Diesel Emission with DPF+SCR in VERTdePN - Testing & Potentials

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ABSTRACT

The most efficient way and the best available technology (BAT) to radically reduce the critical Diesel emission components particles (PM&NP) and nitric oxides (NO_x) are combined exhaust gas aftertreatment systems (DPF+SCR). SCR (selective catalytic reduction) is regarded as the most efficient de NO_x -system, diesel particle filters are most efficient for soot abatement. Today, several suppliers offer combined systems for retrofitting of HD vehicles.

The presented results are part of the work in the international network project VERT^{*} dePN (de-activation, de-contamination, disposal of particles and NO_x), which has the objectives to establish test procedures and quality standards and to introduce the SCR-, or combined DPF+SCR-systems in the VERT verification procedure.

Examples of results for some of the investigated systems are given and the most important findings are:

- the average NO_x conversion rate at transient operation strongly depends on the operation load profile, on the exhaust gas temperature and the resulting urea dosing control,
- the particle number filtration efficiency, which is verified at stationary engine operation, is valid also at the transient operation,
- secondary nanoparticles are produced due to urea injection, they nevertheless do not impact significantly the overall filtration efficiency of the system (here: DPF upstream & SCR downstream, differences of PCFE in the range of 0.1%),
- the OEM NO_x -sensors of the investigated systems are appropriate tools for the in-use control,
- the system with catalyzed DPF (upstream) attains higher overall de NO_x -efficiencies due to NO_2 -production in the DPF,
- for the investigated systems there are no critical emissions of unregulated components, NH_3 & N_2O .

^{*}) Abbreviations see at the end of paper

INTRODUCTION & OBJECTIVES

Laboratories for IC-Engines and Exhaust Emission Control of the University of Applied Sciences Biel, Switzerland (AFHB) participate since 1992 at the Swiss activities about nanoparticle analytics and DPF verification.

The upcoming developments of deNO_x (especially SCR) systems and the combinations with DPF's offer a large number of variants and technical complexity representing new challenges not only for the manufacturers, but also for the users and for the responsible authorities.

The Swiss Federal Office of Environment BAFU and the Swiss Federal Roads Office ASTRA decided to support further activities of VERT to develop appropriate testing procedures and to define the quality criteria of dePN systems for retrofitting.

In the VERTdePN project AFHB collaborates closely with several Swiss specialists of chemistry, catalysis, measuring techniques and combisystems (EMPA, PSI, SUVA, ME, UMTEC), as well as European specialist from JRC Ispra, I; TNO & VROM, NL; AEEDA, B; FAD and TÜV D; AKPF, A and the VERT Association, CH.

The application of combined systems (DPF+SCR) as retrofitting devices raises different technical and commercial problems. In general opinion, this retrofitting will be possible mostly through incentives, or restrictions with respect to low emission zones LEZ, [1] and new regulations of the respective authorities.

The combination of diesel particle filters (DPF) and deNO_x technology (SCR) is widely considered as the best solution, up to date, to minimize the emissions of Diesel engines. Intense developments are on the way by the OEM's and a lot of research is performed on the implementation of such technologies [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14].

The removal of NO_x from lean exhaust gas of Diesel engines (also lean-burn gasoline engines) is a challenge. Selective catalytic reduction (SCR) uses a supplementary substance, a reducing agent, which in presence of catalysts supports the transformation of NO_x in N₂ and H₂O.

The preferred reducing agent for toxicological and safely reasons is a water solution of urea (AdBlue), which after thermal decomposition and hydrolysis decomposes to ammonia NH₃, the actual reducing agent.

Diesel Particle Filter (DPF) eliminate very efficiently the particle mass and the nanoparticles from exhaust gas.

The filtration efficiency of a DPF can be properly judged only for the solid particles. In this context the nanoparticles are considered in VERT/LRV as the most important criterion, [15, 16].

Nanoparticles can be measured with different methods and due to the aptitude of penetrating very easily into living organisms they are regarded as dangerous for health, [17, 18, 19].

The present paper shows some research results on different combined systems (DPF+SCR) in the VERTdePN project and is related previous work [20].

Herein we will discuss new findings on:

- results in different dynamic test cycles,
- emissions of secondary nanoparticles,
- results obtained in the urea switch-on tests,
- comparisons of different investigated systems.

2. TEST-ENGINE, FUEL AND LUBRICANT

TEST ENGINE

There are following engine data:

Manufacturer:	Iveco, Torino Italy
Type:	F1C Euro 3
Displacement:	3.00 Liters
RPM:	max. 4200 rpm
Rated power:	100 kW@3500rpm
Model:	4 cylinder in-line
Combustion process:	direct injection
Injection system:	Bosch Common Rail / 1600 bar
Supercharging:	turbocharger with intercooling
Emission control:	none
Development period:	until 2000 (Euro 3)

Fig. 1 shows the engine and the equipment for nanoparticle analyses. A SMPS & NanoMet was used at the AFHB.

Fig. 1a. IVECO engine FC1 with the dynamic Dynamometer

Fig. 1b. Equipment for nanoparticle measurements in the engine room

FUEL

Table 1 represents the most important data of the fuel, which was a commercial Shell Formula Diesel fuel with Swiss summer quality (10 ppm S) according to SN EN 590

Table 1. Fuel properties as per EU-standards (EN)

		Diesel
Density at 15°C	g/m	0.842*
Viscosity at 40°C	mm ² /s	2.0 - 4.5
Flash point		above 55°C
Cloud point		max -10°C
Filterability CFPP		max -20°C
Ash	%	max 0.010
Sulfur	ppm	<10
Cetane Number		51
Calorific value	MJ/kg	42.7
C fraction	in %	86.7
H fraction	in %	13.3
O fraction	in %	0
Air / Fuel _{stoichiom}	kg/kg	14.52
Boiling range 10-90% °C		180 - 340

LUBRICANT

For all tests a lubricating oil Mobil 1 ESP Formula 5W-30 was used. This oil is recommended by the engine manufacturer.

Table 2. Data of the applied lubrication oil (EN)

Property	Mobil	
Viscosity kin 40°C	72.8	mm ² /s
Viscosity kin 100°C	12.1	mm ² /s
Viscosity index	164	(--)
Density 15°C	0.850	kg/m ³
Pourpoint	-45	°C
Flamepoint	254	°C
Total Base Number TBN	14.2	mg KOH/g
Sulfur ashes	6000	mg/kg
Sulfur	7'280	mg/kg
Mg	<10	mg/kg
Zn	1'570	mg/kg
Ca	4'760	mg/kg
P	1'370	mg/kg

Table 2 shows the available data of this oil,

ACEA classes: C3, A3, B3/B4,

API classes: SL / SM; CF

3. MEASURING SET-UP AND INSTRUMENTATION

ENGINE DYNAMOMETER AND STANDARD TEST EQUIPMENT

Fig. 2 represents the equipment installed on the engine, or in its periphery for analysis of the regulated and unregulated emissions.

Laboratory equipment employed:

- Dynamic test bench Kristl & Seibt with force transducer HBM T10F
- Tornado Software Kristl & Seibt
- Fuel flow measurement AIC 2022
- Air mass meter ABB Sensiflow P
- Pressure transducers Keller KAA-2/8235, PD-4/8236
- Thermo-couples Type K.

Fig. 2. Engine dynamometer and test equipment

TEST EQUIPMENT FOR EXHAUST GAS EMISSIONS

Measurements are performed according to the exhaust gas emissions regulations for heavy duty vehicles, which are valid for Switzerland (Directive 2005/55/EC & ISO 8178):

- Volatile components:
 - Horiba exhaust gas measurement devices
 - Type: VIA-510 for CO₂, CO, HC_{IR}, O₂,
 - Type: CLA-510 for NO, NO_x (this standard hot analyser with one reactor is marked in this report as “1 CLD”)
 - Amluk exhaust gas measurement device Type: FID 2010 for HC_{FID},
 - NH₃ and N₂O:
 - With SCR several unregulated and secondary pollutants can be produced. The slip of gaseous components such as ammonia NH₃ and nitrous oxide N₂O was measured by means of:
 - Siemens LDS 6 Laser Analyzer 7MB 6021, NH₃
 - Siemens ULTRAMAT 6E 7MB2121, N₂O
 - Eco physics CLD 822 CM hr with hot line for NO, NO₂, NO₃, NH₃ (this analyzer with two reactors is marked in this report as “2 CLD”)
 - FTIR (Fourier Transform Infrared) Spectrometer (AVL SESAM) with the possibility of simultaneous, time-resolved measurement of approx. 30 emission components - among those validated are: NO, NO₂, NO_x, NH₃, N₂O.
- #### PARTICLE SIZE ANALYSIS
- To estimate the filtration efficiency of the DPF, as well as to detect the possible formation of secondary nanoparticles, the particle size and number distributions were analysed with the following equipment, Fig. 1b:
- SMPS - Scanning Mobility Particle Sizer, TSI (DMA TSI 3081, CPC TSI 3010)
 - NanoMet - System consisting of:
 - PAS - Photoelectric Aerosol Sensor (Eco Chem PAS 2000) indicates the carbonaceous total surface of the aerosol
 - DC - Diffusion Charging Sensor (Matter Eng. LQ1-DC) indicates the totale surface of the aerosol independently of the chemical properties
 - MD19 tunable minidiluter (Matter Eng. MD19-2E)
 - Thermoconditioner (TC) (i.e. MD19 + post-dilution sample heating until 300°C).

A minidiluter MD19 with thermoconditioner (300°C) was used to sample nanoparticles at the tail pipe. Nanoparticle measurements were performed at constant engine speed

(warm) with SMPS and NanoMet. During dynamic engine operation, NanoMet and CPC were used.

This NP measuring set-up is in accordance with the requirements of the EC GRPE Particle Measuring Program (PMP).

4. TEST PROCEDURES

The dynamic testing was started with the European Transient Cycle ETC and continued with the WHTC (worldwide heavy duty transient cycle), Fig. 3. Also two city-bus cycles: NYCC (New York City Cycle) and Braunschweig Bus Cycle were investigated. All these cycles were defined on the basis of the full (non-limited) engine map. They cause very different operating conditions of the engine, which is depicted with different profiles of exhaust gas temperatures at the tailpipe (Fig. 3, bottom).

The tests were performed after a warm-up phase, when the engine coolant temperature and lube oil temperature reached their stationary values (stationary points tests).

Before starting a dynamic cycle the same conditioning procedure was used to stabilize the thermal conditions of the exhaust gas aftertreatment system. This conditioning was: 5 min at point 1 (2200 rpm/FL) and 0.5 min of idling.

For the low-load cycles (NYCC and Braunschweig), the conditioning was: 5 min 1600 rpm / 165 Nm and 0.5 min idling.

For the tests concerning: filtration efficiency, secondary NP, deNO_x-rate, unregulated parameters, some basic studies on the investigated systems were performed in the 4-points test according to VPNT1.

These operating points are (in the following sequence):

- operating point 7: 50% load, intermediate speed 1, 1600 rpm / 50%,
- operating point 4: 10% load, intermediate speed 2, 2200 rpm / 10%,
- operating point 1: 100% load, intermediate speed 2, 2200 rpm / 100%,
- operating point 3: 50% load, intermediate speed 2, 2200 rpm / 50%,
- operating point 7: repetition.

Fig. 3. Speed, torque and exhaust temperature in the investigated dynamic test cycles

These four operating points were chosen to study the effects of “off” and “on” switching of the urea-dosing (pt. 7 → pt. 4 and pt. 4 → pt. 1).

Different sampling positions (SP) were used to analyse exhaust compositions and temperatures in more detail (see Fig. 2):

- SP 0 sampling engine out w/o aftertreatment system
- SP 1 sampling engine out with aftertreatment system
- SP 2 sampling after DPF (before urea dosing) with aftertreatment system
- SP 3 sampling at tailpipe with aftertreatmentsystem.

This designation of sampling positions is used in the presented figures and in the discussion of results.

Another useful procedure is the urea switch-on test (SW). This test consists of a warm-up of the engine in a low load operation point, without any urea injection, and then increasing the engine load in a controlled way to an engine load where urea injection starts.

This quite simple procedure can be repeated during each warm-up of the engine and of the exhaust system. The SW-test can be joint with the OEM datalogging and it gives additional information on the extent of emissions and NO_x reduction efficiency. The urea switch-on test is considered as a simple and reliable check of SCR quality on vehicles (chassis dyno).

For testing the passive regeneration of DPF's and the NO₂-increase of catalyzed DPF-systems according to the VERT/LRV procedures, a steps-test, Fig. 4, is also used. This test was performed in the present work to correlate the emissions and exhaust gas temperatures at 2200 rpm with increasing engine load: 10%, 20% 30%, 40% 50%, 75% and 100%.

Fig. 4. Torque & exhaust temperature in the steps-test

5. (DPF+SCR) SYSTEMS

A combined system consisting of a DPF upstream of the urea dosing point and a vanadium-based SCR catalyst downstream of the filter was used (as in Fig. 2).

A mixing tube of 1.0m, without mixer was used between the DPF and SCR.

In certain experiments, an ammonia slip catalyst was used at the tail pipe. The combined DPF+SCR system is designed for transient application with an electronic control unit, using the signals of: air flow, NO_x before/after system, and temperatures before/after the SCR catalyst.

Following three variants were investigated:

- PF1 + SCR
- PF1 + SCR + slip cat.
- PF3 + SCR

PF1 is a catalytically coated Cordierite DPF, PF3 is a uncoated SiC DPF with FBC (40 ppm Fe, double dosing for testing purposes). Both DPF's are VERT-approved with average NP filtration efficiencies FE > 99%.

A feed factor of $\alpha = 0.9$ was generally used (during investigations on secondary nanoparticles in Fig. 7 & 8 a feed factor $\alpha = 1.0$ was applied).

6. RESULTS

DIFFERENT TEST CYCLES

Tests were performed with different driving cycles with non limited engine map (NEM).

The exhaust temperatures at the tailpipe over cycle time for all investigated test cycles are given in Fig. 3 together with engine speed and torque.

Fig. 5 summarizes average exhaust concentrations for the different test cycles and Fig. 6 shows the conversion efficiencies in different driving cycles.

In Table 3 the fuel consumption and the average exhaust temperatures in all driving cycles are represented.

The New York City Cycle (NYCC) and the Braunschweig cycle are low-load cycles, which were developed in those cities and represent the city bus driving.

Exhaust temperatures in these low load cycles are too low (< 200°C) to enable the full working potential of the SCR-system. The urea injection is usually cut off at t_{exh} 190-200°C to prevent the deposition of solid matter in the system.

Average NO_x emissions in the low load cycles are lower too, but there is also a poor NO_x-conversion due to the urea dosing strategy.

Fig. 5. Integral average emission values in dynamic cycles, PF1+SCR, $\alpha=0.9$

Fig. 6. Comparison of reduction efficiencies in dynamic cycles, PF1+SCR, $\alpha=0.9$

Table 3. Fuel consumption and average exhaust temperatures in different driving cycles, PF1+SCR, $\alpha=0.9$

		ETC		WHTC		NYCC		Braunschweig	
		1800 s		1800 s		598 s		1740 s	
		OEM	DPF+SCR	OEM	DPF+SCR	OEM	DPF+SCR	OEM	DPF+SCR
Fuel	[l/test]	4.15	4.30	2.58	2.64	0.25	0.26	1.02	1.05
T Engine Out	[°C]	282	310	247	261	144	151	149	156
T Tailpipe	[°C]	248	291	210	241	139	182	127	150

N₂O emissions are generally very low (< 2 ppm) and NH₃ was found only in ETC with SCR NH₃ but its concentrations are typically < 8 ppm at urea feed factors of 0.9.

Comparing different measuring techniques as shown in Figures 5 & 6 one can conclude:

- good correlation of NO_x & NO₂ measured with FTIR and with two CLD,
- good correlation of NH₃ measured with FTIR and with LDS,
- poor correlation of N₂O measured with FTIR and with ULTRAMAT; This is the case, because N₂O concentrations are low - mostly at the detection limits of the analytical devices,
- the relative values, like conversion efficiencies K_x are well correlated with all measuring methods.

These conclusions are supported from several other internal investigations not presented in this paper.

Finally we conclude that the investigated SCR-system has low NO_x conversion efficiencies of 40 and 15% in both low-load city driving cycles. This has been observed before, when comparing the NO_x emissions of the high-load-ETC (non-limited engine map NEM) with those in the low-load-ETC (limited engine map LEM [20]).

SECONDARY NANOPARTICLES

The production of secondary nanoparticles downstream of the urea dosing point was noticed earlier [20]. Such nanoparticles are possibly formed during the deNO_x process. The chemical composition of these particles is yet unknown and further investigations are on the way. They may consist of unreacted urea or derivatives thereof such as cyanuric acid, or salts from acidic and basic compounds such as ammonium nitrite, nitrate, and sulfates and others.

In the present status of these investigations, the objective was to systematically study the number and particle size of these secondary NP by means of PM, SMPS and NanoMet at sampling positions SP2 & SP3, (SP2 ... after DPF & before urea dosing, SP3 ... after SCR).

SMPS measurements after the DPF (SP2) and after the SCR (SP3) confirmed the presence of secondary nanoparticles in all load stages of the 4-points test.

Fig. 7 shows an example of the SMPS size distributions and the integrated particle number in different parts of the size spectra at 2200 rpm / 50%. The increase of particle mass emissions between SP2 and SP3 as a result of a secondary particles formation was noticed as well.

Fig. 8 represents the particle mass PM, the mass-related filtration-efficiency PMFE and the particle number related filtration efficiency PCFE in all operating points and at all sampling positions SP0, SP2 & SP3. At two OP's, there is a little, but consistent increase of PM between SP2 and SP3. This causes a significant reduction of PMFE, but no significant reduction of PCFE. This indicates that these secondary particles mainly contribute to particle mass but not much to particle numbers.

It can be summarized that the presence of secondary nanoparticles after the SCR-system was confirmed. In some cases, secondary NP contribute to an increase of the particle mass.

Fig. 7. SMPS-size spectra at SP2 & SP3, PF1+SCR, $\alpha=1.0$

Fig. 8. Particle mass and counts reduction in the 4 points test, PF1+SCR, $\alpha=1.0$

UREA SWITCH-ON TESTS

The urea switch-on test (SW) was developed to study effects during the SCR light-off. Engine and exhaust system in this test are warmed up at a low load OP (e.g. 1200 rpm / 60 Nm) without urea injection. After a jump to higher engine loads OP (e.g. 1600 rpm / 165 Nm), urea injection is activated.

In the 1st operating point the engine slowly warms up, but the exhaust gas temperature is still too low to allow urea injection. After a jump to higher loads, the 2nd operating point, urea injection is activated after certain time after the exhaust temperature t_{exh} has increased.

Measurements were started shortly before the load jump to register the changes of exhaust concentrations during the urea activation period.

Fig. 9. Estimate of the NO_x reduction rate with OEM-datalogging, PF1, $\alpha=0.9$

Fig. 10. Comparison of switch on of urea injection with 2 different PF

Fig. 9 represents changes of NO_x and NO₂ concentrations over time measured with the OEM-UDS-sensors and with the laboratory equipment (CLD & FTIR) during an urea switch-on test. There are small deviations between the NO_x-readings of the different instruments. The OEM-NO_x-sensors depict very well the NO_x conversion rates K_{NOX} , which are obtained from laboratory analyzers (CLD & FTIR).

At the operating condition with higher NO_x-concentrations (without urea injection), the FTIR shows higher NO_x & NO concentrations than the CLD. This is due to several reasons, one of them being a much shorter sampling line for FTIR.

We conclude that the original system NO_x-sensors are a well suited to observe the NO_x conversion rate; they can be recommended as suitable tools for a field control.

Fig. 10 compares SW-tests of PF1, a catalysed cordierite, with PF3, a SiC not catalysed + FBC. Both filters differ in their NO₂-emissions in the phase between load jump and the start of the urea injection. The catalysed DPF generates substantial amounts of NO₂, whereas the FBC-DPF doesn't. The duration of this phase is also different for both systems most probably because of different conditions of heat transfer and different thermal capacities in the exhaust system.

Fig. 11 shows the repeatability of several switch-on trials (SW12, 13, 14).

During SW12 temperatures were higher at the beginning. This may be a reason for lower concentrations of NO₂, formaldehyde, and formic acid in this period. Also the history of the SCR-catalyst can influence its chemistry by variable amounts of residues, or adsorbed substances.

The time period from "load on" to "urea on" varied in the range of 20s in these tests.

The NO_x reduction efficiencies K_{NOX} during the urea switch-on are also quite repetitive. This procedure can be regarded as a simple check of the SCR system on the HD chassis dynamometer.

Fig. 11. Repeatability of switch-on tests (PF3, $\alpha=0.9$)

COMPARISONS OF DIFFERENT AFTERTREATMENT SYSTEMS

Fig. 12 represents the conversion efficiencies of regulated gaseous components with the investigated aftertreatment systems in the 4-points test.

With uncatalysed PF3, negative CO conversion efficiencies were noticed, mostly at the highest OP, with the highest backpressure. HC is also converted in a vanadium-based SCR-catalyst, and there are as high conversion efficiencies K_{HC} in combination with the PF3 system (FBC).

Fig. 12. Conversion efficiencies of regulated pollutants and N_2O in the 4-points test with different DPF+SCR systems

NO_x is not reduced at the lowest OP due to urea switch-off. At higher OP's, with active SCR catalyst, there is a tendency of slightly lower K_{NOx} -values with the fuel-borne catalyzed PF3. The principal reason is the lower NO_2 concentration after this filter.

Emissions of nitrous oxide N_2O are very low (< 2 ppm) and deviate less than 1 ppm from values without aftertreatment (OEM).

Emissions of ammonia NH_3 are not represented, since they are generally at zero level, except of one value (10 ppm) for the PF1 (cat.) + SCR at the highest OP (2200 rpm / 332 Nm).

Fig. 13 compares the different exhaust aftertreatment systems in the steps-test at 2200 rpm. Following effects were observed:

- reduction of NO_x at $t_{exh} \geq 190^\circ C$,
- emission of NO_2 increase with PF1 (cat) in the t_{exh} range 240-340°C
- emission of NH_3 increase up to 8 ppm with PF3 in the t_{exh} range 240-340°C
- emission of NH_3 increase up to 10 ppm with PF1 in the t_{exh} range $< 390^\circ C$

- NO_x conversion starts at slightly lower t_{exh} , with PF1 than with the fuel-borne catalyzed PF3 ($\Delta t \approx 10\text{-}15^\circ\text{C}$),
- similar maximum conversion efficiencies K_{NO_x} were found for both systems.

Fig. 13. Comparison of different converter systems in steps-tests at 2200 rpm: Reference - PF1(cat.)+SCR - PF3(FBC)+SCR, 60s average values of stationary operating

7. CONCLUSIONS

The most important results from the combined DPF+SCR systems are summarized as follows:

DIFFERENT TEST CYCLES

- in the low-load transient cycles (NYCC & Braunschweig), there are rather low NO_x conversion efficiencies due to low exhaust gas temperatures and limited urea dosing,
- the SCR-systems in the tested configuration has moderate deNO_x efficiencies at low-load city driving, but substantial deNO_x efficiencies were found at higher engine loads e.g. at highway conditions

MEASURING TECHNIQUES

- there are generally good correlations of NO_x, NO & NO₂ concentrations measured with CLD and with FTIR; for very low concentrations, after the SCR, the correlations of some parameters become weaker,
 - there is a good correlation between NH₃ concentrations measured with FTIR and LDS, nevertheless with a clear tendency of higher readings with FTIR; this difference is negligible at concentrations below 10 ppm.
 - there is a poor correlation of N₂O levels measured with FTIR and with ULTRAMAT; Both techniques are not sensitive enough to detect N₂O-levels at concentrations below 1 ppm.
 - the differences are partly caused by differing sampling positions and by differing sampling line lengths,
 - relative values, like conversion efficiencies K_x are well estimated with all measuring methods.
- Similar findings are also found in other internal investigations not presented in this paper.

SECONDARY NANOPARTICLES

- the production of secondary nanoparticles (NP) in the SCR-system was confirmed; in certain cases, such NP also increase particle mass (PM) emissions to some degree.

UREA SWITCH-ON TESTS

- the original system NO_x-sensors are valid instruments to determine the NO_x conversion efficiency; they can be recommended as suitable tools for the field control,
- the repetitive engine load increase during the urea switch-on procedure (SW) was confirmed as a useful way to determine the: switch-on-temperature, switch-on-time and the resulting NO_x conversion rate,
- with this procedure, response times for deNO_x systems up to 8min after the load jump were found,
- PF3 with a FBC has a considerably longer response time than coated PF1; different heat transfer and thermal capacity are possible reasons for this difference
- PF3 with FBC produces lower NO₂ concentrations in the time period from load jump to SCR light-off,
- the switch-on procedure (SW) can be recommended as a simple check of the SCR system on the HD chassis dynamometer.

COMPARISONS OF DIFFERENT SYSTEMS

- the DPN system with FBC has a slightly lower NO_x conversion than the coated system due to lower NO₂-levels,
- the DPN systems with a coated PF1 efficiently lowered CO and HC, but even with an SCR catalyst downstream can produce higher NO₂/NO_x-ratios at certain operating conditions,
- for both systems there are no critical emissions of unregulated components, like ammonia, and nitrous oxide.

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10. ABBREVIATIONS

AFHB

Abgasprüfstelle FH Bid, CH

AKPF

Arbeitskreis der Partikelfilterhersteller, Austria

Air min

stoichiometric air requirement

ASTRA

Amt für Strassen, CH, Swiss Road Authority

BAFU

Bundesamt für Umwelt, CH (Swiss EPA)

CARB

Californian Air Resources Board

CDI

Common Rail Diesel Injection

CFPP

cold filter plugging point

CLD

chemoluminescence detector

CNC

condensation nuclei counter

CPC

condensation particle counter

DC

Diffusion Charging Sensor

dePN

de Particles + deNO_x

DI

Direct Injection

DMA

differential mobility analyzer

DPF

Diesel Particle Filter

ECU

electronic control unit

EMPA

Eidgenössische Material Prüf- und Forschungsanstalt

EPA

Environmental Protection Agency

ETC

European Transient Cycle

FAD

Förderkreis Abgasnachbehandlungs-technologien für Dieselmotoren, Germany

FBC

fuel borne catalyst (regeneration additive)

FE

filtration efficiency

FID

flame ionization detector

FL

full load

FOEN

Federal Office of Environment (BAFU)

FTIR

Fourrier Transform Infrared Spectrometer

HD	heavy duty	OP	operating point
ICE	internal combustion engines	PAS	Photoelectric Aerosol Sensor
JRC	EU Joint Research Center	PC	particle counts
LDS	Laser Diode Spectrometer (for NH ₃)	PCFE	particle counts filtration efficiency
LEM	limited engine map	PF1	DPF catalyzed cordierite
LEZ	low emission zones	PF3	DPF uncoated SiC+ FBC
LRV	Luftreinhalteverordnung	PM	particulate matter, particle mass
ME	Matter Engineering	PMFE	particle mass filtration efficiency
MD19	heated minidiluter	PMP	particle measuring program of the EC GRPE
NanoMet	NanoMetnanoparticle summary surface analyser (PAS + DC + MD19) PAS + DC + sampling & dilution unit	PSD	particle size distribution
NEM	nonlimited engine map	PSI	Paul Scherrer Institute
NP	nanoparticles < 999 nm (SMPS range)	RE	reduction efficiency
NRTC	nonroad transient cycle	SCR	selective catalytic reduction
NYCC	New York City Cycle	SMPS	Scanning Mobility Particle Sizer
OEM	original equipment manufacturer	SP	sampling position
		SUVA	Schweiz. Unfallversicherungs-Anstalt

SW	urea switch-on	α	feed factor of urea dosing;
TC	thermoconditioner. Total Carbon		ratio: urea injected / urea stoichio-metric; calculated by the ECU.
TNO	Netherland National, Laboratories		
TÜV	Technischer Überwachungsverein, D		
ULSD	ultra low sulfur Diesel		
UMTEC	Umwelttechnik Institut FH Rapperswil, CH		
VERT	<u>V</u> erminderung der <u>E</u> missionen von <u>R</u> ealmaschinen in <u>T</u> unnelbau <u>V</u> erification of <u>E</u> mission <u>R</u> eduction <u>T</u> echnologies		
VERTdePN	VERT DPF + VERT deNO _x		
VROM	Netherlands EPA		
VSET	VERT Secondary Emissions Test		
WHTC	worldwide heavy duty transient cycle		

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