$$m_{ed} = 1.293 \times V_0 \times n_p \times p_p \times 273 / (101.3 \times T) \quad (38)$$

where:

V_0 is the volume of gas pumped per revolution under test conditions, m³/rev

n_p is the total revolutions of pump per test

p_p is the absolute pressure at pump inlet, kPa

T is the average temperature of the diluted exhaust gas at pump 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:

$$m_{ed,i} = 1.293 \times V_0 \times n_{p,i} \times p_p \times 273 / (101.3 \times T) \quad (39)$$

where:

$n_{p,i}$ is the total revolutions of pump per time interval

8.4.1.3. CFV-CVS system

The calculation of the mass flow over the cycle is as follows, if the temperature of the diluted exhaust is kept within ± 11 K over the cycle by using a heat exchanger:

$$m_{ed} = 1.293 \times t \times K_v \times p_p / T^{0.5} \quad (40)$$

where:

t is the cycle time, s

K_v is the calibration coefficient of the critical flow venturi for standard conditions,

p_p 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:

$$m_{ed,i} = 1.293 \times \Delta t_i \times K_v \times p_p / T^{0.5} \quad (41)$$

where:

Δt_i is the time interval, s

8.4.1.4. SSV-CVS system

The calculation of the mass flow over the cycle shall be as follows, if the temperature of the diluted exhaust is kept within ± 11 K over the cycle by using a heat exchanger:

$$m_{ed} = 1.293 \times Q_{SSV} \quad (42)$$

with

$$Q_{SSV} = A_0 \times d_V \times^2 C_d p_p \times \sqrt{\left[\frac{1}{T} \times (r_p^{1.4286} - r_p^{1.7143}) \times \left(\frac{I}{1 - r_D^4 \times r_p^{1.4286}} \right) \right]} \quad (43)$$

where:

$$A_0 \text{ is } 0.006111 \text{ in SI units of } \left(\frac{m^3}{\text{min}} \right) \left(\frac{K^{\frac{1}{2}}}{kPa} \right) \left(\frac{1}{mm^2} \right)$$

d_V is the diameter of the SSV throat, m

C_d is the discharge coefficient of the SSV

p_p is the absolute pressure at venturi inlet, kPa

T is the temperature at the venturi inlet, K

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

r_D is the ratio of the SSV throat diameter, d , to the inlet pipe inner diameter 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:

$$m_{ed} = 1.293 \times Q_{SSV} \times \Delta t_i \quad (44)$$

where:

Δt_i is the time interval, s

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

During all emissions tests, the Reynolds number at the SSV throat shall be in the range of Reynolds numbers used to derive the calibration curve developed in paragraph 9.5.4.

8.4.2. Determination of the gaseous components

8.4.2.1. Introduction

The gaseous components in the diluted exhaust gas emitted by the engine submitted for testing shall be measured by the methods described in Appendix 3. Dilution of the exhaust shall be done with filtered ambient air, synthetic air or nitrogen. The flow capacity of the full flow system shall be large enough to completely eliminate water condensation in the dilution and sampling systems. Data evaluation and calculation procedures are described in paragraphs 8.4.2.3. and 8.4.2.4.

8.4.2.2. Sampling for gaseous emissions

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements laid down in Appendix 3. 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:

- (a) the emissions are sampled into a sampling bag over the cycle and measured after completion of the test; for HC, the sample bag shall be heated to 464 ± 11 K ($191 \pm 11^\circ\text{C}$), for NO_x , the sample bag temperature shall be above the dew point temperature;
- (b) the emissions are sampled continuously and integrated over the cycle.

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

8.4.2.3. Data evaluation

For continuous sampling, the emission concentrations (HC, CO and NO_x) shall be recorded and stored with at least 1 Hz on a computer system, for bag sampling one mean value per test is required. The diluted exhaust gas mass flow rate and all other data shall be recorded with a sample rate of at least 1 Hz. For analogue analyzers the response will be recorded, and the calibration data may be applied online or offline during the data evaluation.

8.4.2.4. Calculation of mass emission

8.4.2.4.1. Systems with constant mass flow

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

$$m_{\text{gas}} = u_{\text{gas}} \times c_{\text{gas}} \times m_{\text{ed}} \quad (\text{in g/test}) \quad (45)$$

where:

u_{gas} is the ratio between density of exhaust component and density of air
 c_{gas} is the average background corrected concentration of the component, ppm
 m_{ed} is the total diluted exhaust mass over the cycle, kg

If measured on a dry basis, the dry/wet correction according to paragraph 8.1. shall be applied.

For the calculation of NO_x , the mass emission shall be multiplied with the humidity correction factor $k_{\text{h,D}}$, or $k_{\text{h,G}}$, as determined according to paragraph 8.2.

The u values are given in table 5. For calculating the u_{gas} values, the density of the diluted exhaust gas has been assumed to be equal to air density. Therefore, the u_{gas} values are identical for single gas components, but different for HC.

Alternatively, the exact equation method described in paragraph 8.3.2.5., equations 27 or 28 may be used.

Fuel	ρ_{de}	Gas					
		NO _x	CO	HC	CO ₂	O ₂	CH ₄
		ρ_{gas} [kg/m ³]					
		2.053	1.250	a)	1.9636	1.4277	0.716
u_{gas} ^{b)}							
Diesel	1.293	0.001588	0.000967	0.000480	0.001519	0.001104	0.000553
Ethanol	1.293	0.001588	0.000967	0.000795	0.001519	0.001104	0.000553
CNG ^{c)}	1.293	0.001588	0.000967	0.000584 ^{d)}	0.001519	0.001104	0.000553
Propane	1.293	0.001588	0.000967	0.000507	0.001519	0.001104	0.000553
Butane	1.293	0.001588	0.000967	0.000501	0.001519	0.001104	0.000553
LPG ^{e)}	1.293	0.001588	0.000967	0.000505	0.001519	0.001104	0.000553

a) depending on fuel
b) at $\lambda = 2$, dry air, 273 K, 101.3 kPa
c) u accurate within 0.2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 %
d) NMHC on the basis of CH_{2.93} (for total HC the u_{gas} coefficient of CH₄ shall be used)
e) u accurate within 0.2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %

Table 5:
Diluted exhaust gas u values and component densities

8.4.2.4.2. Determination of the background corrected concentrations

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

$$c = c_e - c_d \times (1 - (1/D)) \quad (46)$$

where:

c_e is the concentration of the component measured in the diluted exhaust gas, ppm

c_d is the concentration of the component measured in the dilution air, ppm

D is the dilution factor

The dilution factor shall be calculated as follows:

a) for diesel and LPG fueled gas engines

$$D = \frac{F_S}{c_{\text{CO}_2,e} + (c_{\text{HC},e} + c_{\text{CO},e}) \times 10^{-4}} \quad (47)$$

b) for NG fueled gas engines

$$D = \frac{F_S}{c_{\text{CO}_2,e} + (c_{\text{NMHC},e} + c_{\text{CO},e}) \times 10^{-4}} \quad (48)$$

where:

$c_{\text{CO}_2,e}$ is the wet concentration of CO₂ in the diluted exhaust gas, per cent vol

$c_{\text{HC},e}$ is the wet concentration of HC in the diluted exhaust gas, ppm C1

$c_{\text{NMHC},e}$ is the wet concentration of NMHC in the diluted exhaust gas, ppm C1

$c_{\text{CO},e}$ is the wet concentration of CO in the diluted exhaust gas, ppm

F_S is the stoichiometric factor

The stoichiometric factor shall be calculated as follows:

$$F_S = 100 \times \frac{1}{1 + \frac{\alpha}{2} + 3.76 \times \left(1 + \frac{\alpha}{4}\right)} \quad (49)$$

where:

α is the molar hydrogen ratio of the fuel (H/C)

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

$$F_S \text{ (diesel)} = 13.4$$

$$F_S \text{ (LPG)} = 11.6$$

$$F_S \text{ (NG)} = 9.5$$

8.4.2.4.3 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 equation shall be applied:

$$m_{\text{gas}} = \sum_{i=1}^n [(m_{\text{ed},i} \times c_e \times u_{\text{gas}})] - [(m_{\text{ed}} \times c_d \times (1 - 1/D) \times u_{\text{gas}})] \quad (50)$$

where:

- c_e is the concentration of the component measured in the diluted exhaust gas, ppm
- c_d is the concentration of the component measured in the dilution air, ppm
- $m_{\text{ed},i}$ 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 5
- D is the dilution factor

8.4.3. Particulate determination

8.4.3.1. Introduction

The determination of the particulates requires double dilution of the sample with filtered ambient air, synthetic air or nitrogen. The flow capacity of the full flow double 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 > 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 filter, a microgram balance, and a temperature and humidity controlled weighing chamber, are required. The details of the system are described in paragraph 9.4.

8.4.3.2. Particulate sampling

The particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, but sufficiently distant as to not cause interference, in the dilution tunnel. Therefore, the installation provisions of paragraph 8.3.2.2. also apply to particulate sampling. The sampling line shall conform to the requirements laid down in Appendix 3.

8.4.3.3. Calculation of mass emission

The particulate mass (g/test) shall be calculated after buoyancy correction of the particulate sample mass according to paragraph 9.4.3.5. as follows:

$$m_{PM} = \frac{m_f}{m_{sep}} \times \frac{m_{ed}}{1,000} \quad (51)$$

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

with

$$m_{sep} = m_{set} - m_{ssd} \quad (52)$$

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 paragraph 7.8.2.5, the particulate mass may be background corrected. In this case, the particulate mass (g/test) shall be calculated as follows:

$$m_{PM} = \left[\frac{m_f}{m_{sep}} - \left(\frac{m_b}{m_{sd}} \times \left(1 - \frac{1}{D} \right) \right) \right] \times \frac{m_{ed}}{1,000} \quad (53)$$

where:

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

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

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

D is the dilution factor as determined in paragraph 8.4.2.4.2.

8.5. General calculations8.5.1. Calculation of NMHC and CH₄ with the non-methane cutter

The concentration of NMHC and CH₄ shall be calculated as follows:

$$c_{NMHC} = \frac{c_{HC(w/oCutter)} \times (1 - E_M) - c_{HC(w/Cutter)}}{E_E - E_M} \quad (54)$$

$$c_{CH4} = \frac{c_{HC(w/Cutter)} - c_{HC(w/oCutter)} \times (1 - E_E)}{E_E - E_M} \quad (55)$$

where:

- $c_{\text{HC(w/Cutter)}}$ is the HC concentration with sample gas flowing through the NMC, ppm
- $c_{\text{HC(w/oCutter)}}$ is the HC concentration with sample gas bypassing the NMC, ppm
- E_{M} is the methane efficiency as determined per paragraph 9.3.8.1.
- E_{E} is the ethane efficiency as determined per paragraph 9.3.8.2.

8.5.2. Calculation of the specific emissions

The specific emissions e_{gas} or e_{PM} (g/kWh) shall be calculated for each individual component in the following ways depending on the type of test cycle.

8.5.2.1. Test result

For the WHSC, hot WHTC, or cold WHTC, the following formula shall be applied:

$$e = \frac{m}{W_{\text{act}}} \quad (56)$$

where:

- m is the mass emission of the component, g/test
- W_{act} is the actual cycle work as determined according to paragraph 7.7.1., kWh

For the WHTC, the final test result shall be a weighted average from cold start test and hot start test by using the following equation:

$$e = \frac{(0.1 \times m_{\text{cold}}) + (0.9 \times m_{\text{hot}})}{(0.1 \times W_{\text{act,cold}}) + (0.9 \times W_{\text{act,hot}})} \quad (57)$$

8.5.2.2. Exhaust after-treatment systems with periodic regeneration

The hot start emissions shall be weighted as follows:

$$e_w = \frac{n \times \bar{e} + n_r \times \bar{e}_r}{n + n_r} \quad (58)$$

where:

- n is the number of WHTC hot start tests outside regenerations
- n_r is the number of WHTC hot start tests during regeneration (minimum one test)
- e is the average specific emission outside regeneration, g/kWh
- e_r is the average specific emission during regeneration, g/kWh

The regeneration factor k_r shall be determined as follows:

$$k_r = \frac{e_w}{e} \quad (59)$$

The regeneration factor k_r :

- (a) shall be applied to the weighted WHTC test result of paragraph 8.5.2.2.,
- (b) may be applied to the WHSC and cold WHTC, if a regeneration occurs during the cycle,
- (c) may be extended to other members of the same engine family,
- (d) may be extended to other engine families using the same aftertreatment system with the prior approval of the type approval authority based on technical evidence to be supplied by the manufacturer that the emissions are similar.

9. MEASUREMENT EQUIPMENT

This annex does not contain details of flow, pressure, and temperature measuring equipment or systems. Instead, only the linearity requirements of such equipment or systems necessary for conducting an emissions test are given in paragraph 9.2.

9.1. Dynamometer specification

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

The instrumentation for torque and speed measurement shall allow the measurement accuracy of the shaft power as needed to comply with the cycle validation criteria. Additional calculations may be necessary. The accuracy of the measuring equipment shall be such that the linearity requirements given in paragraph 9.2, table 6 are not exceeded.

9.2. Linearity requirements

The calibration of all measuring instruments and systems shall be traceable to national (international) standards. The measuring instruments and systems shall comply with the linearity requirements given in table 6. The linearity verification according to paragraph 9.2.1. shall be performed for the gas analyzers at least every 3 months or whenever a system repair or change is made that could influence calibration. For the other instruments and systems, the linearity verification shall be done as required by internal audit procedures, by the instrument manufacturer or in accordance with ISO 9000 requirements.

Measurement system	Intercept b	Slope m	Standard error SEE	Coefficient of determination r^2
Engine speed	≤ 0.05 % max	0.98 - 1.02	≤ 2 % max	≥ 0.990
Engine torque	≤ 1 % max	0.98 - 1.02	≤ 2 % max	≥ 0.990
Fuel flow	≤ 1 % max	0.98 - 1.02	≤ 2 % max	≥ 0.990
Airflow	≤ 1 % max	0.98 - 1.02	≤ 2 % max	≥ 0.990
Exhaust gas flow	≤ 1 % max	0.98 - 1.02	≤ 2 % max	≥ 0.990
Dilution airflow	≤ 1 % max	0.98 - 1.02	≤ 2 % max	≥ 0.990
Diluted exhaust gas flow	≤ 1 % max	0.98 - 1.02	≤ 2 % max	≥ 0.990
Sample flow	≤ 1 % max	0.98 - 1.02	≤ 2 % max	≥ 0.990
Gas analyzers	≤ 0.5 % max	0.99 - 1.01	≤ 1 % max	≥ 0.998
Gas dividers	≤ 0.5 % max	0.98 - 1.02	≤ 2 % max	≥ 0.990
Temperatures	≤ 1 % max	0.99 - 1.01	≤ 1 % max	≥ 0.998
Pressures	≤ 1 % max	0.99 - 1.01	≤ 1 % max	≥ 0.998
PM balance	≤ 1 % max	0.99 - 1.01	≤ 1 % max	≥ 0.998

Table 6:
Linearity requirements of instruments and measurement systems

9.2.1. Linearity verification

9.2.1.1. Introduction

A linearity verification shall be performed for each measurement system listed in table 6. At least 10 reference values shall be introduced to the measurement system, and the measured values shall be compared to the reference values by using a least squares linear regression. The maximum limits in table 6 refer to the maximum values expected during testing.

9.2.1.2. General requirements

The measurement systems shall be warmed up according to the recommendations of the instrument manufacturer. The measurement systems shall be operated at their specified temperatures, pressures and flows.

9.2.1.3. Procedure

The linearity verification shall be run for each normally used operating range with the following steps.

- (a) The instrument shall be set at zero by introducing a zero signal. For gas analyzers, purified synthetic air (or nitrogen) shall be introduced directly to the analyzer port.

- (b) The instrument shall be spanned by introducing a span signal. For gas analyzers, an appropriate span gas shall be introduced directly to the analyzer port.
- (c) The zero procedure of (a) shall be repeated.
- (d) The verification shall be established by introducing at least 10 reference values (including zero) that are within the range from zero to the highest values expected during emission testing. For gas analyzers, known gas concentrations shall be introduced directly to the analyzer port.
- (e) At a recording frequency of at least 1 Hz, the reference values shall be measured and the measured values recorded for 30 s.
- (f) The arithmetic mean values over the 30 s period shall be used to calculate the least squares linear regression parameters according to equation 6 in paragraph 7.7.2.
- (g) The linear regression parameters shall meet the requirements of paragraph 9.2., table 6.
- (h) The zero setting shall be rechecked and the verification procedure repeated, if necessary.

9.3. Gaseous emissions measurement and sampling system

9.3.1. Analyzer specifications

9.3.1.1. General

The analyzers shall have a measuring range and response time appropriate for the accuracy required to measure the concentrations of the exhaust gas components under transient and steady state conditions.

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

9.3.1.2. Accuracy

Accuracy is defined as the deviation of the analyzer reading from the reference value. The accuracy shall not exceed ± 2 per cent of the reading or ± 0.3 per cent of full scale whichever is larger.

9.3.1.3. Precision

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than 1 per cent of full scale concentration for each range used above 155 ppm (or ppm C) or 2 per cent of each range used below 155 ppm (or ppm C).

9.3.1.4. Noise

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

9.3.1.5. Zero drift

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

9.3.1.6. Span drift

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

9.3.1.7. Rise time

The rise time of the analyzer installed in the measurement system shall not exceed 2.5 s.

9.3.1.8. Gas drying

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

9.3.2. Gas analyzers

9.3.2.1. Introduction

Paragraphs 9.3.2.2 to 9.2.3.7 describe the measurement principles to be used. A detailed description of the measurement systems is given in Appendix 3. The gases to be measured shall be analysed with the following instruments. For non-linear analyzers, the use of linearizing circuits is permitted.

9.3.2.2. Carbon monoxide (CO) analysis

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

9.3.2.3. Carbon dioxide (CO₂) analysis

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

9.3.2.4. Hydrocarbon (HC) analysis

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

hydrocarbon analyzer may be of the non-heated flame ionization detector (FID) type depending upon the method used (see paragraph A.3.1.3.).

9.3.2.5. Non-methane hydrocarbon (NMHC) analysis

The determination of the non-methane hydrocarbon fraction shall be performed with a heated non-methane cutter (NMC) operated in line with an FID as per paragraph A.3.1.4. by subtraction of the methane from the hydrocarbons.

9.3.2.6. Oxides of nitrogen (NO_x) analysis

If measured on a dry basis, the oxides of nitrogen analyzer shall be of the chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD) type with a NO₂/NO converter. If measured on a wet basis, a HCLD with converter maintained above 328 K (55 °C) shall be used, provided the water quench check (see paragraph 9.3.9.2.2.) is satisfied. For both CLD and HCLD, the sampling path shall be maintained at a wall temperature of 328 K to 473 K (55 °C to 200 °C) up to the converter for dry measurement, and up to the analyzer for wet measurement.

9.3.2.7. Air to fuel measurement

The air to fuel measurement equipment used to determine the exhaust gas flow as specified in paragraph 8.3.1.6. shall be a wide range air to fuel ratio sensor or lambda sensor of Zirconia type. The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.

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

± 3 per cent of reading	for	$\lambda < 2$
± 5 per cent of reading	for	$2 \leq \lambda < 5$
± 10 per cent of reading	for	$5 \leq \lambda$

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

9.3.3. Calibration gases

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

9.3.3.1. Pure gases

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

Purified nitrogen

(Contamination \leq 1 ppm C1, \leq 1 ppm CO, \leq 400 ppm CO₂, \leq 0.1 ppm NO)

Purified oxygen

(Purity $>$ 99.5 per cent vol O₂)

Hydrogen-helium mixture

(40 \pm 2 per cent hydrogen, balance helium)

(Contamination \leq 1 ppm C1, \leq 400 ppm CO₂)

Purified synthetic air

(Contamination \leq 1 ppm C1, \leq 1 ppm CO, \leq 400 ppm CO₂, \leq 0.1 ppm NO)

(Oxygen content between 18-21 per cent vol.)

9.3.3.2. Calibration and span gases

Mixtures of gases having the following chemical compositions shall be available. Other gas combinations are allowed provided the gases do not react with one another.

C₃H₈ and purified synthetic air (see paragraph 9.3.3.1.);

CO and purified nitrogen;

NO_x and purified nitrogen (the amount of NO₂ contained in this calibration gas shall not exceed 5 per cent of the NO content);

CO₂ and purified nitrogen;

CH₄ and purified synthetic air;

C₂H₆ and purified synthetic air;

The true concentration of a calibration and span gas shall be within \pm 1 per cent of the nominal value, and shall be traceable to national and international standards. All concentrations of calibration gas shall be given on a volume basis (volume percent or volume ppm).

9.3.3.3. Gas dividers

The gases used for calibration and span may also be obtained by means of gas dividers (precision blending devices), diluting with purified N₂ or with purified synthetic air. The accuracy of the gas divider shall be such that the concentration of the blended calibration gases is accurate to within ± 2 per cent. This accuracy implies that primary gases used for blending shall be known to an accuracy of at least ± 1 per cent, traceable to national or international gas standards. The verification shall be performed at between 15 and 50 per cent of full scale for each calibration incorporating a gas divider. An additional verification may be performed using another calibration gas, if the first verification has failed.

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

For conducting the linearity verification according to paragraph 9.2.1., the gas divider shall be accurate to within ± 1 per cent.

9.3.3.4. Oxygen interference check gases

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

Type of engine	O ₂ concentration (per cent)
Compression ignition	21 (20 to 22)
Compression and positive ignition	10 (9 to 11)
Compression and positive ignition	5 (4 to 6)
Positive ignition	0 (0 to 1)

Table 7:
Oxygen interference check gases

9.3.4. Leakage test

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

The maximum allowable leakage rate on the vacuum side shall be 0.5 per cent of the in-use flow rate for the portion of the system being checked. The analyzer flows and bypass flows may be used to estimate the in-use flow rates.

Alternatively, the system may be evacuated to a pressure of at least 20 kPa vacuum (80 kPa absolute). After an initial stabilization period the pressure increase Δp (kPa/min) in the system shall not exceed:

$$\Delta p = p / V_s \times 0.005 \times q_{vs} \quad (60)$$

where:

V_s is the system volume, l

q_{vs} is the system flow rate, l/min

Another method is the introduction of a concentration step change at the beginning of the sampling line by switching from zero to span gas. If for a correctly calibrated analyzer after an adequate period of time the reading is ≤ 99 per cent compared to the introduced concentration, this points to a leakage problem that shall be corrected.

9.3.5. Response time check of the analytical system

The system settings for the response time evaluation shall be exactly the same as during measurement of the test run (i.e. pressure, flow rates, filter settings on the analyzers and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0.1 s. The gases used for the test shall cause a concentration change of at least 60 per cent full scale (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 per cent of the final reading (t_{10}). The rise time is defined as the time between 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$).

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

The system response time shall be ≤ 10 s with a rise time of ≤ 2.5 s in accordance with paragraph 9.3.1.7. for all limited components (CO, NO_x, HC or NMHC) and all ranges used. When using a NMC for the measurement of NMHC, the system response time may exceed 10 s.

9.3.6. Efficiency test of NO_x converter

The efficiency of the converter used for the conversion of NO₂ into NO is tested as given in paragraphs 9.3.6.1 to 9.3.6.8 (see figure 8).

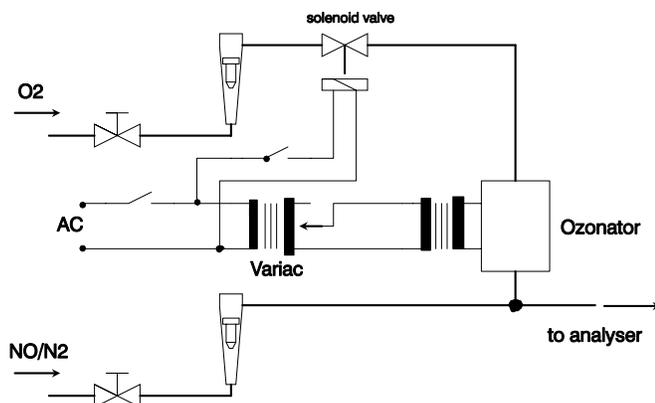


Figure 8:
Scheme of NO₂ converter efficiency device

9.3.6.1. Test setup

Using the test setup as schematically shown in figure 8 and the procedure below, the efficiency of the converter shall be tested by means of an ozonator.

9.3.6.2. Calibration

The CLD and the HCLD shall be calibrated in the most common operating range following the manufacturer's specifications using zero and span gas (the NO content of which shall amount to about 80 per cent of the operating range and the NO₂ concentration of the gas mixture to less than 5 per cent of the NO concentration). The NO_x analyzer shall be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

9.3.6.3. Calculation

The per cent efficiency of the converter shall be calculated as follows:

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

where:

- a* is the NO_x concentration according to paragraph 9.3.6.6.
- b* is the NO_x concentration according to paragraph 9.3.6.7.
- c* is the NO concentration according to paragraph 9.3.6.4.
- d* is the NO concentration according to paragraph 9.3.6.5.

9.3.6.4. Adding of oxygen

Via a T-fitting, oxygen or zero air shall be added continuously to the gas flow until the concentration indicated is about 20 per cent less than the indicated calibration concentration given in paragraph 9.3.6.2. (the analyzer is in the NO mode).

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

9.3.6.5. Activation of the ozonator

The ozonator shall be activated to generate enough ozone to bring the NO concentration down to about 20 per cent (minimum 10 per cent) of the calibration concentration given in paragraph 9.3.6.2. The indicated concentration (*d*) shall be recorded (the analyzer is in the NO mode).

9.3.6.6. NO_x mode

The NO analyzer shall be switched to the NO_x mode so that the gas mixture (consisting of NO, NO₂, O₂ and N₂) now passes through the converter. The indicated concentration (*a*) shall be recorded (the analyzer is in the NO_x mode).

9.3.6.7. Deactivation of the ozonator

The ozonator is now deactivated. The mixture of gases described in paragraph 9.3.6.6. passes through the converter into the detector. The indicated concentration (*b*) shall be recorded (the analyzer is in the NO_x mode).

9.3.6.8. NO mode

Switched to NO mode with the ozonator deactivated, the flow of oxygen or synthetic air shall be shut off. The NO_x reading of the analyzer shall not deviate by more than ± 5 per cent from the value measured according to paragraph 9.3.6.2. (the analyzer is in the NO mode).

9.3.6.9. Test interval

The efficiency of the converter shall be tested at least once per month.

9.3.6.10. Efficiency requirement

The efficiency of the converter E_{NOx} shall not be less than 95 per cent.

If, with the analyzer in the most common range, the ozonator cannot give a reduction from 80 per cent to 20 per cent according to paragraph 9.3.6.5., the highest range which will give the reduction shall be used.

9.3.7. Adjustment of the FID

9.3.7.1. Optimization of the detector response

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

With the fuel and airflow rates set at the manufacturer's recommendations, a 350 ± 75 ppm C span gas shall be introduced to the analyzer. The response at a given fuel flow shall be determined from the difference between the span gas response and the zero gas response. The fuel flow shall be incrementally adjusted above and below the manufacturer's specification. The span and zero response at these fuel flows shall be recorded. The difference between the span and zero response shall be plotted and the fuel flow adjusted to the rich side of the curve. This is the initial flow rate setting which may need further optimization depending on the results of the hydrocarbon response factors and the oxygen interference check according to paragraphs 9.3.7.2. and 9.3.7.3. If the oxygen interference or the hydrocarbon response factors do not meet the following specifications, the airflow shall be incrementally adjusted above and below the manufacturer's specifications, repeating paragraphs 9.3.7.2. and 9.3.7.3. for each flow.

The optimization may optionally be conducted using the procedures outlined in SAE paper No. 770141.

9.3.7.2. Hydrocarbon response factors

A linearity verification of the analyzer shall be performed using propane in air and purified synthetic air according to paragraph 9.2.1.3.

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

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

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

- (a) Methane and purified synthetic air $1.00 \leq r_h \leq 1.15$
- (b) Propylene and purified synthetic air $0.90 \leq r_h \leq 1.1$
- (c) Toluene and purified synthetic air $0.90 \leq r_h \leq 1.1$

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

9.3.7.3. Oxygen interference check

For raw exhaust gas analyzers only, the oxygen interference check shall be performed when introducing an analyzer into service and after major service intervals.

A measuring range shall be chosen where the oxygen interference check gases will fall in the upper 50 per cent. The test shall be conducted with the oven temperature set as required. Oxygen interference check gas specifications are found in paragraph 9.3.3.4.

- (a) The analyzer shall be set at zero.
- (b) The analyzer shall be spanned with the 0 per cent oxygen blend for positive ignition engines. Compression ignition engine instruments shall be spanned with the 21 per cent oxygen blend.
- (c) The zero response shall be rechecked. If it has changed by more than 0.5 per cent of full scale, steps (a) and (b) of this paragraph shall be repeated.
- (d) The 5 per cent and 10 per cent oxygen interference check gases shall be introduced.
- (e) The zero response shall be rechecked. If it has changed by more than ± 1 per cent of full scale, the test shall be repeated.
- (f) The oxygen interference E_{O_2} shall be calculated for each mixture in step (d) as follows:

$$E_{O_2} = (c_{\text{ref,d}} - c) \times 100 / c_{\text{ref,d}} \quad (62)$$

with the analyzer response being

$$c = \frac{c_{\text{ref,b}} \times c_{\text{FS,b}}}{c_{\text{m,b}}} \times \frac{c_{\text{m,d}}}{c_{\text{FS,d}}} \quad (63)$$

where:

$c_{\text{ref,b}}$ is the reference HC concentration in step (b), ppm C

$c_{\text{ref,d}}$ is the reference HC concentration in step (d), ppm C

$c_{\text{FS,b}}$ is the full scale HC concentration in step (b), ppm C

$c_{\text{FS,d}}$ is the full scale HC concentration in step (d), ppm C

$c_{\text{m,b}}$ is the measured HC concentration in step (b), ppm C

$c_{\text{m,d}}$ is the measured HC concentration in step (d), ppm C

- (g) The oxygen interference E_{O_2} shall be less than ± 1.5 per cent for all required oxygen interference check gases prior to testing.

- (h) If the oxygen interference E_{O_2} is greater than ± 1.5 per cent, corrective action may be taken by incrementally adjusting the airflow above and below the manufacturer's specifications, the fuel flow and the sample flow.
- (i) The oxygen interference shall be repeated for each new setting.

9.3.8. Efficiency of the non-methane cutter (NMC)

The NMC is used for the removal of the non-methane hydrocarbons from the sample gas by oxidizing all hydrocarbons except methane. Ideally, the conversion for methane is 0 per cent, and for the other hydrocarbons represented by ethane is 100 per cent. For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emission mass flow rate (see paragraph 8.5.1.).

9.3.8.1. Methane Efficiency

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

$$E_M = 1 - \frac{c_{HC(w/cutter)}}{c_{HC(w/o\ cutter)}} \quad (64)$$

where:

$c_{HC(w/cutter)}$ is the HC concentration with CH_4 flowing through the NMC, ppm C

$c_{HC(w/o\ cutter)}$ is the HC concentration with CH_4 bypassing the NMC, ppm C

9.3.8.2. Ethane Efficiency

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

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

where:

$c_{HC(w/cutter)}$ is the HC concentration with C_2H_6 flowing through the NMC, ppm C

$c_{HC(w/o\ cutter)}$ is the HC concentration with C_2H_6 bypassing the NMC, ppm C

9.3.9. Interference effects

Other gases than the one being analysed can interfere with the reading in several ways. Positive interference occurs in NDIR instruments where the interfering gas gives the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments by the interfering gas broadening the absorption band of the measured gas, and in CLD instruments by the interfering gas quenching the reaction. The interference checks in paragraphs 9.3.9.1. and 9.3.9.2. shall be performed prior to an analyzer's initial use and after major service intervals.

9.3.9.1. CO analyzer interference check

Water and CO₂ can interfere with the CO analyzer performance. Therefore, a CO₂ span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyzer response recorded. The analyzer response shall not be more than 1 per cent of full scale for ranges equal to or above 300 ppm or more than 3 ppm for ranges below 300 ppm.

9.3.9.2. NO_x analyzer quench checks

The two gases of concern for CLD (and HCLD) analyzers are CO₂ and water vapour. Quench responses to these gases are proportional to their concentrations, and therefore require test techniques to determine the quench at the highest expected concentrations experienced during testing.

9.3.9.2.1. CO₂ quench check

A CO₂ span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range shall be passed through the NDIR analyzer and the CO₂ value recorded as *A*. It shall then be diluted approximately 50 per cent with NO span gas and passed through the NDIR and CLD, with the CO₂ and NO values recorded as *B* and *C*, respectively. The CO₂ shall then be shut off and only the NO span gas be passed through the (H)CLD and the NO value recorded as *D*.

The per cent quench shall be calculated as follows:

$$E_{\text{CO}_2} = \left[1 - \left(\frac{(C \times A)}{(D \times A) - (D \times B)} \right) \right] \times 100 \quad (66)$$

where:

- A* is the undiluted CO₂ concentration measured with NDIR, per cent
- B* is the diluted CO₂ concentration measured with NDIR, per cent
- C* is the diluted NO concentration measured with (H)CLD, ppm
- D* is the undiluted NO concentration measured with (H)CLD, ppm

Alternative methods of diluting and quantifying of CO₂ and NO span gas values such as dynamic mixing/blending are permitted with the approval of the type approval authority.

9.3.9.2.2. Water quench check

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

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

The water vapour concentration (in per cent) of the mixture shall be calculated as follows:

$$H = 100 \times (G / p_b) \quad (67)$$

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

$$D_e = D \times (1 - H/100) \quad (68)$$

and recorded as *D_e*. For diesel exhaust, the maximum exhaust water vapour concentration (in per cent) expected during testing shall be estimated, under the assumption of a fuel H/C ratio of 1.8/1, from the maximum CO₂ concentration in the exhaust gas *A* as follows:

$$H_m = 0.9 \times A \quad (69)$$

and recorded as *H_m*

The per cent water quench shall be calculated as follows:

$$E_{H_2O} = 100 \times ((D_e - C) / D_e) \times (H_m / H) \quad (70)$$

where:

- D_e* is the expected diluted NO concentration, ppm
- C* is the measured diluted NO concentration, ppm
- H_m* is the maximum water vapour concentration, per cent
- H* is the actual water vapour concentration, per cent

9.3.9.2.3. Maximum allowable quench

- (a) For raw measurement:
 - (i) CO₂ quench according to paragraph 9.3.9.2.1.: 2 per cent of full scale
 - (ii) water quench according to paragraph 9.3.9.2.2.: 3 per cent of full scale
- (b) For dilute measurement:
 - (i) 2 per cent combined CO₂ and water quench.

9.3.9.2.4. Efficiency of the cooling bath

For dry CLD analyzers, it shall be demonstrated that for the highest expected water vapour concentration *H_m* (see paragraph 9.3.9.2.2.), the water removal technique

maintains CLD humidity at ≤ 5 g water/kg dry air (or about 0.008 per cent H₂O), which is 100 per cent relative humidity at 3.9 °C and 101.3 kPa. This humidity specification is also equivalent to about 25 per cent relative humidity at 25 °C and 101.3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD. Humidity of the CLD exhaust might also be measured as long as the only flow into the CLD is the flow from the dehumidifier.

9.4. Particulate measurement and sampling system

9.4.1. General specifications

To determine the mass of the particulates, a particulate sampling system, a particulate sampling filter, a microgram balance, and a temperature and humidity controlled weighing chamber, are required. The particulate sampling system shall be designed to ensure a representative sample of the particulates proportional to the exhaust flow.

9.4.2. Particulate sampling filters

The diluted exhaust shall be sampled by a filter that meets the following requirements of paragraphs 9.4.2.1. to 9.4.2.3. during the test sequence.

9.4.2.1. Filter specification

All filter types shall have a 0.3 µm DOP (di-octylphthalate) collection efficiency of at least 99 per cent. The filter material shall be fluorocarbon (PTFE) coated glass fiber.

9.4.2.2. Filter size

The filter size shall be 70 mm diameter.

9.4.2.3. Filter face velocity

The face velocity through the filter shall not exceed 1 m/s. The pressure drop increase between the beginning and the end of the test shall not exceed 25 kPa.

9.4.3. Weighing chamber and analytical balance specifications

9.4.3.1. Weighing chamber conditions

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within 295 K \pm 3 K (22 °C \pm 3 °C) during all filter conditioning and weighing. The humidity shall be maintained to a dew point of 282.5 K \pm 3 K (9.5 °C \pm 3 °C) and a relative humidity of 45 per cent \pm 8 per cent. For sensitive balances, it is recommended that the tolerance for the weighing chamber room air temperature and the dew point be \pm 1 K.

9.4.3.2. Reference filter weighing

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilization. Disturbances to weighing room specifications as outlined in paragraph 9.4.3.1. will be allowed if the duration of the disturbances does not exceed 30 minutes. The weighing room shall meet the required specifications prior to personal entrance into the weighing room. At least two unused reference filters shall be weighed within 12 hours of, but preferably at the same time as the sample filter weighing. 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, all sample filters shall be discarded and the emissions test repeated.

9.4.3.3. Analytical balance

The analytical balance used to determine the filter weight shall meet the linearity verification criterion of paragraph 9.2., table 6. This implies a precision (standard deviation) of at least 2 µg and a resolution of at least 1 µg (1 digit = 1 µg).

9.4.3.4. Elimination of static electricity effects

The filter shall be neutralized prior to weighing, e.g. by a Polonium neutralizer or a device of similar effect.

9.4.3.5. Buoyancy correction

The sampling filter shall be corrected for its buoyancy in air. The buoyancy correction depends on sampling filter density, air density and the density of the balance calibration weight, and does not account for the buoyancy of the PM itself.

If the density of the filter material is not known, the following densities shall be used:

- (a) teflon coated glass fiber filter: 2,300 kg/m³
- (b) teflon membrane filter: 2,144 kg/m³
- (c) teflon membrane filter with polymethylpentene support ring: 920 kg/m³

For stainless steel calibration weights, a density of 8,000 kg/m³ shall be used. If the material of the calibration weight is different, its density must be known.

The following equation shall be used:

$$m_f = m_{\text{uncor}} \times \left(\frac{1 - \frac{\rho_a}{\rho_w}}{1 - \frac{\rho_a}{\rho_f}} \right) \quad (71)$$

with

$$\rho_a = \frac{p_b \times 28.836}{8.3144 \times T_a} \quad (72)$$

where:

m_{uncor}	is the uncorrected particulate sample mass, mg
ρ_a	is the density of the air, kg/m ³
ρ_w	is the density of balance calibration weight, kg/m ³
ρ_f	is the density of the particulate sampling filter, kg/m ³
p_b	is the total atmospheric pressure, kPa
T_a	is the air temperature in the balance environment, K
28.836	is the molar mass of the air at reference humidity (9.5 K), g/mol
8.3144	is the molar gas constant

9.4.4. Specifications for differential flow measurement (partial flow dilution only)

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:

$$q_{mp} = q_{mdew} - q_{mdw} \quad (73)$$

In this case, the maximum error of the difference shall be such that the accuracy of q_{mp} is within ± 5 per cent when the dilution ratio is less than 15. It can be calculated by taking root-mean-square of the errors of each instrument.

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

- The absolute accuracies of q_{mdew} and q_{mdw} are ± 0.2 per cent which guarantees an accuracy of q_{mp} of ≤ 5 per cent 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 details see paragraph 9.4.6.2.
- The accuracy of q_{mp} is determined indirectly from the accuracy of the dilution ratio as determined by a tracer gas, e.g. CO₂. Accuracies equivalent to method (a) for q_{mp} are required.
- The absolute accuracy of q_{mdew} and q_{mdw} is within ± 2 per cent of full scale, the maximum error of the difference between q_{mdew} and q_{mdw} is within 0.2 per cent, and the linearity error is within ± 0.2 per cent of the highest q_{mdew} observed during the test.

9.4.5. Additional specifications

All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder, which are in contact with raw and diluted exhaust gas, shall be designed to minimize deposition or alteration of the particulates. All parts shall be made of

electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

9.4.6. Calibration of the flow measurement instrumentation

9.4.6.1. General specifications

Each flow meter used in a particulate sampling and partial flow dilution system shall be subjected to the linearity verification, as described in paragraph 9.2.1., as often as necessary to fulfil the accuracy requirements of this gr. For the flow reference values, an accurate flow meter traceable to international and/or national standards shall be used.

9.4.6.2. Calibration of differential flow measurement (partial flow dilution only)

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 fulfil the accuracy requirements of paragraph 9.4.4.:

- (a) The flow meter for q_{mdw} shall be connected in series to the flow meter for q_{mdew} , the difference between the two flow meters shall be calibrated for at least 5 set points with flow values equally spaced between the lowest q_{mdw} value used during the test and the value of q_{mdew} used during the test. The dilution tunnel may be bypassed.
- (b) A calibrated flow device shall be connected in series to the flow meter for q_{mdew} and the accuracy shall be checked for the value used for the test. The calibrated flow device shall be connected in series to the flow meter for q_{mdw} , and the accuracy shall be checked for at least 5 settings corresponding to dilution ratio between 3 and 50, relative to q_{mdew} used during the test.
- (c) The transfer tube TT shall be disconnected from the exhaust, and a calibrated flow-measuring device with a suitable range to measure q_{mp} shall be connected to the transfer tube. q_{mdew} shall be set to the value used during the test, and q_{mdw} shall be sequentially set to at least 5 values corresponding to dilution ratios between 3 and 50. Alternatively, a special calibration flow path may be provided, in which the tunnel is bypassed, but the total and dilution airflow through the corresponding meters as in the actual test.
- (d) A tracer gas, shall be fed into the exhaust transfer tube TT. This tracer gas may be a component of the exhaust gas, like CO₂ or NO_x. After dilution in the tunnel the tracer gas component shall be measured. This shall be carried out for 5 dilution ratios between 3 and 50. The accuracy of the sample flow shall be determined from the dilution ratio r_d :

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

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

9.4.7. Special requirements for the partial flow dilution system

9.4.7.1. Carbon flow check

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

The engine shall be operated at peak torque load and speed or any other steady state mode that produces 5 per cent or more of CO₂. 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 Appendix 5 shall be applied. The carbon flow rates shall be calculated according to equations 80 to 82 in Appendix 5. All carbon flow rates should agree to within 3 per cent.

9.4.7.2. Pre-test check

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

The accuracy of the flow meters shall be checked by the same method as used for calibration (see paragraph 9.4.6.2.) 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 paragraph 9.4.6.2. that the flow meter calibration is stable over a longer period of time, the pre-test check may be omitted.

9.4.7.3. Determination of the transformation time

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

An independent reference flow meter with a measurement range appropriate for the probe flow shall be put in series with and closely coupled to the probe. This flow meter 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 airflow if exhaust flow is calculated) input of the partial flow dilution system, from a low flow to at least 90 per cent of full scale. The trigger for the step change shall be the same one used to start the look-ahead control in actual testing. The exhaust flow step stimulus and the flow meter 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 per cent 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 paragraph 8.3.3.3.).

The calculation shall be repeated for at least 5 rise and fall stimuli, and the results shall be averaged. The internal transformation time (<100 ms) of the reference flow meter 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 paragraph 8.3.3.3.

9.5. Calibration of the CVS system

9.5.1. General

The CVS system shall be calibrated by using an accurate flow meter 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 types of flow meters may be used, e.g. calibrated venturi, calibrated laminar flow meter, calibrated turbine meter.

9.5.2. Calibration of the positive displacement pump (PDP)

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

Temperature stability shall be maintained during calibration.

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

9.5.2.1. Data analysis

The airflow rate ($q_{v, CVS}$) at each restriction setting (minimum 6 settings) shall be calculated in standard m^3/s from the flow meter data using the manufacturer's prescribed method. The airflow rate shall then be converted to pump flow (V_0) in m^3/rev at absolute pump inlet temperature and pressure as follows:

$$V_0 = \frac{q_{v, CVS}}{n} \times \frac{T}{273} \times \frac{101.3}{p_p} \quad (75)$$

where:

$q_{v, CVS}$ is the airflow rate at standard conditions (101.3 kPa, 273 K), m^3/s

T is the temperature at pump inlet, K

p_p is the absolute pressure at pump inlet, kPa

n is the pump speed, rev/s

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

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

where:

Δp_p is the pressure differential from pump inlet to pump outlet, kPa

p_p is the absolute outlet pressure at pump outlet, kPa

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

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

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

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

The calculated values from the equation shall be within ± 0.5 per cent of the measured value of V_0 . Values of m will vary from one pump to another. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for m . Therefore, calibration shall be performed at pump start-up, after major maintenance, and if the total system verification indicates a change of the slip rate.

9.5.3. Calibration of the critical flow venturi (CFV)

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

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

9.5.3.1. Data analysis

The airflow rate (q_{vCVS}) at each restriction setting (minimum 8 settings) shall be calculated in standard m^3/s from the flow meter data using the manufacturer's prescribed method. The calibration coefficient shall be calculated from the calibration data for each setting as follows:

$$K_v = \frac{q_{vCVS} \times \sqrt{T}}{p_p} \quad (78)$$

where:

q_{vCVS} is the airflow rate at standard conditions (101.3 kPa, 273 K), m^3/s

T is the temperature at the venturi inlet, K

p_p is the absolute pressure at venturi inlet, kPa

The average K_v and the standard deviation shall be calculated. The standard deviation shall not exceed ± 0.3 per cent of the average K_v .

9.5.4. Calibration of the subsonic venturi (SSV)

Calibration of the SSV is based upon the flow equation for a subsonic venturi. Gas flow is a function of inlet pressure and temperature, pressure drop between the SSV inlet and throat, as shown in equation 43 (see paragraph 8.4.1.4.).

9.5.4.1. Data analysis

The airflowrate (Q_{SSV}) at each restriction setting (minimum 16 settings) shall be calculated in standard m^3/s from the flowmeter data using the manufacturer's prescribed method. The discharge coefficient shall be calculated from the calibration data for each setting as follows:

$$C_d = \frac{Q_{SSV}}{d_v^2 \times p_p \times \sqrt{\left[\frac{1}{T} \times (r_p^{1.4286} - r_p^{1.7143}) \times \left(\frac{1}{1 - r_D^4 \times r_p^{1.4286}} \right) \right]}} \quad (79)$$

where:

Q_{SSV} is the airflow rate at standard conditions (101.3 kPa, 273 K), m³/s

T is the temperature at the venturi inlet, K

d_V is the diameter of the SSV throat, m

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

r_D is the ratio of the SSV throat diameter, d_V , to the inlet pipe inner diameter D

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

$$Re = A_1 \times \frac{Q_{SSV}}{d_V \times \mu} \quad (80)$$

with

$$\mu = \frac{b \times T^{1.5}}{S + T} \quad (81)$$

where:

A_1 is 25.55152 in SI units of $\left(\frac{1}{m^3}\right)\left(\frac{min}{s}\right)\left(\frac{mm}{m}\right)$

Q_{SSV} is the airflow rate at standard conditions (101.3 kPa, 273 K), m³/s

d_V is the diameter of the SSV throat, m

μ is the absolute or dynamic viscosity of the gas, kg/ms

b is 1.458×10^6 (empirical constant), kg/ms K^{0.5}

S is 110.4 (empirical constant), K

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

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

9.5.5. Total system verification

The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of a pollutant gas into the system while it is being operated in the normal manner. The pollutant is analysed, and the mass calculated according to paragraph 8.4.2.4. except in the case of propane where a u factor of 0.000472 is used in place of 0.000480 for HC. Either of the following two techniques shall be used.

9.5.5.1. Metering with a critical flow orifice

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

9.5.5.2. Metering by means of a gravimetric technique

The mass of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ± 0.01 g. For about 5 to 10 minutes, the CVS system shall be operated as in a normal exhaust emission test, while carbon monoxide or propane is injected into the system. The quantity of pure gas discharged shall be determined by means of differential weighing. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined shall be within ± 3 per cent of the known mass of the gas injected.

Annex 10 - Appendix 1

WHTC ENGINE DYNAMOMETER SCHEDULE

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	per cent	per cent	s	per cent	per cent	s	per cent	per cent
1	0.0	0.0	47	0.0	0.0	93	32.8	32.7
2	0.0	0.0	48	0.0	0.0	94	33.7	32.5
3	0.0	0.0	49	0.0	0.0	95	34.4	29.5
4	0.0	0.0	50	0.0	13.1	96	34.3	26.5
5	0.0	0.0	51	13.1	30.1	97	34.4	24.7
6	0.0	0.0	52	26.3	25.5	98	35.0	24.9
7	1.5	8.9	53	35.0	32.2	99	35.6	25.2
8	15.8	30.9	54	41.7	14.3	100	36.1	24.8
9	27.4	1.3	55	42.2	0.0	101	36.3	24.0
10	32.6	0.7	56	42.8	11.6	102	36.2	23.6
11	34.8	1.2	57	51.0	20.9	103	36.2	23.5
12	36.2	7.4	58	60.0	9.6	104	36.8	22.7
13	37.1	6.2	59	49.4	0.0	105	37.2	20.9
14	37.9	10.2	60	38.9	16.6	106	37.0	19.2
15	39.6	12.3	61	43.4	30.8	107	36.3	18.4
16	42.3	12.5	62	49.4	14.2	108	35.4	17.6
17	45.3	12.6	63	40.5	0.0	109	35.2	14.9
18	48.6	6.0	64	31.5	43.5	110	35.4	9.9
19	40.8	0.0	65	36.6	78.2	111	35.5	4.3
20	33.0	16.3	66	40.8	67.6	112	35.2	6.6
21	42.5	27.4	67	44.7	59.1	113	34.9	10.0
22	49.3	26.7	68	48.3	52.0	114	34.7	25.1
23	54.0	18.0	69	51.9	63.8	115	34.4	29.3
24	57.1	12.9	70	54.7	27.9	116	34.5	20.7
25	58.9	8.6	71	55.3	18.3	117	35.2	16.6
26	59.3	6.0	72	55.1	16.3	118	35.8	16.2
27	59.0	4.9	73	54.8	11.1	119	35.6	20.3
28	57.9	m	74	54.7	11.5	120	35.3	22.5
29	55.7	m	75	54.8	17.5	121	35.3	23.4
30	52.1	m	76	55.6	18.0	122	34.7	11.9
31	46.4	m	77	57.0	14.1	123	45.5	0.0
32	38.6	m	78	58.1	7.0	124	56.3	m
33	29.0	m	79	43.3	0.0	125	46.2	m
34	20.8	m	80	28.5	25.0	126	50.1	0.0
35	16.9	m	81	30.4	47.8	127	54.0	m
36	16.9	42.5	82	32.1	39.2	128	40.5	m
37	18.8	38.4	83	32.7	39.3	129	27.0	m
38	20.7	32.9	84	32.4	17.3	130	13.5	m
39	21.0	0.0	85	31.6	11.4	131	0.0	0.0
40	19.1	0.0	86	31.1	10.2	132	0.0	0.0
41	13.7	0.0	87	31.1	19.5	133	0.0	0.0
42	2.2	0.0	88	31.4	22.5	134	0.0	0.0
43	0.0	0.0	89	31.6	22.9	135	0.0	0.0
44	0.0	0.0	90	31.6	24.3	136	0.0	0.0
45	0.0	0.0	91	31.9	26.9	137	0.0	0.0
46	0.0	0.0	92	32.4	30.6	138	0.0	0.0

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
139	0.0	0.0	189	0.0	5.9	239	0.0	0.0
140	0.0	0.0	190	0.0	0.0	240	0.0	0.0
141	0.0	0.0	191	0.0	0.0	241	0.0	0.0
142	0.0	4.9	192	0.0	0.0	242	0.0	0.0
143	0.0	7.3	193	0.0	0.0	243	0.0	0.0
144	4.4	28.7	194	0.0	0.0	244	0.0	0.0
145	11.1	26.4	195	0.0	0.0	245	0.0	0.0
146	15.0	9.4	196	0.0	0.0	246	0.0	0.0
147	15.9	0.0	197	0.0	0.0	247	0.0	0.0
148	15.3	0.0	198	0.0	0.0	248	0.0	0.0
149	14.2	0.0	199	0.0	0.0	249	0.0	0.0
150	13.2	0.0	200	0.0	0.0	250	0.0	0.0
151	11.6	0.0	201	0.0	0.0	251	0.0	0.0
152	8.4	0.0	202	0.0	0.0	252	0.0	0.0
153	5.4	0.0	203	0.0	0.0	253	0.0	31.6
154	4.3	5.6	204	0.0	0.0	254	9.4	13.6
155	5.8	24.4	205	0.0	0.0	255	22.2	16.9
156	9.7	20.7	206	0.0	0.0	256	33.0	53.5
157	13.6	21.1	207	0.0	0.0	257	43.7	22.1
158	15.6	21.5	208	0.0	0.0	258	39.8	0.0
159	16.5	21.9	209	0.0	0.0	259	36.0	45.7
160	18.0	22.3	210	0.0	0.0	260	47.6	75.9
161	21.1	46.9	211	0.0	0.0	261	61.2	70.4
162	25.2	33.6	212	0.0	0.0	262	72.3	70.4
163	28.1	16.6	213	0.0	0.0	263	76.0	m
164	28.8	7.0	214	0.0	0.0	264	74.3	m
165	27.5	5.0	215	0.0	0.0	265	68.5	m
166	23.1	3.0	216	0.0	0.0	266	61.0	m
167	16.9	1.9	217	0.0	0.0	267	56.0	m
168	12.2	2.6	218	0.0	0.0	268	54.0	m
169	9.9	3.2	219	0.0	0.0	269	53.0	m
170	9.1	4.0	220	0.0	0.0	270	50.8	m
171	8.8	3.8	221	0.0	0.0	271	46.8	m
172	8.5	12.2	222	0.0	0.0	272	41.7	m
173	8.2	29.4	223	0.0	0.0	273	35.9	m
174	9.6	20.1	224	0.0	0.0	274	29.2	m
175	14.7	16.3	225	0.0	0.0	275	20.7	m
176	24.5	8.7	226	0.0	0.0	276	10.1	m
177	39.4	3.3	227	0.0	0.0	277	0.0	m
178	39.0	2.9	228	0.0	0.0	278	0.0	0.0
179	38.5	5.9	229	0.0	0.0	279	0.0	0.0
180	42.4	8.0	230	0.0	0.0	280	0.0	0.0
181	38.2	6.0	231	0.0	0.0	281	0.0	0.0
182	41.4	3.8	232	0.0	0.0	282	0.0	0.0
183	44.6	5.4	233	0.0	0.0	283	0.0	0.0
184	38.8	8.2	234	0.0	0.0	284	0.0	0.0
185	37.5	8.9	235	0.0	0.0	285	0.0	0.0
186	35.4	7.3	236	0.0	0.0	286	0.0	0.0
187	28.4	7.0	237	0.0	0.0	287	0.0	0.0
188	14.8	7.0	238	0.0	0.0	288	0.0	0.0

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
289	0.0	0.0	339	0.0	0.0	389	25.2	14.7
290	0.0	0.0	340	0.0	0.0	390	28.6	28.4
291	0.0	0.0	341	0.0	0.0	391	35.5	65.0
292	0.0	0.0	342	0.0	0.0	392	43.8	75.3
293	0.0	0.0	343	0.0	0.0	393	51.2	34.2
294	0.0	0.0	344	0.0	0.0	394	40.7	0.0
295	0.0	0.0	345	0.0	0.0	395	30.3	45.4
296	0.0	0.0	346	0.0	0.0	396	34.2	83.1
297	0.0	0.0	347	0.0	0.0	397	37.6	85.3
298	0.0	0.0	348	0.0	0.0	398	40.8	87.5
299	0.0	0.0	349	0.0	0.0	399	44.8	89.7
300	0.0	0.0	350	0.0	0.0	400	50.6	91.9
301	0.0	0.0	351	0.0	0.0	401	57.6	94.1
302	0.0	0.0	352	0.0	0.0	402	64.6	44.6
303	0.0	0.0	353	0.0	0.0	403	51.6	0.0
304	0.0	0.0	354	0.0	0.5	404	38.7	37.4
305	0.0	0.0	355	0.0	4.9	405	42.4	70.3
306	0.0	0.0	356	9.2	61.3	406	46.5	89.1
307	0.0	0.0	357	22.4	40.4	407	50.6	93.9
308	0.0	0.0	358	36.5	50.1	408	53.8	33.0
309	0.0	0.0	359	47.7	21.0	409	55.5	20.3
310	0.0	0.0	360	38.8	0.0	410	55.8	5.2
311	0.0	0.0	361	30.0	37.0	411	55.4	m
312	0.0	0.0	362	37.0	63.6	412	54.4	m
313	0.0	0.0	363	45.5	90.8	413	53.1	m
314	0.0	0.0	364	54.5	40.9	414	51.8	m
315	0.0	0.0	365	45.9	0.0	415	50.3	m
316	0.0	0.0	366	37.2	47.5	416	48.4	m
317	0.0	0.0	367	44.5	84.4	417	45.9	m
318	0.0	0.0	368	51.7	32.4	418	43.1	m
319	0.0	0.0	369	58.1	15.2	419	40.1	m
320	0.0	0.0	370	45.9	0.0	420	37.4	m
321	0.0	0.0	371	33.6	35.8	421	35.1	m
322	0.0	0.0	372	36.9	67.0	422	32.8	m
323	0.0	0.0	373	40.2	84.7	423	45.3	0.0
324	4.5	41.0	374	43.4	84.3	424	57.8	m
325	17.2	38.9	375	45.7	84.3	425	50.6	m
326	30.1	36.8	376	46.5	m	426	41.6	m
327	41.0	34.7	377	46.1	m	427	47.9	0.0
328	50.0	32.6	378	43.9	m	428	54.2	m
329	51.4	0.1	379	39.3	m	429	48.1	m
330	47.8	m	380	47.0	m	430	47.0	31.3
331	40.2	m	381	54.6	m	431	49.0	38.3
332	32.0	m	382	62.0	m	432	52.0	40.1
333	24.4	m	383	52.0	m	433	53.3	14.5
334	16.8	m	384	43.0	m	434	52.6	0.8
335	8.1	m	385	33.9	m	435	49.8	m
336	0.0	m	386	28.4	m	436	51.0	18.6
337	0.0	0.0	387	25.5	m	437	56.9	38.9
338	0.0	0.0	388	24.6	11.0	438	67.2	45.0

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
439	78.6	21.5	489	45.5	m	539	56.7	m
440	65.5	0.0	490	40.4	m	540	46.9	m
441	52.4	31.3	491	49.7	0.0	541	37.5	m
442	56.4	60.1	492	59.0	m	542	30.3	m
443	59.7	29.2	493	48.9	m	543	27.3	32.3
444	45.1	0.0	494	40.0	m	544	30.8	60.3
445	30.6	4.2	495	33.5	m	545	41.2	62.3
446	30.9	8.4	496	30.0	m	546	36.0	0.0
447	30.5	4.3	497	29.1	12.0	547	30.8	32.3
448	44.6	0.0	498	29.3	40.4	548	33.9	60.3
449	58.8	m	499	30.4	29.3	549	34.6	38.4
450	55.1	m	500	32.2	15.4	550	37.0	16.6
451	50.6	m	501	33.9	15.8	551	42.7	62.3
452	45.3	m	502	35.3	14.9	552	50.4	28.1
453	39.3	m	503	36.4	15.1	553	40.1	0.0
454	49.1	0.0	504	38.0	15.3	554	29.9	8.0
455	58.8	m	505	40.3	50.9	555	32.5	15.0
456	50.7	m	506	43.0	39.7	556	34.6	63.1
457	42.4	m	507	45.5	20.6	557	36.7	58.0
458	44.1	0.0	508	47.3	20.6	558	39.4	52.9
459	45.7	m	509	48.8	22.1	559	42.8	47.8
460	32.5	m	510	50.1	22.1	560	46.8	42.7
461	20.7	m	511	51.4	42.4	561	50.7	27.5
462	10.0	m	512	52.5	31.9	562	53.4	20.7
463	0.0	0.0	513	53.7	21.6	563	54.2	13.1
464	0.0	1.5	514	55.1	11.6	564	54.2	0.4
465	0.9	41.1	515	56.8	5.7	565	53.4	0.0
466	7.0	46.3	516	42.4	0.0	566	51.4	m
467	12.8	48.5	517	27.9	8.2	567	48.7	m
468	17.0	50.7	518	29.0	15.9	568	45.6	m
469	20.9	52.9	519	30.4	25.1	569	42.4	m
470	26.7	55.0	520	32.6	60.5	570	40.4	m
471	35.5	57.2	521	35.4	72.7	571	39.8	5.8
472	46.9	23.8	522	38.4	88.2	572	40.7	39.7
473	44.5	0.0	523	41.0	65.1	573	43.8	37.1
474	42.1	45.7	524	42.9	25.6	574	48.1	39.1
475	55.6	77.4	525	44.2	15.8	575	52.0	22.0
476	68.8	100.0	526	44.9	2.9	576	54.7	13.2
477	81.7	47.9	527	45.1	m	577	56.4	13.2
478	71.2	0.0	528	44.8	m	578	57.5	6.6
479	60.7	38.3	529	43.9	m	579	42.6	0.0
480	68.8	72.7	530	42.4	m	580	27.7	10.9
481	75.0	m	531	40.2	m	581	28.5	21.3
482	61.3	m	532	37.1	m	582	29.2	23.9
483	53.5	m	533	47.0	0.0	583	29.5	15.2
484	45.9	58.0	534	57.0	m	584	29.7	8.8
485	48.1	80.0	535	45.1	m	585	30.4	20.8
486	49.4	97.9	536	32.6	m	586	31.9	22.9
487	49.7	m	537	46.8	0.0	587	34.3	61.4
488	48.7	m	538	61.5	m	588	37.2	76.6

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
589	40.1	27.5	639	39.8	m	689	46.6	0.0
590	42.3	25.4	640	36.0	m	690	32.3	34.6
591	43.5	32.0	641	29.7	m	691	32.7	68.6
592	43.8	6.0	642	21.5	m	692	32.6	67.0
593	43.5	m	643	14.1	m	693	31.3	m
594	42.8	m	644	0.0	0.0	694	28.1	m
595	41.7	m	645	0.0	0.0	695	43.0	0.0
596	40.4	m	646	0.0	0.0	696	58.0	m
597	39.3	m	647	0.0	0.0	697	58.9	m
598	38.9	12.9	648	0.0	0.0	698	49.4	m
599	39.0	18.4	649	0.0	0.0	699	41.5	m
600	39.7	39.2	650	0.0	0.0	700	48.4	0.0
601	41.4	60.0	651	0.0	0.0	701	55.3	m
602	43.7	54.5	652	0.0	0.0	702	41.8	m
603	46.2	64.2	653	0.0	0.0	703	31.6	m
604	48.8	73.3	654	0.0	0.0	704	24.6	m
605	51.0	82.3	655	0.0	0.0	705	15.2	m
606	52.1	0.0	656	0.0	3.4	706	7.0	m
607	52.0	m	657	1.4	22.0	707	0.0	0.0
608	50.9	m	658	10.1	45.3	708	0.0	0.0
609	49.4	m	659	21.5	10.0	709	0.0	0.0
610	47.8	m	660	32.2	0.0	710	0.0	0.0
611	46.6	m	661	42.3	46.0	711	0.0	0.0
612	47.3	35.3	662	57.1	74.1	712	0.0	0.0
613	49.2	74.1	663	72.1	34.2	713	0.0	0.0
614	51.1	95.2	664	66.9	0.0	714	0.0	0.0
615	51.7	m	665	60.4	41.8	715	0.0	0.0
616	50.8	m	666	69.1	79.0	716	0.0	0.0
617	47.3	m	667	77.1	38.3	717	0.0	0.0
618	41.8	m	668	63.1	0.0	718	0.0	0.0
619	36.4	m	669	49.1	47.9	719	0.0	0.0
620	30.9	m	670	53.4	91.3	720	0.0	0.0
621	25.5	37.1	671	57.5	85.7	721	0.0	0.0
622	33.8	38.4	672	61.5	89.2	722	0.0	0.0
623	42.1	m	673	65.5	85.9	723	0.0	0.0
624	34.1	m	674	69.5	89.5	724	0.0	0.0
625	33.0	37.1	675	73.1	75.5	725	0.0	0.0
626	36.4	38.4	676	76.2	73.6	726	0.0	0.0
627	43.3	17.1	677	79.1	75.6	727	0.0	0.0
628	35.7	0.0	678	81.8	78.2	728	0.0	0.0
629	28.1	11.6	679	84.1	39.0	729	0.0	0.0
630	36.5	19.2	680	69.6	0.0	730	0.0	0.0
631	45.2	8.3	681	55.0	25.2	731	0.0	0.0
632	36.5	0.0	682	55.8	49.9	732	0.0	0.0
633	27.9	32.6	683	56.7	46.4	733	0.0	0.0
634	31.5	59.6	684	57.6	76.3	734	0.0	0.0
635	34.4	65.2	685	58.4	92.7	735	0.0	0.0
636	37.0	59.6	686	59.3	99.9	736	0.0	0.0
637	39.0	49.0	687	60.1	95.0	737	0.0	0.0
638	40.2	m	688	61.0	46.7	738	0.0	0.0

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
739	0.0	0.0	789	17.2	m	839	38.1	m
740	0.0	0.0	790	14.0	37.6	840	37.2	42.7
741	0.0	0.0	791	18.4	25.0	841	37.5	70.8
742	0.0	0.0	792	27.6	17.7	842	39.1	48.6
743	0.0	0.0	793	39.8	6.8	843	41.3	0.1
744	0.0	0.0	794	34.3	0.0	844	42.3	m
745	0.0	0.0	795	28.7	26.5	845	42.0	m
746	0.0	0.0	796	41.5	40.9	846	40.8	m
747	0.0	0.0	797	53.7	17.5	847	38.6	m
748	0.0	0.0	798	42.4	0.0	848	35.5	m
749	0.0	0.0	799	31.2	27.3	849	32.1	m
750	0.0	0.0	800	32.3	53.2	850	29.6	m
751	0.0	0.0	801	34.5	60.6	851	28.8	39.9
752	0.0	0.0	802	37.6	68.0	852	29.2	52.9
753	0.0	0.0	803	41.2	75.4	853	30.9	76.1
754	0.0	0.0	804	45.8	82.8	854	34.3	76.5
755	0.0	0.0	805	52.3	38.2	855	38.3	75.5
756	0.0	0.0	806	42.5	0.0	856	42.5	74.8
757	0.0	0.0	807	32.6	30.5	857	46.6	74.2
758	0.0	0.0	808	35.0	57.9	858	50.7	76.2
759	0.0	0.0	809	36.0	77.3	859	54.8	75.1
760	0.0	0.0	810	37.1	96.8	860	58.7	36.3
761	0.0	0.0	811	39.6	80.8	861	45.2	0.0
762	0.0	0.0	812	43.4	78.3	862	31.8	37.2
763	0.0	0.0	813	47.2	73.4	863	33.8	71.2
764	0.0	0.0	814	49.6	66.9	864	35.5	46.4
765	0.0	0.0	815	50.2	62.0	865	36.6	33.6
766	0.0	0.0	816	50.2	57.7	866	37.2	20.0
767	0.0	0.0	817	50.6	62.1	867	37.2	m
768	0.0	0.0	818	52.3	62.9	868	37.0	m
769	0.0	0.0	819	54.8	37.5	869	36.6	m
770	0.0	0.0	820	57.0	18.3	870	36.0	m
771	0.0	22.0	821	42.3	0.0	871	35.4	m
772	4.5	25.8	822	27.6	29.1	872	34.7	m
773	15.5	42.8	823	28.4	57.0	873	34.1	m
774	30.5	46.8	824	29.1	51.8	874	33.6	m
775	45.5	29.3	825	29.6	35.3	875	33.3	m
776	49.2	13.6	826	29.7	33.3	876	33.1	m
777	39.5	0.0	827	29.8	17.7	877	32.7	m
778	29.7	15.1	828	29.5	m	878	31.4	m
779	34.8	26.9	829	28.9	m	879	45.0	0.0
780	40.0	13.6	830	43.0	0.0	880	58.5	m
781	42.2	m	831	57.1	m	881	53.7	m
782	42.1	m	832	57.7	m	882	47.5	m
783	40.8	m	833	56.0	m	883	40.6	m
784	37.7	37.6	834	53.8	m	884	34.1	m
785	47.0	35.0	835	51.2	m	885	45.3	0.0
786	48.8	33.4	836	48.1	m	886	56.4	m
787	41.7	m	837	44.5	m	887	51.0	m
788	27.7	m	838	40.9	m	888	44.5	m

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
889	36.4	m	939	32.7	56.5	989	32.6	m
890	26.6	m	940	33.4	62.8	990	30.9	m
891	20.0	m	941	34.6	68.2	991	29.9	m
892	13.3	m	942	35.8	68.6	992	29.2	m
893	6.7	m	943	38.6	65.0	993	44.1	0.0
894	0.0	0.0	944	42.3	61.9	994	59.1	m
895	0.0	0.0	945	44.1	65.3	995	56.8	m
896	0.0	0.0	946	45.3	63.2	996	53.5	m
897	0.0	0.0	947	46.5	30.6	997	47.8	m
898	0.0	0.0	948	46.7	11.1	998	41.9	m
899	0.0	0.0	949	45.9	16.1	999	35.9	m
900	0.0	0.0	950	45.6	21.8	1000	44.3	0.0
901	0.0	5.8	951	45.9	24.2	1001	52.6	m
902	2.5	27.9	952	46.5	24.7	1002	43.4	m
903	12.4	29.0	953	46.7	24.7	1003	50.6	0.0
904	19.4	30.1	954	46.8	28.2	1004	57.8	m
905	29.3	31.2	955	47.2	31.2	1005	51.6	m
906	37.1	10.4	956	47.6	29.6	1006	44.8	m
907	40.6	4.9	957	48.2	31.2	1007	48.6	0.0
908	35.8	0.0	958	48.6	33.5	1008	52.4	m
909	30.9	7.6	959	48.8	m	1009	45.4	m
910	35.4	13.8	960	47.6	m	1010	37.2	m
911	36.5	11.1	961	46.3	m	1011	26.3	m
912	40.8	48.5	962	45.2	m	1012	17.9	m
913	49.8	3.7	963	43.5	m	1013	16.2	1.9
914	41.2	0.0	964	41.4	m	1014	17.8	7.5
915	32.7	29.7	965	40.3	m	1015	25.2	18.0
916	39.4	52.1	966	39.4	m	1016	39.7	6.5
917	48.8	22.7	967	38.0	m	1017	38.6	0.0
918	41.6	0.0	968	36.3	m	1018	37.4	5.4
919	34.5	46.6	969	35.3	5.8	1019	43.4	9.7
920	39.7	84.4	970	35.4	30.2	1020	46.9	15.7
921	44.7	83.2	971	36.6	55.6	1021	52.5	13.1
922	49.5	78.9	972	38.6	48.5	1022	56.2	6.3
923	52.3	83.8	973	39.9	41.8	1023	44.0	0.0
924	53.4	77.7	974	40.3	38.2	1024	31.8	20.9
925	52.1	69.6	975	40.8	35.0	1025	38.7	36.3
926	47.9	63.6	976	41.9	32.4	1026	47.7	47.5
927	46.4	55.2	977	43.2	26.4	1027	54.5	22.0
928	46.5	53.6	978	43.5	m	1028	41.3	0.0
929	46.4	62.3	979	42.9	m	1029	28.1	26.8
930	46.1	58.2	980	41.5	m	1030	31.6	49.2
931	46.2	61.8	981	40.9	m	1031	34.5	39.5
932	47.3	62.3	982	40.5	m	1032	36.4	24.0
933	49.3	57.1	983	39.5	m	1033	36.7	m
934	52.6	58.1	984	38.3	m	1034	35.5	m
935	56.3	56.0	985	36.9	m	1035	33.8	m
936	59.9	27.2	986	35.4	m	1036	33.7	19.8
937	45.8	0.0	987	34.5	m	1037	35.3	35.1
938	31.8	28.8	988	33.9	m	1038	38.0	33.9

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
1039	40.1	34.5	1,089	46.3	24.0	1139	51.7	0.0
1040	42.2	40.4	1,090	47.8	20.6	1140	59.2	m
1041	45.2	44.0	1,091	47.2	3.8	1141	47.2	m
1042	48.3	35.9	1,092	45.6	4.4	1142	35.1	0.0
1043	50.1	29.6	1,093	44.6	4.1	1143	23.1	m
1044	52.3	38.5	1,094	44.1	m	1144	13.1	m
1045	55.3	57.7	1,095	42.9	m	1145	5.0	m
1046	57.0	50.7	1,096	40.9	m	1146	0.0	0.0
1047	57.7	25.2	1,097	39.2	m	1147	0.0	0.0
1048	42.9	0.0	1,098	37.0	m	1148	0.0	0.0
1049	28.2	15.7	1,099	35.1	2.0	1149	0.0	0.0
1050	29.2	30.5	1,100	35.6	43.3	1150	0.0	0.0
1051	31.1	52.6	1,101	38.7	47.6	1151	0.0	0.0
1052	33.4	60.7	1,102	41.3	40.4	1152	0.0	0.0
1053	35.0	61.4	1,103	42.6	45.7	1153	0.0	0.0
1054	35.3	18.2	1,104	43.9	43.3	1154	0.0	0.0
1055	35.2	14.9	1,105	46.9	41.2	1155	0.0	0.0
1056	34.9	11.7	1,106	52.4	40.1	1156	0.0	0.0
1057	34.5	12.9	1,107	56.3	39.3	1157	0.0	0.0
1058	34.1	15.5	1108	57.4	25.5	1158	0.0	0.0
1059	33.5	m	1109	57.2	25.4	1159	0.0	0.0
1060	31.8	m	1110	57.0	25.4	1160	0.0	0.0
1061	30.1	m	1111	56.8	25.3	1161	0.0	0.0
1062	29.6	10.3	1112	56.3	25.3	1162	0.0	0.0
1063	30.0	26.5	1113	55.6	25.2	1163	0.0	0.0
1064	31.0	18.8	1114	56.2	25.2	1164	0.0	0.0
1065	31.5	26.5	1115	58.0	12.4	1165	0.0	0.0
1066	31.7	m	1116	43.4	0.0	1166	0.0	0.0
1067	31.5	m	1117	28.8	26.2	1167	0.0	0.0
1068	30.6	m	1118	30.9	49.9	1168	0.0	0.0
1069	30.0	m	1119	32.3	40.5	1169	0.0	0.0
1070	30.0	m	1120	32.5	12.4	1170	0.0	0.0
1071	29.4	m	1121	32.4	12.2	1171	0.0	0.0
1072	44.3	0.0	1122	32.1	6.4	1172	0.0	0.0
1073	59.2	m	1123	31.0	12.4	1173	0.0	0.0
1074	58.3	m	1124	30.1	18.5	1174	0.0	0.0
1075	57.1	m	1125	30.4	35.6	1175	0.0	0.0
1076	55.4	m	1126	31.2	30.1	1176	0.0	0.0
1077	53.5	m	1127	31.5	30.8	1177	0.0	0.0
1078	51.5	m	1128	31.5	26.9	1178	0.0	0.0
1079	49.7	m	1129	31.7	33.9	1179	0.0	0.0
1080	47.9	m	1130	32.0	29.9	1180	0.0	0.0
1081	46.4	m	1131	32.1	m	1181	0.0	0.0
1082	45.5	m	1132	31.4	m	1182	0.0	0.0
1083	45.2	m	1133	30.3	m	1183	0.0	0.0
1084	44.3	m	1134	29.8	m	1184	0.0	0.0
1085	43.6	m	1135	44.3	0.0	1185	0.0	0.0
1086	43.1	m	1136	58.9	m	1186	0.0	0.0
1087	42.5	25.6	1137	52.1	m	1187	0.0	0.0
1088	43.3	25.7	1138	44.1	m	1188	0.0	0.0

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
1189	0.0	0.0	1239	58.5	85.4	1289	61.9	76.1
1190	0.0	0.0	1240	59.5	85.6	1290	65.6	73.7
1191	0.0	0.0	1241	61.0	86.6	1291	69.9	79.3
1192	0.0	0.0	1242	62.6	86.8	1292	74.1	81.3
1193	0.0	0.0	1243	64.1	87.6	1293	78.3	83.2
1194	0.0	0.0	1244	65.4	87.5	1294	82.6	86.0
1195	0.0	0.0	1245	66.7	87.8	1295	87.0	89.5
1196	0.0	20.4	1246	68.1	43.5	1296	91.2	90.8
1197	12.6	41.2	1247	55.2	0.0	1297	95.3	45.9
1198	27.3	20.4	1248	42.3	37.2	1298	81.0	0.0
1199	40.4	7.6	1249	43.0	73.6	1299	66.6	38.2
1200	46.1	m	1250	43.5	65.1	1300	67.9	75.5
1201	44.6	m	1251	43.8	53.1	1301	68.4	80.5
1202	42.7	14.7	1252	43.9	54.6	1302	69.0	85.5
1203	42.9	7.3	1253	43.9	41.2	1303	70.0	85.2
1204	36.1	0.0	1254	43.8	34.8	1304	71.6	85.9
1205	29.3	15.0	1255	43.6	30.3	1305	73.3	86.2
1206	43.8	22.6	1256	43.3	21.9	1306	74.8	86.5
1207	54.9	9.9	1257	42.8	19.9	1307	76.3	42.9
1208	44.9	0.0	1258	42.3	m	1308	63.3	0.0
1209	34.9	47.4	1259	41.4	m	1309	50.4	21.2
1210	42.7	82.7	1260	40.2	m	1310	50.6	42.3
1211	52.0	81.2	1261	38.7	m	1311	50.6	53.7
1212	61.8	82.7	1262	37.1	m	1312	50.4	90.1
1213	71.3	39.1	1263	35.6	m	1313	50.5	97.1
1214	58.1	0.0	1264	34.2	m	1314	51.0	100.0
1215	44.9	42.5	1265	32.9	m	1315	51.9	100.0
1216	46.3	83.3	1266	31.8	m	1316	52.6	100.0
1217	46.8	74.1	1267	30.7	m	1317	52.8	32.4
1218	48.1	75.7	1268	29.6	m	1318	47.7	0.0
1219	50.5	75.8	1269	40.4	0.0	1319	42.6	27.4
1220	53.6	76.7	1270	51.2	m	1320	42.1	53.5
1221	56.9	77.1	1271	49.6	m	1321	41.8	44.5
1222	60.2	78.7	1272	48.0	m	1322	41.4	41.1
1223	63.7	78.0	1273	46.4	m	1323	41.0	21.0
1224	67.2	79.6	1274	45.0	m	1324	40.3	0.0
1225	70.7	80.9	1275	43.6	m	1325	39.3	1.0
1226	74.1	81.1	1276	42.3	m	1326	38.3	15.2
1227	77.5	83.6	1277	41.0	m	1327	37.6	57.8
1228	80.8	85.6	1278	39.6	m	1328	37.3	73.2
1229	84.1	81.6	1279	38.3	m	1329	37.3	59.8
1230	87.4	88.3	1280	37.1	m	1330	37.4	52.2
1231	90.5	91.9	1281	35.9	m	1331	37.4	16.9
1232	93.5	94.1	1282	34.6	m	1332	37.1	34.3
1233	96.8	96.6	1283	33.0	m	1333	36.7	51.9
1234	100.0	m	1284	31.1	m	1334	36.2	25.3
1235	96.0	m	1285	29.2	m	1335	35.6	m
1236	81.9	m	1286	43.3	0.0	1336	34.6	m
1237	68.1	m	1287	57.4	32.8	1337	33.2	m
1238	58.1	84.7	1288	59.9	65.4	1338	31.6	m

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
1339	30.1	m	1389	50.4	50.2	1439	36.3	98.8
1340	28.8	m	1390	53.0	26.1	1440	37.7	100.0
1341	28.0	29.5	1391	59.5	0.0	1441	39.2	100.0
1342	28.6	100.0	1392	66.2	38.4	1442	40.9	100.0
1343	28.8	97.3	1393	66.4	76.7	1443	42.4	99.5
1344	28.8	73.4	1394	67.6	100.0	1444	43.8	98.7
1345	29.6	56.9	1395	68.4	76.6	1445	45.4	97.3
1346	30.3	91.7	1396	68.2	47.2	1446	47.0	96.6
1347	31.0	90.5	1397	69.0	81.4	1447	47.8	96.2
1348	31.8	81.7	1398	69.7	40.6	1448	48.8	96.3
1349	32.6	79.5	1399	54.7	0.0	1449	50.5	95.1
1350	33.5	86.9	1400	39.8	19.9	1450	51.0	95.9
1351	34.6	100.0	1401	36.3	40.0	1451	52.0	94.3
1352	35.6	78.7	1402	36.7	59.4	1452	52.6	94.6
1353	36.4	50.5	1403	36.6	77.5	1453	53.0	65.5
1354	37.0	57.0	1404	36.8	94.3	1454	53.2	0.0
1355	37.3	69.1	1405	36.8	100.0	1455	53.2	m
1356	37.6	49.5	1406	36.4	100.0	1456	52.6	m
1357	37.8	44.4	1407	36.3	79.7	1457	52.1	m
1358	37.8	43.4	1408	36.7	49.5	1458	51.8	m
1359	37.8	34.8	1409	36.6	39.3	1459	51.3	m
1360	37.6	24.0	1410	37.3	62.8	1460	50.7	m
1361	37.2	m	1411	38.1	73.4	1461	50.7	m
1362	36.3	m	1412	39.0	72.9	1462	49.8	m
1363	35.1	m	1413	40.2	72.0	1463	49.4	m
1364	33.7	m	1414	41.5	71.2	1464	49.3	m
1365	32.4	m	1415	42.9	77.3	1465	49.1	m
1366	31.1	m	1416	44.4	76.6	1466	49.1	m
1367	29.9	m	1417	45.4	43.1	1467	49.1	8.3
1368	28.7	m	1418	45.3	53.9	1468	48.9	16.8
1369	29.0	58.6	1419	45.1	64.8	1469	48.8	21.3
1370	29.7	88.5	1420	46.5	74.2	1470	49.1	22.1
1371	31.0	86.3	1421	47.7	75.2	1471	49.4	26.3
1372	31.8	43.4	1422	48.1	75.5	1472	49.8	39.2
1373	31.7	m	1423	48.6	75.8	1473	50.4	83.4
1374	29.9	m	1424	48.9	76.3	1474	51.4	90.6
1375	40.2	0.0	1425	49.9	75.5	1475	52.3	93.8
1376	50.4	m	1426	50.4	75.2	1476	53.3	94.0
1377	47.9	m	1427	51.1	74.6	1477	54.2	94.1
1378	45.0	m	1428	51.9	75.0	1478	54.9	94.3
1379	43.0	m	1429	52.7	37.2	1479	55.7	94.6
1380	40.6	m	1430	41.6	0.0	1480	56.1	94.9
1381	55.5	0.0	1431	30.4	36.6	1481	56.3	86.2
1382	70.4	41.7	1432	30.5	73.2	1482	56.2	64.1
1383	73.4	83.2	1433	30.3	81.6	1483	56.0	46.1
1384	74.0	83.7	1434	30.4	89.3	1484	56.2	33.4
1385	74.9	41.7	1435	31.5	90.4	1485	56.5	23.6
1386	60.0	0.0	1436	32.7	88.5	1486	56.3	18.6
1387	45.1	41.6	1437	33.7	97.2	1487	55.7	16.2
1388	47.7	84.2	1438	35.2	99.7	1488	56.0	15.9

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
1489	55.9	21.8	1539	57.0	59.5	1589	56.8	42.9
1490	55.8	20.9	1540	56.7	57.0	1590	56.5	42.8
1491	55.4	18.4	1541	56.7	69.8	1591	56.7	43.2
1492	55.7	25.1	1542	56.8	58.5	1592	56.5	42.8
1493	56.0	27.7	1543	56.8	47.2	1593	56.9	42.2
1494	55.8	22.4	1544	57.0	38.5	1594	56.5	43.1
1495	56.1	20.0	1545	57.0	32.8	1595	56.5	42.9
1496	55.7	17.4	1546	56.8	30.2	1596	56.7	42.7
1497	55.9	20.9	1547	57.0	27.0	1597	56.6	41.5
1498	56.0	22.9	1548	56.9	26.2	1598	56.9	41.8
1499	56.0	21.1	1549	56.7	26.2	1599	56.6	41.9
1500	55.1	19.2	1550	57.0	26.6	1600	56.7	42.6
1501	55.6	24.2	1551	56.7	27.8	1601	56.7	42.6
1502	55.4	25.6	1552	56.7	29.7	1602	56.7	41.5
1503	55.7	24.7	1553	56.8	32.1	1603	56.7	42.2
1504	55.9	24.0	1554	56.5	34.9	1604	56.5	42.2
1505	55.4	23.5	1555	56.6	34.9	1605	56.8	41.9
1506	55.7	30.9	1556	56.3	35.8	1606	56.5	42.0
1507	55.4	42.5	1557	56.6	36.6	1607	56.7	42.1
1508	55.3	25.8	1558	56.2	37.6	1608	56.4	41.9
1509	55.4	1.3	1559	56.6	38.2	1609	56.7	42.9
1510	55.0	m	1560	56.2	37.9	1610	56.7	41.8
1511	54.4	m	1561	56.6	37.5	1611	56.7	41.9
1512	54.2	m	1562	56.4	36.7	1612	56.8	42.0
1513	53.5	m	1563	56.5	34.8	1613	56.7	41.5
1514	52.4	m	1564	56.5	35.8	1614	56.6	41.9
1515	51.8	m	1565	56.5	36.2	1615	56.8	41.6
1516	50.7	m	1566	56.5	36.7	1616	56.6	41.6
1517	49.9	m	1567	56.7	37.8	1617	56.9	42.0
1518	49.1	m	1568	56.7	37.8	1618	56.7	40.7
1519	47.7	m	1569	56.6	36.6	1619	56.7	39.3
1520	47.3	m	1570	56.8	36.1	1620	56.5	41.4
1521	46.9	m	1571	56.5	36.8	1621	56.4	44.9
1522	46.9	m	1572	56.9	35.9	1622	56.8	45.2
1523	47.2	m	1573	56.7	35.0	1623	56.6	43.6
1524	47.8	m	1574	56.5	36.0	1624	56.8	42.2
1525	48.2	0.0	1575	56.4	36.5	1625	56.5	42.3
1526	48.8	23.0	1576	56.5	38.0	1626	56.5	44.4
1527	49.1	67.9	1577	56.5	39.9	1627	56.9	45.1
1528	49.4	73.7	1578	56.4	42.1	1628	56.4	45.0
1529	49.8	75.0	1579	56.5	47.0	1629	56.7	46.3
1530	50.4	75.8	1580	56.4	48.0	1630	56.7	45.5
1531	51.4	73.9	1581	56.1	49.1	1631	56.8	45.0
1532	52.3	72.2	1582	56.4	48.9	1632	56.7	44.9
1533	53.3	71.2	1583	56.4	48.2	1633	56.6	45.2
1534	54.6	71.2	1584	56.5	48.3	1634	56.8	46.0
1535	55.4	68.7	1585	56.5	47.9	1635	56.5	46.6
1536	56.7	67.0	1586	56.6	46.8	1636	56.6	48.3
1537	57.2	64.6	1587	56.6	46.2	1637	56.4	48.6
1538	57.3	61.9	1588	56.5	44.4	1638	56.6	50.3

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
1639	56.3	51.9	1689	57.6	8.9	1739	56.1	46.8
1640	56.5	54.1	1690	57.5	8.0	1740	56.1	45.8
1641	56.3	54.9	1691	57.5	5.8	1741	56.2	46.0
1642	56.4	55.0	1692	57.3	5.8	1742	56.3	45.9
1643	56.4	56.2	1693	57.6	5.5	1743	56.3	45.9
1644	56.2	58.6	1694	57.3	4.5	1744	56.2	44.6
1645	56.2	59.1	1695	57.2	3.2	1745	56.2	46.0
1646	56.2	62.5	1696	57.2	3.1	1746	56.4	46.2
1647	56.4	62.8	1697	57.3	4.9	1747	55.8	m
1648	56.0	64.7	1698	57.3	4.2	1748	55.5	m
1649	56.4	65.6	1699	56.9	5.5	1749	55.0	m
1650	56.2	67.7	1700	57.1	5.1	1750	54.1	m
1651	55.9	68.9	1701	57.0	5.2	1751	54.0	m
1652	56.1	68.9	1702	56.9	5.5	1752	53.3	m
1653	55.8	69.5	1703	56.6	5.4	1753	52.6	m
1654	56.0	69.8	1704	57.1	6.1	1754	51.8	m
1655	56.2	69.3	1705	56.7	5.7	1755	50.7	m
1656	56.2	69.8	1706	56.8	5.8	1756	49.9	m
1657	56.4	69.2	1707	57.0	6.1	1757	49.1	m
1658	56.3	68.7	1708	56.7	5.9	1758	47.7	m
1659	56.2	69.4	1709	57.0	6.6	1759	46.8	m
1660	56.2	69.5	1710	56.9	6.4	1760	45.7	m
1661	56.2	70.0	1711	56.7	6.7	1761	44.8	m
1662	56.4	69.7	1712	56.9	6.9	1762	43.9	m
1663	56.2	70.2	1713	56.8	5.6	1763	42.9	m
1664	56.4	70.5	1714	56.6	5.1	1764	41.5	m
1665	56.1	70.5	1715	56.6	6.5	1765	39.5	m
1666	56.5	69.7	1716	56.5	10.0	1766	36.7	m
1667	56.2	69.3	1717	56.6	12.4	1767	33.8	m
1668	56.5	70.9	1718	56.5	14.5	1768	31.0	m
1669	56.4	70.8	1719	56.6	16.3	1769	40.0	0.0
1670	56.3	71.1	1720	56.3	18.1	1770	49.1	m
1671	56.4	71.0	1721	56.6	20.7	1771	46.2	m
1672	56.7	68.6	1722	56.1	22.6	1772	43.1	m
1673	56.8	68.6	1723	56.3	25.8	1773	39.9	m
1674	56.6	68.0	1724	56.4	27.7	1774	36.6	m
1675	56.8	65.1	1725	56.0	29.7	1775	33.6	m
1676	56.9	60.9	1726	56.1	32.6	1776	30.5	m
1677	57.1	57.4	1727	55.9	34.9	1777	42.8	0.0
1678	57.1	54.3	1728	55.9	36.4	1778	55.2	m
1679	57.0	48.6	1729	56.0	39.2	1779	49.9	m
1680	57.4	44.1	1730	55.9	41.4	1780	44.0	m
1681	57.4	40.2	1731	55.5	44.2	1781	37.6	m
1682	57.6	36.9	1732	55.9	46.4	1782	47.2	0.0
1683	57.5	34.2	1733	55.8	48.3	1783	56.8	m
1684	57.4	31.1	1734	55.6	49.1	1784	47.5	m
1685	57.5	25.9	1735	55.8	49.3	1785	42.9	m
1686	57.5	20.7	1736	55.9	47.7	1786	31.6	m
1687	57.6	16.4	1737	55.9	47.4	1787	25.8	m
1688	57.6	12.4	1738	55.8	46.9	1788	19.9	m

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
1789	14.0	m						
1790	8.1	m						
1791	2.2	m						
1792	0.0	0.0						
1793	0.0	0.0						
1794	0.0	0.0						
1795	0.0	0.0						
1796	0.0	0.0						
1797	0.0	0.0						
1798	0.0	0.0						
1799	0.0	0.0						
1800	0.0	0.0						

m = motoring

Annex 10 - Appendix 2

DIESEL REFERENCE FUEL

Parameter	Unit	Limits ^{1/}		Test method	
		Minimum	Maximum		
Cetene number		52	54	ISO 5165	
Density at 15 °C	kg/m ³	833	837	ISO 3675	
Distillation:					
- 50 per cent vol.	°C	245		ISO 3405	
- 95 per cent vol.	°C	345	350		
- final boiling point	°C		370		
Flash point	°C	55		ISO 2719	
Cold filter plugging point	°C		-5	EN 116	
Kinematic viscosity at 40 °C	mm ² /s	2.3	3.3	ISO 3104	
Polycyclic aromatic hydrocarbons	per cent m/m	2.0	6.0	EN 12916	
Conradson carbon residue (10 per cent DR)	per cent m/m		0.2	ISO 10370	
Ash content	per cent m/m		0.01	EN-ISO 6245	
Water content	per cent m/m		0.02	EN-ISO 12937	
Sulphur content	mg/kg		10	EN-ISO 14596	
Copper corrosion at 50 °C			1	EN-ISO 2160	
Lubricity (HFRR at 60 °C)	µm		400	CEC F-06-A-96	
Neutralisation number	mg KOH/g		0.02		
Oxidation stability	mg/ml		0.025	EN-ISO 12205	

^{1/} The values quoted in the specification are "true values". In establishment of their limit values the terms of ISO 4259 "Petroleum products - Determination and application of precision data in relation to methods of test." have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility).

Notwithstanding this measure, which is necessary for statistical reasons, the manufacturer of fuels should nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify the question as to whether a fuel meets the requirements of the specifications, the terms of ISO 4259 should be applied.

Annex 10 - Appendix 3

MEASUREMENT EQUIPMENT

A.3.1. Analytical system

A.3.1.1. Introduction

This annex contains the basic requirements and the general descriptions of the sampling and analyzing systems. Since various configurations can produce equivalent results, exact conformance with figures 9 and 10 is not required. However, conformance with the basic requirements such as sampling line dimensions, heating and design is mandatory. Components such as instruments, valves, solenoids, pumps, flow devices and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

A.3.1.2. Description of the analytical system

Analytical system for the determination of the gaseous emissions in the raw exhaust gas (figure 9) or in the diluted exhaust gas (figure 10) are described based on the use of:

- (a) HFID or FID analyzer for the measurement of hydrocarbons;
- (b) NDIR analyzers for the measurement of carbon monoxide and carbon dioxide;
- (c) HCLD or CLD analyzer for the measurement of the oxides of nitrogen.

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

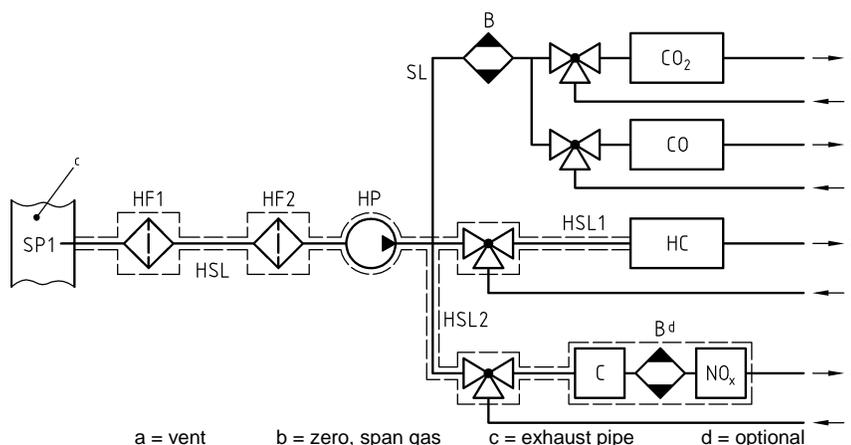


Figure 9

Schematic flow diagram of raw exhaust gas analysis system for CO, CO₂, NO_x, HC

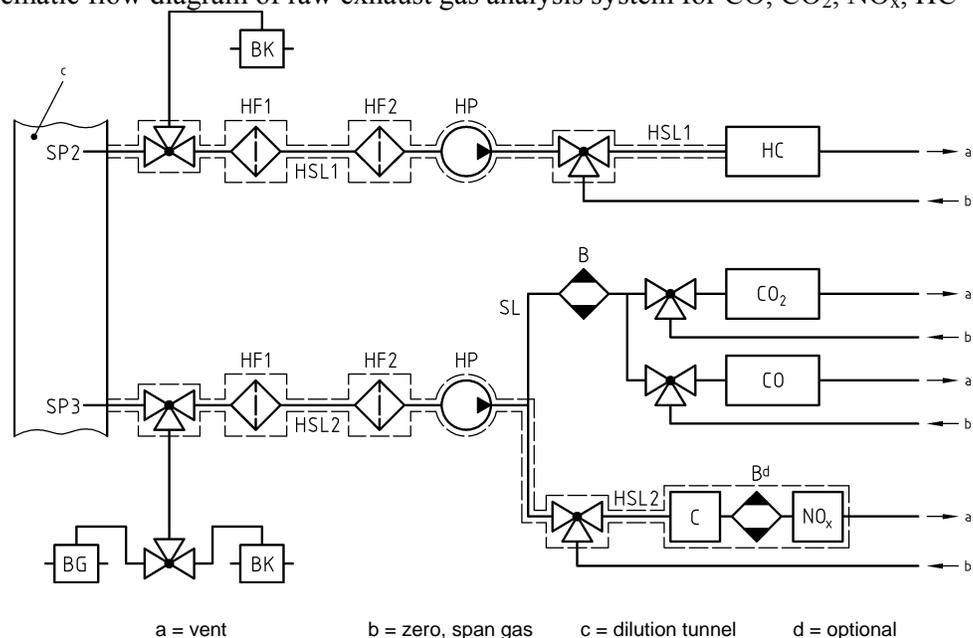


Figure 10

Schematic flow diagram of diluted exhaust gas analysis system for CO, CO₂, NO_x, HC

A.3.1.3. Components of figures 9 and 10

EP Exhaust pipe

SP Raw exhaust gas sampling probe (figure 9 only)

A stainless steel straight closed end multi-hole probe is recommended. The inside diameter shall not be greater than the inside diameter of the sampling line. The wall thickness of the probe shall not be greater than 1 mm. There shall be a minimum of 3 holes in 3 different radial planes sized to sample approximately the same flow. The probe shall extend across at least 80 per cent of the diameter of the exhaust pipe. One or two sampling probes may be used.

SP2 Dilute exhaust gas HC sampling probe (figure 10 only)

The probe shall:

- (a) be defined as the first 254 mm to 762 mm of the heated sampling line HSL1;
- (b) have a 5 mm minimum inside diameter;
- (c) be installed in the dilution tunnel DT (figure 15) at a point where the dilution air and exhaust gas are well mixed (i.e. approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel);
- (d) be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;

- (e) be heated so as to increase the gas stream temperature to $463\text{ K} \pm 10\text{ K}$ ($190\text{ }^\circ\text{C} \pm 10\text{ }^\circ\text{C}$) at the exit of the probe, or to $385\text{ K} \pm 10\text{ K}$ ($112\text{ }^\circ\text{C} \pm 10\text{ }^\circ\text{C}$) for positive ignition engines;
- (f) non-heated in case of FID measurement (cold).

SP3 Dilute exhaust gas CO, CO₂, NO_x sampling probe (figure 10 only)

The probe shall:

- (a) be in the same plane as SP2;
- (b) be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
- (c) be heated and insulated over its entire length to a minimum temperature of 328 K ($55\text{ }^\circ\text{C}$) to prevent water condensation.

HF1 Heated pre-filter (optional)

The temperature shall be the same as HSL1.

HF2 Heated filter

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

HSL1 Heated sampling line

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

The sampling line shall:

- (a) have a 4 mm minimum and a 13.5 mm maximum inside diameter;
- (b) be made of stainless steel or PTFE;
- (c) maintain a wall temperature of $463\text{ K} \pm 10\text{ K}$ ($190\text{ }^\circ\text{C} \pm 10\text{ }^\circ\text{C}$) as measured at every separately controlled heated section, if the temperature of the exhaust gas at the sampling probe is equal to or below 463 K ($190\text{ }^\circ\text{C}$);
- (d) maintain a wall temperature greater than 453 K ($180\text{ }^\circ\text{C}$), if the temperature of the exhaust gas at the sampling probe is above 463 K ($190\text{ }^\circ\text{C}$);
- (e) maintain a gas temperature of $463\text{ K} \pm 10\text{ K}$ ($190\text{ }^\circ\text{C} \pm 10\text{ }^\circ\text{C}$) immediately before the heated filter HF2 and the HFID.

HSL2 Heated NO_x sampling line

The sampling line shall:

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

HP Heated sampling pump

The pump shall be heated to the temperature of HSL.

SL Sampling line for CO and CO₂

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

HC HFID analyzer

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

CO, CO₂ NDIR analyzer

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

NO_x CLD analyzer

CLD or HCLD analyzer for the determination of the oxides of nitrogen. If a HCLD is used it shall be kept at a temperature of 328 K to 473 K (55 °C to 200 °C).

B Cooling bath (optional for NO measurement)

To cool and condense water from the exhaust sample. It is optional if the analyzer is free from water vapour interference as determined in paragraph 9.3.9.2.2. If water is removed by condensation, the sample gas temperature or dew point shall be monitored either within the water trap or downstream. The sample gas temperature or dew point shall not exceed 280 K (7 °C). Chemical dryers are not allowed for removing water from the sample.

BK Background bag (optional; figure 10 only)

For the measurement of the background concentrations.

BG Sample bag (optional; figure 10 only)

For the measurement of the sample concentrations.

A.3.1.4. Non-methane cutter method (NMC)

The cutter oxidizes all hydrocarbons except CH₄ to CO₂ and H₂O, so that by passing the sample through the NMC only CH₄ is detected by the HFID. In addition to the usual HC sampling train (see figures 9 and 10), a second HC sampling train shall be installed equipped with a cutter as laid out in figure 11. This allows simultaneous measurement of total HC and NMHC.

The cutter shall be characterized at or above 600 K (327°C) prior to test work with respect to its catalytic effect on CH₄ and C₂H₆ at H₂O values representative of exhaust stream conditions. The dew point and O₂ level of the sampled exhaust stream must be known. The relative response of the FID to CH₄ and C₂H₆ shall be determined in accordance with paragraph 9.3.8.

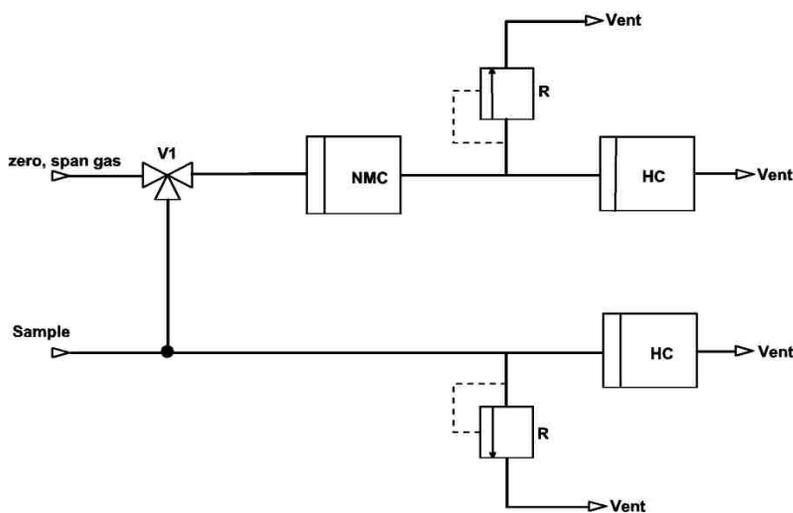


Figure 11
Schematic flow diagram of methane analysis with the NMC

A.3.1.5. Components of figure 11

NMC Non-methane cutter

To oxidize all hydrocarbons except methane.

HC

Heated flame ionization detector (HFID) or flame ionization detector (FID) to measure the HC and CH₄ concentrations. The temperature of the HFID shall be kept at 453 K to 473 K (180 °C to 200 °C).

V1 Selector valve

To select zero and span gas.

R Pressure regulator

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

A.3.2. Dilution and particulate sampling system

A.3.2.1. Introduction

This annex contains the basic requirements and the general descriptions of the dilution and particulate sampling systems. Since various configurations can produce equivalent results, exact conformance with figures 12 to 17 is not required. However, conformance with the basic requirements such as sampling line dimensions, heating and design is mandatory. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgment.

A.3.2.2. Description of partial flow system

A dilution system is described based upon the dilution of a part of the exhaust stream. Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire dilute exhaust gas or only a portion of the dilute exhaust gas is passed to the particulate sampling system. The first method is referred to as total sampling type, the second method as fractional sampling type. The calculation of the dilution ratio depends upon the type of system used.

With the total sampling system as shown in figure 12, raw exhaust gas is transferred from the exhaust pipe (EP) to the dilution tunnel (DT) through the sampling probe (SP) and the transfer tube (TT). The total flow through the tunnel is adjusted with the flow controller FC2 and the sampling pump (P) of the particulate sampling system (see figure 16). The dilution airflow is controlled by the flow controller FC1, which may use q_{mew} or q_{maw} and q_{mf} as command signals, for the desired exhaust split. The sample flow into DT is the difference of the total flow and the dilution airflow. The dilution airflow rate is measured with the flow measurement device FM1, the total flow rate with the flow measurement device FM3 of the particulate sampling system (see figure 16). The dilution ratio is calculated from these two flow rates.

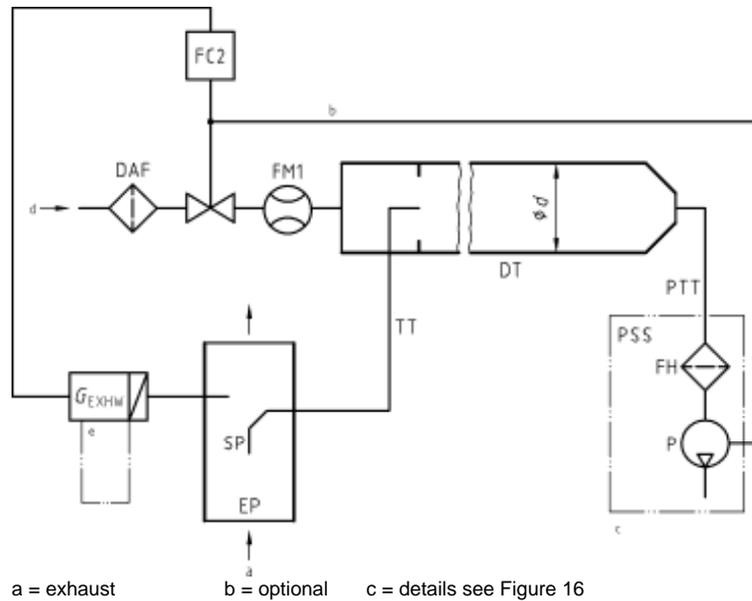


Figure 12
 Scheme of partial flow dilution system (total sampling type)

With the fractional sampling system as shown in figure 13, raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe (SP) and the transfer tube (TT). The total flow through the tunnel is adjusted with the flow controller FC1 connected either to the dilution airflow or to the suction blower for the total tunnel flow. The flow controller FC1 may use q_{mew} or q_{maw} and q_{mf} as command signals for the desired exhaust split. The sample flow into DT is the difference of the total flow and the dilution airflow. The dilution airflow rate is measured with the flow measurement device FM1, the total flow rate with the flow measurement device FM2. The dilution ratio is calculated from these two flow rates. From DT, a particulate sample is taken with the particulate sampling system (see figure 16).

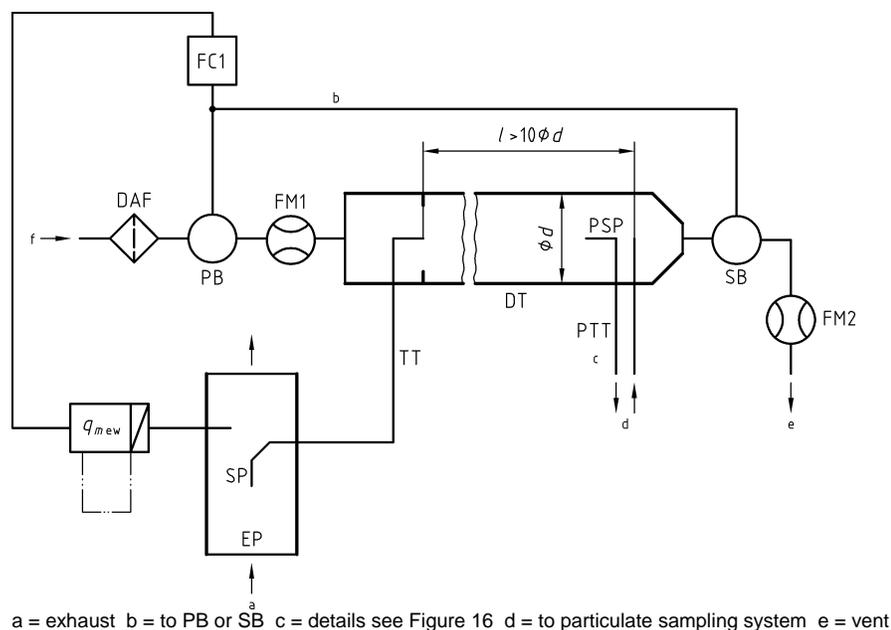


Figure 13
Scheme of partial flow dilution system (fractional sampling type)

A.3.2.3. Components of figures 12 and 13

EP Exhaust pipe

The exhaust pipe may be insulated. To reduce the thermal inertia of the exhaust pipe a thickness to diameter ratio of 0.015 or less is recommended. The use of flexible sections shall be limited to a length to diameter ratio of 12 or less. Bends shall be minimized to reduce inertial deposition. If the system includes a test bed silencer the silencer may also be insulated. It is recommended to have a straight pipe of 6 pipe diameters upstream and 3 pipe diameters downstream of the tip of the probe.

SP Sampling probe

The type of probe shall be either of the following

- open tube facing upstream on the exhaust pipe centreline
- open tube facing downstream on the exhaust pipe centreline
- multiple hole probe as described under SP in paragraph A.3.1.3.
- hatted probe facing upstream on the exhaust pipe centreline as shown in figure 14

The minimum inside diameter of the probe tip shall be 4 mm. The minimum diameter ratio between exhaust pipe and probe shall be 4.

When using probe type (a), an inertial pre-classifier (cyclone or impactor) with at 50 per cent cut point between 2.5 and 10 μm shall be installed immediately upstream of the filter holder.

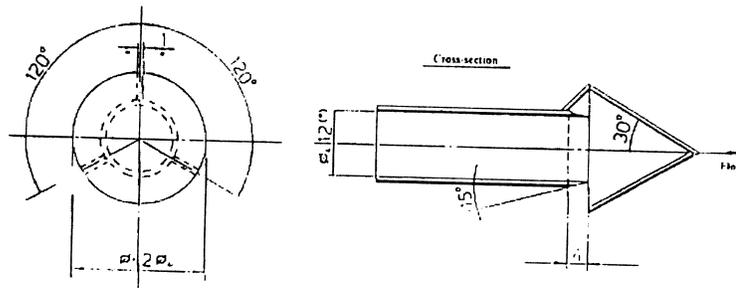


Figure 14
Scheme of hatted probe

TT Exhaust transfer tube

The transfer tube shall be:

- (a) as short as possible, but not more than 1 m in length;
- (b) equal to or greater than the probe diameter, but not more than 25 mm in diameter;
- (c) exiting on the centreline of the dilution tunnel and pointing downstream.

The tube shall be insulated with material with a maximum thermal conductivity of 0.05 W/mK with a radial insulation thickness corresponding to the diameter of the probe, or heated.

FC1 Flow controller

A flow controller shall be used to control the dilution airflow through the pressure blower PB and/or the suction blower SB. It may be connected to the exhaust flow sensor signals specified in paragraph 8.3.1. The flow controller may be installed upstream or downstream of the respective blower. When using a pressurized air supply, FC1 directly controls the airflow.

FM1 Flow measurement device

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

DAF Dilution air filter

The dilution air (ambient air, synthetic air, or nitrogen) shall be filtered with a high-efficiency (HEPA) filter that has an initial minimum collection efficiency of 99.97 per cent. The dilution air shall have a temperature of higher than 288 K (15 °C), and may be dehumidified.

FM2 Flow measurement device (fractional sampling type, figure 13 only)

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

PB Pressure blower (fractional sampling type, figure 13 only)

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

SB Suction blower (fractional sampling type, figure 13 only)

SB may be used to measure the diluted exhaust gas flow, if calibrated.

DT Dilution tunnel

The dilution tunnel:

- (a) shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions for a fractional sampling system, i.e. complete mixing is not required for a total sampling system;
- (b) shall be constructed of stainless steel;
- (c) shall be at least 75 mm in diameter for the fractional sampling type;
- (d) is recommended to be at least 25 mm in diameter for the total sampling type;
- (e) may be heated to no greater than 325 K (52 °C) wall temperature;
- (f) may be insulated.

PSP Particulate sampling probe (fractional sampling type, figure 13 only)

The particulate sampling probe is the leading section of the particulate transfer tube PTT (see paragraph A.3.2.5.) and

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

A.3.2.4. Description of full flow dilution system

A dilution system is described based upon the dilution of the total amount of raw exhaust gas in the dilution tunnel DT using the CVS (constant volume sampling) concept, and is shown in figure 15.

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

For subsequent collection of the particulates, a sample of the dilute exhaust gas shall be passed to the double dilution particulate sampling system (see figure 17). Although partly a dilution system, the double dilution system is described as a modification of a particulate sampling system, since it shares most of the parts with a typical particulate sampling system.

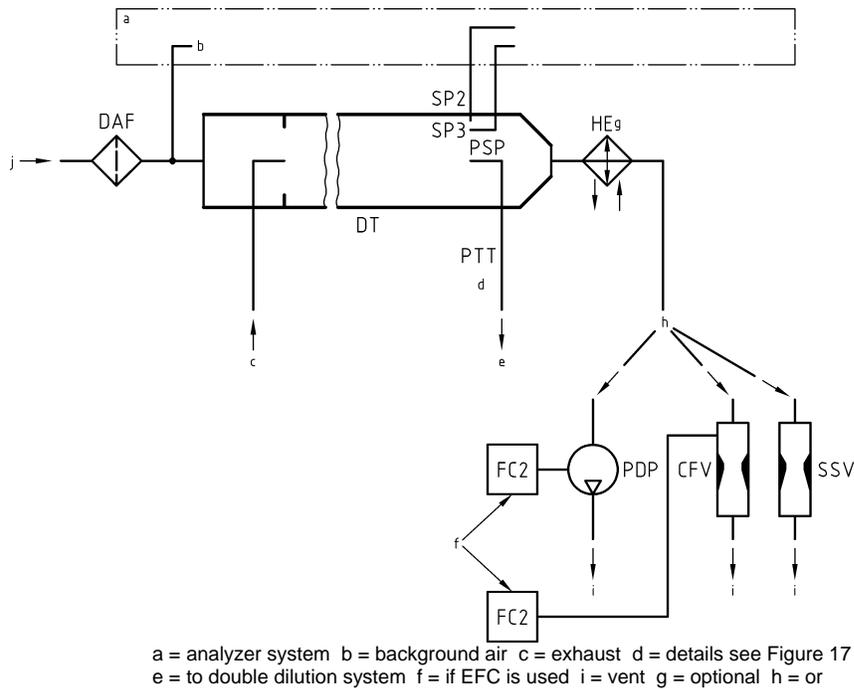


Figure 15
 Scheme of full flow dilution system (CVS)

A.3.2.5. Components of figure 15

EP Exhaust pipe

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

PDP Positive displacement pump

The PDP meters total diluted exhaust flow from the number of the pump revolutions and the pump displacement. The exhaust system backpressure shall not be artificially lowered by the PDP or dilution air inlet system. Static exhaust backpressure measured with the PDP system operating shall remain within ± 1.5 kPa of the static pressure measured without connection to the PDP at identical engine speed and load. The gas mixture temperature immediately ahead of the PDP shall be within ± 6 K of the average operating temperature observed during the test, when no flow compensation (EFC) is used. Flow compensation is only permitted, if the temperature at the inlet to the PDP does not exceed 323 K (50 °C).

CFV Critical flow venturi

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

SSV Subsonic venturi

SSV measures total diluted exhaust flow by using the gas flow function of a subsonic venturi in dependence of inlet pressure and temperature and pressure drop between venturi inlet and throat. Static exhaust backpressure measured with the SSV system operating shall remain within ± 1.5 kPa of the static pressure measured without connection to the SSV at identical engine speed and load. The gas mixture temperature immediately ahead of the SSV shall be within ± 11 K of the average operating temperature observed during the test, when no flow compensation (EFC) is used.

HE Heat exchanger (optional)

The heat exchanger shall be of sufficient capacity to maintain the temperature within the limits required above. If EFC is used, the heat exchanger is not required.

EFC Electronic flow compensation (optional)

If the temperature at the inlet to the PDP, CFV or SSV is not kept within the limits stated above, a flow compensation system is required for continuous measurement of the flow rate and control of the proportional sampling into the double dilution system. For that purpose, the continuously measured flow rate signals are used to maintain the proportionality of the sample flow rate through the particulate filters of the double dilution system (see figure 17) within ± 2.5 per cent.

DT Dilution tunnel

The dilution tunnel

- (a) shall be small enough in diameter to cause turbulent flow (Reynolds Number greater than 4,000) and of sufficient length to cause complete mixing of the exhaust and dilution air;
- (b) shall be at least 75 mm in diameter;
- (c) may be insulated.

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

For the double dilution system, a sample from the dilution tunnel is transferred to the secondary dilution tunnel where it is further diluted, and then passed through the sampling filters (figure 17). The flow capacity of the PDP or CFV must be sufficient to maintain the diluted exhaust stream in the DT at a temperature of less than or equal to 464 K (191 °C) at the sampling zone. The secondary dilution system shall provide sufficient secondary dilution air to maintain the doubly diluted exhaust stream at a temperature between 315 K (42 °C) and 325 K (52 °C) immediately before the particulate filter.

DAF Dilution air filter

The dilution air (ambient air, synthetic air, or nitrogen) shall be filtered with a high-efficiency (HEPA) filter that has an initial minimum collection efficiency of 99.97 per cent. The dilution air shall have a temperature of > 288 K (15 °C), and may be dehumidified.

PSP Particulate sampling probe

The probe is the leading section of PTT and

- (a) shall be installed facing upstream at a point where the dilution air and exhaust gases are well mixed, i.e. on the dilution tunnel DT centreline of the dilution

systems, approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;

- (b) shall be of 12 mm minimum inside diameter;
- (c) may be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel;
- (d) may be insulated.

A.3.2.6. Description of particulate sampling system

The particulate sampling system is required for collecting the particulates on the particulate filter and is shown in figures 16 and 17. In the case of total sampling partial flow dilution, which consists of passing the entire diluted exhaust sample through the filters, the dilution and sampling systems usually form an integral unit (see figure 12). In the case of fractional sampling partial flow dilution or full flow dilution, which consists of passing through the filters only a portion of the diluted exhaust, the dilution and sampling systems usually form different units.

For a partial flow dilution system, a sample of the diluted exhaust gas is taken from the dilution tunnel DT through the particulate sampling probe PSP and the particulate transfer tube PTT by means of the sampling pump P, as shown in figure 16. The sample is passed through the filter holder(s) FH that contain the particulate sampling filters. The sample flow rate is controlled by the flow controller FC3.

For of full flow dilution system, a double dilution particulate sampling system shall be used, as shown in figure 17. A sample of the diluted exhaust gas is transferred from the dilution tunnel DT through the particulate sampling probe PSP and the particulate transfer tube PTT to the secondary dilution tunnel SDT, where it is diluted once more. The sample is then passed through the filter holder(s) FH that contain the particulate sampling filters. The dilution airflow rate is usually constant whereas the sample flow rate is controlled by the flow controller FC3. If electronic flow compensation EFC (see figure 15) is used, the total diluted exhaust gas flow is used as command signal for FC3.

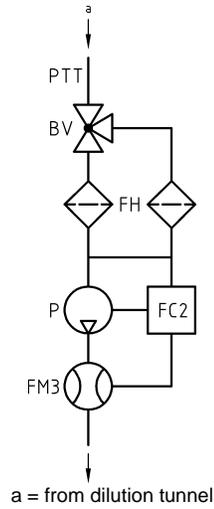


Figure 16
Scheme of particulate sampling system

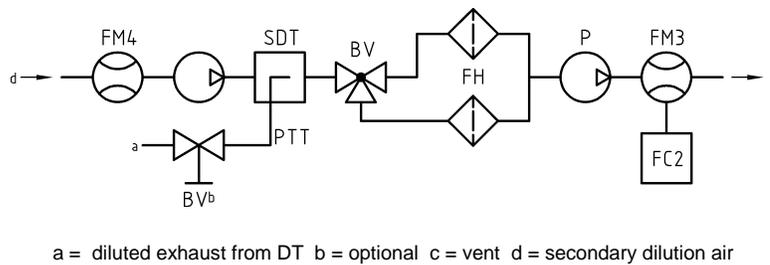


Figure 17
Scheme of double dilution particulate sampling system

A.3.2.7. Components of figures 16 (partial flow system only) and 17 (full flow system only)

PTT Particulate transfer tube

The particulate transfer tube shall not exceed 1,020 mm in length, and shall be minimized in length whenever possible.

The dimensions are valid for:

- (a) the partial flow dilution fractional sampling system from the probe tip to the filter holder;
- (b) the partial flow dilution total sampling system from the end of the dilution tunnel to the filter holder;
- (c) the full flow double dilution system from the probe tip to the entrance of the secondary dilution tunnel.

The transfer tube:

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

SDT Secondary dilution tunnel (figure 17 only)

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

The secondary dilution tunnel

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

FH Filter holder

The filter holder:

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

An inertial pre-classifier with a 50 per cent cut point between 2.5 µm and 10 µm shall be installed immediately upstream of the filter holder, if an open tube sampling probe facing upstream is used.

P Sampling pump

FC2 Flow controller

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

FM3 Flow measurement device

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

FM4 Flow measurement device

Gas meter or flow instrumentation to determine the secondary dilution airflow through the particulate filter.

BV Ball valve (optional)

The ball valve shall have an inside diameter not less than the inside diameter of the particulate transfer tube PTT, and a switching time of less than 0.5 s.

Annex 10 - Appendix 4

DETERMINATION OF SYSTEM EQUIVALENCE

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

This statistical method examines the hypothesis that the sample standard deviation and sample mean value for an emission measured with the candidate system do not differ from the sample standard deviation and sample mean value for that emission measured with the reference system. The hypothesis shall be tested on the basis of a 10 per cent significance level of the F and t values. The critical F and t values for 7 to 10 sample pairs are given in table 8. If the F and t values calculated according to the equation below are greater than the critical F and t values, the candidate system is not equivalent.

The following procedure shall be followed. The subscripts R and C refer to the reference and candidate system, respectively:

- (a) Conduct at least 7 tests with the candidate and reference systems operated in parallel. The number of tests is referred to as n_R and n_C .
- (b) Calculate the mean values \bar{x}_R and \bar{x}_C and the standard deviations s_R and s_C .
- (c) Calculate the F value, as follows:

$$F = \frac{s_{\text{major}}^2}{s_{\text{minor}}^2} \quad (82)$$

(the greater of the two standard deviations s_R or s_C must be in the numerator).

- (d) Calculate the t value, as follows:

$$t = \frac{|\bar{x}_C - \bar{x}_R|}{\sqrt{(n_C - 1) \times s_C^2 + (n_R - 1) \times s_R^2}} \times \sqrt{\frac{n_C \times n_R \times (n_C + n_R - 2)}{n_C + n_R}} \quad (83)$$

- (e) Compare the calculated F and t values with the critical F and t values corresponding to the respective number of tests indicated in table 8. If larger sample sizes are selected, consult statistical tables for 10 per cent significance (90 per cent confidence) level.
- (f) Determine the degrees of freedom (df), as follows:
 - for the F -test: $df = n_R - 1 / n_C - 1$ (84)
 - for the t -test: $df = n_C + n_R - 2$ (85)
- (g) Determine the equivalency, as follows:
 - (i) if $F < F_{\text{crit}}$ and $t < t_{\text{crit}}$, then the candidate system is equivalent to the reference system of this annex;

- (ii) if $F \geq F_{\text{crit}}$ or $t \geq t_{\text{crit}}$, then the candidate system is different from the reference system of this annex.

Sample Size	<i>F</i> -test		<i>t</i> -test	
	<i>Df</i>	F_{crit}	<i>df</i>	t_{crit}
7	6/6	3.055	12	1.782
8	7/7	2.785	14	1.761
9	8/8	2.589	16	1.746
10	9/9	2.440	18	1.734

Table 8
t and *F* values for selected sample sizes

Annex 10 - Appendix 5

CARBON FLOW CHECK

A.5.1. Introduction

All but a tiny part of the carbon in the exhaust comes from the fuel, and all but a minimal part of this is manifest in the exhaust gas as CO₂. This is the basis for a system verification check based on CO₂ measurements.

The flow of carbon into the exhaust measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO₂ concentrations and gas flow rates at those points.

In this sense, the engine provides a known source of carbon flow, and observing the same carbon flow in the exhaust pipe and at the outlet of the partial flow PM sampling system verifies leak integrity and flow measurement accuracy. This check has the advantage that the components are operating under actual engine test conditions of temperature and flow.

Figure 18 shows the sampling points at which the carbon flows shall be checked. The specific equations for the carbon flows at each of the sample points are given below.

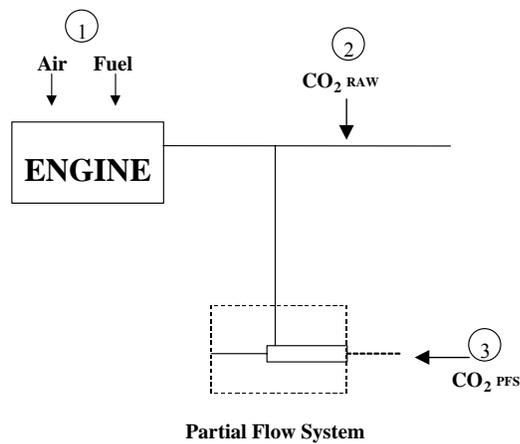


Figure 18
Measuring points for carbon flow check

A.5.2. Carbon flow rate into the engine (location 1)

The carbon mass flow rate into the engine for a fuel $\text{CH}_\alpha\text{O}_\varepsilon$ is given by:

$$q_{mCf} = \frac{12.011}{12.011 + \alpha + 15.9994 \times \varepsilon} \times q_{mf} \quad (86)$$

where:

q_{mf} is the fuel mass flow rate, kg/s

A.5.3. Carbon flow rate in the raw exhaust (location 2)

The carbon mass flow rate in the exhaust pipe of the engine shall be determined from the raw CO_2 concentration and the exhaust gas mass flow rate:

$$q_{mCe} = \left(\frac{c_{\text{CO}_2,r} - c_{\text{CO}_2,a}}{100} \right) \times q_{mew} \times \frac{12.011}{M_{re}} \quad (87)$$

where:

$c_{\text{CO}_2,r}$ is the wet CO_2 concentration in the raw exhaust gas, per cent

$c_{\text{CO}_2,a}$ is the wet CO_2 concentration in the ambient air, per cent

q_{mew} is the exhaust gas mass flow rate on wet basis, kg/s

M_e is the molar mass of exhaust gas, g/mol

If CO_2 is measured on a dry basis it shall be converted to a wet basis according to paragraph 8.1.

A.5.4. Carbon flow rate in the dilution system (location 3)

For the partial flow dilution system, the splitting ratio also needs to be taken into account. The carbon flow rate shall be determined from the dilute CO_2 concentration, the exhaust gas mass flow rate and the sample flow rate:

$$q_{mCp} = \left(\frac{c_{\text{CO}_2,d} - c_{\text{CO}_2,a}}{100} \right) \times q_{mdev} \times \frac{12.011}{M_e} \times \frac{q_{mew}}{q_{mp}} \quad (88)$$

where:

$c_{\text{CO}_2,d}$ is the wet CO_2 concentration in the dilute exhaust gas at the outlet of the dilution tunnel, per cent

$c_{\text{CO}_2,a}$ is the wet CO_2 concentration in the ambient air, per cent

q_{mew} is the exhaust gas mass flow rate on wet basis, kg/s

q_{mp} is the sample flow of exhaust gas into partial flow dilution system, kg/s

M_e is the molar mass of exhaust gas, g/mol

If CO₂ is measured on a dry basis, it shall be converted to wet basis according to paragraph 8.1.

A.5.5. Calculation of the molar mass of the exhaust gas

The molar mass of the exhaust gas shall be calculated according to equation 28 (see paragraph 8.3.2.5.)

Alternatively, the following exhaust gas molar masses may be used:

M_e (diesel) =	28.9 g/mol
M_e (LPG) =	28.6 g/mol
M_e (NG) =	28.3 g/mol

Annex 10 - Appendix 6

EXAMPLE OF CALCULATION PROCEDURE

A.6.1. Basic data for stoichiometric calculations

Atomic mass of hydrogen	1.00794 g/atom
Atomic mass of carbon	12.011 g/atom
Atomic mass of sulphur	32.065 g/atom
Atomic mass of nitrogen	14.0067 g/atom
Atomic mass of oxygen	15.9994 g/atom
Atomic mass of argon	39.9 g/atom
Molar mass of water	18.01534 g/mol
Molar mass of carbon dioxide	44.01 g/mol
Molar mass of carbon monoxide	28.011 g/mol
Molar mass of oxygen	31.9988 g/mol
Molar mass of nitrogen	28.011 g/mol
Molar mass of nitric oxide	30.008 g/mol
Molar mass of nitrogen dioxide	46.01 g/mol
Molar mass of sulphur dioxide	64.066 g/mol
Molar mass of dry air	28.965 g/mol

Assuming no compressibility effects, all gases involved in the engine intake/combustion/exhaust process can be considered to be ideal and any volumetric calculations shall therefore be based on a molar volume of 22.414 l/mol according to Avogadro's hypothesis.

A.6.2. Gaseous emissions (diesel fuel)

The measurement data of an individual point of the test cycle (data sampling rate of 1 Hz) for the calculation of the instantaneous mass emission are shown below. In this example, CO and NO_x are measured on a dry basis, HC on a wet basis. The HC concentration is given in propane equivalent (C3) and has to be multiplied by 3 to result in the C1 equivalent. The calculation procedure is identical for the other points of the cycle.

The calculation example shows the rounded intermediate results of the different steps for better illustration. It should be noted that for actual calculation, rounding of intermediate results is not permitted (see paragraph 8).

$T_{a,i}$ (K)	$H_{a,i}$ (g/kg)	W_{act} kWh	$q_{mew,i}$ (kg/s)	$q_{maw,i}$ (kg/s)	$q_{mf,i}$ (kg/s)	$c_{HC,i}$ (ppm)	$c_{CO,i}$ (ppm)	$c_{NOx,i}$ (ppm)
295	8.0	40	0.155	0.150	0.005	10	40	500

The following fuel composition is considered:

Component	Molar ratio	per cent mass
H	$\alpha = 1.8529$	$w_{ALF} = 13.45$
C	$\beta = 1.0000$	$w_{BET} = 86.50$
S	$\gamma = 0.0002$	$w_{GAM} = 0.050$
N	$\delta = 0.0000$	$w_{DEL} = 0.000$
O	$\varepsilon = 0.0000$	$w_{EPS} = 0.000$

Step 1: Dry/wet correction (paragraph 8.1.):

$$\text{Equation (11): } k_f = 0.055584 \times 13.45 - 0.0001083 \times 86.5 - 0.0001562 \times 0.05 = 0.7382$$

$$\text{Equation (8): } k_{w,a} = \left(1 - \frac{1.2434 \times 8 + 111.12 \times 13.45 \times \frac{0.005}{0.148}}{773.4 + 1.2434 \times 8 + \frac{0.005}{0.148} \times 0.7382 \times 1,000} \right) \times 1.008 = 0.9331$$

$$\begin{aligned} \text{Equation (7): } \quad c_{CO,i}(\text{wet}) &= 40 \times 0.9331 &&= 37.3 \text{ ppm} \\ c_{NOx,i}(\text{wet}) &= 500 \times 0.9331 &&= 466.6 \text{ ppm} \end{aligned}$$

Step 2: NO_x correction for temperature and humidity (paragraph 8.2.1.):

$$\text{Equation (18): } k_{h,D} = \frac{15.698 \times 8.00}{1,000} + 0.832 = 0.9576$$

Step 3: Calculation of the instantaneous emission of each individual point of the cycle (paragraph 8.3.2.4.):

$$\begin{aligned} \text{Equation (25): } \quad m_{HC,i} &= 10 \times 3 \times 0.155 &&= 4.650 \\ m_{CO,i} &= 37.3 \times 0.155 &&= 5.782 \\ m_{NOx,i} &= 466.6 \times 0.9576 \times 0.155 &&= 69.26 \end{aligned}$$

Step 4: Calculation of the mass emission over the cycle by integration of the instantaneous emission values and the *u* values from table 4 (paragraph 8.3.2.4.):

The following calculation is assumed for the WHTC cycle (1,800 s) and the same emission in each point of the cycle.

$$\begin{aligned} \text{Equation (25): } m_{\text{HC}} &= 0.000479 \times \sum_{i=1}^{1800} 4.650 &= 4.01 \text{ g/test} \\ m_{\text{CO}} &= 0.000966 \times \sum_{i=1}^{1800} 5.782 &= 10.05 \text{ g/test} \\ m_{\text{NOx}} &= 0.001586 \times \sum_{i=1}^{1800} 69.26 &= 197.72 \text{ g/test} \end{aligned}$$

Step 5: Calculation of the specific emissions (paragraph 8.5.2.1.):

$$\begin{aligned} \text{Equation (56): } e_{\text{HC}} &= 4.01 / 40 &= 0.10 \text{ g/kWh} \\ e_{\text{CO}} &= 10.05 / 40 &= 0.25 \text{ g/kWh} \\ e_{\text{NOx}} &= 197.72 / 40 &= 4.94 \text{ g/kWh} \end{aligned}$$

A.6.2. Particulate Emission (Diesel Fuel)

p_b kPa	W_{act} kWh	$q_{\text{mew},i}$ (kg/s)	$q_{\text{mf},i}$ (kg/s)	$q_{\text{mdw},i}$ (kg/s)	$q_{\text{mdew},i}$ (kg/s)	m_{uncor} (mg)	m_{sep} (kg)
99	40	0.155	0.005	0.0015	0.0020	1.7000	1.515

Step 1: Calculation of m_{edf} (paragraph 8.3.3.5.2.):

$$\begin{aligned} \text{Equation (37): } r_{d,i} &= \frac{0.002}{(0.002 - 0.0015)} &= 4 \\ \text{Equation (36): } q_{\text{medf},i} &= 0.155 \times 4 &= 0.620 \text{ kg/s} \\ \text{Equation (35): } m_{\text{edf}} &= \sum_{i=1}^{1800} 0.620 &= 1,116 \text{ kg/test} \end{aligned}$$

Step 2: Buoyancy correction of the particulate mass (paragraph 9.4.3.5.)

$$\begin{aligned} \text{Equation (72): } \rho_a &= \frac{99 \times 28.836}{8.3144 \times 295} &= 1.164 \text{ kg/m}^3 \\ \text{Equation (71): } m_f &= 1.7000 \times \frac{(1 - 1.164/8,000)}{(1 - 1.164/2,300)} &= 1.7006 \text{ mg} \end{aligned}$$

Step 3: Calculation of the particulate mass emission (paragraph 8.3.3.5.2.):

$$\text{Equation (34): } m_{\text{PM}} = \frac{1.7006}{1.515} \times \frac{1,116}{1,000} = 1.253 \text{ g/test}$$

Step 4: Calculation of the specific emission (paragraph 8.5.2.1.):

$$\text{Equation (56): } e_{\text{PM}} = 1.253 / 40 = 0.031 \text{ g/kWh}$$

Annex 11

TECHNICAL REQUIREMENTS FOR ON-BOARD DIAGNOSTIC SYSTEMS (OBD)
FOR DIESEL ENGINES OF ROAD VEHICLES (WWH-OBD, gtr No. 5)

1. APPLICABILITY

This annex is not applicable, for the time being, for the purpose of type approval according to this Regulation. It will be made applicable in the future.

2. Reserved 1/.

3. DEFINITIONS

3.1. "Alert system" means a system on-board the vehicle which informs the driver of the vehicle or any other interested party that the OBD system has detected a malfunction.

3.2. "Approval authority" means the authority that grants the compliance approval of an OBD system considered by this annex. Per extension, it means also the technical service that has been accredited to evaluate the technical compliance of the OBD system.

3.3. "Calibration verification number" means the number that is calculated and reported by the engine system to validate the calibration/software integrity.

3.4. "Component monitoring" means the monitoring of input components for electrical circuit failures and rationality failures and monitoring of output components for electrical circuit failures and functionality failures. It refers to components that are electrically connected to the controller(s) of the engine system.

3.5. "Confirmed and active DTC" means a DTC that is stored during the time the OBD system concludes that a malfunction exists.

3.6. "Continuous-MI" means the malfunction indicator showing a steady indication at all times while the key is in the on (run) position with the engine running (ignition on - engine on).

3.7. "Deficiency" means an OBD monitoring strategy or other OBD feature that does not meet all the detailed requirements of this annex.

3.8. "Diagnostic trouble code (DTC)" means a numeric or alphanumeric identifier which identifies or labels a malfunction.

1/ The numbering of this annex is consistent with the numbering of the draft gtr on WWH-OBD. However, some paragraphs of the WWH-OBD gtr are not needed in this annex.

- 3.9. "Electrical circuit failure" means a malfunction (e.g. open circuit or short circuit) that leads to the measured signal (i.e. voltages, currents, frequencies, etc.) being outside the range where the transfer function of the sensor is designed to operate.
- 3.10. "Emission OBD family" means a manufacturer's grouping of engine systems having common methods of monitoring/diagnosing emission-related malfunctions.
- 3.11. "Emission threshold monitoring" means monitoring of a malfunction that leads to an excess of the OTLs. It consists of:
- (a) direct emissions measurement via a tailpipe emissions sensor(s) and a model to correlate the direct emissions to test-cycle specific emissions; and/or
 - (b) indication of an emissions increase via correlation of computer input/output information to test-cycle specific emissions.
- 3.12. "Engine system" means the engine as it would be configured when tested for its exhaust emissions on a approval test-bed, including:
- (a) the engine's electronic management controller(s);
 - (b) the exhaust after-treatment system(s);
 - (c) any emission-related component of the engine or the exhaust system which supplies input to, or receives output from, the engine's electronic management controller(s); and
 - (d) the communication interface (hardware and messages) between the engine's electronic management controller(s) and any other power train or vehicle control unit if the exchanged information has an influence on the control of emissions.
- 3.13. "Functionality failure" means a malfunction where an output component does not respond to a computer command in the expected way.
- 3.14. "Malfunction emission control strategy (MECS)" means a strategy within the engine system that is activated as a result of an emission-related malfunction.
- 3.15. "Malfunction indicator (MI)" is an indicator which clearly informs the driver of the vehicle in the event of a malfunction. The MI is part of the alert system (see "continuous-MI", "on-demand-MI", and "short-MI").
- 3.16. "Malfunction" means a failure or deterioration of an engine system, including the OBD system, that may lead either to an increase in any of the regulated pollutants emitted by the engine system or to a reduction in the effectiveness of the OBD system.
- 3.17. "MI status" means the command status of the MI, being either continuous-MI, Short-MI, on-demand-MI, or off.
- 3.18. "Monitoring" (see "emission threshold monitoring", "performance monitoring", and "total functional failure monitoring")

- 3.19. "OBD test-cycle" means the cycle over which an engine system is operated on an engine test-bed to evaluate the response of an OBD system to the presence of a qualified deteriorated component.
- 3.20. "OBD-parent engine system" means an engine system that has been selected from an emission-OBD family for which most of its OBD elements of design are representative of that family.
- 3.21. "On-board diagnostic system (OBD)" means a system on-board a vehicle or engine which has the capability:
- (a) of detecting malfunctions, affecting the emission performance of the engine system;
 - (b) of indicating their occurrence by means of an alert system;
 - (c) of identifying the likely area of the malfunctions by means of information stored in computer memory and/or communicating that information off-board.
- 3.22. "On-demand-MI" means the malfunction indicator showing a steady indication in response to a manual demand from the driving position when the key is in the on (run) position with the engine off (ignition on - engine off).
- 3.23. "Operating sequence" means a sequence consisting of an engine start-up, an operating period, an engine shut-off, and the time until the next start-up, where a specific OBD monitor runs to completion and a malfunction would be detected if present.
- 3.24. "Pending DTC" means a DTC that is stored by the OBD system because a monitor has detected a situation where a malfunction may be present during the current or last completed operating sequence.
- 3.25. "Performance monitoring" means malfunction monitoring that consists of functionality checks and monitoring parameters that are not correlated to emission thresholds. Such monitoring is typically done on components or systems to verify that they are operating within the proper range (e.g. differential pressure in case of a DPF).
- 3.26. "Potential DTC" means a DTC that is stored by the OBD system because a monitor has detected a situation where a malfunction may be present but requires further evaluation to be confirmed. A potential DTC is a pending DTC which is not a confirmed and active DTC.
- 3.27. "Previously active DTC" means a formerly confirmed and active DTC that remains stored after the OBD system has concluded that the malfunction that caused the DTC is no longer present.
- 3.28. "Qualified deteriorated component or system (QDC)" means a component or system that has been intentionally deteriorated (e.g. accelerated aging) and/or manipulated in a controlled manner and which has been accepted by the authorities according to the provisions set in this annex.
- 3.29. "Rationality failure" means a malfunction where the signal from an individual sensor or component is at variance with that expected when assessed against signals available from other sensors or components within the control system. Rationality failures include malfunctions that lead to the measured signal (i.e. voltages, currents, frequencies, etc.) being inside the range where the

transfer function of the sensor is designed to operate.

3.30. "Readiness" means a status indicating whether a monitor or a group of monitors have run since the last erasing by request of an external OBD scan-tool.

3.31. "Scan-tool" means an external test equipment used for standardised off-board communication with the OBD system in accordance with the requirements of this annex.

3.32. "Short-MI" means the malfunction indicator showing a steady indication from the time the key is moved to on (run) position and the engine is started (ignition on - engine on) and extinguishing after 15 seconds or the key is moved to off, whichever occurs first.

3.33. "Software calibration identification" means a series of alphanumeric characters that identifies the emission-related calibration / software version(s) installed in the engine system.

3.34. "Total functional failure monitoring" means monitoring a malfunction which is leading to a complete loss of the desired function of a system.

3.35. "Warm-up cycle" means sufficient engine operation such that the coolant temperature has risen by at least 295 K (22 °C / 40 °F) from engine starting and reaches a minimum temperature of 333 K (60 °C / 140 °F) ^{2/}.

3.36. Abbreviations

CV	Crankcase Ventilation
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter or Particulate Trap including catalyzed DPFs and Continuously Regenerating Traps (CRT)
DTC	Diagnostic trouble code
EGR	Exhaust Gas Recirculation
HC	Hydrocarbon
LNT	Lean NO _x Trap (or NO _x absorber)
MECS	Malfunction Emission Control Strategy
NO _x	Oxides of Nitrogen
OTL	OBD Threshold Limit
PM	Particulate Matter
SCR	Selective Catalytic Reduction
SW	Screen Wipers
TFF	Total Functional Failure monitoring
VGT	Variable Geometry Turbocharger
VVT	Variable Valve Timing

4. GENERAL REQUIREMENTS

^{2/} This definition does not imply that a temperature sensor is necessary to measure the coolant temperature.

In the context of this annex, the OBD system shall have the capability of detecting In malfunctions, of indicating their occurrence by means of a malfunction indicator, of identifying the likely area of the malfunctions by means of information stored in computer memory, and communicating that information off-board.

The OBD system shall be designed and constructed so as to enable it to identify types of malfunctions over the complete life of the vehicle/engine. In achieving this objective, the administrative department will recognize that engines which have been used in excess of their regulatory useful life may show some deterioration in OBD system performance and sensitivity such that the OBD thresholds may be exceeded before the OBD system signals a malfunction to the driver of the vehicle.

The above paragraph does not extend the engine manufacturer's compliance liability for an engine beyond its regulated useful life (i.e. the time or distance period during which emission standards or emission limits continue to apply).

4.1. Application for approval of an OBD system

4.1.1. Primary approval

The manufacturer of an engine system may apply for the approval of its OBD system in one of the three following manners:

- (a) The manufacturer of an engine system applies for the approval of an individual OBD system by demonstrating that OBD system complies with all the provisions of this annex.
- (b) The manufacturer of an engine system applies for the approval of an emission-OBD family by demonstrating that the OBD-parent engine system of the family complies with all the provisions of this annex.

The manufacturer of an engine system applies for the approval of an OBD system by demonstrating that OBD system meets the criteria for belonging to an emission-OBD family that has already been certified.

4.1.2. Extension / Modification of an existing certificate

4.1.2.1. Extension to include a new engine system into an emission-OBD family

At the request of the manufacturer and upon approval of the administrative department, a new engine system may be included as a member of a certified emission-OBD family if all the engine systems within the so-extended emission-OBD family still have common methods of monitoring / diagnosing emission-related malfunctions.

If all OBD elements of design of the OBD-parent engine system are representative of those of the new engine system, then the OBD-parent engine system shall remain unchanged and the manufacturer shall modify the documentation package according to paragraph 8 of this annex.

If the new engine system contains elements of design that are not represented by the OBD-parent engine system but itself would represent the whole family, then the new engine system shall become the new OBD-parent engine system. In this case the new OBD elements of design shall be demonstrated to comply with the provisions of this annex, and the documentation package shall be modified according to paragraph 8. of this annex.

4.1.2.2. Extension to address a design change that affects the OBD system

At the request of the manufacturer and upon approval of the administrative department, an extension of an existing certificate may be granted in the case of a design change of the OBD system if the manufacturer demonstrates that the design changes comply with the provisions of this annex.

The documentation package shall be modified according to paragraph 8. of this annex.

If the existing certificate applies to an emission-OBD family, the manufacturer shall justify to the administrative department that the methods of monitoring/diagnosing emission-related malfunctions are still common within the family and that the OBD-parent engine system remains representative of the family.

4.1.2.3. Certificate modification to address a malfunction reclassification

This paragraph applies when, following a request by the authority that granted the approval, or at its own initiative, the manufacturer applies for a modification of an existing certificate in order to reclassify one or several malfunctions.

The compliance of the new classification shall then be demonstrated according to the provisions of this annex and the documentation package shall be modified according to paragraph 8 of this annex.

4.2. Monitoring requirements

All emission-related components and systems included in an engine system shall be monitored by the OBD system in accordance with the requirements set in appendix 3. However, the OBD system is not required to use a unique monitor to detect each malfunction referred to in appendix 3.

The OBD system shall also monitor its own components.

The items of appendix 3 list the systems or components required to be monitored by the OBD system and describes the types of monitoring expected for each of these

components or systems (i.e. emission threshold monitoring, performance monitoring, total functional failure monitoring, or component monitoring).

The manufacturer can decide to monitor additional systems and components.

4.2.1. Selection of the monitoring technique

Approval authorities may approve a manufacturer's use of another type of monitoring technique than the one mentioned in appendix 3. The chosen type of monitoring shall be shown by the manufacturer, to be robust, timely and efficient (i.e. through either technical considerations, test results, previous agreements, etc.).

In case a system and / or component is not covered by appendix 3 the manufacturer shall submit for approval to the administrative department an approach to monitoring. The administrative department will approve the chosen type of monitoring and monitoring technique (i.e. emission threshold monitoring, performance monitoring, total functional failure monitoring, or component monitoring) if it has been shown by the manufacturer, by reference to those detailed in appendix 3, to be robust, timely and efficient (i.e. through either technical considerations, test results, previous agreements, etc.).

4.2.1.1. Correlation to actual emissions

In the case of emission threshold monitoring, a correlation to test-cycle specific emissions shall be required. This correlation would typically be demonstrated on a test engine in a laboratory setting.

In all other monitoring cases (i.e. performance monitoring, total functional failure monitoring, or component monitoring), no correlation to actual emissions is necessary. However, the administrative department may request test data to verify the classification of the malfunction effects as described in paragraph 6.2. of this annex.

Examples:

An electrical malfunction may not require a correlation because this is a yes/no malfunction. A DPF malfunction monitored via delta pressure may not require a correlation because it anticipates a malfunction.

If the manufacturer demonstrates, according to the demonstration requirements of this annex, that emissions would not exceed the OBD threshold limits upon total failure or removal of a component or system, a performance monitoring of this component or system shall be accepted.

When a tailpipe emission sensor is used for monitoring the emissions of a specific pollutant all other monitors may be exempted from further correlation to the actual emissions of that pollutant. Nevertheless, such exemption shall not preclude the need to include these monitors, using other monitoring techniques, as part of the OBD system as the monitors are still needed for the purpose of malfunction isolation.

A malfunction shall always be classified according to paragraph 4.5. based on its impact on emissions, regardless of the type of monitoring used to detect the malfunction.

4.2.2. Component monitoring (input/output components/systems)

In the case of input components that belong to the engine system, the OBD system shall at a minimum detect electrical circuit failures and, where feasible, rationality failures.

The rationality failure diagnostics shall then verify that a sensor output is neither inappropriately high nor inappropriately low (i.e. there shall be "two-sided" diagnostics).

To the extent feasible, and with the agreement of the administrative department, the OBD system shall detect separately, rationality failures (e.g. inappropriately high and inappropriately low), and electrical circuit failures (e.g. out-of-range high and out-of-range low). Additionally, unique DTCs for each distinct malfunction (e.g. out-of-range low, out-of-range high and rationality failure) shall be stored.

In the case of output components that belong to the engine system, the OBD system shall at a minimum detect electrical circuit failures, and, where feasible, if the proper functional response to computer commands does not occur.

To the extent feasible, and with the agreement of the administrative department, the OBD system shall detect separately functionality failures, electrical circuit failures (e.g. out-of-range high and out-of-range low) and store unique DTCs for each distinct malfunction (e.g. out-of-range low, out-of-range high, functionality failure).

The OBD system shall also perform rationality monitoring on the information coming from or provided to components that do not belong to the engine system when this information compromises the emission control system and/or the engine system for proper performance.

4.2.2.1. Exception to component monitoring

Monitoring of electrical circuit failures, and to the extent feasible, functionality, and rationality failures of the engine system shall not be required if all the following conditions are met:

- (a) the failure results in an emission increase of any pollutant of less than 50 per cent of the regulated emission limit, and

- (b) the failure does not cause any emission to exceed the regulated emission limit 3/, and
- (c) the failure does not affect a component or system enabling the proper performance of the OBD system.

Determination of the emissions impact shall be performed on a stabilized engine system in an engine dynamometer test cell, according to the demonstration procedures of this annex.

4.2.3. Monitoring frequency

Monitors shall run continuously, at any time where the monitoring conditions are fulfilled, or once per operating sequence (e.g. for monitors that lead to an increase of emission when it runs).

When a monitor does not run continuously, the manufacturer shall clearly inform the administrative department and describe the conditions under which the monitor runs.

The monitors shall run during the applicable OBD test-cycle as specified in paragraph 7.2.2.

A monitor shall be regarded as running continuously, if it runs at a rate not less than once per second. If a computer input or output component is sampled less frequently than one sample per second for engine control purpose, a monitor shall also be regarded as running continuously, if the signal of the component is evaluated each time sampling occurs.

For components or systems monitored continuously, it is not required to activate an output component/system for the sole purpose of monitoring that output component/system.

4.3. Requirements for recording OBD information

When a malfunction has been detected but is not yet confirmed, the possible malfunction shall be considered as a "Potential DTC" and accordingly a "Pending DTC" status shall be recorded. A "Potential DTC" shall not lead to an activation of the alert system according to paragraph 4.6.

Within the first operating sequence, a malfunction may be directly considered "confirmed and active" without having been considered a "potential DTC". It shall be given the "Pending DTC" and a "confirmed and active DTC" status.

In case a malfunction with the previously active status occurs again, that malfunction

3/ The measured value shall be considered taking into account the relevant precision tolerance of the test-cell system and the increased variability in the test results due to the malfunction.

may at the choice of manufacturer be directly given the "Pending DTC " and "confirmed and active DTC" status. Without having been given the "potential DTC" status. If that malfunction is given the potential status, it shall also keep the previously active status during the time it is not yet confirmed or active.

The monitoring system shall conclude whether a malfunction is present before the end of the next operating sequence following its first detection. At this time, a "confirmed and active" DTC shall be stored and the alert system be activated according to paragraph 4.6.

In case of a recoverable MECS (i.e. the operation automatically returns to normal and the MECS is de-activated at the next engine ON), a "confirmed and active" DTC need not be stored unless the MECS is again activated before the end of the next operating sequence. In case of a non-recoverable MECS, a "confirmed and active" DTC shall be stored as soon as the MECS is activated.

In some specific cases where monitors need more than two operating sequences to accurately detect and confirm a malfunction (e.g. monitors using statistical models or with respect to fluid consumption on the vehicle), the administrative department may permit the use of more than two operating sequences for monitoring provided the manufacturer justifies the need for the longer period (e.g. by technical rationale, experimental results, in house experience, etc.).

When a confirmed and active malfunction is no longer detected by the system during a complete operating sequence, it shall be given the previously active status by the start of the next operating sequence and keep that status until this malfunction is erased by a scan tool or erased from the computer memory according to paragraph 4.4.

Note: The requirements prescribed in this paragraph are illustrated in appendix 2 .

4.4. Requirements for erasing OBD information

DTC and the applicable information (inclusive the associated freeze frame) shall not be erased by the OBD system itself from the computer memory until that DTC has been in the previously active status for at least 40 warm-up cycles or 200 engine operating hours, whichever occurs first. The OBD system shall erase all the DTCs and the applicable information (inclusive the associated freeze frame) upon request of a scan tool or a maintenance tool.

4.5. Requirements for malfunction classification

Malfunction classification specifies the class to which a malfunction is assigned when such a malfunction is detected, according to the requirements of paragraph 4.2. of this annex.

A malfunction shall be assigned to one class for the actual life of the vehicle unless the authority that granted the certificate or the manufacturer determines that reclassification

of that malfunction is necessary.

If a malfunction would result in a different classification for different regulated pollutant emissions or for its impact on other monitoring capability, the malfunction shall be assigned to the class that takes precedence in the discriminatory display strategy.

If an MECS is activated as a result of the detection of a malfunction, this malfunction shall be classified based on either the emission impact of the activated MECS or its impact on other monitoring capability. The malfunction shall then assigned to the class that takes precedence in the discriminatory display strategy.

4.5.1. Class A malfunction

A malfunction shall be identified as Class A when the relevant OBD threshold limits (OTLs) are assumed to be exceeded.

It is accepted that the emissions may not be above the OTLs when this class of malfunction occurs.

4.5.2. Class B1 malfunction

A malfunction shall be identified as Class B1 where circumstances exist that have the potential to lead to emissions being above the OTLs but for which the exact influence on emission cannot be estimated and thus the actual emissions according to circumstances may be above or below the OTLs.

Examples of Class B1 malfunctions may include malfunctions detected by monitors that infer emission levels based on readings of sensors or restricted monitoring capability.

Class B1 malfunctions shall include malfunctions that restrict the ability of the OBD system to carry out monitoring of Class A or B1 malfunctions.

4.5.3. Class B2 malfunction

A malfunction shall be identified as Class B2 when circumstances exist that are assumed to influence emissions but not to a level that exceeds the OTL.

Malfunctions that restrict the ability of the OBD system to carry out monitoring of Class B2 malfunctions of shall be classified into Class B1 or B2.

4.5.4. Class C malfunction

A malfunction shall be identified as Class C when circumstances exist that, if monitored, are assumed to influence emissions but to a level that would not exceed the regulated emission limits.

Malfunctions that restrict the ability of the OBD system to carry out monitoring of

Class C malfunctions shall be classified into Class B1 or B2.

4.6. Alert system

The failure of a component of the alert system shall not cause the OBD system to stop functioning.

4.6.1. MI specification

The malfunction indicator shall be perceptible by the driver from the driver's seat position under all lighting conditions. The malfunction indicator shall comprise a yellow (as defined in Annex 5 to UNECE Regulation No. 7) or amber (as defined in Annex 5 to UNECE Regulation No. 6) warning signal identified by the F01 symbol in accordance with ISO Standard 2575:2004.

4.6.2. MI illumination schemes

Depending on the malfunction(s) detected by the OBD system, the MI shall be illuminated according to one of the activation modes described in the following table

	Activation mode 1	Activation mode 2	Activation mode 3	Activation mode 4
Conditions of activation	No malfunction	Class C malfunction	Class B malfunction and B1 counters < 200 h	Class A malfunction or B1 counter > 200 h
Key on engine on	No display	Discriminatory display strategy	Discriminatory display strategy	Discriminatory display strategy
Key on engine off	Harmonized display strategy	Harmonized display strategy	Harmonized display strategy	Harmonized display strategy

The display strategy requires the MI to be activated according to the class in which a malfunction has been classified. This strategy shall be locked by software coding that shall not be routinely available via the scan tool.

The MI activation strategy at key on, engine off is described in paragraph 4.6.4.

Figures B1 and B2 illustrate the prescribed activation strategies at key on, engine on or off.

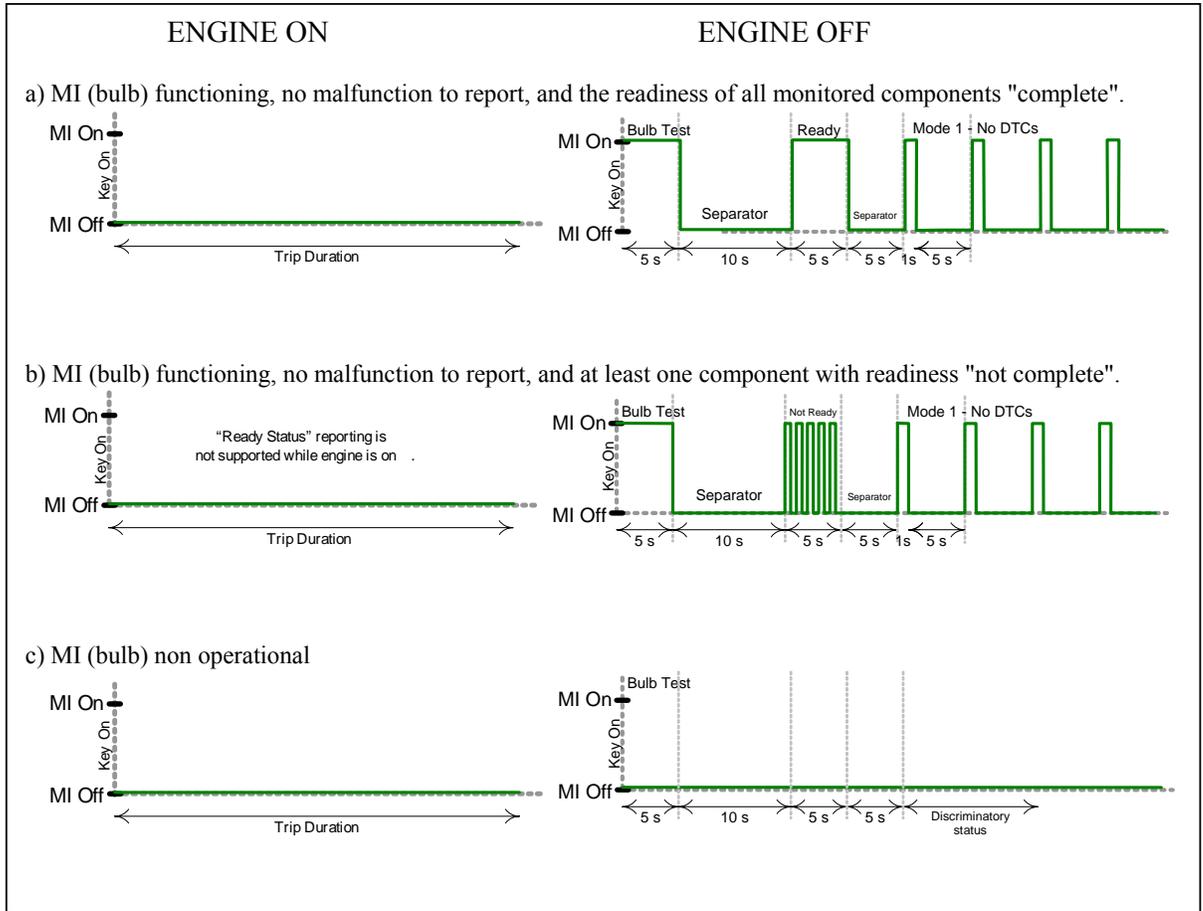


Figure B1
 Bulb test and readiness indication

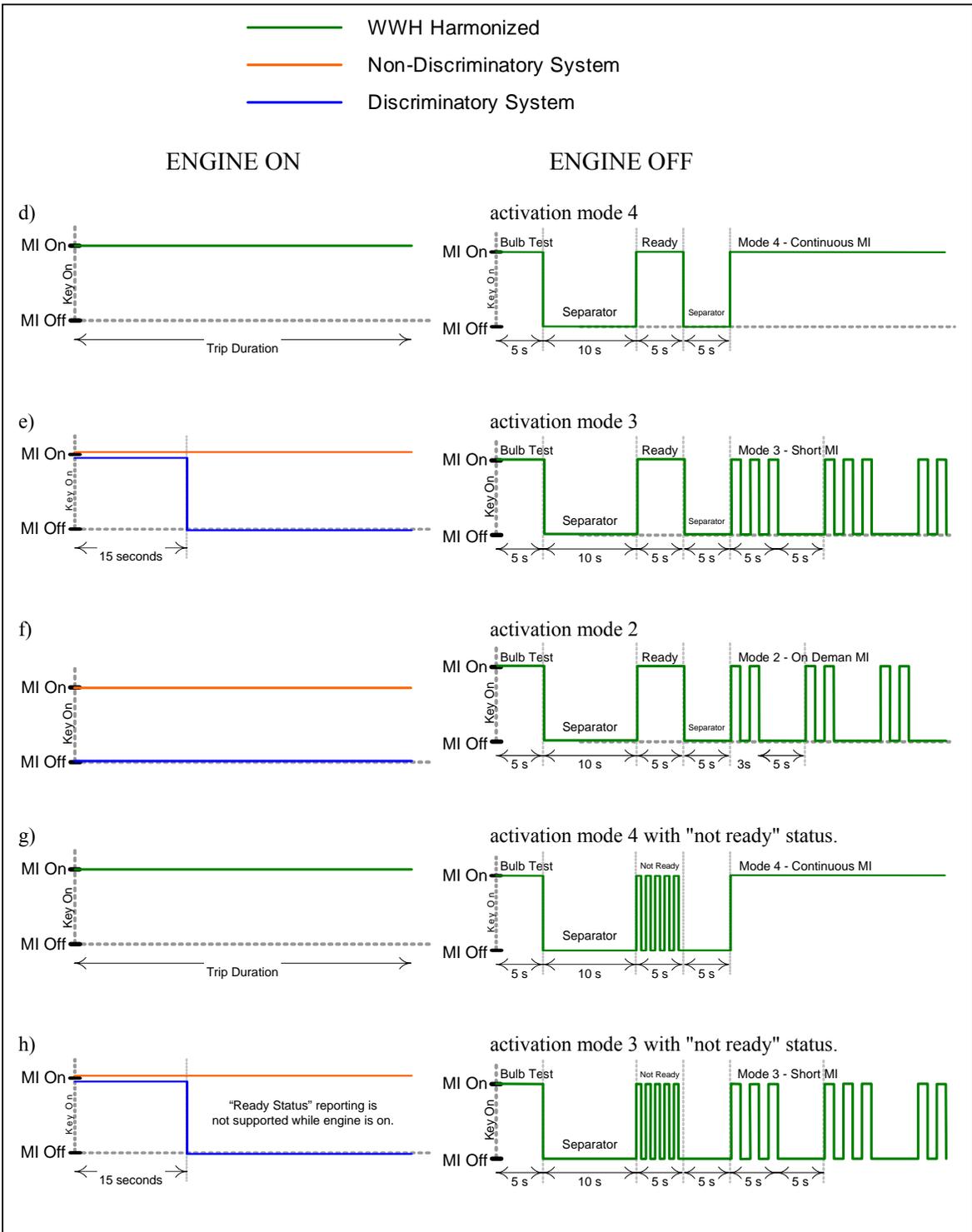


Figure B2:
 Malfunction display strategy: only the discriminatory strategy is applicable

4.6.3. MI activation at "engine on"

When the key is placed in the on position and the engine is started (engine on), the MI shall be commanded off unless the provisions of paragraph 4.6.3.1. and/or paragraph 4.6.3.2. have been met.

4.6.3.1. MI display strategy

For the purpose of activating the MI, continuous-MI shall take precedence to short-MI and on-demand-MI. For the purpose of activating the MI, short-MI shall take precedence to on-demand-MI.

4.6.3.1.1. Class A malfunctions

The OBD system shall command a continuous-MI upon storage of a confirmed DTC associated with a Class A malfunction.

4.6.3.1.2. Class B malfunctions

The OBD system shall command a "short-MI" at the next key-on event following storage of a confirmed and active DTC associated with a Class B malfunction.

Whenever a B1 counter reaches 200 hours, the OBD system shall command a continuous-MI.

4.6.3.1.3. Class C malfunctions

The manufacturer may make available information on Class C malfunctions through the use of an on-demand-MI that shall be available until the engine is started.

4.6.3.1.4. MI de-activation scheme

The "continuous-MI" shall switch to a "short-MI" if a single monitoring event occurs and the malfunction that originally activated the continuous-MI is not detected during the current operating sequence and a continuous-MI is not activated due to another malfunction.

The "short-MI" shall be deactivated if the malfunction is not detected during 3 subsequent sequential operating sequences and the MI is not activated due to another Class A or B malfunction.

4.6.4. MI activation at key-on/engine-off

The MI activation at key-on/engine-off shall consist of two sequences separated by a 5 seconds MI off:

- (a) the first sequence is designed to provide an indication of the MI functionality and the readiness of the monitored components;
- (b) the second sequence is designed to provide an indication of the presence of a malfunction.

The second sequence is repeated until engine is started (engine-on) or the key set on key-off position.

4.6.4.1. MI functionality/readiness

The MI shall show a steady indication for 5 seconds to indicate that the MI is functional.

The MI shall remain at the off position for 10 seconds.

The MI shall then remain at the on position for 5 seconds to indicate that the readiness for all monitored components is complete.

The MI shall blink once per second for 5 seconds to indicate that the readiness for one or more of the monitored components is not complete.

The MI shall then remain off for 5 seconds.

4.6.4.2. Presence / absence of a malfunction

Following the sequence described in paragraph 4.6.4.1, the MI shall indicate the presence of a malfunction by a series of flashes or a continuous illumination, depending on the applicable activation mode, as described in the following paragraphs, or absence of a malfunction by a series of single flashes. When applicable, each flash consists of a 1s MI-on followed by a 1s MI-off, and the series of flashes will be followed by a period of 5 seconds with the MI off.

Four activation modes are considered, where activation mode 4 shall take precedence over activation modes 1, 2 and 3, activation mode 3 shall take precedence over activation modes 1 and 2, and activation mode 2 shall take precedence over activation mode 1.

4.6.4.2.1. Activation mode 1 - absence of malfunction

The MI shall blink for one flash.

4.6.4.2.2. Activation mode 2 - "On-demand-MI"

The MI shall show blink for two flashes if the OBD system would command an on-demand-MI according to the discriminatory display strategy described in paragraph 4.6.3.1.

4.6.4.2.3. Activation mode 3 - "short-MI"

The MI shall blink for three flashes if the OBD system would command a short-MI according to the discriminatory display strategy described in paragraph 4.6.3.1.

4.6.4.2.4. Activation mode 4 - "continuous-MI"

The MI shall remain continuously ON ("continuous-MI") if the OBD system would command a continuous-MI according to the discriminatory display strategy described in paragraph 4.6.3.1.

4.6.5. Counters associated with malfunctions

4.6.5.1. MI counters

4.6.5.1.1. Continuous-MI Counter

The OBD system shall contain a continuous-MI counter to record the number of hours during which the engine has been operated while a continuous-MI is activated.

The continuous-MI counter shall count up to the maximum value provided in a 2 byte counter with 1 hour resolution and hold that value unless the conditions allowing the counter to be reset to zero are met.

The continuous-MI counter shall operate as follows:

- (a) if starting from zero, the continuous-MI counter shall begin counting as soon as a continuous-MI is activated;
- (b) the continuous-MI counter shall halt and hold its present value when the continuous-MI is no longer activated;
- (c) the continuous-MI counter shall continue counting from the point at which it had been held if a malfunction that results in a continuous-MI is detected within 3 operating sequences;
- (d) the continuous-MI counter shall start again counting from zero when a malfunction that results in a continuous-MI is detected after 3 operating sequences since the counter was last held;
- (e) the continuous-MI counter shall be reset to zero when:
 - (i) no malfunction that results in a continuous-MI is detected during 40 warm-up cycles or 200 engine operating hours since the counter was last held whichever occurs first; or
 - (ii) the OBD scan tool commands the OBD System to clear OBD information.

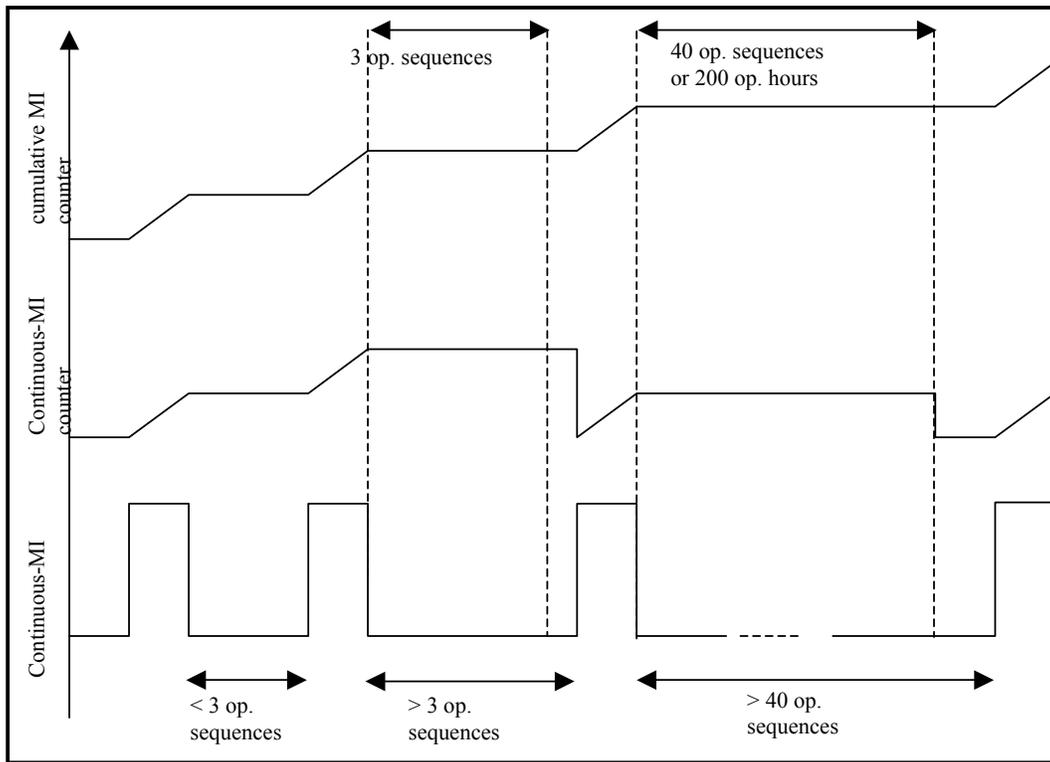


Figure C1:
Illustration of the MI counters activation principles

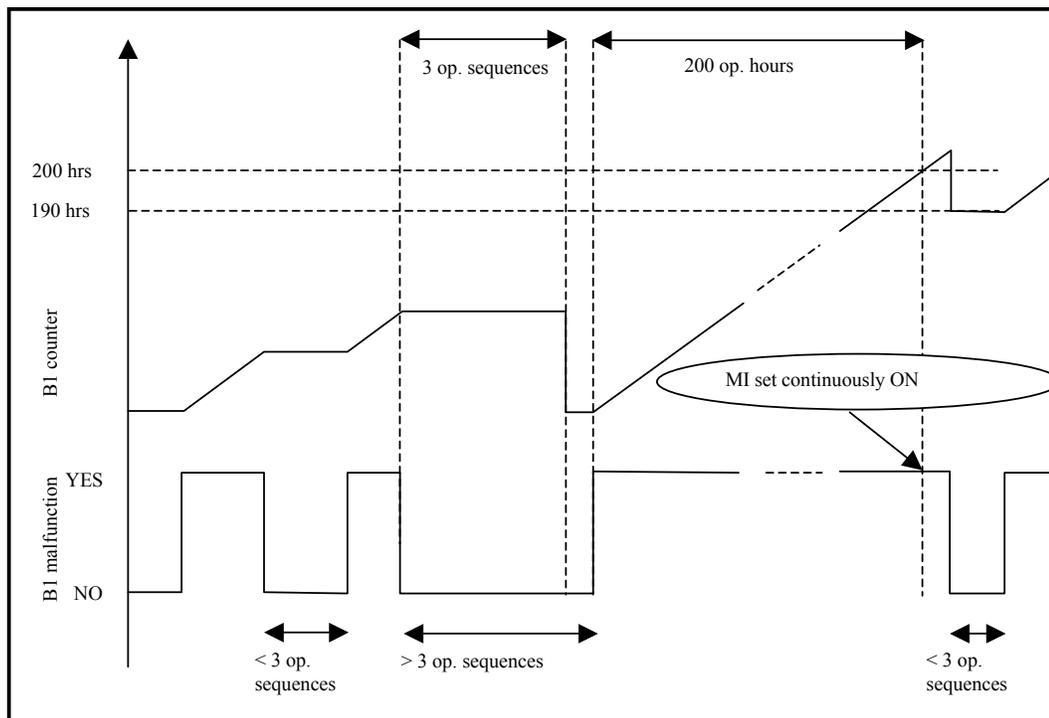


Figure C2:

Illustration of the B1 counter activation principles

4.6.5.1.2. Cumulative continuous-MI counter

The OBD system shall contain a cumulative continuous-MI counter to record the cumulative number of hours during which the engine has been operated over its life while a continuous-MI is activated.

The cumulative continuous-MI counter shall count up to the maximum value provided in a 2-byte counter with 1 hour resolution and hold that value.

The cumulative continuous-MI counter shall not be reset to zero by the engine system, a scan tool or a disconnection of a battery.

The cumulative continuous-MI counter shall operate as follows:

- (a) the cumulative continuous-MI counter shall begin counting when the continuous-MI is activated.
- (b) the cumulative continuous-MI counter shall halt and hold its present value when the continuous-MI is no longer activated.
- (c) the cumulative continuous-MI counter shall continue counting from the point it had been held when a continuous-MI is activated.

Figure C1 illustrates the principle of the cumulative continuous-MI counter and appendix 2 contains examples that illustrate the logic.

4.6.5.2. Counters associated with Class B1 malfunctions

4.6.5.2.1. Single B1-counter

The OBD system shall contain a B1 counter to record the number of hours during which the engine has operated while a Class B1 malfunction is present.

The B1 counter shall operate as follows:

- (a) the B1 counter shall begin counting as soon as a Class B1 malfunction is detected and a confirmed and active DTC has been stored.
- (b) the B1 counter shall halt and hold its present value if no Class B1 malfunction is confirmed and active, or when all Class B1 malfunctions have been erased by a scan tool.
- (c) the B1 counter shall continue counting from the point it had been held if a subsequent Class B1 malfunction is detected within 3 operating sequences.

In the case where the B1 counter has exceeded 200 engine running hours, the OBD system shall set the counter to 190 engine running hours when the OBD system has determined that a Class B1 malfunction is no longer confirmed and active, or when all Class B1 malfunctions have been erased by a scan tool. The B1 counter shall begin counting from 190 engine running hours if a subsequent Class B1 malfunction is present within 3 operating sequences.

The B1 counter shall be reset to zero when three consecutive operating sequences have

occurred during which no Class B1 malfunctions have been detected.

Note: The B1 counter does not indicate the number of engine running hours with a single Class B1 malfunction present.

The B1 counter may accumulate the number of hours of 2 or more different Class B1 malfunctions, none of them having reached the time the counter indicates.

The B1 counter is only intended to determine when the continuous-MI shall be activated.

Figure C2 illustrates the principle of the B1 counter and appendix 2 contains examples that illustrate the logic.

4.6.5.2.2. Multiple B1-counters

A manufacturer may use multiple B1 counters. In that case the system shall be capable of assigning a specific B1 counter to each class B1 malfunction.

The control of the specific B1 counter shall follow the same rules as the single B1 counter, where each specific B1 counter shall begin counting when the assigned Class B1 malfunction is detected.

4.7. OBD information

4.7.1. Recorded information

The information recorded by the OBD system shall be available upon off-board request in the following packages manner:

- (a) information about the engine state;
- (b) information about active emission-related malfunctions;
- (c) information for repair.

4.7.1.1. Information about the engine state

This information will provide an enforcement agency 4/ with the malfunction indicator status and associated data (e.g. continuous-MI counter, readiness).

The OBD system shall provide all information (according to the applicable standard set in appendix 6) for the external roadside check test equipment to assimilate the data and provide an enforcement agent with the following information:

- (a) discriminatory/non-discriminatory display strategy;
- (b) the VIN (vehicle identification number);
- (c) presence of a continuous-MI;

4/ A typical use of this information package may be to establish basic emission road-worthiness of the engine system.

- (d) the readiness of the OBD system;
- (e) the number of engine operating hours during which a continuous-MI was last activated (continuous-MI counter).

This information shall be read only access (i.e. no clearing).

4.7.1.2. Information about active emission-related malfunctions

This information will provide any inspection station 5/ with a subset of engine related OBD data including the malfunction indicator status and associated data (MI counters), a list of active/confirmed malfunctions of classes A and B and associated data (e.g. B1-counter).

The OBD system shall provide all information (according to the applicable standard set in appendix 6) for the external inspection test equipment to assimilate the data and provide an inspector with the following information:

- (a) the gtr (and revision) number, to be integrated into Regulation No. 49 type approval marking;
- (b) discriminatory/ non-discriminatory display strategy;
- (c) the VIN (vehicle identification number);
- (d) the Malfunction Indicator status;
- (e) the Readiness of the OBD system;
- (f) number of warm-up cycles and number of engine operating hours since recorded OBD information was last cleared;
- (g) the number of engine operating hours during which a continuous-MI was last activated (continuous-MI counter);
- (h) the cumulated operating hours with a continuous-MI (cumulative continuous-MI counter);
- (i) the value of the B1 counter with the highest number of engine operating hours;
- (j) the confirmed and active DTCs for Class A malfunctions;
- (k) the confirmed and active DTCs for Classes B (B1 and B2) malfunctions;
- (l) the confirmed and active DTCs Class B1 malfunctions;
- (m) the software calibration identification(s);
- (n) the calibration verification number(s).

This information shall be read only access (i.e. no clearing).

4.7.1.3. Information for repair

This information will provide repair technicians with all OBD data specified in this annex (e.g. freeze frame information).

The OBD system shall provide all information (according to the applicable standard set in appendix 6) for the external repair test equipment to assimilate the data and provide a

5/ A typical use of this information package may be to establish detailed understanding of the emission road-worthiness of the engine system.

repair technician with the following information:

- (a) gtr (and revision) number, to be integrated into Regulation No. 49 type approval marking;
- (b) VIN (vehicle identification number);
- (c) malfunction indicator status;
- (d) readiness of the OBD system;
- (e) number of warm-up cycles and number of engine operating hours since recorded OBD information was last cleared;
- (f) monitor status (i.e. disabled for the rest of this drive cycle complete this drive cycle, or not complete this drive cycle) since last engine shut-off for each monitor used for readiness status;
- (g) number of engine operating hours since the malfunction indicator has been activated (continuous MI counter);
- (h) confirmed and active DTCs for Class A malfunctions;
- (i) confirmed and active DTCs for Classes B (B1 and B2) malfunctions;
- (j) cumulated operating hours with a continuous-MI (cumulative continuous-MI counter);
- (k) value of the B1 counter with the highest number of engine operating hours;
- (l) confirmed and active DTCs for Class B1 malfunctions and the number of engine operating hours from the B1-counter(s);
- (m) confirmed and active DTCs for Class C malfunctions;
- (n) pending DTCs and their associated class;
- (o) previously active DTCs and their associated class;
- (p) real-time information on OEM selected and supported sensor signals, internal and output signals (see paragraph 4.7.2 and appendix 5);
- (q) freeze frame data requested by this annex (see paragraph 4.7.1.4. and appendix 5);
- (r) software calibration identification(s);
- (s) calibration verification number(s).

The OBD system shall clear all the recorded malfunctions of the engine system and related data (operating time information, freeze frame, etc.) in accordance with the provisions of this annex, when this request is provided via the external repair test equipment according to the applicable standard set in appendix 6.

4.7.1.4. Freeze frame information

At least one "freeze frame" of information shall be stored at the time that either a potential DTC or a confirmed and active DTC is stored at the decision of the manufacturer. The manufacturer is allowed to update the freeze frame information whenever the pending DTC is detected again.

The freeze frame shall provide the operating conditions of the vehicle at the time of malfunction detection and the DTC associated with the stored data. The freeze frame shall include the information as shown in table 1 in appendix 5 of this annex. The freeze frame shall also include all of the information in tables 2 and 3 of appendix 5 of this annex that are used for monitoring or control purposes in the specific control unit that stored the DTC.

Storage of freeze frame information associated with a Class A malfunction shall take precedence over information associated with a Class B1 malfunction which shall take precedence over information associated with a Class B2 malfunction and likewise for information associated with a Class C malfunction. The first malfunction detected shall take precedence over the most recent malfunction unless the most recent malfunction is of a higher class.

In case a device is monitored by the OBD system and is not covered by appendix 5 the freeze frame information shall include elements of information for the sensors and actuators of this device in a way similar to those described in appendix 5. This shall be submitted for approval by the administrative department at the time of approval.

4.7.1.5. Readiness

A readiness shall be set to "complete" when a monitor or a group of monitors addressed by this status have run since the last erasing by request of an external OBD scan-tool. Readiness shall be set to "not complete" by erasing the fault code memory of a monitor or group of monitors by request of an external scan-tool.

Normal engine shutdown shall not cause the readiness to change.

The manufacturer may request, subject to approval by the administrative department, that the ready status for a monitor be set to indicate "complete" without the monitor having completed if monitoring is disabled for a multiple number of operating sequences due to the continued presence of extreme operating conditions (e.g. cold ambient temperatures, high altitudes). Any such request must specify the conditions for monitoring system disablement and the number of operating sequences that would pass without monitor completion before ready status would be indicated as "complete".

4.7.2 Data stream information

The OBD system shall make available to a scan tool in real time the information shown in tables 1 to 4 in appendix 5 of this annex, upon request (actual signal values should be used in favour of surrogate values).

For the purpose of the calculated load and torque parameters, the OBD system shall report the most accurate values that are calculated within the applicable electronic control unit (e.g. the engine control computer).

Table 1 in appendix 5 gives the list of mandatory OBD information relating to the

engine load and speed.

Table 2 in appendix 5 shows the other OBD information which must be included if used by the emission or OBD system to enable or disable any OBD monitors.

Table 3 in appendix 5 shows the information which is required to be included if the engine is so equipped, senses or calculates the information 6/. At the decision of the manufacturer, other freeze frame or data stream information may be included.

In case a device is monitored by the OBD system and is not covered by appendix 5 (e.g. SCR), the data-stream information shall include elements of information for the sensors and actuators of this device in a way similar to those described in appendix 5. This shall be submitted for approval by the administrative department at the time of approval.

4.7.3. Access to OBD information

Access to OBD information shall be provided only in accordance with the standards mentioned in appendix 6 of this annex and the following sub-paragraphs 7/.

Access to the OBD information shall not be dependent on any access code or other device or method obtainable only from the manufacturer or its suppliers. Interpretation of the OBD information shall not require any unique decoding information, unless that information is publicly available.

A single access method (e.g. a single access point/node) to OBD information shall be supported to retrieve all OBD information. This method shall permit access to the complete OBD information required by this annex. This method shall also permit access to specific smaller information packages as defined in this annex (e.g. road worthiness information packages in case of emission related OBD)

Access to OBD information shall be provided using, at least one of the following series of standards mentioned in appendix 6:

- (a) ISO/PAS 27145 (CAN-based)
- (b) ISO 27145 (TCP/IP-based)
- (c) SAE J1939-71

Access to OBD information shall be possible by the means of a wired connection.

OBD data shall be provided by the OBD system upon request using scan tool that complies with the requirements of the applicable standards mentioned in appendix 6

6/ It is not required to equip the engine for the sole purpose of providing the information data mentioned in tables 2 and 3 of Annex 5.

7/ The manufacturer is allowed to use an additional on-board diagnostic display, such as a dashboard mounted video display device, for providing access to OBD information. Such an additional device is not subject to the requirements of this annex.

(communication with external tester).

4.7.3.1. CAN based wired communication

The communication speed on the wired data link of the OBD system shall be either 250 kbps or 500 kbps.

It is the manufacturer's responsibility to select the baud-rate and to design the OBD system according to the requirements specified in the standards mentioned in appendix 6, and referred to in this annex. The OBD system shall be tolerant against the automatic detection between these two baud-rates exercised by the external test equipment.

The connection interface between the vehicle and the external diagnostic test equipment (e.g. scan-tool) shall be standardised and shall meet all of the requirements of ISO 15031-3 Type A (12 VDC power supply), Type B (24 VDC power supply) or SAE J1939-13 (12 or 24 VDC power supply).

4.7.3.2. (reserved for TCP/IP (Ethernet) based wired communication.)

4.7.3.3. Connector location

The connector shall be located in the driver's side foot-well region of the vehicle interior in the area bound by the driver's side of the vehicle and the driver's side edge of the centre console (or the vehicle centreline if the vehicle does not have a centre console) and at a location no higher than the bottom of the steering wheel when in the lowest adjustable position. The connector may not be located on or in the centre console (i.e. neither on the horizontal faces near the floor-mounted gear selector, parking brake lever, or cup holders nor on the vertical faces near the stereo/radio, climate system, or navigation system controls). The location of the connector shall be capable of being easily identified and accessed (e.g. to connect an off-board tool). For vehicles equipped with a driver's side door, the connector shall be capable of being easily identified and accessed by someone standing (or "crouched") outside the driver's side of the vehicle with the driver's side door open.

The administrative department may approve upon request of the manufacturer an alternative location provided the installation position shall be easily accessible and protected from accidental damage during normal conditions of use, e.g. the location as described in ISO 15031 series of standards.

If the connector is covered or located in a specific equipment box, the cover or the compartment door must be removable by hand without the use of any tools and be clearly labelled "OBD" to identify the location of the connector.

The manufacturer may equip vehicles with additional diagnostic connectors and data-links for manufacturer-specific purposes other than the required OBD functions. If the additional connector conforms to one of the standard diagnostic connectors allowed in

appendix 6, only the connector required by this annex shall be clearly labelled "OBD" to distinguish it from other similar connectors.

4.7.4. Erasing / resetting OBD information by a scan-tool

On request of the scan tool, the following data shall be erased or reset to the value specified in this annex from the computer memory.

OBD information data	Erasable	Resettable ^{8/}
malfunction indicator status		X
readiness of the OBD system		X
number of engine operating hours since the malfunction indicator has been activated (continuous MI counter)	X	
all DTCs	X	
the value of the B1 counter with the highest number of engine operating hours		X
the number of engine operating hours from the B1-counter(s)		X
the freeze frame data requested by this annex	X	

OBD information shall not be erased by disconnection of the vehicle's battery(s).

4.8. Electronic security

Any vehicle with an emission control unit must include features to deter modification, except as authorized by the manufacturer. The manufacturer shall authorize modifications if these modifications are necessary for the diagnosis, servicing, inspection, retrofitting or repair of the vehicle.

Any reprogrammable computer codes or operating parameters shall be resistant to tampering and afford a level of protection at least as good as the provisions in ISO 15031-7 (SAE J2186) or J1939-73 provided that the security exchange is conducted using the protocols and diagnostic connector as prescribed in this annex. Any removable calibration memory chips shall be potted, encased in a sealed container or protected by electronic algorithms and shall not be changeable without the use of specialised tools and procedures.

Computer-coded engine operating parameters shall not be changeable without the use of specialised tools and procedures (e.g. soldered or potted computer components or sealed (or soldered) computer enclosures).

Manufacturers shall take adequate steps to protect the maximum fuel delivery setting from tampering while a vehicle is in-service.

Manufacturers may apply to the administrative department for an exemption from one of

^{8/} to the value specified in the appropriate section of this annex

these requirements for those vehicles that are unlikely to require protection. The criteria that the administrative department will evaluate in considering an exemption will include, but are not limited to, the current availability of performance chips, the high-performance capability of the vehicle and the projected sales volume of the vehicle.

Manufacturers using programmable computer code systems (e.g. electrical erasable programmable read-only memory, EEPROM) shall deter unauthorized reprogramming. Manufacturers shall include enhanced tamper-protection strategies and write protect features requiring electronic access to an off-site computer maintained by the manufacturer. Alternative methods giving an equivalent level of tamper protection may be approved by the administrative department

4.9. Durability of the OBD system

The OBD system shall be designed and constructed so as to enable it to identify types of malfunctions over the complete life of the vehicle or engine system.

Any additional provisions addressing the durability of OBD systems are contained in this annex.

An OBD system shall not be programmed or otherwise designed to partially or totally deactivate based on age and/or mileage of the vehicle during the actual life of the vehicle, nor shall the system contain any algorithm or strategy designed to reduce the effectiveness of the OBD system over time.

5. PERFORMANCE REQUIREMENTS

5.1. Thresholds

The OTLs for the applicable monitoring criteria defined in appendix 3 are defined in the main part of this Regulation

5.2. Temporary disablement of the OBD system

Approval authorities may approve that an OBD system be temporarily disabled under the conditions specified in the following sub-paragraphs.

At the time of approval or type-approval, the manufacturer shall provide the administrative department with the detailed description of each of the OBD system's temporary disablement strategies and the data and/or engineering evaluation demonstrating that monitoring during the applicable conditions would be unreliable or impractical.

In all cases, monitoring shall resume once the conditions justifying temporary disablement are no longer present.

5.2.1. Engine/vehicle operational safety

Manufacturers may request approval to disable the affected OBD monitoring systems when operational safety strategies are activated.

The OBD monitoring system is not required to evaluate components during malfunction if such evaluation would result in a risk to the safe use of the vehicle.

5.2.2. Ambient temperature and altitude conditions

Manufacturers may request approval to disable OBD system monitors at ambient engine start temperatures below 266 K (-7 degrees Celsius or 20 degrees Fahrenheit) or above 308 K (35 degrees Celsius or 95 degrees Fahrenheit), or at elevations above 2,500 meters (8,202 feet) above sea level.

A manufacturer may further request approval that an OBD system monitor be disabled at other ambient engine start temperatures upon determining that the manufacturer has demonstrated with data and/or an engineering evaluation that misdiagnosis would occur at the ambient temperatures because of its effect on the component itself (e.g. component freezing).

Note: Ambient conditions may be estimated by indirect methods. For example ambient temperature conditions may be determined based on intake air temperature.

5.2.3. Low fuel level

Manufacturers may request approval to disable monitoring systems that are affected by low fuel level or running out of fuel (e.g. diagnosis of a malfunction of the fuelling system or misfiring). The low fuel level considered for such a disablement shall not exceed 100 litres or 20 per cent of the nominal capacity of the fuel tank, whichever is lower.

5.2.4. Vehicle battery or system voltage levels

Manufacturers may request approval to disable monitoring systems that can be affected by vehicle battery or system voltage levels.

5.2.4.1. Low voltage

For monitoring systems affected by low vehicle battery or system voltages, manufacturers may request approval to disable monitoring systems when the battery or system voltage is below 90 per cent of the nominal voltage (or 11.0 Volts for a 12 Volt battery, 22.0 Volts for a 24 volt battery). Manufacturers may request approval to utilize a voltage threshold higher than this value to disable system monitoring.

The manufacturer shall demonstrate that monitoring at the voltages would be unreliable and that either operation of a vehicle below the disablement criteria for extended periods of time is unlikely or the OBD system monitors the battery or system voltage

and will detect a malfunction at the voltage used to disable other monitors.

5.2.4.2. High voltage

For emission related monitoring systems affected by high vehicle battery or system voltages, manufacturers may request approval to disable monitoring systems when the battery or system voltage exceeds a manufacturer-defined voltage.

The manufacturer shall demonstrate that monitoring above the manufacturer-defined voltage would be unreliable and that either the electrical charging system/alternator warning light is illuminated (or voltage gauge is in the "red zone") or the OBD system monitors the battery or system voltage and will detect a malfunction at the voltage used to disable other monitors.

5.2.5. Active PTO (power take-off units)

The manufacturer may request approval to temporarily disable affected monitoring systems in vehicles equipped with a PTO unit, under the condition where that PTO unit is temporarily active.

5.2.6. Forced regeneration

The manufacturer may request approval to disable the affected OBD monitoring systems during the forced regeneration of an emission control system downstream of the engine (e.g. a particulate filter).

5.2.7. AECS

The manufacturer may request approval to disable OBD system monitors during the operation of an AECS, including MECS, under conditions not already covered in paragraph 5.2. if the monitoring capability of a monitor is affected by the operation of an AECS.

6. DEMONSTRATION REQUIREMENTS

The basic elements for demonstrating the compliance of an OBD system with the requirements of this annex are as follows:

- (a) procedure for selecting the OBD-parent engine system. The OBD-parent engine system is selected by the manufacturer in agreement with the administrative department.
- (b) procedure for demonstrating the classification of a malfunction. The manufacturer submits to the administrative department the classification of each malfunction for that OBD-parent engine system and the necessary supporting data in order to justify each classification.
- (c) procedure for qualifying a deteriorated component. The manufacturer shall provide, on request of the administrative department, deteriorated components for OBD testing purposes. These components are qualified on the basis of supporting

data provided by the manufacturer.

6.1. Emission-OBD family

The manufacturer is responsible for determining the composition of an emission-OBD family. Grouping engine systems within an emission-OBD family shall be based on good engineering judgement and be subject to approval by the administrative department.

Engines that do not belong to the same engine family may still belong to the same emission-OBD family.

6.1.1. Parameters defining an emission-OBD family

An emission-OBD family is characterised by basic design parameters that shall be common to engine systems within the family.

In order that engine systems are considered to belong to the same OBD-engine family, the following list of basic parameters shall be similar:

- (a) mission control systems
- (b) methods of OBD monitoring
- (c) criteria for performance and component monitoring
- (d) monitoring parameters (e.g. frequency)

These similarities shall be demonstrated by the manufacturer by means of relevant engineering demonstration or other appropriate procedures and subject to the approval of the administrative department.

The manufacturer may request approval by the administrative department of minor differences in the methods of monitoring/diagnosing the engine emission control system due to engine system configuration variation, when these methods are considered similar by the manufacturer and:

- (a) they differ only to match specificities of the considered components (e.g. size, exhaust flow, etc.); or
- (b) their similarities are based on good engineering judgement.

6.1.2. OBD-parent engine system

Compliance of an emission-OBD family with the requirements of this annex is achieved by demonstrating the compliance of the OBD-parent engine system of this family.

The selection of the OBD-parent engine system is made by the manufacturer and subject to the approval of the administrative department.

Prior to testing the administrative department may decide to request the manufacturer to select an additional engine for demonstration.

The manufacturer may also propose to the administrative department to test additional engines to cover the complete emission-OBD family.

6.2. Procedures for demonstrating the malfunction classification

The manufacturer shall provide the documentation justifying the proper classification of each malfunction to the administrative department. This documentation shall include a failure analysis (for example elements of a "failure mode and effect analysis") and may also include:

- (a) simulation results
- (b) test results
- (c) reference to previously approved classification

In the following paragraphs the requirements for demonstrating the correct classification are listed, including requirements for testing. The minimum number of tests is four and the maximum number of tests is four times the number of engine families considered within the emission OBD family. The administrative department may decide to curtail the test at any time before this maximum number of failure tests has been reached.

In specific cases where the classification testing is not possible (for example, if an MECS is activated and the engine cannot run the applicable test, etc.), the malfunction may be classified based on technical justification. This exception shall be documented by the manufacturer and is subject to the agreement of the administrative department.

6.2.1. Demonstration of classification into A

The classification by the manufacturer of a malfunction into Class A shall not be subject to a demonstration test.

If the administrative department disagrees with a manufacturer's classification of a malfunction as Class A, the administrative department requires the classification of the malfunction into Class B1, B2 or C, as appropriate.

In that case the approval document shall record that the malfunction classification has been assigned according to the request of the administrative department.

6.2.2. Demonstration of classification into B1 (distinguishing between A and B1)

In order to justify the classification of a malfunction into Class B1 the documentation shall clearly demonstrate that, in some circumstances ^{9/}, the malfunction results in emissions that are lower than the OTLs.

^{9/} Examples of circumstances that may influence if and when OTLs are exceeded are the age of the engine system or whether the test is conducted with a new or aged component.

In the case that the administrative department requires an emission test for demonstrating the classification of a malfunction into Class B1 the manufacturer shall demonstrate that the emissions due to that particular malfunction are, in selected circumstances, below the OTLs:

- (a) the manufacturer selects the circumstances of the test in agreement with the administrative department;
- (b) the manufacturer shall not be required to demonstrate that in other circumstances the emissions due to the malfunction are actually above the OTLs.

If the manufacturer fails to demonstrate the classification as Class B1, the malfunction is classified as Class A.

6.2.3. Demonstration of classification into B1 (distinguishing between B2 and B1)

If the administrative department disagrees with a manufacturer's classification of a malfunction as Class B1 because it considers that the OTLs are not exceeded, the administrative department requires the reclassification of that malfunction into Class B2 or C. In that case the approval documents shall record that the malfunction classification has been assigned according to the request of the administrative department.

6.2.4. Demonstration of classification into B2 (distinguishing between B2 and B1)

In order to justify the classification of a malfunction into Class B2 the manufacturer shall demonstrate that emissions are lower than the OTLs.

In case the administrative department disagrees with the classification of a malfunction as Class B2 because it considers that the OTLs are exceeded, the manufacturer may be required to demonstrate by testing that the emissions due to the malfunction are below the OTLs. If the test fails, then the administrative department shall require the reclassification of that malfunction into A or B1 and the manufacturer shall subsequently demonstrate the appropriate classification and the documentation shall be updated.

6.2.5. Demonstration of classification into B2 (distinguishing between B2 and C)

If the administrative department disagrees with a manufacturer's classification of a malfunction as Class B2 because it considers the regulated emission limits are not exceeded, the administrative department requires the reclassification of that malfunction into Class C. In that case the approval documents shall record that the malfunction classification has been assigned according to the request of the administrative department.

6.2.6. Demonstration of classification into C

In order to justify the classification of a malfunction into Class C the manufacturer shall demonstrate that emissions are lower than the regulated emission limits.

In case the administrative department disagrees with the classification of a malfunction as Class C the manufacturer may be required to demonstrate by testing that the emissions due to the malfunction are below the regulated emission limits.

If the test fails, then the administrative department shall request the reclassification of that malfunction and the manufacturer shall subsequently demonstrate the appropriate reclassification and the documentation shall be updated.

6.3. Procedures for demonstrating the OBD performance

The manufacturer shall submit to the administrative department a complete documentation package justifying the compliance of the OBD system as regards its monitoring capability, which may include:

- (a) algorithms and decision charts
- (b) tests and/or simulation results
- (c) reference to previously approved monitoring systems, etc.

In the following paragraphs the requirements for demonstrating the OBD performance are listed, including requirements for testing. The minimum number of tests is four and the maximum number of tests is four times the number of engine families considered within the emission OBD family. The administrative department may decide to curtail the test at any time before this maximum number of failure tests has been reached.

6.3.1. Procedures for demonstrating the OBD performance by testing

In addition to the supporting data referred to in paragraph 6.3., the manufacturer shall demonstrate the proper monitoring of specific emission control systems or components by testing them on an engine test-bed according to the test procedures specified in paragraph 7.2. of this annex.

In that case, the manufacturer shall make available the qualified deteriorated components or the electrical device which would be used to simulate a malfunction.

The proper detection of the malfunction by the OBD system and its proper response to that detection (cf. MI indication, DTC storage, etc.) shall be demonstrated according to paragraph 7.2.

6.3.2. Procedures for qualifying a deteriorated component (or system)

This paragraph applies to the cases where the malfunction selected for an OBD demonstration test is monitored against tailpipe emissions 10/ (emission threshold monitoring - see paragraph 4.2.), by an emission test, the qualification of that deteriorated component.

10/ This paragraph will be extended to other monitors than mission threshold monitors at a later stage.

In very specific cases the qualification of deteriorated components or systems by testing may not be possible (for example, if an MECS is activated and the engine cannot run the applicable test, etc.). In such cases, the deteriorated component shall be qualified without testing. This exception shall be documented by the manufacturer and is subject to the agreement of the administrative department.

6.3.2.1. Procedure for qualifying a deteriorated component used to demonstrate the detection of classes A and B1 malfunctions

In the case the malfunction selected by the administrative department results in tailpipe emissions that may exceed an OBD threshold limit, the manufacturer shall demonstrate by an emission test according to paragraph 7. that the deteriorated component or device does not result in the relevant emission exceeding its OTL by more than 20 per cent.

6.3.2.2. Qualification of deteriorated components used to demonstrate the detection of Class B2 malfunctions

In the case of Class B2 malfunctions, and upon request of the administrative department, the manufacturer shall demonstrate by an emission test according to paragraph 7. that the deteriorated component or device does not lead the relevant emission to exceed its applicable OTL.

6.3.2.3. Qualification of deteriorated components used to demonstrate the detection of Class C malfunctions

In the case of Class C malfunctions, and upon request of the administrative department, the manufacturer shall demonstrate by an emission test according to paragraph 7. that the deteriorated component or device does not lead the relevant emission to exceed its applicable regulated emission limit.

6.3.3. Test report

The test report shall contain, at a minimum, the information set out in appendix 4.

6.4. Approval of an OBD system containing deficiencies

6.4.1. Approval authorities may approve upon request of a manufacturer an OBD system even though the system contains one or more deficiencies.

In considering the request, the administrative department shall determine whether compliance with the requirements of this annex is feasible or unreasonable.

The administrative department shall take into consideration data from the manufacturer that details such factors as, but not limited to, technical feasibility, lead time and production cycles including phase-in or phase-out of engines designs and programmed upgrades of computers, the extend to which the resultant OBD system will be effective

in complying with the requirements of this annex and that the manufacturer has demonstrated an acceptable level of effort toward meeting the requirements of the annex.

The administrative department will not accept any deficiency request that includes the complete lack of a required diagnostic monitor (i.e. a complete lack of the monitors required in appendix 3).

6.4.2. Deficiency period

A deficiency is granted for a period of one year after the date of approval of the engine system.

If the manufacturer can adequately demonstrate to the administrative department that substantial engine modifications and additional lead time would be necessary to correct the deficiency, then this deficiency can be granted again for an additional one year, provided that the total deficiency period does not exceed 3 years (i.e. 3 times one year deficiency allowance is permitted).

The manufacturer cannot apply for a renewal of the deficiency period.

7. TEST PROCEDURES

7.1. Testing process

The demonstration by testing of the proper malfunction classification and the demonstration by testing of the proper monitoring performance of an OBD system are issues that shall be considered separately during the testing process. For example, a Class A malfunction will not require a classification test while it may be subject to an OBD performance test.

Where appropriate, the same test may be used to demonstrate the correct classification of a malfunction, the qualification of a deteriorated component provided by the manufacturer and the correct monitoring by the OBD system.

The engine system on which the OBD system is tested shall comply with the emission requirements of this Regulation.

7.1.1. Testing process for demonstrating the malfunction classification

When, according to paragraph 6.2., the administrative department requests the manufacturer to justify by testing the classification of a specific malfunction, the compliance demonstration will consist of a series of emission tests.

According to paragraph 6.2.2., when testing is required by the administrative department to justify the classification of a malfunction into Class B1 rather than in Class A, the manufacturer shall demonstrate that the emissions due to that particular

malfunction are, in selected circumstances, below the OTLs:

- (a) the manufacturer selects these circumstances of test in agreement with the administrative department
- (b) the manufacturer shall not be required to demonstrate that in other circumstances the emissions due to the malfunction are actually above the OTLs.

The emission test may be repeated upon request of the manufacturer up to three times.

If any of these tests leads to emissions below the considered OTL, then the malfunction classification into Class B1 shall be approved.

When testing is required by the administrative department to justify the classification of a malfunction into Class B2 rather than in Class B1 or into Class C rather than in Class B2, the emission test shall not be repeated. If the emissions measured in the test are above the OTL or the emission limit, respectively, then the malfunction shall require a reclassification.

Note: According to paragraph 6.2.1., this paragraph does not apply to malfunctions classified into Class A.

7.1.2. Testing process for demonstrating the OBD performance

When the administrative department requests according to paragraph 6.3. to test the OBD system performance, the compliance demonstration shall consist of the following phases:

- (a) a malfunction is selected by the administrative department and a corresponding deteriorated component or system shall be made available by the manufacturer;
- (b) when appropriate and if requested, the manufacturer shall demonstrate by an emission test that the deteriorated component is qualified for a monitoring demonstration;
- (c) the manufacturer shall demonstrate that the OBD system responds in a manner that complies with the provisions of this annex (i.e. MI indication, DTC storage, etc.) at the latest by the end of a series of OBD test-cycles.

7.1.2.1. Qualification of the deteriorated component

When the administrative department requests the manufacturer to qualify a deteriorated component by testing according to paragraph 6.3.2., this demonstration shall be made by performing an emissions test.

If it is determined that the installation of a deteriorated component or device on an engine system means that a comparison with the OBD threshold limits is not possible (e.g. because the statistical conditions for validating the applicable emission test cycle are not met), the malfunction of that component or device may be considered as qualified upon the agreement of the administrative department based on technical rationale provided by the manufacturer.

In the case that the installation of a deteriorated component or device on an engine means that the full load curve (as determined with a correctly operating engine) cannot be attained during the test, the deteriorated component or device may be considered as qualified upon the agreement of the administrative department based on technical rationale provided by the manufacturer.

7.1.2.2. Malfunction detection

Each monitor selected by the administrative department to be tested on an engine test-bed, shall respond to the introduction of a qualified deteriorated component in a manner that meets the requirements of this annex within two consecutive OBD test-cycles according to paragraph 7.2.2. of this annex.

When it has been specified in the monitoring description and agreed by the administrative department that a specific monitor needs more than two operating sequences to complete its monitoring, the number of OBD test-cycles may be increased according to the manufacturer's request.

Each individual OBD test-cycle in the demonstration test shall be separated by an engine shut-off. The time until the next start-up shall take into consideration any monitoring that may occur after engine shut-off and any necessary condition that must exist for monitoring to occur at the next start up.

The test is considered complete as soon as the OBD system has responded in a manner that meets the requirements of this annex.

7.2. Applicable tests

The emission test is the test-cycle used for the measurement of the regulated emissions.

The OBD test-cycle is the test-cycle used when evaluating the performance of the OBD monitor. In many cases these test-cycles are the same.

7.2.1. Emission test cycle

The test-cycle considered in this annex for measuring emissions is the WHTC test-cycle as described in Annex 10.

7.2.2. OBD test cycle

The World-wide harmonized OBD test-cycle considered in this annex is the hot part of the WHTC cycle as described in Annex 10.

On request of the manufacturer and with approval of the administrative department, the cold part of the WHTC cycle can be used as an alternative OBD test-cycle. The request shall contain elements (technical considerations, simulation, test results, etc.) demonstrating:

- (a) the requested test-cycle results in a monitor that will run in real world driving, and;
- (b) the applicable world-wide harmonized or regionally accepted OBD test-cycle is shown to be less appropriate for the considered monitoring (e.g. fluid consumption monitoring).

7.2.3. Test operating conditions

The conditions (i.e. temperature, altitude, fuel quality etc.) for conducting the tests referred to in paragraphs 7.2.1. and 7.2.2. shall be those required for operating the WHTC test cycle as described in Annex 10.

In the case of an emission test aimed at justifying the classification of a specific malfunction into Class B1, the test operating conditions may, per decision of the manufacturer, deviate from the ones in the paragraphs above according to paragraph 6.2.2.

7.3. Test reports

The test report shall contain, at a minimum, the information set out in appendix 4.

8. DOCUMENTATION REQUIREMENTS

8.1. Documentation for purpose of approval

The manufacturer shall provide a documentation package that includes a full description of the OBD system. The documentation package shall be made available in two parts:

- (a) a first part, which may be brief, provided that it exhibits evidence concerning the relationships between monitors, sensors/actuators, and operating conditions (i.e. describes all enable conditions for monitors to run and disable conditions that cause monitors not to run). The documentation shall describe the functional operation of the OBD, including the malfunction ranking within the hierarchical classification. This material shall be retained by the administrative department. This information may be made available to interested parties upon request.
- (b) a second part containing any data, including details of qualified deteriorated components or systems and associated test results, which are used as evidence to support the decision process referred to above, and a listing of all input and output signals that are available to the engine system and monitored by the OBD system. This second part shall also outline each monitoring strategy and the decision process.

This second part shall remain strictly confidential. It may be kept by the administrative department, or, at the discretion of the administrative department, may be retained by the manufacturer but shall be made open for inspection by the administrative department at the time of approval or at any time during the validity of the approval.

8.1.1. Documentation associated with each monitored component or system

The documentation package included in the second part shall contain but shall not be limited to the following information for each monitored component or system:

- (a) the malfunctions and associated DTC(s);
- (b) the monitoring method used for malfunction detection;
- (c) the parameters used and the conditions necessary for malfunction detection and when applicable the fault criteria limits (performance and component monitoring);
- (d) the criteria for storing a DTC;
- (e) the monitoring "time length" (i.e. the operation time/procedure necessary to complete the monitoring) and the monitoring "frequency" (e.g. continuous, once per trip, etc.).

8.1.2. Documentation associated with the malfunction classification

The documentation package included in the second part shall contain but shall not be limited to the following information for malfunction classification:

The malfunction classification of each DTC shall be documented. This classification may be different for different engine types (e.g. different engine ratings) within the same emission-OBD family.

This information shall include the technical justification required in paragraph 4.2. of this annex for classification into Class A, Class B1 or Class B2.

8.1.3. Documentation associated with the emission-OBD family

The documentation package included in the second part shall contain but shall not be limited to the following information for emission OBD-family:

A description of the emission-OBD family shall be provided. This description shall include a list and a description of the engine types within the family, the description of the OBD-parent engine system, and all elements that characterise the family according to paragraph 6.1.1. of this annex.

In the case where the emission-OBD family includes engines belonging to different engine families, a summary description of these engine families shall be provided.

In addition, the manufacturer shall provide a list of all electronic input and output an identification of the communication protocol utilized by each emission-OBD family.

8.2. Documentation for installing in a vehicle an OBD equipped engine system

The engine manufacturer shall include in the installation documents of its engine system the appropriate requirements that will ensure the vehicle, when used on the road or elsewhere as appropriate, will comply with the requirements of this annex. This

documentation shall include but is not limited to:

- (a) the detailed technical requirements, including the provisions ensuring the compatibility with the OBD system of the engine system;
- (b) the verification procedure to be completed.

The existence and the adequacy of such installation requirements may be checked during the approval process of the engine system.

Note: In the case a vehicle manufacturer applies for a direct approval of the installation of the OBD system on the vehicle, this documentation is not required.

8.3. Documentation regarding OBD related information

Requirements of Appendix 7 have to be fulfilled.

9. APPENDICES

- Appendix 1: Approval of installation of OBD systems
- Appendix 2: Malfunctions - Illustration of the DTC status - illustration of the MI and counters activation schemes
- Appendix 3: Monitoring Requirements
- Appendix 4: Technical compliance REPORT
- Appendix 5: Freeze frame and data stream information
- Appendix 6: Reference Standard Documents
- Appendix 7: Documentation regarding OBD related information

Annex 11 - Appendix 1

APPROVAL OF INSTALLATION OF OBD SYSTEMS

This appendix considers the case where the vehicle manufacturer requests approval of the installation on a vehicle of (an) OBD system(s) within an emission OBD family, that is (are) certified to the requirements of this annex.

In this case, and in addition to the general requirements of this annex, a demonstration of the correct installation is required. This demonstration shall be done on the basis of the appropriate element of design, results of verification tests, etc. and address the conformity of the following elements to the requirements of this annex:

- (a) the installation on-board the vehicle as regards its compatibility with the OBD system of the engine-system;
- (b) the MI (pictogram, activation schemes, etc.);
- (c) the wired communication interface.

Correct MI illumination, information storage and on-board off-board OBD communication will be checked. But any check shall not force dismantling the engine system (e.g. an electric disconnection may be selected).

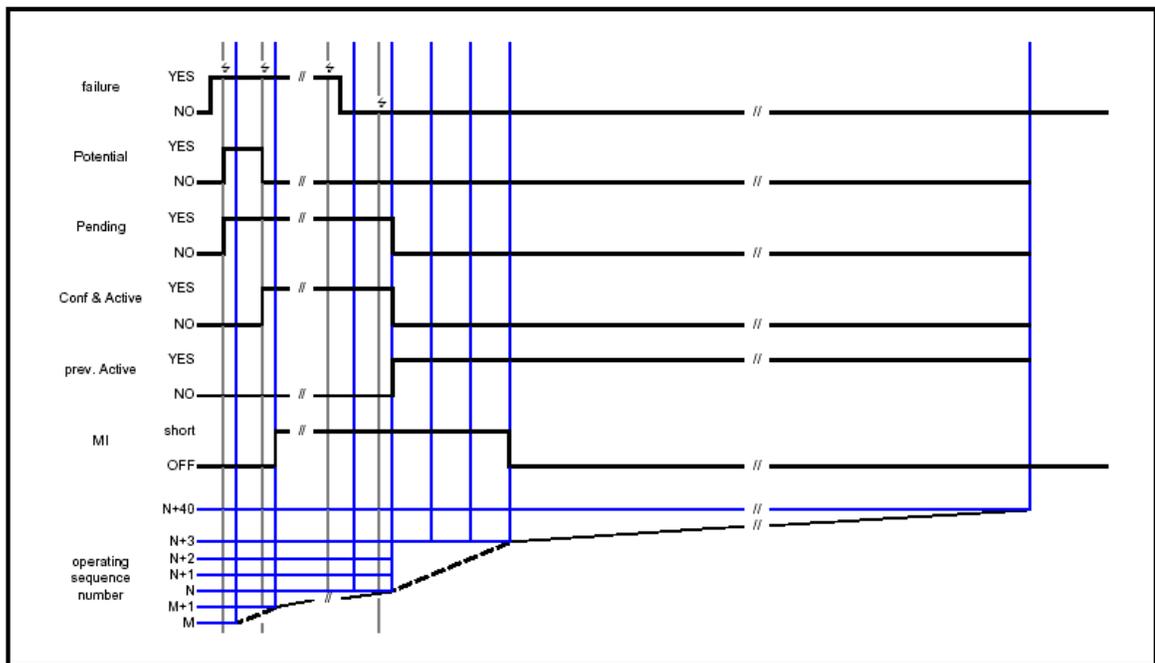
Annex 11 - Appendix 2

MALFUNCTIONS
ILLUSTRATION OF THE DTC STATUS
ILLUSTRATION OF THE MI AND COUNTERS ACTIVATION SCHEMES

This appendix aims at illustrating the requirements set in paragraphs 4.3. and 4.6.6. of this annex. It contains the following figures:

- Figure 1: DTC status in case of a class B1 malfunction
- Figure 2: DTC status in case of 2 consecutive different class B1 malfunctions
- Figure 3: DTC status in case of the re-occurrence of a class B1 malfunction
- Figure 4: Class A malfunction -activation of the MI and MI counters
- figure 5: Class B1 malfunction - activation of the B1 counter in 5 use Cases.

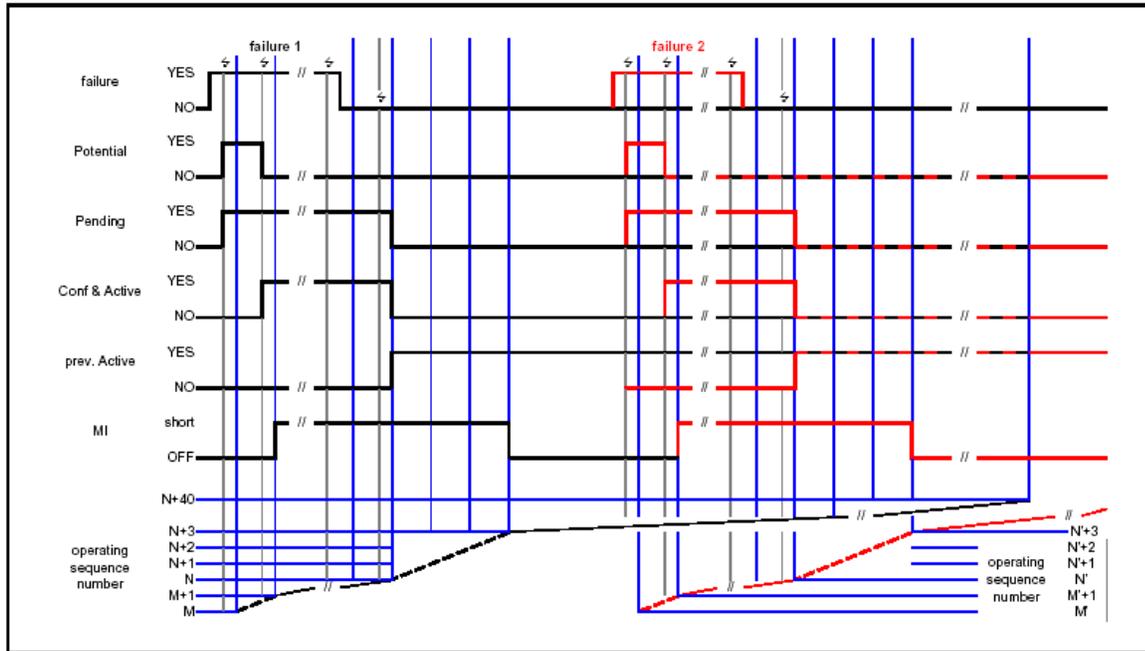
Figure 1: DTC status in case of a class B1 malfunction



Notes:

- ⚡ means the point a monitoring of the concerned malfunction occurs
- N, M The annex requires the identification of "key" operating sequences during which some events occurs, and the counting of the subsequent operating sequences. For the purpose of illustrating this requirement, the "key" operating sequences have been given the values N and M.
E.g. M means the first operating sequence following the detection of a potential malfunction, and N means the operating sequence during which the MI is switched OFF.

Figure 2: DTC status in case of 2 consecutive different class B1 malfunctions



Notes:

⚡ means the point a monitoring of the concerned malfunction occurs

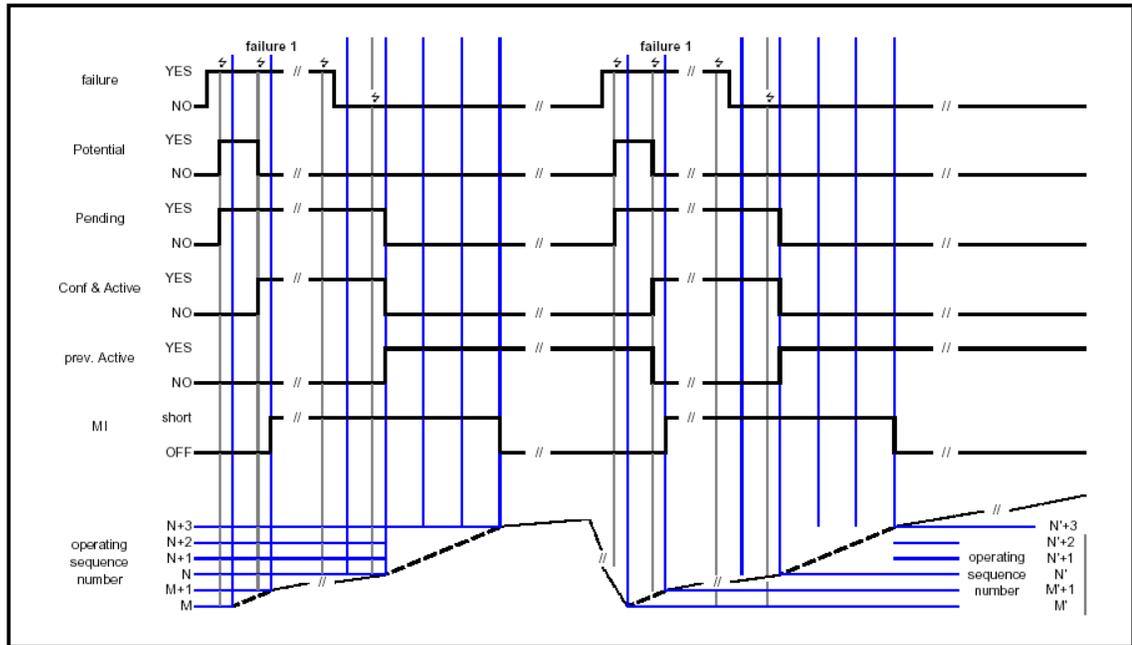
N, M,

N', M' The annex requires the identification of "key" operating sequences during which some events occurs, and the counting of the subsequent operating sequences. For the purpose of illustrating this requirement, the "key" operating sequences have been given the values N and M for the first malfunction, respectively N' and M' for the second one.

E.g. M means the first operating sequence following the detection of a potential malfunction, and N means the operating sequence during which the MI is switched OFF.

N + 40 the fortieth operating sequence after the first extinction of the MI or 200 engine operating hours, whichever the earliest.

Figure 3: DTC status in case of the re-occurrence of a class B1 malfunction



Notes:

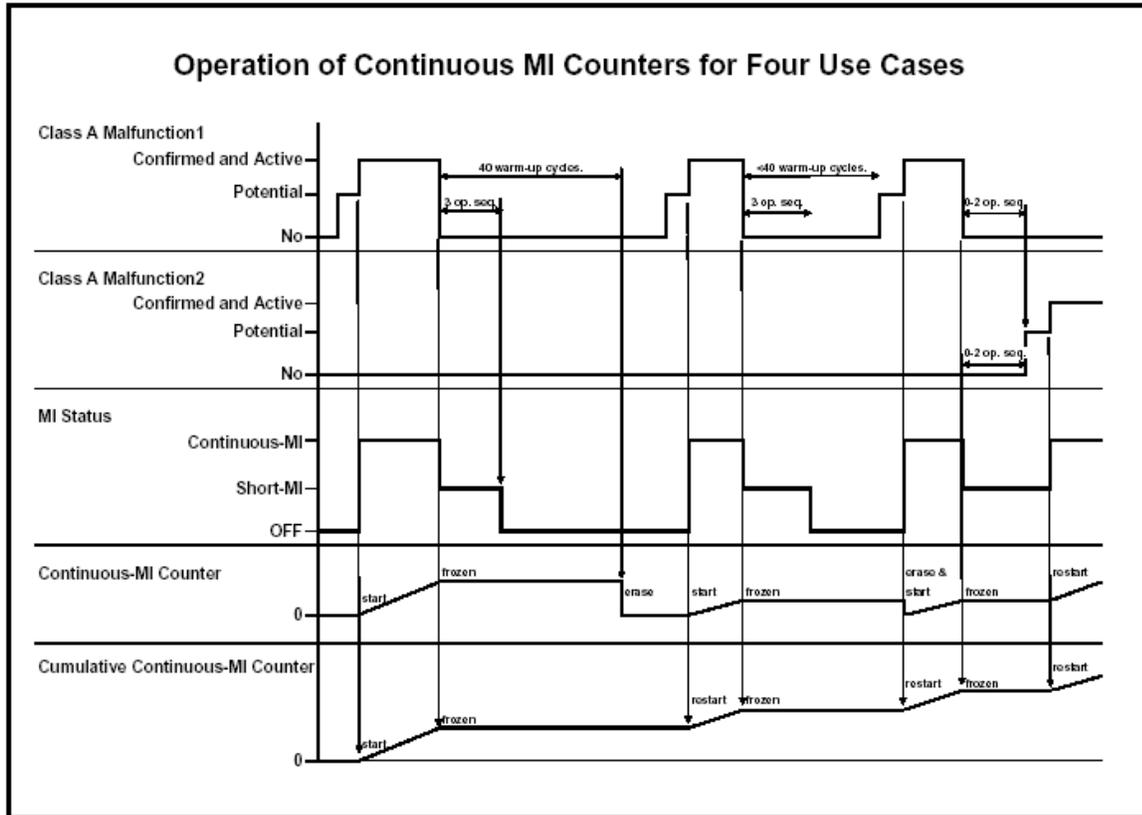
⚡ means the point a monitoring of the concerned malfunction occurs

N, M,

N', M'

The annex requires the identification of "key" operating sequences during which some events occurs, and the counting of the subsequent operating sequences. For the purpose of illustrating this requirement, the "key" operating sequences have been given the values N and M for the first occurrence of a malfunction, respectively N' and M' for the second one. E.g. M means the first operating sequence following the detection of a potential malfunction, and N means the operating sequence during which the MI is switched OFF.

Figure 4: Class A malfunction - activation of the MI and MI counters



Annex 11 - Appendix 3

MONITORING REQUIREMENTS

The Items of this appendix list the systems or components required to be monitored by the OBD system, according to paragraph 4.2.

Appendix 3 - Item 1

ELECTRIC / ELECTRONIC COMPONENTS MONITORING

Electric/electronic components used to control or monitor the emission control systems described in this appendix shall be subject to Component Monitoring according to the provisions of paragraph 4.1. of this annex. This includes, but is not limited to, pressure sensors, temperature sensors, exhaust gas sensors, in-exhaust fuel or reductant injector(s), in-exhaust burners or heating elements, glow plugs, intake air heaters.

Wherever a feedback control loop exists, the OBD system shall monitor the system's ability to maintain feedback control as designed (e.g. to enter feedback control within a manufacturer specified time interval, system fails to maintain feedback control, feedback control has used up all the adjustment allowed by the manufacturer) - component monitoring.

Appendix 3 - Item 2

DIESEL PARTICULATE FILTER (DPF), OR PARTICULATE MATTER TRAP

The OBD system shall monitor the following elements of the DPF system on engines so-equipped for proper operation:

- (a) DPF substrate: the presence of the DPF substrate - total functional failure monitoring
- (b) DPF performance: clogging of the DPF - total functional failure
- (c) DPF performance: filtering and regeneration processes (e.g. particulate accumulation during the filtering process and particulate removal during a forced regeneration process) - performance monitoring (for example, evaluation of measurable DPF properties such as backpressure or differential pressure, which may not detect all failure modes that reduce trapping efficiency).

Appendix 3 - Item 3

SELECTIVE CATALYTIC REDUCTION (SCR) MONITORING

For the purpose of this Item, SCR means selective catalytic reduction or other lean NO_x catalyst device. The OBD system shall monitor the following elements of the SCR system on engines so-equipped for proper operation:

- (a) active/intrusive reductant injection system: the system's ability to regulate reductant delivery properly, whether delivered via an in-exhaust injection or an in-cylinder injection - performance monitoring.
- (b) active/intrusive reductant: the on-board availability of the reductant, the proper consumption of the reductant if a reductant other than fuel is used (e.g. urea) - performance monitoring.
- (c) active/intrusive reductant: to the extent feasible the quality of the reductant if a reductant other than fuel is used (e.g. urea) - performance monitoring.

Appendix 3 - Item 4

LEAN-NOX TRAP (LNT, OR NOX ADSORBER)

The OBD system shall monitor the following elements of the LNT system on engines so-equipped for proper operation:

- (a) LNT capability: the LNT system's ability to adsorb/store and convert NO_x - performance monitoring.
- (b) LNT active/intrusive reductant injection system: the system's ability to regulate reductant delivery properly, whether delivered via an in-exhaust injection or an in-cylinder injection - performance monitoring.

Appendix 3 - Item 5

DIESEL OXIDATION CATALYST (DOC) MONITORING

This Item applies to DOC that are separate from other after-treatment systems. Those that are included in the canning of an after-treatment system are covered within the appropriate Item of this appendix.

The OBD system shall monitor the following elements of the DOC on engines so-equipped for proper operation:

- (a) HC conversion efficiency: the DOC's ability to convert HC upstream of other after-treatment devices - total functional failure monitoring.
- (b) HC conversion efficiency: the DOC's ability to convert HC downstream of other after-treatment devices - total functional failure monitoring.

Appendix 3 - Item 6

EXHAUST GAS RECIRCULATION (EGR) SYSTEM MONITORING

The OBD system shall monitor the following elements of the EGR system on engines so-equipped for proper operation:

- (a) EGR low/high flow: the EGR system's ability to maintain the commanded EGR flow rate, detecting both "flow rate too low" and "flow rate too high" conditions - emission threshold monitoring.
- (b) slow response of the EGR actuator: the EGR system's ability to achieve the commanded flow rate within a manufacturer specified time interval following the command - performance monitoring.
- (c) EGR cooler undercooling performance: the EGR cooler system's ability to achieve the manufacturer's specified cooling performance - performance monitoring

Appendix 3 - Item 7

FUEL SYSTEM MONITORING

The OBD system shall monitor the following elements of the Fuel system on engines so-equipped for proper operation:

- (a) Fuel system pressure control: fuel system ability to achieve the commanded fuel pressure in closed loop control - performance monitoring.
- (b) Fuel system pressure control: fuel system ability to achieve the commanded fuel pressure in closed loop control in the case where the system is so constructed that the pressure can be controlled independently of other parameters - performance monitoring.
- (c) Fuel injection timing: fuel system ability to achieve the commanded fuel timing for at least one of the injection events when the engine is equipped with the appropriate sensors - performance monitoring.

Appendix 3 - Item 8

AIR HANDLING AND TURBOCHARGER/BOOST PRESSURE CONTROL SYSTEM

The OBD system shall monitor the following elements of the Air Handling and Turbocharger/Boost Pressure Control System system on engines so-equipped for proper operation:

- (a) Turbo under/over boost: turbo boost system's ability to maintain the commanded boost pressure, detecting both "boost pressure too low" and "boost pressure too high" conditions - emission threshold monitoring.
- (b) Variable geometry turbo (VGT) slow response: VGT system's ability to achieve the commanded geometry within a manufacturer specified time -performance monitoring.
- (c) Charge air cooling: Charge air cooling system efficiency - total functional failure.

Appendix 3 - Item 9

VARIABLE VALVE TIMING (VVT) SYSTEM

The OBD system shall monitor the following elements of the Variable Valve Timing (VVT) System on engines so-equipped for proper operation:

- (a) VVT target error: VVT system's ability to achieve the commanded valve timing - performance monitoring.
- (b) VVT slow response: VVT system's ability to achieve the commanded valve timing within a manufacturer specified time interval following the command-performance monitoring.

Appendix 3 - Item 10

MISFIRE MONITORING

No prescriptions.

Appendix 3 - Item 11

CRANKCASE VENTILATION SYSTEM MONITORING

No prescriptions.

Annex 11 - Appendix 3 - Item 12

ENGINE COOLING SYSTEM MONITORING

The OBD system shall monitor the following elements of the Engine cooling system for proper operation:

- (a) Engine coolant temperature (thermostat): Stuck open thermostat Manufacturers need not monitor the thermostat if its failure will not disable any other OBD monitors - total functional failure.

Manufacturers need not monitor the engine coolant temperature or the engine coolant temperature sensor if the engine coolant temperature or the engine coolant temperature sensor is not used to enable closed-loop/feedback control of any emissions control systems and/or will not disable any other monitor.

Manufacturers may suspend or delay the monitor for the time to reach close loop enable temperature if the engine is subjected to conditions that could lead to false diagnosis (e.g. vehicle operation at idle for more than 50 to 75 per cent of the warm-up time).

Appendix 3 - Item 13

EXHAUST GAS SENSOR MONITORING

The OBD system shall monitor the electrical elements of the exhaust gas sensors on engines so-equipped for proper operation according to item 1 to this appendix.

Appendix 3 - Item 14

IDLE SPEED CONTROL SYSTEM MONITORING

The OBD system shall monitor the electrical elements of the idle speed control systems on engines so-equipped for proper operation according to item 1 to this appendix.

Annex 11 - Appendix 4

TECHNICAL COMPLIANCE REPORT

This report is issued by the administrative department, according to paragraphs 6.3.3. and 7.3., after examination of an OBD system or an emission OBD family when that system or family complies with the requirements of this appendix.

The exact reference (including its version number) of this appendix shall be included in this report. The exact reference (including its version number) to this Regulation shall be included.

This report contains a cover page indicating the final compliance of the OBD system or emission OBD family and the following 5 items:

- Item 1 INFORMATION CONCERNING THE OBD SYSTEM
- Item 2 INFORMATION CONCERNING THE CONFORMITY OF THE OBD SYSTEM
- Item 3 INFORMATION CONCERNING DEFICIENCIES
- Item 4 INFORMATION CONCERNING DEMONSTRATION TESTS OF THE OBD SYSTEM
- Item 5 TEST PROTOCOL

The content of the technical report, including its Items, shall, at a minimum, include the elements given in the following examples.

This report shall state that reproduction or publication in extracts of this report is not permitted without the written consent of the undersigned administrative department.

FINAL COMPLIANCE REPORT

The documentation package and the herewith described OBD system / emission OBD family comply with the requirements of the following regulation:

Regulation ... / version ... / enforcement date

gtr ... / A + B / version ... / date

The technical compliance report encompasses ... pages.

Place, date:

Author (name and signature)
Administrative department (name, stamp)

Item 1 to the technical compliance report (example)

INFORMATION CONCERNING THE OBD SYSTEM

1. Type of requested approval

<u>Requested Approval</u>	
- Approval of an individual OBD system	YES / NO
- Approval of an emission OBD family	YES / NO
- Approval of an OBD system as member of a certified emission OBD family	YES / NO
- Extension to include a new engine system into an emission OBD family	YES / NO
- Extension to address a design change that affects the OBD system	YES / NO
- Extension to address a malfunction reclassification	YES / NO

2. Information concerning the OBD system

<u>Approval of an individual OBD system</u>	
- type(s) <u>11/</u> of the engine system family (where applicable, see paragraph 6.1. of this annex), or type(s) <u>11/</u> of the single engine system(s)	.... ....
- OBD description (issued by the manufacturer): reference and date	
<u>Approval of an emission OBD family</u>	
- List of the engine families concerned by the emission OBD family (when applicable, see paragraph 6.1.)	....
- Type <u>11/</u> of the parent engine system within the emission OBD family	....
- List of the engine types <u>11/</u> within the emission OBD family	....
- OBD description (issued by the manufacturer): reference and date	....
<u>Approval of an OBD system as member of a certified emission OBD family</u>	
- List of the engine families concerned by the emission OBD family (when applicable, see paragraph 6.1.)	
- Type <u>11/</u> of the parent engine system within the emission OBD family	....
- List of the engine types <u>11/</u> within the emission OBD family	....
- Name of the engine system family concerned by the new OBD system (when applicable)	....
- Type <u>11/</u> of the engine system concerned by the new OBD system	....
- Extended OBD description (issued by the manufacturer): reference and date	........

11/ as reported in the approval document

<p><u>Extension to include a new engine system into an emission OBD family</u></p> <ul style="list-style-type: none"> - List (extended if necessary) of the engine families concerned by the emission OBD family (when applicable, see paragraph 6.1.) - List (extended if necessary) of the engine types <u>11/</u> within the emission OBD family - Actualised (new or unchanged) type<u>11/</u> of the parent engine system within the emission OBD family - Extended OBD description (issued by the manufacturer): reference and date 	<p>....</p> <p>....</p> <p>....</p> <p>....</p>
<p><u>Extension to address a design change that affects the OBD system</u></p> <ul style="list-style-type: none"> - List of the engine families (when applicable) concerned by the design change - List of the engine types <u>11/</u> concerned by the design change - Actualised (when applicable, new or unchanged) type <u>11/</u> of the parent engine system within the emission OBD family - Modified OBD description (issued by the manufacturer): reference and date 	<p>....</p> <p>....</p> <p>....</p> <p>....</p>
<p><u>Extension to address a malfunction reclassification</u></p> <ul style="list-style-type: none"> - List of the engine families (when applicable) concerned by the reclassification - List of the engine types <u>11/</u> concerned by the reclassification - Modified OBD description (issued by the manufacturer): reference and date 	<p>....</p> <p>....</p> <p>....</p>

Item 2 to the technical compliance report (example)

INFORMATION CONCERNING THE CONFORMITY OF THE OBD SYSTEM

1. Documentation package

<p>The elements provided by the manufacturer in the documentation package of the emission OBD family, is complete and complies with the requirements of paragraph 8. of this annex, on the following issues:</p> <ul style="list-style-type: none"> - documentation associated with each monitored component or system - documentation associated with each DTC - documentation associated with the malfunction classification - documentation associated with the emission OBD family 	<p>YES / NO YES / NO YES / NO YES / NO</p>
<p>The documentation required in paragraph 8.2. of this annex for installing an OBD system in a vehicle has been provided by the manufacturer in the documentation package, is complete, and complies with the requirements of this annex:</p>	<p>YES / NO</p>
<p>The installation of the engine system equipped with the OBD system complies with Appendix 1 of this annex:</p>	<p>YES / NO</p>

2. Content of the documentation

<p><u>Monitoring</u> The monitors comply with the requirements of paragraph 4.2. of this annex:</p>	<p>YES / NO</p>
<p><u>Classification</u> The malfunction classification complies with the requirements of paragraph 4.5. of this annex:</p>	<p>YES / NO</p>
<p><u>MI activation scheme</u> According to paragraph 4.6.3. of this annex, the MI-activation scheme is:</p> <p>The activation and the extinguishing of the malfunction indicator comply with the requirements of paragraph 4.6. of this annex:</p>	<p>Discriminatory / Non-discriminatory</p> <p>YES / NO</p>
<p><u>DTCs recording & erasing</u> The recording and erasing of DTCs comply with the requirements of paragraphs 4.3. and 4.4. of this annex:</p>	<p>YES / NO</p>

<u>Disabling of the OBD system</u> The strategies described in the documentation package for a momentary disconnection or disabling of the OBD system comply with the requirements of paragraph 5.2. of this annex	YES / NO
<u>Electronic system security</u> The measures described by the manufacturer for electronic system security comply with the requirements of paragraph 4.8. of this annex	YES / NO

Item 3 to the technical compliance report (example)

INFORMATION CONCERNING DEFICIENCIES

Number of deficiencies of OBD system	(ex: 4 deficiencies)
The deficiencies comply with the requirements of paragraph 6.4. of this annex	YES / NO
<u>Deficiency No. 1</u> - Object of the deficiency - Period of the deficiency	e.g. measuring of the Urea concentration (SCR) within defined tolerances e.g. one year / six months after the date of approval
(Description of deficiencies 2 to n-1)	
<u>Deficiency No. n</u> - Object of the deficiency - Period of the deficiency	e.g. measuring of NH ₃ concentration behind SCR system e.g. one year / six months after the date of approval

Item 4 to the technical compliance report (example)

DEMONSTRATION TESTS OF THE OBD SYSTEM

1. Test result of the OBD system

<p><u>Results of the tests</u> The OBD system described in the above complying documentation package has been tested with success according to Paragraph 6 of this annex for demonstrating the compliance of monitors and of malfunction classifications as listed in item 5:</p>	<p>YES / NO</p>
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Details to the conducted demonstration tests are given in item 5.

1.1. OBD system tested on the engine test-bed

<p><u>Engine</u></p> <ul style="list-style-type: none"> - Engine name (manufacturer and commercial names): - Engine type (as reported in the approval document): - Engine number (serial number): 	<p>....</p>
<p><u>Control units concerned by this annex (incl. engine ECUs)</u></p> <ul style="list-style-type: none"> - Main functionality: - Identification number (software and calibration): 	<p>....</p>
<p><u>Diagnostic tool (scan tool used during testing)</u></p> <ul style="list-style-type: none"> - Manufacturer: - Type: - Software / version 	<p>....</p>
<p><u>Test information</u></p> <ul style="list-style-type: none"> - Ambient testing conditions (temperature, humidity, pressure): - Place of test (incl. altitude): - Testing fuel: - Engine lubricating oil: - Date of test: 	<p>....</p>

2. Demonstration tests of the installation of the OBD system

<p>In addition to the demonstration of the OBD system / emission OBD family, the installation of the OBD system / of the OBD systems within the emission OBD family has been tested on a vehicle, according to the provisions of Appendix 1 of the referenced annex:</p>	<p>YES / NO</p>
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2.1. Test result of the installation of the OBD system

<p><u>Results of the test</u> If the installation of the OBD system has been tested on a vehicle, the installation of the OBD system has been tested with success according to Appendix 1 to the referenced annex</p>	<p>YES / NO</p>
--	-----------------

2.2. Tested installation

If the installation of the OBD system has been tested on a vehicle:

<p><u>Tested vehicle</u></p> <ul style="list-style-type: none"> - Vehicle name (manufacturer and commercial names): - Vehicle type: - Vehicle Identification Number (VIN): 	<p>....</p> <p>....</p> <p>....</p>
<p><u>Diagnostic tool (scan tool used for testing)</u></p> <ul style="list-style-type: none"> - Manufacturer: - Type: - Software / version: 	<p>...</p> <p>....</p> <p>....</p>
<p><u>Test information</u></p> <ul style="list-style-type: none"> - Place and date: 	<p>....</p>

Item 5 to the technical compliance report (example)

TEST PROTOCOL

OBD System Demonstration Test																
- General -		- Demonstration of the Failure Classification -						- Demonstration of the OBD Performance -								
		- Test -		- Emission Level -		- Classification -		- Qualification of the Deteriorated Component -			- MI Activation -					
Failure Mode	Fault Code	Tested according to point	Test Cycle	above OTL	below OTL	below EL + X	Manufacturer proposed Classification	Final Classification (1)	Tested according to point	Test Cycle	qualified	Tested according to point	Test Cycle	Continuous-MI after ... cycle	short-MI after ... cycle	On-demand-MI after ... cycle
SCR System Dosing Valve	P 2...	not tested		-	-	-	A	A	6.3.2.1	WHTC	yes	6.3.1	WHTC	2nd		
EGR Valve Electrical	P 1...	not tested					A	B1	6.3.2.1	WHTC	yes	6.3.1	WHTC		1st	
EGR Valve Mechanical	P 1...	not tested					B1	B1	6.3.2.1	WHTC	yes	6.3.1	WHTC		2nd	
EGR Valve Mechanical	P 1...	6.2.2	WHTC		X		B1	B1	not tested		yes					
EGR Valve Mechanical	P 1...	6.2.2	WHTC		X		B1	B1	6.3.2.1	WHTC	yes	6.3.1	WHTC		2nd	
Air Temp. Sensor Electrical	P 1...	Not tested					B2	B2	6.3.2.2	WHTC	yes	6.3.1	WHTC		1st	
Oil Temp. Sensor Electrical	P 1...	6.2.6	ETC			X	C	C	not tested		yes					

Remarks: 1) Upon request of the certification authority the failure may be re-classified into a class different from the one proposed by the manufacturer.

Only the failures that have been tested either for classification or for performance and the failures that have been reclassified at the certification authority request are listed in this sheet

A malfunction may be tested either for its classification, or for its performance, or for both. Example given of the EGR mechanical valve gives the way each of these 3 cases are considered in the table

Annex 11 - Appendix 5

FREEZE FRAME AND DATA STREAM INFORMATION

The following tables list the pieces of information that are considered in paragraphs 4.7.1.4. and 4.7.2. of this annex.

Table 1: MANDATORY REQUIREMENTS:

	Freeze frame	Data stream
Calculated load (engine torque as a percentage of maximum torque available at the current engine speed)	x	x
Engine speed	x	x
Engine coolant temperature (or equivalent)	x	x
Barometric pressure (directly measured or estimated)	x	x

Table 2: OPTIONAL ENGINE SPEED AND LOAD INFORMATION:

	Freeze frame	Data stream
driver's demand engine torque (as a percentage of maximum engine torque)	x	x
actual engine torque (calculated as a percentage of maximum engine torque, e.g. calculated from commanded injection fuel quantity)	x	x
reference engine maximum torque		x
reference maximum engine torque as a function of engine speed		x
time elapsed since engine start	x	x

Table 3: OPTIONAL INFORMATION, IF USED BY THE EMISSION OR THE OBD SYSTEM TO ENABLE OR DISABLE ANY OBD INFORMATION

	Freeze frame	Data stream
fuel level	x	x
Engine oil temperature	x	x
vehicle speed	x	x
engine control computer system voltage (for the main control chip)	x	x

Table 4: OPTIONAL INFORMATION, IF THE ENGINE IS SO EQUIPPED, SENSES OR CALCULATES THE INFORMATION:

	Freeze frame	Data stream
Absolute throttle position / intake air throttle position (position of valve used to regulate intake air)	x	x
Diesel fuel control system status in case of a close loop system (e.g. in case of a fuel pressure close loop system)	x	x
Fuel rail pressure	x	x
Injection control pressure (i.e. pressure of the fluid controlling fuel injection)	x	x
Representative fuel injection timing (beginning of first main injection)	x	x
Commanded fuel rail pressure,	x	x
Commanded injection control pressure (i.e. pressure of the fluid controlling fuel injection)	x	x
Intake air temperature	x	x
Ambient air temperature	x	x
Turbocharger inlet / outlet air temperature (compressor and turbine)	x	x
Turbocharger inlet / outlet pressure (compressor and turbine)	x	x
Charge air temperature (post intercooler if fitted)	x	x
Actual boost pressure	x	x
Air flow rate from mass air flow sensor	x	x
Commanded EGR valve duty cycle/position, (provided EGR is so controlled)	x	x
Actual EGR valve duty cycle/position	x	x
PTO status (active or not active)	x	x
Accelerator pedal position	x	x
Redundant absolute pedal position	x	if sensed
Instantaneous fuel consumption	x	x
Commanded/target boost pressure (if boost pressure used to control turbo operation)	x	x
DPF inlet pressure	x	x
DPF outlet pressure	x	x
DPF delta pressure	x	x
Engine-out exhaust pressure	x	x
DPF inlet temperature	x	x
DPF outlet temperature	x	x
Engine-out exhaust gas temperature	x	x
Turbocharger/turbine speed	x	x
Variable geometry turbo position	x	x
Commanded variable geometry turbo position	x	x
Wastegate valve position	x	x
Air/fuel ratio sensor output		x
Oxygen sensor output		x
NO _x sensor output		x

REFERENCE STANDARD DOCUMENTS

This appendix contains the references to the industry standards that are to be used in accordance to the provisions in this annex to provide the serial communications interface to the vehicle/engine. There are three allowed solutions identified, ISO 15765-4 or SAE J1939-73 or ISO/PAS 27145. In addition there are other ISO or SAE standards that are applicable in accordance to the provisions in this annex.

ISO 15765-4 and those specifications included by reference therein to accomplish the WWH-OBD requirements.

ISO 15765-4 "Road vehicles - Diagnostics on Controller Area Network (CAN) - Part 4: Requirements for emissions-related systems", dated on year 2006.

SAE J1939-73 and those specifications included by reference therein to accomplish the WWH-OBD requirements.

J1939-73 "APPLICATION LAYER - DIAGNOSTICS", dated on year 2006.

ISO/PAS 27145 and those specifications included by reference therein to accomplish the WWH-OBD requirements.

- (i) ISO/PAS 27145-1:2006 Road vehicles - On board diagnostics (WWH-OBD) implementation - Part 1 - General Information and use case definitions
- (ii) ISO/PAS 27145-2:2006 Road vehicles – Implementation of WWH-OBD communication requirements - Part 2 - Common emissions-related data dictionary;
- (iii) ISO/PAS 27145-3:2006 Road vehicles – Implementation of WWH-OBD communication requirements - Part 3 - Common message dictionary;
- (iv) ISO/PAS 27145-4:2006 Road vehicles – Implementation of WWH-OBD communication requirements - Part 4 - Connection between vehicle and test equipment;

The following International Organization of Standards (ISO) documents are incorporated by reference into this Regulation:

ISO 15031-3:2004 "Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics — Part 3: Diagnostic connector and related electrical circuits, specification and use".

The following Society of Automotive Engineers (SAE) (ISO) documents are incorporated by reference into this Regulation:

SAE J2403 "Medium/Heavy-Duty E/E Systems Diagnosis Nomenclature", dated on August 2004.
SAE J1939-13 "Off-Board Diagnostic Connector", dated on March 2004.

Annex 11 - Appendix 7

DOCUMENTATION REGARDING OBD RELATED INFORMATION

The OBD related information requested by this appendix shall be provided by the vehicle manufacturer for the purposes of enabling the manufacture of OBD-compatible replacement or service parts and diagnostic tools and test equipment in the manner prescribed in the main part of this Regulation.

REPLACEMENT PARTS, DIAGNOSTIC TOOLS AND TEST EQUIPMENT

The information shall enable manufacturers of replacement or retrofit components to make the parts they manufacture compatible with the OBD system with a view to fault-free operation assuring the vehicle user against malfunctions. Similarly, such relevant information shall enable the manufacturers of diagnostic tools and test equipment to make tools and equipment that provide for effective and accurate diagnosis of emission control systems.

In the case of replacement or service components, information can only be requested for such components that are subject to type-approval, or for components that form part of a system that is subject to type-approval.

The request for information must identify the exact specification of the engine model type/engine model type within an engine family for which the information is required. It must confirm that the information is required for the development of replacement or retrofit parts or components or diagnostic tools or test equipment.

REPAIR INFORMATION

No later than three months after the manufacturer has provided any authorised dealer or repair shop with repair information, the manufacturer shall make that information (including all subsequent amendments and supplements) available upon reasonable and non-discriminatory payment.

The manufacturer must also make accessible, where appropriate upon payment the technical information required for the repair or maintenance of motor vehicles unless that information is covered by an intellectual property right or constitutes essential, secret know-how which is identified in an appropriate form; in such case, the necessary technical information must not be withheld improperly.

Entitled to such information is any person engaged in commercially servicing or repairing, road-side rescuing, inspecting or testing of vehicles or in manufacturing or selling replacement or retro-fit components, diagnostic tools and test equipment.

In the event of failure to comply with these provisions the administrative department shall take appropriate measures to ensure that repair information is available, in accordance with the procedures laid down for type-approval and in-service surveys.
