United Nations ECE/TRANS/WP.29/GRPE/2011/[--]

Economic and Social Council

Distr.: General
[Day / Month / Year]

Original: English

Economic Commission for Europe

Inland Transport Committee

World Forum for Harmonization of Vehicle Regulations

Working Party on Pollution and Energy

[-------] session
Geneva, [Day / Month / Year]
Item [X] of the provisional agenda
Retrofit Emission Control devices (REC)

Draft new Regulation on uniform requirements for retrofit emission control devices for heavy duty vehicles equipped with engines type approved according to Regulation No. 49 and NRMM and tractors with engines type approved according to Regulation No. 96.

Submitted by the expert from [_____]

The text reproduced below was prepared by the expert from [_____] as a result of the discussion of the informal group on retrofit emission control devices (REC) regarding a proposal for a new Regulation on REC.

Draft Version 21.04.2011 – REC-05-03

Remarks are highlighted in green.

[Values], [dates], [provisions] and [parameter] not fixed yet are indicated in [square brackets], indicated in [red] and [highlighted in yellow].

I. Proposal

Draft new Regulation on uniform requirements for retrofit emission control devices for heavy duty vehicles equipped with engines type approved according to Regulation No. 49 and NRMM and tractors with engines type approved according to Regulation No. 96.

[Contents here: Table of Contents showing *page* only (**macro** TofCp)

Page

1. Scope 1

2. Definitions ..... 3]

….

1. Purpose

[This regulation aims at providing a harmonized method for the retrofit of emission control systems (REC) for NO_X and / or PM mass and PM number and the determination of the levels of emissions from compression-ignition (C.I.) engines used in vehicles and non-road mobile machinery applicable to the scope indicated under paragraph 2. The results can be the basis for the regulation of retrofit emission control systems within regional type-approval and certification procedures.]

OR

[This regulation is intended to provide a harmonized method for the evaluation, approval, and classification of retrofit emission control systems (REC) for NO_X and / or PM mass and PM number and for the determination of the levels of emissions from compression-ignition (C.I.) engines used in vehicles and non-road mobile machinery within the scope indicated in paragraph 2. The procedures and classifications may be used as the basis for the regulation of retrofit emission control systems within regional type-approval and certification procedures.]

2. Scope

2.1 This Regulation applies to retrofit emission control systems (REC) to be installed in vehicles of categories M > 3.5t and N [1] and their C.I. engines approved in accordance with Regulation No. 49 and

2.2 to retrofit emission control systems (REC) to be installed on C.I. engines approved in accordance with Regulation No. 96:

2.3 to retrofit emission control systems (REC) to be installed on C.I. engines used in category T vehicles [1/] having an installed net power higher than 18 kW but not more than 560 kW,

2.4 to retrofit emission control systems (REC) to be installed on C.I. engines operated under variable speed and having an installed net power higher than 18 kW but not more than 560 kW and used in non-road machinery ,

2.5 to retrofit emission control systems (REC) to be installed on C.I. engines operated under constant speed having an installed net power higher than 18 kW but not more than 560 kW, and used in non-road mobile machinery.

not approved in accordance to Reg.96.

2.6 Contracting parties may choose to recognise other regulations as being equivalent to this regulation.

[1/] As defined in Annex 7 to the Consolidated Resolution on the Construction of Vehicles (R.E.3), (document TRANS/WP.29/78/Rev.1/Amend.2, as last amended by Amend.4).

3. Definitions

3.1. *"Adjustment factors"* means additive upward adjustment factor and downward adjustment factor or multiplicative factors to be considered during periodic regeneration;

3.2. *"Particulate reduction REC"* means a particulate reduction system that has a gravimetric particulate reduction or particle number reduction efficiency, determined in accordance with the procedure in Section 9, which meets one of the reduction levels indicated in Section 3;

3.3. "*Category A* retrofit emission control device (REC)" means a retrofit emission control device which is intended to control particulate matter emissions only, and which does not increase the direct NO_2 emissions

3.4. "*Category B* retrofit emission control device (REC)" means a retrofit emission control device which is intended to control particulate matter emissions only, and which does not increase the direct NO_2 emissions by more than [20]% based on the engine out [NO_2]level;

[In order for a diesel emission control strategy to be verified, effective January 1, 2007, the diesel emission control strategy must not increase emissions of NO2 by more than an increment equivalent in mass to 30 percent of the baseline NOx emission level. Effective January 1, 2009, the increment is reduced to 20 percent of the baseline NOx emission level.

Or adjusted to more European language

In order for a diesel emission control strategy to be verified, with effect from 1st January 2007, the diesel emission control strategy must not increase emissions of NO_2 by more than an increment equivalent in mass to 30 percent of the baseline NO_x emission level. With effect from 1st January 2009, the increment is reduced to 20 percent of the baseline NO_x emission level.]

(Text highlighted in light blue copied from California Code of Regulations, Title 13, Division 3, Chapter 14.)

3.5. "*Category C* retrofit emission control device (REC)" means a retrofit emission control device which is intended to control NOx emissions only;

3.6. "*Category D* retrofit emission control device (REC)" means a retrofit emission control device which is intended to control both particulate matter emissions and NOx emissions, and thus NO_2 emissions;

3.7. *"Reduction level"* means a reduction efficiency in percent to be met by the retrofit emission control device (REC) in order to be certified as meeting one of the reduction levels specified in Section 3;

3.8. *"Combined deNOx- particulate filter"* means an exhaust aftertreatment system designed to simultaneously reduce emissions of oxides of nitrogen (NO_x) and particulate pollutants;

3.9. *"Continuous regeneration"* means the regeneration process of an exhaust after-treatment system that occurs either permanently or at least once per applicable test cycle;

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3.10. *"deNOx system"* means an exhaust after-treatment system designed to reduce emissions of oxides of nitrogen (NO_x) (for example, passive and active lean NO_x catalysts, NO_x adsorbers, and selective catalytic reduction (SCR) systems);

3.11. *"Emission control monitoring system"* means the system that ensures correct operation of the emission control measures implemented in the engine and/or REC system in accordance with the requirements of paragraph [---];

3.12. *"ESC test"* means a test cycle consisting of 13 steady state modes to be applied in accordance with paragraph [---] of Regulation No. 49;

3.13. *"ETC test"* means a test cycle consisting of 1800 second-by-second transient modes defined in, and to be applied in accordance with, paragraph [---] of Regulation No.49;

3.14. *"Reduction efficiency"* means the ratio between the mass emissions measured downstream and upstream of an after-treatment reduction system.

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3.15. *"Gaseous pollutants"* means carbon monoxide, hydrocarbons (assuming a ratio of $CH_{1.85}$ for diesel) and oxides of nitrogen, the last-named being expressed in nitrogen dioxide (NO_2) equivalent;

3.16. *"Load condition"* means the loading of particulate matter being stored at any moment in a particulate reduction system (such as a filter) expressed as a proportion of the maximum loading of particulate matter that may be stored in the system under specific driving conditions without external regeneration measures being initiated;

[3.17. *"Nitrogen dioxide (NO_2)"* to be discussed]

3.18 *"NOx-reduction system"* means a deNO_x system that has a mass emission reduction efficiency, determined in accordance with paragraph number [--] or number [---], which qualifies it to be certified as meeting one of the classification levels indicated in paragraph [---];

3.19. *"NRSC cycle"* means a test cycle consisting of steady state modes which is defined in, and is to be applied in accordance with, paragraph [---] of [which regulation to be used, not yet inside R.96]

3.20. *"NRTC cycle"* means a test cycle consisting of 1173 second-by-second transient modes defined in, and to be applied in accordance with paragraph, [---] of [which regulation to be used, not yet inside R.96];

3.21. *"Particulate reduction system"* means an exhaust gas after-treatment system for reducing particulate emissions by means such as mechanical and / or aerodynamic separation, or by diffusion and / or inertial or electrostatic separation, or by any combination of these processes. The definition includes any sensors essential to the operation of the device. The regeneration system and strategy are part of the particulate reduction system. Engine-specific modifications to structural components of the engine or the vehicle, electronic control elements and electronic components are not considered part of the particulate reduction system;

Deleted: [and control software]

3.22. "*Particulate matter / PM mass*" means any material collected on a specified filter medium [in accordance with the procedure set out in ----] after diluting C.I. engine exhaust gas with clean filtered air so that the temperature does not exceed 325K (52 °C);

[3.23. "PM number " means any material counted with an instrument in accordance with the procedure defined in paragraph number [---] after diluting C.I. engine exhaust gas with clean filtered air.];

3.24. *"Particulate reduction system family"* means a family of particulate reduction systems that are technically identical with respect to their functioning when compared in accordance with the harmonisation criteria for system families in paragraph number [---];

3.25. *"Periodic regeneration"* means the regeneration process of an emission control device that occurs periodically in less than 100 hours of normal engine operation. During cycles where regeneration occurs, emission standards can be exceeded;

3.26. *"Reagent"* means any medium that is stored on-board the vehicle in a tank and provided to the exhaust after-treatment system (if required) upon request of the emission control system;

3.27. *"Retrofit emission control device (REC)"* means any particulate reduction system, NO_x-reduction system or combinations of both which is used for retrofit purposes.

3.28 *"WHSC cycle"* means a test cycle consisting of 13 steady state modes defined in, and to be applied in accordance with, paragraph [---] of [Global technical regulation No.4];

3.29 *"WHTC cycle"* means a test cycle consisting of 1800 second-by-second transient modes defined in, and to be applied in accordance with, paragraph [---] of [Global technical regulation No. 4];

To be inserted in a later paragraph:

Any engine operation parameter specified by the original engine manufacturer, such as maximum allowable exhaust gas back pressure, [to be completed] shall not be affected by the REC.

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In cases where additional measures with respect to emission-relevant components and / or system components, such as modifications to the exhaust gas recirculation (EGR) control, are necessary in order to ensure proper functioning of the engine and exhaust after-treatment systems in conjunction with the REC, the applicant must provide a detailed description of the design modification along with an explanation of how the modification will change the operation and performance of the diesel emission control strategy. To support its claims, the applicant must submit additional test data, engineering justification and analysis, or any other information deemed necessary by the Type Approval Authority / Technical Service to address the differences between the modified and original designs.

The emission control system of the original engine manufacturer shall not be modified, expect for modifications allowed by written permission of the original engine manufacturer. Any modification up-stream an existing de-NOx System is not allowed. Modifications down-stream an existing de-NOx system are possible if the above mentioned parameter defined by the original engine manufacturer are not affected.

4. Reduction levels

4.1. In order to receive certification for an REC, the reduction levels indicated in table 3.1 must be achieved: Those levels are to be applied to the engine raw emissions of the test engine as defined in paragraph [---].

Which test / cycle shall be applicable to the determination of the reduction level?

Table 4.1:
Reduction levels

	Reduction efficiency (%)	
	NOx	PM mass
Reduction Level 1	[t.b.d]	50
Reduction Level 2	[t.b.d]	90 / [PM Number, see separate Euro VI Annex]

4.2 For the purpose of this regulation the reduction level for NO_x shall be applicable to systems which are intended to reduce only NO_x, and the PM reduction level to systems intended to reduce only particulate. Combined systems which are intended to reduce emissions of both NO_x and particulate matter are permitted to have any combination of the reduction levels for these two pollutants shown in table 4.1. There is no requirement for a system to have the same reduction level for both pollutants.

4.3 A Category A , Category B, Category C or Category D REC can be approved to any reduction level applicable to its performance with respect to each of the pollutants, as indicated in table 4.2.

Table 4.2:
REC Categories / Reduction level

	Reduction level applicable	
	NOx	PM mass
Category A	-	1 or 2
Category B	-	1 or 2
Category C	1 or 2	-
Category D	1 or 2	1 or 2

4.5 The minimum requirement for approval is that the engine system of the vehicle or machinery fitted with the REC shall be capable of achieving the next higher emission level with respect to the limits of Regulation No. 49 and No. 96 to the one that it achieved when originally type-approved. For engines / engine systems not type approved in accordance to Regulation No. 49 and No. 96 the base emission level must be determined for checking the ability to achieve the next higher emission level.

The minimum requirements for each category of REC are illustrated in table 4.3, table 4.4. and table 4.5..

4.6 REC may be approved as capable of reducing the NOx and/or PM or PN emission values by more than one emission level step provided that they the applicable testing procedure in accordance with [---] is applied.

Table 4.3:
REC Matrix for Regulation No. 49

Base	Component	Category A / B	Category C		Category D	
		to B1 / B2 / C	to B1	to B2	to B1	to B2 / C
Stage A	NOx	-	3,5 g/kWh	2,0 g/kWh	3,5 g/kWh	2,0 g/kWh
	PM	0,02[1)] / 0,03[2)] g/kWh	-		0,02[1)] / 0,03[2)] g/kWh	

Base	Component	Category A / B	Category C	Category D
		to C	to B2	to B2 / C
Stage B1	NOx	-	2,0 g/kWh	2,0 g/kWh
	PM	0,02 g/kWh	-	0,02 g/kWh

[1)] for the ESC cycle
[2)] for the ETC cycle

For retrofit to Euro VI see separate Annex

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Table 4.4:
REC Matrix for Regulation No. 96 / Stage II engine base

Base	net. Power	Component	Category A / B	Category C			Category D		
			to IIIB	to IIIA	to IIIB	to IV	to IIIA	to IIIB	to IV
Stage II	130 ≤ P ≤ 560	NOx	-	4,0 g/kWh	2 g/kWh	0,4 g/kWh	4,0 g/kWh	2 g/kWh	0,4 g/kWh
		PM	0,025 g/kWh	-	-	-	0,025 g/kWh		
	75 ≤ P ≤ 130	NOx	-	4,0 g/kWh	3,3 g/kWh	0,4 g/kWh	4,0 g/kWh	3,3 g/kWh	0,4 g/kWh
		PM	0,025 g/kWh	-	-	-	0,025 g/kWh		
	37 ≤ P ≤ 75	NOx	-	4,0 g/kWh	3,3 g/kWh	0,4 g/kWh	4,0 g/kWh	3,3 g/kWh	0,4 g/kWh
		PM	0,025 g/kWh	-	-	-	0,025 g/kWh		
	18 ≤ P ≤ 37	NOx	-	[4,0 g/kWh]	[3,3 g/kWh]	[0,4 g/kWh]	[4,0 g/kWh]	[3,3 g/kWh]	[0,4 g/kWh]
		PM	[0,025 g/kWh]	-	-	-	[0,025 g/kWh]		

Table 4.4:
REC Matrix for Regulation No. 96 / Stage IIIA engine base

Base	net. Power	Component	Category A / B	Category C		Category D	
			to IIIB / IV	to IIIB	to IV	to IIIB	to IV
Stage IIIA	130 ≤ P ≤ 560	NOx	-	2 g/kWh	0,4 g/kWh	2 g/kWh	0,4 g/kWh
		PM	0,025 g/kWh	-	-	0,025 g/kWh	
	75 ≤ P ≤ 130	NOx	-	3,3 g/kWh	0,4 g/kWh	3,3 g/kWh	0,4 g/kWh
		PM	0,025 g/kWh	-	-	0,025 g/kWh	
	37 ≤ P ≤ 75	NOx	-	3,3 g/kWh	0,4 g/kWh	3,3 g/kWh	0,4 g/kWh
		PM	0,025 g/kWh	-	-	0,025 g/kWh	
	18 ≤ P ≤ 37	NOx	-	[3,3 g/kWh]	[0,4 g/kWh]	[3,3 g/kWh]	[0,4 g/kWh]
		PM	[0,025 g/kWh]	-	-	[0,025 g/kWh]	

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5. Requirements for retrofit emission control devices

5.1 The applicant shall provide evidence of the proper performance of the tests described in paragraph numbers [---] and confirm that the REC system will comply with the applicable provisions during normal operation over a useful life of:

a) Vehicles of category M1> 3.5 t and N over a mileage of [200,000] km or a service life of up to [6] years, depending on which criterion is first reached,

[or]

b) Non-road mobile machinery over [4000] operating hours or a service life of up to [6] years, depending on which criterion is first reached.

The requirements of paragraph number [--] apply in any case where a particulate reduction system is fitted with a device (such as a by-pass valve) which is capable of rendering the system inoperative.

5.2 The applicant shall conduct a 1000 hour durability test on an engine and REC combination. This test shall be either a field test in a typical vehicle or machine application or a test [using an appropriate duty cycle] in an engine test cell. The engine for the durability run may be a different one to the engine used for tests to establish the reduction level of the REC, but must be an engine within the declared application range of the particular REC.

5.3 If the durability test is performed in an engine test cell the REC manufacturer shall determine the test points where NO_x and/or PM and/or PN emissions will be measured during the applicable test cycles. The minimum number of test points shall be three, one at the beginning, one approximately in the middle and one at the end of the 1000 hour period. [The test points at the beginning and the end of the test period shall be in the first 100 hours and the last 100 hours of the test period respectively.

5.4 For each pollutant NO_x and / or PM / PN emissions tests at each test point during the 1000 hour period a "best fit" linear regression analysis shall be made on the basis of all test results in order to determine the final emission result.

5.5 If the durability test is performed as a field test in a typical vehicle or machine application the REC shall be demounted after the durability test and be installed with the chosen test engine on the same test bed as was used for the testing to establish the baseline and the emissions reduction level. The final NO_x and / or PM / PN reduction result for each relevant pollutant will be then based on the control testing with the aged REC.

Accelerated aging procedure to be added?

6. Compliance criteria for particulate reduction REC

6.1 The approval of a particulate reduction system will continue to be valid for a nominally similar system in a different configuration or application provided that it does not deviate from the tested system with with respect to the following features:

a) Type of retention and functioning of reduction material (for example, adhesive or mechanical fixing, metallic or ceramic material, barrier filtration or aerodynamic sepration).

b) Design and characteristics of the filter [or other active] material (for example, whether it consists of sheets or plates, or is braided or wound, the cell, material, or non-woven density, the porosity and pore diameter of barrier filter media, the

number of pockets, blades or balls in aerodynamic seperators, the surface roughness of critical components, and the diameters of wires, balls, or fibres).

c) Minimum total charge of catalytically active materials of the particulate reduction system or upstream catalysers (g/ft3).

d) The design characteristics of the canning or packaging (for example, the storage or retention of the carrier of the active elements)

e) [Active] Volume, which must be within ± 30% of the volume of the tested device.

f) Type of regeneration (whether periodic or continuous)

g) Regeneration strategy (for example, catalytic, thermal, or electrothermal regeneration)

h) Method [and control strategy] for introducing additives or reagents (if used)

i) Type of additive or reagent (if used)

j) Introduction conditions for any additive or reagent (which must be introduced at a point providing the same distribution and condition of the additive or reagent at the point where it is required. This condition will not be considered to have been met if the introduction point is further than a maximum of. 0.5 metres from its position relative to either the the turbocharger outlet (turbine) or the inlet of the particulate reduction system in the tested device.)

k) With or without an upstream oxidation catalyser

When testing the particulate reduction REC in the engine test cell, the REC must be fitted so that there is a distance of at least 2 metres from the outlet of the turbocharger (turbine) to the REC inlet. If the applicant can show that a distance shorter than the minimum distance specified here is used in all subsequent applications of the REC, the length of the pipe used in the test cell may be correspondingly reduced. Insulation or similar means of maintaining the exhaust temperature are permissible only if they are also used in the subsequent installation of the REC on the vehicle or machine..

7. Compliance criteria for NOx reduction REC

[Text to be inserted]

8. Active devices

8.1 If a particulate reduction REC is presented for approval that is associated with a device or devices (such as a by-pass valve) which would have the effect of altering the reduction level of the REC under certain circumstances in such a way that the REC no longer met the limits set out in paragraph [--] for which the applicant wishes the REC to be approved, then the applicant shall demonstrate

a) the conditions under which such devices are activated/deactivated,

b) that the devices are used only for the protection of the particulate reduction REC or the engine, or for the regeneration of the particulate reduction REC, and are not permanently activated,

c) that after an activation the device is deactivated not later than after two test cycles specified for the REC in accordance with paragraph number [---], and that after deactivation the original condition and reduction level is restored [within four minutes]. Operation of the device in accordance with this condition must be demonstrated in an endurance run that includes at least 5 activation and deactivation cycles.

e) that the specified endurance criteria are complied with [for both the device and the REC] and

f) that the driver or operator is informed of the activation of such a device.

g) that the average reduction level of the REC during an endurance run that includeds at least 5 activation and deactivation cycles meets the limits for which the applicant wishes the REC to be approved.

9. Fuel

9.1 The testing of the REC shall be conducted with commercially available fuel representative of that generally used for the type of vehicle or machine to which the REC will be fitted.

9.2 The REC manufacturer may, as an alternative to using market fuel, apply to the Approval Authority for permission to perform the tests on the REC using a reference fuel. The reference fuel to be used in this case will be the fuel specified in either Regulation No. 49 or Regulation No. 96 for testing of engines for type-approval to the standard indicated in paragraph 4 that the vehicle or machine is intended to achieve after the REC under test has been fitted.

9.3 The specific fuel consumption of the engine during the applicable test cycle shall be not more than [4% for PM REC, ?% for NOx REC?] greater in the retrofitted condition than the mean specific consumption in the non-retrofitted condition.

The measurements for determining the fuel consumption may be carried out in parallel with the measurements carried out in accordance with paragraph number [---] for continuously regenerating systems or carried out in accordance with paragraph number [---] for periodically regenerating systems. [If the fuel consumption measurements (for technical or other reasons) are not carried out in parallel with the measurements to establish the reduction level of the REC, then they must be carried out using an identical procedure to that specified for those measurements.]

10. Choice of the test engine

The engine chosen for testing should originate from a family of engines corresponding to the subsequent application range of the REC. The emissions performance of the chosen test engine shall be within the limits set for type-approval to the applicable base emission limit.

The test engine [and REC combination] for the selected application area shall meet the following criteria.

- the engine shall have a nominal power between 100% and [60%] of the power of the parent engine in the particular family when assessed in accordance with the procedure in Regulation No. 49
- the engine and REC shall have the smallest used filter volume (V_{FI}) that corresponds to the subsequent application range for the selected test engine.

Space velocity better to be used e.g. for overlapping power ranges! Catalytic surface area / max. Power => CARB

In all cases, the applicable test cycles [drawn from Regultion number 49 or Regultion number 96] are to be used for the exhaust gas verification measurements. The emissions of the relevant pollutants are to be measured during at least every fifth test cycle during the measurements for verification of the regeneration characteristic.

For REC intended to be used on engines type-approved in accordance with Regulation No. 96 testing on one test engine for each power category for which the REC is intended to be used is mandatory.

The selected test engine must comply in both series production condition and in retrofitted condition with all of the pollutant emissions limits associated with the stage or standard to which it was originally type-approved.. Any modification made to the test engine for the purposes of the REC approval tests must be a modification that will be made to all engines with which the REC is subsequently used. Where vehicles or machines are fitted with on-board diagnostic systems those systems shall not be limited with respect to their monitoring function after the retrofit system has been installed. The characteristics of the electronic engine control unit (as regards, for example, injection timing, air-mass flow metering, or exhaust emissions reduction strategies) shall not be altered by the retrofitting.

REC testing is conducted for the purpose of this Regulation in order to show the capability of the REC to reduce the PM or PN and/or the NOx emissions from a vehicle or machine from one emission stage or standard [as defined in Regulation No 49 or Regulation No 96] to the subsequent emission stage [or to an emissions stage or standard subsequent to that one].

11. Test of a particulate reduction REC

11.1 In order to assess a particulate reduction system, an endurance run of at least [100] ETC or WHTC test cycles, or [50] NRTC cycles, must be carried out. [The test cycle used must be a cycle appropriate to the emissions stage or standard that the reduction system is intended to permit the vehicle or machuine to meet.] The endurance run is used to verify the functional capability and stability of the system and also its reduction efficiency. The gaseous emissions and the particulate mass, and the particulate number when appropriate, must be measured during at least each fifth test cycle. A separate test of the particulate reduction system is carried out for each family or application range defined in the type approval procedure for the engine with which the REC is intended to be used. That is, one system test takes place for each application area.

The endurance run is used, in addition, to verify whether the particulate reduction system is a continuous or periodically regenerating system.

If the applicant can prove that a particulate reduction system that has been tested for vehicles of Category M < 3.5 t or Category N, is designed for use in the same manner [and will work effectively] on C.I. engines for use in non-road mobile machinery, and the family of test engines used in accordance with the requirements of pragraph 4.2 is representative for such applications and meets the compliance criteria of paragraph 7.1.2, then the application range for which the system is approved may be extended to C.I. engines for use in non-road mobile machinery. Extending the range of a particulate reduction system that has been approved for use with C.I. engines in non-road mobile machinery to cover on-road applications in the way described in this paragraph is not permitted. .

11.2 A particulate reduction REC is considered to have been proved to have a continuously operating regeneration process if a suitable assessment variable can be regarded as constant over at least 25 applicable test cycles. The particulate emission and the exhaust gas backpressure are regarded as suitable assessment variables for this purpose. [If an applicant wishes to use one or more different assessment variables, he must present a robust technical case to the approval authority in support of his request to do so.]

The particulate emission and the exhaust gas backpressure are considered constant within the meaning of this regulation where there is a coefficient of variance of less than 15% over 25 test cycles. The exhaust gas backpressure is measured continuously for the purposes of this assessment and the particulate emissions are measured during at least every fifth test cycle.

The coefficient of variance (CoV) is calculated as follows.

$$\text{Variance} = \frac{\text{Standard deviation X (n)}}{\text{Average value X (n)}}$$

with:

$$\text{Standard deviation} = \sqrt{\frac{\text{n } \Sigma x^2 - (\Sigma x)^2}{n^2}}$$

and:

$$\text{Average value} = (x_1 + x_2 + \ldots + x_n) / \text{n}$$

where:

n = number of measured values

x = respective single measured value

11.3 If an REC manufacturer intends to apply for approval for an REC that can reduce emissions of one or more of the relevant pollutants by two subsequent emission stages, then additional verification becomes necessary.

This additional verification required in this case is performed in accordance with the procedure set out in paragraph number 10.2 and paragraph number 10.7. on a test engine selected in accordance with the procedure set out in paragraph 9.3 on the basis of the final emission level to be achieved by the retrofitted engine.

It will be considered sufficient to perform the additional testing on only one engine family member representative of the application range. For that reason it is permissible to transfer the emission category extension that has been gained by this additional testing to other engine families in the same application range. .

The REC used in the additional verification procedure required in order to extend the approval to a further (subsequent) emission category must be from from the application range of the basic REC for which the approval was issued. [It must not be a REC which has been approved by extension of the original approval.] If the REC is not from the application range of the basic REC for which the approval was issued,, and the system is not identical, then a full test for a new type in accordance with this regulation is necessary.

If the scope of application is widened, then the applicant must additionally certify in the letter of application for approval that the REC is also designed and suitable for higher raw emission burdens when used on lower emission level engines.

11.4 Test of the regeneration characteristic of a particulate reduction REC for Reduction level 2 and 3[??]..

Particulate systems achieving reduction level 1 and reduction level 2 are subjected to further testing in order to verify their regeneration characteristic.

This further testing is carried out by loading the system [with particulate matter] until a constant exhaust gas backpressure is reached or over a time period of a maximum of 100 hours [if no constant value for the backpressure has been achieved before that time]. . The exhaust gas backpressure is considered constant if, when measured after a period of at least 50 hours, the exhaust gas backpressure does not vary by more than plus or minus 4 mbar within a period of 30 min. The test points of the cycle used for loading the system are to be selected so that a maximum exhaust gas temperature of 180 C at the inlet of the particulate reduction system is not exceeded. The loading of the system with particulate matter is preferably carried out by running the test engine at a constant speed of between 50% and 75% of its rated speed.

After the REC has been loaded with particulate matter until the backpressure is constant, or after a maximum of 100 hours of running to load the system as defined above, regeneration is activated. This can, for example, be activated by running the engine at a higher load mode step so as to increase the exhaust temperature. After completion of the regeneration, exhaust gas measurements are to be taken during at least three appropriate test cycles (That is, three ESC cycles, ETC cycles, WHSC cycles, WHTC cycles, NRSC cycles, or NRTC cycles.) The measured exhaust gas pollutant values shall not deviate from the measured exhaust gas pollutant values before the REC loading procedure by more than 15% for the gaseous emissions or more than 20% for the particulate mass or particulate number emissions.

The manufacturer shall confirm in writing that the maximum temperatures occurring during the regeneration process will not damage or significantly shorten the effective life of the REC.

As an alternative to using the loading procedure described above, the manufacturer may provide a particulate reduction REC already loaded to the limit for the regeneration test.

11.6 Assessment criteria for continuously regenerating particulate reduction systems

The REC system test of the particulate reduction REC is considered satisfactory if the reduction level criteria defined in paragraph number 3 are met.

11.6.1 Regulated pollutants

The emissions of the regulated pollutants (CO, HC, PM,and NO_x) in the initial condition and in the retrofitted condition shall be within the limit values for the emissions stage or standard for which the engine was originally type-approved. The NO_2 to NOx ratio for the initial condition and the retrofitted condition is to be recorded and shown in the test report.

The determination of the NO_2 and NO_x mass emissions is to be determined by simultaneous measurement in accordance with [---]. UBA NO2 measurement procedure to be added.

11.7 Assessment criteria for periodically regenerating particulate reduction systems

This provision only applies to REC which are regenerated on a periodic basis.

The emissions shall be measured during at least three appropriate hot-start test cycles (That is, three hot-start ESC cycles, ETC cycles, WHSC cycles, WHTC cycles, NRSC cycles, or NRTC cycles.) One of the cycles from which measurements are taken should include a regeneration event on a stabilized REC system. The other two cycles from which measurements are taken should be cycles in which regeneration does not occur. If regeneration takes longer than one test cycle, consecutive test cycles shall be run until regeneration is complete.

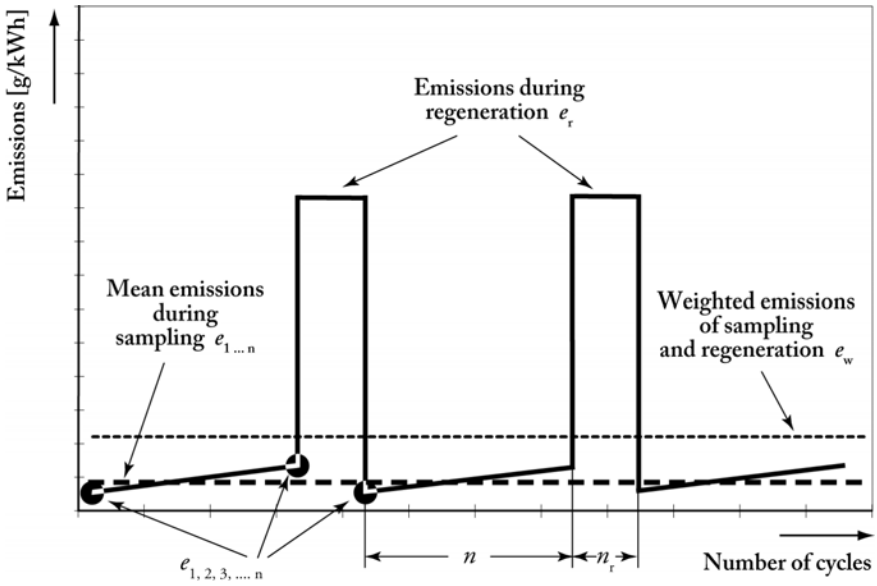
The REC manufacturer shall declare the conditions under which the regeneration process normally occurs (the particulate loading, temperature, exhaust back-pressure, or other relevant parameters.). The manufacturer shall also provide the frequency of the regeneration event in terms of the fraction of tests during which the regeneration occurs. The exact procedure used to determine this fraction shall be agreed [with the manufacturer] by the type approval authority on the basis of good engineering judgement. (This frequency fraction is the factor *F* in the procedure for calculation of [nominal] particulate emissions set out below.)

For a regeneration test, the manufacturer shall provide a particulate reduction REC system that has been loaded with particulate matter. As an option, the manufacturer may run consecutive test cycles [as set out in paragraph 10.4] until the particulate reduction REC is loaded. Emissions measurement is not required on cycles run for the purposes of loading the REC with particulate matter..

Average emissions between regeneration phases shall be determined from the arithmetic mean of several tests approximately equidistant in terms of the number of unmeasured test cycles between them. As a minimum, at least one test cycle as close as possible prior to a regeneration test and one test cycle immediately after a regeneration test shall be included in the calculation of the arithmentic mean..

During the regeneration test, all the data needed to detect regeneration shall be recorded (CO or NO_x emissions, temperature before and after the REC, exhaust back pressure, and any other relevant parameters..). It is permissible for the applicable emission limits to be exceeded during the regeneration process. The test procedure is shown schematically in **figure 9.1**.

Figure 9.1:
Scheme of periodic regeneration



The system test of a periodically regenerating particulate reduction REC is considered passed if the [nominal] particulate emissions calculated using the procedure set out below are within the limit set for the reduction level for which the applicant wishes the REC to be approved.

The particulate emissions PT (g/kWh) for periodically regenerating systems are determined as follows.

$$PT = PT_r \times F + (1-F) \times PT_{wor}$$

Where:

F = frequency of the regeneration event in terms of fraction of tests during which the regeneration occurs [-]

PT_{wor} = average specific emission from a test in which the regeneration does not occur [g/kWh]

PT_r = average specific emission from a test in which the regeneration occurs [g/kWh]

The manufacturer may choose, on the basis of good engineering analysis, to calculate either a multiplicative or an additive regeneration adjustment factor kr, expressing the average emission rate, as follows:

$k_r = PT / PT_{wor}$ (multiplicative adjustment factor)

or

$k_{Ur} = PT - PT_{wor}$ (upward adjustment factor)

or

$k_{Dr} = PT - PT_{r}$ (downward adjustment factor)

If more than two measurements between the regeneration phases are used to determine the emissions, these further measurements must be taken at equal intervals and an arithmetical average taken.

11.7.1 Regulated pollutants

The emissions of regulated pollutants (CO, HC, PM and NO_x) shall be within the limit values for the standard to which the engine was originally type approved, both in the initial condition and in the retrofitted condition. . The NO_2 / NOx ratio for both the initial condition and the retrofitted condition are to be recorded and shown in the test report.

The determination of the NO_2 - and NOx- mass emissions is to be determined by simultaneous measurement in accordance with [---].UBA NO2 measurement procedure to be added.

11.7.2 Weighted gaseous emissions

The emission of gaseous components Mgas (g/kWh) for periodically regenerating systems is determined as follows.

$$Mgas = Mgas_{r} \times F + (1-F) \times Mgas_{wor}$$

where:

F = frequency of the regeneration event in terms of the fraction of tests during which the regeneration occurs [-]

$Mgas_{wor}$ = average specific emission from a test in which the regeneration does not occur [g/kWh]

Mgs_{r} = average specific emission from a test in which the regeneration occurs [g/kWh]

The manufacturer may choose, on the basis of good engineering analysis, to calculate either a multiplicative or an additive the regeneration adjustment factor kr, expressing the average emission rate, as follows:

$k_{r} = Mgas / Mgas_{wor}$ (multiplicative adjustment factor)

or

k_{Ur} = Mgas - $Mgas_{wor}$ (upward adjustment factor)

or

k_{Dr} = Mgas - $Mgas_{r}$ (downward adjustment factor)

12. Family criteria for particulate reduction REC

Families may be formed from particulate reduction REC of different sizes and/or volumes provided that the following compliance criteria are met.

Where a particulate reduction REC of the same construction, but with different volumes, is specified as suitable for various engines and vehicle or machinery types, the family shall not differ with respect to the features set out in paragraph No. 5.

Where the application range for a particulate reduction REC family is aligned with an engine manufacturer's engine family covered by the respective test engine in accordance with Regulation No. 49 for vehicles of category M>3.5t and N.

If the applicant can show that other engine families produced by that manufacturer, or other engine families of other manufacturers of the applicant range covered by the test engine are identical with respect to the family formation criteria, then the application area can be extended to these engine families.

The family formation criteria for the extension of the application range are

a) within [± 15%] of the displacement of a single cylinder
b) the method of aspiration (turbocharged or normally-aspirated engine)
c) with or without EGR.
d) whether a constant speed or a variable speed engine.

To be extended for SCR

13. Operating behaviour

No impairment of the operating behaviour of the vehicle or machine, and no additional safety hazards associated with the vehicle or machine shall arise as a result of the installation of the particulate reduction system.

Consider machinery directive

14. Noise

The applicant shall prove that the retrofitting of a particulate reduction system will not lead to deterioration in the noise. Noise measurement may be omitted in the case of particulate reduction systems fitted in addition to the [original equipment manufacturer's] standard production silencer system. [If testing is done, then it must comply with applicable international standards.]

15. Use of additives

In the case of a particulate reduction REC which makes use of a consumable additive or reagent, testing of the non-regulated emissions in accordance with Annex I becomes necessary.

Add SNR provisions in Annex I / [max. allowable values to be defined].

Deleted: ¶

16. Electromagnetic compatibility

If electronic components or control units are used, they shall comply with the applicable requirements.

17. Installation of a REC

Retrofitting with a REC must be performed in accordance with the installation instructions provided by the REC manufacturer. Any additional instructions (provided, for instance, by the vehicle or machine manufacturer) must also be taken into consideration. The user or operator of the vehicle or machine that has been retrofitted is responsible for proper installation.

The REC manufacturer must provide proper installation guidelines.

The vehicle or machine to be retrofitted must be in a [properly amintaned and] serviceable condition. Defects that could prevent achievement of the emission reduction level for which the REC is approved, or could adversely affect its endurance are to be rectified as necessary before the retrofitting.

Annex []

Measurement of secondary emissions

Text below is from SNR 277205, text needs to be adapted to this draft and it needs to make clear that secondary emission testing is not directly linked to each type approval measure. Standards recommended only [?]

1. Introduction

Depending on the method of exhaust gas treatment and the properties of the catalytically active substances, a variety of reaction products may be formed. The most important of these are toxic substances with carcinogenic, mutagenic, teratogenic or hormone-like effects. For example, it is known that platinum-based catalytic converters increase NO2-emissions, while those containing copper produce substantial amounts of polychlorinated dibenzodioxins and -furanes (PCDD/F) if chlorine is present. On the other hand, particle filter systems often significantly reduce emissions of polycyclic aromatic hydrocarbons (PAH), including the carcinogenic ones. The data cited in section [5.5 of SNR 277205] and in this [Appendix] are binding for catalytic particle filter systems. Because it is not possible to list all potential secondary emissions, the catalogue of substances to be measured should be adjusted whenever reasons for a potential formation of further secondary pollutants exist.

2. Secondary emissions

2.1 Nitrogen dioxide (NO2)

Nitrogen dioxide (NO2), a toxic secondary pollutant formed in the presence of strongly oxidizing catalytic converters (e.g. platinum), has to be measured in addition to nitrogen monoxide (NO). Here the dry exhaust gas (permeation dryer) is analyzed with a chemiluminescence detector (CLD).

2.2 Volatile organic compounds (VOC)

Benzene and 1,3-butadiene, both carcinogenic substances, have to be analyzed as toxicologically relevant leading compounds for more than 100 known gaseous hydrocarbons. A proportion of the exhaust is collectein gas-tight bags. The content of each hydrocarbon is determined with a gas chromatography system coupled with flame ionization detector (GC-FID).

2.3 Oxidized volatile organic compounds (VOCOX)

Formaldehyde and acetaldehyde, both highly reactive and carcinogenic gases, have to be measured astoxicologically relevant leading compounds in the class of partially oxidized volatile hydrocarbons. A proportion of the exhaust is fed through a dinitrophenylhydrazine solution during the sampling process (chemisorption). The reactive aldehydes are converted to the corresponding hydrazones and thus stabilised. The derivatives are separated by means of liquid chromatography and the contents are measured with a UV/VIS photometer (LC-UV/VIS).

2.4 Polycyclic aromatic hydrocarbons (PAH)

As leading compounds for the PAH class of substances, at least the following carcinogenic substances have to be analysed: chrysene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene,indeno(1,2,3-cd)pyrene. In addition, the contents of pyrene and fluoranthene, which are precursor compounds for mutagenic nitro-PAH, also has to be measured. PAH can appear both in particulate and gaseous form. A proportion of the exhaust is filtered into a multi-stage glass apparatus (dioxin train), cooled below dew point and fed through an adsorption material. The integral sample, which includes PAH present in the gas-, liquidand solid-phase, is purified and fractionated by means of liquid chromatography. Separation is carried out with a gas chromatograph (GC), and quantification is achieved by means of high resolution mass spectrometry (GC-HRMS).

2.5 Nitrated polycyclic aromatic hydrocarbons (nitro-PAH)

There are numerous nitration products found in NOx-rich diesel exhaust. As leading compounds for the nitro-PAH class of compounds, at least the mutagenic substances 3-nitrofluoroanthene and 1-nitropyrene have to be measured. In order to evaluate the nitration potential of the filter system, the following substances which are more common and thus more readily accessible for analysis are measured as representatives of other mutagenic and carcinogenic nitro-PAH: 1-nitronaphthalene, 2-nitronaphthalene, 3-nitrophenanthrene, 9-nitrophenanthrene, and 9-nitroanthracene. Other mutagenic and carcinogenic nitro- and di-nitro-PAH are also of interest, but their contents are generally lower. Nitro-PAH are also sampled in the glass apparatus described above. Separation of individual isomers and quantification are carried out by means of GC-HRMS.

2.6 Polychlorinated dibenzodioxins / furanes (PCDD/F)

As leading compounds for the 210 PCDD/Fs, at least the 17 toxic 2,3,7,8-chlorinated PCDD/Fs and the resulting overall toxicity (TEQ or toxicity equivalent) have to be determined. The overall toxicity is deduced from the concentrations of the 17 toxic isomers and their relative toxicity (toxicity equivalence factor). PCDD/Fs are also retained in the glass apparatus described above. The integral sample is purified by means of liquid chromatography. Separation and quantification of individual isomers is achieved with gas chromatography, combined with high-resolution mass spectrometry (GC-HRMS).

2.7 Catalytically active elements (coating metals and additives)

The catalytically active elements of fuel additives and filter coatings have to be measured in accordance with the manufacturer’s specifications. The particles or particle-bound compounds are fractionated into 13 size classes from proportionally diluted exhaust using a 12-stage electric low-pressure impactor and a backup filter. The metal content of each size class is quantified using microwave digestion followed by inductivelycoupled plasma mass spectrometry (ICP-MS).

Component	Sampling	Analytical method	Standard / Reference
NO2	Heated sampling line and permeation dryer from undiluted exhaust gas	Chemiluminescence detector (CLD)	EN 14792 ISO 16000 DIN EN ISO 16017 [UBA Procedure]
VOC	From exhaust gas diluted to a constant volume flow (Constant Volume Sampling Tunnel, CVS tunnel) [Partial flow]	Gas chromatography flame ionization detector (GC-FID)	ISO 16000 DIN EN ISO 16017
VOCOX	From exhaust diluted to a constant volume flow (CVS tunnel), chemisorptions in dinitrophenylhydrazine solution	Liquid chromatography ultraviolet detector (LCUV/ VIS)	ISO 16000 DIN EN ISO 16017
PAH	Flow proportional sampling from undiluted exhaust, multiple stage glass apparatus based on the filter/condenser method (UNE-EN 1948-1)	Gas chromatography high-resolution mass spectrometry (GCHRMS) or liquid chromatography ultraviolet/fluorescence detector (LCUV/ fluorescence)	VDI 3874
Nitro-PAH	Flow proportional sampling from undiluted exhaust, multiple level glass apparatus based on filter / condenser method (UNE-EN 1948-1)	Gas chromatography high-resolution mass spectrometry (GCHRMS)	VDI 3874
PCDD/F	Flow proportional sampling from undiluted exhaust gas, multiple stage glass apparatus based on filter/condenser method (UNE-EN 1948-1)	Gas chromatography high-resolution mass spectrometry (GCHRMS)	UNE-EN 1948
Catalytically active elements (metals)	Flow proportional sampling from undiluted exhaust, size-fractionated sampling with 12-stage electric low pressure impactor (ELPI) plus backup filter	Microwave digestion, inductively-coupled plasma mass spectrometry (ICP-MS)	DIN EN 13890 DIN 51002-1