

Proposal for Supplement 6 to the 05 series of amendments to Regulation No. 49 (compression ignition and positive ignition (LPG and CNG) engines) - document ECE-TRANS-WP29-GRPE-2013-07e

Amendments and complements to be taken into consideration

I. Background

Document ECE-TRANS-WP29-GRPE-2013-07e was prepared by the Chair of the informal group on Gaseous Fuelled Vehicles (GFV) – Heavy Duty Dual Fuel–Task-Force (HDDF-TF), to introduce modifications to the 05 series of amendments of UN Regulation No. 49 (Euro V) in order to extend the pollutant emission requirements to dual-fuel heavy duty engines and vehicles. With the agreement of GRPE, this document was due to be completed and when necessary amended in order to take into consideration the latest works of the GFV informal group. This informal document presents these complements and amendments. The modifications to the original English text are marked using track changes.

II. Proposal

Annex 4A, section 1.3., amend to read

“1.3. Measurement principle

The emissions to be measured from the exhaust of the engine include the gaseous components (carbon monoxide, total hydrocarbons for diesel and type 3B dual-fuel engines on the ESC test only; non-methane hydrocarbons for diesel, dual-fuel, and gas engines on the ETC test only; methane for gas and dual-fuel engines on the ETC test only and oxides of nitrogen), the particulates (diesel and dual-fuel engines only) and smoke (diesel and dual-fuel engines on the ELR test only). Additionally, carbon dioxide is often used as a tracer gas for determining the dilution ratio of partial and full flow dilution systems. Good engineering practice recommends the general measurement of carbon dioxide as an excellent tool for the detection of measurement problems during the test run.”

Annex 4A, section 2.1.1., item (a), title, amend to read

“ (a) For compression-ignition and dual-fuel engines:”

Annex 4A, Appendix 1, paragraph 4.1.2., amend to read:

“4.1.2. Air and fuel measurement method

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

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

In case of dual-fuel engines operating in dual-fuel mode, the fuel flows for both the gaseous and the diesel fuel shall be measured and their masses added.”

Annex 4A, Appendix 1, paragraph 5.2, amend to read:

“5.2. Dry / wet correction

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

The u_{gas} -values and molar ratios as described in sections A.5.2. and A.5.3. of Appendix 5 to Annex 11 shall be used for dual-fuel engines, operating in dual-fuel mode,

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

For the raw exhaust gas:

$$k_{w,r} = \left(1 - \frac{1,2442 \times H_a + 111,19 \times w_{ALF} \times \frac{q_{mf}}{q_{mad}}}{773,4 + 1,2442 \times H_a + \frac{q_{mf}}{q_{mad}} \times k_f \times 1000} \right) \times 1,008$$

or

$$k_{w,r} = \left(1 - \frac{1,2442 \times H_a + 111,19 \times w_{ALF} \times \frac{q_{mf}}{q_{mad}}}{773,4 + 1,2442 \times H_a + \frac{q_{mf}}{q_{mad}} \times k_f \times 1000} \right) \left/ \left(1 - \frac{p_r}{p_b} \right) \right.$$

or

$$k_{w,a} = \left(\frac{1}{1 + \alpha \times 0,005 \times (c_{CO_2} + c_{CO})} - k_{w1} \right) \times 1,008$$

with

$$k_f = 0,055594 \times w_{ALF} + 0,0080021 \times w_{DEL} + 0,0070046 \times w_{EPS}$$

and

$$k_{w1} = \frac{1,608 \times H_a}{1000 + (1,608 \times H_a)}$$

where:

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

w_{ALF} = hydrogen content of the fuel, per cent mass

$q_{mf,i}$ = instantaneous fuel mass flow rate, kg/s

$q_{mad,i}$ = instantaneous dry intake air mass flow rate, kg/s

p_r = water vapour pressure after cooling bath, kPa

p_b = total atmospheric pressure, kPa

w_{DEL} = nitrogen content of the fuel, per cent mass

w_{EPS} = oxygen content of the fuel, per cent mass

α = molar hydrogen ratio of the fuel

c_{CO_2} = dry CO_2 concentration, per cent

c_{CO} = dry CO concentration, per cent

For the diluted exhaust gas:

$$K_{w_{e1}} = \left(1 - \frac{\alpha \times \% c_{wCO_2}}{200} \right) - K_{w1}$$

or,

$$K_{w_{e2}} = \left(\frac{(1 - K_{w1})}{1 + \frac{\alpha \times \% c_{dCO_2}}{200}} \right)$$

For the diluent:

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

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

For the intake air:

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

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

where:

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

H_d = diluent humidity, g water per kg dry air

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

Annex 4A, Appendix 1, section 6.2, amend to read:

“6.2. Partial flow dilution system

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

In case of dual-fuel engines operating in dual-fuel mode, the exhaust mass flow shall be determined according to the direct measurement method as specified in 6.2.4.”

Annex 4A, Appendix 1, section 6.3, amend to read:

“6.3. Full flow dilution system

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

In case of dual-fuel engines operating in dual-fuel mode, the calculations shall be performed according to appendix 4 to Annex 11.”

Annex 4A, Appendix 2, section 3.4., title, amend to read

“3.4. Starting the particulate sampling system (diesel and dual-fuel engines only)”

Annex 4A, Appendix 2, section 4.2., amend to read:

“4.2. Determination of raw exhaust gas mass flow

For calculation of the emissions in the raw exhaust gas and for controlling of a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For the determination of the exhaust mass flow rate, either of the methods described in paragraphs 4.2.2. to 4.2.5. of this appendix may be used.

Only the direct measurement of the exhaust flow is applicable for dual-fuel engines operating in dual-fuel mode. The use of the air and fuel measurement method is not allowed in this mode.”

Annex 4A, Appendix 2, section 5., amend to read:

“5. Calculation of the gaseous emissions

The calculation procedures as specified in Annex 4B as adapted in Appendix 4 of Annex 11 shall be used for dual-fuel engines operating in dual-fuel mode.”

Annex 4A, Appendix 2, section 6., amend to read:

“6. Calculation of the particulate emission (if applicable)

The calculation procedures as specified in Annex 4B as adapted in Appendix 4 of Annex 11 shall be used for dual-fuel engines operating in dual-fuel mode.”

Annex 4B, paragraph 1., amend to read:

“1. Applicability

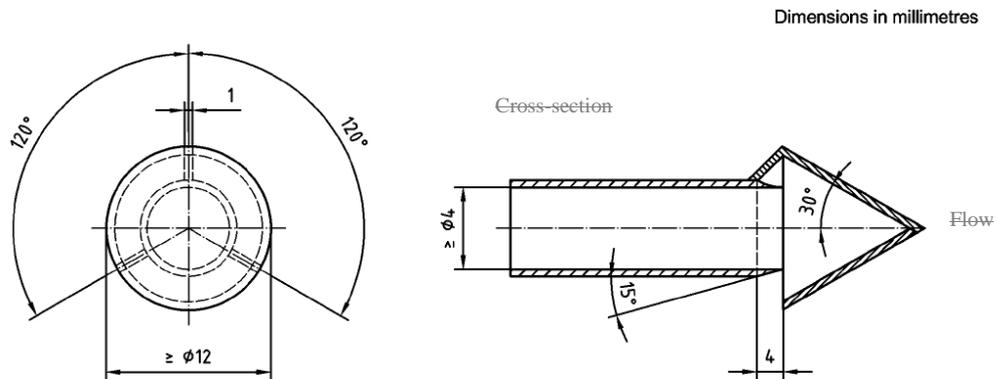
This annex is not applicable for the purpose of type approval according to this Regulation for the time being. It will be made applicable in the future.

This Annex is applicable for dual-fuel engines when referenced from Annex 4A or Appendix 4 of Annex 11.”

Annex 4B, Appendix 3, Figure 14, amend to read:

“Figure 14

Scheme of hatted probe



Annex 5, The title of the section 1.2., amend to read:

“1.2. Diesel reference fuel for testing diesel engines to the emission limits given in rows B1, B2 or C of the tables in paragraph 5.2.1. of this Regulation and dual-fuel engines”

Annex 5, the first paragraph of section 2, amend to read:

" Compressed Natural gas - European market fuels are available in two ranges:

- (a) The H range, whose extreme reference fuels are G_R and G_{23} ;
- (b) The L range, whose extreme reference fuels are G_{23} and G_{25} .

Liquefied Natural gas – European market fuels are available in a range whose extreme reference fuels are G_{20} and G_R

The characteristics of G_R , G_{20} , G_{23} and G_{25} reference fuels are summarized below:"

Annex 5, Insert new table after the table specifying the characteristics of the G_R reference fuel, to read:

Reference fuel G_{20}					
Characteristics	Units	Basis	Limits		Test method
			minimum	maximum	
...
Reference fuel G_{20}					
Composition:					
Methane	% mole	100	99	100	ISO 6974
Balance ⁽¹⁾	% mole	—	—	1	ISO 6974
N ₂	% mole				ISO 6974
Sulphur content	mg/m ³ ⁽²⁾	—	—	10	ISO 6326-5
Wobbe Index (net)	MJ/m ³ ⁽³⁾	48.2	47.2	49.2	
⁽¹⁾ Inerts (different from N ₂) + C ₂ + C ₂ +. ⁽²⁾ Value to be determined at 293,2 K (20 °C) and 101,3 kPa. ⁽³⁾ Value to be determined at 273,2 K (0 °C) and 101,3 kPa.					

Annex 11, paragraph 5.1, amend to read:

“5.1. Emission limits applicable to Type 1A and Type 1B dual-fuel engines ~~operating in dual fuel mode~~”

Annex 11, paragraph 5.2, amend to read:

“5.2. Emission limits applicable to Type 2B dual-fuel engines ~~operating in dual-fuel mode~~”

Annex 11, section 5.2.1, amend to read:

“5.2.1. Emission limits applicable over the ESC test-cycle

- ~~5.2.1.1. The CO, NO_x and PM mass emission limits over the ESC test cycle applicable to Type 2B dual-fuel engines operating in dual-fuel mode are those applicable to Diesel engines over the ESC test cycle and defined in rows B2 and C of Table 1 of paragraph 5.2.1. of this Regulation.~~
- ~~5.2.1.2. The HC emission limits over the ESC test cycle applicable to Type 2B dual-fuel engines operating in dual-fuel mode are the HC emission limits applicable to Diesel engines over the ESC test cycle and defined in rows B2 and C of Table 1 of paragraph 5.2.1. of this Regulation.~~
- 5.2.1.3. The emission limits over the ESC test-cycle applicable to Type 2B dual-fuel engines operating in diesel mode are those applicable to Diesel engines over the ESC test-cycle and defined in rows B2 and C of Table 1 of paragraph 5.2.1. of this Regulation.”

Annex 11, section 5.2.2., amend to read:

- “5.2.2. Emission limits applicable over the ETC test-cycle
- 5.2.2.1. Emission limits for CO, NO_x and PM mass
- The CO, NO_x and PM mass emission limits over the ETC test-cycle applicable to Type 2B dual-fuel engines operating in dual-fuel and diesel mode over the ETC test-cycle are defined in rows B2 and C of table 2 of paragraph 5.2.1. of this Regulation.
- 5.2.2.2. Emission limits for Hydrocarbons
- 5.2.2.2.1. NG dual-fuel engines operating in dual-fuel mode
- The THC, NMHC and CH₄ emission limits over the ETC test-cycle applicable to Type 2B dual-fuel engines operating with Natural Gas in dual-fuel mode are calculated from the NMHC and CH₄ limits applicable to Diesel and gas engines over the ETC test-cycle and defined in rows B2 and C of table 2 of paragraph 5.2.1. of this Regulation. The calculation procedure is specified in paragraph 5.2.3. of this annex.
- 5.2.2.2.2. LPG dual-fuel engines operating in dual-fuel mode
- The THC emission limits over the ETC test-cycle applicable to Type 2B dual-fuel engines operating with LPG in dual-fuel mode are the THC limits for Diesel engines as considered in paragraph 5.2.2.1. of this Regulation.
- 5.2.2.4.2.3. Dual-fuel engines operating in diesel mode
- The NMHC emission limits over the ETC test-cycle applicable to Type 2B dual-fuel engines operating in diesel mode are those defined in rows B2 and C of table 2 of paragraph 5.2.1. of this Regulation.”
- 5.2.3. Calculation procedure to determine the hydrocarbon limits (in g/kWh) applicable to Type 2B dual-fuel engines operating in dual-fuel mode during the ETC test cycle.
- The following calculation procedure applies to Type 2B dual-fuel engines tested over the ETC cycle while operating in dual-fuel mode :
- Calculate the average gas ratio GER_{ETC} over the ETC test cycle
- Calculate a corresponding THC_{GER} in g/kWh using the following formula:
- $$\text{THC}_{\text{GER}} = \text{NMHC}_{\text{NG}} + (\text{CH}_4_{\text{NG}} * \text{GER}_{\text{ETC}})$$

Determine the applicable THC limit in g/kWh using the following method:

If $\text{THC}_{\text{GER}} \leq \text{CH4}_{\text{NG}}$, then

- (a) THC limit value = THC_{GER} and
- (b) No applicable CH_4 and NMHC limit value

If $\text{THC}_{\text{GER}} > \text{CH4}_{\text{NG}}$, then

- (a) No applicable THC limit value; and
- (b) Both the NMHC_{NG} and CH4_{NG} limit values are applicable.

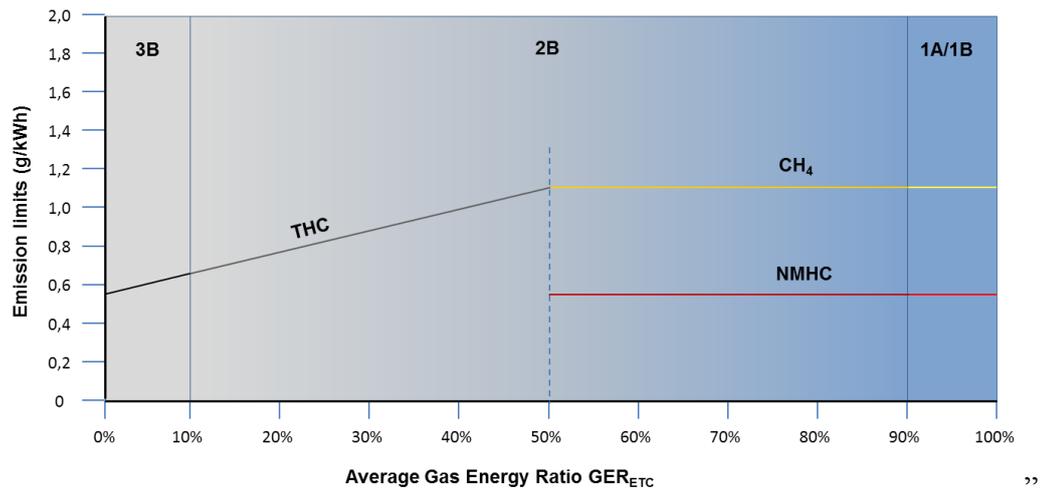
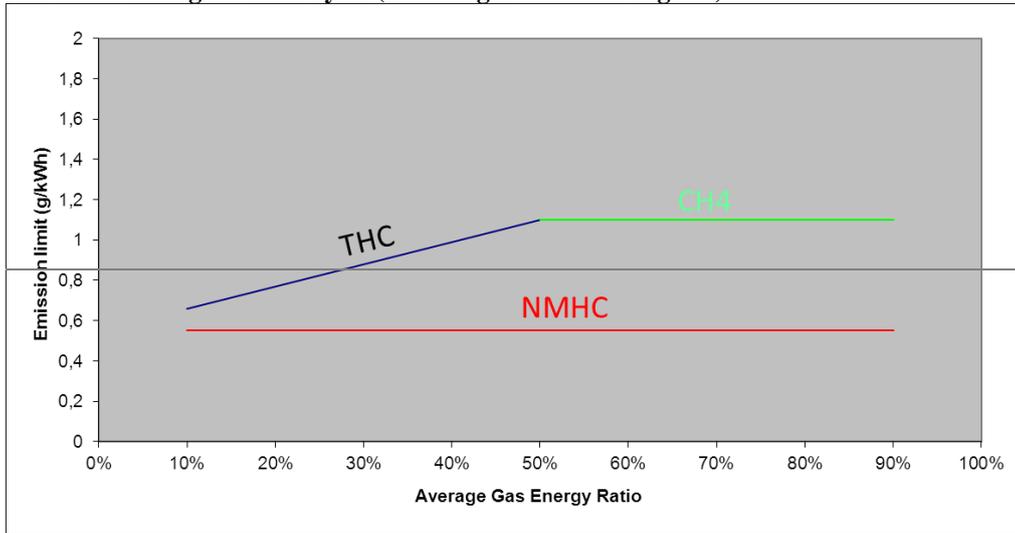
In this procedure,

NMHC_{NG} is the NMHC emission limit over the ETC test-cycle and made applicable to NG engine in rows B2 and C of table 2 of paragraph 5.2.1 of this Regulation.

CH4_{NG} is the CH_4 emission limit over the ETC test-cycle and applicable to NG engine in rows B2 and C of table 2 of paragraph 5.2.1 of this Regulation.

Annex 11, section 5.2., figure 1, title and figure, amend to read:

“Figure 1
Illustration of the HC limits in the case of a Type 2B dual-fuel engine operating in dual-fuel mode during the ETC cycle (natural gas dual-fuel engines)



Annex 11, section 5.3., amend to read:

- “5.3. Emission limits applicable to Type 3B dual-fuel engines
- 5.3.1. Emission limits applicable to Type 3B dual-fuel engines operating in dual-fuel mode
- 5.3.1.1. ~~The emissions limits over the ESC test-cycle applicable to Type 3B dual-fuel engines whether operating in dual-fuel mode or in diesel mode are the exhaust emission limits applicable to diesel engines and specified in rows B2 and C of table 21 of paragraph 5.2.1. of this Regulation.~~
The emissions limits over the ESC test-cycle applicable to Type 3B dual-fuel engines operating in dual-fuel mode are the exhaust emission limits applicable to diesel engines and specified in rows B2 and C of table 21 of paragraph 5.2.1. of this Regulation.
- 5.3.1.2. The CO, NO_x and PM mass emission limits over the ETC test-cycle applicable to Type 3B dual-fuel engines operating in dual-fuel mode are the exhaust emission limits applicable to diesel engines and specified in rows B2 and C of table 2 of paragraph 5.2.1. of this Regulation.
- 5.3.1.3 The THC emission limit over the ETC test-cycle applicable to Type 3B dual-fuel engines operating in dual-fuel mode is calculated from the NMHC and CH₄ limits applicable to diesel and gas engines over the ETC test-cycle and defined in rows B2 and C of table 2 of paragraph 5.2.1. of this Regulation.
- The calculation procedure is the following :
- Calculate the average gas ratio GER_{ETC} over the ETC test cycle
- Calculate a corresponding THC_{GER} in g/kWh using the following formula:
- $$\text{THC} = \text{NMHC}_{\text{NG}} + (\text{CH}_4_{\text{NG}} * \text{GER}_{\text{ETC}})$$
- In this procedure,
- NMHC_{NG} is the NMHC emission limit over the ETC test-cycle and made applicable to NG engine in rows B2 and C of table 2 of paragraph 5.2.1 of this Regulation.
- CH₄_{NG} is the CH₄ emission limit over the ETC test-cycle and applicable to NG engine in rows B2 and C of table 2 of paragraph 5.2.1 of this Regulation.
- 5.3.2 Emission limits applicable to Type 3B dual-fuel engines operating in diesel mode
- The emission limits applicable to Type 3B dual-fuel engines operating in diesel mode are those defined for diesel engines in rows B2 and C of tables 1 and 2 of paragraph 5.2.1. of this Regulation.”
6. Demonstration requirements
- 6.1 Laboratory tests

Annex 11, section 6.1., table 1, amend to read:

“Table 1

Laboratory tests to be performed by a dual-fuel engine

	Type 1A	Type 1B	Type 2B	Type 3B

ETC	NMHC; CH ₄ ; CO; NO _x ; PM _{2.5}	<u>Dual-fuel mode:</u> NMHC; CH ₄ ; CO; NO _x ; PM <u>Diesel mode:</u> NMTHC NMHC; CO; NO _x ; PM	<u>Dual-fuel mode:</u> THC or; NMHC ⁺⁺ ; CH ₄ ; CO; NO _x ; PM <u>Diesel mode:</u> NMTHC NMHC; CO; NO _x ; PM	<u>Dual-fuel mode:</u> THC; CO; NO _x ; PM <u>Diesel mode:</u> NMHC; CO; NO _x ; PM
ESC	GER determination only	<u>Dual-fuel mode:</u> GER determination only <u>Diesel mode:</u> THC HC; CO; NO _x ; PM	<u>Dual-fuel mode:</u> GER determination only <u>Diesel mode:</u> HC; CO; NO _x ; PM <u>Diesel mode:</u> THC HC; CO; NO _x ; PM	<u>Dual-fuel mode:</u> HC; CO; NO _x ; PM <u>Diesel mode:</u> THC HC; CO; NO _x ; PM

Annex 11, Appendix 4, paragraph A.4.1., amend to read:

“A.4.1. General

This appendix defines the additional requirements and exceptions to ~~Annex~~Annexes 4A and 4B of this regulation 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 4B.~~

Emission testing of a dual-fuel engine is complicated by the fact that the fuel used by the engine can vary between pure diesel fuel and a combination of mainly gaseous fuel with only a small amount of diesel 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.”

Annex 11, Appendix 4, section A.4.2.1., amend to read:

“A.4.2.1. Laboratory test conditions (Annex 4A, paragraph 2.1. or Annex 4B, paragraph 6.1.)

The parameter f_a for dual-fuel engines shall be determined with formula (a)(2) in paragraph 6.1. of Annex 4B to this regulation.”

Annex 11, Appendix 4, section A.4.3., title, amend to read:

“A.4.3. Test procedures (annex 4A, paragraph 1. and Annex 4B, paragraph 7.)”

Annex 11, Appendix 4, section A.4.4.1., title, amend to read:

“A.4.4.1. Dry/wet correction (Annex 4A, appendix 1, section 5.2. and Annex 4B, section 8.1.)”

Annex 11, Appendix 4, paragraphs A.4.4.1.1. and A.4.4.1.2., amend to read:

- “A.4.4.1.1. Raw exhaust gas (Annex 4B, paragraph 8.1.1.)
Equations 15 and 17 in Annex 4B paragraph 8.1.1. shall be used to calculate the dry/wet correction.
The fuel specific parameters shall be determined according to sections A.65.2 and A.65.3. of Appendix 5.
- A.4.4.1.2. Diluted exhaust gas (Annex 4B, paragraph 8.1.2.)
Equations 19 and 20 in Annex 4B paragraph 8.1.2. shall be used to calculate the wet/dry correction.
The molar hydrogen ratio α of the combination of the two fuels shall be used for the dry/wet correction. This molar hydrogen ratio shall be calculated from the fuel consumption measurement values of both fuels according to section A.65.4. of Appendix 5.”

Annex 11, Appendix 4, paragraphs A.4.4.3.1. to A.4.4.3.3., amend to read:

- “A.4.4.3.1. Determination of exhaust gas mass flow (Annex 4A, Appendix 2, paragraph 4.2. and Annex 4B, section 8.4.1.)
The exhaust mass flow shall be determined according to the direct measurement method as described in section 8.4.1.3 of Annex 4B.
Alternatively the airflow and air to fuel ratio measurement method according to section ~~8.4.1.6~~ 8.4.1.5. (equations 30, 31 and 32 of Annex 4B) may be used only if α , γ , δ and ε values are determined according to sections A.65.2. and A.65.3. of Appendix 5. The use of a zirconia-type sensor to determine the air fuel ratio is not allowed.
- A.4.4.3.2. Determination of the gaseous components (Annex 4B, section 8.4.2.)
The calculations shall be performed according to Annex 4B, section 8. but the u_{gas} -values and molar ratios as described in sections A.65.2. and A.65.3. of Appendix 5 shall be used.
- A.4.4.3.3. Particulate determination (Annex 4B, section 8.4.3.)
For the determination of particulate emissions with the partial dilution measurement method the calculation shall be performed according to Annex 4B, section 8.4.3.2.
For controlling the dilution ratio one of the following two methods may be used:
(a) The direct mass flow measurement as described in section 8.4.1.3.;
(b) The airflow and air to fuel ratio measurement method according to section 8.4.1.6. (Equations 30, 31 and 32) may only be used when this is combined with the look ahead method described in section 8.4.1.2. and if α , γ , δ and ε values are determined according to sections A.65.2. and A.65.3. of Appendix 5.
The quality check according to section 9.4.6.1. shall be performed for each measurement.”

Annex 11, Appendix 4, paragraphs A.4.4.4. and A.4.4.4.1., amend to read:

“A.4.4.4. Full flow dilution measurement (CVS) (Annex 4B, section 8.5.)

The possible variation of the fuel composition will only influence the hydrocarbons measurement results calculation. For all other components the appropriate equations from section 8.5.2. of Annex 4B shall be used.

The exact equations shall be applied for the calculation of the hydrocarbon emissions using the molar component ratios determined from the fuel consumption measurements of both fuels according to section A.65.4. of Appendix 5.

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

To determine the stoichiometric factor, the molar hydrogen ratio α of the fuel shall be calculated as the average molar hydrogen ratio of the fuel mix during the test according to section A.65.4. of Appendix 5.

Alternatively the F_s value of the gaseous fuel may be used in equation 59 or 60 of Annex 4B.”

Annex 11, Appendix 4, paragraph A.4.5.3., amend to read:

“A.4.5.3. Water quench check (Annex 4A, Appendix 5, paragraph 1.9.2.2. and Annex 4B, paragraph 9.3.9.2.2.)

~~The water quench check in paragraph 9.3.9.2.2. of Annex 4B to this regulation applies~~ to wet NO_x concentration measurements only. For dual-fuel engines fuelled with natural gas this check should be performed with an assumed H/C ratio of 4 (Methane). In that case $H_m = 2 \times A$. For dual-fuel engines fuelled with LPG this check should be performed with an assumed H/C ratio of 2.525. In that case $H_m = 1.25 \times A$.”

Annex 11, Appendix 5, , amend to read:

“Annex 11 – Appendix 5

Determination of molar component ratios and u_{gas} values for dual-fuel engines

A.65.1. General

This appendix defines the determination of molar component ratios and u_{gas} values for the dry-wet factor and emissions calculations for emission testing of dual-fuel engines.

A.65.2. Operation in dual-fuel mode

A.65.2.1. For Type 1A or 1B dual-fuel engines operating in dual-fuel mode the molar component ratios and the u_{gas} values of the gaseous fuel shall be used.

A.65.2.2. For Type ~~2A or~~ 2B dual-fuel engines operating in dual-fuel mode the molar component ratios and the u_{gas} values from tables A6.1 and A6.2 shall be used.

Table A6.1

Molar component ratios for a mixture of 50% gaseous fuel and 50% diesel fuel (mass %)

Gaseous Fuel	α	γ	δ	ε
CH ₄	2.8681	0	0	0.0040
G _R	2.7676	0	0	0.0040
G ₂₃	2.7986	0	0.0703	0.0043
G ₂₅	2.7377	0	0.1319	0.0045
Propane	2.2633	0	0	0.0039
Butane	2.1837	0	0	0.0038
LPG	2.1957	0	0	0.0038
LPG Fuel A	2.1740	0	0	0.0038
LPG Fuel B	2.2402	0	0	0.0039

Table ~~A6~~A5.2

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

Gaseous Fuel	ρ_e	Gas					
		NO _x	CO	HC	CO ₂	O ₂	CH ₄
		ρ_{gas} [kg/m ³]					
		2.053	1.250	^{a)}	1.9636	1.4277	0.716
u_{gas} ^{b)}							
CNG/LNG ^{c)}	1.2786	0.001606	0.000978	0.000528 ^{d)}	0.001536	0.001117	0.000560
Propane	1.2869	0.001596	0.000972	0.000510	0.001527	0.001110	0.000556
Butane	1.2883	0.001594	0.000971	0.000503	0.001525	0.001109	0.000556
LPG ^{e)}	1.2881	0.001594	0.000971	0.000506	0.001525	0.001109	0.000556

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, G_R, G₂₃ and G₂₅)

d) NMHC on the basis of CH_{2.93} (for total HC the u_{gas} coefficient of CH₄ shall be used)

e) u accurate within 0.2 % for mass composition of: C3 = 27 - 90 %; C4 = 10 - 73 % (LPG Fuels A and B)

A.65.2.3. For Type 3B dual-fuel engines operating in dual-fuel mode the molar component ratios and the u_{gas} values of diesel fuel shall be used.

A.65.2.4. For the calculation of the hydrocarbon emissions of all types of dual-fuel engines operating in dual-fuel mode, the following shall apply:

(a) For the calculation of the THC emissions, the u_{gas} value of the gaseous fuel shall be used.

(b) For the calculation of the NMHC emissions, the u_{gas} value on the basis of $CH_{2.93}$ shall be used.

(c) For the calculation of the CH_4 emissions, the u_{gas} value of CH_4 shall be used.

A.65.3. Operation in diesel mode

For Type 1B, 2B or 3B dual-fuel engines operating in diesel mode, the molar component ratios and the u_{gas} values of diesel fuel shall be used.

A.65.4. Determination of the molar component ratios when the fuel mix is known

A.65.4.1. Calculation of the fuel mixture components

$$w_{ALF} = \frac{w_{ALF1} \times q_{mf1} + w_{ALF2} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad (A6A5.1)$$

$$w_{BET} = \frac{w_{BET1} \times q_{mf1} + w_{BET2} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad (A6A5.2)$$

$$w_{GAM} = \frac{w_{GAM1} \times q_{mf1} + w_{GAM2} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad (A6A5.3)$$

$$w_{DEL} = \frac{w_{DEL1} \times q_{mf1} + w_{DEL2} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad (A6A5.4)$$

$$w_{EPS} = \frac{w_{EPS1} \times q_{mf1} + w_{EPS2} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad (A6A5.5)$$

where:

q_{mf1}	fuel mass flow rate of fuel1, kg/s
q_{mf2}	fuel mass flow rate of fuel2, kg/s
w_{ALF}	hydrogen content of fuel, per cent mass
w_{BET}	carbon content of fuel, per cent mass
w_{GAM}	sulphur content of fuel, per cent mass
w_{DEL}	nitrogen content of fuel, per cent mass
w_{EPS}	oxygen content of fuel, per cent mass

A.65.4.2. Calculation of the molar ratios of H, C, S, N and O related to C for the fuel mixture (according to ISO8178-1, Annex A-A.2.2.2).

$$\alpha = 11.9164 \times \frac{w_{ALF}}{w_{BET}} \quad (\text{A6A5.6})$$

$$\gamma = 0.37464 \times \frac{w_{GAM}}{w_{BET}} \quad (\text{A6A5.7})$$

$$\delta = 0.85752 \times \frac{w_{DEL}}{w_{BET}} \quad (\text{A6A5.8})$$

$$\varepsilon = 0.75072 \times \frac{w_{EPS}}{w_{BET}} \quad (\text{A6A5.9})$$

where:

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

referring to a fuel $\text{CH}_\alpha\text{O}_\varepsilon\text{N}_\delta\text{S}_\gamma$

A.65.4.3. Calculation of the u_{gas} values for a fuel mixture

The raw exhaust gas u_{gas} values for a fuel mixture can be calculated with the exact equations in section 8.4.2.4. of Annex 4B and the molar ratios calculated according to this section.

For systems with constant mass flow, equation 57 in section 8.5.2.3.1. of Annex 4B is needed to calculate the diluted exhaust gas u_{gas} values."