Commission Delegated Regulation (EU) 2017/654 of 19 December 2016 supplementing Regulation (EU) 2016/1628 of the European Parliament and of the Council with regard to technical and general requirements relating to emission limits and type-approval for internal combustion engines for non-road mobile machinery

ANNEX VIII

Performance requirements and test procedures for dual-fuel engines

1. Scope

This Annex shall apply for dual-fuel engines as defined in Article 3(18) of Regulation (EU) 2016/1628 when they are being operated simultaneously on both a liquid and a gaseous fuel (dual-fuel mode).

This Annex shall not apply for testing engines, including dual-fuel engines, when they are being operated solely on liquid or solely on gaseous fuels (i.e. when the GER is either 1 or 0 according to the type of fuel). In this case the requirements are the same as for any single-fuel engine.

Type approval of engines operated simultaneously on a combination of more than one liquid fuel and a gaseous fuel or a liquid fuel and more than one gaseous fuel shall follow the procedure for new technologies or new concepts given in Article 33 of Regulation (EU) 2016/1628.

2. Definitions and abbreviations

For the purposes of this Annex the following definitions shall apply:

2.1. 'GER (Gas Energy Ratio)' has the meaning defined in Article 3(20) of Regulation (EU) 2016/1628 based on the lower heating value;

2.2. 'GER_{cycle}' means the average GER when operating the engine on the applicable engine test cycle;

2.3. 'Dual-fuel Type 1A engine' means either:

(a) a dual-fuel engine of a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the hot-start NRTC test-cycle with an average gas energy ratio that is not lower than 90 % ($GER_{NRTC, hot} \geq 0,9$) and that does not idle using exclusively liquid fuel, and that has no liquid-fuel mode, or;

(b) a dual-fuel engine of any (sub-) category other than a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the NRSC with an average gas energy ratio that is not lower than 90 % ($GER_{NRSC} \geq 0,9$) and that does not idle using exclusively liquid fuel, and that has no liquid-fuel mode;

2.4. 'Dual-Fuel Type 1B engine' means either:

(a) a dual-fuel engine of a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the hot-start NRTC test-cycle with an average gas energy ratio that is not lower than 90 % ($GER_{NRTC, hot} \geq 0,9$) and that does not idle using exclusively liquid fuel in dual-fuel mode, and that has a liquid-fuel mode, or;

(b) a dual-fuel engine of any (sub-) category other than a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the NRSC with an average gas energy ratio that is not lower than 90 % ($GER_{NRSC} \geq 0,9$) and that does not idle using exclusively liquid fuel in dual-fuel mode, and that has a liquid-fuel mode;

2.5. 'Dual-Fuel Type 2A engine' means either:

(a) a dual-fuel engine of a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the hot-start NRTC test-cycle with an average gas energy ratio between 10 % and 90 % ($0,1 < GER_{NRTC, hot} < 0,9$) and that has no liquid-fuel mode or that operates over the hot-start NRTC test-cycle with an average gas energy ratio that is not lower than 90 % ($GER_{NRTC, hot} \geq 0,9$), but that idles using exclusively liquid fuel, and that has no liquid-fuel mode, or;

(b) a dual-fuel engine of any (sub-) category other than a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the NRSC with an average gas energy ratio between 10 % and 90 % ($0,1 < GER_{NRSC} < 0,9$), and that has no liquid-fuel mode or that operates over the NRSC with an average gas energy ratio that is not lower than 90 % ($GER_{NRSC} \geq 0,9$), but that idles using exclusively liquid fuel, and that has no liquid-fuel mode;

2.6. ‘Dual-Fuel Type 2B engine’ means either:

(a) a dual-fuel engine of a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the hot-start NRTC test-cycle with an average gas energy ratio between 10 % and 90 % ($0,1 < GER_{NRTC, hot} < 0,9$) and that has a liquid-fuel mode or that operates over the hot-start NRTC test-cycle with an average gas energy ratio that is not lower than 90 % ($GER_{NRTC, hot} \geq 0,9$), and that has a liquid-fuel mode but that can idle using exclusively liquid fuel in dual-fuel mode, or;

(b) a dual-fuel engine of any (sub-) category other than a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the NRSC with an average gas energy ratio between 10 % and 90 % ($0,1 < GER_{NRSC} < 0,9$), and that has no liquid-fuel mode or that operates over the NRSC with an average gas energy ratio that is not lower than 90 % ($GER_{NRSC} \geq 0,9$), and that has a liquid-fuel mode but that can idle using exclusively liquid fuel in dual-fuel mode;

2.7. ‘Dual-Fuel Type 3B engine’ means either:

(a) a dual-fuel engine of a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the hot-start NRTC test-cycle with an average gas energy ratio that does not exceed 10 % ($GER_{NRTC, hot} \leq 0,1$) and that has a liquid-fuel mode, or:

(b) a dual-fuel engine of any (sub-) category other than a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the NRSC with an average gas energy ratio that does not exceed 10 % ($GER_{NRSC} \leq 0,1$) and that has a liquid-fuel mode;

3. **Dual-fuel specific additional approval requirements**

3.1. Engines with operator-adjustable control of GER_{cycle}.

In the case for a given engine type the value of GER_{cycle} can be reduced from the maximum by an operator-adjustable control, the minimum GER_{cycle} shall not be limited but the engine shall be capable of meeting the emission limit values at any value of GER_{cycle} permitted by the manufacturer.

4. **General requirements**

4.1. Operating modes of dual-fuel engines

4.1.1. Conditions for a dual-fuel engine to operate in liquid mode

A dual-fuel engine may only operate in liquid-fuel mode if, when operating in liquid-fuel mode, it has been certified according to all the requirements of this Regulation concerning operation solely on the specified liquid fuel.

When a dual-fuel engine is developed from an already certified liquid-fuel engine, then a new EU type approval certificate is required in the liquid-fuel mode.

4.1.2. Conditions for a dual-fuel engine to idle using liquid fuel exclusively

4.1.2.1. Dual-fuel Type 1A engines shall not idle using liquid fuel exclusively except under the conditions defined in point 4.1.3 for warm-up and start.

4.1.2.2. Dual-fuel Type 1B engines shall not idle using liquid fuel exclusively in dual-fuel mode.

4.1.2.3. Dual-fuel Types 2A, 2B and 3B engines may idle using liquid fuel exclusively.

4.1.3. Conditions for a dual-fuel engine to warm-up or start using liquid fuel solely

4.1.3.1. A Type 1B, Type 2B, or Type 3B dual-fuel engine may warm-up or start using liquid fuel solely. In the case that the emission control strategy during warm-up or start-up in dual-fuel mode is the same as the corresponding emission control strategy in liquid-fuel mode the engine may operate in dual-fuel mode during warm-up or start-up. If this condition is not met the engine shall only warm-up or start-up using liquid fuel solely when in liquid-fuel mode.

4.1.3.2. A Type 1A or Type 2A dual-fuel engine may warm-up or start-up using liquid fuel solely. However, in that case, the strategy shall be declared as an AECS and the following additional requirements shall be met:

4.1.3.2.1. The strategy shall cease to be active when the coolant temperature has reached a temperature of 343 K (70 °C), or within 15 minutes after it has been activated, whichever occurs first; and

4.1.3.2.2. The service mode shall be activated while the strategy is active.

4.2. Service mode

4.2.1. Conditions for dual-fuel engines to operate in service mode

When an engine is operating in service mode it is subject to an operability restriction and is temporarily exempted from complying with the requirements related to exhaust emissions and NO_x control described in this Regulation.

4.2.2. Operability restriction in service mode

4.2.2.1. Requirement for engine categories other than IWP, IWA, RLL and RLR

The operability restriction applicable to non-road mobile machinery fitted with a dual-fuel engine of engine categories other than IWP, IWA, RLL and RLR operated in service mode is the one activated by the 'severe inducement system' specified in point 5.4 of Appendix 1 of Annex IV.

In order to account for safety concerns and to allow for self-healing diagnostics, use of an inducement override function for releasing full engine power is permitted according to point 5.5 of Appendix 1 of Annex IV.

The operability restriction shall not otherwise be deactivated by either the activation or deactivation of the warning and inducement systems specified in Annex IV.

The activation and the deactivation of the service mode shall not activate or deactivate the warning and inducement systems specified in Annex IV.

4.2.2.2. Requirement for engine categories IWP, IWA, RLL and RLR

For engines of category IWP, IWA, RLL and RLR, in order to account for safety concerns operation in service mode shall be permitted without limitation on engine torque or speed. In this case whenever an operability restriction would have been active according to point 4.2.2.3 the on-board computer log shall record in non-volatile computer memory all incidents of engine operation where the service mode is active in a manner to ensure that the information cannot be intentionally deleted.

It shall be possible for national inspection authorities to read these records with a scan tool. **[**[F1]A description of the connection for, and method to read, those records shall be included in the information folder as set out in Part A of Annex I of Implementing Regulation (EU) 2017/656.**]**

Textual Amendments

F1 Inserted by Commission Delegated Regulation (EU) 2018/989 of 18 May 2018 amending and correcting Delegated Regulation (EU) 2017/654 supplementing Regulation (EU) 2016/1628 of the European Parliament and of the Council with regard to technical and general requirements relating to emission limits and type-approval for internal combustion engines for non-road mobile machinery (Text with EEA relevance).

4.2.2.3. Activation of the operability restriction

The operability restriction shall be automatically activated when the service mode is activated.

In the case where the service mode is activated according to point 4.2.3 because of a malfunction of the gas supply system, the operability restriction shall become active within 30 minutes operating time after the service mode is activated.

In the case where the service mode is activated because of an empty gaseous fuel tank, the operability restriction shall become active as soon as the service mode is activated.

4.2.2.4. Deactivation of the operability restriction

The operability restriction system shall be deactivated when the engine no longer operates in service mode.

4.2.3. Unavailability of gaseous fuel when operating in a dual-fuel mode

In order to permit the non-road mobile machinery to move to a position of safety, upon detection of an empty gaseous fuel tank, or of a malfunctioning gas supply system:

(a) Dual-fuel engines of Types 1A and 2A shall activate the service mode;

(b) Dual-fuel engines of Types 1B, 2B and 3B shall operate in liquid mode.

4.2.3.1. Unavailability of gaseous fuel — empty gaseous fuel tank

In the case of an empty gaseous fuel tank, the service mode or, as appropriate according to point 4.2.3, the liquid fuel mode shall be activated as soon as the engine system has detected that the tank is empty.

When the gas availability in the tank again reaches the level that justified the activation of the empty tank warning system specified in point 4.3.2, the service mode may be deactivated, or, when appropriate, the dual-fuel mode may be reactivated.

4.2.3.2. Unavailability of gaseous fuel — malfunctioning gas supply

In the case of a malfunctioning gas supply system that causes the unavailability of gaseous fuel, the service mode or, as appropriate according to point 4.2.3, the liquid fuel mode shall be activated when gaseous fuel supply is not available.

As soon as the gaseous fuel supply becomes available the service mode may be deactivated, or, when appropriate, the dual-fuel mode may be reactivated.

4.3. Dual-fuel indicators

4.3.1. Dual-fuel operating mode indicator

The non-road mobile machinery shall provide to the operator a visual indication of the mode under which the engine operates (dual-fuel mode, liquid mode, or service mode).

The characteristics and the location of this indicator shall be left to the discretion of the OEM and may be part of an already existing visual indication system.

This indicator may be completed by a message display. The system used for displaying the messages referred to in this point may be the same as the ones used for NO_x control diagnostics, or other maintenance purposes.

The visual element of the dual-fuel operating mode indicator shall not be the same as the one used for the purpose of NO_x control diagnostics, or for other engine maintenance purposes.

Safety alerts always have display priority over the operating mode indication.

4.3.1.1. The dual-fuel mode indicator shall be set to service mode as soon as the service mode is activated (i.e. before it becomes actually active) and the indication shall remain as long as the service mode is active.

4.3.1.2. The dual-fuel mode indicator shall be set for at least one minute on dual-fuel mode or liquid-fuel mode as soon as the engine operating mode is changed from liquid fuel to dual-fuel mode or vice-versa. This indication is also required for at least one minute at key-on, or at the request of the manufacturer at engine cranking. The indication shall also be given upon the operator's request.

4.3.2. Empty gaseous fuel tank warning system (dual-fuel warning system)

Non-road mobile machinery fitted with a dual-fuel engine shall be equipped with a dual-fuel warning system that alerts the operator that the gaseous fuel tank will soon become empty.

The dual-fuel warning system shall remain active until the tank is refuelled to a level above which the warning system is activated.

The dual-fuel warning system may be temporarily interrupted by other warning signals providing important safety-related messages.

It shall not be possible to turn off the dual-fuel warning system by means of a scan-tool as long as the cause of the warning activation has not been rectified.

4.3.2.1. Characteristics of the dual-fuel warning system

The dual-fuel warning system shall consist of a visual alert system (icon, pictogram, etc.) left to the choice of the manufacturer.

It may include, at the choice of the manufacturer, an audible component. In that case, the cancelling of that component by the operator is permitted.

The visual element of the dual-fuel warning system shall not be the same as the one used for the purpose of NO_x control diagnostics, or for other engine maintenance purposes.

In addition the dual-fuel warning system may display short messages, including messages indicating clearly the remaining distance or time before the activation of the operability restriction.

The system used for displaying the warning or messages referred to in this point may be the same as the one used for displaying the warning or messages related the NO_x control diagnostics, or warning or messages for other maintenance purposes.

A facility to permit the operator to dim the visual alarms provided by the warning system may be provided on non-road mobile machinery for use by the rescue services or on non-road mobile machinery designed and constructed for use by the armed services, civil defense, fire services and forces responsible for maintaining public order.

4.4. Communicated torque

4.4.1. Communicated torque when a dual-fuel engine operates in dual-fuel mode

When a dual-fuel engine operates in dual-fuel mode:

(a) The reference torque curve retrievable shall be the one obtained when that engine is tested on an engine test bench in the dual-fuel mode;

(b) The recorded actual torques (indicated torque and friction torque) shall be the result of the dual-fuel combustion and not the one obtained when operating with liquid fuel exclusively.

4.4.2. Communicated torque when a dual-fuel engine operates in liquid-fuel mode

When a dual-fuel engine operates in liquid-fuel mode, the reference torque curve retrievable shall be the one obtained when the engine is tested on an engine test bench in liquid-fuel mode.

4.5. Additional requirements

4.5.1. Where used for a dual-fuel engine, adaptive strategies shall, in addition to satisfying the requirements of Annex IV, additionally comply with the following requirements:

(a) The engine shall always remain within the dual-fuel engine type (that is Type 1A, Type 2B, etc.) that has been declared for EU type-approval; and

(b) **[**[F2]In case of a Type 2 engine, the resulting difference between the highest and the lowest maximum GER_{cycle} within the family shall never exceed the range set out in point 2.4.15 of Annex IX to Implementing Regulation (EU) 2017/656, except as permitted by point 3.1.**]**

Textual Amendments

F2 Substituted by Commission Delegated Regulation (EU) 2018/989 of 18 May 2018 amending and correcting Delegated Regulation (EU) 2017/654 supplementing Regulation (EU) 2016/1628 of the European Parliament and of the Council with regard to technical and general requirements relating to emission limits and type-approval for internal combustion engines for non-road mobile machinery (Text with EEA relevance).

4.6 The type-approval shall be conditional upon providing to the OEM and end-users, **[**F3 as required by**]** in accordance with Annexes XIV and XV, instructions for installation and operation of the dual-fuel engine including the service mode set out in point 4.2 and the dual-fuel indicator system set out in point 4.3.

Textual Amendments

F3 Deleted by Commission Delegated Regulation (EU) 2018/989 of 18 May 2018 amending and correcting Delegated Regulation (EU) 2017/654 supplementing Regulation (EU) 2016/1628 of the European Parliament and of the Council with regard to technical and general requirements relating to emission limits and type-approval for internal combustion engines for non-road mobile machinery (Text with EEA relevance).

5. **Performance requirements**

5.1. The performance requirements, including emission limit values, and the requirements for EU type-approval applicable to dual-fuel engines are identical to those of any other engine of the respective engine category as set out in this Regulation and in Regulation (EU) 2016/1628, except as set out in this Annex.

5.2 The hydrocarbon (HC) limit for operation in dual-fuel mode shall be determined using the average gas energy ratio (GER) over the specified test cycle as set out in Annex II to Regulation (EU) 2016/1628.

5.3 The technical requirements on emission control strategies, including documentation required to demonstrate these strategies, technical provisions to resist tampering and the prohibition of defeat devices are identical to those of any other engine of the respective engine category as set out in Annex IV.

5.4 The detailed technical requirements on the area associated with the relevant NRSC, within which there is control of the amount that the emissions shall be permitted to exceed the limit values set out in Annex II to Regulation (EU) 2016/1628 are identical to those of any other engine of the respective engine category as set out in Annex IV.

6. **Demonstration requirements**

6.1. The demonstration requirements applicable to dual-fuel engines are identical to those of any other engine of the respective engine category as set out in this Regulation and in Regulation (EU) 2016/1628, except as set out in section 6.

6.2. Compliance with the applicable limit values shall be demonstrated in dual-fuel mode.

6.3. For dual-fuel engine types with a liquid-fuel mode (i.e. types 1B, 2B, 3B) compliance with the applicable limit values shall additionally be demonstrated in liquid-fuel mode.

6.4. Additional demonstration requirements in case of a Type 2 engine

[F2 6.4.1 The manufacturer shall present the approval authority with evidence showing that the GER_{cycle} span of all members of the dual-fuel engine family remains within the range set out in point 2.4.15 of Annex IX to Implementing Regulation (EU) 2017/656, or in the case of engines with an operator-adjustable GER_{cycle} satisfy the requirements of point 6.5 (for example, through algorithms, functional analyses, calculations, simulations, results of previous tests, etc.).**]**

6.5 Additional demonstration requirements in case of an engine with an operator-adjustable GER_{cycle}

6.5.1 Compliance with the applicable limit values shall be demonstrated at the minimum and maximum value of GER_{cycle} permitted by the manufacturer.

6.6. Requirements for demonstrating the durability of a dual-fuel engine

6.6.1 Provisions of Annex III shall apply.

6.7. Demonstration of the dual-fuel indicators, warning and operability restriction

6.7.1 As part of the application for EU type-approval under this Regulation, the manufacturer shall demonstrate the operation of dual-fuel indicators and of the warning and operability restriction in accordance with the provisions of Appendix 1.

[[F1]6.8. Documentation of the demonstration

A demonstration report shall document the demonstration conducted pursuant to points 6.1 to 6.7.1 The report shall:

(a) describe the demonstration performed, including the applicable test cycle;

(b) be included in the information folder as set out in Part A of Annex I of Implementing Regulation (EU) 2017/656.**]**

7. **Requirements to ensure the correct operation of NO_x control measures**

7.1. Annex IV (technical requirements on NO_x control measures) shall apply to dual-fuel engines, whether operating in dual-fuel or liquid mode.

7.2. Additional NO_x control requirements in case of Type 1B, Type 2B and Type 3B dual-fuel engines

7.2.1. The torque considered to apply to the severe inducement defined in point 5.4 of Appendix 1 of Annex IV shall be the lowest of the torques obtained in liquid-fuel mode and in dual-fuel mode.

7.2.2 A possible influence of the mode of operation on the malfunction detection shall not be used to extend the time until an inducement becomes active.

7.2.3. In the case of malfunctions the detection of which does not depend on the operation mode of the engine, the mechanisms specified in Appendix 1 of Annex IV that are associated with the DTC status shall not depend on the operation mode of the engine (for example, if a DTC reached the potential status in dual-fuel mode, it will get the confirmed and active status the next time the failure is detected, even in liquid-fuel mode).

7.2.4. In the case of malfunctions where the detection depends on the operation mode of the engine, DTCs shall not get a previously active status in a different mode than the mode in which they reached the confirmed and active status.

7.2.5. A change of the mode of operation (dual-fuel to liquid fuel or vice-versa) shall not stop nor reset the mechanisms implemented to comply with the requirements set out in Annex IV (e.g. counters). However, in the case where one of these mechanisms (for example a diagnostic system) depends on the actual operation mode the counter associated with that mechanism may, at the request of the manufacturer and upon approval of the approval authority:

(a) Halt and, when applicable, hold their present value when the operation mode changes;

(b) Restart and, when applicable, continue counting from the point at which they have been held when the operation mode changes backs to the other operation mode.

Appendix 1

Dual-fuel engine dual-fuel indicator, warning system, operability restriction — Demonstration requirements

1. **Dual-fuel indicators**

1.1. Dual-fuel mode indicator

The ability of the engine to command the activation of the dual-fuel mode indicator when operating in dual-fuel mode shall be demonstrated at EU type-approval.

1.2. Liquid-fuel mode indicator

In the case of a Type 1B, Type 2B, or Type 3B dual-fuel engine the ability of the engine to command the activation of the liquid-fuel mode indicator when operating in liquid-fuel mode shall be demonstrated at EU type-approval.

1.3. Service mode indicator

The ability of the engine to command the activation of the service mode indicator when operating in service mode shall be demonstrated at EU type-approval.

1.3.1. When so-equipped it is sufficient to perform the demonstration related to the service mode indicator by activating a service mode activation switch and to present the approval authority with evidence showing that the activation occurs when the service mode is commanded by the engine system itself (for example, through algorithms, simulations, result of in-house tests, etc. …).

2. **Warning system**

The ability of the engine to command the activation of the warning system in the case that the amount of gaseous fuel in the gaseous fuel tank is below the warning level, shall be demonstrated at EU type-approval. For that purpose the actual amount of gaseous fuel may be simulated.

3. **Operability restriction**

In the case of a Type 1A or Type 2A dual-fuel engine the ability of the engine to command the activation of the operability restriction upon detection of an empty gaseous fuel tank and of a malfunctioning gas supply system shall be demonstrated at EU type-approval. For that purpose the empty gaseous fuel tank and the malfunctioning of the gas supply may be simulated.

3.1. It is sufficient to perform the demonstration in a typical use-case selected with the agreement of the approval authority and to present that authority with evidence showing that the operability restriction occurs in the other possible use-cases (for example, through algorithms, simulations, result of in-house tests, etc.).

Appendix 2

Emission test procedure requirements for dual-fuel engines

1. General

This point defines the additional requirements and exceptions of this Annex 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 point 6.10 of Annex VI. 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 under Regulation (EU) 2016/1628.

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.

2. Test conditions

Section 6 of Annex VI shall apply.

3. Test procedures

Section 7 of Annex VI shall apply.

4. Measurement procedures

Section 8 of Annex VI shall apply except as set out in this Appendix.

A full-flow dilution measurement procedure for dual-fuel engines is illustrated in Figure 6.6 of Annex VI (CVS system).

This measurement procedure ensures that the variation of the fuel composition during the test will mainly influence the hydrocarbon measurement results. **[**[F2]This shall be compensated via one of the methods described in point 7**]**.

Raw gaseous/partial flow measurement illustrated in Figure 6.7 of Annex VI may be used with some precautions regarding exhaust gas mass flow determination and calculation methods.

5. Measurement equipment

Section 9 of Annex VI shall apply.

6. Particle number emissions measurement

Appendix 1 of Annex VI shall apply.

7. Emission calculation

The emission calculation shall be performed according to Annex VII except as set out in this section. The additional requirements set out in point 7.1 shall apply for mass-based calculations and the additional requirements set out in point 7.2 shall apply for molar-based calculations.

The emission calculation requires knowledge of the composition of the fuels being used. When a gaseous fuel is supplied with a certificate confirming the properties of the fuel (e.g. gas from bottles) it is acceptable to use the composition specified by the supplier. Where the composition is not available (e.g. pipeline fuel) the fuel composition shall be analysed at least prior to and after the engine emission test is conducted. More frequent analysis shall be permitted and the results used in the calculation.

Where the gas energy ratio (GER) is used it shall be consistent with the definition in Article 3(2) of Regulation (EU) 2016/1628 and the specific provisions on total hydrocarbon (HC) limits for fully and partially gaseous-fuelled engines in Annex II of that Regulation. The average value of GER over the cycle shall be calculated by one of the following methods:

(a) For hot-start NRTC and RMC NRSC by dividing the sum of the GER at each measurement point by the number of measurement points;

(b) 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 1 of Annex XVII for the applicable cycle.

7.1. Mass-based emission calculation

Section 2 of Annex VII shall apply except as set out in this section.

7.1.1. Dry/wet correction

7.1.1.1. Raw exhaust gas

Equations (7-3) and (7-4) of Annex VII shall be used to calculate the dry/wet correction.

The fuel specific parameters shall be determined in accordance with point 7.1.5.

7.1.1.2. Diluted exhaust gas

Equation (7-3) with either equation (7-25) or (7-26) of Annex VII 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 in accordance with point 7.1.5.

7.1.2. NO_x correction for humidity

The NO_x humidity correction for compression ignition engines as specified in equation (7-9) of Annex VII shall be used.

7.1.3. Partial flow dilution (PFS) and raw gaseous measurement

7.1.3.1. Determination of exhaust gas mass flow

The exhaust gas mass flow shall be determined using a raw exhaust flow meter as described in point 9.4.5.3 of Annex VI.

Alternatively the airflow and air to fuel ratio measurement method according to equations (7-17) to (7-19) of Annex VII may be used only if α, γ, δ and ε values are determined according to point 7.1.5.3. The use of a zirconia-type sensor to determine the air fuel ratio is not allowed.

In the case of testing engines subject to steady-state test cycles only the exhaust gas mass flow may be determined by the air and fuel measurement method in accordance with equation (7-15) of Annex VII.

7.1.3.2. Determination of the gaseous components

Point 2.1 of Annex VII shall apply except as set out in this section.

The possible variation of fuel composition will influence all the u_{gas} factors and molar component ratios used in the emission calculations. One of the following approaches shall be used to determine u_{gas} factors and molar component ratios at the choice of the manufacturer.

(a) The exact equations in point 2.1.5.2 or 2.2.3 of Annex VII shall be applied to calculate instantaneous values of u_{gas} using the instantaneous proportions of liquid and gaseous fuel (determined from instantaneous fuel consumption measurements or calculations) and instantaneous molar component ratios determined in accordance with point 7.1.5; or,

(b) When the mass-based calculation in section 2 of Annex VII is used for the specific case of a dual-fuel engine operated on gas and diesel fuel, tabulated values may be used for the molar component ratios and u_{gas} values. These tabulated values shall be applied as follows:

(i) For engines operated on the applicable test cycle with an average gas energy ratio greater than or equal to 90 % (GER ≥ 0,9) the required values shall be those for the gaseous fuel taken from Tables 7.1 or 7.2 of Annex VII.

(ii) For engines operated on the applicable test cycle with an average gas energy ratio between 10 % and 90 % (0,1 < GER < 0,9) the required values shall be assumed to be represented by those for a mixture of 50 % gaseous fuel and 50 % diesel fuel taken from Tables 8.1 and 8.2.

(iii) For engines operated on the applicable test cycle with an average gas energy ratio less than or equal to 10 % (GER ≤ 0,1) the required values shall be those for diesel fuel taken from taken from Tables 7.1 or 7.2 of Annex VII.

(iv) For the calculation of HC emissions the u_{gas} value of the gaseous fuel shall be used in all cases irrespective of the average gas energy ratio (GER).

TABLE 8.1

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

7.1.3.2.1. Mass per test of a gaseous emission

[F2 In the case that the exact equations are applied to calculate instantaneous values of u_{gas} in accordance with paragraph 7.1.3.2(a) then, when calculating the mass per test of a gaseous emission for transient (NRTC and LSI-NRTC) test cycles and RMC, u_{gas} shall be included in the summation in equation (7-2) of point 2.1.2 of Annex VII by means of equation (8-1):]

$m_{gas} = \frac{1}{f} \times k_h \times k \times \sum_{N}^{i=1} (u_{gas,i} \times q_{mew,i} \times c_{gas,i})$	(8-1)

Where:

$u_{gas,i}$ is the instantaneous value of u_{gas}

The remaining terms of the equation are as set out in point 2.1.2 of Annex VII.

TABLE 8.2

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

Gaseous fuel	**Gas**						
	ρ_e	**NO_x**	**CO**	**HC**	**CO_2**	**O_2**	**CH_4**
				ρ_{gas} [kg/m³]			
		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 λ = 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 % (CH_4, G_{20}, G_{23}, and G_{25}).

d NMHC on the basis of $CH_{2,93}$ (for total HC the u_{gas} coefficient of CH_4 shall be used).

e *u* accurate within 0,2 % for mass composition of: C_3 = 27 – 90 %; C4 = 10 – 73 % (LPG Fuels A and B)

7.1.3.3. Particulate determination

For the determination of particulate emissions with the partial dilution measurement method the calculation shall be performed according to the equations in point 2.3 of Annex VII.

[F2The requirements of point 8.2.1.2 of Annex VI shall apply for controlling the dilution ratio. In particular, if the combined transformation time of the exhaust gas flow measurement and the partial flow system exceeds 0,3 s, look-ahead control based on a pre-recorded test run shall be used. In this case, the combined rise time shall be ≤ 1 s and the combined delay time ≤ 10 s. Except in the case that the exhaust gas mass flow is measured directly the determination of exhaust gas mass flow shall use values of α, γ, δ and ε determined in accordance with point 7.1.5.3.]

The quality check according to point 8.2.1.2 of Annex VI shall be performed for each measurement.

7.1.3.4. Additional requirements regarding the exhaust gas mass flow meter

[F2The flow meter referred to in points 9.4.5.3 and 9.4.5.4 of Annex VI 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 gas density) may be neglected.

7.1.4. Full flow dilution measurement (CVS)

Point 2.2 of Annex VII shall apply except as set out in this section.

The possible variation of the fuel composition will mainly influence the tabulated hydrocarbon u_{gas} value. 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 point 7.1.5.

[F27.1.4.1. Determination of the background corrected concentrations]

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 point 7.1.5.3.

Alternatively the F_s value of the gaseous fuel may be used in equation (7-28) of Annex VII.

7.1.5. Determination of molar component ratios

7.1.5.1. General

This section shall be used for the determination of molar component ratios when the fuel mix is known (exact method).

[F27.1.5.2. Calculation of the fuel mixture components

Equations (8-2) to (8-7) shall be used to calculate the elemental composition of the fuel mixture:

$q_{mf} = q_{mf1} + q_{mf2}$	(8-2)
$w_H = \frac{w_{H1} \times q_{mf1} + w_{H2} \times q_{mf2}}{q_{mf1} + q_{mf2}}$	(8-3)
$w_C = \frac{w_{C1} \times q_{mf1} + w_{C2} \times q_{mf2}}{q_{mf1} + q_{mf2}}$	(8-4)
$w_S = \frac{w_{S1} \times q_{mf1} + w_{S2} \times q_{mf2}}{q_{mf1} + q_{mf2}}$	(8-5)
$w_N = \frac{w_{N1} \times q_{mf1} + w_{N2} \times q_{mf2}}{q_{mf1} + q_{mf2}}$	(8-6)
$w_O = \frac{w_{O1} \times q_{mf1} + w_{O2} \times q_{mf2}}{q_{mf1} + q_{mf2}}$	(8-7)

where:

q_{mf1} is the fuel mass flow rate of fuel 1 [kg/s]
q_{mf2} is the fuel mass flow rate of fuel 2 [kg/s]
w_H is the hydrogen content of fuel [% mass]
w_C is the carbon content of fuel [% mass]
w_S is the sulphur content of fuel [% mass]
w_N is the nitrogen content of fuel [% mass]
w_O is the oxygen content of fuel [% mass]]

[F1 7.1.5.3. Calculation of the molar ratios of H, C, S, N and O related to C for the fuel mixture

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

$\alpha = 11{,}9164 \times \frac{w_H}{w_C}$	(8-8)
$\gamma = 0{,}37464 \times \frac{w_S}{w_C}$	(8-9)
$\delta = 0{,}85752 \times \frac{w_N}{w_C}$	(8-10)
$\varepsilon = 0{,}75072 \times \frac{w_O}{w_C}$	(8-11)

where:

w_H	is the hydrogen content of fuel, mass fraction [g/g] or [% mass]
w_C	is the carbon content of fuel, mass fraction [g/g] or [% mass]
w_S	is the sulphur content of fuel, mass fraction [g/g] or [% mass]
w_N	is the nitrogen content of fuel, mass fraction [g/g] or [% mass]
w_O	is the oxygen content of fuel, mass fraction [g/g] or [% mass]
α	is the molar hydrogen ratio (H/C)
γ	is the molar sulphur ratio (S/C)
δ	is the molar nitrogen ratio (N/C)
ε	is the molar oxygen ratio (O/C)

referring to a fuel $CH_{\alpha}O_{\varepsilon}N_{\delta}S_{\gamma}$ **]**

7.2. Molar-based emission calculation

Annex VII section 3 shall apply except as set out in this section.

7.2.1. NO_x correction for humidity

Equation (7-102) of Annex VII (correction for compression ignition engines) shall be used.

7.2.2. Determination of exhaust gas mass flow when not using a raw exhaust flow meter

Equation (7-112) of Annex VII (molar flow rate calculation based on intake air) shall be used. Equation (7-113) of Annex VII (molar flow rate calculation based on fuel mass flow rate) may alternatively be used only when conducting an NRSC test.

7.2.3. Molar component ratios for determination of the gaseous components

The exact approach shall be used to determine the molar component ratios using the instantaneous proportions of liquid and gaseous fuel determined from instantaneous fuel consumption measurements or calculations. **[**F2 The instantaneous molar component ratios shall be input in the equations (7-88), (7-90), and (7-91) of Annex VII for the continuous chemical balance.**]**

The determination of the ratios shall be either performed according to point 7.2.3.1 or point 7.1.5.3.

Gaseous fuels, either blended or sourced from a land line, may contain significant amounts of inert constituents such as CO_2 and N_2. The manufacturer shall either include these constituents in the atomic ratio calculations described in point 7.2.3.1 or point 7.1.5.3 as applicable, or, alternatively, the manufacturer shall exclude the inert constituents from the atomic ratios and allocate them appropriately to the chemical balance intake air parameters x_{O2int}, x_{CO2int}, and x_{H2Oint} in point 3.4.3 of Annex VII.

7.2.3.1. Determination of molar component ratios

Instantaneous molar component ratios of the number of hydrogen, oxygen, sulphur, and nitrogen atoms to carbons atoms in the mixed fuel for the dual-fuel engines may be calculated by means of equations (8-12) to (8-15):

$\alpha(t)=\frac{\frac{\dot{m}_{liquid}(t)\times w_{H,liquid}}{M_H}+\frac{\dot{m}_{gas}(t)\times w_{H,gas}}{M_H}}{\frac{\dot{m}_{liquid}(t)\times w_{C,liquid}}{M_C}+\frac{\dot{m}_{gas}(t)\times w_{C,gas}}{M_C}}=\frac{M_C\times\left[\left(\dot{m}_{liquid}(t)\times w_{H,liquid}\right)+\left(\dot{m}_{gas}(t)\times w_{H,gas}\right)\right]}{M_H\times\left[\left(\dot{m}_{liquid}(t)\times w_{C,liquid}\right)+\left(\dot{m}_{gas}(t)\times w_{C,gas}\right)\right]}$	(8-12)
$\beta(t)=\frac{\frac{\dot{m}_{liquid}(t)\times w_{O,liquid}}{M_O}+\frac{\dot{m}_{gas}(t)\times w_{O,gas}}{M_O}}{\frac{\dot{m}_{liquid}(t)\times w_{C,liquid}}{M_C}+\frac{\dot{m}_{gas}(t)\times w_{C,gas}}{M_C}}=\frac{M_C\times\left[\left(\dot{m}_{liquid}(t)\times w_{O,liquid}\right)+\left(\dot{m}_{gas}(t)\times w_{O,gas}\right)\right]}{M_O\times\left[\left(\dot{m}_{liquid}(t)\times w_{C,liquid}\right)+\left(\dot{m}_{gas}(t)\times w_{C,gas}\right)\right]}$	(8-13)
$\gamma(t)=\frac{\frac{\dot{m}_{liquid}(t)\times w_{S,liquid}}{M_S}+\frac{\dot{m}_{gas}(t)\times w_{S,gas}}{M_S}}{\frac{\dot{m}_{liquid}(t)\times w_{C,liquid}}{M_C}+\frac{\dot{m}_{gas}(t)\times w_{C,gas}}{M_C}}=\frac{M_C\times\left[\left(\dot{m}_{liquid}(t)\times w_{S,liquid}\right)+\left(\dot{m}_{gas}(t)\times w_{S,gas}\right)\right]}{M_S\times\left[\left(\dot{m}_{liquid}(t)\times w_{C,liquid}\right)+\left(\dot{m}_{gas}(t)\times w_{C,gas}\right)\right]}$	(8-14)
$\delta(t)=\frac{\frac{\dot{m}_{liquid}(t)\times w_{N,liquid}}{M_N}+\frac{\dot{m}_{gas}(t)\times w_{N,gas}}{M_N}}{\frac{\dot{m}_{liquid}(t)\times w_{C,liquid}}{M_C}+\frac{\dot{m}_{gas}(t)\times w_{C,gas}}{M_C}}=\frac{M_C\times\left[\left(\dot{m}_{liquid}(t)\times w_{N,liquid}\right)+\left(\dot{m}_{gas}(t)\times w_{N,gas}\right)\right]}{M_N\times\left[\left(\dot{m}_{liquid}(t)\times w_{C,liquid}\right)+\left(\dot{m}_{gas}(t)\times w_{C,gas}\right)\right]}$	(8-15)

Where:

$w_{i,fuel}$	=	the mass fraction of the element of interest, C, H, O, S, or N, of liquid or gaseous fuel;
$\dot{m}_{liquid}(t)$	=	the instantaneous mass flow rate of the liquid fuel at time t, [kg/hr];
$\dot{m}_{gas}(t)$	=	the instantaneous mass flow rate of the gaseous fuel at time t, [kg/hr];

[[F2]In cases where exhaust gas mass flow rate is calculated based on the mixed fuel rate then w_C in equation (7-113) of Annex VII shall be calculated by means of equation (8-16):**]**

$w_C=\frac{\dot{m}_{liquid}\times w_{C,liquid}+\dot{m}_{gas}\times w_{C,gas}}{\dot{m}_{liquid}+\dot{m}_{gas}}$	(8-16)

Where:

w_C	=	the mass fraction of the carbon in the diesel or gaseous fuel;
$\dot{m}_{liquid}$	=	the mass flow rate of the liquid fuel, [kg/hr];
$\dot{m}_{gas}$	=	the mass flow rate of the gaseous fuel, [kg/hr].

7.3. CO_2 determination

Annex VII shall apply except when the engine is tested on transient (NRTC and LSI-NRTC) test cycles or RMC using raw gas sampling.

7.3.1 CO_2 determination when testing on transient (NRTC and LSI-NRTC) test cycles or RMC using raw gas sampling

Calculation of CO_2 emissions from measurement of CO_2 in the exhaust gas in accordance with Annex VII shall not apply. Instead the following provisions shall apply:

The measured test-averaged fuel consumption 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 CO_2 emissions.

The mass of each fuel consumed shall be used to determine, in accordance with section 7.1.5, the molar hydrogen ratio and the mass fractions of the fuel mix in the test.

The total corrected fuel mass of both fuels $m_{fuel,corr}$ [g/test] and CO_2 mass emission coming from the fuel $m_{CO2,\ fuel}$ [g/test] shall be determined by means of equations (8-17) and (8-18).

$m_{fuel,corr} = m_{fuel} - \left(m_{THC} + \frac{A_C + \alpha \times A_H}{M_{CO}} \times m_{CO} + \frac{w_{GAM} + w_{DEL} + w_{EPS}}{100} \times m_{fuel}\right)$	(8-17)
$m_{CO_2\ fuel} = \frac{M_{CO_2}}{A_C + \alpha + A_H} \times m_{fuel,corr}$	(8-18)

Where:

m_{fuel}	=	total fuel mass of both fuels [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 fuels [per cent mass]
w_{DEL}	=	nitrogen content of the fuels [per cent mass]
w_{EPS}	=	is the oxygen content of the fuels [per cent mass]
α	=	is the molar hydrogen ratio of the fuels (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_{CO2}	=	is the molecular mass of Carbon dioxide: 44,01 [g/mol]

The CO_2 emission resulting from urea $m_{CO2,urea}$ [g/test] shall be calculated by means of equation (8-19):

$m_{CO_2,urea} = \frac{c_{urea}}{100} \times \frac{M_{CO2}}{M_{CO(NH_2)_2}} \times m_{urea}$	(8-19)

Where:

c_{urea}	=	urea concentration [per cent]
m_{urea}	=	total urea mass consumption [g/test]
$M_{CO(NH2)2}$	=	Molecular mass of urea: 60,056 [g/mol]

Then the total CO_2 emission m_{CO2} [g/test] shall be calculated by means of equation (8-20):

$m_{CO2} = m_{CO2,fuel} + m_{CO2,urea}$	(8-20)

The total CO_2 emission calculated by means of equation (8-20) shall be used in the calculation of brake specific CO_2 emissions, e_{CO2} [g/kWh] in section 2.4.1.1 or 3.8.1.1 of Annex VII. Where applicable, the correction for CO_2 in the exhaust gas arising from CO_2 in the gaseous fuel shall be performed in accordance with Appendix 3 to Annex IX.

Appendix 3

Types of dual-fuel engines operated on natural gas/biomethane or LPG and a liquid fuel — illustration of the definitions and main requirements

Dual-fuel type	**GER_{cycle}**	**Idle on liquid fuel**	**Warm-up on liquid fuel**	**Operation on liquid fuel solely**	**Operation in absence of gas**	**Comments**
1A	$GER_{NRTC, hot} \geq 0{,}9$ or $GER_{NRSC,} \geq 0{,}9$	NOT allowed	Allowed only on service mode	Allowed only on service mode	Service mode	
1B	$GER_{NRTC, hot} \geq 0{,}9$ or $GER_{NRSC} \geq 0{,}9$	Allowed only on liquid-fuel mode	Allowed only on liquid-fuel mode	Allowed only on liquid-fuel and service modes	Liquid-fuel mode	
2A	$0{,}1 < GER_{NRTC, hot} < 0{,}9$ or $0{,}1 < GER_{NRSC} < 0{,}9$	Allowed	Allowed only on service mode	Allowed only on service mode	Service mode	$GER_{NRTC, hot} \geq 0{,}9$ or $GER_{NRSC} \geq 0{,}9$ Allowed
2B	$0{,}1 < GER_{NRTC, hot} < 0{,}9$ or $0{,}1 < GER_{NRSC} < 0{,}9$	Allowed	Allowed	Allowed	Liquid-fuel mode	$GER_{NRTC, hot} \geq 0{,}9$ or $GER_{NRSC} \geq 0{,}9$ allowed
3A	Neither defined nor allowed					
3B	$GER_{NRTC, hot} \leq 0{,}1$ or $GER_{NRSC} \leq 0{,}1$	Allowed	Allowed	Allowed	Liquid-fuel mode	