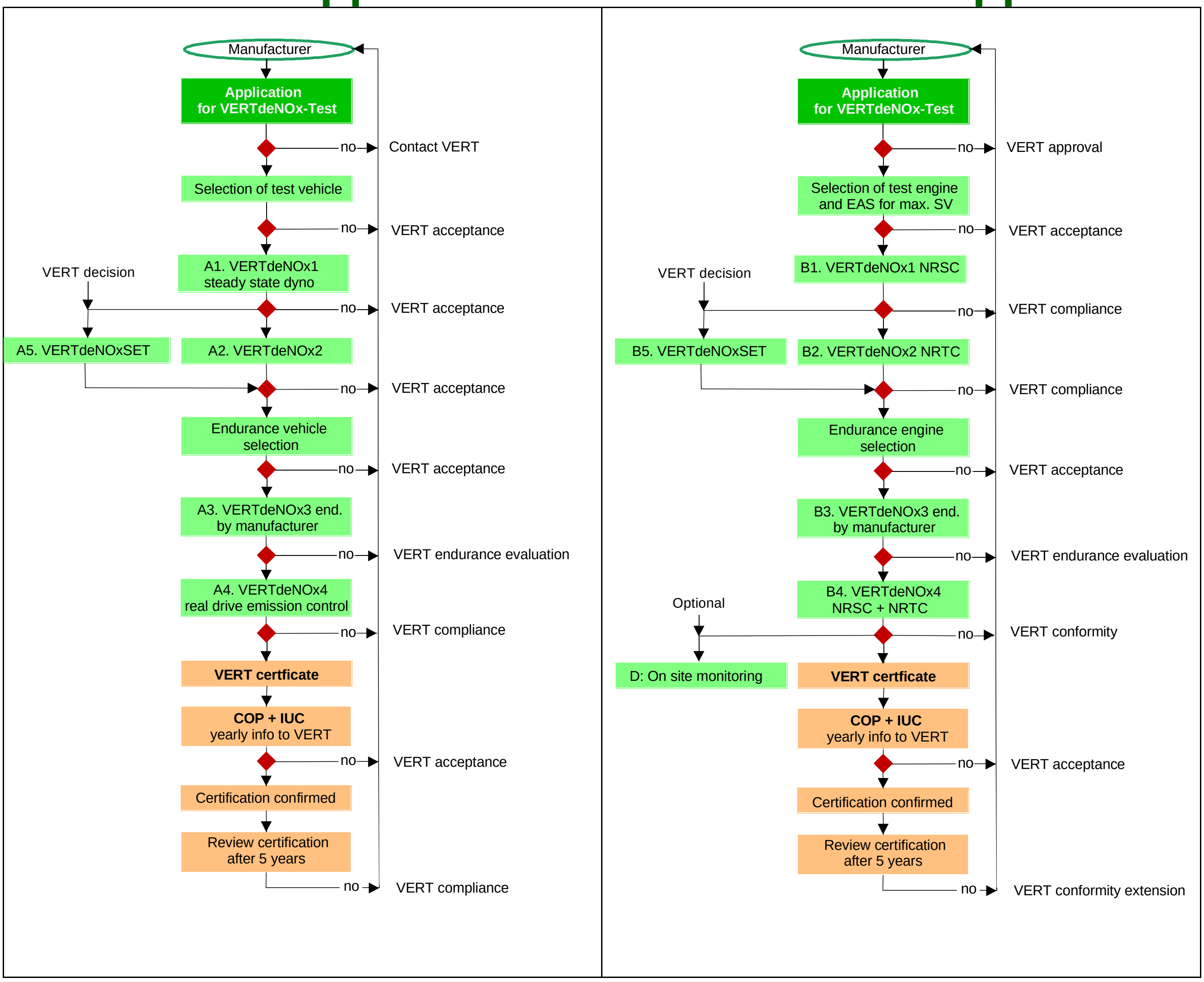
TA Technische Anleitung
Technical Instruction
Instruction technique

TA-004.2/20 Edition December 2020

VERT - CERTIFICATION of deNOx – EAS

A. Onroad Application B. Nonroad Application



Preamble

Certification for Retrofit-EAS can be Engine-independent but will provide best available technology for each application and operation condition

First-Fit Homologation and Retrofit Quality Control

First Fit Homologation is the emission control of a complete system "engine+EAS+controls". Emission laws for new vehicles do not require best available technology for the engine and the EAS and the control independently but they establish integrating overall emission limits for the whole system which cannot be exceeded during a specified test cycle under specified operating conditions. This permits a quality comparison of different (competing) products but does not guarantee lowest possible emission in each application. The limit values reflect an absolute value of a toxic air contaminant e.g. mg/km and this philosophy improves emission only stepwise by vehicle generation layers.
Retrofit EAS must be quality controlled independent of the engine and the operation profile since at the moment of the certification test of the EAS engine application and the actual working cycle are yet unknown. In this case the emission quality cannot be defined by an absolute emission value but by a relative emission reduction property, in general by a non-dimensional value for efficiency or conversion which has a general validity. The only assumption we have to make here is that a better efficiency will always lead to lower emission and not inverse. With this philosophy retrofit can reduce the emission of a whole mixed fleet to the lowest possible fleet emission level in one step.

DPF - the Classic Retrofit Case

Although DPF systems might be complex active systems to guarantee regeneration, filtration itself does not depend on the engine nor the thermo-management impacts. Given the macro-geometry of the filter structure and the micro-geometry of filter pore distribution it mainly depends on particle size, space velocity and regeneration status. Since particle size distribution is quite uniform between internal combustion engines the test of the DPF on one engine at worst operation conditions is sufficient. Worst operation conditions are max. space-velocity and highest temperature where the filter substrate might be fully regenerated. The filtration efficiency a given filter reached during this certification test will be reached on any other engine under any other working cycle as long as the space velocity is not higher. This physical behavior makes VERT DPF certification so universal and a stationary test cycle is sufficient. Even the formation of secondary emission in case of catalytic coatings can be regarded as a filter related property.

SCR-DeNOx

This process philosophy is basically not different. Assuming a stoichiometric supply of the reactant is guaranteed the conversion of NOx to N2 depends mainly on the temperature of the exhaust gas and the space velocity. This includes the conversion of the NO to NO_2 in the pre-SCR DOC and the conversion of ammonia slip by a post-SCR DOC. We have however to observe store and release phenomena which require a dynamic testing program.
Running a certification test which includes a stationary test cycle (scanning the whole range of SV and temperatures) and an additional dynamic test cycle (reflecting typical transients of engines) using the optimal reactant injection strategy the manufacturer can offer will reveal the overall map of $NO_x \rightarrow N_2$ conversion and also permit to evaluate a typical conversion factor for this stationary and this transient operation. Different SCR-DeNOx systems tested this way can be compared with respect to their NOx-conversion quality under these stationary and transient conditions.
This does not mean however, that the same conversion will be observed in every application and under any operation cycle where the exhaust temperatures profile may be very different in particular it the engine is operating at very low temperatures. Even the best of all SCR-systems will than lose conversion efficiency and the only way to check the actual conversion level is a local conversion test by a short on-site monitoring, which is also offered by VERT and described here.

A. ONROAD Application

Background and Trigger

In the past 8 years VERT has performed extensive research on SCR and SDPF-Systems on engine test benches and on HDV vehicles as well as supervised a pilot test fleet in Switzerland. Most of this work has been published. VERT has also established a VERTdePN certification method and has listed one certified SCR-system in 2012 with > 75% NO_x-conversion. However, no large scale applications followed since public/legal pressure did not materialize.

Now time seems to change: following the diesel scandal und due to stricter EU-enforcement of NO_2 limits, many cities are planning to use the chances of SCR-retrofit for public fleets. However, no list of independently tested Exhaust Aftertreatment Systems EAS is available, from which the cities can select appropriate systems according to their performance and quality criteria. VERT will use the opportunity to fill this gap and help to build up confidence in this technology in Europe and as well in Korea, China, India and Latin Amerika. For this reason the VERTdeNOx certification procedures as well as the certification procedure for combined systems with SCR and DPF in combination with DOC are described here.

This VERTdeNOx certification protocol reflects the VERT BAT-principles and is structured in such a way that cities will feel confident to select from this list mature technology with highest possible performance to clean the air from toxic contaminants like solid particles, volatile hydrocarbon substances as well as NO + NO_2 without creating additional toxic so-called secondary substances.
These EAS systems shall be available at prices which are low compared to the health cost avoided. The elements of in-use compliance IUC, independent supervision/auditing and Periodic Technical Inspection PTI shall also be included as confidence building elements for this new market.

Pre-Condition

This VERT-Certification has been developed for EAS ready for sale and retrofit installations. It is assumed that the manufacturer has already successfully performed all state of the art tests with respect to functionality, mechanical and thermal stress and failure modes, aging, pollution and poisoning properties. It is also assumed that he has developed the dosing strategies to achieve a certain $deNO_x$ target as well as maintenance strategies to be able to guarantee two years operation without maintenance and six years useful life prior to submit a representative sample of this EAS family for certification testing.

Test Object

Test object is a vehicle, which according to the declaration of the manufacturer is representative for the vehicle family the manufacturer intents to apply. This might be HDV or LDV and within these families it might be limited to city bus application or coaches or waste transporters – this remains up to the manufacturer commitment.
The vehicle can be of any EU emission class but must be equipped with a VERT certified DPF and a complete SCR system in a technically final and ready-to-sell form including an on board control unit (OBC) with telemetry features.
It must be perfectly maintained regarding safety and emission relevant elements, degreened and operated with the system for not more than 10’000 km but not less than 1000 km and the manufacturer must provide his maintenance data on emissions relevant elements at the time the vehicle is presented to the testing laboratory.

For the emission testing the vehicle must be equipped with access ports for emission measurement (gases and particles) upstream and downstream of the after-treatment emission control elements, which are designed such that measurement during real world operation (RDE) of the vehicle is possible. Electronic access to the system sensor signals and the OBC must be provided for the testing direct at the vehicle and via the telemetric path on internet.

Manufacturer Data to be Disclosed

(according to the VERT-application form)

The manufacturer must disclose to the VERT-certification officer:

- Physical structure of the system – drawings, catalyst materials.
- $DeNO_x$-process strategy
- Control and alert strategy
- Operation and maintenance procedures
- Target performance
- Target life
- DPF-certification data
- System experience: number of systems retrofitted in the selected vehicle family
- Hours (km) tested so far

Testing Protocol

This test consists of 5 phases, A1 ÷ A5.

A1. VERTdeNOx1: Steady state test on chassis dynamometer

- Engine load ramp at two engine speeds in order to determine the exhaust temperature at which AdBlue injection starts and at which 80% conversion is reached
- Full load and low idle should also be tested
- Each operation point during 15 mins or until thermal stability is reached
- Measured operation data: velocity, RPM, power, temperatures of exhaust gas, engine water and lube oil, exhaust mass flow
- Measurement of emissions: CO, HC, CO_2, O_2, NO, NO_2, PN
- Measurement of NH_3 at tailpipe only
- Download system sensors data for NO, NO_2 at all operation points

A2. VERTdeNOx2: Real drive emission (RDE)

- RDE-conform trajectory
- 3 repetitions on different days
- Log operation data: velocity, RPM, ambient climate data
- PEMS-conform measurement of emissions: CO, HC, CO_2, O_2, NO, NO_2, PN, NH_3
- Download system sensors data for NO, NO_2 during whole test, compare with PEMS

A3. VERTdeNOx3: 10’000 km with telemetric data transfer to VERT laboratory

- System checked and sealed by the VERT certification inspector
- Operation of the vehicle under supervision of the manufacturer who must supply a logbook on all relevant observations to the VERT-laboratory
- Continuous access to OBC via internet telemetry
- AdBlue consumption to be measured
- Fuel consumption to be measured
- NO_x upstream and downstream continuously measured and stored
- Further measurements of: temperatures, pressures, RPM, vehicle speed
- Monitor ambient temperature, humidity, pressure
- Monitor vehicle position by GPS

The System must be checked by the VERT-inspector before release for VERTdeNOx4
Any system problem, maintenance or repair must be immediately transmitted to the VERT inspector.

A4. VERTdeNOx4: Real Drive Emission Control

Download all System OBC data stored during VERTdeNOx3.
Repetition of VERTdeNOx2

A5. VERTdeNOxSET, the Secondary Emission Test

It can be waived, if all relevant data is already available from technically similar systems. If the system however uses a catalyst formulation or catalyst concentration or catalyst morphology which is new and not yet VERT-tested, a VERT Secondary emission test similar to VSET for DPF must be performed to make sure that no additional toxic substances are generated in significant concentrations.
This test and the related analytics will be performed according to SN 277206 and expected secondary toxic nitrogen substances like N_2O, NH_3, HNCO, CH_2O_2, HCN, HCHO, and CH_4 shall be included.
In all cases however, a size specific metal analysis for all catalyst materials must be performed in order to make sure that no metal emission happens with the new and the aged system in the whole operation range; this shall also follow SN 277206.

Metrology

Measurement 'upstream/downstream' and 'with/without' AdBlue injection only during VERTdeNOx1.
Metrology is in accordance with

- SN 277206
- PMP/PEMS-Protocol
- RDE-Protocol
- Noise according to VTS, SR 741.41 and EU-70/157/EWG
  Noise measurement before installation by the manufacturer

Testing Conditions

- Testing at ambient conditions >10 °C
- Engine warmed up
- Engine maintained
- Air filter replaced
- Fuel: EN 590 – Swiss market quality
- Lubrication oil: changed, manufacturer specified quality
- DPF regenerated at start of the test
- AdBlue tank full, filled by the VERT inspector who will take an AdBlue sample

Testing Time

A1. Dynamometer test: one day
A2. Road Test on 3 different days
A3. Maybe one month depends on the applicants organization
A4. 1 day
A5. One week

Reporting

- All data measured and downloaded
- Interpretation of all important findings
- Conclusions with respect to conformity criteria, operation and findings
- Document system design and strategy
- Compare OBC sensors data and test data
- Physical observation, pictures

VERT-Conformity Criteria

Certification is limited to the defined vehicle family and must fulfill the following criteria:

- PN filtration efficiency > 98% for solid particles 10-500 nm in all operation points
- Backpressure (max.) during endurance test < 200 mbar
- NO_x-conversion during RDE: 3 classes > 85% / 75-85 % / 65-75 %; < 65% rejected
- Light off (50% NO_x-conversion) below 230°C after SCR
- NH_3 < 20 ppm at all operation points
- CO, HC according to the EU emission class of the vehicle
- Fuel economy (and CO_2) deterioration by retrofit < 3 %
- $CO_2e = ((298 \times N_2O) + (25 \times CH_4)) < 5\%$ of CO_2 based on A5: Secondary emission test data
- Noise emission: no deterioration after replacement of muffler by EAS
- Aging for NO_x-reduction during 10'000 km < 5%
- Aging for particle filtration: none

VERT Certification is valid for 5 years if yearly failure rate remains < 3%

Accredited Testing Laboratories

VERT accredited Testing Organizations (see VERT-Filter list)

Overall Testing Cost

- To be confirmed by a detailed cost calculation
- Cost for endurance test, which will be organized by the applicant, are covered by the applicant
- Transfer of finances by the VERT finance department
- Payment in advance

Confidentiality of Data and Reports

All data and reports are confidential between the manufacturer, VERT and the testing laboratory. A respective NDA shall be signed.

Harmonization with Political Bodies

VERT shall try to get approval for this procedure from political bodies

B. NONROAD Application

Test Object

Test object is an EAS Exhaust Aftertreatment System containing a VERT certified DPF and a complete SCR system including AdBlue injection and control for nonroad dynamic application.
The system must be sized such that the gas flow during nominal load of the test engine (MP1 of NRSC test cycle) reaches the max. space velocity SV which is used in application within a tolerance of $\pm$ 20%. Whereas space velocity SV [1/s] is defined as max. exhaust gas volume flow [m^3/s] at given temperature and pressure divided by the SCR substrate volume [m^3].
The system must be in a technically final and ready-to-sell form including an on-board control unit (OBC) with telemetry features.
The system must be perfectly maintained regarding safety and all emission relevant elements, de-greened and operated not less than 100 hours and the manufacturer must provide his approval data on emissions at the time the vehicle is presented to the testing laboratory.
For the emission testing the system must be equipped with access ports for emission measurement (gases and particles) upstream and downstream of the aftertreatment emission control elements, which are designed such that measurement during NRSC and NRTC is possible. Electronic access to the system sensor signals must be provided for the testing in particular for NO_x-sensors upstream and downstream of the ECR-system for the engine testing and via the telemetric path on internet for the endurance testing.

Manufacturer Data to be Disclosed
(according to VERT-application form)

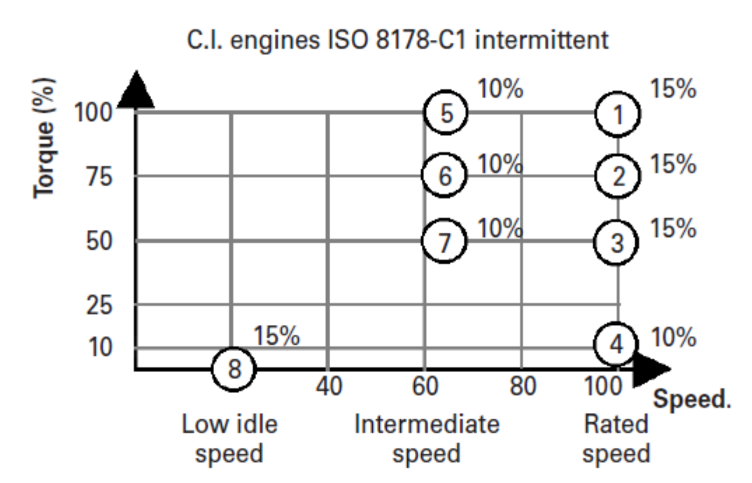
The manufacturer must disclose to the VERT-certification officer:
- Physical structure of the system – drawings, catalyst materials.
- DeNOx-process strategy
- Control and alert strategy
- Operation and maintenance procedures
- Target performance
- Target life
- DPF-certification data
- System experience: number of systems retrofitted in the selected vehicle family
- Hours tested so far

Testing Protocol

This test consists of 5 phases, B1 ÷ B5.

B1. VERTdeNOx1: Steady State Test on Engine Dynamometer

- Engine load ramp at two engine speeds in order to determine the exhaust temperature at which AdBlue injection starts and at which 80% conversion is reached
- Full load and low idle should also be tested
- Each operation point during 15 mins or until thermal stability is reached
- Measured operation data: velocity, RPM, power, temperatures of exhaust gas, engine water and lube oil, exhaust mass flow
- Measurement of emissions: CO, HC, CO_2, O_2, NO, NO_2, PN
- Measurement of NH_3 at tailpipe only
- Download system sensors data for NO, NO_2 at all operation points
- The test program of VERTdeNOx1 will also include all measuring points MP of the NRSC according to ISO 8178 C1
- The laboratory will supply a full report in English on results and evaluations of VERTdeNOx1 and deNOx2 according to VERT report standards.

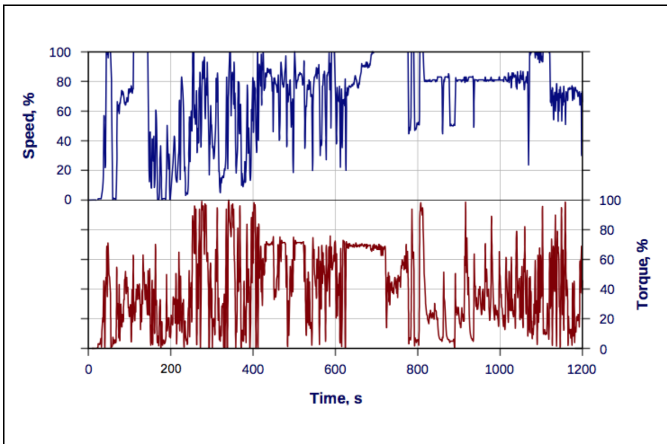


NRSC Nonroad stationary test cycle acc. ISO 8178 C1

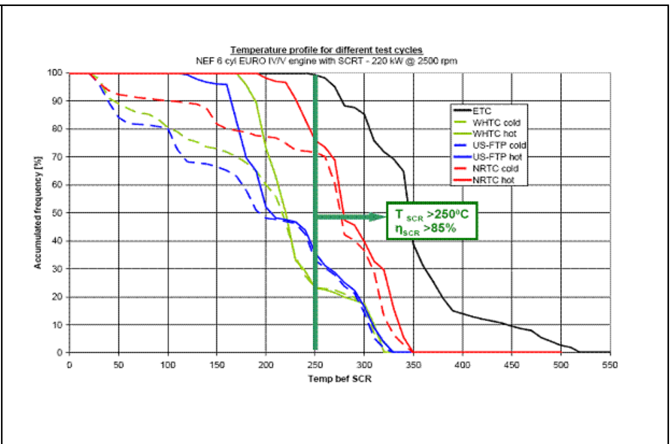
B2. VERTdeNOx2: Dynamic Test on Engine Dynamometer (NRTC)

This EU conform Nonroad Test Cycle (EU-Regulation 2016/1628) shall be used to properly test the dynamic behavior of the system with respect to load variations and exhaust temperature gradients.

- NRTC cold NRTC hot shall be performed
- For averaging emissions cold NRTC shall contribute 10% and hot NRTC 90% (following EU directive 2017/654, Appendix VI 7,4,2.1)
- One repetition of each on different days
- Measurement of emissions: CO, HC, CO_2, O_2, NO, NO_2, PN, NH_3
- Download system sensors data for NO, NO_2 during whole test, compare with laboratory tests



NRTC Nonroad emission test cycle



Temperature profiles for different test cycles

B3. VERTdeNOx3: 200 Operation Hours with Telemetric Data Transfer to VERT Laboratory

- This operation shall not be interrupted by any repair or modification downtime phases
- System checked and sealed by the VERT certification inspector
- Operation of the nonroad machine under supervision of the manufacturer
- logbook on all relevant observations to the VERT-laboratory
- Continuous access to OBC via internet telemetry
- AdBlue consumption to be measured
- Fuel consumption to be measured
- NOx upstream and downstream continuously measured and stored
- Further measurements of: temperatures, pressures, RPM, vehicle speed,
- Monitor ambient temperature, humidity, pressure
- Monitor position by GPS

The System must be checked by the VERT-inspector before release for VERTdeNOx4.
Any system problem, maintenance or repair must be immediately transmitted to the VERT inspector.

B4. VERTdeNOx4: Control of System Functions after > 200 Operation Hours

Download all system OBS data stored during VERTdeNOx3.
Perform a repetition of NRSC and NRTC cold and hot on the engine dynamometer.
In case the endurance test VERTdeNOx3 is performed on an engine which is very different (larger or smaller) from the laboratory engine, which was used for VERTdeNOx1 und VERTdeNOx2, the control test after completing the 200 hors operation may be performed in the field without dismantling the test system. The exception requires a permission of the VERT-SC which must be taken before starting the endurance test.
The laboratory will supply a full report in English which contains all relevant data and evaluations of VERTdeNOx3 and VERTdeNOx4

B5. VERTdeNOxSET, the Secondary Emission Test

It can be waived, if the system uses either a standard VTT-catalyst or a Cu- or Fe-exchanged Zeolite catalyst for which VERT has already analyzed all relevant toxic substances.
If the system however uses a catalyst formulation or catalyst concentration or catalyst morphology which is new and not yet VERT-tested, a VERT Secondary Emission Test must be performed to make sure that no additional toxic substances are generated in significant concentrations.
This test and the related analytics will be performed according to SN 277206 and expected secondary toxic nitrogen substances like N_2O, NH_3, HNCO, CH_2O_2, HCN, HCHO and CH_4 shall be included.
In all cases however, a size specific metal analysis for all catalyst materials must be included in order to make sure that no metals are emitted in the lung penetrating size fractions with the new and the aged system in the whole operation range; this shall also follow SN 277206.

Metrology

Measurements shall be performed 'upstream/downstream' and 'with/without' AdBlue injection during VERTdeNOx1 and VERTdeNOx2.

The VERT performance criterion is NO_x-conversion by the SCR catalyst and not an absolute emission value of NO or NO_2 or NO_x

Metrology is in accordance with:
- SN 277206
- EU 2016/1628
- ISO 8178

Testing Conditions

- Testing at ambient conditions >10 °C
- Engine warmed up
- Engine maintained
- Fuel: EN 590 – Swiss market quality
- Lubrication oil: changed, manufacturer specified quality
- DPF regenerated at start of the test
- AdBlue tank full, filled by the VERT inspector who will take and check an AdBlue sample

Reporting

- All data measured and downloaded
- Interpretation of all important findings
- Conclusions with respect to conformity criteria, operation and findings
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Certification is limited to the defined vehicle family and must fulfill the following criteria:

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- Backpressure (max.) during endurance test < 200 mbar
- NO_x-conversion during NRTC weighed average 10% cold and 90% hot:
  3 classes > 85% / 75-85 % / 65-75 %; < 65% will be rejected and cannot be VERT listed
- Light off (50% NOx-conversion) below 230°C after SCR
- NH_3 < 20 ppm at all operation points
- NH_3 < 20 ppm in average over each NRTC
- Fuel economy (and CO_2) deterioration by retrofit < 3 %
- $CO_2e = ((298 \times N_2O) + (25 \times CH_4)) < 5\%$ of CO_2 ; based on B5 Secondary emission test data
- Aging for NO_x-reduction during 200 operation hours < 5%
- Aging for particle filtration: none

VERT Certification is valid for 5 years if yearly failure rate remains < 3%

Accredited Testing Laboratories

VERT accredited Testing Organizations (see VERT-Filter list)

Overall Testing Cost

- To be confirmed by a detailed cost calculation
- Cost for endurance test, which will be organized by the applicant, are covered by the applicant
- Payment to the VERT finance department in advance

Confidentiality of Data and Reports

All data and reports are confidential between the manufacturer, VERT and the testing laboratory. A respective NDA shall be signed on request of the manufacturer

C. ONROAD + NONROAD application

If the manufacturer has developed a technology to be applied to vehicles for ONROAD as well as for NONROAD applications, VERT offers a combined certification procedure under the following conditions:

- Both versions use the same DPF, which is VERT certified already.
- Both versions use the same SCR-catalyst which is either a VTW type catalyst or a Cu-exchanged or a Fe-exchanged zeolite, for which VERT has already investigated secondary emissions
- SCR catalyst is coated on a separate catalyst substrate and not on the DPF itself, which otherwise would require an additional investigation of the DPF regeneration behavior, based on the results of the VERT research program SDPF under BAFU UTF 431.27.12, which is however not specified in this TA yet.

The manufacturer will supply to the VERT test laboratory

- A complete system NONROAD matched to the selected test engine such, that it comes close to the max. space velocity declared by the manufacturer when the engine operates at nominal power.
- A vehicle equipped with the same system in the ONROAD version with build-in Adblue injection strategy optimized by the manufacturer and equipped with OBD instrumentation of at least one NOx sensor upstream and one NOx sensor downstream of the system, a backpressure sensor and an exhaust temperature sensor both upstream of the system where the data measured in a second by second sequence will be stored and available for download by the VERT laboratory. Before transferring the vehicle to the VERT laboratory for the test this vehicle must have performed at least 10’000 km under real world driving conditions, sealed by VERT, and the data must be acknowledged by the manufacturer to reflect his expectations.

The manufacturer must supply first his application according to the VERT standard form, as it is attached to this TA and this application must be approved by VERT-SC. Furthermore the manufacturer must propose a vehicle and this vehicle must be accepted by VERT.

- A3 After this the ONROAD system will be sealed by VERT and the 10’000 km test run may begin.

Testing Protocol to be performed at the VERT certification laboratory:

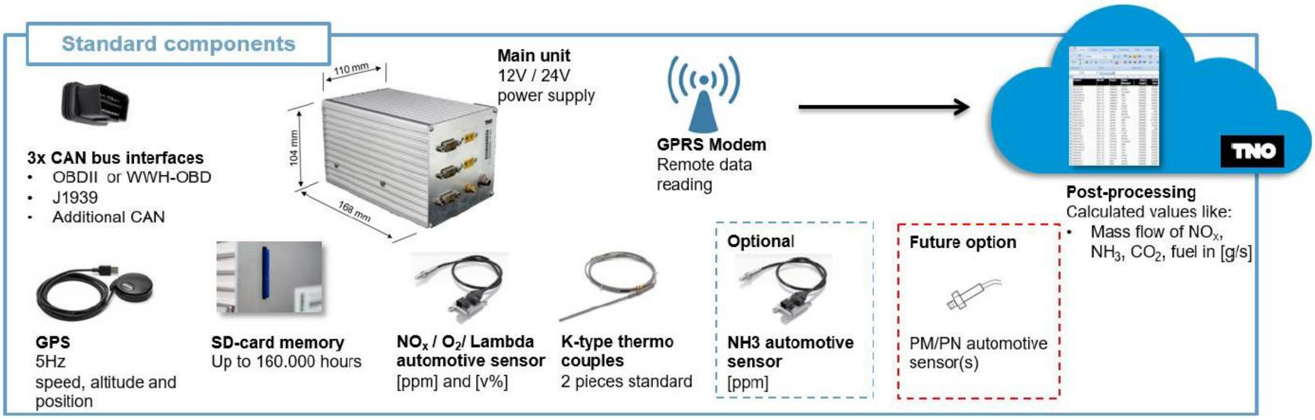
- B1. VERTdeNOx1: steady state test following test cycle NRSC according to ISO 8178 C1
  as described in detail in part B of the TA
- B2. VERTdeNOx2: dynamic test following NRTC
  as described in detail in part B of this TA
- A4. VERTdeNO4: real drive emission control with the system which has passed A3 successfully
  as described in detail in part A of this TA

If the system fulfills the VERT conformity criteria as outlined in detail in this TA in the parts A and B it can be VERT certified and listed on the VERT Filter List on request of the manufacturer for both applications on-road and off-road.

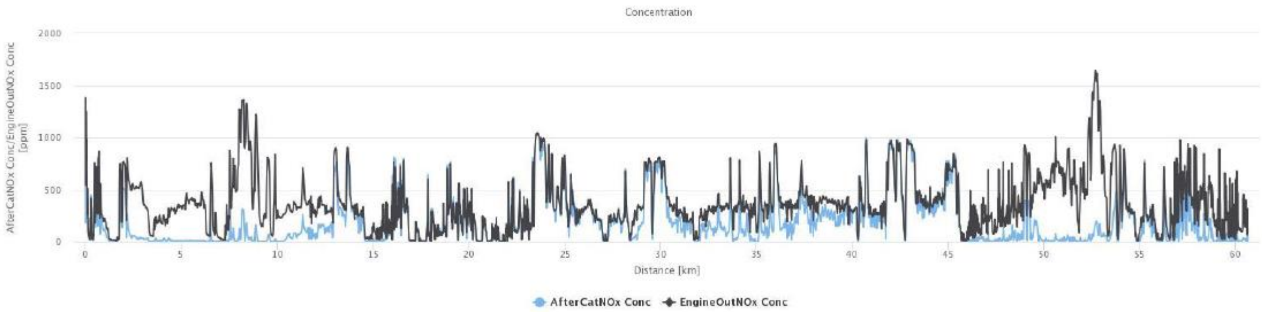
D. On Site Monitoring

As operating conditions can by very different from the conditions simulated in the test cycles, which often is the case in off-road applications, the clients might request proof of proper functioning of the installed EAS system under operating conditions. For this on site monitoring SEMS is offered as a complementary option of the emission quality control procedure.
SEMS, the smart emission measurement system is offered on the market in different versions. It basically consists of the on-board sensors, a GPS systems to localize the object and permit to evaluate mobility profiles and a GSM unit to transfer the data safely to the laboratory.

The following is an example, similar systems are available by HORIBA, PNE and others.



VERT requires two NOx-sensors upstream and downstream of the SCR, a temperature sensor upstream and GPS; additional sensors are optional.
With this the following information will be supplied: volume concentration of NOx upstream and downstream of the SCR – system [ppm], which provide sufficient information on conversion of NO_x to N_2 as well as on the overall functionality of the system and will thereby permit a comparison with the certification data



The information on temperature and the GPS-signal will help to explain conversion differences between on-site operation and certification conditions.

If required by the local authorities with SEMS also mass flow and engine power can be collected from the vehicle CAN bus interfaces and this will permit to also calculate the absolute emission values in overall mass or mass specific to km, kW or m^3 of exhaust gas volume.

Finally it should be mentioned that no EAS system should be used without proper Periodic Technical Inspection (see VERT TA-024/21) and for PTI purpose this SEMS system can also be recommended.

Reviewed
20.December 2020
VERT Scientific Committee

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The PDF version of this publication can be downloaded at www.VERT-certification.eu