Proposal for amendments to Regulation No. 49 (Emissions of compression ignition and positive ignition (LPG and CNG) engines)

Submitted by the experts from the International Organization of Motor Vehicle Manufacturers

The text reproduced below was prepared by the experts from the International Organization of Motor Vehicle Manufacturers (OICA). This document aims at permitting the use of hydrogen (H₂) as fuel for emissions type approval of heavy duty vehicles. The modifications to the current text of the Regulation are marked in bold for new or strikethrough for deleted characters.
I. Proposal

Paragraph 4.6.2., amend to read:

"4.6.2. If the manufacturer permits the engine family to run on market fuels that do not comply neither with the reference fuels included in Annex 5 nor CEN standard EN 228 (in the case of unleaded petrol) or grade D (type I or II) of ISO standard ISO 14687 (in the case of hydrogen) or CEN standard EN 590 (in the case of diesel), such as running on FAME B100 (CEN standard EN14214), FAME diesel blends B20/B30 (CEN standard EN 16709), paraffinic fuel (CEN standard EN 15940) or others the manufacturer shall, in addition to the requirements in paragraph 4.6.1. comply with the following requirements:" Insert new paragraph 4.12.3.3.7., to read:

"4.12.3.3.7. For hydrogen fuelled engines the approval mark shall contain a letter/s after the national symbol, the purpose of which is to distinguish the fuel type and the working principal the approval has been granted. This letter/s will be as follows:

(a) T in case of the PI engine being approved and calibrated for gaseous hydrogen
(b) TD in case of the CI engine being approved and calibrated for gaseous hydrogen
(c) U in case of the PI engine being approved and calibrated for liquefied hydrogen
(d) UD in case of the CI engine being approved and calibrated for liquefied hydrogen"

Paragraph 4.12.3.3.7. (former), renumber as paragraph 4.12.3.3.8., amend to read:

"4.12.3.3.8. For dual-fuel engines the approval mark shall contain a series of digits after the national symbol, the purpose of which is to distinguish for which dual-fuel engine type and with which range of gases the approval has been granted.

This series of digits will be constituted of two digits identifying the dual-fuel engine type as defined in Annex 15 followed by the letter(s) specified in paragraphs 4.12.3.3.1. to 4.12.3.3.7. corresponding to the natural gas/biomethane/hydrogen composition used by the engine.

The two digits identifying the dual-fuel engines types according to the definitions of Annex 15 are the following:

(a) 1A for dual-fuel engines of Type 1A;
(b) 1B for dual-fuel engines of Type 1B;
(c) 2A for dual-fuel engines of Type 2A;
(d) 2B for dual-fuel engines of Type 2B;
(e) 3B for dual-fuel engines of Type 3B."

Paragraph 5.3., amend to read:

"5.3. Emission limits

Table 1 provides the emissions limits that apply to this Regulation."
### Limit values

<table>
<thead>
<tr>
<th></th>
<th>CO (mg/kWh)</th>
<th>THC (mg/kWh)</th>
<th>NMHC (mg/kWh)</th>
<th>CH₄ (mg/kWh)</th>
<th>NOₓ *) (mg/kWh)</th>
<th>NH₃ (ppm)</th>
<th>PM mass (mg/kWh)</th>
<th>PM number (#/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHSC (CI)</td>
<td>1,500</td>
<td>130</td>
<td>400</td>
<td>10</td>
<td>10</td>
<td></td>
<td>8.0 x 10¹¹</td>
<td></td>
</tr>
<tr>
<td>WHTC (CI)</td>
<td>4,000</td>
<td>160</td>
<td>460</td>
<td>10</td>
<td>10</td>
<td></td>
<td>6.0 x 10¹¹**</td>
<td></td>
</tr>
<tr>
<td>WHTC (PI)</td>
<td>4,000</td>
<td>160</td>
<td>500</td>
<td>460</td>
<td>10</td>
<td>10</td>
<td>6.0 x 10¹¹**</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

PI = Positive Ignition  
CI = Compression Ignition  
*) The admissible level of NO₂ component in the NOₓ limit value may be defined at a later stage.  
**) The limit shall apply as from the dates set out in row B of Table 1 in Appendix 9 to Annex 1 to this Regulation.

CO, THC, NMHC and CH₄ do not need to be demonstrated for engines where all of the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.

**Paragraph 8.3.3.3., amend to read:**

"8.3.3.3. For diesel, ethanol (ED95), petrol, E85, hydrogen, LNG20, LNG and LPG fuelled, including dual-fuel, engines, all these tests may be conducted with the applicable market fuels. However, at the manufacturer’s request, the reference fuels described in Annex 5 to this Regulation may be used. This implies tests, as described in paragraph 4. of this Regulation."

**Annex 1**

**Annex 1, Paragraph 3.2.2.2., amend to read:**

"3.2.2.2. Heavy duty vehicles Diesel/Petrol/LPG/NG-H/NG-L/NG-HL/Ethanol (ED95)/Ethanol (E85)/Hydrogen (T)/Hydrogen (TD)/Hydrogen (U)/Hydrogen (UD) ¹"  

**Annex 1, Paragraph 3.2.17.1., amend to read:**

"3.2.17.1. Fuel: LPG/NG-H/NG-L/NG-HL/Hydrogen (T)/Hydrogen (TD)/Hydrogen (U)/Hydrogen (UD) ¹"  

**Addendum to Annex 2A, Paragraph 1.1.5., amend to read:**

"1.1.5. Category of engine: Diesel/Petrol/LPG/NG-H/NG-L/NG-HL/Ethanol (ED95)/Ethanol (E85)/LNG/LNG20 1)/Hydrogen (T)/Hydrogen (TD)/Hydrogen (U)/Hydrogen (UD) ¹"  

**Addendum to Annex 2A, Paragraph 1.4.1., amend to read:**
1.4.1. WHSC test

Table 4

WHSC test

<table>
<thead>
<tr>
<th>WHSC test (if applicable) *; **</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DF</strong></td>
</tr>
<tr>
<td>Mult/add ¹)</td>
</tr>
<tr>
<td>Emissions</td>
</tr>
<tr>
<td>Test result</td>
</tr>
<tr>
<td>Calculated with DF</td>
</tr>
</tbody>
</table>

CO₂ emissions mass emission ***: ............................................................ (g/kWh)

Fuel consumption: ............................................................ (g/kWh)

Notes:

*  In the case of engines considered in paragraphs 4.6.3. and 4.6.6. of this Regulation, repeat the information for all fuels tested, when applicable.

**  In the case of dual-fuel engines of Type 1B, Type 2B, and Type 3B, types as defined in Annex 15 to this Regulation, repeat the information in both dual-fuel and diesel mode.

***  Not required for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.

†  In the cases laid down in Table 1 of Annex 15 to this Regulation for dual-fuel engines, and for positive ignition engines.”

Addendum to Annex 2A, Paragraph 1.4.2., amend to read:

1.4.2. WHTC test

Table 5

WHTC test

<table>
<thead>
<tr>
<th>WHTC test *; **</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DF</strong></td>
</tr>
<tr>
<td>Mult/addr ¹)</td>
</tr>
</tbody>
</table>

Addendum to Annex 2A, Paragraph 1.4.2., amend to read:
<table>
<thead>
<tr>
<th>Emissions</th>
<th>CO *** (mg/kWh)</th>
<th>THC *** (mg/kWh)</th>
<th>NMHC ***,‡ (mg/kWh)</th>
<th>CH4 ***,‡ (mg/kWh)</th>
<th>NOx (mg/kWh)</th>
<th>PM Mass (mg/kWh)</th>
<th>NH3 ppm</th>
<th>PM Number (#/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold start</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot start w/o regeneration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot start with regeneration ¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kr,u (mult/add) ¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kr,d (mult/add) ¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weighted test result</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final test result with DF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ emissions mass emission ***: ............................................................ (g/kWh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel consumption: .................. ..................................................... (g/kWh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
* In the case of engines considered in paragraphs 4.6.3. and 4.6.6. of this Regulation, repeat the information for all fuels tested, when applicable.

** In the case of dual-fuel engines of Type 1B, Type 2B, and Type 3B, types as defined in Annex 15 to this Regulation, repeat the information in both dual-fuel and diesel mode.

*** Not required for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.

¹ In the cases laid down in Table 1 of Annex 15 to this Regulation for dual-fuel engines, and for positive ignition engines.

Addendum to Annex 2C, Paragraph 1.1.5., amend to read:
"1.1.5. Category of engine: Diesel/Petrol/LPG/NG-H/NG-L/NG-HL/Ethanol (ED95)/Ethanol (E85)/LNG/LNG20 ¹) /Hydrogen (T) /Hydrogen (TD) /Hydrogen (U) /Hydrogen (UD) ¹)"

Addendum to Annex 2C, Paragraph 1.4.1., amend to read:
"1.4.1. WHSC test
Table 4
WHSC test

WHSC test (if applicable) "**"
Addendum to Annex 2C, Paragraph 1.4.2., amend to read:

"1.4.2. WHTC test

Table 5

WHTC test *; **
<table>
<thead>
<tr>
<th>Hot start with regeneration (^1)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( kr_u ) (mult/add) (^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( kr_d ) (mult/add) (^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weighted test result</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final test result with DF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CO\(_2\) emissions mass emission** \(^{***}\): ............................................................ (g/kWh)

**Fuel consumption:** ............................................................ (g/kWh)

Notes:

* In the case of engines considered in paragraphs 4.6.3. and 4.6.6. of this Regulation, repeat the information for all fuels tested, when applicable.

** In the case of dual-fuel engines of Type 1B, Type 2B, and Type 3B, types as defined in Annex 15 to this Regulation, repeat the information in both dual-fuel and diesel mode.

*** Not required for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.

\(^1\) In the cases laid down in Table 1 of Annex 15 to this Regulation for dual-fuel engines, and for positive ignition engines."

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**Annex 3**

**Annex 3, Table 2, amend to read:**

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel fuelled CI engine</td>
<td>D</td>
</tr>
<tr>
<td>Ethanol (ED95) fuelled CI engine</td>
<td>ED</td>
</tr>
<tr>
<td>Ethanol (E85) fuelled PI engine</td>
<td>E85</td>
</tr>
<tr>
<td>Petrol fuelled PI engine</td>
<td>P</td>
</tr>
<tr>
<td>LPG fuelled PI engine</td>
<td>Q</td>
</tr>
<tr>
<td>Natural gas fuelled PI engine</td>
<td>See paragraph 4.12.3.6. of this Regulation</td>
</tr>
<tr>
<td><strong>Hydrogen fuelled engine</strong></td>
<td>See paragraph 4.12.3.7. of this Regulation</td>
</tr>
<tr>
<td>Dual-fuel engines</td>
<td>See paragraph 4.12.3.38. of this Regulation</td>
</tr>
</tbody>
</table>

---

**Annex 4**

**Annex 4, paragraph 3.3., amend to read:**
3.3. Symbols and abbreviations for the fuel composition

\( w_{\text{ALF}} \) Hydrogen content of fuel, per cent mass

\( w_{\text{BET}} \) Carbon content of fuel, per cent mass

\( w_{\text{GAM}} \) Sulphur content of fuel, per cent mass

\( w_{\text{DEL}} \) Nitrogen content of fuel, per cent mass

\( w_{\text{EPS}} \) Oxygen content of fuel, per cent mass

\( \alpha \) Molar hydrogen ratio \((\frac{\text{H}}{\text{C}})\)

\( \beta \) Molar carbon ratio

\( \gamma \) Molar sulphur ratio \((\frac{\text{S}}{\text{C}})\)

\( \delta \) Molar nitrogen ratio \((\frac{\text{N}}{\text{C}})\)

\( \varepsilon \) Molar oxygen ratio \((\frac{\text{O}}{\text{C}})\)

referring to a fuel \( \text{C}_\beta \text{H}_\alpha \text{O}_\varepsilon \text{N}_\delta \text{S}_\gamma \text{C}_\beta \), with \( \beta=1 \) for fuels containing carbon and \( \beta=0 \) for fuels not containing carbon.

Annex 4, paragraph 3.4., amend to read:

3.4. Symbols and abbreviations for the chemical components

\( \text{C}_1 \) Carbon 1 equivalent hydrocarbon

\( \text{CH}_4 \) Methane

\( \text{C}_2\text{H}_6 \) Ethane

\( \text{C}_3\text{H}_8 \) Propane

\( \text{CO} \) Carbon monoxide

\( \text{CO}_2 \) Carbon dioxide

\( \text{DOP} \) Di-octylphthalate

\( \text{HC} \) Hydrocarbons

\( \text{H}_2 \) Hydrogen

\( \text{H}_2\text{O} \) Water

\( \text{NMHC} \) Non-methane hydrocarbons

\( \text{NO}_x \) Oxides of nitrogen

\( \text{NO} \) Nitric oxide

\( \text{NO}_2 \) Nitrogen dioxide

\( \text{O}_2 \) Oxygen

\( \text{PM} \) Particulate matter

Annex 4, paragraph 5.2.3.6., amend to read:

5.2.3.6. Fuel type

(a) Diesel;

(b) Natural gas (NG);

(c) Liquefied petroleum gas (LPG);
(d) Ethanol;

(e) Hydrogen."

Annex 4, paragraph 8., amend to read:

"8. Emission calculation

The final test result shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure, in accordance with ASTM E 29-06B. No rounding of intermediate values leading to the final break-specific emission result is permitted.

Calculation of hydrocarbons and/or non-methane hydrocarbons is based on the following molar carbon/hydrogen/oxygen ratios (C/H/O) of the fuel:

CH$_{1.86}$O$_{0.006}$ for diesel (B7),

CH$_{2.92}$O$_{0.46}$ for ethanol for dedicated C.I. engines (ED95),

CH$_{1.93}$O$_{0.032}$ for petrol (E10),

CH$_{2.74}$O$_{0.385}$ for ethanol (E85),

CH$_{2.525}$ for LPG (liquefied petroleum gas),

CH$_4$ for NG (natural gas) and biomethane,

H$_2$ for hydrogen.

Examples of the calculation procedures are given in Appendix 5 to this annex.

Emissions calculation on a molar basis, in accordance with Annex 7 of gtr No. 11 concerning the exhaust emission test protocol for Non-Road Mobile Machinery (NRMM), is permitted with the prior agreement of the Type Approval Authority."

Annex 4, paragraph 8.1., amend to read:

"8.1. Dry/wet correction

If the emissions are measured on a dry basis, the measured concentration shall be converted to a wet basis according to the following equation:

$$cw = kw \times cd$$

(12)

Where:

c$_d$ is the dry concentration in ppm or per cent volume

k$_w$ is the dry/wet correction factor (k$_{w,r}$, k$_{w,cr}$, k$_{w,ci}$, or k$_{w,d}$ depending on respective equation used)

If all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. to this annex, then the concentration of CO (c$_{CO}$) and CO2 (c$_{CO2}$) shall be set to zero in paragraph 8.1.1. and 8.1.2. to this annex."

Annex 4, paragraph 8.1.1. Equation (15), amend to read:

"$$k_{w,r} = \left( \frac{1}{1 + a \times 0.005 \times (c_{CO2} + c_{CO})} - k_{w1} \right) \times 1,008$$

$$k_{w,cr} = \left( \frac{1}{1 + a \times 0.005 \times (c_{CO2} + c_{CO})} - k_{w1} \right) \times 1,008$$"
Annex 4, paragraph 8.1.3. Equation (22), amend to read:

\[ k_{w_2} = \frac{1.608 \times H_d}{1000 + (1.608 \times H_d)} \]

\[ k_{w_3} = \frac{1.608 \times H_d}{1000 + (1.608 \times H_d)} \]

Annex 4, paragraph 8.4.1.1., amend to read:

"8.4.1.1. Introduction

For calculation of the emissions in the raw exhaust gas and for controlling of a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For the determination of the exhaust mass flow rate, one of the methods described in paragraphs 8.4.1.3. to 8.4.1.7 may be used."

Annex 4, paragraph 8.4.1.2., amend to read:

"8.4.1.2. Response time

For the purpose of emissions calculation, the response time of any of the methods described in paragraphs 8.4.1.3. to 8.4.1.7 shall be equal to or less than the analyser response time of ≤ 10 seconds, as required in paragraph 9.3.5.

For the purpose of controlling of a partial flow dilution system, a faster response is required. For partial flow dilution systems with online control, the response time shall be ≤ 0.3 second. For partial flow dilution systems with look ahead control based on a pre-recorded test run, the response time of the exhaust flow measurement system shall be ≤ 5 seconds with a rise time of ≤ 1 second. The system response time shall be specified by the instrument manufacturer. The combined response time requirements for the exhaust gas flow and partial flow dilution system are indicated in paragraph 9.4.6.1."

Annex 4, paragraph 8.4.1.6., amend to read:

"... With

\[ \frac{A/F_{st}}{A/F_{st}} = \frac{138.0 \times (\theta + \frac{c_H}{c_C} \times 10^{-4})}{12.011 \times \theta + 1.0794 \times \alpha + 15.9994 \times \epsilon + 14.0067 \times \delta + 32.065 \times \gamma} \]

\[ \lambda_1 = \frac{4.764 \times (1.0 \times \frac{1}{2} + \beta \times \gamma) \times \left(100 \times c_{COd} \times 10^{-4} \times c_{H2O} \times 10^{-4}\right)}{\left(100 \times c_{COd} \times 10^{-4} \times c_{H2O} \times 10^{-4}\right) \times \left(100 \times c_{COd} \times 10^{-4} \times c_{H2O} \times 10^{-4}\right)} \] (31)

(32)

Where:

\( q_{maw,i} \) is the instantaneous intake air mass flow rate, kg/s

\( A/F_{st} \) is the stoichiometric air to fuel ratio, kg/kg

...
\[ \beta \] is the molar carbon ratio of the fuel, with \( \beta=1 \) for fuels containing carbon and \( \beta=0 \) for fuels not containing carbon

\[ \lambda_i \] is the instantaneous excess air ratio

\[ c_{CO2d} \] is the dry CO\(_2\) concentration, per cent

\[ c_{COD} \] is the dry CO concentration, ppm

\[ c_{HCw} \] is the wet HC concentration, ppm

Equation (32) is not applicable, if one of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8.

"Add new paragraph 8.4.1.8. to Annex 4, to read:

"8.4.1.8. Oxygen balance method

The following formula can be used for the calculation of the exhaust mass flow on the basis of the oxygen balance method.

\[
q_{new} = q_{mad} \times \left( 1 + \frac{H_m}{1000} \right) + q_{mf}
\]

\[
q_{med} = q_{mf} \times \left( 1 - 0.00936 \times w_{ALF} \times 0.232 - f_2 \times w_{EPS} \right) \frac{0.232 - \frac{4 \times w_{GAM}}{\rho_{gas}}}{\rho_{gas}}
\]

With

\[
f_2 = w_{ALF} \times 7.9367 + w_{BET} \times 2.6641 + w_{GAM} \times 0.9979
\]

"Annex 4, paragraph 8.4.2.3. Table 5, amend to read:

"Table 5
Raw exhaust gas u values and component densities

<table>
<thead>
<tr>
<th>Fuel</th>
<th>( \rho_e )</th>
<th>( \rho_{gas} ) [kg/m(^3)]</th>
<th>( u_{gas} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NO(_x)</td>
<td>CO</td>
</tr>
<tr>
<td>Diesel (B7)</td>
<td>1.2943</td>
<td>2.053</td>
<td>1.250</td>
</tr>
<tr>
<td>Ethanol (ED95)</td>
<td>1.2768</td>
<td>0.001586</td>
<td>0.000966</td>
</tr>
<tr>
<td>CNG(^c)</td>
<td>1.2661</td>
<td>0.001621</td>
<td>0.000987</td>
</tr>
<tr>
<td>Propane</td>
<td>1.2805</td>
<td>0.001603</td>
<td>0.000976</td>
</tr>
<tr>
<td>Butane</td>
<td>1.2832</td>
<td>0.001600</td>
<td>0.000974</td>
</tr>
<tr>
<td>LPG(^e)</td>
<td>1.2811</td>
<td>0.001602</td>
<td>0.000976</td>
</tr>
<tr>
<td>Petrol (E10)</td>
<td>1.2931</td>
<td>0.001587</td>
<td>0.000966</td>
</tr>
</tbody>
</table>
Ethanol (E85)  1.2797  0.001604  0.000977  0.000730  0.001534  0.001116  0.000559
Hydrogen  1.1872  0.001729  0.001053  0.000075  0.001654  0.001203  0.000603

a depending on fuel
b at λ = 2, dry air, 273 K, 101.3 kPa
c accurate within 0.2 % for mass composition of: C=66 - 76 %; H=22 - 25 %; N=0 - 12 %
d NMHC on the basis of CH2.93 (for total HC the ūgas coefficient of CH4 shall be used)
e accurate within 0.2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %

Annex 4, paragraph 8.4.2.4., amend to read:

"...

The molar mass of the exhaust, M_e, shall be derived for a general fuel composition CβHαOεNδSγ under the assumption of complete combustion, as follows:

\[
M_e = \frac{q_{mf1}}{q_{maw1}} \left( 1 + \frac{\alpha}{1.00794 x + 15.9994 x + 14.0067 x + 32.665 x} \right) \left( 1 + \frac{H_a}{10^{-3}} \right)
\]

(41)

Annex 4, paragraph 8.5.2.3.1. Table 6, amend to read:

"Table 6
Diluted exhaust gas ū values and component densities

<table>
<thead>
<tr>
<th>Fuel</th>
<th>ρ_de</th>
<th>ρ_gas [kg/m³]</th>
<th>NOx</th>
<th>CO</th>
<th>HC</th>
<th>CO2</th>
<th>O2</th>
<th>CH4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel (B7)</td>
<td>1.293</td>
<td>2.053</td>
<td>1.250</td>
<td>2.50</td>
<td>a</td>
<td>1.9636</td>
<td>1.4277</td>
<td>0.716</td>
</tr>
<tr>
<td>Ethanol (ED95)</td>
<td>1.293</td>
<td>0.001588</td>
<td>0.000967</td>
<td>0.000483</td>
<td>0.001519</td>
<td>0.001104</td>
<td>0.000553</td>
<td></td>
</tr>
<tr>
<td>CNGc</td>
<td>1.293</td>
<td>0.001588</td>
<td>0.000967</td>
<td>0.000517d</td>
<td>0.001519</td>
<td>0.001104</td>
<td>0.000553</td>
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<td>0.001588</td>
<td>0.000967</td>
<td>0.000507</td>
<td>0.001519</td>
<td>0.001104</td>
<td>0.000553</td>
<td></td>
</tr>
<tr>
<td>Butane</td>
<td>1.293</td>
<td>0.001588</td>
<td>0.000967</td>
<td>0.000501</td>
<td>0.001519</td>
<td>0.001104</td>
<td>0.000553</td>
<td></td>
</tr>
<tr>
<td>LPGc</td>
<td>1.293</td>
<td>0.001588</td>
<td>0.000967</td>
<td>0.000505</td>
<td>0.001519</td>
<td>0.001104</td>
<td>0.000553</td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>Density</td>
<td>CO₂, e</td>
<td>HC, e</td>
<td>NMHC, e</td>
<td>CO, e</td>
<td>H₂O, e</td>
<td>H₂O, DA</td>
<td>CO₂, e/CO₂, DA</td>
</tr>
<tr>
<td>------------</td>
<td>---------</td>
<td>--------</td>
<td>-------</td>
<td>---------</td>
<td>-------</td>
<td>--------</td>
<td>---------</td>
<td>---------------</td>
</tr>
<tr>
<td>Petrol (E10)</td>
<td>1.293</td>
<td>0.001588</td>
<td>0.000967</td>
<td>0.000499</td>
<td>0.001519</td>
<td>0.001104</td>
<td>0.000554</td>
<td></td>
</tr>
<tr>
<td>Ethanol (E85)</td>
<td>1.293</td>
<td>0.001588</td>
<td>0.000967</td>
<td>0.000722</td>
<td>0.001519</td>
<td>0.001104</td>
<td>0.000554</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>1.293</td>
<td>0.001588</td>
<td>0.000967</td>
<td>0.000070</td>
<td>0.001519</td>
<td>0.001104</td>
<td>0.000554</td>
<td></td>
</tr>
</tbody>
</table>

\( ^a \) depending on fuel
\( ^b \) at \( \lambda = 2 \), dry air, 273 K, 101.3 kPa
\( ^c \) accurate within 0.2 \% for mass composition of: C=66 - 76 \%; H=22 - 25 \%; N=0 - 12 \%
\( ^d \) NMHC on the basis of CH\(_2\).93 (for total HC the \( u \)gas coefficient of CH\(_4\) shall be used)
\( ^e \) accurate within 0.2 \% for mass composition of: C3 = 70 - 90 \%; C4 = 10 - 30 \%
\( ^f \) calculated based on \( \rho \)gas for Diesel (B7)

Annex 4, paragraph 8.5.2.3.2., amend to read:

"8.5.2.3.2. Determination of the background corrected concentrations...

The dilution factor shall be calculated as follows:

a) For diesel fuelled engines, and LPG fuelled gas engines and dual-fuel hydrogen engines

\[
D = \frac{F_S}{c_{CO_2,e} + (c_{HC,e} + c_{CO, e}) \times 10^{-4}}
\]

b) For natural gas fuelled gas engines

\[
D = \frac{F_S}{c_{CO_2,e} + (c_{NMHC,e} + c_{CO, e}) \times 10^{-4}}
\]

c) For hydrogen fuelled engines

\[
D = \frac{35.03}{c_{H_2O} - c_{H_2O, DA} + c_{H_2} \times 10^{-4}}
\]

Where:

- \( c_{CO_2,e} \) is the wet concentration of CO\(_2\) in the diluted exhaust gas, per cent vol
- \( c_{HC,e} \) is the wet concentration of HC in the diluted exhaust gas, ppm C1
- \( c_{NMHC,e} \) is the wet concentration of NMHC in the diluted exhaust gas, ppm C1
- \( c_{CO, e} \) is the wet concentration of CO in the diluted exhaust gas, ppm
- \( F_S \) is the stoichiometric factor
- \( c_{H_2O} \) is the wet concentration of H\(_2\)O in the diluted exhaust gas, per cent vol
- \( c_{H_2O, DA} \) is wet the concentration of H\(_2\)O in the air used for dilution, per cent vol
\( c_{H_2} \) is the wet concentration of hydrogen in the diluted exhaust, ppm

Annex 5

Annex 5, amend to read:

"… Technical data on fuels for testing compression-ignition or positive ignition and dual-fuel engines

Type: Hydrogen

<table>
<thead>
<tr>
<th>Constituents 1)</th>
<th>Unit</th>
<th>Limits</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Hydrogen purity 2)</td>
<td>% mole</td>
<td>99.97</td>
<td></td>
</tr>
<tr>
<td>Total non-hydrogen gases</td>
<td>μmol/mol</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Water (H₂O)</td>
<td>μmol/mol</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Total hydrocarbons except methane 3) (C₁ equivalent)</td>
<td>μmol/mol</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>μmol/mol</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td>μmol/mol</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Helium (He)</td>
<td>μmol/mol</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N₂)</td>
<td>μmol/mol</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Argon (Ar)</td>
<td>μmol/mol</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>μmol/mol</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Carbon Monoxide (CO) 4)</td>
<td>μmol/mol</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Total Sulphur compounds 5) (S₁ equivalent)</td>
<td>μmol/mol</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Formaldehyde (HCHO) 4)</td>
<td>μmol/mol</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Formic acid (HCOOH) 4)</td>
<td>μmol/mol</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Ammonia (NH₃)</td>
<td>μmol/mol</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Halogenated compounds 6) (Halogen ion equivalent)</td>
<td>μmol/mol</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Maximum particulate concentration 7)</td>
<td>mg/kg</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

1) For the constituents that are additive, such as total hydrocarbons and total sulphur compounds, the sum of the constituents shall be less than or equal to the acceptable limit.

2) The hydrogen fuel index is determined by subtracting the "total non-hydrogen gases" in this table, expressed in mole percent, from 100 mole percent.

3) Total hydrocarbons except methane include oxygenated organic species. Total hydrocarbons except methane shall be measured on a C₁ equivalent (μmol/mol).

4) The sum of measured CO, HCHO and HCOOH shall not exceed 0.2 μmol/mol.

5) As a minimum, total sulphur compounds include H₂S, COS, CS₂ and mercaptans, which are typically found in natural gas.

6) All halogenated compounds which could potentially be in the hydrogen gas [for example, hydrogen chloride (HCl) and organic chlorides (R-Cl)] should be determined by the hydrogen quality control plan discussed in ISO 19880-8. Halogenated compounds shall be measured on a halogen ion equivalent (μmol/mol).
7) Particulate includes solid and liquid particulates comprises of oil mist. Large particulates can cause issues with vehicle components and should be limited by using filter as specified in ISO 19880-1. No visible oil shall be found in fuel at a nozzle.

Annex 6
Annex 6, paragraph 1.2., amend to read:

"1.2. This annex does not apply to dual-fuel engines and vehicles or engines and vehicles where all of the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4." 

Annex 8
Annex 8, paragraph 6.2., amend to read:

"6.2. The conformity factors shall be calculated and presented for both the CO₂ mass based method and the work based method. The pass/fail decision shall be made on the basis of the results of the work based method. The CO₂ mass based method may be omitted, if the molar carbon to hydrogen ratio of at least one of the fuels used is 0 as defined in paragraph 8. of Annex 4." Annex 8, paragraph 10.1.1.11., amend to read:

"10.1.1.11. Type of engine: petrol, ethanol (E85), diesel/NG/LPG/ethanol (ED95)/hydrogen (Delete as appropriate)"

Annex 8, paragraph 10.1.5.1., amend to read:

"10.1.5.1. Engine fuel type (e.g. diesel, ethanol ED95, NG, LPG, petrol, E85, hydrogen)"

Annex 8, paragraph 10.1.8.1., amend to read:

"10.1.8.1. THC concentration [ppm] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.8.2., amend to read:

"10.1.8.2. CO concentration [ppm] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.8.4., amend to read:

"10.1.8.4. CO₂ concentration [ppm] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.1., amend to read:

"10.1.9.1. THC mass [g/s] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.2., amend to read:

"10.1.9.2. CO mass [g/s] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."
"10.1.9.4. CO₂ mass \([g/s]\) for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.5., amend to read:
"10.1.9.5. CH₄ mass \([g/s]\) for \textit{natural-gas} fuelled engines only"

Annex 8, paragraph 10.1.9.6., amend to read:
"10.1.9.6. THC cumulated mass \([g]\) for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.7., amend to read:
"10.1.9.7. CO cumulated mass \([g]\) for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.9., amend to read:
"10.1.9.9. CO₂ cumulated mass \([g]\) for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.16., amend to read:
"10.1.9.16. Work window THC conformity factor \([-\] \) for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.17., amend to read:
"10.1.9.17. Work window CO conformity factor \([-\] \) for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.20., amend to read:
"10.1.9.20. CO₂ mass window duration \([s]\) for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.21., amend to read:
"10.1.9.21. CO₂ mass window THC conformity factor \([-\] \) for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.22., amend to read:
"10.1.9.22. CO₂ mass window CO conformity factor \([-\] \) for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.23., amend to read:
"10.1.9.23. CO₂ mass window NOₓ conformity factor \([-\] \) for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.9.24a., amend to read:
"10.1.9.24a. CO₂ mass window PM number conformity factor [-] for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.10.8., amend to read:

"10.1.10.8. THC emissions [g] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.10.9., amend to read:

"10.1.10.9. CO emissions [g] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.10.11., amend to read:

"10.1.10.11. CO₂ emissions [g] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.11.2., amend to read:

"10.1.11.2. Work window THC conformity factor [-] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.11.3., amend to read:

"10.1.11.3. Work window CO conformity factor [-] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.11.6., amend to read:

"10.1.11.6. CO₂ mass window THC conformity factor [-] for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.11.7., amend to read:

"10.1.11.7. CO₂ mass window NOₓ conformity factor [-] for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.11.8., amend to read:

"10.1.11.8. Work window CO conformity factor [-] for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.11.11., amend to read:

"10.1.11.11. CO₂ mass window: Minimum and maximum window duration [s] for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.11.13., amend to read:

"10.1.11.13. CO₂ mass window: Percentage of valid windows for engines for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."
Annex 8, paragraph 10.1.12.1., amend to read:

"10.1.12.1. THC analyser zero, span and audit results, pre and post test for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.12.2., amend to read:

"10.1.12.2. CO analyser zero, span and audit results, pre and post test for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, paragraph 10.1.12.4., amend to read:

"10.1.12.4. CO2 analyser zero, span and audit results, pre and post test for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4."

Annex 8, Appendix 1

Annex 8, Appendix 1, paragraph A.1.1., amend to read:

"A.1.1. Introduction

This Appendix describes the procedure to determine pollutant emissions from on-vehicle on-road measurements using Portable Emissions Measurement Systems (hereinafter “PEMS”). The pollutant emissions to be measured from the exhaust of the engine include the following components: carbon monoxide, total hydrocarbons, nitrogen oxides and PM number for compression ignition engines and carbon monoxide, non- methane hydrocarbons, methane, nitrogen oxides and PM number for positive ignition engines. Additionally, carbon dioxide shall be measured to enable the calculation procedures described in paragraph A.1.4.

For engines fuelled with natural gas, the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions only instead of measuring the methane and non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as the one shown in paragraph 5.3. of this Regulation for methane emissions. For the purposes of the calculation of the conformity factors pursuant to paragraphs A.1.4.2.3. and A.1.4.3.2., the applicable limit shall in that case be the methane emission limit only.

For engines fuelled with gases other than natural gas, the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions instead of measuring the non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as shown in paragraph 5.3. of this Regulation for non-methane hydrocarbon emissions. For the purposes of the calculations of the conformity factors pursuant to paragraphs A.1.4.2.3. and A.1.4.3.2., the applicable limit shall in that case be the non-methane emission limit.

For engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4, the manufacturer may choose to measure only nitrogen oxides and PM number. In this case oxygen shall be measured as well to enable the data consistency check as described in paragraph A.1.3.2."
Table 1 in Annex 8, Appendix 1, paragraph A.1.2.2., amend to read:

"Table 1
Test parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>THC concentration¹, ⁵</td>
<td>ppm</td>
<td>Gas analyser</td>
</tr>
<tr>
<td>CO concentration¹, ⁵</td>
<td>ppm</td>
<td>Gas analyser</td>
</tr>
<tr>
<td>NOₓ concentration¹</td>
<td>ppm</td>
<td>Gas analyser</td>
</tr>
<tr>
<td>CO₂ concentration¹, ⁵</td>
<td>ppm</td>
<td>Gas analyser</td>
</tr>
<tr>
<td>CH₄ concentration¹, ², ⁵</td>
<td>ppm</td>
<td>Gas analyser</td>
</tr>
<tr>
<td>O₂ concentration⁶</td>
<td>ppm</td>
<td>Gas analyser</td>
</tr>
<tr>
<td>PM number concentration</td>
<td>#/cm³</td>
<td>PM number analyser</td>
</tr>
<tr>
<td>Dilution setting (if applicable)</td>
<td>-</td>
<td>PM number analyser</td>
</tr>
<tr>
<td>Exhaust gas flow</td>
<td>kg/h</td>
<td>Exhaust Flow Meter (hereinafter EFM)</td>
</tr>
<tr>
<td>Exhaust temperature</td>
<td>K</td>
<td>EFM</td>
</tr>
<tr>
<td>Ambient temperature³</td>
<td>K</td>
<td>Sensor</td>
</tr>
<tr>
<td>Ambient pressure</td>
<td>kPa</td>
<td>Sensor</td>
</tr>
<tr>
<td>Engine torque⁴</td>
<td>Nm</td>
<td>ECU or Sensor</td>
</tr>
<tr>
<td>Engine speed</td>
<td>rpm</td>
<td>ECU or Sensor</td>
</tr>
<tr>
<td>Engine fuel flow</td>
<td>g/s</td>
<td>ECU or Sensor</td>
</tr>
<tr>
<td>Engine coolant temperature</td>
<td>K</td>
<td>ECU or Sensor</td>
</tr>
<tr>
<td>Engine intake air temperature³</td>
<td>K</td>
<td>Sensor</td>
</tr>
<tr>
<td>Vehicle ground speed</td>
<td>km/h</td>
<td>ECU and GPS</td>
</tr>
<tr>
<td>Vehicle latitude</td>
<td>degree</td>
<td>GPS</td>
</tr>
<tr>
<td>Vehicle longitude</td>
<td>degree</td>
<td>GPS</td>
</tr>
</tbody>
</table>

Notes:

¹ Measured or corrected to a wet basis
² Only for gas engines fuelled with natural gas
³ Use the ambient temperature sensor or an intake air temperature sensor
⁴ The recorded value shall be either (a) the net brake engine torque according to paragraph A.1.2.4.4. of this appendix or (b) the net brake engine torque calculated from the torque values according to paragraph A.1.2.4.4. of this appendix.
⁵ Not applicable for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.
⁶ Only for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4"

Annex 8, Appendix 1, paragraph A.1.3.2.1., amend to read:

"A.1.3.2.1. Analysers and EFM data

The consistency of the data (exhaust mass flow measured by the EFM and gas concentrations) shall be verified using a correlation between the measured fuel flow from the ECU and the fuel flow calculated using the formula in paragraph 8.4.1.7. of Annex 4 to this Regulation. If the molar carbon to hydrogen ratio of all the fuels used is 0 as defined in paragraph 8. of Annex 4, then the
formula in paragraph 8.4.1.8. of Annex 4 shall be used instead. A linear regression shall be performed for the measured and calculated fuel rate values. The method of least squares shall be used, with the best fit equation having the form:

..."

Annex 9

Table 2 in Annex 9, paragraph 3.2.2., amend to read:

"Table 2
OTLs (positive ignition engines)

<table>
<thead>
<tr>
<th></th>
<th>Limit in mg/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO\textsubscript{x}</td>
</tr>
<tr>
<td>Phase-in period</td>
<td>1,500</td>
</tr>
<tr>
<td>General requirements</td>
<td>1,200</td>
</tr>
</tbody>
</table>

\textsuperscript{(1)} The transitional provisions related to introduction of the CO OTLs are specified in paragraphs 13.2.2. and 13.3.2. of this Regulation.

\textsuperscript{(2)} not applicable if the molar carbon to hydrogen ratio of all the fuel used is 0 as defined in paragraph 8. of Annex 4."

Annex 9B, paragraph 3.26., amend to read:

"3.26. Abbreviations

AES  Auxiliary Emission Strategy

\textbf{CI}  \textbf{Compressed Ignition}

CV  Crankcase Ventilation

DOC  Diesel Oxidation Catalyst

DPF  Diesel Particulate Filter or Particulate Trap including catalyzed DPFs, and Continuously Regenerating Traps (CRT) and other soot particle filters

DTC  Diagnostic trouble code

EGR  Exhaust Gas Recirculation

HC  Hydrocarbon

LNT  Lean NO\textsubscript{x} Trap (or NO\textsubscript{x} absorber)

LPG  Liquefied Petroleum Gas

MECS  Malfunction Emission Control Strategy

NG  Natural Gas

NO\textsubscript{x}  Oxides of Nitrogen

OTL  OBD Threshold Limit

\textbf{PI}  \textbf{Positive Ignition}
Annex 9B, paragraph 5.2.3., amend to read:

"5.2.3. Low fuel level

Manufacturers may request approval to disable monitoring systems that are affected by low fuel level / pressure or running out of fuel (e.g. diagnosis of a malfunction of the fuelling system or misfiring) as follows:

<table>
<thead>
<tr>
<th>Diesel</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>NG</td>
<td>X</td>
</tr>
<tr>
<td>LPG</td>
<td>X</td>
</tr>
</tbody>
</table>

(a) The low fuel level considered for such a disablement shall not exceed 100 litres or 20 per cent of the nominal capacity of the fuel tank, whichever is lower.

(b) The low fuel pressure in the tank considered for such a disablement shall not exceed 20 per cent of the usable range of fuel tank pressure.

---

Annex 9B, Appendix 3 – Item 6, amend to read:

"Appendix 3 - Item 6

Exhaust Gas Recirculation (EGR) system monitoring

The OBD system shall monitor the following elements of the EGR system on engines so equipped for proper operation:

<table>
<thead>
<tr>
<th>Diesel CI engine</th>
<th>Gas PI engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

---

Annex 9B, Appendix 3 – Item 6

"Appendix 3 - Item 6

Exhaust Gas Recirculation (EGR) system monitoring

The OBD system shall monitor the following elements of the EGR system on engines so equipped for proper operation:
Annex 9B, Appendix 3 – Item 7, amend to read:

"Appendix 3 - Item 7
Fuel System monitoring

The OBD system shall monitor the following elements of the fuel system on engines so-equipped for proper operation:

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Diesel CI engine</th>
<th>Gas PI engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Fuel system pressure control: fuel system ability to achieve the commanded fuel pressure in closed loop control – performance monitoring.</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Annex 9B, Appendix 3 – Item 8, amend to read:

"Appendix 3 - Item 8

Air handling and turbocharger/Boost pressure control system

The OBD system shall monitor the following elements of the Air handling and turbocharger/Boost pressure control system on engines so-equipped for proper operation:

<table>
<thead>
<tr>
<th></th>
<th>Diesel CI engine</th>
<th>Gas PI engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a1) Turbo under/over boost: turbo boost system's ability to maintain the commanded boost pressure, detecting both “boost pressure too low” and “boost pressure too high” conditions – emission threshold monitoring.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>(a2) Turbo under/over boost: turbo boost system's ability to maintain the commanded boost pressure, detecting both “boost pressure too low” and “boost pressure too high” conditions – performance monitoring.</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>(a3) Turbo under boost: turbo boost system's ability to maintain the commanded boost pressure, detecting “boost pressure too low” conditions – total functional failure or performance monitoring as specified in this item.</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>(b) Variable Geometry Turbo (VGT) slow response: VGT system's ability to achieve the commanded geometry within a manufacturer specified time-performance monitoring.</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>(c) Charge air cooling: Charge air cooling system efficiency - total functional failure.</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Annex 9B, Appendix 3 – Item 10, amend to read:

"Appendix 3 - Item 10

Misfire Monitoring

<table>
<thead>
<tr>
<th></th>
<th>Diesel CI engine</th>
<th>Gas PI engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>No prescriptions.</td>
<td>X</td>
</tr>
<tr>
<td>(b)</td>
<td>Misfire that may cause catalyst damage (e.g. by monitoring a certain percentage of misfiring in a certain period of time) – performance monitoring.</td>
<td>X</td>
</tr>
</tbody>
</table>

Annex 9B, Appendix 3 – Item 13, amend to read:

"Appendix 3 - Item 13

Exhaust gas and oxygen sensors monitoring

The OBD system shall monitor:

<table>
<thead>
<tr>
<th></th>
<th>Diesel CI engine</th>
<th>Gas PI engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>The electrical elements of the exhaust gas sensors on engines so-equipped for proper operation according to item 1 to this appendix – component monitoring.</td>
<td>X</td>
</tr>
<tr>
<td>(b)</td>
<td>Both the primary and secondary (fuel control) oxygen sensors. These sensors are considered as exhaust gas sensors to be monitored for proper operation according to item 1 to this appendix – component monitoring.</td>
<td>X</td>
</tr>
</tbody>
</table>

Annex 9B, Appendix 3 – Item 15, amend to read:

"Appendix 3 - Item 15

Three-way catalyst

The OBD system shall monitor the three-way catalyst on engines so-equipped for proper operation:

<table>
<thead>
<tr>
<th></th>
<th>Diesel CI engine</th>
<th>Gas PI engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Three-way Catalyst Conversion efficiency: the catalyst ability to convert NOx and CO – performance monitoring</td>
<td>X</td>
</tr>
</tbody>
</table>
Annex 10, paragraph 5.2.2., amend to read:

"5.2.2. The applicable emission limits shall be the following:

(a) For CO: 2,000 mg/kWh\(^1\);
(b) For THC: 220 mg/kWh\(^1\);
(c) For NOx: 600 mg/kWh;
(d) For PM: 16 mg/kWh.

\(^1\) the measurement shall not be required if the molar carbon to hydrogen ratio of all the fuels used is 0 as defined in paragraph 8. of Annex 4."

Annex 12

Annex 12, paragraph 3.1., amend to read:

"3.1. Raw measurement

This paragraph shall apply, if CO\(_2\) is measured in the raw exhaust gas and the molar carbon to hydrogen ratio of all the fuels used is greater than 0 as defined in paragraph 8. of Annex 4."

Annex 12, paragraph 3.2., amend to read:

"3.2. Dilute measurement

This paragraph shall apply, if CO\(_2\) is measured in the dilute exhaust gas and the molar carbon to hydrogen ratio of all the fuels used is greater than 0 as defined in paragraph 8. of Annex 4."

Annex 12, Insert new paragraph 3.3., to read:

"3.3. Calculation from fuel consumption

This paragraph shall apply, if the molar carbon to hydrogen ratio of the all the fuels used is 0 as defined in paragraph 8. of Annex 4.

The fuel consumption shall be determined according to paragraph 4. of this annex and the measured test-averaged fuel consumption shall be used as the base for calculating the test averaged CO\(_2\) emissions.

The mass of CO\(_2\) (g/test) shall be set to zero according to the following equation:

\[
\text{m}_{\text{CO}_2} = \frac{\beta \times M_{\text{CO}_2}}{\beta \times A_C + \alpha \times A_H} \times q_{mf}
\]

Annex 12, Paragraph 3.3. (former), renumber as paragraph 3.4.

Annex 12, Appendix 1, Paragraph A.1.2.1.2., amend to read:

"A.1.2.1.2. Paragraph 5.2.4. of Regulation No.101 shall be understood as follows:

(1) Density: measured on the test fuel according to ISO 3675 or an equivalent method. For petrol, diesel, ethanol (E85) and ethanol for dedicated C.I. engines (ED95) the density measured at 288 K (15 °C) will be used; for LPG and natural gas/biogas a reference density shall be used, as follows:
0.538 kg/litre for LPG;
0.654 kg/m3 for NG.

(2) Hydrogen-carbon-oxygen ratio: fixed values shall be used which are:
C\(_1\)H\(_{1.93}\)O\(_{0.032}\) for petrol (E10);
C\(_1\)H\(_{1.86}\)O\(_{0.006}\) for diesel (B7);
C\(_1\)H\(_{2.525}\) for LPG (liquefied petroleum gas);
CH\(_4\) for NG (natural gas) and biomethane;
C\(_1\)H\(_{2.74}\)O\(_{0.385}\) for ethanol (E85);
C\(_1\)H\(_{2.92}\)O\(_{0.46}\) for ethanol for dedicated C.I. engines (ED95);
H\(_2\) for hydrogen.

Annex 12, Appendix I, Paragraph A.1.2.1.2., amend to read:

"A.1.2.1.3. Paragraph 1.4.3. of Annex 6. of Regulation No. 101 shall be understood as:

1.4.3. The fuel consumption, expressed in litres per 100 km (in the case of petrol, LPG, ethanol (E85 and ED95) and diesel) or in m\(^3\) per 100 km (in the case of NG/biomethane) is calculated by means of the following formulae:

(a) For vehicles with a positive ignition engine fuelled with petrol (E10):

\[
FC = \frac{0.120}{D} \cdot [(0.831 - HC) + (0.429 - CO) + (0.273 \cdot CO_2)]
\]

(b) For vehicles with a positive ignition engine fuelled with LPG:

\[
FC_{\text{norm}} = \frac{0.1212}{0.538} \cdot [(0.825 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]
\]

If the composition of the fuel used for the test differs from the composition that is assumed for the calculation of the normalised consumption, on the manufacturer’s request a correction factor cf may be applied, as follows:

\[
FC_{\text{norm}} = \frac{0.1212}{0.538} \cdot (cf) \cdot [(0.825 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]
\]

The correction factor cf, which may be applied, is determined as follows:

\[
cf = 0.825 + 0.0693 \cdot n_{\text{actual}}
\]

Where:

\(n_{\text{actual}}\) is the actual H/C ratio of the fuel used

(c) For vehicles with a positive ignition engine fuelled with NG/biomethane:

\[
FC_{\text{norm}} = \frac{0.1336}{0.654} \cdot [(0.749 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]
\]

(d) For vehicles with a positive ignition engine fuelled with ethanol (E85):

\[
FC = \frac{0.1742}{D} \cdot [(0.574 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]
\]

(e) For vehicles with a compression ignition engine fuelled with diesel (B7):

\[
FC = \frac{0.1165}{D} \cdot [(0.859 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]
\]
(f) For vehicles with a dedicated compression ignition engine fuelled with ethanol (ED95)

\[ FC = \frac{0.186}{D} \cdot [(0.538 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)] \]

(g) For vehicles fuelled by gaseous hydrogen:

\[ FC = 0.024 \cdot \frac{V}{d} \cdot \left( \frac{1}{Z_1 T_1} - \frac{1}{Z_2 T_2} \right) \]

Under previous agreement with the type-approval authority, and for vehicles fuelled either by gaseous or liquid hydrogen, the manufacturer may choose as alternative to the method above, either the formula

\[ FC = 0.1 \cdot (0.1119 \cdot H_2O + H_2) \]

for vehicles powered by internal combustion engine only, or a method according to standard protocols such as SAE J2572 or ISO 23828.

In these formulae:

- FC is the fuel consumption in litre per 100 km (in the case of petrol, ethanol, LPG, diesel or biodiesel) or in m³ per 100 km (in the case of natural gas)
- HC is the measured emission of hydrocarbons in g/km
- CO is the measured emission of carbon monoxide in g/km
- CO₂ is the measured emission of carbon dioxide in g/km
- H₂O is the measured emission of H₂O in g/km
- H₂ is the measured emission of H₂ in g/km
- D is the density of the test fuel. In the case of gaseous fuels this is the density at 288 K (15 °C).
- d is the theoretical length of the applicable phase or cycle, in km
- p₁ is the pressure in gaseous fuel tank before the operating cycle in Pa
- p₂ is the pressure in gaseous fuel tank after the operating cycle in Pa
- T₁ is the temperature in gaseous fuel tank before the operating cycle in K
- T₂ is the temperature in gaseous fuel tank after the operating cycle in K
- Z₁ is the compressibility factor of the gaseous fuel at p₁ and T₁
- Z₂ is the compressibility factor of the gaseous fuel at p₂ and T₂
- V is the inner volume of the gaseous fuel tank in m³

Annex 15

Annex 15, Paragraph 4.2.2.3., amend to read:
"4.2.2.3. Repair and maintenance of LNG or Hydrogen Type A dual-fuel engines and vehicles.

In the case of LNG or Hydrogen Type A dual-fuel engines and vehicles, the manufacturer may, instead of limiting the vehicle speed at 20 km/h, opt for limiting the power of the engine to 20 per cent of the declared maximum power in dual-fuel mode, and this at any engine speed, when the service mode is activated during a repair or maintenance operation."

Annex 15, Paragraph 5.2.2.2.2., amend to read:

"5.2.2.2.2. LPG and Hydrogen engines

The THC emission limits over the WHTC test-cycle applicable to HDDF Type 2A engines and HDDF Type 2B engines operating with LPG or a fuel that has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4 in dual-fuel mode are those applicable to CI engines over the WHTC test-cycle and defined in paragraph 5.3. of this Regulation."

Annex 15, Paragraph 10.3. Equation (24), amend to read:

\[ m_{\text{CO}_2} = \beta \times M_{\text{CO}_2} \times q_{\text{mf}} \]

Annex 15, Appendix 4, Paragraph A.4.4.4.1., amend to read:

"A.4.4.4.1. Determination of the background corrected concentrations (Annex 4, paragraph 8.5.2.3.2.)

To determine the stoichiometric factor, the molar hydrogen ratio \( \alpha \) of the fuel shall be calculated as the average molar hydrogen ratio of the fuel mix during the test according to section A.6.4. of Appendix 6.

Alternatively the Fs value of the gaseous fuel may be used in equation 59 or 60 of Annex 4. If the carbon to hydrogen ratio of one of the fuels is 0 as defined in paragraph 8. of Annex 4 equation 59 shall be used."

Annex 15, Appendix 6, Paragraph A.6.2.1., amend to read:

"A.6.2.1. For Type 1A or 1B dual-fuel engines operating in dual-fuel mode the molar component ratios and the \( u_{\text{gas}} \) values of the gaseous fuel shall be used. For Type 1A or 1B dual-fuel engines fuelled with hydrogen the molar components shall be set to table A6.1.

Table A6.1

<table>
<thead>
<tr>
<th>Gaseous Fuel</th>
<th>( \alpha )</th>
<th>( \gamma )</th>
<th>( \delta )</th>
<th>( \varepsilon )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>46.1826</td>
<td>0</td>
<td>0</td>
<td>0.0060</td>
</tr>
</tbody>
</table>

"Annex 15, Appendix 6, Paragraph A.6.2.2., amend to read:

"A.6.2.2 For Type 2A or 2B dual-fuel engines operating in dual-fuel mode the molar component ratios and the \( u_{\text{gas}} \) values from tables A6.12 and A6.23 shall be used.

Table A6.12"
Molar component ratios for a mixture of 50% gaseous fuel and 50% diesel fuel (mass %)

<table>
<thead>
<tr>
<th>Gaseous Fuel</th>
<th>α</th>
<th>γ</th>
<th>δ</th>
<th>ε</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>2.8681</td>
<td>0</td>
<td>0</td>
<td>0.0040</td>
</tr>
<tr>
<td>G₂</td>
<td>2.7676</td>
<td>0</td>
<td>0</td>
<td>0.0040</td>
</tr>
<tr>
<td>G₂₃</td>
<td>2.7986</td>
<td>0</td>
<td>0.0703</td>
<td>0.0043</td>
</tr>
<tr>
<td>G₂₅</td>
<td>2.7377</td>
<td>0</td>
<td>0.1319</td>
<td>0.0045</td>
</tr>
<tr>
<td>Propane</td>
<td>2.2633</td>
<td>0</td>
<td>0</td>
<td>0.0039</td>
</tr>
<tr>
<td>Butane</td>
<td>2.1837</td>
<td>0</td>
<td>0</td>
<td>0.0038</td>
</tr>
<tr>
<td>LPG</td>
<td>2.1957</td>
<td>0</td>
<td>0</td>
<td>0.0038</td>
</tr>
<tr>
<td>LPG Fuel A</td>
<td>2.1740</td>
<td>0</td>
<td>0</td>
<td>0.0038</td>
</tr>
<tr>
<td>LPG Fuel B</td>
<td>2.2402</td>
<td>0</td>
<td>0</td>
<td>0.0039</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>15.7327</td>
<td>0</td>
<td>0</td>
<td>0.0060</td>
</tr>
</tbody>
</table>

Table A6.23
Raw exhaust gas $u_{gas}$ values and component densities for a mixture of 50% gaseous fuel and 50% diesel fuel (mass %)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>$\rho_{de}$</th>
<th>$\rho_{gas}$ [kg/m³]</th>
<th>$u_{gas}$ b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NOₓ</td>
<td>CO</td>
</tr>
<tr>
<td>CNG/LNG c)</td>
<td>1.2786</td>
<td>0.001606</td>
<td>0.000978</td>
</tr>
<tr>
<td>Propane</td>
<td>1.2869</td>
<td>0.001596</td>
<td>0.000972</td>
</tr>
<tr>
<td>Butane</td>
<td>1.2883</td>
<td>0.001594</td>
<td>0.000971</td>
</tr>
<tr>
<td>LPG e)</td>
<td>1.2881</td>
<td>0.001594</td>
<td>0.000971</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>1.2175</td>
<td>0.001686</td>
<td>0.001027</td>
</tr>
</tbody>
</table>

a) depending on fuel
b) at $\lambda = 2$, dry air, 273 K, 101.3 kPa
c) $u$ accurate within 0.2 % for mass composition of: C = 58 - 76 %; H = 19 - 25 %; N = 0 - 14 % (CH₄, G₂₀, G₂₅, G₂₃ and G₂₅)
d) NMHC on the basis of CH₂.93 (for total HC the $u_{gas}$ coefficient of CH₄ shall be used)
e) $u$ accurate within 0.2 % for mass composition of: C3 = 27 - 90 %; C₄ = 10 - 73 % (LPG Fuels A and B)
f) calculated based on $\rho_{gas}$ for Diesel (B7)
II. Justification

1. Hydrogen fuelled vehicles are covered in UN Regulation 83 and UN Regulation 154 (LD regulation), but hydrogen fuelled engines are not yet covered in UN Regulation 49 and UN Regulation 85.

2. Hydrogen fuelled engines could be one complementary option to reduce CO2 emission of future heavy duty vehicles.

3. Thus hydrogen fuel should be integrated in UN Regulation 49 and UN Regulation 85 for better alignment with UN Regulation 83 and UN Regulation 154.

To mark the proposed amendments to the existing text of the UN Regulations, UN Global Technical Regulations (UN GTRs) and UN Rules, the proposals for consideration by the GRs can be prepared either on track change mode or using bold text (for the additions) and strikethrough (for the deleted text).