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Item 6(a) of the provisional agenda

**Agricultural and forestry tractors, non-road mobile machinery:
UN Regulations Nos. 96 (Diesel emission (agricultural tractors))
and 120 (Net power of tractors and non-road mobile machinery)**

Proposal for a new Supplement to the 05 series of amendments to UN Regulation No. 96 (Uniform provisions concerning the approval of engines to be installed in agricultural and forestry tractors and in nonroad mobile machinery with regard to the emissions of pollutants by the engine)

Submitted by the experts from EUROMOT *

The text reproduced below was prepared by the experts from the European Association of Internal Combustion Engine Manufacturers (EUROMOT). This document aims at permitting the type-approval of dual-fuel hydrogen (H₂) engines of Type 1A for installation in agricultural and forestry tractors and in non-road mobile machinery, with regard to the emissions of pollutants by the engine, as well as correcting errors in the Regulation, merging amendments from documents GRPE-93-09 and GRPE-93-11. The document utilises the 05 series of amendments to UN Regulation No. 96, inclusive of the amendments contained in the documents ECE-TRANS-WP29-GRPE-2024-16e and ECE-TRANS-WP29-GRPE-2024-24e as its technical basis. The modifications to the current text of the Regulation are marked in bold for new or strikethrough for deleted characters.

* In accordance with the programme of work of the Inland Transport Committee for 2026 as outlined in proposed programme budget for 2026 (A/80/6 (Sect. 20), table 20.7), the World Forum will develop, harmonize and update UN Regulations in order to enhance the performance of vehicles. The present document is submitted in conformity with that mandate.



I. Proposal

Contents, Annexes, 4. Test Procedure, insert new Appendix A.7 to read:

"Annexes

...

4 Test Procedure.....

...

Appendix A.7 – Procedure for the measurement of water (H₂O)

..."

Contents, Annexes, insert new Annexes and their appendices to read:

"Annexes

...

11 Method for data evaluation and calculation for engines other than those operated solely on hydrogen

12 Technical requirements for dual-fuel engines of Type 1A with hydrogen as a main fuel....

Appendix A.1 - Dual-fuel engines with hydrogen as a main fuel dual-fuel indicator, warning system, operability restriction - Demonstration requirements.....

Appendix A.2 - Emission test procedure requirements for dual-fuel engines with hydrogen as the main fuel.....

Appendix A.3 - Types of dual-fuel engines operated on hydrogen and a liquid fuel – illustration of the definitions and main requirements.....

"

Insert a new Paragraph 2.1.102., to read:

"2.1.102. "Instrument manufacturer" is the manufacturer of a measurement device (e.g. analyzers), test systems (e.g. dynamometers) and calibration and diagnostic check devices (e.g. gas dividers). "

Insert a new Paragraph 2.1.103., to read:

"2.1.103. "Type of analyzer", also referred to as "analyzer type", means a group of analyzers produced by the same "Instrument manufacturer" based on the identical analytical principle to determine the concentration of one or more specified gaseous exhaust gas components. "

Paragraph 2.2.2., add new rows to the table as follows:

"2.2.2. Abbreviations

...

FID	Flame Ionization Detector
FTIR	Fourier Transform Infrared Analyser
GC	Gas Chromatograph
...	
PTFE	Polytetrafluoroethylene (commonly known as Teflon™)
QCL-IR	Quantum Cascade Laser Mid-Infrared detection
RMC	Ramped-modal cycle
...	

"

Paragraph 3.1.1., amend to read:

"3.1.1. In the case of an application for type approval of engines operated ~~solely~~ on hydrogen, hydrogen shall be the fuel the engine is designed to operate on primarily. **This shall include dual-fuel engines of Type 1A with hydrogen as a main fuel.** Requirements for **all other types** of dual-fuel hydrogen engines have not yet been established under this regulation. "

Paragraph 5.6.4.(d), amend to read:

"5.6.4. Test requirements

...

- (d) For engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4., emissions values shall be calculated using Annex 11. **For dual-fuel engines of Type 1A with hydrogen as a main fuel, emissions values shall be calculated using Annex 12.** For engines operated on all other fuels, emissions values may be calculated on a mass basis using Appendix A.1. of Annex 5 or on a molar basis using Appendix A.2. of Annex 5. In all cases, the method used for the transient test cycle (where applicable) shall be consistent with the method used for the discrete mode NRSC or RMC test-;

..."

Paragraph 6.1.4., amend to read:

"6.1.4. For engines other than those operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4. manufacturers shall make available to OEMs the value of the carbon dioxide (CO₂) emissions determined during the type-approval process and shall instruct the OEMs to communicate that information, together with explanatory information on the test conditions, to the end-user of the non-road mobile machinery or category T vehicle in which the engine is intended to be installed. For engines operated solely on hydrogen as specified in Appendix 4 Paragraph A.4.4., it is not required to make this value available to the OEM."

Paragraph 8.7.2.3., amend to read:

"8.7.2.3. ~~Engines shall be subjected to emissions testing in accordance with the requirements of Annex 4, or, in the case of dual fuel engines, in accordance with Annex 7, or, in the case of engine operated solely on hydrogen, in accordance with Annex 11, and shall be subject to the test cycles relevant for the engine type in accordance with Appendix A.6 to Annex 4.~~

Engines shall be subject to the test cycles relevant for the engine type in accordance with Appendix A.6 to Annex 4. Engines shall be subjected to emissions testing in accordance with the applicable Annex as follows:

- (a) **Annex 4, in the case of engines operated solely on a fuel other than hydrogen;**
- (b) **Annex 7 dual-fuel engines with the exception of dual-fuel engines of Type 1A with hydrogen as a main fuel;**
- (c) **Annex 11 in the case of engines operated solely on hydrogen;**
- (d) **Annex 12 in the case of dual-fuel engines of Type 1A with hydrogen as a main fuel."**

Appendix 4, paragraph A.4.2.5.1.2., amend to read:

"A.4.2.5.1.2. In all other cases the manufacturer shall apply for a universal fuel engine according to the specifications set out in paragraph ~~A.4.2.1.3.2.~~ **A.4.2.3.1.**"

Appendix 4, paragraph A.4.2.7., amend to read:

"A.4.2.7. Additional requirements for dual-fuel engines **with the exception of dual-fuel engines of Type 1A with hydrogen as the main fuel.**

In order to receive a type-approval of a dual-fuel engine or engine family, the manufacturer shall:

- (a) Conduct the tests in accordance with Table 25;
- (b) In addition to the requirements set out in paragraph A.4.2., demonstrate that the dual-fuel engines are subject to the tests and comply with the requirements set out in Annex 7."

Appendix 4, insert new paragraph, to read:

"A.4.2.7.1. In addition to the requirements set out in paragraph A.4.2., demonstrate that the dual-fuel engines of Type 1A with hydrogen as the main fuel are subject to the tests and comply with the requirements set out in Annex 12.

Appendix 4, paragraph A.4.3.1., amend to read:

"A.4.3.1. **Tables 19-25 to 2127.** show a summary of the approval process for natural gas fuelled engines and LPG fuelled engines and of the minimum number of tests required for approval of dual-fuel engines."

Appendix 4, Table 27, amend to read:

"Table 27

Minimum number of tests required for type-approval of dual-fuel engines

Dual-fuel type	Liquid-fuel mode	Dual-fuel mode				
		CNG	LNG	LNG ₂₀	LPG	H ₂
1A		Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)	Fuel-specific (1 test)
1B	Universal (1 test)	Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)	
2A		Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)	
2B	Universal (1 test)	Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)	
3B	Universal (1 test)	Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)	

"

Appendix 4, paragraph A.4.4., amend to read:

"A.4.4. Requirements for an engine operated ~~solely~~ on hydrogen"

Appendix 4, insert new paragraph, to read:

"A.4.4.4. In order to receive a type-approval of a dual-fuel engine of Type 1A with hydrogen as a main fuel, the manufacturer shall comply with the requirements set out in Annex 12."

Appendix 5, paragraph A.5.4.14., amend to read:

"A.5.4.14. in the case of dual-fuel engines:

- (a) A statement indicating that the OEM shall provide a dual-fuel operating mode indicator as described in ~~Appendix A.5. to Annex 7 paragraph 4.3.1.,~~
- (b) A statement indicating that the OEM shall provide a dual-fuel warning system as described in ~~Appendix A.5. to Annex 7 paragraph 4.3.2.,~~
- (c) Information on the interface between the engine and the non-road mobile machinery or category T vehicles for the operator indication and warning system, referred to in paragraphs (14)(a) and (b);"

Annex 2 Part B, Paragraph 11.2., amend to read:

"11.2. CO₂ result⁵:"

Annex 2 Part B, Paragraph 11.3.2., amend to read:

"11.3.2. NRTC reference CO₂ (g)⁵:"

Annex 2, Appendix A.1, Paragraph 11.3.2., amend to read:

"11.3.2. NRTC reference CO₂ (g)⁽⁶⁾⁽⁷⁾:"

Annex 3, Appendix A.1, Table 3, amend to read:

<i>Approved Gas specification</i>	<i>Dual-fuel Suffix (column 2)</i>
Dual-fuel engine approved and calibrated for the H-range of gases as gaseous component of fuel	1
Dual-fuel engine approved and calibrated for the L-range of gases as gaseous component of fuel	2
Dual-fuel engine being and calibrated for both the H-range and L-range of gases as gaseous component of fuel	3
Dual-fuel engine 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 as gaseous component of fuel	4
Dual-fuel engine 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 as gaseous component of fuel	5
Dual-fuel engine 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 as gaseous component of fuel	6
Dual-fuel engine approved and calibrated for a specific liquefied natural gas / liquefied biomethane composition resulting in a λ -shift factor not differing by more than 3 percent the λ -shift factor of the G20 gas specified in Appendix 4 to this Regulation, and the ethane content of which does not exceed 1.5 percent as gaseous component of fuel	7
Dual-fuel engine approved and calibrated for any other (than above) liquefied natural gas / liquefied biomethane composition as gaseous component of fuel	8
Dual-fuel engine approved for operation on LPG as gaseous component of fuel	9
Dual-fuel engine approved for operation on hydrogen as gaseous component of fuel	10

"

Annex 4, Paragraph 5.1.2., amend to read:

"5.1.2. Emissions of gaseous and particulate pollutants

The pollutants are represented by:

- (a) Oxides of nitrogen, NO_x;
- (b) Hydrocarbons, which are expressed as total hydrocarbons, HC (or THC);

- (c) Particulate matter, PM;
- (d) Particle number, PN;
- (e) Carbon monoxide, CO.

The measured values of gaseous and particulate matter pollutants exhausted by the engine refer to the brake-specific emissions in grams per kilowatt-hour (g/kWh), while for particulate number the measured values refers to the brake-specific emissions in number of particles per kilowatt-hour (#/kWh). Other system of units may be used with appropriate conversion.

The gaseous and particulate pollutants that shall be measured are those for which limit values are applicable to the engine sub-category being tested as set out in Appendix 2 to this Regulation.

~~Brake specific emissions shall be determined using Annex 11 for engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4., and determined using Annex 5 for engines operated on all other fuels, fuel mixtures or emulsions.~~

Brake specific emissions shall be determined using the applicable Annex as follows:

- (a) **Annex 5 for engines operated solely on a fuel other than hydrogen;**
- (b) **Annex 7 for dual-fuel engines with the exception of dual-fuel engines of Type 1A with hydrogen as a main fuel;**
- (c) **Annex 11 for engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4.;**
- (d) **Annex 12 for dual-fuel engines of Type 1A with hydrogen as a main fuel.**

The results determined as set out in paragraph 5.1 of this Regulation shall not exceed the applicable limit values.

The CO₂ emission values shall be measured and reported for all engine sub-categories where required by paragraph 6.1.4. of this Regulation.

The mean emission of ammonia (NH₃) shall additionally be measured, as required in accordance with paragraph 3.4. of Annex 9, when the NO_x control measures that are part of the engine emission control system, include use of a reagent and shall not exceed the values set out in that paragraph.

The emissions shall be determined on the duty cycles (steady-state and/or transient), as described in paragraph 7 of this Annex. The measurement systems shall meet the calibration and performance checks set out in paragraph 8 of this Annex. with the measurement equipment described in paragraph 9 of this Annex. For engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4. the requirements set out in Annex 11 shall additionally apply. **For dual-fuel engines of Type 1A with hydrogen as a main fuel, the requirements set out in Annex 12 shall additionally apply.**

Other systems or analysers may be approved by the Type Approval Authority if it is found that they yield equivalent results in accordance with paragraph 5.1.3. of this Annex."

Annex 4, Paragraph 7.3.1.1., 4th sub-paragraph, amend to read:

"7.3.1.1. General requirements for preconditioning the sampling system and the engine
...

Emissions may be measured during preconditioning cycles, as long as a predefined number of preconditioning cycles are performed and the measurement system has been ~~started~~ **prepared** according to the requirements of paragraph 7.3.1.4. of this Annex. The amount of preconditioning shall be identified by the engine manufacturer before starting to precondition.

Preconditioning shall be performed as follows, noting that the specific cycles for preconditioning are the same ones that apply for emission testing."

Annex 4, Paragraph 7.7.2.2., amend to read:

"7.7.2.2. Denormalisation of engine speed.

The engine speed shall be denormalised using by means of equation (A.4-15):

$$n_{ref} = \frac{\%speed.(MTS - n_{idle})}{100} + n_{idle} \quad (A.4-15)$$

where:

n_{ref} is the reference speed

MTS is the maximum test speed

n_{idle} is the idle speed

$\%speed$ is the ~~the~~ value of NRTC or LSI-NRTC normalised speed taken from Appendix A.6 to this Annex. "

Annex 4, Paragraph 7.7.2.3., amend to read:

"7.7.2.3. Denormalisation of engine torque

The torque values in the engine dynamometer schedule of Appendix A.6 to Annex 4 are normalised to the maximum torque at the respective speed. The torque values of the reference cycle shall be denormalised, using the mapping curve determined according to paragraph 7.6.2. of this Annex, by means of equation (A.4 -16):

$$T_{ref} = \frac{\%torque.max\ torque\ T_{max} - T_{AUX}}{100} \quad (A.4-16)$$

for the respective reference speed as determined in paragraph 7.7.2.2.

Where:

T_{ref} is the reference torque for the respective reference speed

~~max.torque~~ T_{max} is the maximum torque for the respective test speed taken from the engine mapping performed in accordance with paragraph 7.6.2. adjusted where necessary in accordance with sub-paragraph (b) of this paragraph.

$\%torque$ is the value of NRTC or LSI-NRTC normalised torque taken from Appendix A.6 to Annex 4

T_{AUX} **is given by equation A.4-18**

(a) Declared minimum torque

A minimum torque that is representative of in-use operation may be declared. For example, if the engine is typically connected to a non-road mobile machinery that does not operate below a certain minimum torque, this torque may be declared and used for any load point that would otherwise fall below this value.

(b) Adjustment of engine torque due to auxiliaries fitted for the emissions test

Where auxiliaries are fitted in accordance with Appendix A.2 to this Annex, there shall be no adjustment to the maximum torque for the respective test speed taken from the engine mapping performed according to paragraph 7.6.2. of this Annex.

Where, according to paragraphs 6.3.2. or 6.3.3. of this Annex necessary auxiliaries that should have been fitted for the test are not installed, or auxiliaries that should have been removed for the test are installed, the value T_{max} **used in equation (A.4-16)** shall be adjusted by means of

equation (A.4-17).

$$T_{\max} = T_{\text{map}} + T_{\text{AUX}} \quad (\text{A.4-17})$$

with:

$$T_{\text{AUX}} = T_r - T_f \quad (\text{A.4-18})$$

where:

T_{map} is the unadjusted maximum torque for the respective test speed taken from the engine mapping performed in accordance with paragraph 7.6.2. of this Annex.

T_f is the torque required to drive auxiliaries that should have been fitted but were not installed for the test

T_r is the torque required to drive auxiliaries that should have been removed for the test but were installed for the test"

Annex 4, Table A.4-2, amend to read:

"Table A.4-2

Regression line tolerances

	<i>Speed</i>	<i>Torque</i>	<i>Power</i>
Standard error of estimate (<i>SEE</i>) of <i>y</i> on <i>x</i>	≤ 5.0 per cent of maximum test speed	≤ 10.0 per cent of maximum mapped torque	≤ 10.0 per cent of maximum mapped power
Slope of the regression line, <i>a</i> ₁	0.95 to 1.03	0.83 to 1.03	0.89 to 1.03
Coefficient of determination, <i>r</i> ²	minimum 0.970	minimum 0.850	minimum 0.910
<i>y</i> intercept of the regression line, <i>a</i> ₀	≤ ±10 per cent of idle	±20 Nm or ±2 per cent of maximum torque whichever is greater	±4 kW or ±2 per cent of maximum power whichever is greater

"

Annex 4, paragraph 8.1.8.4.1. (f) (iii) c., amend to read:

"8.1.8.4.1. Overview

...

- (f) CFV or SSV may alternatively be removed from its permanent position for calibration as long as the following requirements are met when installed in the CVS:

...

- (iii) In order to verify the ex-situ calibration for a CVS with more than a single CFV, the following verification shall be conducted:

...

- c. The concentration of hydrocarbon background in the dilution air shall be measured at the beginning and end of this test. The average background concentration from each measurement at each flow point must be subtracted before performing the regression analysis in paragraph ~~(iv)~~d.

..."

Annex 4, Paragraph 8.1.8.5.1. (a), amend to read:

- "(a) A propane check serves as a CVS verification to determine if there is a discrepancy in measured values of diluted exhaust flow. A propane check also serves as a batch-sampler verification to determine if there is a discrepancy in a batch sampling system that extracts a sample from a CVS, as described in ~~sub-paragraph (f) of this paragraph 8.1.8.5.7.~~ Using good engineering judgment and safe practices, this check may be performed using a gas other than propane, such as CO₂ or CO. A failed propane check might indicate one or more problems that may require corrective action, as follows:
- (i) Incorrect analyser calibration. The FID analyser shall be re-calibrated, repaired, or replaced;
 - (ii) Leak checks shall be performed on CVS tunnel, connections, fasteners, and HC sampling system according to paragraph 8.1.8.7. of this Annex;
 - (iii) The verification for poor mixing shall be performed in accordance with paragraph 9.2.2. of this Annex;
 - (iv) The hydrocarbon contamination verification in the sample system shall be performed as described in paragraph 7.3.1.3. of this Annex;
 - (v) Change in CVS calibration. An in-situ calibration of the CVS flowmeter shall be performed as described in paragraph 8.1.8.4. of this Annex;
 - (vi) Other problems with the CVS or sampling verification hardware or software. The CVS system, CVS verification hardware, and software shall be inspected for discrepancies;"

Annex 4, insert new paragraphs, to read:

"8.1.13. FTIR interference check

Due to the physical properties of a FTIR analyzer, interferences between some gases are possible. Compensation algorithms may be used to reduce interference effects. Compensation algorithms that are used during an emission test shall be active when performing interference checks.

Linearisation shall be done, as specified by the instrument manufacturer, at least annually or after major service intervals.

The spectral resolution of the laser or target wavelength shall have a nominal value $\leq 0.5 \text{ cm}^{-1}$ in order to minimise cross interference from other gases present in the exhaust gas.

8.1.13.1. Procedure

8.1.13.1.1. Start the FTIR analyzer and wait long enough until all temperatures and pressures have reached their operation value. Create a new background as would be the case before an emission test.

8.1.13.1.2. Use a span gas to get a reference value for the measured component. Allow the analyzer to stabilise its reading. After that record its output for 30 seconds and calculate the arithmetic mean of this data. If the span gas is created by vaporising a liquid, avoid condensation at all parts of the system.

8.1.13.1.3. For different analyzer technologies different interference components shall be considered. The instrument manufacturer shall use good engineering judgement for checking and reporting gases interfering on target components as this depends on the wavelengths used to measure the target component.

Multi-component span gas or span mixtures that incorporates the target interference species and the specifications included in paragraph 9.5. of this annex shall be used.

- 8.1.13.1.4.** The levels of the interference gases should be at least as high as expected during the emission tests. If the interference gas levels are higher than the maximum levels expected during testing, it is allowable to scale down each observed interference value.
- 8.1.13.1.5.** Allow gas to stabilise, then record 30 seconds of data and calculate the arithmetic mean. The combined interference shall be less than 2 per cent of the measured value or 2 ppm, whichever is larger.
- 8.1.14.** **QCL-IR interference check**
- Due to the physical properties of a QCL-IR analyzer interferences between some gases are possible. The interference test shall be performed for the gas analyzers upon initial installation.
- Linearisation shall be done, as specified by the instrument manufacturer, at least annually or after major service intervals.
- The spectral resolution of the laser or target wavelength shall have a nominal value $\leq 0.5 \text{ cm}^{-1}$ in order to minimise cross interference from other gases present in the exhaust gas.
- 8.1.14.1.** **Procedure**
- 8.1.14.1.1** Start the QCL-IR analyzer and wait long enough until all temperatures and pressures have reached their operation value.
- 8.1.14.1.2.** Use a span gas to get a reference value for the measured component. Allow the analyzer to stabilise its reading. After that, record its output for 30 seconds and calculate the arithmetic mean of this data. If the span gas is created by vaporising a liquid, avoid condensation at all parts of the system.
- 8.1.14.1.3.** For different analyzer technologies different interference components shall be considered. The instrument manufacturer must use good engineering judgement for checking and reporting gases interfering on target components as this depends on the wavelengths used to measure the target component
- Multi-component span gas or span mixtures that incorporates the target interference species and the specifications included in paragraph 9.3.3. of this annex shall be used.**
- 8.1.14.1.4.** The levels of the interference gases should be at least as high as expected during the emission tests. If the interference gas levels are higher than the maximum levels expected during testing, it is allowable to scale down each observed interference value.
- 8.1.14.1.5.** Allow gas to stabilise, then record 30 seconds of data and calculate the arithmetic mean. The combined interference shall be less than 2 per cent of the measured value or 2 ppm, whichever is larger."

Annex 4, paragraph 8.2.4.3., amend to read:

"8.2.4.3. Electrical grounding

To handle PM samples, electrically grounded tweezers or a grounding strap shall be used, as described in paragraph 9.3.4.56. below."

Annex 4, paragraph 8.2.4.6., amend to read:

"8.2.4.6. Determination of post-test filter mass

The procedures in paragraph 8.2.3. shall be repeated (paragraphs 8.2.3.6. through 8.2.3.98. of this Annex) to determine the post-test filter mass. "

Annex 4, paragraph 9.2.2.(c), amend to read:

"9.2.2. Full flow system

...

"(c) To support mixing the raw exhaust shall be introduced into the tunnel by directing it downstream along the centreline of the tunnel. A fraction of dilution air ~~maybe~~ **may be** introduced radially from the tunnel's inner surface to minimise exhaust interaction with the tunnel walls;

..."

Annex 4, paragraph 9.2.2.(f), amend to read:

"9.2.2. Full flow system

...

(f) Flow measurement preconditioning. The diluted exhaust may be conditioned before measuring its flow rate, as long as this conditioning takes place downstream of heated HC or PM sample probes, as follows:

- (i) Flow straighteners, pulsation dampeners, or both of these ~~maybe~~ **may be** used;
- (ii) A filter ~~maybe~~ **may be** used;
- (iii) A heat exchanger ~~maybe~~ **may be** used to control the temperature upstream of any flowmeter but steps shall be taken to prevent aqueous condensation;

..."

Annex 4, Paragraph 9.3.2.3.1.1., amend to read:

"9.3.2.3.1.1. Requirements

Sample dryers may be used for removing moisture from the sample in order to decrease the effect of water on gaseous emissions measurement. **Sample dryers may not be used to remove moisture from a sample from which H₂O or NH₃ will be measured.** Sample dryers shall meet the requirements set out in paragraph 9.3.2.3.1.1. and in paragraph 9.3.2.3.1.2. of this Annex. The moisture content of 0.8 volume per cent H₂O is used in equation (A.5-13).

For the highest expected water vapour concentration H_m, the water removal technique shall maintain humidity at ≤ 5 g water/kg dry air (or about 0.8 volume per cent H₂O), which is 100 per cent relative humidity at 277.1 K (3.9 °C) and 101.3 kPa. This humidity specification is also equivalent to about 25 per cent relative humidity at 298 K (25 °C) and 101.3 kPa. This may be demonstrated by either:

- (a) Measuring the temperature at the outlet of the sample dryer; or,
- (b) Measuring humidity at a point just upstream of the CLD; or,
- (c) Performing the verification procedure in paragraph 8.1.8.5.8. of this Annex."

Annex 4, Paragraph 9.4.6., amend to read:

"9.4.6. CO and CO₂ measurements

A Non-dispersive infrared (NDIR) analyser shall be used to measure CO and CO₂ concentrations in raw or diluted exhaust for either batch or continuous sampling.

The NDIR-based system shall meet the calibration and verifications set out in paragraph 8.1.9.1. or 8.1.9.2. of this Annex, as applicable.

When CO or CO₂ are measured from raw exhaust, an FTIR or QCL-IR analyzer may be used as an alternative to NDIR provided it meets the criteria specified in paragraphs 9.4.13. or 9.4.14., respectively."

Annex 4, Paragraph 9.4.8., amend to read:

"9.4.8. NOx measurements

Two measurement instruments are specified for NOx measurement and either instrument may be used provided it meets the criteria specified in paragraph 9.4.8.1. or 9.4.8.2. of this Annex, respectively. The chemiluminescent detector shall be used as the reference procedure for comparison with any proposed alternate measurement procedure under paragraph 5.1.3. of this Annex.

When NOx (i.e., NO + NO₂) are measured from raw exhaust, an FTIR or QCL-IR analyzer may be used as an alternative to NDIR provided it meets the criteria specified in paragraphs 9.4.13. or 9.4.14., respectively."

Annex 4, Paragraph 9.4.10., amend to read:

"9.4.10. Air-to-fuel ratio measurements

A Zirconia (ZrO₂) analyser may be used to measure air-to-fuel ratio in raw exhaust for continuous sampling. O₂ measurements with intake air or fuel flow measurements may be used to calculate exhaust flow rate according to Annex 5.

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

The accuracy of the sensor with incorporated electronics shall be as follows:

- (a) ±3% of reading for $\lambda < 2$;
- (b) ±5% of reading for $2 \leq \lambda < 5$;
- (c) ±10% of reading for $5 \leq \lambda$."

Annex 4, insert new paragraphs, to read:

"9.4.13. Fourier Transform Infrared (hereinafter FTIR) analyzer

The FTIR employs the broad waveband infrared spectroscopy principle. It allows simultaneous measurement of exhaust components whose spectra are available in the instrument. The absorption spectrum (intensity/wavelength) is calculated from the measured interferogram (intensity/time) by means of the Fourier transform method.

The FTIR shall be installed in accordance with the instrument manufacturer's instructions. For the exhaust measurement the evaluation method has to be selected, which is specified by the instrument manufacture for the fuel type used. The sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to set point between 110 – 191 °C in order to minimise NH₃ losses and sampling artefacts. In addition, the sampling line shall be as short as practicably possible.

The spectral resolution of the laser shall have a nominal value $\leq 0.5 \text{ cm}^{-1}$ in order to minimise cross interference from other gases present in the exhaust gas.

The portable analyzers shall be assessed according to CEN EN 17507:2021 (Road vehicles – Portable Emission Measuring Systems (PEMS) – Performance assessment).

9.4.13.1. The instrument manufacturer shall declare, in an "Analyzer compliance declaration", which gases interfere with measured components and how

strong the expected interference is depending on the fuel type and based on concentrations which can be generally expected at emission tests.

The instrument manufacturer shall specify for which range of fuel types the interferences specification applies. Especially spectrometer evaluations, like FTIR, may be tuned for individual fuel types (e.g.: Gasoline, Diesel, H₂, ethanol, or others).

The analyzer compliance declaration shall at least include:

- (a) Analyzer type.
- (b) Analyzer accuracy, noise, drift, linearity and repeatability specifications
- (c) Required intervals between calibration and zero/span drift checks.
- (d) Range of ambient conditions covered.
- (e) Matrix including cross interference gases for each type of fuel for which the specifications apply. Cross interference specifications. The gases for which cross sensitivities exist and how large the maximum interferences are.
- (f) The concentration/s of the gas/es used to check potential interferences.
- (g) Types of fuels and fuel mixtures for which the specifications apply.
- (h) In cases, where different analytical evaluation methods are applied, the definition which evaluation method shall be used, depending on the fuel used and test application.

On request of the authority, engineering data shall be made available, which are the base for such a compliance declaration.

The analyzer type shall be examined by an international or national metrological institute, a type-approval authority or by a designated technical service which shall provide a written confirmation of the requirements present in the compliance declaration and in the specifications included in paragraph 9.3.1. of this Annex for the different types of fuels for which the analyzer type applies.

9.4.14. Laser Infrared Analyzer

A Quantum Cascade Laser mid-Infrared detection (QCL-IR) can emit coherent light in the near-infrared region or in the mid-infrared region respectively, where nitrogen compounds including NH₃ have strong absorption. These laser optics give a pulsed-mode high resolution narrow band near-infrared or mid-infrared spectrum. Therefore, laser infrared analyzers can reduce interference caused by the spectral overlap of co-existing components in engine exhaust gas.

The analyzer shall be installed either directly in the exhaust pipe (in-situ) or within an analyzer cabinet using extractive sampling in accordance with the instrument manufacturer's instructions. If installed in an analyzer cabinet, the sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to set point between 110 – 191 °C in order to minimise NH₃ losses and sampling artefacts. In addition, the sampling line shall be as short as practicably possible.

The portable analyzers shall be assessed according to CEN EN 17507:2021 (Road vehicles – Portable Emission Measuring Systems (PEMS) – Performance assessment).

9.4.14.1. The instrument manufacturer shall declare, in an "Analyzer compliance declaration", which gases interfere with measured components and how

strong the expected interference is depending on the fuel type and based on concentrations which can be generally expected at emission tests.

The instrument manufacturer shall specify for which range of fuel types the interferences specification apply.

The analyzer compliance declaration shall at least include:

- (a) Analyzer type.
- (b) Analyzer accuracy, noise, drift, linearity and repeatability specifications
- (c) Required intervals between calibration and zero/span drift checks.
- (d) Range of ambient conditions covered.
- (e) Matrix including cross interference gases for each type of fuel for which the specifications apply. Cross interference specifications. For which gases cross sensitivities exist and how large the maximum interferences are.
- (f) The concentration/s of the gas/es used to check potential interferences.
- (g) Types of fuels and fuel mixtures for which the specifications apply.
- (h) In cases, where different analytical evaluation methods are applied, the definition which evaluation method shall be used, depending on the fuel used and test application.

On request of the authority, engineering data shall be made available, which are the base for such a compliance declaration.

The analyzer type shall be examined by an international or national metrological institute, a type-approval authority or by a designated technical service which shall provide a written confirmation of the requirements present in the compliance declaration and in the specifications included in paragraph 9.3.1. of this Annex for the different types of fuels for which the analyzer type applies.

- 9.4.15.** A check for interference effects and the correct functionality of analyzers shall be performed by the analyzer manufacturer prior to market introduction, at least once for each type of analyzer or device addressed in paragraphs 9.4.6., 9.4.7., 9.4.8., 9.4.13., and 9.4.14."

Annex 4 - Appendix A.1, paragraph A.1.1.3.3., amend to read:

"A.1.1.3.3. Correction of PM measurement

When a particle number sample flow is extracted from a total sampling partial flow dilution system, the mass of particulates (m_{PM}) calculated in paragraph A.1.2-3.1.1. of Appendix A.1 to Annex 5. shall be corrected as follows to account for the flow extracted. This correction is required even where filtered extracted flow is fed back into the partial flow dilution systems, as set out in equation (A.4-31):

$$m_{PM,corr} = m_{PM} \times \frac{m_{sed}}{(m_{sed} - m_{ex})} \quad (A.4-31)$$

Where:

m_{PM} is the mass of particulates determined in accordance with paragraph A.1.2-3.1.1. of Appendix A.1 to Annex 5., g/test,

m_{sed} is the total mass of diluted exhaust gas passing through the dilution tunnel, kg,

m_{ex} is the total mass of diluted exhaust gas extracted from the dilution tunnel for particle number sampling, kg."

Annex 4 - Appendix A.1, paragraph A.1.2.1.2.1., second instance of sub-paragraph (b), amend to read:

"A.1.2.1.2.1. The particle sampling point shall be located within a dilution system.

...

(b) In the case of partial flow dilution systems, it shall have a flow Reynolds number (Re) of $< 1,700$ in the PTFE i.e. downstream of the sampling probe or point;

..."

Annex 4 - Appendix A.1, paragraph A.1.2.1.4.2. penultimate sub-paragraph, amend to read:

"A.1.2.1.4.2. Particle transfer system

...

Sample gas flow through the POT shall have a residence time of ≤ 0.8 second.

..."

Annex 4, Add a new Appendix A.7, to read:

"Annex 4 - Appendix A.7

Procedure for the measurement of water (H_2O)

A.7.1. This appendix describes the procedure for measurement of water (H_2O). For non-linear analyzers, the use of linearising circuits shall be permitted.

A.7.2. The analyzer used for H_2O measurement shall meet the criteria specified in paragraph A.7.2.1. or A.7.2.2.

When measuring H_2O , the H_2O analyzer shall be calibrated with an accurately humidified gas using one of the options in paragraph A.7.5.

A.7.2.1. Quantum cascade laser mid-infrared detector (hereinafter QCL-IR) analyzer

A.7.2.1.1. Measurement principle

A quantum cascade laser mid-infrared detector (QCL-IR) can emit coherent light in the near-infrared region or in the mid-infrared region respectively, where H_2O have strong absorption. These laser optics give a pulsed-mode high resolution narrow band near-infrared or mid-infrared spectrum. Therefore, laser infrared analyzers can reduce interference caused by the spectral overlap of co-existing components in engine exhaust gas.

A.7.2.1.2. Installation and sampling

The analyzer shall be installed within an analyzer cabinet using extractive sampling in accordance with the instrument manufacturer's instructions. The H_2O wavelength shall be selected for evaluation.

The analyzer shall be heated and all surfaces that are exposed to emissions maintained at a temperature of 110 to 191 °C. In addition, the sampling line shall be as short as practically possible and the sampling point as close as practicably possible to that of the criteria gaseous pollutants analyzers.

A.7.2.1.3. Cross interference

The spectral resolution of the laser shall have a nominal value $\leq 0.5 \text{ cm}^{-1}$ in order to minimise cross interference from other gases present in the exhaust gas.

Interference shall be verified for laser infrared analyzers using the procedures described in paragraph A.7.2.1.3.1.

Good engineering judgment shall be used to determine interference species for analyzer that are appropriate for each H₂O infrared absorption band, or the interference species may be identified based on the instrument manufacturer's recommendations.

Note that interference species are dependent on the H₂O infrared absorption band chosen by the instrument manufacturer.

A.7.2.1.3.1. Interference verification for H₂O Laser Infrared Analyzer.

The amount of interference shall be determined after initial analyzer installation and after major maintenance.

If the analyzer uses compensation algorithms that utilise measurements of other gases to meet this interference verification, these other measurements shall be conducted simultaneously to test the compensation algorithms during the analyzer interference verification.

An H₂O laser infrared analyzer shall have a combined interference that is within $(0.0 \pm 0.4) \text{ mmol/mol}$

Procedure:

- (1) Start, operate, zero, and span the H₂O laser infrared analyzer as would be the case before an emission test.
- (2) Flow a multi-component span gas that incorporates the target interference species and the specifications included in paragraph 9.5. of this Annex through the analyzer inlet. Use interference span gas concentrations that are at least as high as the maximum expected during testing.
- (3) Allow time for the analyzer response to stabilise. Stabilisation time may include time to purge the transfer line and account for analyzer response.
- (4) Record the analyzer output for 30 seconds while it measures the sample's concentration. Calculate the arithmetic mean of this data. When performed with all the gases simultaneously, this is the combined interference. The analyzer meets the interference verification if this value is within $(0.0 \pm 0.4) \text{ mmol/mol}$.

Interference verification procedures can be performed for individual interference species. If the concentration of any interference species used is higher than the maximum levels expected during testing, each observed interference value may be scaled down by multiplying the observed interference value by the ratio of the maximum expected concentration value to the concentration in the span gas. The sum of the scaled interference values must meet the tolerance for combined interference.

A.7.2.2. Fourier Transform Infrared (hereinafter FTIR) analyzer

A.7.2.2.1. Measurement principle

The FTIR employs the broad waveband infrared spectroscopy principle. It allows simultaneous measurement of exhaust components whose spectra are available in the instrument. The absorption spectrum (intensity/wavelength) is calculated from the measured interferogram (intensity/time) by means of the Fourier transform method.

A.7.2.2.2. Installation and sampling

The FTIR shall be installed in accordance with the instrument manufacturer's instructions. For the exhaust measurement the evaluation method has to be selected, which is specified by the instrument manufacture for the fuel type used. The FTIR analyzer shall be heated and all surfaces that are exposed to emissions maintained at a temperature of 110 to 191 °C. In addition, the sampling line shall be as short as practicably possible and the sampling point as close as practicably possible to that of the criteria gaseous pollutants analyzers.

A.7.2.2.3. Cross interference

The spectral resolution of the H₂O wavelength shall be have a nominal value $\leq 0.5 \text{ cm}^{-1}$ in order to minimise cross interference from other gases present in the exhaust gas.

CO₂ interference shall be verified for FTIR analyzers using the procedures described in paragraph A.7.2.2.3.1.

Good engineering judgment shall be used to determine other interference species for FTIR analyzers. Possible interference species include, but are not limited to: CO, NO, C₂H₄, and C₇H₈. Interference verification shall be performed using the procedures described in paragraph A.7.2.2.3.1., replacing occurrences of CO₂ with the targeted interferent species.

This verification for CO₂ may be omitted for engines operating only on hydrogen. For each analyzer the H₂O infrared absorption band shall be determined. For each H₂O infrared absorption band, good engineering judgment shall be used to determine interference species to use in the verification.

A.7.2.2.3.1. CO₂ interference verification for H₂O FTIR analyzers

The amount of CO₂ interference shall be determined after initial analyzer installation and after major maintenance.

If the FTIR analyzer uses compensation algorithms that utilise measurements of other gases to meet this interference verification, these other measurements shall be conducted simultaneously to test the compensation algorithms during the analyzer interference verification.

An H₂O FTIR analyzer shall have a CO₂ interference that is within (0.0 ± 0.4) mmol/mol.

Procedure:

- (1) Start, operate, zero, and span the H₂O FTIR analyzer as would be the case before an emission test.
- (2) Flow a multi-component span gas that incorporates the target interference species and the specifications included in paragraph 9.5. to this Annex through the analyzer inlet. Use interference span gas concentrations that are at least as high as the maximum expected during testing.
- (3) Allow time for the analyzer response to stabilize. Stabilisation time may include time to purge the transfer line and to account for analyzer response.
- (4) While the analyzer measures the sample's concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of this data. When performed with all the gases simultaneously, this is the combined interference. The analyzer meets the interference verification if this value is within (0.0 ± 0.4) mmol/mol.

Interference verification procedures can be performed for individual interference species. If the concentration of any interference species used is higher than the maximum levels expected during testing, each observed

interference value may be scaled down by multiplying the observed interference value by the ratio of the maximum expected concentration value to the concentration in the span gas. The sum of the scaled interference values must meet the tolerance for combined interference.

A.7.3. Emissions test procedure and evaluation

A.7.3.1. Checking the analyzers

Prior to the emissions test, the analyzer range shall be selected. Emission analyzers with automatic or manual range switching shall be permitted. During the test cycle, switching of analog amplifiers in the analyzer shall not be allowed.

Zero and span response shall be determined, if the provisions of paragraph A.7.3.4.2. do not apply for the instrument. For the span response, a H₂O gas that meets the specifications of paragraph A.9.5. shall be used.

A.7.3.2. Collection of emission relevant data

The H₂O data collection shall be commenced before the start of the test sequence. The H₂O concentration shall be measured continuously and stored with at least 1 Hz on a computer system.

A.7.3.3. Operations after test

At the completion of the test, sampling shall continue until system response times have elapsed. Determination of analyzer's drift according to paragraph A.7.3.4.1. shall only be required if the information in paragraph A.7.3.4.2. is not available.

A.7.3.4. Analyzer drift

A.7.3.4.1. As soon as practical but no later than 30 minutes after the test cycle is complete or during the soak period, the zero and span responses of the analyzer shall be determined. The difference between the pre-test and post-test results shall be less than 2 per cent of full scale.

A.7.3.4.2. Determination of analyzer drift is not required in the following situations:

- (a) If the zero drift and span drift specified by the instrument manufacturer in paragraphs A.7.4.2.3. and A.7.4.2.4. meet the requirements of paragraph A.7.3.4.1.,
- (b) The time interval for zero drift and span drift specified by the instrument manufacturer in paragraphs A.7.4.2.3. and A.7.4.2.4. exceed the duration of the test.

A.7.4. Analyzer specification and verification

A.7.4.1. Linearity requirements

The analyzer shall comply with the linearity requirements specified in Table 7 of this annex. The linearity verification in accordance with paragraph 8.1.4. of this annex, shall be performed at least every 12 months or whenever a system repair or change is made that could influence linearity.

For the linearity verification, purified nitrogen or purified synthetic air meeting the requirements in Annex 4 paragraph 9.5. and H₂O contamination $\leq 5 \mu\text{mol/mol}$ shall be used.

Instruments, whose signals are used for compensation algorithms, shall meet the linearity requirements specified in Table A.4-5 of this annex. Linearity verification shall be done as required by internal audit procedures, by the instrument manufacturer or in accordance with ISO 9000 requirements.

Note that the system shall meet the linearity verification in using a water generation system that meets the requirements of paragraph A.7.5.

A.7.4.2. Analyzer specifications

A.7.4.2.1. Reserved

A.7.4.2.2. Accuracy

The accuracy, defined as the deviation of the analyzer reading from the reference value, shall not exceed ± 2 per cent of the reading or ± 0.3 per cent of full scale, whichever is greater.

A.7.4.2.3. Zero drift

The drift of the zero response and the related time interval shall be specified by the instrument manufacturer.

A.7.4.2.4. Span drift

The drift of the span response and the related time interval shall be specified by the instrument manufacturer.

A.7.4.2.5. System response time

The system response time shall be ≤ 10 seconds.

A.7.4.2.6. Rise time

The rise time of the analyzer shall be ≤ 2.5 seconds.

A.7.4.2.7. Noise

The analyzer peak-to-peak response to zero and calibration or span gases over any 10 seconds period shall not exceed ± 1 per cent of the maximum value.

A.7.5. H₂O calibration gas

A gas mixture with the following chemical composition shall be available. The H₂O calibration gas may be created with a calibration gas generator that meets the uncertainty requirement for the H₂O calibration gas.

H₂O in purified air or purified nitrogen.

H₂O calibration gases shall be generated with a humidity generator.

The H₂O concentration uncertainty shall be within $\pm 3\%$ of reading (Note it is not $\pm 3\%$ of absolute H₂O humidity).

A.7.6. Alternative systems

Other systems or analyzers may be approved by the Type Approval Authority, if it is found that they yield equivalent results in accordance with paragraph 5.1.3. of this annex."

Annex 5 Title, amend to read:

"Annex 5

Method for data evaluation and calculation for engines other than those operated solely on hydrogen"

Annex 5, paragraph 1, amend to read:

"1. General requirements

For engines other than those operated solely on hydrogen as specified in ~~Appendix 4 paragraph A.4.4.~~, calculation of emissions shall be performed according to either Appendix A.1 (mass based calculations) or Appendix A.2 (molar based calculations). Mixture between the two methods is not permitted.

It shall not be required to perform the calculations according to both Appendix A.1 and Appendix A.2.

The specific requirements for particle number (PN) measurement, where applicable, are laid down in Appendix A.6."

Annex 5, paragraph 1.3., add new row to the table as follows:

"1.3. Symbols and abbreviations for the chemical components (also used as a subscript)

Appendix A.1.	Appendix A.2.	Quantity
...		
	N ₂	Molecular nitrogen
NH ₃	NH ₃	Ammonia
NO _x	NO _x	Oxides of nitrogen
...		

...

"

Annex 5, Appendix A.1, paragraph A.1.1.6., amend to read:

"A.1.1.6. Mass flow rate of the exhaust gas

Mass flow rate of the exhaust gas may be measured directly using a system that meets the requirements of Annex 4 paragraph 9.4.5. Alternatively, mass flow rate of the exhaust gas may be determined using one of the methods described in paragraphs A.1.1.6.1 to A.1.1.6.4.."

Annex 5, Appendix A.2., paragraph A.2.4.3. (b), amend to read:

"A.2.4.3. Chemical balance procedure

...

- (b) Equations ~~(A.5-6)~~ **(A.5-84)** to ~~(A.5-23)~~ **(A.5-101)** in sub-paragraph (d) of this paragraph have to be entered into a computer program to iteratively solve for $x_{\text{H}_2\text{Oexh}}$, x_{Ccombdry} and $x_{\text{dil/exh}}$. Good engineering judgment shall be used to guess initial values for $x_{\text{H}_2\text{Oexh}}$, x_{Ccombdry} , and $x_{\text{dil/exh}}$. Guessing an initial amount of water that is about twice the amount of water in the intake or dilution air is recommended. Guessing an initial value of x_{Ccombdry} as the sum of the measured CO₂, CO, and THC values is recommended. Guessing an initial x_{dil} between 0.75 and 0.95, such as 0.8 is also recommended. Values in the system of equations shall be iterated until the most recently updated guesses are all within ± 1 per cent of their respective most recently calculated values ~~values~~;

..."

Annex 5, Appendix A.2., paragraph A.2.5.3. (c), amend to read:

"A.2.5.3. Exhaust gas molar flow rate

...

- (c) Molar flow rate calculation based on fuel mass flow rate

Based on \dot{m}_{fuel} , \dot{n}_{exh} [mol/s] shall be calculated as follows:

When conducting laboratory testing this calculation may only be used for discrete-mode and ramped-modal steady-state cycles equation (A.5-113):

$$\dot{n}_{\text{exh}} = \frac{\dot{m}_{\text{fuel}} \cdot w_{\text{C}} \cdot (1 + x_{\text{H}_2\text{Oexhdry}})}{M_{\text{C}} \cdot x_{\text{Ccombdry}}} \quad (\text{A.5-113})$$

Where:

\dot{n}_{exh}	= raw exhaust molar flow rate from which emissions are measured
\dot{m}_{fuel}	= fuel flow rate including humidity in intake air [g/s]
w_{C}	= carbon mass fraction for the given fuel [g/g]
$x_{\text{H}_2\text{Oexhdry}}$	= amount of H ₂ O per dry mole of measured flow [mol/mol]
M_{C}	= molar mass of carbon 12.011 g/mol
x_{Ccombdry}	= amount of carbon from fuel in the exhaust per mole of dry exhaust [mol/mol]
...	"

Annex 5, Appendix A.2., paragraph A.2.6.3.(a), amend to read:

"A.2.6.3. Exhaust gas molar flow rate

(a) Calculation via chemical balance;

The molar flow rate \dot{n}_{exh} [mol/s] can be calculated based on fuel mass flow rate \dot{m}_{fuel} by means of equation (A.5-113) from paragraph A.2.5.3.(c):

$$\dot{n}_{\text{exh}} = \frac{\dot{m}_{\text{fuel}} \cdot w_{\text{C}} \cdot (1 + x_{\text{H}_2\text{Oexhdry}})}{M_{\text{C}} \cdot x_{\text{Ccombdry}}} \quad (\text{A.5-113})$$

Where:

\dot{n}_{exh}	= raw exhaust molar flow rate from which emissions are measured [mol/s]
\dot{m}_{fuel}	= fuel flow rate including humidity in intake air [g/s]
w_{C}	= carbon mass fraction for the given fuel [g/g]
$x_{\text{H}_2\text{Oexhdry}}$	= amount of H ₂ O per dry mole of measured flow [mol/mol]
M_{C}	= molar mass of carbon 12.0107 g/mol
x_{Ccombdry}	= amount of carbon from fuel in the exhaust per mole of dry exhaust [mol/mol]"

Annex 5, Appendix A.2., paragraph A.2.7.1.(a), amend to read:

"2.7.1. Sampling

(a) Sampling from a varying flow rate:

If a batch sample from a changing exhaust flow rate is collected, a sample proportional to the changing exhaust flow rate shall be extracted. The flow rate shall be integrated over a test interval to determine the total flow. The mean PM concentration \bar{M}_{PM} (which is already in units of mass per mole of sample) shall be multiplied by the total flow to obtain the total mass of PM m_{PM} [g] by means of equation (A.5-121):

$$m_{\text{PM}} = \bar{M}_{\text{PM}} \cdot \sum_{i=1}^N (\dot{n}_i \cdot \Delta t_i) \quad (\text{A.5-121})$$

Where:

\dot{n}_i = instantaneous exhaust molar flow rate [mol/s]

\bar{M}_{PM} = mean PM concentration [g/mol]

$\Delta t_{\#i}$ = sampling interval [s]

..."

Annex 5, Appendix A.6., paragraph A.6.1.1., amend to read:

"A.6.1.1. Time alignment

For partial flow dilution systems residence time in the particle number sampling and measurement system shall be accounted for by time aligning the particle number signal with the test cycle and the exhaust gas mass flow rate according to the procedure in paragraph 8.2.1.2. of Annex 4. The transformation time of the particle number sampling and measurement system shall be determined in accordance with paragraph A.1.2.1.3.7. of Appendix A.1 to Annex 4. "

Annex 5, paragraph A.6.1.3., equation (A.5-168), amend to read:

$$" \bar{c}_s = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n} \quad (A.5-168) "$$

Annex 7, Appendix A.2, paragraph A.2.1., amend to read:

"A.2.1. General

This Appendix defines the additional requirements and exceptions to enable emission testing of dual-fuel engines independent whether these emissions are solely exhaust emissions or also crankcase emissions added to the exhaust emissions according to paragraph 6.10. of Annex 4. In the case that no additional requirement or exception is listed, the requirements of this Regulation shall apply to dual-fuel engines in the same way as they apply to any other approved engine types or engine families.

Emission testing of a dual-fuel engine is complicated by the fact that the fuel used by the engine can vary between pure liquid fuel and a combination of mainly gaseous fuel with only a small amount of liquid fuel as an ignition source. The ratio between the fuels used by a dual-fuel engine can also change dynamically depending of the operating condition of the engine. As a result special precautions and restrictions are necessary to enable emission testing of these engines.

This Appendix is not applicable if one of the fuels used in a dual fuel engine is hydrogen. In that case Appendix A.2 of Annex 12 applies."

Annex 11, paragraph 8.2, amend to read:

"8.2 Dry-to-wet concentration conversion

If the emissions are measured on a dry basis, ~~Equation A.5-7 shall not be used for engines operated solely on hydrogen.~~ **the measured concentration c_d on dry basis shall be converted to the concentration c_w on a wet basis by means of equation (A.11-1):**

$$k_{w,e} = \left(1 - \frac{c_{H_2O}}{100} \right) \times 1.008 \quad (A.11-1)$$

Where:

c_{H_2O} is the concentration of H₂O in the raw exhaust gas determined in accordance with Annex 4 Appendix 7, per cent"

Insert new Annex 12, to read:

"Annex 12

Technical requirements for dual-fuel engines of Type 1A with hydrogen as a main fuel

1. Scope

This Annex defines the additional requirements and exceptions to enable emission testing of dual-fuel engines of Type 1A with hydrogen as a main fuel independent of whether these emissions are solely exhaust emissions or also crankcase emissions added to the exhaust emissions according to paragraph 6.10. of Annex 4. In the case that no additional requirement or exception is listed, the requirements of this Regulation shall apply to dual-fuel engines of Type 1A with hydrogen as a main fuel in the same way as they apply to any other approved engine types or engine families.

2. Applicability of Annex 7

The requirements of Annex 7 and Appendix A.1 to that Annex that apply to dual-fuel engines of Type 1A also apply in the case of dual-fuel engines of Type 1A with hydrogen as the main fuel.

Annex 12 Appendix A.1

Dual-fuel engines with hydrogen as a main fuel dual-fuel indicator, warning system, operability restriction - Demonstration requirements

A.1.1. Applicability of Annex 7 Appendix A.1

The requirements of Annex 7 Appendix A.1 that apply to dual-fuel engines of Type 1A also apply in the case of dual-fuel engines of Type 1A with hydrogen as the main fuel.

Annex 12 Appendix A.2

Emission test procedure requirements for dual-fuel engines with hydrogen as the main fuel

A.2.1. General

This Appendix defines the additional requirements and exceptions to enable emission testing of dual-fuel engines with hydrogen as the main fuel independent whether these emissions are solely exhaust emissions or also crankcase emissions added to the exhaust emissions according to paragraph 6.10. of Annex 4. In the case that no additional requirement or exception is listed, the requirements of this Regulation shall apply to dual-fuel engines with hydrogen as the main fuel in the same way as they apply to any other approved engine types or engine families.

A.2.2. Test conditions

Paragraph 6. of Annex 4 shall apply.

A.2.3. Test procedures

Paragraph 7. of Annex 4 shall apply except as set out in paragraph A.2.3.1.

A.2.3.1. The total mass of each gaseous constituent shall be determined over the applicable test cycle using continuous sampling where the constituent's concentration is measured continuously from raw exhaust.

A.2.4. Measurement procedures

Paragraph 8. of Annex 4 shall apply except as set out in paragraph A.2.4.1.

A.2.4.1. The emissions measurement system shall comply with the calibration and performance checks at the highest exhaust water content expected during emission testing. In particular it shall be ensured that the temperatures of all sample gas carrying components of the emission measurement system, except for sample dryers, remain at least 10 K above the dew point of the sample gas at the corresponding location.

A.2.5. Measurement equipment

Paragraph 9. of Annex 4 shall apply except as set out in paragraph A.2.5.1. of this Annex.

A.2.5.1. The dilution procedure set out in paragraph 9.2. of Annex 4 shall not apply to gaseous emissions measurements.

A.2.6. Particle number emissions measurement

Appendix A.1 to Annex 4 shall apply.

A.2.7. Emission calculation

The emission calculation shall be performed according to Annex 5 Appendix A.1. (mass based calculations) except as set out in this paragraph. The molar-based calculations of Annex 5 shall not be used for the calculation of emissions for dual-fuel engines with hydrogen as the main fuel.

Where the gas energy ratio (GER) is used it shall be consistent with the definition in paragraph 2 of this Regulation and the specific provisions on hydrocarbon (HC) limits for fully and partially gaseous-fuelled engines in Appendix 2 to this Regulation. The average value of GER over the cycle shall be calculated by one of the following methods: For hot-start transient cycle and RMC NRSC by dividing the sum of the GER at each measurement point by the number of measurement points; For discrete-

mode NRSC by multiplying the average GER for each test mode by the corresponding weighting factor for that mode and calculating the sum for all modes. The weighting factors shall be taken from Appendix A.6 to Annex 4 for the applicable cycle.

A.2.7.1. Mass-based emission calculation

Appendix A.1 to Annex 5 shall apply except as set out in this paragraph.

A.2.7.2. Dry/wet correction

For dual-fuel engines of Type 1A with hydrogen as the main fuel (A.12.1) shall be used to calculate the dry/wet correction:

$$k_{w,e} = 1 - \frac{c_{H2O}}{100} \times 1.008 \quad (\text{A.12-1})$$

Where:

c_{H2O} is the concentration of H₂O in the raw exhaust gas determined in accordance with paragraph Annex 4 Appendix 7, per cent"

A.2.7.3. NO_x correction for humidity

The NO_x humidity correction for compression ignition engines as specified in equation (A.5-9) of Annex 5 shall be used.

A.2.7.4. Determination of exhaust gas mass flow

The exhaust mass flow shall be determined using a raw exhaust flowmeter as described in paragraph 9.4.5.3. of Annex 4.

A.2.7.5. Determination of the component specific factor u

For dual-fuel engines of Type 1A with hydrogen as the main fuel the tabulated values for the gaseous fuel shall be taken from Table A.11-1 of Annex 11.

A.2.7.6. Mass per test of a gaseous emission

Calculation of mass per test of gaseous emissions over a discrete-mode NRSC test shall be conducted according to equation (A.5-1) of Appendix A.1 to Annex 5.

Calculation of mass per test of gaseous emissions of a transient or ramped modal cycle shall be conducted according to equation (A.5-2) of Appendix A.1 to Annex 5.

A.2.7.7. Particulate determination

For the determination of particulate emissions with the partial dilution measurement method the calculation shall be performed according to the equations in paragraph A.1.3. of Appendix A.1 to Annex 5. The requirements of paragraph 8.2.1.2. of Annex 5 shall apply for controlling the dilution ratio. In particular, if the combined transformation time of the exhaust flow measurement and the partial flow system exceeds 0.3 s, lookahead control based on a pre-recorded test run shall be used. In this case, the combined rise time shall be ≤ 1 s and the combined delay time ≤ 10 s. Except in the case that the exhaust mass flow is measured directly the determination of exhaust mass flow shall use values of α , γ , δ and ε determined according to paragraph A.2.7.1.5.3..

The quality check according to paragraph 8.2.1.2. of Annex 4 shall be performed for each measurement.

A.2.7.8. Additional requirements regarding the exhaust gas mass flowmeter

The flowmeter referred to in paragraphs 9.4.1.5.3. and 9.4.1.5.4. of Annex 4 shall not be sensitive to the changes in exhaust gas composition and density. The small errors of e.g. pitot tube or orifice-type of measurement (equivalent with the square root of the exhaust density) may be neglected.

A.2.7.9. Calculation of the molar ratios of H, C, S, N and O related to C for the diesel fuel

The calculation of the atomic ratios (especially the H/C-ratio α) is given in Annex 5 by means of equations (A.7-8) to (A.7-11):

A.2.7.10. CO₂ determination

A.2.7.10.1. CO₂ determination when testing on a transient or ramped modal cycle (RMC) using raw gas sampling

Calculation of CO₂ emissions from measurement of CO₂ in the exhaust gas in accordance with Annex 5 shall not apply. Instead the following provisions shall apply:

The measured test-averaged fuel consumption for the diesel fuel only shall be determined from the sum of the instantaneous values over the cycle and shall be used as the base for calculating the test averaged CO₂ emissions.

The total corrected fuel mass of diesel fuel $m_{\text{fuel,corr}}$ [g/test] and CO₂ mass emission coming from the fuel $m_{\text{CO}_2, \text{fuel}}$ [g/test] shall be determined by means of equations (A.12-2) and (A.12-3).

$$m_{\text{fuel,corr}} = m_{\text{fuel}} - \left(m_{\text{THC}} + \frac{A_{\text{C}} + \alpha \cdot A_{\text{H}}}{M_{\text{CO}}} \times m_{\text{CO}} + \frac{w_{\text{GAM}} + w_{\text{DEL}} + w_{\text{EPS}}}{100} \times m_{\text{fuel}} \right) \quad (\text{A.12-2})$$

$$m_{\text{CO}_2, \text{fuel}} = \frac{M_{\text{CO}_2}}{A_{\text{C}} + \alpha \cdot A_{\text{H}}} \times m_{\text{fuel,corr}} \quad (\text{A.12-3})$$

Where:

m_{fuel} = total fuel mass of the diesel fuel [g/test]

m_{THC} = mass of total hydrocarbon emissions in the exhaust gas [g/test]

m_{CO} = mass of carbon monoxide emissions in the exhaust gas [g/test]

w_{GAM} = sulphur content of the diesel fuel [per cent mass]

w_{DEL} = nitrogen content of the diesel fuel [per cent mass]

w_{EPS} = is the oxygen content of the diesel fuel [per cent mass]

α = is the molar hydrogen ratio of the diesel fuel (H/C) [-]

A_{C} = is the atomic mass of Carbon: 12.011 [g/mol]

A_{H} = is the atomic mass of Hydrogen: 1.0079 [g/mol]

M_{CO} = is the molecular mass of Carbon monoxide: 28.011 [g/mol]

M_{CO_2} = is the molecular mass of Carbon dioxide: 44.01 [g/mol]

The CO₂ emission resulting from urea $m_{\text{CO}_2, \text{urea}}$ [g/test] shall be calculated by means of equation (A.12-4):

$$m_{\text{CO}_2, \text{urea}} = \frac{c_{\text{urea}}}{100} \times \frac{M_{\text{CO}_2}}{M_{\text{CO(NH}_2)_2}} \times m_{\text{urea}} \quad (\text{A.12-4})$$

Where:

c_{urea} = urea concentration [per cent]

m_{urea} = total urea mass consumption [g/test]

$M_{\text{CO(NH}_2)_2}$ = Molecular mass of urea: 60.056 [g/mol]

Then the total CO₂ emission m_{CO_2} [g/test] shall be calculated by means of equation (A.12-5):

$$m_{CO_2} = m_{CO_2, fuel} + m_{CO_2, urea} \quad (A.12-5)$$

The total CO₂ emission calculated by means of equation (A.12-5) shall be used in the calculation of brake specific CO₂ emissions, e_{CO_2} [g/kWh] in paragraph A.1.4.1.1. of Appendix A.1. Where applicable, the correction for CO₂ in the exhaust arising from CO₂ in the gaseous fuel shall be performed in accordance with Appendix A.3 to Annex 6."

Annex 12 - Appendix A.3

Types of dual-fuel engines operated on hydrogen and a liquid fuel – illustration of the definitions and main requirements

<i>Dual-fuel type</i>	<i>GER_{cycle}</i>	<i>Idle on liquid fuel</i>	<i>Warm-up on liquid fuel</i>	<i>Operation on liquid fuel solely</i>	<i>Operation in absence of gas</i>	<i>Comments</i>
1A	GER _{NRTC, hot} ≥ 0.9 or GER _{NRSC} ≥ 0.9	NOT allowed	Allowed only on service mode	Allowed only on service mode	Service mode	
	"					

II. Justification

1. This document aims at permitting the type-approval of dual-fuel hydrogen (H₂) engines of Type 1A for installation in agricultural and forestry tractors and in non-road mobile machinery, with regard to the emissions of pollutants by the engine
2. It is correcting errors in the Regulation, merging amendments from documents GRPE-93-09 and GRPE-93-11.