CORRIGENDA

Corrigendum to Regulation No 49 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of compression-ignition (C.I.) and natural gas (NG) engines as well as positive-ignition (P.I.) engines fuelled with liquefied petroleum gas (LPG) and vehicles equipped with C.I. and NG engines and P.I. engines fuelled with LPG, with regard to the emissions of pollutants by the engine

(Official Journal of the European Union L 375 of 27 December 2006)

Regulation No 49 should read as follows:

Regulation No 49 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of compression-ignition (C.I.) and natural gas (NG) engines as well as positive-ignition (P.I.) engines fuelled with liquefied petroleum gas (LPG) and vehicles equipped with C.I. and NG engines and P.I. engines fuelled with LPG, with regard to the emissions of pollutants by the engine

Revision 3

Incorporating:

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Corrigendum 1 to the 02 series of amendments subject of depositary notification
Corrigendum 2 to the 02 series of amendments subject of depositary notification
Corrigendum 1 to Revision 2 (Erratum — English only)
Supplement 1 to the 02 series of amendments — Date of entry into force: 18 May 1996
Supplement 2 to the 02 series of amendments — Date of entry into force: 28 August 1996
Corrigendum 1 to Supplement 1 to the 02 series of amendments subject of depositary notification
Corrigendum 2 to Supplement 1 to the 02 series of amendments subject of depositary notification
   C.N.272.1999.TREATIES-2 dated 12 April 1999
Corrigendum 1 to Supplement 2 to the 02 series of amendments subject of depositary notification
   C.N.271.1999.TREATIES-1 dated 12 April 1999
03 series of amendments — Date of entry into force: 27 December 2001
04 series of amendments — Date of entry into force: 31 January 2003

1. SCOPE

This Regulation applies to the emission of gaseous and particulate pollutants from C.I. and NG engines and P.I. engines fuelled with LPG, used for driving motor vehicles having a design speed exceeding 25 km/h of categories (1) M1, having a total mass exceeding 3.5 tonnes, M2, N1, N2 and N3.

(1) In conformity with annex 7 of the Consolidated Resolution on the Construction of Vehicles (R.E.3), (TRANS/WP.29/78/Rev.1/Amend.2).
(2) Engines used by category N1, N2 and M1 power-driven vehicles are not approved according to this Regulation, provided that such vehicles are approved according to Regulation No 83.
2. DEFINITIONS AND ABBREVIATIONS

For the purposes of this Regulation:

2.1. ‘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);

2.2. ‘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;

2.3. ‘diesel engine’ means an engine which works on the compression-ignition principle;

2.4. ‘gas engine’ means an engine, which is fuelled with natural gas (NG) or liquid petroleum gas (LPG);

2.5. ‘engine type’ means a category of engines which do not differ in such essential respects as engine characteristics as defined in annex 1 to this Regulation;

2.6. ‘engine family’ means a manufacturers grouping of engines which, through their design as defined in annex 1, appendix 2 to this Regulation, have similar exhaust emission characteristics; all members of the family must comply with the applicable emission limit values;

2.7. ‘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;

2.8. ‘gaseous pollutants’ means carbon monoxide, hydrocarbons (assuming a ratio of CH1,85 for diesel, CH2,525 for LPG and an assumed molecule CH3O0,5 for ethanol-fuelled diesel engines), non-methane hydrocarbons (assuming a ratio of CH1,85 for diesel fuel, CH2,525 for LPG and CH2,93 for NG), methane (assuming a ratio of CH4 for NG) and oxides of nitrogen, the last-named being expressed in nitrogen dioxide (NO2) equivalent;

2.9. ‘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);

2.10. ‘net power’ means the power in ECE kW obtained on the test bench at the end of the crankshaft, or its equivalent, measured in accordance with the method of measuring power as set out in Regulation No 24.

2.11. ‘declared maximum power (Pmax)’ means the maximum power in ECE kW (net power) as declared by the manufacturer in his application for approval;

2.12. ‘per cent load’ means the fraction of the maximum available torque at an engine speed;

2.13. ‘ESC test’ means a test cycle consisting of 13 steady state modes to be applied in accordance with paragraph 5.2. of this Regulation;

2.14. ‘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. of this Regulation;

2.15. ‘ETC test’ means a test cycle consisting of 1 800 second-by-second transient modes to be applied in accordance with paragraph 5.2. of this Regulation;

2.16. ‘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 annex 4 to this Regulation.
2.16. ‘low speed (n_{lo})’ means the lowest engine speed where 50 per cent of the declared maximum power occurs;

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

2.18. ‘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 annex 4, appendix 1 to this Regulation;

2.19. ‘control area’ means the area between the engine speeds A and C and between 25 to 100 per cent load;

2.20. ‘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 annex 4, appendix 2 to this Regulation;

2.21. ‘opacimeter’ means an instrument designed to measure the opacity of smoke particles by means of the light extinction principle;

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

2.23. ‘self adaptability’ means any engine device allowing the air/fuel ratio to be kept constant;

2.24. ‘recalibration’ means a fine-tuning of a NG engine in order to provide the same performance (power, fuel consumption) in a different range of natural gas;

2.25. ‘Wobbe Index (lower W_{l} or upper W_{u})’ 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:

\[ W = \frac{H_{gas} \times \sqrt{\rho_{air} / \rho_{gas}}}{\sqrt{\rho_{air} / \rho_{gas}}} \]

2.26. ‘\( \lambda \)-shift factor \( (S_{\lambda}) \)’ means an expression that describes the required flexibility of the engine management system regarding a change of the excess-air ratio \( \lambda \) if the engine is fuelled with a gas composition different from pure methane (see annex 8 for the calculation of \( S_{\lambda} \));

2.27. ‘EEV’ means Enhanced Environmentally Friendly Vehicle which is a type of vehicle propelled by an engine complying with the permissive emission limit values given in row C of the Tables in paragraph 5.2.1. of this Regulation;

2.28. ‘Defeat Device’ means a device which measures, 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 activating, modulating, delaying or deactivating the operation of any component or function of the emission control system such that the effectiveness of the emission control system is reduced under conditions encountered during normal vehicle use unless the use of such a device is substantially included in the applied emission certification test procedures.

2.29. ‘Auxiliary control device’ means a system, function or control strategy installed to an engine or on a vehicle, that is used to protect the engine and/or its ancillary equipment against operating conditions that could result in damage or failure, or is used to facilitate engine starting. An auxiliary control device may also be a strategy or measure that has been satisfactorily demonstrated not to be a defeat device.

2.30. ‘Irrational emission control strategy’ means any strategy or measure that, when the vehicle is operated under normal conditions of use, reduces the effectiveness of the emission control system to a level below that expected on the applicable emission test procedures.
### 2.31. Symbols and Abbreviations

#### 2.31.1. Symbols for Test Parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_p$</td>
<td>m$^2$</td>
<td>Cross sectional area of the isokinetic sampling probe</td>
</tr>
<tr>
<td>$A_T$</td>
<td>m$^2$</td>
<td>Cross sectional area of the exhaust pipe</td>
</tr>
<tr>
<td>$C_{EE}$</td>
<td>—</td>
<td>Ethane efficiency</td>
</tr>
<tr>
<td>$C_{EM}$</td>
<td>—</td>
<td>Methane efficiency</td>
</tr>
<tr>
<td>$C_1$</td>
<td>—</td>
<td>Carbon 1 equivalent hydrocarbon</td>
</tr>
<tr>
<td>conc</td>
<td>ppm/vol%</td>
<td>Subscript denoting concentration</td>
</tr>
<tr>
<td>$D_0$</td>
<td>m$^3$/s</td>
<td>Intercept of PDP calibration function</td>
</tr>
<tr>
<td>DF</td>
<td>—</td>
<td>Dilution factor</td>
</tr>
<tr>
<td>D</td>
<td>—</td>
<td>Bessel function constant</td>
</tr>
<tr>
<td>E</td>
<td>—</td>
<td>Bessel function constant</td>
</tr>
<tr>
<td>$E_Z$</td>
<td>g/kWh</td>
<td>Interpolated NO$_x$ emission of the control point</td>
</tr>
<tr>
<td>$f_a$</td>
<td>—</td>
<td>Laboratory atmospheric factor</td>
</tr>
<tr>
<td>$f_c$</td>
<td>s$^{-1}$</td>
<td>Bessel filter cut-off frequency</td>
</tr>
<tr>
<td>$F_{FH}$</td>
<td>—</td>
<td>Fuel specific factor for the calculation of wet concentration for dry concentration</td>
</tr>
<tr>
<td>$F_S$</td>
<td>—</td>
<td>Stoichiometric factor</td>
</tr>
<tr>
<td>$G_{AIRW}$</td>
<td>kg/h</td>
<td>Intake air mass flow rate on wet basis</td>
</tr>
<tr>
<td>$G_{AIRD}$</td>
<td>kg/h</td>
<td>Intake air mass flow rate on dry basis</td>
</tr>
<tr>
<td>$G_{DLW}$</td>
<td>kg/h</td>
<td>Dilution air mass flow rate on wet basis</td>
</tr>
<tr>
<td>$G_{EDFW}$</td>
<td>kg/h</td>
<td>Equivalent diluted exhaust gas mass flow rate on wet basis</td>
</tr>
<tr>
<td>$G_{EXHW}$</td>
<td>kg/h</td>
<td>Exhaust gas mass flow rate on wet basis</td>
</tr>
<tr>
<td>$G_{FUEL}$</td>
<td>kg/h</td>
<td>Fuel mass flow rate</td>
</tr>
</tbody>
</table>

![Figure 1: Specific definitions of the test cycles](image-url)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>G&lt;sub&gt;TOTW&lt;/sub&gt;</td>
<td>kg/h</td>
<td>Diluted exhaust gas mass flow rate on wet basis</td>
</tr>
<tr>
<td>H</td>
<td>MJ/m³</td>
<td>Calorific value</td>
</tr>
<tr>
<td>H&lt;sub&gt;REF&lt;/sub&gt;</td>
<td>g/kg</td>
<td>Reference value of absolute humidity (10.71 g/kg)</td>
</tr>
<tr>
<td>H&lt;sub&gt;a&lt;/sub&gt;</td>
<td>g/kg</td>
<td>Absolute humidity of the intake air</td>
</tr>
<tr>
<td>H&lt;sub&gt;d&lt;/sub&gt;</td>
<td>g/kg</td>
<td>Absolute humidity of the dilution air</td>
</tr>
<tr>
<td>H&lt;sub&gt;T&lt;/sub&gt;</td>
<td>mol/mol</td>
<td>Hydrogen-to-Carbon ratio</td>
</tr>
<tr>
<td>I</td>
<td>—</td>
<td>Subscript denoting an individual mode</td>
</tr>
<tr>
<td>K&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Bessel constant</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>m&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>Light absorption coefficient</td>
</tr>
<tr>
<td>K&lt;sub&gt;DLD&lt;/sub&gt;</td>
<td>—</td>
<td>Humidity correction factor for NO&lt;sub&gt;x&lt;/sub&gt; for diesel engines</td>
</tr>
<tr>
<td>K&lt;sub&gt;HG&lt;/sub&gt;</td>
<td>—</td>
<td>Humidity correction factor for NO&lt;sub&gt;x&lt;/sub&gt; for gas engines</td>
</tr>
<tr>
<td>K&lt;sub&gt;V&lt;/sub&gt;</td>
<td>—</td>
<td>CFV calibration function</td>
</tr>
<tr>
<td>K&lt;sub&gt;W,a&lt;/sub&gt;</td>
<td>—</td>
<td>Dry to wet correction factor for the intake air</td>
</tr>
<tr>
<td>K&lt;sub&gt;W,d&lt;/sub&gt;</td>
<td>—</td>
<td>Dry to wet correction factor for the dilution air</td>
</tr>
<tr>
<td>K&lt;sub&gt;W,c&lt;/sub&gt;</td>
<td>—</td>
<td>Dry to wet correction factor for the diluted exhaust gas</td>
</tr>
<tr>
<td>K&lt;sub&gt;W,e&lt;/sub&gt;</td>
<td>—</td>
<td>Dry to wet correction factor for the raw exhaust gas</td>
</tr>
<tr>
<td>L</td>
<td>%</td>
<td>Percent torque related to the maximum torque for the test engine</td>
</tr>
<tr>
<td>L&lt;sub&gt;a&lt;/sub&gt;</td>
<td>m</td>
<td>Effective optical path length</td>
</tr>
<tr>
<td>M&lt;sub&gt;dd&lt;/sub&gt;</td>
<td>g/h or g</td>
<td>Subscript denoting emissions mass flow (rate)</td>
</tr>
<tr>
<td>M&lt;sub&gt;DIL&lt;/sub&gt;</td>
<td>kg</td>
<td>Mass of the dilution air sample passed through the particulate sampling filters</td>
</tr>
<tr>
<td>M&lt;sub&gt;d&lt;/sub&gt;</td>
<td>mg</td>
<td>Particulate sample mass of the dilution air collected</td>
</tr>
<tr>
<td>M&lt;sub&gt;f&lt;/sub&gt;</td>
<td>mg</td>
<td>Particulate sample mass collected</td>
</tr>
<tr>
<td>M&lt;sub&gt;f,p&lt;/sub&gt;</td>
<td>mg</td>
<td>Particulate sample mass collected on primary filter</td>
</tr>
<tr>
<td>M&lt;sub&gt;f,b&lt;/sub&gt;</td>
<td>mg</td>
<td>Particulate sample mass collected on back-up filter</td>
</tr>
<tr>
<td>M&lt;sub&gt;SAM&lt;/sub&gt;</td>
<td>kg</td>
<td>Mass of the diluted exhaust sample passed through the particulate sampling filters</td>
</tr>
<tr>
<td>M&lt;sub&gt;SEC&lt;/sub&gt;</td>
<td>kg</td>
<td>Mass of secondary dilution air</td>
</tr>
<tr>
<td>M&lt;sub&gt;TOTW&lt;/sub&gt;</td>
<td>kg</td>
<td>Total CVS mass over the cycle on wet basis</td>
</tr>
<tr>
<td>M&lt;sub&gt;TOTW,i&lt;/sub&gt;</td>
<td>kg</td>
<td>Instantaneous CVS mass on wet basis</td>
</tr>
<tr>
<td>N&lt;sub&gt; opacity&lt;/sub&gt;</td>
<td>%</td>
<td>Opacity</td>
</tr>
<tr>
<td>N&lt;sub&gt;p&lt;/sub&gt;</td>
<td>—</td>
<td>Total revolutions of PDP over the cycle</td>
</tr>
<tr>
<td>N&lt;sub&gt;p,i&lt;/sub&gt;</td>
<td>—</td>
<td>Revolutions of PDP during a time interval</td>
</tr>
<tr>
<td>N&lt;sub&gt;s&lt;/sub&gt;</td>
<td>min&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>Engine speed</td>
</tr>
<tr>
<td>n&lt;sub&gt;p&lt;/sub&gt;</td>
<td>s&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>PDP speed</td>
</tr>
<tr>
<td>n&lt;sub&gt;hi&lt;/sub&gt;</td>
<td>min&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>High engine speed</td>
</tr>
<tr>
<td>n&lt;sub&gt;lo&lt;/sub&gt;</td>
<td>min&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>Low engine speed</td>
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<tr>
<td>Symbol</td>
<td>Unit</td>
<td>Term</td>
</tr>
<tr>
<td>--------</td>
<td>-------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>$n_{ref}$</td>
<td>min$^{-1}$</td>
<td>Reference engine speed for ETC test</td>
</tr>
<tr>
<td>$P_a$</td>
<td>kPa</td>
<td>Saturation vapour pressure of the engine intake air</td>
</tr>
<tr>
<td>$P_A$</td>
<td>kPa</td>
<td>Absolute pressure</td>
</tr>
<tr>
<td>$P_b$</td>
<td>kPa</td>
<td>Total atmospheric pressure</td>
</tr>
<tr>
<td>$P_d$</td>
<td>kPa</td>
<td>Saturation vapour pressure of the dilution air</td>
</tr>
<tr>
<td>$P_s$</td>
<td>kPa</td>
<td>Dry atmospheric pressure</td>
</tr>
<tr>
<td>$P_1$</td>
<td>kPa</td>
<td>Pressure depression at pump inlet</td>
</tr>
<tr>
<td>$P(a)$</td>
<td>kW</td>
<td>Power absorbed by auxiliaries to be fitted for test</td>
</tr>
<tr>
<td>$P(b)$</td>
<td>kW</td>
<td>Power absorbed by auxiliaries to be removed for test</td>
</tr>
<tr>
<td>$P(n)$</td>
<td>kW</td>
<td>Net power non-corrected</td>
</tr>
<tr>
<td>$P(m)$</td>
<td>kW</td>
<td>Power measured on test bed</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>—</td>
<td>Bessel constant</td>
</tr>
<tr>
<td>$Q_s$</td>
<td>m$^3$/s</td>
<td>CVS volume flow rate</td>
</tr>
<tr>
<td>$q$</td>
<td>—</td>
<td>Dilution ratio</td>
</tr>
<tr>
<td>$r$</td>
<td>—</td>
<td>Ratio of cross sectional areas of isokinetic probe and exhaust pipe</td>
</tr>
<tr>
<td>$R_a$</td>
<td>%</td>
<td>Relative humidity of the intake air</td>
</tr>
<tr>
<td>$R_d$</td>
<td>%</td>
<td>Relative humidity of the dilution air</td>
</tr>
<tr>
<td>$R_f$</td>
<td>—</td>
<td>FID response factor</td>
</tr>
<tr>
<td>$\rho$</td>
<td>kg/m$^3$</td>
<td>Density</td>
</tr>
<tr>
<td>$S$</td>
<td>kW</td>
<td>Dynamometer setting</td>
</tr>
<tr>
<td>$S_i$</td>
<td>m$^{-1}$</td>
<td>Instantaneous smoke value</td>
</tr>
<tr>
<td>$S_{\lambda}$</td>
<td>—</td>
<td>$\lambda$-shift factor</td>
</tr>
<tr>
<td>$T$</td>
<td>K</td>
<td>Absolute temperature</td>
</tr>
<tr>
<td>$T_a$</td>
<td>K</td>
<td>Absolute temperature of the intake air</td>
</tr>
<tr>
<td>$t$</td>
<td>s</td>
<td>Measuring time</td>
</tr>
<tr>
<td>$t_e$</td>
<td>s</td>
<td>Electrical response time</td>
</tr>
<tr>
<td>$t_f$</td>
<td>s</td>
<td>Filter response time for Bessel function</td>
</tr>
<tr>
<td>$t_p$</td>
<td>s</td>
<td>Physical response time</td>
</tr>
<tr>
<td>$\Delta t$</td>
<td>s</td>
<td>Time interval between successive smoke data (= 1/sampling rate)</td>
</tr>
<tr>
<td>$\Delta t_i$</td>
<td>s</td>
<td>Time interval for instantaneous CFV flow</td>
</tr>
<tr>
<td>$\tau$</td>
<td>%</td>
<td>Smoke transmittance</td>
</tr>
<tr>
<td>$V_0$</td>
<td>m$^3$/rev</td>
<td>PDP volume flow rate at actual conditions</td>
</tr>
<tr>
<td>$W$</td>
<td>—</td>
<td>Wobbe index</td>
</tr>
<tr>
<td>$W_{act}$</td>
<td>kWh</td>
<td>Actual cycle work of ETC</td>
</tr>
<tr>
<td>$W_{ref}$</td>
<td>kWh</td>
<td>Reference cycle work of ETC</td>
</tr>
<tr>
<td>$WF$</td>
<td>—</td>
<td>Weighting factor</td>
</tr>
<tr>
<td>$WF_{ef}$</td>
<td>—</td>
<td>Effective weighting factor</td>
</tr>
<tr>
<td>$X_0$</td>
<td>m$^3$/rev</td>
<td>Calibration function of PDP volume flow rate</td>
</tr>
<tr>
<td>$Y_i$</td>
<td>m$^{-1}$</td>
<td>1 s Bessel averaged smoke value</td>
</tr>
</tbody>
</table>
2.31.2. Symbols for the Chemical Components

CH$_4$ Methane
C$_2$H$_6$ Ethane
C$_2$H$_5$OH Ethanol
C$_3$H$_8$ Propane
CO Carbon monoxide
DOP Di-octylphthalate
CO$_2$ Carbon dioxide
HC Hydrocarbons
NMHC Non-methane hydrocarbons
NO$_x$ Oxides of nitrogen
NO Nitric oxide
NO$_2$ Nitrogen dioxide
PT Particulates

2.31.3. 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 Analyser
NG Natural Gas
NMC Non-Methane Cutter

3. APPLICATION FOR APPROVAL

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

3.1.1. The application for approval of an engine type with regard to the level of the emission of gaseous and particulate pollutants is submitted by the engine manufacturer or by his duly accredited representative.

3.1.2. It shall be accompanied by the necessary documents in triplicate. It will at least include the essential characteristics of the engine as referred to in annex 1 to this Regulation.

3.1.3. An engine conforming to the ‘engine type’ 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 of a vehicle type in respect of its engine

3.2.1. The application for approval of a vehicle type with regard to emission of gaseous and particulate pollutants by its engine is submitted by the vehicle manufacturer or his duly accredited representative.
3.2.2. It shall be accompanied by the necessary documents in triplicate. It will at least include:

3.2.2.1. The essential characteristics of the engine as referred to in annex 1;

3.2.2.2. A description of the engine related components as referred to in annex 1;

3.2.2.3. A copy of the type approval communication form (annex 2A) for the engine type installed.

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 engine family and with regard to the level of the emission of gaseous pollutants by its approved gas engine or engine family must be submitted by the vehicle manufacturer or a duly accredited representative.

3.3.2. It must be accompanied by the necessary 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.

4. APPROVAL

4.1. Universal fuel approval

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

4.1.1. In the case of diesel fuel: if pursuant to paragraphs 3.1., 3.2. or 3.3. of this Regulation, the engine or vehicle meets the requirements of paragraphs 5, 6 and 7 below on the reference fuel specified in annex 5 of this Regulation, approval of that type of engine or vehicle must be granted.

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 ($S_\lambda$). The formulae for the calculation of the Wobbe index and $S_\lambda$ are given in paragraphs 2.25. and 2.26. Natural gases with a $\lambda$-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 $\lambda$-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 $S_\lambda$.

The parent engine must meet the requirements of this Regulation on the reference fuels GR (fuel 1) and G25 (fuel 2), as specified in annex 6, 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 must be run-in using the procedure given in paragraph 3 of appendix 2 to annex 4.
4.1.2. On the manufacturer’s request the engine may be tested on a third fuel (fuel 3) if the λ-shift factor ($S_{\lambda}$) lies between 0.89 (i.e. the lower range of GR) and 1.19 (i.e. the upper range of G25), 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 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 must be tested at each position of the switch on the reference fuel relevant for the respective position as specified in annex 6 for each range. The fuels are GR (fuel 1) and G23 (fuel 3) for the H-range of gases and G25 (fuel 2) and G23 (fuel 3) for the L-range of gases. The parent engine must meet the requirements of this Regulation at both positions of the switch without any readjustment to the fuelling between the two tests at the respective 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 must be run-in using the procedure given in paragraph 3 of appendix 2 to annex 4.

4.1.3.1. On the manufacturer’s request the engine may be tested on a third fuel instead of G23 (fuel 3) if the λ-shift factor ($S_{\lambda}$) lies between 0.89 (i.e. the lower range of GR) and 1.19 (i.e. the upper range of G25), 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 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,

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

and,

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

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 7 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 must be run-in using the procedure defined in paragraph 3 of appendix 2 to annex 4.

4.1.5.1. The ratio of emission results $r$ must 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 must be tested on the relevant reference fuel as specified in annex 6 for the relevant range. The fuels are GR (fuel 1) and G23 (fuel 3) for the H-range of gases and G25 (fuel 2) and G23 (fuel 3) for the L-range of gases. The parent engine must 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 must be run-in using the procedure defined in paragraph 3 of appendix 2 to annex 4.

4.2.1.1. On the manufacturer’s request the engine may be tested on a third fuel instead of G23 (fuel 3) if the λ-shift factor ($S_\lambda$) lies between 0.89 (i.e. the lower range of GR) and 1.19 (i.e. the upper range of G25), 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 $r$ must 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. Upon delivery to the customer the engine must 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 must meet the emission requirements on the reference fuels GR and G25 in the case of natural gas, or the reference fuels A and B in the case of LPG, as specified in annex 7.

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. On the manufacturer’s request the engine may be tested on the reference fuels GR and G23, or on the reference fuels G25 and G23, in which case the approval is only valid for the H-range or the L-range of gases respectively.

4.2.2.3. Upon delivery to the customer the engine must bear a label (see paragraph 4.11.) stating for which fuel composition the engine has been calibrated.
## APPROVAL OF NG-FUELLED ENGINES

### Para. 4.1. Granting of a universal fuel approval

<table>
<thead>
<tr>
<th>Number of test runs</th>
<th>Calculation of $r'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$r = \frac{\text{fuel 2 (G25)}}{\text{fuel 1 (GR)}}$</td>
</tr>
<tr>
<td>(max. 3)</td>
<td>and, if tested with an additional fuel</td>
</tr>
<tr>
<td></td>
<td>$ra = \frac{\text{fuel 2 (G25)}}{\text{fuel 3 (market fuel)}}$</td>
</tr>
<tr>
<td></td>
<td>and</td>
</tr>
<tr>
<td></td>
<td>$rb = \frac{\text{fuel 1 (GR)}}{\text{fuel 3 (G23 or market fuel)}}$</td>
</tr>
</tbody>
</table>

**Refer to para. 4.1.2.**

NG-engine adaptable to any fuel composition

GR (1) and G23 (2) at manufacturer’s request engine may be tested on an additional market fuel (3), if $S_\lambda = 0.89 - 1.19$

### Para. 4.2. Granting of a fuel restricted approval

<table>
<thead>
<tr>
<th>Number of test runs</th>
<th>Calculation of $r'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$r = \frac{\text{fuel 2 (G25)}}{\text{fuel 1 (GR)}}$</td>
</tr>
<tr>
<td>(max. 3)</td>
<td>and, if tested with an additional fuel</td>
</tr>
<tr>
<td></td>
<td>$ra = \frac{\text{fuel 2 (G25)}}{\text{fuel 3 (market fuel)}}$</td>
</tr>
<tr>
<td></td>
<td>and</td>
</tr>
<tr>
<td></td>
<td>$rb = \frac{\text{fuel 1 (GR)}}{\text{fuel 3 (G23 or market fuel)}}$</td>
</tr>
</tbody>
</table>

**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 $S_\lambda = 0.89 - 1.19$

<table>
<thead>
<tr>
<th>Number of test runs</th>
<th>Calculation of $r'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$rb = \frac{\text{fuel 1 (GR)}}{\text{fuel 3 (G23 or market fuel)}}$</td>
</tr>
<tr>
<td>(max. 3)</td>
<td>for the H-range</td>
</tr>
<tr>
<td>2</td>
<td>$ra = \frac{\text{fuel 2 (G25)}}{\text{fuel 3 (G23 or market fuel)}}$</td>
</tr>
<tr>
<td>(max. 3)</td>
<td>for the L-range</td>
</tr>
</tbody>
</table>

**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 $S_\lambda = 0.89 - 1.19$

<table>
<thead>
<tr>
<th>Number of test runs</th>
<th>Calculation of $r'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$rb = \frac{\text{fuel 1 (GR)}}{\text{fuel 3 (G23 or market fuel)}}$</td>
</tr>
<tr>
<td>(max. 3)</td>
<td>for the H-range</td>
</tr>
<tr>
<td>2</td>
<td>$ra = \frac{\text{fuel 2 (G25)}}{\text{fuel 3 (G23 or market fuel)}}$</td>
</tr>
<tr>
<td>(max. 3)</td>
<td>for the L-range</td>
</tr>
</tbody>
</table>
## APPROVAL OF LPG-FUELLED ENGINES

<table>
<thead>
<tr>
<th>Para. 4.1. Granting of a universal fuel approval</th>
<th>Number of test runs</th>
<th>Calculation of ( r' )</th>
<th>Para. 4.2. Granting of a fuel restricted approval</th>
<th>Number of test runs</th>
<th>Calculation of ( r' )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refer to para. 4.2.2, NG-engine laid out for operation on one specific fuel composition</td>
<td>fuel A and fuel B</td>
<td>2</td>
<td>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</td>
<td>2 or 2 for the H-range or 2 for the L-range</td>
<td>2</td>
</tr>
</tbody>
</table>

---

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 must 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 approval authority determines that, with regard to the selected parent engine the submitted application does not fully represent the engine family defined in the Regulation, appendix 1, an alternative and, if necessary, an additional reference test engine may be selected by the approval authority and tested.

4.4. An approval number shall be assigned to each type approved. Its first two digits (at present 04, corresponding to 04 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);

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 4.4.1.

(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 and Montenegro, 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 and 51 for the Republic of Korea. 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.
However, the approval mark must contain an additional character after the letter 'R', the purpose of which is to distinguish the emission limit values for which the approval has been granted. For those approvals issued to indicate compliance with the limits contained in Row A of the relevant table(s) in paragraph 5.2.1., the letter 'R' will be followed by the Roman number I. For those approvals issued to indicate compliance with the limits contained in Row B1 of the relevant table(s) in paragraph 5.2.1., the letter 'R' will be followed by the Roman number II. For those approvals issued to indicate compliance with the limits contained in Row B2 of the relevant table(s) in paragraph 5.2.1., the letter 'R' will be followed by the Roman number III. For those approvals issued to indicate compliance with the limits contained in Row C of the relevant table(s) in paragraph 5.2.1., the letter 'R' will be followed by the Roman number IV.

For NG fuelled engines the approval mark must 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:

- H in case of the engine being approved and calibrated for the H-range of gases;
- L in case of the engine being approved and calibrated for the L-range of gases;
- HL in case of the engine being approved and calibrated for both the H-range and L-range of gases;
- 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;
- 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;
- 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.

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.

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

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

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

- the trademark or trade name of the manufacturer of the engine;
- 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 must 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 6 or 7 shall be given with the individual constituents and limits specified by the engine manufacturer.

The letters and figures must 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 must 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 must be durable for the useful life of the engine. Labels must be clearly legible and their letters and figures must be indelible. Additionally, labels must 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 must be secured to an engine part necessary for normal engine operation and not normally requiring replacement during engine life. Additionally, these labels must 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 type-approval for a vehicle type in respect of its engine, the marking specified in paragraph 4.11. must also be placed close to fuel filling aperture.

4.13. In case of an application for type-approval for a vehicle type with an approved engine, the marking specified in paragraph 4.11. must 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 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.
5.1.2. **Functions of emission control equipment**

5.1.2.1. The use of a defeat device and/or an irrational emission control strategy is forbidden.

5.1.2.2. An auxiliary control device may be installed to an engine, or on a vehicle, provided that the device:

5.1.2.2.1. operates only outside the conditions specified in paragraph 5.1.2.4., or

5.1.2.2.2. is activated only temporarily under the conditions specified in paragraph 5.1.2.4. for such purposes as engine damage protection, air-handling device protection, smoke management, cold start or warming-up, or

5.1.2.2.3. is activated only by on-board signals for purposes such as operational safety and limp-home strategies;

5.1.2.3. An engine control device, function, system or measure that operates during the conditions specified in paragraph 5.1.2.4. and which results in the use of a different or modified engine control strategy to that normally employed during the applicable emission test cycles will be permitted if, in complying with the requirements of paragraphs 5.1.3. and/or 5.1.4., it is fully demonstrated that the measure does not reduce the effectiveness of the emission control system. In all other cases, such devices shall be considered to be a defeat device.

5.1.2.4. For the purposes of paragraph 5.1.2.2., the defined conditions of use under steady state and transient conditions are:

(i) an altitude not exceeding 1 000 metres (or equivalent atmospheric pressure of 90 kPa),

(ii) an ambient temperature within the range 283 to 303 K (10 to 30 °C),

(iii) engine coolant temperature within the range 343 to 368 K (70 to 95 °C).

5.1.3. **Special requirements for electronic emission control systems**

5.1.3.1. **Documentation requirements**

The manufacturer shall provide a documentation package that gives access to the basic design of the 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 type-approval application, shall include a full description of the system. 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 control device and the boundary conditions under which the device operates. The additional material shall include a description of the fuel system control logic, timing strategies and switch points during all modes of operation.

The additional material shall also contain a justification for the use of any auxiliary control device and include additional material and test data to demonstrate the effect on exhaust emissions of any auxiliary control device installed to the engine or on the vehicle.

This additional material shall remain strictly confidential and be retained by the manufacturer, but be made open for inspection at the time of type-approval or at any time during the validity of the type-approval.
5.1.4. To verify whether any strategy or measure should be considered a defeat device or an irrational emission control strategy according to the definitions given in paragraphs 2.28. and 2.30., the type-approval authority and/or the technical service may additionally request a NOx screening test using the ETC which may be carried out in combination with either the type-approval test or the procedures for checking the conformity of production.

5.1.4.1. As an alternative to the requirements of appendix 4 to annex 4 to this Regulation, the emissions of NOx during the ETC screening test may be sampled using the raw exhaust gas and the technical prescriptions of ISO FDIS 16 183, dated 15 September 2001, shall be followed.

5.1.4.2. In verifying whether any strategy or measure should be considered a defeat device or an irrational emission control strategy according to the definitions given in paragraphs 2.28. and 2.30., an additional margin of 10 per cent, related to the appropriate NOx limit value, shall be accepted.

5.2. For approval to row A of the tables in paragraph 5.2.1., the emissions must be determined on the ESC and ELR tests with conventional diesel engines including those fitted with electronic fuel injection equipment, exhaust gas recirculation (EGR), and/or oxidation catalysts. Diesel engines fitted with advanced exhaust after-treatment systems including deNOx catalysts and/or particulate traps, must additionally be tested on the ETC test.

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

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

The ESC and ELR test procedures are described in annex 4, appendix 1, the ETC test procedure in annex 4, Appendices 2 and 3.

The emissions of gaseous pollutants and particulate pollutants, by the engine submitted for testing, if applicable, must be measured by the method described in annex 4. Annex 4, appendix 4 describes the recommended analytical systems for the gaseous and particulate pollutants and the recommended particulate sampling systems. Other systems or analysers may be approved by the technical service if it is found that they yield equivalent results. For a single laboratory, equivalency is defined as the test results to fall within ± 5 per cent of the test results of one of the reference systems described herein. For particulate emissions only the full-flow dilution system is recognized as the reference system. For introduction of a new system into the Regulation, the determination of equivalency must be based upon the calculation of repeatability and reproducibility by an inter-laboratory test, 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, must not exceed the amounts shown in Table 1.

For diesel engines that are additionally tested on the ETC test, and specifically for gas engines, the specific masses of the carbon monoxide, of the non-methane hydrocarbons, of the methane (where applicable), of the oxides of nitrogen and of the particulates (where applicable) must not exceed the amounts shown in Table 2.
Table 1

Limit values — ESC and ELR tests

<table>
<thead>
<tr>
<th>Row</th>
<th>Mass of carbon monoxide (CO) g/kWh</th>
<th>Mass of hydrocarbons (HC) g/kWh</th>
<th>Mass of nitrogen oxides (NOx) g/kWh</th>
<th>Mass of particulates (PT) g/kWh</th>
<th>Smoke m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (2000)</td>
<td>2,1</td>
<td>0,66</td>
<td>5,0</td>
<td>0,10</td>
<td>0,13 (a)</td>
</tr>
<tr>
<td>B1 (2005)</td>
<td>1,5</td>
<td>0,46</td>
<td>3,5</td>
<td>0,02</td>
<td>0,05</td>
</tr>
<tr>
<td>B2 (2008)</td>
<td>1,5</td>
<td>0,46</td>
<td>2,0</td>
<td>0,02</td>
<td>0,05</td>
</tr>
<tr>
<td>C (EEV)</td>
<td>1,5</td>
<td>0,25</td>
<td>2,0</td>
<td>0,02</td>
<td>0,15</td>
</tr>
</tbody>
</table>

(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 (b)

<table>
<thead>
<tr>
<th>Row</th>
<th>Mass of carbon monoxide (CO) g/kWh</th>
<th>Mass of non-methane hydrocarbons (NMHC) g/kWh</th>
<th>Mass of methane (CH₄) g/kWh</th>
<th>Mass of nitrogen oxides (NOx) g/kWh</th>
<th>Mass of particulates (PT) (c) g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (2000)</td>
<td>5,45</td>
<td>0,78</td>
<td>1,6</td>
<td>5,0</td>
<td>0,16 (a)</td>
</tr>
<tr>
<td>B1 (2005)</td>
<td>4,0</td>
<td>0,55</td>
<td>1,1</td>
<td>3,5</td>
<td>0,03</td>
</tr>
<tr>
<td>B2 (2008)</td>
<td>4,0</td>
<td>0,55</td>
<td>1,1</td>
<td>2,0</td>
<td>0,03</td>
</tr>
<tr>
<td>C (EEV)</td>
<td>3,0</td>
<td>0,40</td>
<td>0,65</td>
<td>2,0</td>
<td>0,02</td>
</tr>
</tbody>
</table>

(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.
(b) The conditions for verifying the acceptability of the ETC tests (see annex 4, appendix 2, paragraph 3.9.) when measuring the emissions of gas fuelled engines against the limit values applicable in row A must be re-examined and, where necessary, modified in accordance with the procedure laid down in Consolidated Resolution R.E.3.
(c) For NG engines only.

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 must not exceed by more than 10 per cent the values interpolated from the adjacent test modes (reference annex 4, appendix 1 paragraphs 4.6.2. and 4.6.3.).

5.2.3.2. The smoke value on the random test speed of the ELR must 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.
6. INSTALLATION ON THE VEHICLE

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

6.1.1. Intake depression shall not exceed that specified for the type approved engine in annex 2A.

6.1.2. Exhaust back-pressure shall not exceed that specified for the type approved engine in annex 2A.

6.1.3. Power absorbed by the auxiliaries needed for operating the engine must not exceed that specified for the type-approved engine in annex 2A.

7. ENGINE FAMILY

7.1. Parameters defining the engine family

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

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

7.1.1. Combustion cycle:
- 2 cycle
- 4 cycle

7.1.2. Cooling medium:
- air
- water
- oil

7.1.3. For gas engines and engines with after-treatment
- 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:
- engines to be within a total spread of 15 per cent

7.1.5. Method of air aspiration:
- naturally aspirated
- pressure charged
- pressure charged with charge air cooler
7.1.6. Combustion chamber type/design:
   - pre-chamber
   - swirl chamber
   - open chamber

7.1.7. Valve and porting — configuration, size and number:
   - cylinder head
   - cylinder wall
   - crankcase

7.1.8. Fuel injection system (diesel engines):
   - pump-line-injector
   - in-line pump
   - distributor pump
   - single element
   - unit injector

7.1.9. Fuelling system (gas engines):
   - mixing unit
   - gas induction/injection (single point, multi-point)
   - liquid injection (single point, multi-point)

7.1.10. Ignition system (gas engines)

7.1.11. Miscellaneous features:
   - exhaust gas recirculation
   - water injection/emulsion
   - secondary air injection
   - charge cooling system

7.1.12. Exhaust after treatment:
   - 3-way-catalyst
   - oxidation catalyst
   - reduction catalyst
   - thermal reactor
   - particulate trap
7.2. Choice of the parent engine

7.2.1. Diesel engines

The parent engine of the family must 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 must 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 characterised 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 must 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 must 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 must be selected using the secondary criteria in the following order:

— the highest fuel delivery per stroke at the speed of declared rated power;
— the most advanced spark timing;
— the lowest EGR rate;
— 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 characterised 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.

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 must 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 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 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 the 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 must be run-in using the procedure defined in paragraph 3 of appendix 2 to annex 4.

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 8.4.2.2., up to a maximum of 100 hours. In this case, the running-in procedure will be conducted by the manufacturer who must 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 8.4.2.2.1., it may be carried out on:

— all the engines that are tested,

or,

— the first engine tested, with the determination of an evolution coefficient as follows:

— the pollutant emissions will be measured at zero and at ‘x’ hours on the first engine tested,
— the evolution coefficient of the emissions between zero and ‘x’ hours will be calculated for each pollutant:

\[
\frac{\text{Emissions x hours}}{\text{Emissions zero hours}}
\]

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:

— the values at ‘x’ hours for the first engine,

— 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 annexes 5 or 7 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:

(i) for H marked engines with a commercial fuel within the H range \((0.89 \leq S_\lambda \leq 1.00)\);

(ii) for L marked engines with a commercial fuel within the L range \((1.00 \leq S_\lambda \leq 1.19)\);

(iii) for HL marked engines with a commercial fuel within the extreme range of the \(\lambda\)-shift factor \((0.89 \leq S_\lambda \leq 1.19)\).

However, at the manufacturer’s request, the reference fuels described in annex 6 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 must 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 4.1.3.2., 4.1.5.1. and 4.2.1.2. If r, ra or rb are less than 1 no correction must take place. The measured results and the calculated results must 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 must be performed on the fuel for which the engine has been calibrated.
9. PENALTIES FOR NON-CONFORMITY OF PRODUCTION

9.1. 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.

9.2. If a Contracting Party to the 1958 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.
10. MODIFICATION AND EXTENSION OF APPROVAL OF THE APPROVED TYPE

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

10.1.1. 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

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

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

10.3. 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.

11. 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 applying this Regulation by means of a communication form conforming to the model in annexes 2A or 2B to this Regulation.

12. TRANSITIONAL PROVISIONS

12.1. General

12.1.1. As from the official date of entry into force of the 04 series of amendments, no Contracting Party applying this Regulation must refuse to grant ECE approval under this Regulation as amended by the 04 series of amendments.

12.1.2. As from the date of entry into force of the 04 series of amendments, Contracting Parties applying this Regulation must grant ECE approvals only if the engine meets the requirements of this Regulation as amended by the 04 series of amendments.

The engine must be subject to the relevant tests set out in paragraph 5.2. to this Regulation and must, in accordance with paragraphs 12.2.1., 12.2.2. and 12.2.3. below, satisfy the relevant emission limits detailed in paragraph 5.2.1. of this Regulation.

12.2. New type approvals

12.2.1. Subject to the provisions of paragraph 12.4.1., Contracting Parties applying this Regulation must, from the date of entry into force of the 04 series of amendments to this Regulation, grant an ECE approval to an engine only if that engine satisfies the relevant emission limits of Rows A, B1, B2 or C in the tables to paragraph 5.2.1. of this Regulation.

12.2.2. Subject to the provisions of paragraph 12.4.1., Contracting Parties applying this Regulation must, from 1 October 2005, grant an ECE approval to an engine only if that engine satisfies the relevant emission limits of Rows B1, B2 or C in the tables to paragraph 5.2.1. of this Regulation.
12.2.3. Subject to the provisions of paragraph 12.4.1., Contracting Parties applying this Regulation must, from 1 October 2008, grant an ECE approval to an engine only if that engine satisfies the relevant emission limits of Rows B2 or C in the tables to paragraph 5.2.1. of this Regulation.

12.3. **Limit of validity of old type approvals**

12.3.1. With the exception of the provisions of paragraphs 12.3.2. and 12.3.3., as from the official date of entry into force of the 04 series of amendments, type approvals granted to this Regulation as amended by the 03 series of amendments must cease to be valid, unless the Contracting Party which granted the approval notifies the other Contracting Parties applying this Regulation that the engine type approved meets the requirements of this Regulation as amended by the 04 series of amendments, in accordance with paragraph 12.2.1. above.

12.3.2. **Extension of type-approval**

12.3.2.1. Paragraphs 12.3.2.2. and 12.3.2.3. below shall only be applicable to new compression-ignition engines and new vehicles propelled by a compression-ignition engine that have been approved to the requirements of row A of the tables in paragraph 5.2.1. of this Regulation.

12.3.2.2. As an alternative to paragraphs 5.1.3. and 5.1.4., the manufacturer may present to the technical service the results of a NOₓ screening test using the ETC on the engine conforming to the characteristics of the parent engine described in annex 1, and taking into account the provisions of paragraphs 5.1.4.1. and 5.1.4.2. The manufacturer shall also provide a written statement that the engine does not employ any defeat device or irrational emission control strategy as defined in paragraph 2. of this Regulation.

12.3.2.3. The manufacturer shall also provide a written statement that the results of the NOₓ screening test and the declaration for the parent engine, as referred to in paragraph 5.1.4., are also applicable to all engine types within the engine family described in annex 1.

12.3.3. **Gas engines**

As from the 1 October 2003, type approvals granted to gas engines to this Regulation as amended by the 03 series of amendments must cease to be valid, unless the Contracting Party which granted the approval notifies the other Contracting Parties applying this Regulation that the engine type approved meets the requirements of this Regulation as amended by the 04 series of amendments, in accordance with paragraph 12.2.1. above.

12.3.4. As from 1 October 2006, type approvals granted to this Regulation as amended by the 04 series of amendments must cease to be valid, unless the Contracting Party which granted the approval notifies the other Contracting Parties applying this Regulation that the engine type approved meets the requirements of this Regulation as amended by the 04 series of amendments, in accordance with paragraph 12.2.2. above.

12.3.5. As from 1 October 2009, type approvals granted to this Regulation as amended by the 04 series of amendments must cease to be valid, unless the Contracting Party which granted the approval notifies the other Contracting Parties applying this Regulation that the engine type approved meets the requirements of this Regulation as amended by the 04 series of amendments, in accordance with paragraph 12.2.3. above.

12.4. **Replacement parts for vehicles in use**

12.4.1. 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 04 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.
13. 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 1

PROCEDURE 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 the Regulation (see Figure 2):

Let:

\[ L = \text{the natural logarithm of the limit value for the pollutant;} \]
\[ x_i = \text{the natural logarithm of the measurement for the } i\text{-th engine of the sample;} \]
\[ s = \text{an estimate of the production standard deviation (after taking the natural logarithm of the measurements);} \]
\[ n = \text{the current sample number.} \]

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

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

5. Then:

— 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;

— 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;

— otherwise, an additional engine is tested according to paragraph 8.3.1. of the Regulation and the calculation procedure is applied to the sample increased by one more unit.

<table>
<thead>
<tr>
<th>Cumulative number of engines tested (sample size)</th>
<th>Pass decision number ( A_n )</th>
<th>Fail decision number ( B_n )</th>
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Appendix 2

PROCEDURE 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 the Regulation 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 values measured in the series are $x_1, x_2, ..., x_i$ and $L$ is the natural logarithm of the limit value for the pollutant, then, define

$$d_i = x_i - L$$

and,

$$\frac{d_n}{n} = \frac{1}{n} \sum_{i=1}^{n} d_i$$

$$V_n^2 = \frac{1}{n} \sum_{i=1}^{n} (d_i - \frac{d_n}{n})^2$$

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 $\frac{d_n}{n}/V_n$ and must be used to determine whether the series has passed or failed as follows:

For $m_0 \leq n \leq m$:

— pass the series if $\frac{d_n}{n}/V_n \leq A_n$

— fail the series if $\frac{d_n}{n}/V_n \geq B_n$

— take another measurement if $A_n \leq \frac{d_n}{n}/V_n \geq B_n$

6. Remarks:

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

$$\frac{d_n}{n} = \left(1 - \frac{1}{n}\right)\frac{d_{n-1}}{n-1} + \frac{1}{n} d_n$$

$$V_n^2 = \left(1 - \frac{1}{n}\right)V_{n-1}^2 + \frac{(\frac{d_n}{n} - d_{n-1})^2}{n-1}$$

$$(n = 2, 3, ..., d_1 = d_1; V_1 = 0)$$
### Table 4

**Pass and Fail decision numbers of appendix 2 Sampling Plan**

Minimum sample size: 3

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<td>21</td>
<td>-0.30072</td>
<td>0.32078</td>
</tr>
<tr>
<td>22</td>
<td>-0.27263</td>
<td>0.28343</td>
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<td>23</td>
<td>-0.24410</td>
<td>0.24943</td>
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<td>24</td>
<td>-0.21509</td>
<td>0.21831</td>
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<td>25</td>
<td>-0.18557</td>
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<tr>
<td>26</td>
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<tr>
<td>27</td>
<td>-0.12483</td>
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</tr>
<tr>
<td>32</td>
<td>0.03876</td>
<td>0.03876</td>
</tr>
</tbody>
</table>
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 the Regulation (see figure 2):

Let:
\[ L = \text{the limit value for the pollutant}, \]
\[ x_i = \text{the value of the measurement for the } i\text{-th engine of the sample}, \]
\[ n = \text{the current sample number}. \]

4. Calculate for the sample the test statistic quantifying the number of non-conforming engines, i.e. \( x_i \geq L \):

5. Then:

— 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;

— 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;

— otherwise, an additional engine is tested according to paragraph 8.3.1. of the 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>
<thead>
<tr>
<th>Cumulative number of engines tested (sample size)</th>
<th>Pass decision number</th>
<th>Fail decision number</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>—</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
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</tr>
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<td>5</td>
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<td>4</td>
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</tr>
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<td>9</td>
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<td>6</td>
</tr>
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<td>3</td>
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</tr>
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<tr>
<td>12</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>13</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Cumulative number of engines tested (sample size)</td>
<td>Pass decision number</td>
<td>Fail decision number</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>----------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>14</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>15</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>16</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>17</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>18</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>19</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>
### ANNEX 1

ESSENTIAL CHARACTERISTICS OF THE (PARENT) ENGINE AND INFORMATION CONCERNING THE CONDUCT OF TEST (1)

<table>
<thead>
<tr>
<th>1. DESCRIPTION OF ENGINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1. Manufacturer: ...........................................................................................................</td>
</tr>
<tr>
<td>1.2. Manufacturer's engine code: ........................................................................................</td>
</tr>
<tr>
<td>1.3. Cycle: four stroke/two stroke (2)</td>
</tr>
<tr>
<td>1.4. Number and arrangement of cylinders:</td>
</tr>
<tr>
<td>1.4.1. Bore: .....................................................................................................................</td>
</tr>
<tr>
<td>1.4.2. Stroke: ...................................................................................................................</td>
</tr>
<tr>
<td>1.4.3. Firing order: ..........................................................................................................</td>
</tr>
<tr>
<td>1.5. Engine capacity: ........................................................................................................</td>
</tr>
<tr>
<td>1.6. Volumetric compression ratio (3): ..............................................................................</td>
</tr>
<tr>
<td>1.7. Drawing(s) of combustion chamber and piston crown: ..............................................</td>
</tr>
<tr>
<td>1.8. Minimum cross-sectional area of inlet and outlet ports: .......................................</td>
</tr>
<tr>
<td>1.9. Idling speed: .............................................................................................................</td>
</tr>
<tr>
<td>1.10. Maximum net power: .................................................................................................</td>
</tr>
<tr>
<td>1.11. Maximum permitted engine speed: ...............................................................................</td>
</tr>
<tr>
<td>1.12. Maximum net torque: ...............................................................................................</td>
</tr>
<tr>
<td>1.13. Combustion system: compression ignition/positive ignition (2)</td>
</tr>
<tr>
<td>1.15. Cooling system</td>
</tr>
<tr>
<td>1.15.1. Liquid</td>
</tr>
<tr>
<td>1.15.1.1. Nature of liquid: ............................................................................................</td>
</tr>
<tr>
<td>1.15.1.2. Circulating pump(s): yes/no (2)</td>
</tr>
<tr>
<td>1.15.1.3. Characteristics or make(s) and type(s) (if applicable): ................................</td>
</tr>
<tr>
<td>1.15.1.4. Drive ratio(s) (if applicable):</td>
</tr>
<tr>
<td>1.15.2. Air</td>
</tr>
<tr>
<td>1.15.2.1. Blower: yes/no (2)</td>
</tr>
<tr>
<td>1.15.2.2. Characteristics or make(s) and type(s) (if applicable):</td>
</tr>
<tr>
<td>1.15.2.3. Drive ratio(s) (if applicable):</td>
</tr>
<tr>
<td>1.16. Temperature permitted by the manufacturer</td>
</tr>
<tr>
<td>1.16.1. Liquid cooling: Maximum temperature at outlet: ..............................................</td>
</tr>
<tr>
<td>1.16.2. Air cooling: Reference point: Maximum temperature at reference point: ..............</td>
</tr>
<tr>
<td>1.16.3. Maximum temperature of the air at the outlet of the intake intercooler (if applicable)</td>
</tr>
<tr>
<td>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):</td>
</tr>
</tbody>
</table>


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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, wastegate, 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 ............................................................... ...................................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 ............................................................... ...................................kPa

Exhaust system volume: ............................................................... ..............................dm³

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): ............................................................... ............................................................... ............................................................... ............................................................... ............................................................... ...............................................................
2.2.2. Oxygen sensor: yes/no (?)

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 (?)

2.2.4.1. Characteristics (flow rate, etc.): ..............................................................................................

2.2.5. Particulate trap: yes/no (?)

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: ............................................

2.2.6. Other systems: yes/no (?)

2.2.6.1. Description and operation: ...........................................................................................

3. FUEL FEED

3.1. Diesel engines

3.1.1. Feed pump

Pressure (?): ............................................................... kPa or characteristic diagram (?): ................................

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 (?) per stroke at engine speed of ...........min⁻¹ at full injection, or characteristic
diagram (?) (?): ............................................................. .................................................

Mention the method used: On engine/on pump bench (?)

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 (?): ...........................................................

3.1.2.1.4.2. Static injection timing (?): ...........................................................

3.1.2.2. Injection piping

3.1.2.2.1. Length: ............................................................... mm

3.1.2.2.2. Internal diameter: ............................................................... mm

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 (°)
or characteristic diagram (°) ..............................................................

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 (°)
3.2.1. Fuel: Natural gas/LPG (°)
3.2.2. Pressure regulator(s) or vaporiser/pressure regulator(s) (°)
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. Approval number according to Reg. No: .............................................  
3.2.3. Fuelling system: mixing unit/gas injection/liquid injection/direct injection (°)
3.2.3.1. Mixture strength regulation: .............................................................  
3.2.3.2. System description and/or diagram and drawings: ......................................  
3.2.3.3. Approval number according to Regulation No ........................................  
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. Approval number according to Regulation No ........................................  
3.2.5. Inlet manifold injection
3.2.5.1. Injection: single point/multi-point (°)
3.2.5.2. Injection: continuous/simultaneously timed/sequentially timed (°)
### Injection equipment

**3.2.5.3.**

- **Make(s):** 
- **Type(s):** 
- **Adjustment possibilities:** 
- **Approval number according to Regulation No:**

**3.2.5.4.**

- **Supply pump (if applicable):**
- **Make(s):** 
- **Type(s):** 
- **Approval number according to Regulation No:**

**3.2.5.5.**

- **Injector(s):**
- **Make(s):** 
- **Type(s):** 
- **Approval number according to Regulation No:**

### Direct injection

**3.2.6.**

- **Injection pump/pressure regulator (2):**
- **Make(s):** 
- **Type(s):** 
- **Injection timing:** 
- **Approval number according to Regulation No:**

**3.2.6.2.**

- **Injector(s):**
- **Make(s):** 
- **Type(s):** 
- **Opening pressure or characteristic diagram:** 
- **Approval number according to Regulation No:**

### Electronic control unit (ECU)

**3.2.7.**

- **Make(s):** 
- **Type(s):** 
- **Adjustment possibilities:**

### 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:**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Basis</th>
<th>Min (%)</th>
<th>Max (%)</th>
<th>Mol %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (CH₄)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethane (C₂H₆)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propane (C₃H₈)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butane (C₄H₁₀)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>C₅/C₅+</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inert (N₂, He etc)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

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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 or equivalent data

4.2. Reference and/or setting ranges (?): ...........................................................

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) (?)

5.2. Ignition control unit

5.2.1. Make(s):
5.2.2. Type(s):

5.3. Ignition advance curve/advance map (? (?): ...........................................................

5.4. Ignition timing (?): ........... 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. ENGINE-DRIVEN EQUIPMENT

The engine must 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.

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 must 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.) must 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,

— if auxiliaries needed for operating the engine, are not fitted to the engine

and/or

— 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:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Power absorbed (kW) at various engine speeds</th>
<th>Idle</th>
<th>Low Speed</th>
<th>High Speed</th>
<th>Speed A (°)</th>
<th>Speed B (°)</th>
<th>Speed C (°)</th>
<th>Ref. Speed (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(a)</td>
<td>Auxiliaries needed for operating the engine (to be subtracted from measured engine power) see item 6.1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(b)</td>
<td>Auxiliaries not needed for operating the engine (to be added to measured engine power) see item 6.2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. ENGINE PERFORMANCE

8.1. Engine speeds (°)

Low speed (n_L): ................................................................. min^{-1}

High speed (n_H): ................................................................. 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) in kW

<table>
<thead>
<tr>
<th>Engine speed</th>
<th>Idle</th>
<th>Speed A (°)</th>
<th>Speed B (°)</th>
<th>Speed C (°)</th>
<th>Ref. Speed (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power measured on test bed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power absorbed by auxiliaries to be fitted for test (item 6.1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>— if fitted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>— if not fitted</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>P(b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power absorbed by auxiliaries to be removed for test (item 6.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>— if fitted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>— if not fitted</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>P(n)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net engine power</td>
<td>= P(m) − P(a) + P(b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.3. Dynamometer settings (kW)

The dynamometer settings for the ESC and ELR tests and for the reference cycle of the ETC test must 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 must be corrected to net conditions using the above formula.

8.3.1. ESC and ELR Tests

The dynamometer settings must be calculated according to the formula in annex 4, appendix 1, paragraph 1.2.
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 4, appendix 2, paragraph 2., to net power or net cycle work must be submitted by the engine manufacturer for the whole operating area of the cycle, and approved by the Technical Service.

(*) In the case of non-conventional engines and systems, particulars equivalent to those referred to here must be supplied by the manufacturer.
(‡) Strike out what does not apply.
(§) Specify the tolerance.
(¶) In the case of systems laid out in a different manner, supply equivalent information (for paragraph 3.2).
(¶) ESC test.
(¶) ETC test only.
(¶) Specify the tolerance; to be within ± 3 per cent of the values declared by the manufacturer.
ANNEX 1

Appendix 1

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

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Power absorbed (kW) at various engine speeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Idle</td>
</tr>
<tr>
<td>P(a)</td>
<td></td>
</tr>
<tr>
<td>Auxiliaries needed for operating the engine (to be subtracted from measured engine power) see annex 1, item 6.1.</td>
<td></td>
</tr>
</tbody>
</table>

(1) ESC test.
(2) ETC test only.

9.3.2007 EN Official Journal of the European Union L 70/45
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:

— charge cooling system (\(^{1}\)): ............................................................. ....................................

— exhaust gas recirculation (\(^{1}\)): ............................................................. ..................................

— water injection/emulsion (\(^{1}\)): ............................................................. ..................................

— air injection (\(^{1}\)): .................................................................................

1.11. Exhaust after-treatment (\(^{1}\)): ............................................................. ..........................................

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:

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>No of cylinders</th>
<th>Rated speed (min(^{-1}))</th>
<th>Fuel delivery per stroke (mm(^3))</th>
<th>Rated net power (kW)</th>
<th>Maximum torque speed (min(^{-1}))</th>
<th>Fuel delivery per stroke (mm(^3))</th>
<th>Maximum torque (Nm)</th>
<th>Low idle speed (min(^{-1}))</th>
<th>Cylinder displacement (in % of parent engine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent Engine</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.2. Name of gas engine family: ............................................................... .......................................

2.2.1. Specification of engines within this family:

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Parent Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of cylinders</td>
<td></td>
</tr>
<tr>
<td>Rated speed (min⁻¹)</td>
<td></td>
</tr>
<tr>
<td>Fuel delivery per stroke (mm³)</td>
<td></td>
</tr>
<tr>
<td>Rated net power (kW)</td>
<td></td>
</tr>
<tr>
<td>Maximum torque speed (min⁻¹)</td>
<td></td>
</tr>
<tr>
<td>Fuel delivery per stroke (mm³)</td>
<td></td>
</tr>
<tr>
<td>Maximum torque (Nm)</td>
<td></td>
</tr>
<tr>
<td>Low idle speed (min⁻¹)</td>
<td></td>
</tr>
<tr>
<td>Cylinder displacement (in % of parent engine)</td>
<td>100</td>
</tr>
<tr>
<td>Spark timing</td>
<td></td>
</tr>
<tr>
<td>EGR flow</td>
<td></td>
</tr>
<tr>
<td>Air pump yes/no</td>
<td></td>
</tr>
<tr>
<td>Air pump actual flow</td>
<td></td>
</tr>
</tbody>
</table>

⁽¹⁾ If not applicable, mark ‘N/A’.
### ESSENTIAL CHARACTERISTICS OF THE ENGINE TYPE WITHIN THE FAMILY

1. **DESCRIPTION OF ENGINE**

1.1. Manufacturer: ............................................................... 

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

1.3. Cycle: four stroke/two stroke (?) 

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 (?)$: ............................................................. 

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 (?) 


1.15. Cooling system 

1.15.1. Liquid 

1.15.1.1. Nature of liquid: ............................................................... 

1.15.1.2. Circulating pump(s): yes/no (?) 

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 (?) 

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: ............................................................... K

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, wastegate, 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: ............................................................... 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: ............................................................... kPa

Exhaust system volume: ............................................................................................... cm³

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. Number of catalytic converters and elements: ............................................................... ...........

2.2.1.2. Dimensions, shape and volume of the catalytic converter(s): ..........................................................

2.2.1.3. Type of catalytic action: ..............................................................................................................

2.2.1.4. Total charge of precious metals: ............................................................................................... ...........

2.2.1.5. Relative concentration: ..............................................................................................................

2.2.1.6. Substrate (structure and material): ............................................................................................... ...........

2.2.1.7. Cell density: ..............................................................................................................................

2.2.1.8. Type of casing for the catalytic converter(s): ...................................................................................

2.2.1.9. Location of the catalytic converter(s) (place and reference distance in the exhaust line): .....................

2.2.2. Oxygen sensor: yes/no (2)

2.2.2.1. Type: ..............................................................................................................................
2.2.3. Air injection: yes/no (?)
2.2.3.1. Type (pulse air, air pump, etc.): ............................................................... ............................................................... 
2.2.4. EGR: yes/no (?)
2.2.4.1. Characteristics (flow rate etc.): ...........................................................................
2.2.5. Particulate trap: yes/no (?)
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: ..........................................
2.2.6. Other systems: yes/no (?)
2.2.6.1. Description and operation: ............................................................................................

3. FUEL FEED
3.1. Diesel engines
3.1.1. Feed pump
3.1.1. Pressure (?): .............................................. kPa or characteristic diagram (?): ..........................................................
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 (?) per stroke at engine speed of ........... min⁻¹ at full injection, or characteristic diagram (?) (?): ..........................................................

Mention the method used: On engine/on pump bench (?)
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 (?) : ..........................................................
3.1.2.1.4.2. Static injection timing (?): ..................................................................................
3.1.2.2. Injection piping
3.1.2.2.1. Length: ................................................................................................................... mm
3.1.2.2.2. Internal diameter: .................................................................................................... mm
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 (?) or characteristic diagram (?) (?): .................................................................
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

3.2.1. Fuel: Natural gas/LPG (?)

3.2.2. Pressure regulator(s) or vaporiser/pressure regulator(s) (?)

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. Approval number: ............................................................... ...........................................

3.2.3. Fuelling system: mixing unit/gas injection/liquid injection/direct injection (?)

3.2.3.1. Mixture strength regulation: ............................................................... ...............................
3.2.3.2. System description and/or diagram and drawings: ............................................................... ......
3.2.3.3. Approval 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. Approval number: ............................................................... ...........................................

3.2.5. Inlet manifold injection

3.2.5.1. Injection: single point/multi-point (?)
3.2.5.2. Injection: continuous/simultaneously timed/sequentially timed (?)
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. Approval 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. Approval 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. Approval 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. Approval 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. Approval 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 (CH4): basis: .......... %mole min. .......... %mole max. .......... %mole
ethane (C2H6): basis: .......... %mole min. .......... %mole max. .......... %mole
propane (C3H8): basis: .......... %mole min. .......... %mole max. .......... %mole
butane (C4H10): basis: .......... %mole min. .......... %mole max. .......... %mole
C5/C5+: basis: .......... %mole min. .......... %mole max. .......... %mole
oxygen (O2): basis: .......... %mole min. .......... %mole max. .......... %mole
inert (N2, 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 (?): ...............................................................

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) (?)

5.2. Ignition control unit

5.2.1. Make(s): ...............................................................

5.2.2. Type(s): ...............................................................

5.3. Ignition advance curve/advance map (? (?)): ...............................................................

5.4. Ignition timing (?): ........... 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): ...............................................................

(1) To be submitted for each engine of the family.

(?) Strike out what does not apply.

(?) Specify the tolerance.
ANNEX 2A

COMMUNICATION
(maximum format: A4 (210 × 297 mm))

issued by: Name of administration:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

concerning (?): APPROVAL GRANTED
APPROVAL EXTENDED
APPROVAL REFUSED
APPROVAL WITHDRAWN
PRODUCTION DEFINITELY DISCONTINUED

of a compression-ignition (C.I.) engine type, of a natural gas (NG) engine type or a positive-ignition (P.I.) LPG-fuelled engine type (?), as a separate technical unit with regard to the emission of pollutants pursuant to Regulation N° 49

Approval N°: …………………….. Extension N°: ……………………..

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

2. Engine type: …………………………………………………………………………………………………………………………………………………………..

3. Combustion type: compression-ignition/positive-ignition (?)

3.1. Type of fuel: …………………………………………………………………………………………………………………………………………………………..

4. Manufacturer’s name and address: ……………………………………………………………………………………………………………………………

5. If applicable, name and address of manufacturer’s representative:
………………………………………………………………………………………………………………………………………………………………………………

6. Maximum allowable intake depression: ……………………………………………………………… kPa

7. Maximum allowable back-pressure: ……………………………………………………………… kPa

8. Maximum permissible power absorbed by the engine driven equipment:
Intermediate: …………………………………… kW; Rated: ………………………………………… kW

9. Restrictions of use (if any): ………………………………………………………………………………………………………………………………………

10. Emission levels of the engine/parent engine

10.1. ESC-test (if applicable):

CO: …………………………………… g/kWh

THC: …………………………………… g/kWh

NOx: …………………………………… g/kWh

PT: …………………………………… g/kWh
10.2. ELR-test (if applicable):

Smoke value: ........................................ m⁻¹

10.3. ETC-test (if applicable):

CO: ...................................................... g/kWh
THC: .................................................... g/kWh
NMHC: .................................................. g/kWh
CH₄: ...................................................... g/kWh
NOₓ: ..................................................... g/kWh
PT: ....................................................... g/kWh

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 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.

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

(‡) Strike out what does not apply.
ANNEX 2B

COMMUNICATION
(maximum format: A4 (210 × 297 mm))

issued by: Name of administration:

……………………………………………………………………………………………………………………
……………………………………………………………………………………………………………………
……………………………………………………………………………………………………………………

concerning (1): APPROVAL GRANTED
APPROVAL EXTENDED
APPROVAL REFUSED
APPROVAL WITHDRAWN
PRODUCTION DEFINITELY DISCONTINUED

of a vehicle type with regard to the emission of pollutants by the engine pursuant to Regulation No 49

Approval No …………………… …………………… …………………… …………………… ……………………

Extension No …………………… …………………… …………………… …………………… ……………………

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

2. Vehicle type: ………………………………………………………………………………………………………………………

3. Manufacturer’s name and address: …………………………………………………………………………………………………

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

……………………………………………………………………………………………………………………

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

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

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

Intermediate: …………………… kW; Rated: ……………………………………………………………………………………… kW

8. Make and type of the engine: ……………………………………………………………………………………………………………

9. Emission levels of the engine/parent engine

9.1. ESC-test (if applicable):

CO: ……………………………………………… g/kWh

THC: ……………………………………………… g/kWh

NOx: ……………………………………………… g/kWh

PT: ……………………………………………… g/kWh

9.2. ELR-test (if applicable):

Smoke value: ………………………… m⁻¹
9.3. ETC-test (if applicable):

CO: .................................................. g/kWh
THC: .................................................. g/kWh
NMHC: ................................................. g/kWh
CH\textsubscript{4}: ........................................ g/kWh
NO\textsubscript{x}: ........................................ g/kWh
PT: ................................................... g/kWh

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. Site of approval mark on the vehicle/engine (\(\ddagger\)): .................................................................

15. Place: .......................................................................................................................................................

16. Date: ........................................................................................................................................................

17. Signature: ..................................................................................................................................................

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

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

---

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

\(\ddagger\ddagger\) Strike out what does not apply.
ANNEX 3

ARRANGEMENTS OF APPROVAL MARKS
(See paragraph 4.6. of this Regulation)

I. APPROVAL 'I' (Row A).
(See paragraph 4.6.3. of this Regulation)

Model A

Engines approved to Row A emission limits and operating on diesel or liquefied petroleum gas (LPG) fuel.

Model B

Engines approved to Row A emission limits and operating on natural gas (NG) fuel. The suffix after the national symbol indicates the fuel qualification determined in accordance with paragraph 4.6.3.1. of this Regulation.

II. APPROVAL 'II' (Row B1).
(See paragraph 4.6.3. of this Regulation)

Model C

Engines approved to Row B1 emission limits and operating on diesel or liquefied petroleum gas (LPG) fuel.

Model D

Engines approved to Row B1 emission limits and operating on natural gas (NG) fuel. 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 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 042439. This approval indicates that the approval was given in accordance with the requirements of Regulation No 49 with the 04 series of amendments incorporated and satisfying the relevant limits detailed in paragraph 5.2.1. of this Regulation.

III. APPROVAL ‘III’ (Row B2).

(See paragraph 4.6.3. of this Regulation)

Model E

Engines approved to Row B2 emission limits and operating on diesel or liquefied petroleum gas (LPG) fuel.

Model F

Engines approved to Row B2 emission limits and operating on natural gas (NG) fuel. The suffix after the national symbol indicates the fuel qualification determined in accordance with paragraph 4.6.3.1. of this Regulation.

IV. APPROVAL ‘IV’ (Row C).

(See paragraph 4.6.3. of this Regulation)

Model G

Engines approved to Row C emission limits and operating on diesel or liquefied petroleum gas (LPG) fuel.

Model H

Engines approved to Row C emission limits and operating on natural gas (NG) fuel. 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 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 042439. This approval indicates that the approval was given in accordance with the requirements of Regulation No 49 with the 04 series of amendments incorporated and satisfying the relevant limits detailed in paragraph 5.2.1. of this Regulation.

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

Model 1

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 (emission level IV) 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 04 series of amendments, and Regulation No 24 the 03 series of amendments.

(1) The second Regulation number is given merely as an example.
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 must be applied according to the provisions of the Regulation, paragraph 5.2:

1.1.1. the ESC which consists of a steady state 13-mode cycle,

1.1.2. the ELR which consists of transient load steps at different speeds, which are integral parts of one test procedure, and are run concurrently;

1.1.3. the ETC which consists of a second-by-second sequence of transient modes.

1.2. The test must 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, gas engines at stage C 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 must be examined continuously by taking a sample from the raw 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 must be determined, and the measured values weighted. The particulate sample must be diluted with conditioned ambient air. One sample over the complete test procedure must be taken, and collected on suitable filters. The grams of each pollutant emitted per kilowatt-hour (kWh) must be calculated as described in appendix 1 to this annex. Additionally, NOx must be measured at three test points within the control area selected by the Technical Service (1) and the measured values compared to the values calculated from those modes of the test cycle enveloping the selected test points. The NOx 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 must 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 (2) must be run, and the value compared to the values of the previous load steps. The smoke peak must be determined using an averaging algorithm, as described in appendix 1 to this annex.

---

(1) The test points must be selected using approved statistical methods of randomisation.
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 must be examined after diluting the total exhaust gas with conditioned ambient air. Using the engine torque and speed feedback signals of the engine dynamometer, the power must be integrated with respect to time of the cycle resulting in the work produced by the engine over the cycle. The concentration of NOx and HC must be determined over the cycle by integration of the analyser signal. The concentration of CO, CO2, and NMHC may be determined by integration of the analyser signal or by bag sampling. For particulates, a proportional sample must be collected on suitable filters. The diluted exhaust gas flow rate must be determined over the cycle to calculate the mass emission values of the pollutants. The mass emission values must be related to the engine work to get the grams of each pollutant emitted per kilowatt-hour (kWh), 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 Kelvins, and the dry atmospheric pressure (p_a), expressed in kPa must be measured and the parameter F must be determined according to the following provisions:

(a) for diesel engines:

<table>
<thead>
<tr>
<th>Naturally aspirated and mechanically supercharged engines:</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ F = \left( \frac{99}{p_a} \right) \times \left( \frac{T_a}{298} \right)^{0.7} ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Turbocharged engines with or without cooling of the intake air:</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ F = \left( \frac{99}{p_a} \right)^{0.7} \times \left( \frac{T_a}{298} \right)^{1.5} ]</td>
</tr>
</tbody>
</table>

(b) for gas engines:

| F = \left( \frac{99}{p_a} \right)^{1.2} \times \left( \frac{T_a}{298} \right)^{0.6} |

2.1.2. Test validity

For a test to be recognised as valid, the parameter F must be such that:

\[ 0.96 \leq F \leq 1.06 \]

2.2. Engines with charge air cooling

The charge air temperature must be recorded and must 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 must be at least 293 K (20 °C).

If a test shop system or external blower is used, the charge air temperature must be within ± 5 K of the maximum charge air temperature specified in annex 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 must be used for the whole test cycle.

2.3. Engine air intake system

An engine air intake system must 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 must be used presenting an exhaust back pressure within \( \pm 1\,000 \text{ Pa} \) of the upper limit of the engine operating at the speed of declared maximum power and full load and a volume within \( \pm 40 \% \) of that specified by the manufacturer. A test shop system may be used, provided it represents actual engine operating conditions. The exhaust system must conform to the requirements for exhaust gas sampling, as set out in annex 4, appendix 4, paragraph 3.4. and in annex 4, appendix 6, paragraph 2.2.1., EP and paragraph 2.3.1., EP.

If the engine is equipped with an exhaust after-treatment device, the exhaust pipe must have the same diameter as found in-use for at least 4 pipe diameters upstream to the inlet of the beginning of the expansion paragraph containing the after-treatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust after-treatment device must be the same as in the vehicle configuration or within the distance specifications of the manufacturer. The exhaust back-pressure or restriction must 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.

2.5. **Cooling system**

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

2.6. **Lubricating oil**

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

2.7. **Fuel**

The fuel must be the reference fuel specified in annexes 5, 6 or 7.

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

For NG and LPG fuelled engines, the fuel temperature and measuring point must 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. **Testing of exhaust after-treatment systems**

If the engine is equipped with an exhaust after-treatment system, the emissions measured on the test cycle(s) must be representative of the emissions in the field. If this cannot be achieved with one single test cycle (e.g. for particulate filters with periodic regeneration), several test cycles must be conducted and the test results averaged and/or weighted. The exact procedure must be agreed by the engine manufacturer and the Technical Service based upon good engineering judgement.
1. ENGINE AND DYNAMOMETER SETTINGS

1.1. Determination of engine speeds A, B and C

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

The high speed $n_{hi}$ must be determined by calculating 70 per cent of the declared maximum net power $P(n)$, as determined in annex 1, appendix 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 $n_{lo}$ must be determined by calculating 50 per cent of the declared maximum net power $P(n)$, as determined in annex 1, appendix 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 must be calculated as follows:

Speed $A = n_{lo} + 25\% (n_{hi} - n_{lo})$

Speed $B = n_{lo} + 50\% (n_{hi} - n_{lo})$

Speed $C = n_{lo} + 75\% (n_{hi} - n_{lo})$

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

(a) Additional test points must be measured during engine power approval according to Regulation No 24 for an accurate determination of $n_{hi}$ and $n_{lo}$. The maximum power, $n_{hi}$ and $n_{lo}$ must be determined from the power curve, and engine speeds A, B and C must be calculated according to the above provisions.

(b) The engine must be mapped along the full load curve, from maximum no load speed to idle speed, using at least 5 measurement points per 1 000 min$^{-1}$ intervals and measurement points within ± 50 min$^{-1}$ of the speed at declared maximum power. The maximum power, $n_{hi}$ and $n_{lo}$ must be determined from this mapping curve, and engine speeds A, B and C must 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 must be used for the emissions test. If the tolerance is exceeded for any of the engine speeds, the measured engine speeds must be used for the emissions test.

1.2. Determination of dynamometer settings

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

$$ S = P(n) \times \frac{L}{100} $$

if tested under net conditions

$$ S = P(n) \times \frac{L}{100} + (P(a) - P(b)) $$

if not tested under net conditions
where:

\[ s = \text{dynamometer setting, kW} \]

\[ P(n) = \text{net engine power as indicated in annex 1, appendix 1, paragraph 8.2., kW} \]

\[ L = \text{per cent load as indicated in paragraph 2.7.1.} \]

\[ P(a) = \text{power absorbed by auxiliaries to be fitted as indicated in annex 1, appendix 1, paragraph 6.1.} \]

\[ P(b) = \text{power absorbed by auxiliaries to be removed as indicated in annex 1, appendix 1, paragraph 6.2.} \]

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 filters**

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

2.2. **Installation of the measuring equipment**

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

2.3. **Starting the dilution system and the engine**

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

For systems that use CO$_2$ or NO$_x$ concentration measurement for dilution ratio control, the CO$_2$ or NO$_x$ content of the dilution air must be measured at the beginning and at the end of each test. The pre- and post test background CO$_2$ or NO$_x$ concentration measurements of the dilution air must be within 100 ppm or 5 ppm of each other, respectively.

2.6. **Checking the analysers**

The emission analysers must be set at zero and spanned.
2.7. **Test cycle**

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

<table>
<thead>
<tr>
<th>Mode Number</th>
<th>Engine Speed</th>
<th>Percent Load</th>
<th>Weighting Factor</th>
<th>Mode Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>idle</td>
<td>—</td>
<td>0.15</td>
<td>4 minutes</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>100</td>
<td>0.08</td>
<td>2 minutes</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>50</td>
<td>0.10</td>
<td>2 minutes</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>75</td>
<td>0.10</td>
<td>2 minutes</td>
</tr>
<tr>
<td>5</td>
<td>A</td>
<td>50</td>
<td>0.05</td>
<td>2 minutes</td>
</tr>
<tr>
<td>6</td>
<td>A</td>
<td>25</td>
<td>0.05</td>
<td>2 minutes</td>
</tr>
<tr>
<td>7</td>
<td>A</td>
<td>100</td>
<td>0.09</td>
<td>2 minutes</td>
</tr>
<tr>
<td>8</td>
<td>B</td>
<td>25</td>
<td>0.10</td>
<td>2 minutes</td>
</tr>
<tr>
<td>9</td>
<td>B</td>
<td>100</td>
<td>0.08</td>
<td>2 minutes</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>25</td>
<td>0.05</td>
<td>2 minutes</td>
</tr>
<tr>
<td>11</td>
<td>C</td>
<td>75</td>
<td>0.05</td>
<td>2 minutes</td>
</tr>
<tr>
<td>12</td>
<td>C</td>
<td>50</td>
<td>0.05</td>
<td>2 minutes</td>
</tr>
</tbody>
</table>

2.7.2. **Test sequence**

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

The engine must be operated for the prescribed time in each mode, completing engine speed and load changes in the first 20 seconds. The specified speed must be held to within ± 50 min⁻¹ and the specified torque must be held to within ± 2 per cent of the maximum torque at the test speed.

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

2.7.3. **Analyser response**

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

2.7.4. **Particulate sampling**

One pair of filters (primary and back-up filters, see annex 4, appendix 4) must be used for the complete test procedure. The modal weighting factors specified in the test cycle procedure must 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 5.6. is met.

The sampling time per mode must be at least 4 seconds per 0.01 weighting factor. Sampling must be conducted as late as possible within each mode. Particulate sampling must 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 back pressure, fuel flow and air or exhaust flow, charge air temperature, fuel temperature and humidity must 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 must be recorded (see paragraphs 4 and 5).
2.7.6. **NOx check within the control area**

The NOx check within the control area must be performed immediately upon completion of mode 13. The engine must be conditioned at mode 13 for a period of three minutes before the start of the measurements. Three measurements must be made at different locations within the control area, selected by the Technical Service (1). The time for each measurement must be 2 minutes.

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

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

2.7.7. **Rechecking the analysers**

After the emission test a zero gas and the same span gas must 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, must be installed after the exhaust silencer or any after-treatment device, if fitted, according to the general installation procedures specified by the instrument manufacturer. Additionally, the requirements of paragraph 10 of ISO 11614 must be observed, where appropriate.

Prior to any zero and full scale checks, the opacimeter must 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 must also be activated and adjusted according to the manufacturer’s recommendations.

3.2. **Checking of the opacimeter**

The zero and full scale checks must 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 $L_{\infty}$, 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 must be adjusted to 0.0 % ± 1.0 % opacity. With the light being prevented from reaching the receiver, the readout must be adjusted to 100.0 % ± 1.0 % opacity.

3.3. **Test cycle**

3.3.1. **Conditioning of the engine**

Warming up of the engine and the system must 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 must 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.

(1) The test points must be selected using approved statistical methods of randomisation.
### 3.3.2. Test sequence

The test consists of a sequence of three load steps at each of the three engine speeds A (cycle 1), B (cycle 2) and C (cycle 3) determined in accordance with annex 4, paragraph 1.1., followed by cycle 4 at a speed within the control area and a load between 10 per cent and 100 per cent, selected by the Technical Service (1). The following sequence must be followed in dynamometer operation on the test engine, as shown in Figure 3.

(a) The engine must be operated at engine speed A and 10 per cent load for 20 ± 2 s. The specified speed must be held to within ± 20 min⁻¹ and the specified torque must be held to within ± 2 per cent of the maximum torque at the test speed.

(b) At the end of the previous segment, the speed control lever must be moved rapidly to, and held in, the wide open position for 10 ± 1 s. The necessary dynamometer load must be applied to keep the engine speed within ± 150 min⁻¹ during the first 3 s, and within ± 20 min⁻¹ during the rest of the segment.

(c) The sequence described in (a) and (b) must be repeated two times.

(d) Upon completion of the third load step, the engine must be adjusted to engine speed B and 10 per cent load within 20 ± 2 s.

(e) The sequence (a) to (c) must be run with the engine operating at engine speed B.

(f) Upon completion of the third load step, the engine must be adjusted to engine speed C and 10 per cent load within 20 ± 2 s.

(g) The sequence (a) to (c) must be run with the engine operating at engine speed C.

(h) Upon completion of the third load step, the engine must be adjusted to the selected engine speed and any load above 10 per cent within 20 ± 2 s.

(i) The sequence (a) to (c) must be run with the engine operating at the selected engine speed.

---

(1) The test points must be selected using approved statistical methods of randomisation.
3.4. **Cycle validation**

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

3.5. **Rechecking of the opacimeter**

The post-test opacimeter zero drift value must not exceed ± 5,0 per cent of the limit value shown in Table 1 of the Regulation.

4. **CALCULATION OF THE GASEOUS EMISSIONS**

4.1. **Data evaluation**

For the evaluation of the gaseous emissions, the chart reading of the last 30 seconds of each mode must be averaged, and the average concentrations \( (\text{conc}) \) of HC, CO and NOx during each mode must 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 NOx check within the control area, the above requirements apply for NOx only.

The exhaust gas flow \( G_{EXHW} \) or the diluted exhaust gas flow \( G_{TGTW} \), if used optionally, must be determined in accordance with annex 4, appendix 4, paragraph 2.3.

4.2. **Dry/Wet correction**

The measured concentration must be converted to a wet basis according to the following formulæ, if not already measured on a wet basis.

\[
\text{conc (wet)} = K_W \times \text{conc (dry)}
\]

For the raw exhaust gas:

\[
K_{W,r} = \left(1 - F_{FH} \times \frac{G_{FUEL}}{G_{AIRD}}\right) - K_{W2}
\]

and

\[
F_{FH} = \frac{1.969}{1 + \frac{G_{FUEL}}{G_{AIRW}}}
\]

For the diluted exhaust gas:

\[
K_{W,e,1} = \left(1 - \frac{HTCRAT \times CO_2\% (\text{wet})}{200}\right) - K_{W1}
\]

or

\[
K_{W,e,2} = \left(1 - K_{W1}\right) \times \frac{\left(1 - K_{W1}\right)}{1 + \frac{HTCRAT \times CO_2\% (\text{dry})}{200}}
\]

For the dilution air:

\[
K_{W,d} = 1 - K_{W1}
\]

For the intake air:

\[
K_{W,a} = 1 - K_{W2}
\]

if different from the dilution air.
\[
\begin{align*}
K_{W1} &= \frac{1.608 \times H_d}{1000 + (1.608 \times H_d)} \\
K_{W2} &= \frac{1.608 \times H_a}{1000 + (1.608 \times H_a)} \\
H_d &= \frac{6.220 \times R_d \times p_d}{p_B - p_d \times R_d \times 10^{-2}} \\
H_a &= \frac{6.220 \times R_a \times p_a}{p_B - p_a \times R_a \times 10^{-2}}
\end{align*}
\]

where:

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

4.3. **Nox Correction for humidity and temperature**

As the NOx emission depends on ambient air conditions, the NOx concentration must be corrected for ambient air temperature and humidity with the factors given in the following formulae:

\[
K_{HD} = \frac{1}{1 + A \times (H_a - 10.71) + B \times (T_a - 298)}
\]

with:

\[
\begin{align*}
A &= 0.309 \frac{G_{FUEL}}{G_{AIR}} - 0.0266 \\
B &= -0.209 \frac{G_{FUEL}}{G_{AIR}} + 0.00954 \\
T_a &= \text{temperature of the air, K} \\
H_a &= \text{humidity of the intake air, g water per kg dry air in which:}
\end{align*}
\]

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

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

4.4. **Calculation of the emission mass flow rates**

The emission mass flow rates (g/h) for each mode must be calculated as follows, assuming the exhaust gas density to be 1.293 kg/m³ at 273 K (0 °C) and 101.3 kPa:

\[
\begin{align*}
\text{(1) NOx mass} &= 0.001587 \times \text{NOx conc} \times K_{HD} \times G_{EXHW} \\
\text{(2) CO mass} &= 0.000966 \times \text{CO conc} \times G_{EXHW} \\
\text{(3) HC mass} &= 0.000479 \times \text{HC conc} \times G_{EXHW}
\end{align*}
\]

where \(\text{NOx conc}, \text{CO conc}, \text{HC conc}\) (1) are the average concentrations (ppm) in the raw exhaust gas, as determined in paragraph 4.1.

If, optionally, the gaseous emissions are determined with a full flow dilution system, the following formulae must be applied:

\[
\begin{align*}
\text{(1) NOx mass} &= 0.001587 \times \text{NOx conc} \times K_{HD} \times G_{TOTW} \\
\text{(2) CO mass} &= 0.000966 \times \text{CO conc} \times G_{TOTW} \\
\text{(3) HC mass} &= 0.000479 \times \text{HC conc} \times G_{TOTW}
\end{align*}
\]

where \(\text{NOx conc}, \text{CO conc}, \text{HC conc}\) (1) are the average background corrected concentrations (ppm) of each mode in the diluted exhaust gas, as determined in annex 4, appendix 2, paragraph 4.3.1.1.

(1) Based on C1 equivalent.
4.5. Calculation of the specific emissions

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

\[
\text{NO}_x = \frac{\sum \text{NO}_{x,\text{mass}} \times WF_i}{\sum P(n)_i \times WF_i}
\]

\[
\text{CO} = \frac{\sum \text{CO}_{\text{mass}} \times WF_i}{\sum P(n)_i \times WF_i}
\]

\[
\text{HC} = \frac{\sum \text{HC}_{\text{mass}} \times WF_i}{\sum P(n)_i \times WF_i}
\]

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

4.6. Calculation of the area control values

For the three control points selected according to paragraph 2.7.6., the NO\textsubscript{x} emission must be measured and calculated according to paragraph 4.6.1. and also determined by interpolation from the modes of the test cycle closest to the respective control point according to paragraph 4.6.2. The measured values are then compared to the interpolated values according to paragraph 4.6.3.

4.6.1. Calculation of the specific emission

The NO\textsubscript{x} emission for each of the control points (Z) must be calculated as follows:

\[
\text{NO}_{x,\text{mass},Z} = 0.001587 \times \text{NO}_{x,\text{conc},Z} \times K_{\text{H,D}} \times G_{\text{EXH,W}}
\]

\[
\text{NO}_{x,Z} = \text{NO}_{x,\text{mass},Z} / P(n)_Z
\]

4.6.2. Determination of the emission value from the test cycle

The NO\textsubscript{x} emission for each of the control points must 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:

\[
\text{Speed}(R) = \text{Speed}(T) = n_{RT}
\]

\[
\text{Speed}(S) = \text{Speed}(U) = n_{SU}
\]

\[
\text{Per cent load}(R) = \text{Per cent load}(S)
\]

\[
\text{Per cent load}(T) = \text{Per cent load}(U).
\]

The NO\textsubscript{x} emission of the selected control point Z must be calculated as follows:

\[
E_Z = E\text{RS} + (E\text{TU} - E\text{RS}) \cdot (n_Z - n_{RT}) / (n_{TU} - n_{RT})
\]

and:

\[
E\text{TU} = E_T + (E_U - E_T) \cdot (n_Z - n_{RT}) / (n_{SU} - n_{RT})
\]

\[
E\text{RS} = E_R + (E_S - E_R) \cdot (n_Z - n_{RT}) / (n_{SU} - n_{RT})
\]

\[
M\text{TU} = M_T + (M_U - M_T) \cdot (n_Z - n_{RT}) / (n_{SU} - n_{RT})
\]

\[
M\text{RS} = M_R + (M_S - M_R) \cdot (n_Z - n_{RT}) / (n_{SU} - n_{RT})
\]

where:

\[
E_k, E_u, E_r, E_t = \text{specific NO}_x \text{ emission of the enveloping modes calculated in accordance with paragraph 4.6.1.}
\]

\[
M_k, M_u, M_r, M_t = \text{engine torque of the enveloping modes}
\]
4.6.3. Comparison of NO\textsubscript{x} emission values

The measured specific NO\textsubscript{x} emission of the control point Z (NO\textsubscript{x,z}) is compared to the interpolated value (E\textsubscript{z}) as follows:

\[ \text{NO}_{x,\text{diff}} = 100 \times \frac{(\text{NO}_{x,z} - E_z)}{E_z} \]

5. CALCULATION OF THE PARTICULATE EMISSION

5.1. Data evaluation

For the evaluation of the particulates, the total sample masses (M\textsubscript{SAM,i}) through the filters must be recorded for each mode.

The filters must 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 must be recorded and the tare weight (see paragraph 1 of this appendix) subtracted. The particulate mass M\textsubscript{f} is the sum of the particulate masses collected on the primary and back-up filters.

If background correction is to be applied, the dilution air mass (M\textsubscript{DIL}) through the filters and the particulate mass (M\textsubscript{f}) must be recorded. If more than one measurement was made, the quotient M\textsubscript{f}/M\textsubscript{DIL} must be calculated for each single measurement and the values averaged.

5.2. Partial flow dilution system

The final reported test results of the particulate emission must be determined through the following steps. Since various types of dilution rate control may be used, different calculation methods for G\textsubscript{EFU} apply. All calculations must be based upon the average values of the individual modes during the sampling period.
5.2.1. Isokinetic systems

\[ G_{EDFW,i} = G_{EXHW,i} \times q_i \]

\[ q_i = \frac{G_{DLW,i} + (G_{EXHW,i} \times r)}{G_{EXHW,i} \times r} \]

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

\[ r = \frac{A_p}{A_r} \]

5.2.2. Systems with measurement of CO₂ or NOₓ concentration

\[ G_{EDFW,i} = G_{EXHW,i} \times q_i \]

\[ q_i = \frac{\text{conc}_{E,i} - \text{conc}_{A,i}}{\text{conc}_{D,1} - \text{conc}_{A,1}} \]

where:

- \( \text{conc}_{E} \) = wet concentration of the tracer gas in the raw exhaust
- \( \text{conc}_{D} \) = wet concentration of the tracer gas in the diluted exhaust
- \( \text{conc}_{A} \) = wet concentration of the tracer gas in the dilution air

Concentrations measured on a dry basis must be converted to a wet basis according to paragraph 4.2. of this appendix.

5.2.3. Systems with CO₂ measurement and carbon balance method (1)

\[ G_{EDFW,i} = \frac{206.5 - G_{FUEL,i}}{\text{CO}_2D,i - \text{CO}_2A,i} \]

where:

- \( \text{CO}_2D \) = CO₂ concentration of the diluted exhaust
- \( \text{CO}_2A \) = CO₂ concentration of the dilution air

(concentrations in Vol % 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:

\[ G_{EDFW,i} = G_{EXHW,i} \times q_i \]

\[ q_i = \frac{206.5 \times G_{FUEL,i} \times (\text{CO}_2D,i - \text{CO}_2A,i)}{G_{EXHW,i} \times (\text{CO}_2D,i - \text{CO}_2A,i)} \]

and,

5.2.4. Systems with flow measurement

\[ G_{EDFW,i} = G_{EXHW,i} \times q_i \]

\[ q_i = \frac{G_{TOTW,i}}{G_{TOTW,i} - G_{DLW,i}} \]

5.3. Full flow dilution system

The reported test results of the particulate emission must be determined through the following steps. All calculations must be based upon the average values of the individual modes during the sampling period.

\[ G_{EDFW,i} = G_{TOTW,i} \]

(1) The value is only valid for the reference fuel specified in the Regulation.
5.4. **Calculation of the particulate mass flow rate**

The particulate mass flow rate must be calculated as follows:

\[
PT_{\text{mass}} = \frac{M_i}{M_{\text{SAM}}} \times \frac{G_{\text{EDFW}}}{1000}
\]

where:

\[
G_{\text{EDFW}} = \sum_{i=1}^{n} G_{\text{EDFW},i} \times W_{Fi}
\]

\[
M_{\text{SAM}} = \sum_{i=1}^{n} M_{\text{SAM},i}
\]

\(i = 1, \ldots n\)

determined over the test cycle by summation of the average values of the individual modes during the sampling period.

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

\[
PT_{\text{mass}} = \left[ \frac{M_i}{M_{\text{SAM}}} - \left( \frac{M_i}{M_{\text{DIL}}} \times \sum_{i=1}^{n} \left( \frac{1}{DF_i} \times W_{Fi} \right) \right) \right] \times \frac{G_{\text{EDFW}}}{1000}
\]

If more than one measurement is made, \(M_i/M_{\text{DIL}}\) must be replaced with the average value of \(M_i/M_{\text{DIL}}\).

\(DF_i = 13.4 / (\text{conc CO}_2 + (\text{conc CO} + \text{conc HC}) \times 10^{-4})\) for the individual modes

or,

\(DF_i = 13.4 / \text{concCO}_2\) for the individual modes

5.5. **Calculation of the specific emission**

The particulate emission must be calculated in the following way:

\[
\overline{PT} = \frac{PT_{\text{mass}}}{\sum P(n) \times W_{Fi}}
\]

5.6. **Effective weighting factor**

The effective weighting factor \(WF_{E,i}\) for each mode must be calculated in the following way:

\[
WF_{E,i} = \frac{M_{\text{SAM},i} \times G_{\text{EDFW}}}{M_{\text{SAM}} \times G_{\text{EDFW},i}}
\]

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

6. **CALCULATION OF THE SMOKE VALUES**

6.1. **Bessel algorithm**

The Bessel algorithm must 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. must be repeated whenever the system response time and/or sampling rate changes.
6.1.1. 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 annex 4, appendix 4, paragraph 5.2.4., and must 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 of 0 to 1 in \( \leq 0.01 \) s (see annex 8). 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 must be obtained by iterating on \( f_c \) until \( t_{90} - t_{10} = t_f \). 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 \( K \) must be calculated by the following equations:

\[
E = \frac{1}{1 + \Omega \sqrt{3 + D + D \times \Omega^2}}
\]

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

where:

\( D = 0.618034 \)

\( \Delta t = 1 / \text{sampling rate} \)

\( \Omega = 1 / [\tan(\pi \times \Delta t \times f_c)] \)

6.1.2. Calculation of the Bessel Algorithm

Using the values of \( E \) and \( K \), the 1 s Bessel averaged response to a step input \( S_i \) must 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 \( t_{90} \) must 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 must be continued until the actual response time is within 1 per cent of the required response as follows:

\[
|t_{90} - t_{10}| - t_f \leq 0.01 \times t_f
\]

6.2. Data evaluation

The smoke measurement values must be sampled with a minimum rate of 20 Hz.
6.3. Determination of smoke

6.3.1. Data conversion

Since the basic measurement unit of all opacimeters is transmittance, the smoke values must 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, %
- \( \tau \) = transmittance, %

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

6.3.2. 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 \( K \) must be calculated. The Bessel algorithm must 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 \( Y_{max} \) must be selected from the individual \( Y_i \) values of each smoke trace.

6.3.3. Final result

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

For test speed A: \[ SV_A = \frac{(Y_{max1,A} + Y_{max2,A} + Y_{max3,A})}{3} \]
For test speed B: \[ SV_B = \frac{(Y_{max1,B} + Y_{max2,B} + Y_{max3,B})}{3} \]
For test speed C: \[ SV_C = \frac{(Y_{max1,C} + Y_{max2,C} + Y_{max3,C})}{3} \]

where:

\( Y_{max1}, Y_{max2}, Y_{max3} \) = highest 1s Bessel averaged smoke value at each of the three load steps

The final value must be calculated as follows:

\[ SV = (0.43 \times SV_A) + (0.56 \times SV_B) + (0.01 \times SV_C) \]
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 = \( n_{\text{max}} \times 1.02 \) or speed where full load torque drops off to zero, whichever is lower

1.2. Performing the engine power map

The engine must 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 must be performed as follows:

The engine must be unloaded and operated at idle speed.

The engine must be operated at full load setting of the injection pump at minimum mapping speed.

The engine speed must be increased at an average rate of 8 ± 1 min⁻¹/s from minimum to maximum mapping speed. Engine speed and torque points must be recorded at a sample rate of at least one point per second.

1.3. Mapping curve generation

All data points recorded under paragraph 1.2. must be connected using linear interpolation between points. The resulting torque curve is the mapping curve and must be used to convert the normalised torque values of the engine cycle into actual torque values for the test cycle, as described in paragraph 2.

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 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 must be approved by the Technical Service along with the justification for their use. In no case, however, must 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 must be remapped prior to a test cycle if:

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

or,

— physical changes or recalibrations have been made to the engine, which may potentially affect engine performance.
2. GENERATION OF THE REFERENCE TEST CYCLE

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

2.1. Actual speed

The speed must be unnormalised using the following equation:

\[
\text{Actual speed} = \frac{\% \text{ speed (reference speed – idle speed)}}{100} + \text{idle speed}
\]

The reference speed \(n_{\text{ref}}\) 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 the Regulation):

\[
n_{\text{ref}} = n_{\text{lo}} + 95 \% \times (n_{\text{hi}} - n_{\text{lo}})
\]

where \(n_{\text{lo}}\) and \(n_{\text{hi}}\) are either specified according to the Regulation, paragraph 2 or determined according to annex 4, appendix 1, paragraph 1.1.

2.2. Actual torque

The torque is normalised to the maximum torque at the respective speed. The torque values of the reference cycle must be unnormalised, using the mapping curve determined according to section 1.3, as follows:

\[
\text{Actual torque} = \frac{\% \text{ torque} \times \text{max. torque}}{100}
\]

for the respective actual speed as determined in paragraph 2.1.

The negative torque values of the motoring points ‘m’ must take on, for purposes of reference cycle generation, unnormalised values determined in either of the following ways:

- negative 40 per cent of the positive torque available at the associated speed point;
- mapping of the negative torque required to motor the engine from minimum to maximum mapping speed;
- 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 unnormalisation procedure

As an example, the following test point must be unnormalised:

\[
\begin{align*}
\% \text{ speed} &= 43 \\
\% \text{ torque} &= 82
\end{align*}
\]

Given the following values:

\[
\begin{align*}
\text{reference speed} &= 2\,200 \text{ min}^{-1} \\
\text{idle speed} &= 600 \text{ min}^{-1}
\end{align*}
\]

results in,

\[
\begin{align*}
\text{actual speed} &= \frac{43 \times (2\,200 - 600)}{100} + 600 = 1\,288 \text{ min}^{-1} \\
\text{actual torque} &= \frac{82 \times 700}{100} = 574 \text{ Nm}
\end{align*}
\]
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 must be run-in using the ETC test. The engine must 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 (pair) must be placed in a closed, but unsealed petri dish and placed in a weighing chamber for stabilisation. At the end of the stabilisation period, each filter (pair) must be weighed and the tare weight must be recorded. The filter (pair) must then be stored in a closed petri dish or sealed filter holder until needed for testing. If the filter (pair) is not used within eight hours of its removal from the weighing chamber, it must be conditioned and reweighed before use.

3.2. **Installation of the measuring equipment**

The instrumentation and sample probes must be installed as required. The tailpipe must be connected to the full flow dilution system.

3.3. **Starting the dilution system and the engine**

The dilution system and the engine must 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 (if applicable)**

The particulate sampling system must 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.

3.5. **Adjustment of the full flow dilution system**

The total diluted exhaust gas flow must be set to eliminate water condensation in the system, and to obtain a maximum filter face temperature of 325 K (52 °C) or less (see annex 4, appendix 6, paragraph 2.3.1., DT).

3.6. **Checking the analysers**

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

3.7. **Engine starting procedure**

The stabilised engine must 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 must be started, if the engine has reached idle speed. The test must be performed according to the reference cycle as set out in paragraph 2 of this appendix. Engine speed and torque command set points must be issued at 5 Hz (10 Hz recommended) or greater. Feedback engine speed and torque must be recorded at least once every second during the test cycle, and the signals may be electronically filtered.

3.8.2. Analyser response

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

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

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

3.8.3. Particulate sampling (if applicable)

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, the particulate sampling system must be switched from by-pass to collecting particulates.

If no flow compensation is used, the sample pump(s) must 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 must 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).

Note: 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 must 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 must be voided. The test must be rerun using a lower flow rate and/or a larger diameter filter.

3.8.4. Engine stalling

If the engine stalls anywhere during the test cycle, the engine must 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 must be voided.

3.8.5. Operations after test

At the completion of the test, the measurement of the diluted exhaust gas volume, the gas flow into the collecting bags and the particulate sample pump must be stopped. For an integrating analyser system, sampling must continue until system response times have elapsed.
The concentrations of the collecting bags, if used, must 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 must be used for re-checking the analysers. The test will be considered acceptable if the difference between the pre-test and post-test results is less than 2 per cent of the span gas value.

For diesel engines only, the particulate filters must be returned to the weighing chamber no later than one hour after completion of the test and must be conditioned in a closed, but unsealed petri dish for at least one hour, but not more than 80 hours before weighing.

3.9. Verification of the test run

3.9.1. Data shift

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

3.9.2. Calculation of the cycle work

The actual cycle work $W_{act}$ (kWh) must be calculated using each pair of engine feedback speed and torque values recorded. This must 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 4.4, and 5.2). The same methodology must 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 must be used.

In integrating the reference and actual cycle work, all negative torque values must be set equal to zero and included. If integration is performed at a frequency of less than 5 Hertz, and if, during a given time segment, the torque value changes from positive to negative or negative to positive, the negative portion must be computed and set equal to zero. The positive portion must be included in the integrated value.

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

3.9.3. Validation statistics of the test cycle

Linear regressions of the feedback values on the reference values must be performed for speed, torque and power. This must be done after any feedback data shift has occurred, if this option is selected. The method of least squares must 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 ($r^2$) must be calculated for each regression line.

It is recommended that this analysis be performed at 1 Hertz. All negative reference torque values and the associated feedback values must be deleted from the calculation of cycle torque and power validation statistics. For a test to be considered valid, the criteria of table 6 must be met.
### Table 6

<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Torque</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard error of estimate (SE) of Y on X</td>
<td>max 100 min$^{-1}$</td>
<td>max 13% (15%) of power map maximum engine torque</td>
<td>max 8% (15%) of power map maximum engine power</td>
</tr>
<tr>
<td>Slope of the regression line, m</td>
<td>0.95 to 1.03</td>
<td>0.83 – 1.03</td>
<td>0.89 – 1.03</td>
</tr>
<tr>
<td>Coefficient of determination, $r^2$</td>
<td>min 0.9700</td>
<td>min 0.8800</td>
<td>min 0.9100</td>
</tr>
<tr>
<td>(min 0.9500)</td>
<td></td>
<td>(min 0.7500)</td>
<td>(min 0.7500)</td>
</tr>
<tr>
<td>Y intercept of the regression line, b</td>
<td>± 50 min$^{-1}$</td>
<td>± 20 Nm or ± 2% (± 20 Nm or ± 3%) of max torque whichever is greater</td>
<td>± 4 kW or ± 2% (± 4 kW or ± 3%) of max power whichever is greater</td>
</tr>
</tbody>
</table>

The figures shown in brackets may be used for the type-approval testing of gas engines until 1 October 2005.

### Table 7

<table>
<thead>
<tr>
<th>Condition</th>
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<tr>
<td>Full load and torque feedback ≠ torque reference</td>
<td>Torque and/or power</td>
</tr>
<tr>
<td>No load, not an idle point, and torque feedback &gt; torque reference</td>
<td>Torque and/or power</td>
</tr>
<tr>
<td>No load/closed throttle, idle point and speed &gt; reference idle speed</td>
<td>Speed and/or power</td>
</tr>
</tbody>
</table>

### 4. CALCULATION OF THE GASEOUS EMISSIONS

#### 4.1. Determination of the diluted exhaust gas flow

The total diluted exhaust gas flow over the cycle (kg/test) must be calculated from the measurement values over the cycle and the corresponding calibration data of the flow measurement device ($V_0$ for PDP or $K_v$ for CFV, as determined in annex 4, appendix 5, paragraph 2.). The following formulae must 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, see annex 4, appendix 6, paragraph 2.3.).

For the PDP-CVS system

$$M_{TOTW} = 1.293 \times V_0 \times N_p \times (p_B - p_1) \times 273 / (101.3 \times T)$$

where:

- $M_{TOTW}$ = mass of the diluted exhaust gas on wet basis over the cycle, kg
- $V_0$ = 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

\[ M_{\text{TOTW}} = 1.293 \times t \times K_v \times \frac{p_A}{T^{0.5}} \]

where:
- \( M_{\text{TOTW}} \) = mass of the diluted exhaust gas on wet basis over the cycle, kg
- \( t \) = cycle time, s
- \( K_v \) = calibration coefficient of the critical flow venturi for standard conditions,
- \( p_A \) = absolute pressure at venturi inlet, kPa
- \( T \) = absolute temperature at venturi inlet, K

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

For the PDP-CVS system:

\[ M_{\text{TOTW},i} = 1.293 \times \frac{V_0 \times N_{P,i} \times (p_B - p_1) \times 273}{(101.3 \approx T)} \]

where:
- \( M_{\text{TOTW},i} \) = instantaneous mass of the diluted exhaust gas on wet basis, kg
- \( N_{P,i} \) = total revolutions of pump per time interval

For the CFV-CVS system:

\[ M_{\text{TOTW},i} = 1.293 \times \Delta t_i \times K_v \times \frac{p_A}{T^{0.5}} \]

where:
- \( M_{\text{TOTW},i} \) = instantaneous mass of the diluted exhaust gas on wet basis, kg
- \( \Delta t_i \) = time interval, s

If the total sample mass of particulates (\( M_{\text{SAM}} \)) and gaseous pollutants exceeds 0.5 per cent of the total CVS flow (\( M_{\text{TOTW}} \)), the CVS flow must be corrected for \( M_{\text{SAM}} \) or the particulate sample flow must be returned to the CVS prior to the flow measuring device (PDP or CFV).

4.2. NO\textsubscript{x} correction for humidity

As the NO\textsubscript{x} emission depends on ambient air conditions, the NO\textsubscript{x} concentration must be corrected for ambient air humidity with the factors given in the following formulae.

(a) for diesel engines:

\[ K_{\text{HD}} = \frac{1}{1 - 0.0182 \times (H_a - 10.71)} \]

(b) for gas engines:

\[ K_{\text{HG}} = \frac{1}{1 - 0.0329 \times (H_a - 10.71)} \]

where:
- \( H_a \) = humidity of the intake air, grams of water per kg of dry air.
in which:

\[
H_i = \frac{6.220 \times R_a \times p_a}{p_b - p_a \times R_a \times 10}\]

\( R_a \) = relative humidity of the intake air, %

\( p_a \) = saturation vapour pressure of the intake air, kPa

\( p_b \) = total barometric pressure, kPa

4.3. Calculation of the emission mass flow

4.3.1. Systems with constant mass flow

For systems with heat exchanger, the mass of the pollutants (g/text) must be determined from the following equations:

1. \( \text{NO}_x \) mass = 0.001587 \cdot \text{NO}_x \text{conc} \cdot K_{H,D} \cdot M_{TOTW} \) (diesel engines)
2. \( \text{NO}_x \) mass = 0.001587 \cdot \text{NO}_x \text{conc} \cdot K_{H,G} \cdot M_{TOTW} \) (gas engines)
3. \( \text{CO} \) mass = 0.000966 \cdot \text{CO} \text{conc} \cdot M_{TOTW} \)
4. \( \text{HC} \) mass = 0.000479 \cdot \text{HC} \text{conc} \cdot M_{TOTW} \) (diesel engines)
5. \( \text{HC} \) mass = 0.000502 \cdot \text{HC} \text{conc} \cdot M_{TOTW} \) (LPG fuelled engines)
6. \( \text{HC} \) mass = 0.000552 \cdot \text{HC} \text{conc} \cdot M_{TOTW} \) (NG fuelled engines)
7. \( \text{NMHC} \) mass = 0.000479 \cdot \text{NMHC} \text{conc} \cdot M_{TOTW} \) (diesel engines)
8. \( \text{NMHC} \) mass = 0.000502 \cdot \text{NMHC} \text{conc} \cdot M_{TOTW} \) (LPG fuelled engines)
9. \( \text{NMHC} \) mass = 0.000516 \cdot \text{NMHC} \text{conc} \cdot M_{TOTW} \) (NG fuelled engines)
10. \( \text{CH}_4 \) mass = 0.000552 \cdot \text{CH}_4 \text{conc} \cdot M_{TOTW} \) (NG fuelled engines)

where:

\( \text{NO}_x \text{conc}, \text{CO} \text{conc}, \text{HC} \text{conc}, \text{NMHC} \text{conc}, \text{CH}_4 \text{conc} \) = average background corrected concentrations over the cycle from integration (mandatory for NO\(_x\) and HC) or bag measurement, ppm

\( M_{TOTW} \) = total mass of diluted exhaust gas over the cycle as determined in paragraph 4.1., kg

\( K_{H,D} \) = humidity correction factor for diesel engines as determined in paragraph 4.2., based on cycle averaged intake air humidity

\( K_{H,G} \) = humidity correction factor for gas engines as determined in paragraph 4.2., based on cycle averaged intake air humidity

Concentrations measured on a dry basis must be converted to a wet basis in accordance with annex 4, appendix 1, paragraph 4.2.

The determination of \( \text{NMHC} \text{conc} \) and \( \text{CH}_4 \text{conc} \) depends on the method used (see annex 4, appendix 4, paragraph 3.3.4.). Both concentrations must be determined as follows, whereby \( \text{CH}_4 \) is subtracted from \( \text{HC} \) for the determination of \( \text{NMHC} \text{conc} \):

(a) GC method

\[ \text{NMHC} \text{conc} = \text{HC} \text{conc} - \text{CH}_4 \text{conc} \]

\( \text{CH}_4 \text{conc} = \text{as measured} \)

(\(^{(1)}\) Based on C\(_1\) equivalent.)
(b) NMC method

\[ \text{NMHC}_{\text{conc}} = \frac{\text{HC}(w/o \text{Cutter}) \cdot (1 - \text{CE}_m) - \text{HC}(w/\text{Cutter})}{\text{CEE} - \text{CE}_m} \]

\[ \text{CH}_{4,\text{conc}} = \frac{\text{HC}(w/\text{Cutter}) - \text{HC}(w/o \text{Cutter}) \cdot (1 - \text{CE}_e)}{\text{CEE} - \text{CE}_m} \]

where:
- \( \text{HC}(w/\text{Cutter}) \) = HC concentration with the sample gas flowing through the NMC
- \( \text{HC}(w/o \text{Cutter}) \) = HC concentration with the sample gas bypassing the NMC
- \( \text{CE}_m \) = methane efficiency as determined per annex 4, appendix 5, paragraph 1.8.4.1.
- \( \text{CE}_e \) = ethane efficiency as determined per annex 4, appendix 5, paragraph 1.8.4.2.

4.3.1.1. Determination of the background corrected concentrations

The average background concentration of the gaseous pollutants in the dilution air must 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 must be used.

\[ \text{conc} = \text{conc}_e - \text{conc}_d \cdot (1 - (1/\text{DF})) \]

where:
- \( \text{conc} \) = concentration of the respective pollutant in the diluted exhaust gas, corrected by the amount of the respective pollutant contained in the dilution air, ppm
- \( \text{conc}_e \) = concentration of the respective pollutant measured in the diluted exhaust gas, ppm
- \( \text{conc}_d \) = concentration of the respective pollutant measured in the dilution air, ppm
- \( \text{DF} \) = dilution factor

The dilution factor shall be calculated as follows:

\[ \text{DF} = \frac{F_s}{\text{CO}_2,\text{conc} + (\text{HC}_{\text{conc}} + \text{CO}_{\text{conc}}) \cdot 10^{-4}} \]

where:
- \( \text{CO}_2,\text{conc} \) = concentration of CO\(_2\) in the diluted exhaust gas, % vol
- \( \text{HC}_{\text{conc}} \) = concentration of HC in the diluted exhaust gas, ppm C\(_1\)
- \( \text{CO}_{\text{conc}} \) = concentration of CO in the diluted exhaust gas, ppm
- \( F_s \) = stoichiometric factor

Concentrations measured on dry basis must be converted to a wet basis in accordance with annex 4, appendix 1, paragraph 4.2.

The stoichiometric factor must be calculated as follows:

\[ F_s = 100 \cdot \frac{x}{x + 3.76 \cdot \left( \frac{y}{2} + 3.76 \cdot \left\lfloor \frac{y}{4} \right\rfloor \right)} \]

where:
- \( x, y \) = fuel composition \( C_xH_y \)
Alternatively, if the fuel composition is not known, the following stoichiometric factors may be used:

\[ F_S \text{ (diesel)} = 13.4 \]
\[ F_S \text{ (LPG)} = 11.6 \]
\[ F_S \text{ (NG)} = 9.5 \]

4.3.2. Systems with flow compensation

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

\[ (1) \text{ NO}_x \text{ mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times NO_x \text{ conc}_{i} \times 0.001587 \times K_{H,D}) - (M_{\text{TOTW}} \times NO_x \text{ concd} \times (1 - 1/DF) \times 0.001587 \times K_{H,D}) \]  
\[ \text{(diesel engines)} \]

\[ (2) \text{ NO}_x \text{ mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times NO_x \text{ conc}_{i} \times 0.001587 \times K_{H,G}) - (M_{\text{TOTW}} \times NO_x \text{ concd} \times (1 - 1/DF) \times 0.001587 \times K_{H,G}) \]  
\[ \text{(gas engines)} \]

\[ (3) \text{ CO mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times CO \text{ conc}_{i} \times 0.000966) - (M_{\text{TOTW}} \times CO \text{ concd} \times (1 - 1/DF) \times 0.000966) \]

\[ (4) \text{ HC mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times HC \text{ conc}_{i} \times 0.000479) - (M_{\text{TOTW}} \times HC \text{ concd} \times (1 - 1/DF) \times 0.000479) \]  
\[ \text{(diesel engines)} \]

\[ (5) \text{ HC mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times HC \text{ conc}_{i} \times 0.000502) - (M_{\text{TOTW}} \times HC \text{ concd} \times (1 - 1/DF) \times 0.000502) \]  
\[ \text{(LPG engines)} \]

\[ (6) \text{ HC mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times HC \text{ conc}_{i} \times 0.000552) - (M_{\text{TOTW}} \times HC \text{ concd} \times (1 - 1/DF) \times 0.000552) \]  
\[ \text{(NG engines)} \]

\[ (7) \text{ NMHC mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times NMHC \text{ conc}_{i} \times 0.000479) - (M_{\text{TOTW}} \times NMHC \text{ concd} \times (1 - 1/DF) \times 0.000479) \]  
\[ \text{(diesel engines)} \]

\[ (8) \text{ NMHC mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times NMHC \text{ conc}_{i} \times 0.000502) - (M_{\text{TOTW}} \times NMHC \text{ concd} \times (1 - 1/DF) \times 0.000502) \]  
\[ \text{(LPG engines)} \]

\[ (9) \text{ NMHC mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times NMHC \text{ conc}_{i} \times 0.000516) - (M_{\text{TOTW}} \times NMHC \text{ concd} \times (1 - 1/DF) \times 0.000516) \]  
\[ \text{(NG engines)} \]

\[ (10) \text{ CH}_4 \text{ mass} = \sum_{i=1}^{n} (M_{\text{TOTW}_i} \times CH_4 \text{ conc}_{i} \times 0.000552) - (M_{\text{TOTW}} \times CH_4 \text{ concd} \times (1 - 1/DF) \times 0.000552) \]  
\[ \text{(NG engines)} \]

where:
\[ \text{conc}_{c} = \text{concentration of the respective pollutant measured in the diluted exhaust gas, ppm} \]
\[ \text{conc}_{d} = \text{concentration of the respective pollutant measured in the dilution air, ppm} \]
\[ M_{\text{TOTW}_i} = \text{instantaneous mass of the diluted exhaust gas (see paragraph 4.1.), kg} \]
\[ M_{\text{TOTW}} = \text{total mass of diluted exhaust gas over the cycle (see paragraph 4.1.), kg} \]
\[ K_{H,D} = \text{humidity correction factor for diesel engines as determined in paragraph 4.2., based on cycle averaged intake air humidity} \]
\[ K_{H,G} = \text{humidity correction factor for gas engines as determined in paragraph 4.2., based on cycle averaged intake air humidity} \]
\[ DF = \text{dilution factor as determined in paragraph 4.3.1.1.} \]
4.4. Calculation of the specific emissions

The emissions (g/kWh) must be calculated for the individual components, as required according to paragraphs 5.2.1. and 5.2.2. for the respective engine technology, in the following way:

\[
\begin{align*}
\text{NO}_x & = \frac{\text{NO}_x \text{ mass}}{W_{\text{act}}} \quad \text{(diesel and gas engines)} \\
\text{CO} & = \frac{\text{CO mass}}{W_{\text{act}}} \quad \text{(diesel and gas engines)} \\
\text{HC} & = \frac{\text{HC mass}}{W_{\text{act}}} \quad \text{(diesel and gas engines)} \\
\text{NMHC} & = \frac{\text{NMHC mass}}{W_{\text{act}}} \quad \text{(diesel and gas engines)} \\
\text{CH}_4 & = \frac{\text{CH}_4 \text{ mass}}{W_{\text{act}}} \quad \text{(NG fuelled gas engines)}
\end{align*}
\]

where:

\[W_{\text{act}} = \text{actual cycle work as determined in paragraph 3.9.2.}, \text{ kWh}\]

5. CALCULATION OF THE PARTICULATE EMISSION (IF APPLICABLE)

5.1. Calculation of the mass flow

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

\[
\text{PT}_{\text{mass}} = \frac{M_{f}}{M_{\text{SAM}} \times 1000} \times M_{\text{TOTW}}
\]

where:

\[
\begin{align*}
M_{f} & = \text{particulate mass sampled over the cycle, mg} \\
M_{\text{TOTW}} & = \text{total mass of diluted exhaust gas over the cycle as determined in paragraph 4.1.}, \text{ kg} \\
M_{\text{SAM}} & = \text{mass of diluted exhaust gas taken from the dilution tunnel for collecting particulates, kg} \\
M_{f,p} & = \text{particulate mass collected on the primary filter, mg} \\
M_{f,b} & = \text{particulate mass collected on the back-up filter, mg}
\end{align*}
\]

and,

\[
M_{f} = M_{f,p} + M_{f,b}, \text{ if weighed separately, mg}
\]

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

\[
M_{\text{SAM}} = M_{\text{TOT}} - M_{\text{SEC}}
\]

where:

\[
\begin{align*}
M_{\text{TOT}} & = \text{mass of double diluted exhaust gas through particulate filter, kg} \\
M_{\text{SEC}} & = \text{mass of secondary dilution air, kg}
\end{align*}
\]

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) must be calculated as follows:

\[
\text{PT}_{\text{mass}} = \left[ \frac{M_{f}}{M_{\text{SAM}} \left( \frac{M_{f}}{M_{\text{SAM}}} \times \left( 1 - \frac{1}{DF} \right) \right) \times 1000} \right] \times M_{\text{TOTW}}
\]
where:

\[ M_p, M_{\text{SAM}}, M_{\text{TOTW}} = \text{see above} \]
\[ M_{\text{DIL}} = \text{mass of primary dilution air sampled by background particulate sampler, kg} \]
\[ M_d = \text{mass of the collected background particulates of the primary dilution air, mg} \]
\[ \text{DF} = \text{dilution factor as determined in paragraph 4.3.1.1.} \]

5.2. **Calculation of the specific emission**

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

\[ \overline{P_T} = \frac{P_{T_{\text{mass}}}}{W_{\text{act}}} \]

where:

\[ W_{\text{act}} = \text{actual cycle work as determined in paragraph 3.9.2., kWh.} \]
ANNEX 4

Appendix 3

ETC ENGINE DYNAMOMETER SCHEDULE

<table>
<thead>
<tr>
<th>Time</th>
<th>Norm. Speed</th>
<th>Norm. Torque</th>
</tr>
</thead>
<tbody>
<tr>
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<td>%</td>
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<td>59,9</td>
<td>20,4</td>
</tr>
<tr>
<td>1 689</td>
<td>59,8</td>
<td>4,4</td>
</tr>
<tr>
<td>1 690</td>
<td>59,4</td>
<td>3,1</td>
</tr>
<tr>
<td>1 691</td>
<td>59,5</td>
<td>26,3</td>
</tr>
<tr>
<td>1 692</td>
<td>59,6</td>
<td>20,1</td>
</tr>
<tr>
<td>1 693</td>
<td>59,4</td>
<td>35</td>
</tr>
<tr>
<td>1 694</td>
<td>60,9</td>
<td>22,1</td>
</tr>
<tr>
<td>1 695</td>
<td>60,5</td>
<td>12,2</td>
</tr>
<tr>
<td>1 696</td>
<td>60,1</td>
<td>11</td>
</tr>
<tr>
<td>1 697</td>
<td>60,1</td>
<td>8,2</td>
</tr>
<tr>
<td>1 698</td>
<td>60,5</td>
<td>6,7</td>
</tr>
<tr>
<td>1 699</td>
<td>60</td>
<td>5,1</td>
</tr>
<tr>
<td>1 700</td>
<td>60</td>
<td>5,1</td>
</tr>
<tr>
<td>1 701</td>
<td>60</td>
<td>9</td>
</tr>
<tr>
<td>1 702</td>
<td>60,1</td>
<td>5,7</td>
</tr>
<tr>
<td>1 703</td>
<td>59,9</td>
<td>8,5</td>
</tr>
<tr>
<td>1 704</td>
<td>59,4</td>
<td>6</td>
</tr>
<tr>
<td>1 705</td>
<td>59,5</td>
<td>5,5</td>
</tr>
<tr>
<td>1 706</td>
<td>59,5</td>
<td>14,2</td>
</tr>
<tr>
<td>1 707</td>
<td>59,5</td>
<td>6,2</td>
</tr>
<tr>
<td>1 708</td>
<td>59,4</td>
<td>10,3</td>
</tr>
<tr>
<td>1 709</td>
<td>59,6</td>
<td>13,8</td>
</tr>
<tr>
<td>1 710</td>
<td>59,5</td>
<td>13,9</td>
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<tr>
<td>1 711</td>
<td>60,1</td>
<td>18,9</td>
</tr>
<tr>
<td>1 712</td>
<td>59,4</td>
<td>13,1</td>
</tr>
<tr>
<td>1 713</td>
<td>59,8</td>
<td>5,4</td>
</tr>
<tr>
<td>1 714</td>
<td>59,9</td>
<td>2,9</td>
</tr>
<tr>
<td>1 715</td>
<td>60,1</td>
<td>7,1</td>
</tr>
<tr>
<td>1 716</td>
<td>59,6</td>
<td>12</td>
</tr>
</tbody>
</table>

'm' = motoring.
A graphical display of the ETC dynamometer schedule is shown in Figure 5.

Figure 5: ETC Dynamometer Schedule
ANNEX 4

Appendix 4

MEASUREMENT AND SAMPLING PROCEDURES

1. INTRODUCTION

Gaseous components, particulates, and smoke emitted by the engine submitted for testing must be measured by the methods described in annex 4, appendix 6. The respective paragraphs of annex 4, appendix 6 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 must 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 must be determined with either a partial flow or a full flow dilution system.

For the ETC, only a full flow dilution system must be used for determining gaseous and particulate emissions, and is considered the reference system. However, partial flow dilution systems may be approved by the Technical Service, if their equivalency according to paragraph 6.2. to the Regulation is proven, and if a detailed description of the data evaluation and calculation procedures is submitted to the Technical Service.

2. DYNAMOMETER AND TEST CELL EQUIPMENT

The following equipment must be used for emission tests of engines on engine dynamometers.

2.1. Engine dynamometer

An engine dynamometer must be used with adequate characteristics to perform the test cycles described in appendices 1 and 2 to this annex. The speed measuring system must have an accuracy of ± 2 per cent of reading. The torque measuring system must have an accuracy of ± 3 per cent of reading in the range > 20 per cent of full scale, and an accuracy of ± 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 must be used, as required. These instruments must satisfy the requirements given in table 8:

<table>
<thead>
<tr>
<th>Measuring instrument</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Consumption</td>
<td>± 2 % of Engine's Maximum Value</td>
</tr>
<tr>
<td>Air Consumption</td>
<td>± 2 % of Engine's Maximum Value</td>
</tr>
<tr>
<td>Temperatures ≤ 600 K (327 °C)</td>
<td>± 2 K Absolute</td>
</tr>
<tr>
<td>Temperatures ≥ 600 K (327 °C)</td>
<td>± 1 % of Reading</td>
</tr>
<tr>
<td>Atmospheric Pressure</td>
<td>± 0.1 kPa Absolute</td>
</tr>
<tr>
<td>Exhaust Gas Pressure</td>
<td>± 0.2 kPa Absolute</td>
</tr>
<tr>
<td>Intake Depression</td>
<td>± 0.05 kPa Absolute</td>
</tr>
<tr>
<td>Other Pressures</td>
<td>± 0.1 kPa Absolute</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>± 3 % Absolute</td>
</tr>
<tr>
<td>Absolute Humidity</td>
<td>± 5 % of Reading</td>
</tr>
</tbody>
</table>
2.3. **Exhaust gas flow**

For calculation of the emissions in the raw exhaust, it is necessary to know the exhaust gas flow (see paragraph 4.4. of appendix 1). For the determination of the exhaust flow either of the following methods may be used:

Direct measurement of the exhaust flow by flow nozzle or equivalent metering system;

Measurement of the air flow and the fuel flow by suitable metering systems and calculation of the exhaust flow by the following equation:

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

The accuracy of exhaust flow determination must be ± 2.5 per cent of reading or better.

2.4. **Diluted exhaust gas flow**

For calculation of the emissions in the diluted exhaust using a full flow dilution system (mandatory for the ETC), it is necessary to know the diluted exhaust gas flow (see paragraph 4.3. of appendix 2). The total mass flow rate of the diluted exhaust \( G_{\text{ETC}} \) or the total mass of the diluted exhaust gas over the cycle \( M_{\text{ETC}} \) must be measured with a PDP or CFV (annex 4, appendix 6, paragraph 2.3.1.). The accuracy must be ± 2 per cent of reading or better, and must be determined according to the provisions of annex 4, appendix 5, paragraph 2.4.

3. **DETERMINATION OF THE GASEOUS COMPONENTS**

3.1. **General analyser specifications**

The analysers must 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 analysers 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 annex 4, appendix 5, paragraph 1.5.5.2.

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

3.1.1. **Measurement error**

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

3.1.2. **Repeatability**

The repeatability, 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 ppm C) or ± 2 per cent of each range used below 155 ppm (or ppm C).

3.1.3. **Noise**

The analyser peak-to-peak response to zero and calibration or span gases over any 10 seconds period must not exceed 2 per cent of full scale on all ranges used.

3.1.4. **Zero drift**

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

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

3.2. **Gas drying**

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

3.3. **Analysers**

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 annex 4, appendix 6. The gases to be measured must be analysed with the following instruments. For non-linear analysers, the use of linearising circuits is permitted.

3.3.1. **Carbon monoxide (CO) analysis**

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

3.3.2. **Carbon dioxide (CO₂) analysis**

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

3.3.3. **Hydrocarbon (HC) analysis**

For diesel and LPG fuelled gas engines, the hydrocarbon analyser must be of the Heated Flame Ionisation Detector (HFID) type with detector, valves, pipework, etc. heated so as to maintain a gas temperature of 463 K ± 10 K (190 ± 10 °C). For NG fuelled gas engines, the hydrocarbon analyser may be of the non heated Flame Ionisation Detector (FID) type depending upon the method used (see annex 4, appendix 6, paragraph 1.3.).

3.3.4. **Non-methane hydrocarbon (NMHC) analysis (NG fuelled gas engines only)**

Non-methane hydrocarbons must be determined by either of the following methods:

3.3.4.1. **Gas chromatographic (GC) method**

Non-methane hydrocarbons must be determined by subtraction of the methane analysed with a Gas Chromatograph (GC) conditioned at 423 K (150 °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 must 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 (NOₓ) analysis**

The oxides of nitrogen analyser must be of the Chemi-Luminescent Detector (CLD) or Heated Chemi-Luminescent 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) must be used, provided the water quench check (see annex 4, appendix 5, paragraph 1.9.2.2.) is satisfied.
3.4. Sampling of gaseous emissions

3.4.1. Raw exhaust gas (ESC only)

The gaseous emissions sampling probes must 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 as far as applicable and 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 must 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 ‘V-engine’ configuration, it is permissible to acquire a sample from each group individually and calculate an average exhaust emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emission calculation the total exhaust mass flow must be used.

If the engine is equipped with an exhaust after-treatment system, the exhaust sample must be taken downstream of the exhaust after-treatment system.

3.4.2. Diluted exhaust gas (mandatory for ETC, optional for ESC)

The exhaust pipe between the engine and the full flow dilution system must conform to the requirements of annex 4, appendix 6, paragraph 2.3.1., EP.

The gaseous emissions sample probe(s) must 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.

For the ETC, sampling can generally be done in two ways:

— the pollutants are sampled into a sampling bag over the cycle and measured after completion of the test;
— the pollutants are sampled continuously and integrated over the cycle; this method is mandatory for HC and NOx.

4. DETERMINATION OF THE PARTICULATES

The determination of the particulates requires a dilution system. Dilution may be accomplished by a partial flow dilution system (ESC only) or a full flow dilution system (mandatory for ETC). The flow capacity of the dilution system must be large enough to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas at or below 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 must be 298 K ± 5 K (25 °C ± 5 °C). If the ambient temperature is below 293 K (20 °C), dilution air pre-heating above the upper temperature limit of 303 K (30 °C) is recommended. However, the dilution air temperature must not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel.

The partial flow dilution system has to be designed to split the exhaust stream into two fractions, the smaller one being diluted with air and subsequently used for particulate measurement. For this it is essential that the dilution ratio be determined very accurately. Different splitting methods can be applied, whereby the type of splitting used dictates to a significant degree the sampling hardware and procedures to be used (annex 4, appendix 6, paragraph 2.2.). The particulate sampling probe must be installed in close proximity to the gaseous emissions sampling probe, and the installation must comply with the provisions of paragraph 3.4.1.

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

For particulate sampling, the single filter method must be applied which uses one pair of filters (see paragraph 4.1.3) for the whole test cycle. For the ESC, considerable attention must be paid to sampling times and flows during the sampling phase of the test.
4.1. Particulate sampling filters

4.1.1. Filter specification

Fluorocarbon coated glass fibre filters or fluorocarbon based membrane filters are required. All filter types must have a 0,3 µm DOP (di-octylphthalate) collection efficiency of at least 95 per cent at a gas face velocity between 35 and 80 cm/s.

4.1.2. Filter size

Particulate filters must have a minimum diameter of 47 mm (37 mm stain diameter). Larger diameter filters are acceptable (paragraph 4.1.5).

4.1.3. Primary and back-up Filters

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

4.1.4. Filter face velocity

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

4.1.5. Filter loading

The recommended minimum filter loading must be 0,5 mg/1 075 mm² stain area. For the most common filter sizes the values are shown in table 9.

<table>
<thead>
<tr>
<th>Filter Diameter (mm)</th>
<th>Recommended Stain</th>
<th>Recommended Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>47</td>
<td>37</td>
<td>0,5</td>
</tr>
<tr>
<td>70</td>
<td>60</td>
<td>1,3</td>
</tr>
<tr>
<td>90</td>
<td>80</td>
<td>2,3</td>
</tr>
<tr>
<td>110</td>
<td>100</td>
<td>3,6</td>
</tr>
</tbody>
</table>

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 must be maintained to within 295 K ± 3 K (22 °C ± 3 °C) during all filter conditioning and weighing. The humidity must be maintained to a dew point of 282,5 K ± 3 K (9,5 °C ± 3 °C) and a relative humidity of 45 % ± 8 %.

4.2.2. Reference filter weighing

The chamber (or room) environment must 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 or reference filter pairs must be weighed within 4 hours of, but preferably at the same time as the sample filter (pair) weighings. They must be the same size and material as the sample filters.
If the average weight of the reference filters (reference filter pairs) changes between sample filter weighings by more than ± 5 per cent (± 7.5 per cent for the filter pair respectively) of the recommended minimum filter loading (paragraph 4.1.5.), then all sample filters must 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 (pair) weighings meet the above criteria, the engine manufacturer has the option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system and rerunning the test.

4.2.3. Analytical balance

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

4.2.4. Elimination of static electricity effects

To eliminate the effects of static electricity, the filters should be neutralised prior to weighing, e.g. by a Polonium neutraliser or a device of similar effect.

4.3. Additional specifications for particulate measurement

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

5. DETERMINATION OF SMOKE OPACITY

This paragraph provides specifications for the required and optional test equipment to be used for the ELR test. The smoke must be measured with an opacimeter having an opacity and a light absorption coefficient readout mode. The opacity readout mode must only be used for calibration and checking of the opacimeter. The smoke values of the test cycle must 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:

— An opacimeter meeting the specifications of annex 4, appendix 6, paragraph 3.

— A data processing unit capable of performing the functions described in annex 4, appendix 1, paragraph 6.

— A printer and/or electronic storage medium to record and output the required smoke values specified in annex 4, appendix 1, paragraph 6.3.

5.2. Specific requirements

5.2.1. Linearity

The linearity must be within ± 2 per cent opacity.

5.2.2. Zero drift

The zero drift during a one hour period must not exceed ± 1 per cent opacity.
5.2.3. **Opacimeter display and range**

For display in opacity, the range must be 0-100 per cent opacity, and the readability 0.1 per cent opacity. For display in light absorption coefficient, the range must 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 must 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 must 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 must have its value known to within 1.0 per cent opacity. The filter's nominal value must 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 minimised and, when required, should be done with care to avoid scratching or soiling of the filter.
ANNEX 4
Appendix 5

CALIBRATION PROCEDURE

1. CALIBRATION OF THE ANALYTICAL INSTRUMENTS

1.1. Introduction

Each analyser must be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method that must be used is described in this paragraph for the analysers indicated in annex 4, appendix 4, paragraph 3, and annex 4, appendix 6, paragraph 1.

1.2. Calibration gases

The shelf life of all calibration gases must be respected.

The expiration date of the calibration gases stated by the manufacturer must be recorded.

1.2.1. Pure gases

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

Purified nitrogen
(Contamination ≤ 1 ppm C1, ≤ 1 ppm CO, ≤ 400 ppm CO2, ≤ 0.1 ppm NO)

Purified oxygen
(Purity > 99.5 % vol O2)

Hydrogen-helium mixture
(40 ± 2 % 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 % vol.)

Purified propane or CO for the CVS verification

1.2.2. Calibration and span gases

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

\( \text{C}_3 \text{H}_8 \) and purified synthetic air (see paragraph 1.2.1);

CO and purified nitrogen;

\( \text{NO}_x \) and purified nitrogen (the amount of \( \text{NO}_x \) contained in this calibration gas must not exceed 5 % of the NO content);

\( \text{CO}_2 \) and purified nitrogen

\( \text{CH}_4 \) and purified synthetic air

\( \text{C}_2 \text{H}_6 \) and purified synthetic air

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

The true concentration of a calibration and span gas must be within ± 2 per cent of the nominal value. All concentrations of calibration gas must 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 must be such that the concentration of the diluted calibration gases may be determined to within ± 2 per cent.

1.3. Operating procedure for analysers and sampling system

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

1.4. Leakage test

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

The maximum allowable leakage rate on the vacuum side must be 0.5 per cent of the in-use flow rate for the portion of the system being checked. The analyser flows and bypass flows may be used to estimate the in-use flow rates.

Another method is the introduction of a concentration step change at the beginning of the sampling line by switching from zero to span gas. If after an adequate period of time the reading shows a lower concentration compared to the introduced concentration, this points to calibration or leakage problems.

1.5. Calibration procedure

1.5.1. Instrument assembly

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

1.5.2. Warming-up time

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

1.5.3. NDIR and HFID analyser

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

1.5.4. Calibration

Each normally used operating range must be calibrated.

Using purified synthetic air (or nitrogen), the CO, CO₂, NOₓ and HC analysers must be set at zero.

The appropriate calibration gases must be introduced to the analysers, the values recorded, and the calibration curve established according to paragraph 1.5.5.

The zero setting must be rechecked and the calibration procedure repeated, if necessary.

1.5.5. Establishment of the calibration curve

1.5.5.1. General guidelines

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

The calibration curve must be calculated by the method of least squares. If the resulting polynomial degree is greater than 3, the number of calibration points (zero included) must be at least equal to this polynomial degree plus 2.
The calibration curve must not differ by more than ±2 per cent from the nominal value of each calibration point and by more than ±1 per cent of full scale at zero.

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

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

1.5.5.2. **Calibration below 15 per cent of Full Scale**

The analyser calibration curve must be established by at least 4 additional calibration points (excluding zero) spaced nominally equally below 15 per cent of full scale.

The calibration curve is calculated by the method of least squares.

The calibration curve must not differ by more than ±4 per cent from the nominal value of each calibration point and by more than ±1 per cent of full scale at zero.

1.5.5.3. **Alternative methods**

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

1.6. **Verification of the calibration**

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

The calibration must 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 must be established in accordance with paragraph 1.5.5.

1.7. **Efficiency test of the NOx converter**

The efficiency of the converter used for the conversion of NO₂ into NO must be tested as given in paragraphs 1.7.1. to 1.7.8. (Figure 6).

![Figure 6: Schematic of NO₂ converter efficiency device](image-url)
1.7.1. Test set-up

Using the test set-up as shown in Figure 6 (see also annex 4, appendix 4, paragraph 3.3.5.) 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 must be calibrated in the most common operating range following the manufacturer’s specifications using zero and span gas (the NO content of which must amount to about 80 per cent of the operating range and the NOx concentration of the gas mixture to less than 5 per cent of the NO concentration). The NOx analyser must be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

1.7.3. Calculation

The efficiency of the NOx converter is calculated as follows:

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

where:

- \(a\) is the NOx concentration according to paragraph 1.7.6
- \(b\) is the NOx 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 analyser is in the NO mode). The indicated concentration \(c\) must 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 \(d\) must be recorded (The analyser is in the NO mode).

1.7.6. NOx mode

The NO analyser is then switched to the NOx mode so that the gas mixture (consisting of NO, NO\(_2\), O\(_2\), and N\(_2\)) now passes through the converter. The indicated concentration \(a\) must be recorded. (The analyser is in the NOx 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 \(b\) must be recorded. (The analyser is in the NOx 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 analyser must not deviate by more than ± 5 per cent from the value measured according to paragraph 1.7.2. (The analyser is in the NO mode).

1.7.9. Test interval

The efficiency of the converter must be tested prior to each calibration of the NOx analyser.
1.7.10. **Efficiency requirement**

The efficiency of the converter must not be less than 90 per cent, but a higher efficiency of 95 per cent is strongly recommended.

Note: If, with the analyser 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 must be used.

1.8. **Adjustment of the FID**

1.8.1. **Optimisation of the detector response**

The FID must 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 must be introduced to the analyser. The response at a given fuel flow must be determined from the difference between the span gas response and the zero gas response. The fuel flow must be incrementally adjusted above and below the manufacturer's specification. The span and zero response at these fuel flows must be recorded. The difference between the span and zero response must be plotted and the fuel flow adjusted to the rich side of the curve.

1.8.2. **Hydrocarbon response factors**

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

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

The concentration of the test gas must be at a level to give a response of approximately 80 per cent of full scale. The concentration must be known to an accuracy of ± 2 per cent in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder must 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 \( 1,00 \leq R_f \leq 1,15 \) (diesel and LPG engines)
- Methane and purified synthetic air \( 1,00 \leq R_f \leq 1,07 \) (NG engines)
- Propylene and purified synthetic air \( 0,90 \leq R_f \leq 1,1 \)
- Toluene and purified synthetic air \( 0,90 \leq R_f \leq 1,10 \)

These values are relative to the response factor \( R_f \) of 1,00 for propane and purified synthetic air.

1.8.3. **Oxygen interference check**

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

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

- Propane and nitrogen \( 0,95 \leq R_f \leq 1,05 \)

This value is relative to the response factor \( R_f \) of 1,00 for propane and purified synthetic air.

The FID burner air oxygen concentration must be within ± 1 mole % of the oxygen concentration of the burner air used in the latest oxygen interference check. If the difference is greater, the oxygen interference must be checked and the analyser adjusted, if necessary.
1.8.4. **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 oxidising all hydrocarbons except methane. Ideally, the conversion for methane is 0 %, and for the other hydrocarbons represented by ethane is 100 %. For the accurate measurement of NMHC, the two efficiencies must be determined and used for the calculation of the NMHC emission mass flow rate (see annex 4, appendix 2, paragraph 4.3.).

1.8.4.1. **Methane efficiency**

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

\[
CE_m = 1 - \frac{\text{conc}_w}{\text{conc}_{w/o}}
\]

where:

- \(\text{conc}_w\) = HC concentration with CH\(_4\) flowing through the NMC
- \(\text{conc}_{w/o}\) = HC concentration with CH\(_4\) bypassing the NMC

1.8.4.2. **Ethane efficiency**

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

\[
CE_e = 1 - \frac{\text{conc}_w}{\text{conc}_{w/o}}
\]

where:

- \(\text{conc}_w\) = HC concentration with C\(_2\)H\(_6\) flowing through the NMC
- \(\text{conc}_{w/o}\) = HC concentration with C\(_2\)H\(_6\) bypassing the NMC

1.9. **Interference effects with CO, CO\(_2\), and NO\(_x\) analysers**

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

1.9.1. **CO Analyser interference check**

Water and CO\(_2\) can interfere with the CO analyser performance. Therefore, a CO\(_2\) span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range used during testing must be bubbled through water at room temperature and the analyser response recorded. The analyser response must 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\(_x\) analyser quench checks**

The two gases of concern for CLD (and HCLD) analysers are CO\(_2\) 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. **CO\(_2\) quench check**

A CO\(_2\) span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range must be passed through the NDIR analyser and the CO\(_2\) value recorded as A. It must then be diluted approximately 50 per cent with NO span gas and passed through the NDIR and (H)CLD, with the CO\(_2\) and NO values recorded as B and C, respectively. The CO\(_2\) must 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 must not be greater than 3 per cent of full scale, must be calculated as follows:

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

where:

- \( A \) is the undiluted CO\textsubscript{2} concentration measured with NDIR in per cent
- \( B \) is the diluted CO\textsubscript{2} 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 CO\textsubscript{2} 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 must consider dilution of the NO span gas with water vapour and scaling of water vapour concentration of the mixture to that expected during testing.

A NO span gas having a concentration of 80 to 100 per cent of full scale of the normal operating range must be passed through the (H)CLD and the NO value recorded as D. The NO span gas must then be bubbled through water at room temperature and passed through the (H)CLD and the NO value recorded as C. The analyser’s absolute operating pressure and the water temperature must be determined and recorded as E and F, respectively. The mixture’s saturation vapour pressure that corresponds to the bubbler water temperature F must be determined and recorded as G. The water vapour concentration (H, in %) of the mixture must be calculated as follows:

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

The expected diluted NO span gas (in water vapour) concentration (\( D_e \)) must be calculated as follows:

\[
D_e = D \times (1 - \frac{H}{100})
\]

For diesel exhaust, the maximum exhaust water vapour concentration (\( H_m \), in %) expected during testing must be estimated, under the assumption of a fuel atom H/C ratio of 1.8:1, from the undiluted CO\textsubscript{2} span gas concentration (\( A \), as measured in paragraph 1.9.2.1) as follows:

\[
H_m = 0.9 \times A
\]

The water quench, which must not be greater than 3 per cent, must be calculated as follows:

\[
\% \text{ Quench} = 100 \times \left( \frac{D_e - C}{D_e} \right) \times \left( \frac{H_m}{H} \right)
\]

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 %
- \( H \) is the actual water vapour concentration in %

Note: It is important that the NO span gas contains minimal NO\textsubscript{2} concentration for this check, since absorption of NO\textsubscript{2} in water has not been accounted for in the quench calculations.

1.10. Calibration intervals

The analysers must 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 must be calibrated by using an accurate flowmeter traceable to national or international standards and a restricting device. The flow through the system must be measured at different restriction settings, and the control parameters of the system must 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 must 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) must 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 must then be determined. If a CVS has a multiple speed drive, the calibration must be performed for each range used. Temperature stability must be maintained during calibration.

2.2.1. Data analysis

The air flow rate \( Q_s \) at each restriction setting (minimum 6 settings) must be calculated in standard m³/min from the flowmeter data using the manufacturer’s prescribed method. The air flow rate must then be converted to pump flow \( V_0 \) in m³/rev at absolute pump inlet temperature and pressure as follows:

\[
V_0 = \frac{Q_s}{n} \times \frac{T}{273} \times \frac{101.3}{P_A}
\]

where:

\( Q_s \) = air flow rate at standard conditions (101.3 kPa, 273 K), m³/s
\( T \) = temperature at pump inlet, K
\( P_A \) = absolute pressure at pump inlet \( (p_B - p_1) \), kPa
\( n \) = pump speed, rev/s

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

\[
X_0 = \frac{1}{n} \times \sqrt{\frac{\Delta p}{P_A}}
\]

where:

\( \Delta p \) = pressure differential from pump inlet to pump outlet, kPa
\( P_A \) = absolute outlet pressure at pump outlet, kPa

A linear least-square fit must 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 must be approximately parallel, and the intercept values \( D_0 \) must increase as the pump flow range decreases.
The calculated values from the equation must 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 must 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, as shown below:

\[
Q_s = \frac{K_v \times p_A}{\sqrt{T}}
\]

where:
- \( K_v \) = calibration coefficient
- \( p_A \) = absolute pressure at venturi inlet, kPa
- \( T \) = temperature at venturi inlet, K

2.3.1. **Data Analysis**

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

\[
K_v = \frac{Q_s \times \sqrt{T}}{p_A}
\]

where:
- \( Q_s \) = air flow rate at standard conditions (101.3 kPa, 273 K), m\(^3\)/s
- \( T \) = temperature at the venturi inlet, K
- \( p_A \) = absolute pressure at venturi inlet, kPa

To determine the range of critical flow, \( K_v \) must 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 must be calculated. The standard deviation must not exceed ± 0.3 per cent of the average \( K_v \).

2.4. **Total system verification**

The total accuracy of the CVS sampling system and analytical system must 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 4, 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 must be used.

2.4.1. **Metering with a critical flow orifice**

A known quantity of pure gas (carbon monoxide or propane) must 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 (e.g. critical flow). The CVS system must be operated as in a normal exhaust emission test for about 5 to 10 minutes. A gas sample must be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined must be within ± 3 per cent of the known mass of the gas injected.
2.4.2. **Metering by means of a gravimetric technique**

The weight of a small cylinder filled with carbon monoxide or propane must be determined with a precision of ± 0.01 gram. For about 5 to 10 minutes, the CVS system must 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 must be determined by means of differential weighing. A gas sample must be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined must be within ± 3 per cent of the known mass of the gas injected.

3. **CALIBRATION OF THE PARTICULATE MEASURING SYSTEM**

3.1. **Introduction**

Each component must be calibrated as often as necessary to fulfill the accuracy requirements of this Regulation. The calibration method to be used is described in this paragraph for the components indicated in annex 4, appendix 4, paragraph 4, and annex 4, appendix 6, paragraph 2.

3.2. **Flow measurement**

The calibration of gas flow meters or flow measurement instrumentation must be traceable to international and/or national standards. The maximum error of the measured value must be within ± 2 per cent of reading.

If the gas flow is determined by differential flow measurement, the maximum error of the difference must be such that the accuracy of $G_{\text{ETM}}$ is within ± 4 per cent (see also annex 4, appendix 6, paragraph 2.2.1., EGA). It can be calculated by taking the root mean square of the errors of each instrument.

3.3. **Checking the partial flow conditions**

The range of the exhaust gas velocity and the pressure oscillations must be checked and adjusted according to the requirements of annex 4, appendix 6, paragraph 2.2.1., EP, if applicable.

3.4. **Calibration intervals**

The flow measurement instrumentation must 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 must be calibrated as often as necessary to fulfill the accuracy requirements of this Regulation. The calibration method to be used is described in this paragraph for the components indicated in annex 4, appendix 4, paragraph 5, and annex 4, appendix 6, paragraph 3.

4.2. **Calibration procedure**

4.2.1. **Warming-up time**

The opacimeter must 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 must be checked in the opacity readout mode as per the manufacturer’s recommendations. Three neutral density filters of known transmittance, which must meet the requirements of annex 4, appendix 4, paragraph 5.2.5., must be introduced to the opacimeter and the value recorded. The neutral density filters must have nominal opacities of approximately 10 %, 20 % and 40 %.
The linearity must 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 must be corrected prior to the test.

4.3. **Calibration intervals**

The opacimeter must 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.
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 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.

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:

- HFID analyser for the measurement of hydrocarbons;
- NDIR analysers for the measurement of carbon monoxide and carbon dioxide;
- HCLD or equivalent analyser for the measurement of the oxides of nitrogen;

Figure 7: Flow diagram of raw exhaust gas analysis system for CO, CO₂, NOₓ, HC ESC only
The sample for all components may be taken with one sampling probe or with two sampling probes located in close proximity and internally split to the different analysers. Care must be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

1.2.1. Components of figures 7 and 8

**EP**
Exhaust pipe

**SP1**
Exhaust gas sampling probe (Figure 7 only)

A stainless steel straight closed end multi-hole probe is recommended. The inside diameter must not be greater than the inside diameter of the sampling line. The wall thickness of the probe must not be greater than 1 mm. There must be a minimum of 3 holes in 3 different radial planes sized to sample approximately the same flow. The probe must 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 must:

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

— have a 5 mm minimum inside diameter;

— be installed in the dilution tunnel DT (see 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);

— be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
— be heated so as to increase the gas stream temperature to 463 K ± 10 K (190 °C ± 10 °C) at the exit of the probe.

**SP3**  
Diluted exhaust gas CO, CO₂, NOₓ sampling probe (Figure 8 only)

The probe must:

— be in the same plane as SP2;

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

— be heated and insulated over its entire length to a minimum temperature of 328 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 analyser.

The sampling line must:

— have a 5 mm minimum and a 13.5 mm maximum inside diameter;

— be made of stainless steel or PTFE.

— maintain a wall temperature of 463 K ± 10 K (190 °C ± 10 °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);

— 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);

— maintain a gas temperature of 463 K ± 10 K (190 °C ± 10 °C) immediately before the heated filter F₂ and the HFID;

**HSL2**  
Heated NOₓ sampling line

The sampling line must:

— 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 analyser when a cooling bath B is not used.

— be made of stainless steel or PTFE.

**SL**  
Sampling line for CO and CO₂

The line must 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 must be the same as HSL1.

**F₂**  
Heated filter

The filter must extract any solid particles from the gas sample prior to the analyser. The temperature must be the same as HSL1. The filter must be changed as needed.

**P**  
Heated sampling pump

The pump must be heated to the temperature of HSL1.
HC  Heated flame ionisation detector (HFID) for the determination of the hydrocarbons. The temperature must be kept at 453 K to 473 K (180 °C to 200 °C).

CO, CO₂  NDIR analysers for the determination of carbon monoxide and carbon dioxide (optional for the determination of the dilution ratio for PT measurement).

NO  CLD or HCLD analyser for the determination of the oxides of nitrogen.

If a HCLD is used it must be kept at a temperature of 328 K to 473 K (55 °C to 200 °C).

C  Converter

A converter must 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 must 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 analyser is free from water vapour interference as determined in annex 4, appendix 5, paragraphs 1.9.1. and 1.9.2. If water is removed by condensation, the sample gas temperature or dew point must be monitored either within the water trap or downstream. The sample gas temperature or dew point must 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 analysers.

FL1, FL2, FL3  Flowmeter

To monitor the sample by-pass flow rate.

FL4 to FL6  Flowmeter (optional)

To monitor the flow rate through the analysers.

V1 to V5  Selector valve

Suitable valving for selecting sample, span gas or zero gas flow to the analysers.

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 analysers.

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 annex 4, appendix 4, paragraph 3.4.2.

For NMHC an automated GC with a FID must be used. The exhaust gas must be sampled into a sampling bag from which a part must 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 must be subtracted from the total HC concentration (see annex 4, appendix 2, paragraph 4.3.1.).

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)](image)

**Components of Figure 9**

- **PC** Porapak column
  - Porapak N, 180/300 μm (50/80 mesh), 610 mm length × 2.16 mm ID must be used and conditioned at least 12 h at 423 K (150 °C) with carrier gas prior to initial use.

- **MSC** Molecular sieve column
  - Type 13X, 250/350 μm (45/60 mesh), 1 220 mm length × 2.16 mm ID must be used and conditioned at least 12 h at 423 K (150 °C) with carrier gas prior to initial use.

- **OV** Oven
  - To maintain columns and valves at stable temperature for analyser operation, and to condition the columns at 423 K (150 °C).

- **SLP** Sample loop
  - A sufficient length of stainless steel tubing to obtain approximately 1 cm³ volume.

- **P** Pump
  - To bring the sample to the gas chromatograph.
D  Dryer
A dryer containing molecular sieve must 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 must 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  Flowmeter
To measure the sample bypass flow rate.

1.3.2. Non-methane cutter method (NMC, Figure 10)

The cutter oxidises 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 must 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) must be observed on the FID and recorded. If the integration method is used, an NMC in line with a second FID must 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) must be observed and recorded.

The cutter must be characterised 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 must be recorded (see annex 4, appendix 5, paragraph 1.8.2.).

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Figure 10: Flow diagram for methane analysis with the non-methane cutter (NMC)
Components of Figure 10

**NMC**
Non-methane cutter
To oxidise all hydrocarbons except methane.

**HC**
Heated flame ionisation detector (HFID)
To measure the HC and CH₄ concentrations. The temperature must 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 122 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 isokinesis is only used for matching the flow conditions and not for matching the size distribution. The latter is typically not necessary, as the particles are sufficiently small as to follow the fluid streamlines.
Flow controlled systems with concentration measurement (Figures 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 CO$_2$ 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, 14) or by the flow into the transfer tube (Figures 12, 13, 14).

Flow controlled systems with flow measurement (Figures 18, 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 flow rates. Accurate calibration of the flow meters relative to one another is required, since the relative magnitude of the two flow rates can lead to significant errors at higher dilution ratios (of 15 and above). Flow control is very straightforward by keeping the dilute exhaust flow rate constant and varying the dilution air flow rate, if needed.

When using partial flow dilution systems, attention must be paid to avoiding the potential problems of loss of particulates in the transfer tube, ensuring that a representative sample is taken from the engine exhaust, and determination of the split ratio. The systems described pay attention to these critical areas.

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**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 air flow rate is measured with the flow measurement device FM1. The dilution ratio is calculated from the dilution air flow rate and the split ratio.
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.

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 NOₓ) are measured in the raw and diluted exhaust gas as well as in the dilution air with the exhaust gas analyser(s) EGA. These signals are transmitted to the flow controller FC2 that controls either the pressure blower PB or the suction blower SB to maintain the desired exhaust split and dilution ratio in DT. The dilution ratio is calculated from the tracer gas concentrations in the raw exhaust gas, the diluted exhaust gas, and the dilution air.
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 CO₂ concentrations are measured in the diluted exhaust gas and in the dilution air with the exhaust gas analyser(s) EGA. The CO₂ and fuel flow GFUEL signals are transmitted either to the flow controller FC2, or to the flow controller FC3 of the particulate sampling system (see Figure 21). FC2 controls the pressure blower PB, FC3 the sampling pump P (see Figure 21), thereby adjusting the flows into and out of the system so as to maintain the desired exhaust split and dilution ratio in DT. The dilution ratio is calculated from the CO₂ concentrations and GFUEL using the carbon balance assumption.

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 (CO₂ or NOₓ) are measured in the raw exhaust gas, the diluted exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA, and the dilution ratio is calculated from the values so measured.

Figure 14: Partial flow dilution system with CO₂ concentration measurement, carbon balance and total sampling

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 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 back-pressure 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 (CO₂ or NO₃) are measured in the raw exhaust gas, the diluted exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA. They are necessary for checking the exhaust split, and may be used to adjust PCV1 and PCV2 for precise split control. The dilution ratio is calculated from the tracer gas concentrations.

Figure 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 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

Figure 17: Partial flow dilution system with multiple tube splitting, concentration measurement and fractional sampling
injecting fresh air into DT at the outlet of TT. The tracer gas concentrations (CO₂ or NOₓ) are measured in the raw exhaust gas, the diluted exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA. They are necessary for checking the exhaust split and may be used to control the injection air flow rate for precise split control. The dilution ratio is calculated from the tracer gas concentrations.

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 \( G_{\text{EXH}} \), \( G_{\text{AIR}} \), or \( G_{\text{FUEL}} \) 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.

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. \( G_{\text{EXH}} \), \( G_{\text{AIR}} \), or \( G_{\text{FUEL}} \) 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 must be limited to a length to diameter ratio of 12 or less. Bends must be minimised 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 must be free of elbows, bends and sudden diameter changes for at least 6 pipe diameters upstream and 3 pipe diameters downstream of the tip of the probe. The gas velocity at the sampling zone must be higher than 10 m/s except at idle mode. Pressure oscillations of the exhaust gas must not exceed ± 500 Pa on the average. Any steps to reduce pressure oscillations beyond using a chassis-type exhaust system (including silencer and after-treatment devices) must 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, 19)

The minimum inside diameter must be 4 mm. The minimum diameter ratio between exhaust pipe and probe must be 4. The probe must 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, 12)

The isokinetic sampling probe must 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 must 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 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 must have the same dimensions (same diameter, length, bend radius), so that the exhaust split depends on the total number of tubes. A control system is necessary for proportional splitting by maintaining a differential pressure of zero between the exit of the multiple tube unit into DC and the exit of TT. Under these conditions, exhaust gas velocities in EP and FD3 are proportional, and the flow TT is a constant fraction of the exhaust gas flow. The two points have to be connected to a differential pressure transducer DPT. The control to provide a differential pressure of zero is done with the flow controller FC1.

EGA  Exhaust gas analyser (Figures 13, 14, 15, 16, 17)

CO₂ or NOx analysers may be used (with carbon balance method CO₂ only). The analysers must be calibrated like the analysers for the measurement of the gaseous emissions. One or several analysers may be used to determine the concentration differences. The accuracy of the measuring systems has to be such that the accuracy of $G_{\text{CO}_2,\text{FW},i}$ is within ± 4 per cent.
Transfer tube (Figures 11 to 19)

The transfer tube must be:

— As short as possible, but not more than 5 m in length.

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

— Exiting on the centreline of the dilution tunnel and pointing downstream.

If the tube is 1 meter or less in length, it must 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 must be insulated and heated to a minimum wall temperature of 523 K (250 °C).

Differential pressure transducer (Figures 11, 12, 17)

The differential pressure transducer must have a range of ± 500 Pa or less.

Flow controller (Figures 11, 12, 17)

For isokinetic systems (figures 11, 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 must not exceed ± 3 Pa. The pressure oscillations in the dilution tunnel must not exceed ± 250 Pa on the average.

For a multi tube system (Figure 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.

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 back-pressure of EP and the pressure in DT. The valves must be located downstream of SP in EP and between PB and DT.

Damping chamber (Figure 17)

A damping chamber must be installed at the exit of the multiple tube unit to minimise the pressure oscillations in the exhaust pipe EP.

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.
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 NOₓ differential signals.

When using a pressurised air supply (Figure 18), FC2 directly controls the air flow.

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.

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.

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.

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

It is recommended that the dilution air be filtered and charcoal scrubbed to eliminate background hydrocarbons. At the engine manufacturers request the dilution air must 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.

The dilution tunnel:

— must be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions;

— must be constructed of stainless steel with:

— thickness/diameter ratio of 0.025 or less for dilution tunnels with inside diameters greater than 75 mm;

— a nominal thickness of no less than 1.5 mm for dilution tunnels with inside diameters of equal to or less than 75 mm;

— must be at least 75 mm in diameter for the fractional sampling type;

— is recommended to be at least 25 mm in diameter for the total sampling type;

— may be heated to no greater than 325 K (52 °C) wall temperature 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.
The engine exhaust must be thoroughly mixed with the dilution air. For fractional sampling systems, the mixing quality must 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, 17)

The heat exchanger must 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 must be measured. Either a PDP or a CFV system may be used.

For subsequent collection of the particulates, a sample of the dilute exhaust gas is passed to the particulate sampling system (paragraph 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.
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 after-treatment device to the dilution tunnel must not exceed 10 m. If the exhaust pipe downstream of the engine exhaust manifold, turbocharger outlet or after-treatment device exceeds 4 m in length, then all tubing in excess of 4 m must be insulated, except for an in-line smokemeter, if used. The radial thickness of the insulation must be at least 25 mm. The thermal conductivity of the insulating material must have a value no greater than 0.1 W/mK measured at 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 must 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 back-pressure must not be artificially lowered by the PDP or dilution air inlet system. Static exhaust back-pressure measured with the PDP system operating must remain within ± 1.3 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 must 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 back-pressure measured with the CFV system operating must 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 must 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 must 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, 22), accordingly.

**DT**  
Dilution tunnel

The dilution tunnel:

- must 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;
- must be at least 460 mm in diameter with a single dilution system;
- must be at least 210 mm in diameter with a double dilution system;
- may be insulated.
The engine exhaust must 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 must 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 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 must 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 must 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 paragraph of PTT and:

- must 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;

- must be of 12 mm minimum inside diameter;

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

- may be insulated.

### 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, 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 some dilution features, like a dilution air supply and a secondary dilution tunnel.

In order to avoid any impact on the control loops, it is recommended that the sample pump be running throughout the complete test procedure. For the single filter method, a bypass system must be used for passing the sample through the sampling filters at the desired times. Interference of the switching procedure on the control loops must be minimised.
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 21: Particulate sampling system

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.

Figure 22: Double dilution system (full flow system only)

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.
2.4.1. Components of Figures 21 and 22

**PTT**  
Particulate transfer tube (Figures 21, 22)

The particulate transfer tube must not exceed 1 020 mm in length, and must be minimised in length whenever possible. Where applicable (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.) must 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 325 K (52 °C) wall temperature by direct heating or by dilution air preheating, 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 must be located within 300 mm of the exit of the SDT.

The secondary dilution tunnel:

- may be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air preheating, 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.

**FH**  
Filter holder(s) (Figures 21, 22)

For primary and back-up filters one filter housing or separate filter housings may be used. The requirements of annex 4, appendix 4, paragraph 4.1.3. must be met.

The filter holder(s):

- may be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air preheating, 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.

**P**  
Sampling pump (Figures 21, 22)

The particulate sampling pump must 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 must be located so that the secondary dilution air is supplied at a temperature of 298 K ± 5 K (25 °C ± 5 °C), if the dilution air is not preheated.

FC3  Flow controller (Figures 21, 22)

A flow controller must be used to compensate the particulate sample flow rate for temperature and back pressure 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, 22)

The gas meter or flow instrumentation for the particulate sample flow must 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 must be located so that the inlet gas temperature remains at 298 K ± 5 K (25 °C ± 5 °C).

BV  Ball valve (optional)

The ball valve must 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 °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 °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 °C).

3. DETERMINATION OF SMOKE OPACITY

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 must 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.
3.2.1. Components of Figure 23

EP Exhaust Pipe

With an in-line opacimeter, there must 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 must be of circular cross section and be free from elbows and bends. The end of the exhaust pipe must be cut off squarely. The opacimeter must 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 must 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 must be determined in accordance with ISO IDS 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 must 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 must be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

LD Light detector

The detector must be a photocell or a photodiode (with a filter, if necessary). In the case of an incandescent light source, the receiver must 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 must be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.
The light output must be collimated to a beam with a maximum diameter of 30 mm. The rays of the light beam must be parallel within a tolerance of 3° of the optical axis.

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](image)

### 3.3.1. Components of Figure 24

- **EP** Exhaust pipe
  - The exhaust pipe must 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 must be an open tube facing upstream on or about the exhaust pipe centreline. The clearance with the wall of the tailpipe must be at least 5 mm. The probe diameter must ensure a representative sampling and a sufficient flow through the opacimeter.

- **TT** Transfer tube
  - The transfer tube must:
    - Be as short as possible and ensure an exhaust gas temperature of 373 ± 30 K (100 °C ± 30 °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 annex 4, appendix 4, paragraph 5.2.4.

— Have no significant effect on the smoke peak.

**Flow measurement device** (FM)

Flow instrumentation to detect the correct flow into the measuring chamber. The minimum and maximum flow rates must be specified by the instrument manufacturer, and must 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.

**Measuring chamber** (MC)

The measuring chamber must 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 must be reduced to a minimum.

The pressure of the gas in the measuring chamber must not differ from the atmospheric pressure by more than 0.75 kPa. Where this is not possible by design, the opacimeter reading must be converted to atmospheric pressure.

The wall temperature of the measuring chamber must 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 must be equipped with appropriate devices for measuring the temperature.

**Optical path length** (OPL)

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 must 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 must be determined in accordance with ISO IDS 11614, paragraph 11.6.5.

**Light source** (LS)

The light source must 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 must be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

**Light detector** (LD)

The detector must be a photocell or a photodiode (with a filter, if necessary). In the case of an incandescent light source, the receiver must 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 must be protected against sooting by means that do not influence the optical path length beyond the manufacturers specifications.

**Collimating lens** (CL)

The light output must be collimated to a beam with a maximum diameter of 30 mm. The rays of the light beam must be parallel within a tolerance of 3° of the optical axis.

**Temperature sensor** (T1)

To monitor the exhaust gas temperature at the entrance to the measuring chamber.

**Sampling pump** (optional) (P)

A sampling pump downstream of the measuring chamber may be used to transfer the sample gas through the measuring chamber.
TECHNICAL CHARACTERISTICS OF REFERENCE FUEL FOR C.I. ENGINES PRESCRIBED FOR APPROVAL TESTS AND TO VERIFY CONFORMITY OF PRODUCTION

1. DIESEL FUEL (1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Limits (1)</th>
<th>Test Method (2)</th>
<th>Publication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Cetane number (3)</td>
<td></td>
<td>52</td>
<td>54</td>
<td>ISO 5165</td>
</tr>
<tr>
<td>Density at 15 °C</td>
<td>kg/m³</td>
<td>833</td>
<td>837</td>
<td>ISO 3675</td>
</tr>
<tr>
<td>Distillation:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>— 50 % point °C</td>
<td>°C</td>
<td>245</td>
<td>—</td>
<td>ISO 3405</td>
</tr>
<tr>
<td>— 95 % point °C</td>
<td>°C</td>
<td>345</td>
<td>350</td>
<td>ISO 3405</td>
</tr>
<tr>
<td>— final boiling point °C</td>
<td>°C</td>
<td>—</td>
<td>370</td>
<td>ISO 3405</td>
</tr>
<tr>
<td>Flash point °C</td>
<td>°C</td>
<td>55</td>
<td>—</td>
<td>EN 27719</td>
</tr>
<tr>
<td>CFPP</td>
<td>°C</td>
<td>—</td>
<td>5</td>
<td>EN 116</td>
</tr>
<tr>
<td>Viscosity at 40 °C</td>
<td>mm²/s</td>
<td>2.5</td>
<td>3.5</td>
<td>EN-ISO 3104</td>
</tr>
<tr>
<td>Polycyclic aromatic hydrocarbons</td>
<td>% m/m</td>
<td>3.0</td>
<td>6.0</td>
<td>IP 391 (*)</td>
</tr>
<tr>
<td>Sulphur content (5)</td>
<td>mg/kg</td>
<td>—</td>
<td>300</td>
<td>pr. EN-ISO/DIS 14596</td>
</tr>
<tr>
<td>Copper corrosion</td>
<td></td>
<td>—</td>
<td>1</td>
<td>EN-ISO 2160</td>
</tr>
<tr>
<td>Conradson carbon residue (10 % DR)</td>
<td>% m/m</td>
<td>—</td>
<td>0.2</td>
<td>EN-ISO 10370</td>
</tr>
<tr>
<td>Ash content</td>
<td>% m/m</td>
<td>—</td>
<td>0.01</td>
<td>EN-ISO 6245</td>
</tr>
<tr>
<td>Water content</td>
<td>% m/m</td>
<td>—</td>
<td>0.05</td>
<td>EN-ISO 12937</td>
</tr>
<tr>
<td>Neutralisation (strong acid number)</td>
<td>mg OH/g</td>
<td>—</td>
<td>0.02</td>
<td>ASTM D 974-95</td>
</tr>
<tr>
<td>Oxidation stability (6)</td>
<td>mg/ml</td>
<td>—</td>
<td>0.025</td>
<td>EN-ISO 12205</td>
</tr>
</tbody>
</table>

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

\[
\text{Specific energy (calorific value) (net) in MJ/kg} = (46,423 - 8,792 d^2 + 3,170 d) (1 - (x + y + s)) + 9,420 x - 2,499 x
\]

where:

- \(d\) = the density at 15 °C
- \(x\) = the proportion by mass of water (% divided by 100)
- \(y\) = the proportion by mass of ash (% divided by 100)
- \(s\) = the proportion by mass of sulphur (% divided by 100).

(2) 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.

(3) 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.

(4) The month of publication will be completed in due course.

(5) The actual sulphur content of the fuel used for the test must be reported. In addition, the sulphur content of the reference fuel used to approve a vehicle or engine against the limit values set out in row B of the Table in paragraph 5.2.1. of this Regulation must have a maximum sulphur content of 30 ppm.

(6) 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.
### 2. ETHANOL FOR DIESEL ENGINES (1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Limits (%)</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol, mass</td>
<td>% m/m</td>
<td>92.4</td>
<td>—</td>
</tr>
<tr>
<td>Other alcohol than ethanol contained in total alcohol, mass</td>
<td>% m/m</td>
<td>—</td>
<td>2</td>
</tr>
<tr>
<td>Density at 15 °C</td>
<td>kg/m³</td>
<td>795</td>
<td>815</td>
</tr>
<tr>
<td>Ash content</td>
<td>% m/m</td>
<td>0.001</td>
<td>ISO 6245</td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>10</td>
<td>ISO 2719</td>
</tr>
<tr>
<td>Acidity, calculated as acetic acid</td>
<td>% m/m</td>
<td>—</td>
<td>0.0025</td>
</tr>
<tr>
<td>Neutralisation (strong acid) number</td>
<td>KOH mg/l</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Colour</td>
<td>According to scale</td>
<td>—</td>
<td>10</td>
</tr>
<tr>
<td>Dry residue at 100 °C</td>
<td>mg/kg</td>
<td>15</td>
<td>ISO 759</td>
</tr>
<tr>
<td>Water content</td>
<td>% m/m</td>
<td>6.5</td>
<td>ISO 760</td>
</tr>
<tr>
<td>Aldehydes calculated as acetic acid</td>
<td>% m/m</td>
<td>0.0025</td>
<td>ISO 1388-4</td>
</tr>
<tr>
<td>Sulphur content</td>
<td>mg/kg</td>
<td>—</td>
<td>10</td>
</tr>
<tr>
<td>Esters, calculated as ethylacetate</td>
<td>% m/m</td>
<td>—</td>
<td>0.1</td>
</tr>
</tbody>
</table>

(1) Cetane improver, as specified by the engine manufacturer, may be added to the ethanol fuel. The maximum allowed amount is 10 % m/m.

(2) 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.

(3) Equivalent ISO methods will be adopted when issued for all properties listed above.
ANNEX 6

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

Type: NATURAL GAS (NG)

European market fuels are available in two ranges:
— the H range, whose extreme reference fuels are GR and G23;
— the L range, whose extreme reference fuels are G23 and G25.

The characteristics of GR, G23 and G25 reference fuels are summarised below:

### Reference fuel GR

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Units</th>
<th>Basis</th>
<th>Limits</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>% mole</td>
<td>87</td>
<td>84</td>
<td>89</td>
</tr>
<tr>
<td>Ethane</td>
<td>% mole</td>
<td>13</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Balance (*)</td>
<td>% mole</td>
<td>—</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Sulphur content</td>
<td>mg/m³ (*)</td>
<td>—</td>
<td>—</td>
<td>10</td>
</tr>
</tbody>
</table>

(*) Inerts + C₂⁺.

(∗) Value to be determined at standard conditions (293.2 K (20 °C) and 101.3 kPa).

### Reference fuel G23

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Units</th>
<th>Basis</th>
<th>Limits</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>% mole</td>
<td>92.5</td>
<td>91.5</td>
<td>93.5</td>
</tr>
<tr>
<td>Balance (*)</td>
<td>% mole</td>
<td>—</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>N₂</td>
<td>% mole</td>
<td>7.5</td>
<td>6.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Sulphur content</td>
<td>mg/m³ (*)</td>
<td>—</td>
<td>—</td>
<td>10</td>
</tr>
</tbody>
</table>

(*) Inerts (different from N₂) + C₁/C₂⁺.

(∗) Value to be determined at standard conditions (293.2 K (20 °C) and 101.3 kPa).

### Reference fuel G25

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Units</th>
<th>Basis</th>
<th>Limits</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>% mole</td>
<td>86</td>
<td>84</td>
<td>88</td>
</tr>
<tr>
<td>Balance (*)</td>
<td>% mole</td>
<td>—</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>N₂</td>
<td>% mole</td>
<td>14</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Sulphur content</td>
<td>mg/m³ (*)</td>
<td>—</td>
<td>—</td>
<td>10</td>
</tr>
</tbody>
</table>

(*) Inerts (different from N₂) + C₁/C₂⁺.

(∗) Value to be determined at standard conditions (293.2 K (20 °C) and 101.3 kPa).
## ANNEX 7

**TYPE: LIQUEFIED PETROLEUM GAS (LPG)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Limits</th>
<th>Fuel A</th>
<th>Limits</th>
<th>Fuel B</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td>Minimum</td>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Motor Octane Number</td>
<td></td>
<td></td>
<td>92.5 (1)</td>
<td></td>
<td>92.5</td>
<td>EN 589 Annex B</td>
</tr>
<tr>
<td>Composition:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3 content</td>
<td>% vol</td>
<td>48</td>
<td>52</td>
<td>83</td>
<td>87</td>
<td>ISO 7941</td>
</tr>
<tr>
<td>C4 content</td>
<td>% vol</td>
<td>48</td>
<td>52</td>
<td>13</td>
<td>17</td>
<td>ISO 7941</td>
</tr>
<tr>
<td>Olefins</td>
<td>% vol</td>
<td>12</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation Residue</td>
<td>mg/kg</td>
<td>50</td>
<td>50</td>
<td>NFM 41015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sulphur content</td>
<td>ppm mass (2)</td>
<td>50</td>
<td>50</td>
<td>EN 24260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>—</td>
<td>None</td>
<td>None</td>
<td>ISO 8819</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper strip corrosion</td>
<td>rating</td>
<td>class 1</td>
<td>class 1</td>
<td>ISO 6251 (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water at 0 °C</td>
<td></td>
<td>free</td>
<td>free</td>
<td>visual inspection</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) Value to be determined at standard conditions 293.2 K (20 °C) and 101.3 kPa.
(2) 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 8

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 NOx 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.

<table>
<thead>
<tr>
<th>P (kW)</th>
<th>T (K)</th>
<th>H (g/kg)</th>
<th>GEXH (kg)</th>
<th>GAIRW (kg)</th>
<th>GFUEL (kg)</th>
<th>HC (ppm)</th>
<th>CO (ppm)</th>
<th>NOx (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>82.9</td>
<td>294.8</td>
<td>7.81</td>
<td>563.38</td>
<td>545.29</td>
<td>18.09</td>
<td>6.3</td>
<td>41.2</td>
<td>495</td>
</tr>
</tbody>
</table>

Calculation of the dry to wet correction factor KW,r (annex 4, appendix 1, paragraph 4.2):

\[ FFH = \frac{1.969}{1 + \frac{18.09}{545.29}} = 1.9058 \] and \[ KW2 = \frac{1.608 \times 7.81}{1000 + (1.608 \times 7.81)} = 0.0124 \]

\[ KW,r = (1 - 1.9058 \times \frac{18.09}{541.06}) - 0.0124 = 0.9239 \]

Calculation of the wet concentrations:

\[ CO = 41.2 \times 0.9239 = 38.1 \text{ ppm} \]

\[ NOx = 495 \times 0.9239 = 457 \text{ ppm} \]

Calculation of the NOx humidity correction factor KH,D (annex 4, appendix 1, paragraph 4.3.):

\[ A = 0.309 \times 18.09 / 541.06 - 0.0266 = -0.0163 \]

\[ B = -0.209 \times 18.09 / 541.06 + 0.00954 = 0.0026 \]

\[ KH,D = \frac{1}{1 - 0.0163 \times (7.81 - 10.71) + 0.0026 \times (294.8 - 298)} = 0.9625 \]

Calculation of the emission mass flow rates (annex 4, appendix 1, paragraph 4.4.):

\[ NOx = 0.001587 \times 457 \times 0.9625 \times 563.38 = 393.27 \text{ g/h} \]

\[ CO = 0.000966 \times 38.1 \times 563.38 = 20.735 \text{ g/h} \]

\[ HC = 0.000479 \times 6.3 \times 3 \times 563.38 = 5.100 \text{ g/h} \]

Calculation of the specific emissions (annex 4, appendix 1, paragraph 4.5.):

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 4, appendix 1, paragraph 2.7.1., and summed up to result in the mean emission mass flow rate over the cycle:

\[ CO = (6.7 \times 0.15) + (24.6 \times 0.08) + (20.5 \times 0.10) + (20.7 \times 0.10) + (20.6 \times 0.05) + (15.0 \times 0.05) + (19.7 \times 0.05) + (74.5 \times 0.09) + (31.5 \times 0.10) + (81.9 \times 0.08) + (34.8 \times 0.05) + (30.8 \times 0.05) + (27.3 \times 0.05) = 30.91 \text{ g/h} \]
The engine power of the individual modes is multiplied by the respective weighting factors, as indicated in annex 4, appendix 1, paragraph 2.7.1., and summed up to result in the mean cycle power:

\[
P(n) = (0.1 \times 0.15) + (96.8 \times 0.08) + (55.2 \times 0.10) + (82.9 \times 0.05) + (70.1 \times 0.05) + (23.0 \times 0.05) + (114.3 \times 0.09) + (27.0 \times 0.10) + (122.0 \times 0.08) + (28.6 \times 0.05) + (87.4 \times 0.05) + (57.9 \times 0.05) = 60.006 \text{ kW}
\]

\[
\text{CO} = \frac{30.91}{60.006} = 0.015 \text{ g/kWh}
\]

Calculation of the specific NO\textsubscript{x} emission of the random point (annex 4, appendix 1, paragraph 4.6.1.):

Assume the following values have been determined on the random point:

\[
\begin{align*}
n_Z &= 1600 \text{ min}^{-1} \\
M_Z &= 495 \text{ Nm} \\
\text{NO}_x \text{ mass,}Z &= 487.9 \text{ g/h} \quad (\text{calculated according to the previous formulae}) \\
P(n)_Z &= 83 \text{ kW} \\
\text{NO}_x,Z &= 487.9 / 83 = 5.878 \text{ g/kWh}
\end{align*}
\]

Determination of the emission value from the test cycle (annex 4, appendix 1, paragraph 4.6.2.):

Assume the values of the four enveloping modes on the ESC to be as follows:

<table>
<thead>
<tr>
<th>nRT</th>
<th>nSU</th>
<th>ER</th>
<th>ES</th>
<th>ET</th>
<th>EU</th>
<th>MR</th>
<th>MS</th>
<th>MT</th>
<th>MU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1368</td>
<td>1785</td>
<td>5,943</td>
<td>5,565</td>
<td>5,889</td>
<td>4,973</td>
<td>515</td>
<td>460</td>
<td>681</td>
<td>610</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
E_{FLU} &= 5,889 + (4,973 - 5,889) \times (1600 - 1368) / (1785 - 1368) = 5,377 \text{ g/kWh} \\
E_{RS} &= 5,943 + (5,565 - 5,943) \times (1600 - 1368) / (1785 - 1368) = 5,732 \text{ g/kWh} \\
M_{FLU} &= 681 + (601 - 681) \times (1600 - 1368) / (1785 - 1368) = 641.3 \text{ Nm} \\
M_{RS} &= 515 + (460 - 515) \times (1600 - 1368) / (1785 - 1368) = 484.3 \text{ Nm} \\
E_z &= 5,732 + (5,377 - 5,732) \times (495 - 484.3) / (641.3 - 484.3) = 5,708 \text{ g/kWh}
\end{align*}
\]

Comparison of the NO\textsubscript{x} emission values (annex 4, appendix 1, paragraph 4.6.3.):

\[
\text{NO}_x \text{ diff} = 100 \times (5.878 - 5.708) / 5.708 = 2.98 \%
\]

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 (MSAM and GEDF) during the individual modes. The calculation of GEDF depends on the system used. In the following examples, a system with CO\textsubscript{2} measurement and carbon balance method and a system with flow measurement are used. When using a full flow dilution system, GEDF is directly measured by the CVS equipment.

Calculation of GEDF (annex 4, appendix 1, paragraphs 5.2.3. and 5.2.4.):

Assume the following measurement data of mode 4. The calculation procedure is identical for the other modes.

<table>
<thead>
<tr>
<th>(G_{\text{EXH}}) (kg/h)</th>
<th>(G_{\text{EXH,u}}) (kg/h)</th>
<th>(G_{\text{DEW}}) (kg/h)</th>
<th>(G_{\text{TOTW}}) (kg/h)</th>
<th>CO\textsubscript{2D} (%)</th>
<th>CO\textsubscript{2A} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>334.02</td>
<td>10.76</td>
<td>5.4435</td>
<td>6.0</td>
<td>0.657</td>
<td>0.040</td>
</tr>
</tbody>
</table>

a) carbon balance method

\[
G_{\text{EDFW}} = \frac{206.5 \times 10.76}{0.657 - 0.040} = 3601.2 \text{ kg/h}
\]

b) flow measurement method

\[
q = \frac{6.0}{(6.0 - 5.4435)} = 10.78
\]

\[
G_{\text{EDFW}} = 334.02 \times 10.78 = 3600.7 \text{ kg/h}
\]
Calculation of the mass flow rate (annex 4, appendix 1, paragraph 5.4.):

The $G_{EDFW}$ flow rates of the individual modes are multiplied by the respective weighting factors, as indicated in annex 4, appendix 1, paragraph 2.7.1., and summed up to result in the mean $G_{EDFW}$ over the cycle. The total sample rate $M_{SAM}$ is summed up from the sample rates of the individual modes.

\[
G_{EDFW} = (3567 \times 0.15) + (3592 \times 0.08) + (3611 \times 0.10) + (3600 \times 0.10) + (3618 \times 0.05) + (3600 \times 0.05) \\
+ (3640 \times 0.05) + (3614 \times 0.09) + (3620 \times 0.10) + (3601 \times 0.08) + (3639 \times 0.05) + (3582 \times 0.05) \\
+ (3635 \times 0.05) = 3604.6 \text{ kg/h}
\]

\[
M_{SAM} = 0.226 + 0.122 + 0.151 + 0.152 + 0.076 + 0.076 + 0.136 + 0.151 + 0.121 + 0.076 + 0.076 \\
+ 0.075 = 1.515 \text{ kg}
\]

Assume the particulate mass on the filters to be 2.5 mg, then

\[
PT_{mass} = \frac{2.5}{1.515} \times \frac{3604.6}{1000} = 5.948 \text{ g/h}
\]

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.

\[
MD = 0.1 \text{ mg; MDIL} = 1.5 \text{ kg}
\]

\[
\text{Sum of } DF = [(1-1/119.15) \times 0.15] + [(1-1/8.89) \times 0.08] + [(1-1/14.75) \times 0.10] + [(1-1/10.10) \times 0.10] \\
+ [(1-1/18.02) \times 0.05] + [(1-1/12.33) \times 0.05] + [(1-1/32.18) \times 0.05] + [(1-1/6.94) \times 0.09] + [(1-1/12.59) \times 0.05] \\
+ [(1-1/6.12) \times 0.08] + [(1-1/20.87) \times 0.05] + [(1-1/8.77) \times 0.05] + [(1-1/12.59) \times 0.05] = 0.923
\]

\[
PT_{mass} = \frac{2.5}{1.515} \left( \frac{1}{1.5} + 0.923 \right) \times \frac{3604.6}{1000} = 5.726 \text{ g/h}
\]

Calculation of the specific emission (annex 4, appendix 1, paragraph 5.5.):

\[
P(n) = (0.1 \times 0.15) + (96.8 \times 0.08) + (55.2 \times 0.10) + (82.9 \times 0.10) + (46.8 \times 0.05) + (70.1 \times 0.05) \\
+ (114.3 \times 0.09) + (27.0 \times 0.10) + (122.0 \times 0.08) + (28.6 \times 0.05) + (87.4 \times 0.05) + (57.9 \times 0.05) = 60.006 \text{ kW}
\]

\[
PT = \frac{5.948}{60.006} = 0.099 \text{ g/kWh, if background corrected}
\]

\[
PT = \frac{5.726}{60.006} = 0.095 \text{ g/kWh}
\]

Calculation of the specific weighting factor (annex 4, appendix 1, paragraph 5.6.):

Assume the values calculated for mode 4 above, then

\[
WF_{EL} = \frac{0.152 \times 3604.6}{1.515 \times 3600.7} = 0.1004
\]

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 characterise 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:

— physical response time of the opacimeter \( t_p \)

— electrical response time of the opacimeter \( t_e \)

— filter response time of the applied Bessel filter \( t_F \)

The resulting overall response time of the system \( t_{\text{aver}} \) is given by:

\[
t_{\text{aver}} = \sqrt{t_F^2 + t_p^2 + t_e^2},
\]

and must 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 must result in the required overall response time \( t_{\text{aver}} \). Since \( t_p \) and \( t_e \) are given values for each individual opacimeter, and \( t_{\text{aver}} \) is defined to be 1.0 s in this Regulation, \( t_F \) can be calculated as follows:

\[
t_F = \sqrt{t_{\text{aver}}^2 - t_p^2 - t_e^2}.
\]

By definition, the filter response time \( t_F \) is the rise time of a filtered output signal between 10% and 90% 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.

In figure (a), the traces of a step input signal and Bessel filtered output signal 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.
**Characteristics of Opacimeter**
- tp, te [s]

**Regulation**
- tAver [s]

**Data Acquisition System**
- Sample Rate [Hz]

---

**Step 1**
- Required overall Bessel filter response time, \( t_F \)

**Step 2**
- Design of Bessel filter algorithm
  - \( f_c, E, K \)

**Step 3**
- Application of Bessel filter on step input
  - \( t(10\%), t(90\%) \)

**Step 4**
- Calculation of iterated filter response time
  - \( t_{Filter} = t(90\%) - t(10\%) \)

**Step 5**
- Deviation between \( t_F \) and \( t_{Filter} \)
  - \( \delta = \frac{t_{Filter} - t_F}{t_F} \)

**Step 6**
- Check for iteration criteria
  - \([\delta] < 0.01 \)
    - **Yes**
    - Final Bessel filter constants and algorithm
      - \( y_i = \ldots \)
    - **No**
      - Iteration
  - \( f_{new} = fc \cdot (1 + \delta) \)
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 4, appendix 1, paragraph 6.1.

For the opacimeter and the data acquisition system, the following characteristics are assumed:

— physical response time $t_p \ 0,15$ s
— electrical response time $t_e \ 0,05$ s
— overall response time $t_{\text{Aver}} \ 1,00$ s (by definition in this Regulation)
— 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:

$$f_c = \frac{3,1415}{10 \times 0,987421} = 0,318152 \text{ Hz}$$

$$\Delta t = \frac{1}{150} = 0,006667 \text{ s}$$

$$\Omega = \frac{1}{\tan (3,1415 \times 0,006667 \times 0,318152)} = 150,076644$$

$$E = \frac{1}{1 + 150,076644 \times \sqrt{3 \times 0,618034 + 0,618034 \times 150,076644}} = 7,07948 \times 10^{-5}$$

$$K = 2 \times 7,07948 \times 10^{-5} \times (0,618034 \times 150,076644 - 1) - 1 = 0,970783$$

This gives the Bessel algorithm:

$$Y_i = Y_{i-1} + 7,07948 \times 10^{-5} \times (S_i + 2 \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + 0,970783 \times (Y_{i-1} - Y_{i-2})$$

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 % and 90 % on a step input signal. For determining the times of 10 % ($t_{10}$) and 90 % ($t_{90}$) 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 % value occurs between index number 30 and 31 and the 90 % value occurs between index number 191 and 192. For the calculation of $t_{\text{iter}}$, the exact $t_{10}$ and $t_{90}$ values are determined by linear interpolation between the adjacent measuring points, as follows:

$$t_{10} = t_{\text{lower}} + \Delta t \times (0,1 - \text{out}_{\text{lower}}) / (\text{out}_{\text{upper}} - \text{out}_{\text{lower}})$$

$$t_{90} = t_{\text{lower}} + \Delta t \times (0,9 - \text{out}_{\text{lower}}) / (\text{out}_{\text{upper}} - \text{out}_{\text{lower}})$$

where $\text{out}_{\text{upper}}$ and $\text{out}_{\text{lower}}$, respectively, are the adjacent points of the Bessel filtered output signal, and $t_{\text{lower}}$ is the time of the adjacent time point, as indicated in table B.

$$t_{10} = 0,200000 + 0,006667 \times (0,1 - 0,099208) / (0,104794 - 0,099208) = 0,200945 \text{ s}$$

$$t_{90} = 1,273333 + 0,006667 \times (0,9 - 0,899147) / (0,901168 - 0,899147) = 1,276147 \text{ s}$$

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Step 4 Filter response time of first iteration cycle:

\[ t_{F,\text{iter}} = 1.276147 - 0.200945 = 1.075202 \text{ s} \]

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:

\[ |\Delta| \leq 0.01 \text{ is required. Since } 0.081641 > 0.01, \text{ the iteration criteria is not met and a further iteration cycle has to be started. For this iteration cycle, a new cut-off frequency is calculated from } f_c \text{ and } \Delta \text{ as follows:} \]

\[ f_{c,\text{new}} = 0.318152 \times (1 + 0.081641) = 0.344126 \text{ Hz} \]

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 criteria is met. The resulting values of the first and second iteration are summarised in table A.

<table>
<thead>
<tr>
<th>Table A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values of the first and second iteration</td>
</tr>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>( f_c ) (Hz)</td>
</tr>
<tr>
<td>( E ) (-)</td>
</tr>
<tr>
<td>( K ) (-)</td>
</tr>
<tr>
<td>( t_{10} ) (s)</td>
</tr>
<tr>
<td>( t_{90} ) (s)</td>
</tr>
<tr>
<td>( t_{F,\text{iter}} ) (s)</td>
</tr>
<tr>
<td>( \Delta ) (-)</td>
</tr>
<tr>
<td>( f_{c,\text{new}} ) (Hz)</td>
</tr>
</tbody>
</table>

Step 7 Final Bessel algorithm:

As soon as the iteration criteria has been met, the final Bessel filter constants and the final Bessel algorithm are calculated according to step 2. In this example, the iteration criteria 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).

\[ Y_1 = Y_{1,-1} + 8.272777 \times 10^{-5} \times (S_1 + 2 \times S_{1,-1} + S_{1,-2} - 4 \times Y_{1,-2}) + 0.968410 \times (Y_{1,-1} - Y_{1,-2}) \]

<table>
<thead>
<tr>
<th>Table B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values of step input signal and Bessel filtered output signal for the first and second iteration cycle</td>
</tr>
<tr>
<td>Index I [-]</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>( -2 )</td>
</tr>
<tr>
<td>( -1 )</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

YI = \( Y_{i-1} + 8.272777 \times 10^{-5} \times (S_i + 2 \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + 0.968410 \times (Y_{i-1} - Y_{i-2}) \)
<table>
<thead>
<tr>
<th>Index I</th>
<th>Time [s]</th>
<th>Step Input Signal $S_i$ [-]</th>
<th>Filtered Output Signal $Y_i$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1. Iteration</td>
</tr>
<tr>
<td>4</td>
<td>0.026667</td>
<td>1</td>
<td>0.002813</td>
</tr>
<tr>
<td>5</td>
<td>0.033333</td>
<td>1</td>
<td>0.004145</td>
</tr>
<tr>
<td>~</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>24</td>
<td>0.160000</td>
<td>1</td>
<td>0.067877</td>
</tr>
<tr>
<td>25</td>
<td>0.166667</td>
<td>1</td>
<td>0.072816</td>
</tr>
<tr>
<td>26</td>
<td>0.173333</td>
<td>1</td>
<td>0.077874</td>
</tr>
<tr>
<td>27</td>
<td>0.180000</td>
<td>1</td>
<td>0.083047</td>
</tr>
<tr>
<td>28</td>
<td>0.186667</td>
<td>1</td>
<td>0.088331</td>
</tr>
<tr>
<td>29</td>
<td>0.193333</td>
<td>1</td>
<td>0.093719</td>
</tr>
<tr>
<td>30</td>
<td>0.200000</td>
<td>1</td>
<td>0.099208</td>
</tr>
<tr>
<td>31</td>
<td>0.206667</td>
<td>1</td>
<td>0.104794</td>
</tr>
<tr>
<td>32</td>
<td>0.213333</td>
<td>1</td>
<td>0.110471</td>
</tr>
<tr>
<td>33</td>
<td>0.220000</td>
<td>1</td>
<td>0.116236</td>
</tr>
<tr>
<td>34</td>
<td>0.226667</td>
<td>1</td>
<td>0.122085</td>
</tr>
<tr>
<td>35</td>
<td>0.233333</td>
<td>1</td>
<td>0.128013</td>
</tr>
<tr>
<td>36</td>
<td>0.240000</td>
<td>1</td>
<td>0.134016</td>
</tr>
<tr>
<td>37</td>
<td>0.246667</td>
<td>1</td>
<td>0.140091</td>
</tr>
<tr>
<td>~</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>175</td>
<td>1.166667</td>
<td>1</td>
<td>0.862416</td>
</tr>
<tr>
<td>176</td>
<td>1.173333</td>
<td>1</td>
<td>0.864968</td>
</tr>
<tr>
<td>177</td>
<td>1.180000</td>
<td>1</td>
<td>0.867484</td>
</tr>
<tr>
<td>178</td>
<td>1.186667</td>
<td>1</td>
<td>0.869964</td>
</tr>
<tr>
<td>179</td>
<td>1.193333</td>
<td>1</td>
<td>0.872410</td>
</tr>
<tr>
<td>180</td>
<td>1.200000</td>
<td>1</td>
<td>0.874821</td>
</tr>
<tr>
<td>181</td>
<td>1.206667</td>
<td>1</td>
<td>0.877197</td>
</tr>
<tr>
<td>182</td>
<td>1.213333</td>
<td>1</td>
<td>0.879540</td>
</tr>
<tr>
<td>183</td>
<td>1.220000</td>
<td>1</td>
<td>0.881849</td>
</tr>
<tr>
<td>184</td>
<td>1.226667</td>
<td>1</td>
<td>0.884125</td>
</tr>
<tr>
<td>185</td>
<td>1.233333</td>
<td>1</td>
<td>0.886367</td>
</tr>
<tr>
<td>186</td>
<td>1.240000</td>
<td>1</td>
<td>0.888577</td>
</tr>
<tr>
<td>187</td>
<td>1.246667</td>
<td>1</td>
<td>0.890755</td>
</tr>
<tr>
<td>188</td>
<td>1.253333</td>
<td>1</td>
<td>0.892900</td>
</tr>
<tr>
<td>189</td>
<td>1.260000</td>
<td>1</td>
<td>0.895014</td>
</tr>
<tr>
<td>190</td>
<td>1.266667</td>
<td>1</td>
<td>0.897096</td>
</tr>
<tr>
<td>191</td>
<td>1.273333</td>
<td>1</td>
<td>0.899147</td>
</tr>
<tr>
<td>192</td>
<td>1.280000</td>
<td>1</td>
<td>0.901168</td>
</tr>
<tr>
<td>193</td>
<td>1.286667</td>
<td>1</td>
<td>0.903158</td>
</tr>
<tr>
<td>194</td>
<td>1.293333</td>
<td>1</td>
<td>0.905117</td>
</tr>
<tr>
<td>195</td>
<td>1.300000</td>
<td>1</td>
<td>0.907047</td>
</tr>
<tr>
<td>~</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
</tbody>
</table>
2.3. Calculation of the Smoke Values

In the scheme below the general procedure of determining the final smoke value is presented. 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.

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.
Calculation of the k-value (annex 4, appendix 1, paragraph 6.3.1):

\[
L_A (m) = 0.430 \\
\text{Index I} = 272 \\
N (%) = 16,783 \\
S_{271} (m^{-1}) = 0.427392 \\
S_{270} (m^{-1}) = 0.427532 \\
Y_{271} (m^{-1}) = 0.542383 \\
Y_{270} (m^{-1}) = 0.542337 \\
\]

\[
k = \frac{1}{0.430} \times \ln \left(1 - \frac{16,783}{100}\right) = 0.427252 \text{ m}^{-1}
\]

This value corresponds to \(S_{272}\) in the equation that follows.

Calculation of Bessel averaged smoke (annex 4, appendix 1, paragraph 6.3.2):

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, \(Y_{271}\) \((Y_i)\) and \(Y_{270}\) \((Y_{i-2})\) are the two preceding filtered k-values.

\[
Y_{272} = 0.542383 + 8.272777 \times 10^{-5} \times (0.427252 + 2 \times 0.427392 + 0.427532 - 4 \times 0.542337) + 0.968410 \times \frac{0.542383 - 0.542337}{0.427396 - 0.427532} = 0.542389 \text{ m}^{-1}
\]

This value corresponds to \(Y_{\text{max},1,A}\) in the following equation.

Calculation of the final smoke value (annex 4, appendix 1, paragraph 6.3.3):

From each smoke trace, the maximum filtered k-value is taken for the further calculation. Assume the following values:

<table>
<thead>
<tr>
<th>Speed</th>
<th>(Y_{\text{max}} (m^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.5424 0.5435 0.5587</td>
</tr>
<tr>
<td>B</td>
<td>0.5596 0.5400 0.5389</td>
</tr>
<tr>
<td>C</td>
<td>0.4912 0.5207 0.5177</td>
</tr>
</tbody>
</table>
SV_A = (0.5424 + 0.5435 + 0.5587) / 3 = 0.5482 m⁻¹
SV_B = (0.5596 + 0.5400 + 0.5389) / 3 = 0.5462 m⁻¹
SV_C = (0.4912 + 0.5207 + 0.5177) / 3 = 0.5099 m⁻¹
SV = (0.43 × 0.5482) + (0.56 × 0.5462) + (0.01 × 0.5099) = 0.5467 m⁻¹

Cycle validation (annex 4, appendix 1, paragraph 3.4.)

Before calculating SV, the cycle must be validated by calculating the relative standard deviations of the smoke of the three cycles for each speed.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Mean SV (m⁻¹)</th>
<th>absolute standard deviation (m⁻¹)</th>
<th>relative standard deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.5482</td>
<td>0.0091</td>
<td>1.7</td>
</tr>
<tr>
<td>B</td>
<td>0.5462</td>
<td>0.0162</td>
<td>2.1</td>
</tr>
<tr>
<td>C</td>
<td>0.5099</td>
<td>0.0162</td>
<td>3.2</td>
</tr>
</tbody>
</table>

In this example, the validation criteria of 15 per cent is met for each speed.

Table C
Values of opacity N, unfiltered and filtered k-value at beginning of load step

<table>
<thead>
<tr>
<th>Index i [-]</th>
<th>Time [s]</th>
<th>Opacity N [%]</th>
<th>Unfiltered k-Value [m⁻¹]</th>
<th>Filtered k-Value [m⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>– 2</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>– 1</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>0</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>1</td>
<td>0.006667</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>2</td>
<td>0.013333</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>3</td>
<td>0.020000</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>4</td>
<td>0.026667</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>5</td>
<td>0.033333</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>6</td>
<td>0.040000</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>7</td>
<td>0.046667</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>8</td>
<td>0.053333</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>9</td>
<td>0.060000</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>10</td>
<td>0.066667</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>11</td>
<td>0.073333</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>12</td>
<td>0.080000</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>13</td>
<td>0.086667</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>14</td>
<td>0.093333</td>
<td>0.020000</td>
<td>0.000465</td>
<td>0.000000</td>
</tr>
<tr>
<td>15</td>
<td>0.100000</td>
<td>0.192000</td>
<td>0.004469</td>
<td>0.000014</td>
</tr>
<tr>
<td>16</td>
<td>0.106667</td>
<td>0.212000</td>
<td>0.004935</td>
<td>0.000018</td>
</tr>
<tr>
<td>17</td>
<td>0.113333</td>
<td>0.212000</td>
<td>0.004935</td>
<td>0.000022</td>
</tr>
<tr>
<td>18</td>
<td>0.120000</td>
<td>0.212000</td>
<td>0.004935</td>
<td>0.000028</td>
</tr>
<tr>
<td>19</td>
<td>0.126667</td>
<td>0.343000</td>
<td>0.007990</td>
<td>0.000036</td>
</tr>
<tr>
<td>20</td>
<td>0.133333</td>
<td>0.566000</td>
<td>0.013200</td>
<td>0.000047</td>
</tr>
<tr>
<td>21</td>
<td>0.140000</td>
<td>0.889000</td>
<td>0.020767</td>
<td>0.000061</td>
</tr>
<tr>
<td>22</td>
<td>0.146667</td>
<td>0.929000</td>
<td>0.021706</td>
<td>0.000082</td>
</tr>
</tbody>
</table>
### Table C (continued)

Values of opacity N, unfiltered and filtered k-value around $Y_{\text{max1,A}}$  
(* peak value, indicated in bold number)

<table>
<thead>
<tr>
<th>Index i [-]</th>
<th>Time [s]</th>
<th>Opacity N [%]</th>
<th>Unfiltered k-Value [m$^{-1}$]</th>
<th>Filtered k-Value [m$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>0.153333</td>
<td>0.929000</td>
<td>0.021706</td>
<td>0.000109</td>
</tr>
<tr>
<td>24</td>
<td>0.160000</td>
<td>1.263000</td>
<td>0.029559</td>
<td>0.000143</td>
</tr>
<tr>
<td>25</td>
<td>0.166667</td>
<td>1.455000</td>
<td>0.034086</td>
<td>0.000185</td>
</tr>
<tr>
<td>26</td>
<td>0.173333</td>
<td>1.697000</td>
<td>0.039804</td>
<td>0.000237</td>
</tr>
<tr>
<td>27</td>
<td>0.180000</td>
<td>2.030000</td>
<td>0.047695</td>
<td>0.000301</td>
</tr>
<tr>
<td>28</td>
<td>0.186667</td>
<td>2.081000</td>
<td>0.048906</td>
<td>0.000378</td>
</tr>
<tr>
<td>29</td>
<td>0.193333</td>
<td>2.081000</td>
<td>0.048906</td>
<td>0.000469</td>
</tr>
<tr>
<td>30</td>
<td>0.200000</td>
<td>2.424000</td>
<td>0.057067</td>
<td>0.000573</td>
</tr>
<tr>
<td>31</td>
<td>0.206667</td>
<td>2.475000</td>
<td>0.058282</td>
<td>0.000693</td>
</tr>
<tr>
<td>32</td>
<td>0.213333</td>
<td>2.475000</td>
<td>0.058282</td>
<td>0.000827</td>
</tr>
<tr>
<td>33</td>
<td>0.220000</td>
<td>2.808000</td>
<td>0.066237</td>
<td>0.000977</td>
</tr>
<tr>
<td>34</td>
<td>0.226667</td>
<td>3.010000</td>
<td>0.071075</td>
<td>0.001144</td>
</tr>
<tr>
<td>35</td>
<td>0.233333</td>
<td>3.253000</td>
<td>0.076909</td>
<td>0.001328</td>
</tr>
<tr>
<td>36</td>
<td>0.240000</td>
<td>3.606000</td>
<td>0.085410</td>
<td>0.001533</td>
</tr>
<tr>
<td>37</td>
<td>0.246667</td>
<td>3.960000</td>
<td>0.093966</td>
<td>0.001758</td>
</tr>
<tr>
<td>38</td>
<td>0.253333</td>
<td>4.455000</td>
<td>0.105983</td>
<td>0.002007</td>
</tr>
<tr>
<td>39</td>
<td>0.260000</td>
<td>4.818000</td>
<td>0.114836</td>
<td>0.002283</td>
</tr>
<tr>
<td>40</td>
<td>0.266667</td>
<td>5.020000</td>
<td>0.119776</td>
<td>0.002587</td>
</tr>
<tr>
<td>~</td>
<td>~</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
</tbody>
</table>
3. ETC TEST

3.1. Gaseous emissions (diesel engine)

Assume the following test results for a PDP-CVS system:

\[
\begin{array}{c|c|c|c|c}
V_0 & 0.1776 \\ \hline N_p & 23073 \\ \hline p_b & 98.0 \\ \hline p_t & 2.3 \\ \hline T & 322.5 \\ \hline H_a & 12.8 \\ \hline NO_{x,conc} & 53.7 \\ \hline NO_{x,conc,d} & 0.4 \\ \hline CO_{conc} & 38.9 \\ \end{array}
\]
Calculation of the diluted exhaust gas flow (annex 4, appendix 2, paragraph 4.1.):

\[ M_{\text{TOTW}} = 1.293 \times 0.1776 \times 23073 \times (98.0 - 2.3) \times 273 / (101.3 \times 322.5) = 4237.2 \text{ kg} \]

Calculation of the \( NO_x \) correction factor (annex 4, appendix 2, paragraph 4.2.):

\[ K_{\text{LD}} = \frac{1}{1 - 0.0182 \cdot (12.8 - 10.71)} = 1.039 \]

Calculation of the NMHC concentration by NMC method (annex 4, appendix 2, paragraph 4.3.1.), assuming a methane efficiency of 0.04 and an ethane efficiency of 0.98:

\[ \text{NMHC}_{\text{conce}} = \frac{9.0 \times (1 - 0.04) - 1.2}{0.98 - 0.04} = 7.91 \text{ ppm} \]

\[ \text{NMHC}_{\text{cond}} = \frac{3.02 \times (1 - 0.04) - 0.65}{0.98 - 0.04} = 2.39 \text{ ppm} \]

Calculation of the background corrected concentrations (annex 4, appendix 2, paragraph 4.3.1.1.):

Assuming a diesel fuel of the composition \( C_{1}H_{1.8} \)

\[ F_i = 100 \cdot \frac{1}{1 + (1.8 / 2) + (3.76 \cdot (1 + (1.8 / 4)))} = 13.6 \]

\[ DF = \frac{13.6}{0.723 + (9.00 + 38.9) \cdot 10^{-4}} = 18.69 \]

\[ \text{NO}_{x}\text{conc} = 53.7 - 0.4 \cdot (1 - (1 / 18.69)) = 53.3 \text{ ppm} \]

\[ \text{CO}_{\text{conc}} = 38.9 - 1.0 \cdot (1 - (1 / 18.69)) = 37.9 \text{ ppm} \]

\[ \text{HC}_{\text{conc}} = 9.00 - 3.02 \cdot (1 - (1 / 18.69)) = 6.14 \text{ ppm} \]

\[ \text{NMHC}_{\text{conc}} = 7.91 - 2.39 \cdot (1 - (1 / 18.69)) = 5.65 \text{ ppm} \]

Calculation of the emissions mass flow (annex 4, appendix 2, paragraph 4.3.1.):

\[ \text{NO}_{x}\text{mass} = 0.001587 \cdot 53.3 \cdot 1.039 \cdot 4237.2 = 372.391 \text{ g} \]

\[ \text{CO}_{\text{mass}} = 0.000966 \cdot 37.9 \cdot 4237.2 = 155.129 \text{ g} \]

\[ \text{HC}_{\text{mass}} = 0.000479 \cdot 6.14 \cdot 4237.2 = 12.462 \text{ g} \]

\[ \text{NMHC}_{\text{mass}} = 0.000479 \cdot 5.65 \cdot 4237.2 = 11.467 \text{ g} \]
Calculation of the specific emissions (annex 4, appendix 2, paragraph 4.4.):

\[
\begin{align*}
\text{NO}_x &= \frac{372,391}{62.72} = 5.94 \text{ g/kWh} \\
\text{CO} &= \frac{155,129}{62.72} = 2.47 \text{ g/kWh} \\
\text{HC} &= \frac{12,462}{62.72} = 0.199 \text{ g/kWh} \\
\text{NMHC} &= \frac{11,467}{62.72} = 0.183 \text{ g/kWh}
\end{align*}
\]

3.2. Particulate Emissions (Diesel Engine)

Assume the following test results for a PDP-CVS system with double dilution

<table>
<thead>
<tr>
<th>( M_{\text{TOTW}} ) (kg)</th>
<th>4,237.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_f ) (mg)</td>
<td>3,030</td>
</tr>
<tr>
<td>( M_{\text{f,b}} ) (mg)</td>
<td>0.044</td>
</tr>
<tr>
<td>( M_{\text{TOT}} ) (kg)</td>
<td>2.159</td>
</tr>
<tr>
<td>( M_{\text{SEC}} ) (kg)</td>
<td>0.909</td>
</tr>
<tr>
<td>( M_d ) (mg)</td>
<td>0.341</td>
</tr>
<tr>
<td>( M_{\text{DL}} ) (kg)</td>
<td>1.245</td>
</tr>
<tr>
<td>DF</td>
<td>18.69</td>
</tr>
<tr>
<td>( W_{\text{act}} ) (kWh)</td>
<td>62.72</td>
</tr>
</tbody>
</table>

Calculation of the mass emission (annex 4, appendix 2, paragraph 5.1.):

\[
\begin{align*}
\text{M}_f &= 3,030 + 0.044 = 3,074 \text{ mg} \\
\text{M}_{\text{SAM}} &= 2.159 - 0.909 = 1.250 \text{ kg} \\
\text{PT}_{\text{mass}} &= \frac{3,074}{1.250} \times \frac{4,237.2}{1,000} = 10.42 \text{ g}
\end{align*}
\]

Calculation of the background corrected mass emission (annex 4, appendix 2, paragraph 5.1.):

\[
\text{PT}_{\text{mass}} = \left[ \frac{3,074}{1.250} \times \left( \frac{0.341}{1.245} \times \left( 1 - \frac{1}{18.69} \right) \right) \right] \times \frac{4,237.2}{1,000} = 9.32 \text{ g}
\]

Calculation of the specific emission (annex 4, appendix 2, paragraph 5.2):

\[
\begin{align*}
\text{NO}_x &= \frac{372,391}{62.72} = 5.94 \text{ g/kWh} \\
\text{CO} &= \frac{155,129}{62.72} = 2.47 \text{ g/kWh} \\
\text{HC} &= \frac{12,462}{62.72} = 0.199 \text{ g/kWh}
\end{align*}
\]

3.3. Gaseous emissions (CNG engine)

Assume the following test results for a PDP-CVS system

<table>
<thead>
<tr>
<th>( M_{\text{TOTW}} ) (kg)</th>
<th>4,237.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{H}_4 ) (g/kg)</td>
<td>12.8</td>
</tr>
<tr>
<td>( \text{NO}<em>x</em>{\text{conce}} ) (ppm)</td>
<td>17.2</td>
</tr>
<tr>
<td>( \text{NO}<em>x</em>{\text{concd}} ) (ppm)</td>
<td>0.4</td>
</tr>
<tr>
<td>( \text{CO}_{\text{conce}} ) (ppm)</td>
<td>44.3</td>
</tr>
<tr>
<td>( \text{CO}_{\text{concd}} ) (ppm)</td>
<td>1.0</td>
</tr>
<tr>
<td>( \text{HC}_{\text{conce}} ) (ppm) without cutter</td>
<td>27.0</td>
</tr>
</tbody>
</table>
Calculation of the NO\textsubscript{x} correction factor (annex 4, appendix 2, paragraph 4.2.):

\[
K_{HG} = \frac{1}{1 - 0.0329 \times (12.8 - 10.71)} = 1.074
\]

Calculation of the NMHC concentration (annex 4, appendix 2, paragraph 4.3.1.):

\(\text{a) GC method}\)

\[
\text{NMHC} = 27.0 - 18.0 = 9.0 \text{ ppm}
\]

\(\text{b) NMC method}\)

Assuming a methane efficiency of 0.04 and an ethane efficiency of 0.98 (see annex 4, appendix 5, paragraph 1.8.4.)

\[
\text{NMHC} = 27.0 \times (1 - 0.04) - 18.0 \times 0.98 - 0.04 = 8.4 \text{ ppm}
\]

\[
\text{NMHC} = 2.02 \times (1 - 0.04) - 0.65 \times 0.98 - 0.04 = 1.37 \text{ ppm}
\]

Calculation of the background corrected concentrations (annex 4, appendix 2, paragraph 4.3.1.1.):

Assuming a 100 % methane fuel of the composition \(C_1H_4\)

\[
F_s = 100 \times \frac{1}{1 + (4/2) + (3.76 \times (1 + (4/4)))} = 9.5
\]

\[
DF = \frac{9.5}{0.723 + (27.0 + 44.3) \times 10^{-3}} = 13.01
\]

For NMHC with GC method, the background concentration is the difference between H\textsubscript{C}\textsubscript{conc} and CH\textsubscript{4}\textsubscript{conc}

\[
\text{NO\textsubscript{x} conc} = 17.2 - 0.4 \times (1 - (1/13.01)) = 16.8 \text{ ppm}
\]

\[
\text{CO conc} = 44.3 - 1.0 \times (1 - (1/13.01)) = 43.4 \text{ ppm}
\]

\[
\text{NMHC conc} = 8.4 - 1.37 \times (1 - (1/13.01)) = 7.13 \text{ ppm} \quad \text{(NMC method)}
\]

\[
\text{NMHC conc} = 9.0 - 0.92 \times (1 - (1/13.01)) = 8.15 \text{ ppm} \quad \text{(GC method)}
\]

\[
\text{CH}_4 \text{ conc} = 18.0 - 1.1 \times (1 - (1/13.01)) = 17.0 \text{ ppm} \quad \text{(GC method)}
\]

Calculation of the emissions mass flow (annex 4, appendix 2, paragraph 4.3.1.):

\[
\text{NO\textsubscript{x} mass} = 0.001587 \times 16.8 \times 1.074 \times 4237.2 = 121,330 \text{ g}
\]

\[
\text{CO mass} = 0.000966 \times 43.4 \times 4237.2 = 177,642 \text{ g}
\]

\[
\text{NMHC mass} = 0.000516 \times 7.13 \times 4237.2 = 15,589 \text{ g} \quad \text{(NMC method)}
\]

\[
\text{NMHC mass} = 0.000516 \times 8.15 \times 4237.2 = 17,819 \text{ g} \quad \text{(GC method)}
\]

\[
\text{CH}_4 \text{ mass} = 0.000552 \times 17.0 \times 4237.2 = 39,762 \text{ g} \quad \text{(GC method)}
\]
Calculation of the specific emissions (annex 4, appendix 2, paragraph 4.4.):

\[
\begin{align*}
\text{NO}_x &= 121,330 / 62,72 = 1,93 \text{ g/kWh} \\
\text{CO} &= 177,642 / 62,72 = 2,83 \text{ g/kWh} \\
\text{NMHC} &= 15,589 / 62,72 = 0,249 \text{ g/kWh (NMC method)} \\
\text{NMHC} &= 17,819 / 62,72 = 0,284 \text{ g/kWh (GC Method)} \\
\text{CH}_4 &= 39,762 / 62,72 = 0,634 \text{ g/kWh (GC method)}
\end{align*}
\]

4. \( \lambda \)-SHIFT FACTOR \((S_\lambda)\)

4.1. Calculation of the \( \lambda \)-shift factor \((S_\lambda)\) \(^{(1)}\)

\[
S_\lambda = \frac{2}{1 - \frac{\text{inert \%}}{100} - \left(\frac{n + m}{4}\right) - \frac{\text{O}_2^*}{100}}
\]

where:

- \( S_\lambda \) = \( \lambda \)-shift factor;
- inert \% = % by volume of inert gases in the fuel (i.e. N\(_2\), CO\(_2\), He, etc.);
- O\(_2^*\) = % by volume of original oxygen in the fuel;
- n and m = refer to average C\(_n\)H\(_m\) representing the fuel hydrocarbons, i.e.:

\[
\begin{align*}
n &= 1 \times \left[ \frac{\text{CH}_4 \%}{100} \right] + 2 \times \left[ \frac{\text{C}_2 \%}{100} \right] + 3 \times \left[ \frac{\text{C}_3 \%}{100} \right] + 4 \times \left[ \frac{\text{C}_4 \%}{100} \right] + 5 \times \left[ \frac{\text{C}_5 \%}{100} \right] + \ldots \\
\end{align*}
\]

\[
\begin{align*}
m &= 4 \times \left[ \frac{\text{CH}_4 \%}{100} \right] + 4 \times \left[ \frac{\text{C}_2 \%}{100} \right] + 6 \times \left[ \frac{\text{C}_3 \%}{100} \right] + 8 \times \left[ \frac{\text{C}_4 \%}{100} \right] + \ldots \\
\end{align*}
\]

where:

- CH\(_4\) = % by volume of methane in the fuel;
- C\(_2\) = % by volume of all C\(_2\) hydrocarbons (e.g. C\(_2\)H\(_6\), C\(_2\)H\(_4\), etc.) in the fuel;
- C\(_3\) = % by volume of all C\(_3\) hydrocarbons (e.g. C\(_3\)H\(_8\), C\(_3\)H\(_6\), etc.) in the fuel;
- C\(_4\) = % by volume of all C\(_4\) hydrocarbons (e.g. C\(_4\)H\(_{10}\), C\(_4\)H\(_8\), etc.) in the fuel;
- C\(_5\) = % by volume of all C\(_5\) hydrocarbons (e.g. C\(_5\)H\(_{12}\), C\(_5\)H\(_{10}\), etc.) in the fuel;
- diluent = % by volume of dilution gases in the fuel (i.e. O\(_2^*\), N\(_2\), CO\(_2\), He, etc.).


4.2. Examples for the calculation of the $\lambda$-shift factor $S_\lambda$:

Example 1: G25: CH$_4$ = 86 %, N$_2$ = 14 % (by vol)

\[
\begin{align*}
1 \times \left[ \frac{\text{CH}_4 \%}{100} \right] + 2 \times \left[ \frac{\text{C}_2 \%}{100} \right] + \cdots & = 1 \times 0.86 + 0.86 = 1 \\
1 - \frac{\text{diluent}\%}{100} & = 1 - \frac{14}{100} \\
4 \times \left[ \frac{\text{CH}_4 \%}{100} \right] + 4 \times \left[ \frac{\text{C}_2H_4 \%}{100} \right] + \cdots & = 4 \times 0.86 = 4 \\
1 - \frac{\text{diluent}\%}{100} & = 1 - \frac{0.86}{100}
\end{align*}
\]

\[
S_\lambda = \frac{2}{1 - \frac{\text{inert} \%}{100}} \left( n + \frac{m}{4} \right) - \frac{\text{O}_2^*}{100} = \frac{2}{1 - \frac{0}{100}} \times \frac{1}{1 + \frac{4}{4}} = 1.16
\]

Example 2: GR: CH$_4$ = 87 %, C$_2$H$_6$ = 13 % (by vol)

\[
\begin{align*}
1 \times \left[ \frac{\text{CH}_4 \%}{100} \right] + 2 \times \left[ \frac{\text{C}_2 \%}{100} \right] + \cdots & = 1 \times 0.87 + 2 \times 0.13 = 1.13 \\
1 - \frac{\text{diluent}\%}{100} & = 1 - \frac{0}{100} \\
4 \times \left[ \frac{\text{CH}_4 \%}{100} \right] + 6 \times \left[ \frac{\text{C}_2H_6 \%}{100} \right] + \cdots & = 4 \times 0.87 + 6 \times 0.13 = 4.26 \\
1 - \frac{\text{diluent}\%}{100} & = 1 - \frac{0.86}{100}
\end{align*}
\]

\[
S_\lambda = \frac{2}{1 - \frac{\text{inert} \%}{100}} \left( n + \frac{m}{4} \right) - \frac{\text{O}_2^*}{100} = \frac{2}{1 - \frac{0}{100}} \times \frac{1}{1 + \frac{4}{4}} = 0.911
\]

Example 3: USA: CH$_4$ = 89 %, C$_2$H$_6$ = 4.5 %, C$_4$H$_8$ = 2.3 %, C$_6$H$_{14}$ = 0.2 %, O$_2$ = 0.6 %, N$_2$ = 4 %

\[
\begin{align*}
1 \times \left[ \frac{\text{CH}_4 \%}{100} \right] + 2 \times \left[ \frac{\text{C}_2 \%}{100} \right] + \cdots & = 1 \times 0.89 + 2 \times 0.045 + 3 \times 0.023 + 4 \times 0.002 = 1.11 \\
1 - \frac{\text{diluent}\%}{100} & = 1 - \frac{0.64}{100} \\
4 \times \left[ \frac{\text{CH}_4 \%}{100} \right] + 4 \times \left[ \frac{\text{C}_2H_4 \%}{100} \right] + 6 \times \left[ \frac{\text{C}_2H_6 \%}{100} \right] + \cdots + 8 \times \left[ \frac{\text{C}_6H_{14} \%}{100} \right] & =
\end{align*}
\]

\[
\begin{align*}
1 - \frac{\text{diluent}\%}{100} & = 1 - \frac{0.64}{100} \\
& = \frac{4 \times 0.89 + 4 \times 0.045 + 8 \times 0.023 + 14 \times 0.002}{1 - \frac{0.64}{100}} = 4.24 \\
S_\lambda = \frac{2}{1 - \frac{\text{inert} \%}{100}} \left( n + \frac{m}{4} \right) - \frac{\text{O}_2^*}{100} = \frac{2}{1 - \frac{0.64}{100}} \times \frac{1}{1 + \frac{4}{4}} = 0.96
\end{align*}
\]
ANNEX 9

SPECIFIC TECHNICAL REQUIREMENTS RELATING TO ETHANOL-FUELLED DIESEL ENGINES

In the case of ethanol-fuelled diesel engines, the following specific modifications to the appropriate paragraphs, equations and factors will apply to the test procedures defined in annex 4 to this Regulation.

In annex 4, appendix 1

4.2. Dry/wet correction

\[ F_{BH} = \frac{1,877}{1 + 2,577 \cdot \frac{G_{FUEL}}{G_{AIRW}}} \]

4.3. \( \text{NO}_x \) correction for humidity and temperature

\[ K_{H,D} = \frac{1}{1 + A \cdot (H_a - 10,71) + B \cdot (T_a - 298)} \]

with:

- \( A = 0.181 \frac{G_{FUEL}}{G_{AIRD}} - 0.0266 \)
- \( B = -0.123 \frac{G_{FUEL}}{G_{AIRD}} + 0.00954 \)
- \( T_a \) = temperature of the air, K
- \( H_a \) = humidity of the intake air, g water per kg dry air

4.4. Calculation of the emission mass flow rates

The emission mass flow rates [g/h] for each mode shall be calculated as follows, assuming the exhaust gas density to be 1.272 kg/m\(^3\) at 273 K (0°C) and 101.3 kPa:

1. \( \text{NO}_x \) mass = \( 0.001613 \cdot \text{NO}_x \text{ conc} \cdot K_{H,D} \cdot G_{EXHW} \)
2. \( \text{CO} \) mass = \( 0.000982 \cdot \text{CO} \text{ conc} \cdot G_{EXHW} \)
3. \( \text{HC} \) mass = \( 0.000809 \cdot \text{HC} \text{ conc} \cdot K_{H,D} \cdot G_{EXHW} \)

where \( \text{NO}_x \text{ conc}, \text{CO} \text{ conc}, \text{HC} \text{ conc} \) (1) are the average concentrations (ppm) in the raw exhaust gas, as determined in paragraph 4.1.

If, optionally, the gaseous emissions are determined with a full flow dilution system, the following formulae must be applied:

1. \( \text{NO}_x \) mass = \( 0.001587 \cdot \text{NO}_x \text{ conc} \cdot K_{H,D} \cdot G_{TOTW} \)
2. \( \text{CO} \) mass = \( 0.000966 \cdot \text{CO} \text{ conc} \cdot G_{TOTW} \)
3. \( \text{HC} \) mass = \( 0.000795 \cdot \text{HC} \text{ conc} \cdot G_{TOTW} \)

where \( \text{NO}_x \text{ conc}, \text{CO} \text{ conc}, \text{HC} \text{ conc} \) (1) are the average background corrected concentrations (ppm) of each mode in the diluted exhaust gas, as determined in annex 4, appendix 2, paragraph 4.3.1.1.

In annex 4, appendix 2

Paragraphs 3.1., 3.4., 3.8.3. and 5. of appendix 2 do not apply solely to diesel engines. They also apply to ethanol-fuelled diesel engines.

(1) Based on C1 equivalent.
4.2. The conditions for the test should be arranged so that the air temperature and the humidity measured at the engine intake is set to standard conditions during the test run. The standard should be 6 ± 0.5 g water per kg dry air at a temperature interval of 298 ± 3 K. Within these limits no further NOx correction should be made. The test is void if these conditions are not met.

4.3. Calculation of the emission mass flow

4.3.1. Systems with constant mass flow

For systems with heat exchanger, the mass of the pollutants (g/test) must be determined from the following equations:

\[(1) \quad \text{NOx mass} = 0.001587 \cdot \text{NOx conc} \cdot K_{\text{H,D}} \cdot M_{\text{TOTW}} \quad \text{(ethanol fuelled engines)}\]
\[(2) \quad \text{CO mass} = 0.000966 \cdot \text{CO conc} \cdot M_{\text{TOTW}} \quad \text{(ethanol fuelled engines)}\]
\[(3) \quad \text{HC mass} = 0.000794 \cdot \text{HC conc} \cdot M_{\text{TOTW}} \quad \text{(ethanol fuelled engines)}\]

where:
\[
\text{NOx conc, CO conc, HC conc (1), NMHC conc} = \text{average background corrected concentrations over the cycle from integration or bag measurement, ppm.}
\]
\[
M_{\text{TOTW}} = \text{total mass of diluted exhaust gas over the cycle as determined in paragraph 4.1., kg.}
\]

4.3.1.1. Determination of the background corrected concentrations

The average background concentration of the gaseous pollutants in the dilution air must 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 must be used:

\[
\text{conc} = \text{conc}_a - \text{conc}_d \times (1 - (1 / \text{DF}))
\]

where:
\[
\text{conc} = \text{concentration of the respective pollutant in the diluted exhaust gas, corrected by the amount of the respective pollutant contained in the dilution air, ppm}
\]
\[
\text{conc}_a = \text{concentration of the respective pollutant measured in the diluted exhaust gas, ppm}
\]
\[
\text{conc}_d = \text{concentration of the respective pollutant measured in the dilution air, ppm}
\]
\[
\text{DF} = \text{dilution factor}
\]

The dilution factor must be calculated as follows:

\[
\text{DF} = \frac{F_S}{\text{CO}_{2,\text{conc}} + (\text{HC}_{\text{conc}} + \text{CO}_{\text{conc}}) \times 10^{-4}}
\]

where:
\[
\text{CO}_{2,\text{conc}} = \text{concentration of CO}_2 \text{ in the diluted exhaust gas, % vol}
\]
\[
\text{HC}_{\text{conc}} = \text{concentration of HC in the diluted exhaust gas, ppm C1}
\]
\[
\text{CO}_{\text{conc}} = \text{concentration of CO in the diluted exhaust gas, ppm}
\]
\[
F_S = \text{stoichiometric factor}
\]

Concentrations measured on dry basis must be converted to a wet basis in accordance with annex 4, appendix 1, paragraph 4.2.

\(^{(1)}\) Based on C1 equivalent.
The stoichiometric factor must, for the general fuel composition \(\text{CH}_\alpha\text{O}_\beta\text{N}_\gamma\), be calculated as follows:

\[
F_S = 100 \cdot \frac{1}{1 + \frac{\alpha}{2} + 3.76 \left(1 + \frac{\alpha}{4} - \frac{\beta}{2} + \frac{\gamma}{2}\right)}
\]

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

\(F_S\) (ethanol) = 12.3

4.3.2. Systems with flow compensation

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

\[
\begin{align*}
(1) \quad \text{NO}_x \text{ mass} &= \sum_{i=1}^{n} (M_{\text{TOTW},i} \cdot \text{NO}_x \text{ conc},i \cdot 0.001587) - (M_{\text{TOTW}} \cdot \text{NO}_x \text{ conc},d \cdot (1 - 1/DF) \cdot 0.001587) \\
(2) \quad \text{CO mass} &= \sum_{i=1}^{n} (M_{\text{TOTW},i} \cdot \text{CO conc},i \cdot 0.000966) - (M_{\text{TOTW}} \cdot \text{CO conc},d \cdot (1 - 1/DF) \cdot 0.000966) \\
(3) \quad \text{HC mass} &= \sum_{i=1}^{n} (M_{\text{TOTW},i} \cdot \text{HC conc},i \cdot 0.000479) - (M_{\text{TOTW}} \cdot \text{HC conc},d \cdot (1 - 1/DF) \cdot 0.000479)
\end{align*}
\]

where:

\(\text{conc},_i\) = concentration of the respective pollutant measured in the diluted exhaust gas, ppm
\(\text{conc},_d\) = concentration of the respective pollutant measured in the dilution air, ppm
\(M_{\text{TOTW},i}\) = instantaneous mass of the diluted exhaust gas (see paragraph 4.1.), kg
\(M_{\text{TOTW}}\) = total mass of diluted exhaust gas over the cycle (see paragraph 4.1.), kg
\(DF\) = dilution factor as determined in paragraph 4.3.1.1.

4.4. Calculation of the specific emissions

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

\[
\frac{\text{NO}_x}{W_{\text{act}}} = \frac{\text{NO}_x \text{ mass}}{W_{\text{act}}}
\]

\[
\frac{\text{CO}}{W_{\text{act}}} = \frac{\text{CO mass}}{W_{\text{act}}}
\]

\[
\frac{\text{HC}}{W_{\text{act}}} = \frac{\text{HC mass}}{W_{\text{act}}}
\]

where:

\(W_{\text{act}}\) = actual cycle work as determined in paragraph 3.9.2., kWh