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Reduction of emissions and unregulated components with DPF + SCR

The combined Diesel exhaust gas aftertreatment systems (DPF + SCR)[1] are today the best available technology (BAT) to radically reduce the critical Diesel emission particles (PM & NP) and nitric oxides (NO_x). SCR (selective catalytic reduction) is regarded as the most efficient deNO_x-system. The combined systems are already offered today by several suppliers for retrofitting the HD vehicles. Quality testing and standards for those quite complex systems are needed to enable decisions of several authorities to promote the retrofitting. The presented results are a part of the international network project VERT[1] dePN (de-activation, decontamination, disposal of particles and NO_x), with the objective 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. The most important findings are:

- the investigated combined dePN systems (DPF+SCR) for dynamic engine application efficiently reduce the target emissions with deNO_x-efficiencies up to 92% (if operated in the right temperature window) and particle number filtration efficiency up to 100%,
- the ammonia slip can be efficiently eliminated by the slip-cat,
- the average NO_x conversion rate at transient operation (ETC) strongly depends on the exhaust gas temperature profile 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.

The presented results will be confirmed in the further project activities in other systems. A special attention has to be paid to the operational profiles, which are representative for low emission zones LEZ.

Redukcja emisji i nielimitowanych składników spalin silnika z DPF + SCR

Zespolone układy obróbki spalin (DPF + SCR) są dzisiaj najbardziej skuteczną technologią radykalnego obniżenia krytycznych składników emisji silnika Diesla, tj. cząstek stałych (PM i NP) i tlenków azotu (NO_x). SCR (selektywna redukcja katalityczna) jest uznana za najbardziej efektywny system redukcji NO_x. Zespolone układy obróbki spalin do retrofittingu pojazdów z ciężkimi silnikami Diesla (HD) są już oferowane przez kilku producentów. Istotnego znaczenia nabierają badania jakości i standardy dla tych dość skomplikowanych systemów, potrzebne dla przekonania władz do promocji retrofittingu. Prezentowane wyniki są częścią międzynarodowego sieciowego projektu VERT dePN (deaktywacja, zapobieganie osadzaniu i usuwanie cząstek stałych i NO_x), ukierunkowanego na wprowadzenie do powszechnego stosowania systemów SCR lub złożonych układów SCR + DPF, weryfikowanych według procedury VERT. W artykule podano wyniki dla niektórych badanych systemów. Najistotniejsze spostrzeżenia:

- badane zespolone systemy dePN (DPF + SCR) przeznaczone do eksploatowanych w warunkach dynamicznych silników efektywnie redukują końcową emisję NO_x – efektywność do 92% (przy utrzymaniu odpowiedniego zakresu temperatur); pod względem ilościowej emisji cząstek stałych sprawność filtracji wynosi do 100%,
- bezwładność w zakresie zmian wymaganej ilości amoniaku może być efektywnie eliminowana przez odpowiedni katalizator (*slip-cat*),
- średni stopień konwersji NO_x w nieustalonych warunkach pracy (ETC) jest mocno uzależniony od profilu zmian temperatury gazów wylotowych i układu regulacji dozowania mocznika,
- efektywność filtracji cząstek stałych pod względem ilości, weryfikowana w stałych warunkach pracy, jest obowiązująca również w warunkach nieustalonych.

Przedstawione wyniki badań będą potwierdzone w innych projektach, z zastosowaniem innych systemów. Szczególnej uwadze poddano profile użytkowania, które są reprezentatywne dla stref niskiej emisji (LEZ).

[1]See abbreviations at the end of paper.

Introduction

The combination of particle filtration (DPF) and the 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 [1, 3, 5].

The application of combined systems (DPF + SCR) as retrofits raises different technical and commercial problems. In general opinion, this retrofitting will be possible mostly through the incentives, or restrictions due to the low emission zones LEZ [6] and decisions of several authorities.

Available technical information – DPF + SCR

The removal of NO$_x$ from the lean exhaust gases of Diesel engines (also lean-burn gasoline engines) is an important challenge. Selective catalytic reduction (SCR) uses a supplementary substance – reduction agent – which in presence of catalysts produces useful reactions transforming NO$_x$ into N_2 and H_2O.

The preferred reduction agent for toxicological and safety reasons is the water solution of urea (AdBlue), which due to reaction with water (hydrolysis) and due to thermal decomposition (thermolysis) produces ammonia NH_3, which is the real reduction substance. A classical SCR deNO$_x$ system consists of four catalytic parts:

- pre-catalyst converting of NO to NO_2 (with the aim of 50/50 proportion),
- injection of AdBlue (with the intention of best distribution and evaporation in the exhaust gas flow),
- hydrolysis catalyst (production of NH_3),
- selective catalyst (several deNO$_x$ reactions),
- oxidation catalyst (minimizing of NH_3 slip).

The main deNO$_x$-reactions between NH_3, NO and NO_2 are widely mentioned in the literature. They have different speeds according to the temperatures of gas and catalysts, space velocity and stoichiometry. This offers a complex situation during the transient engine operation.

Additionally to that there are temperature windows for catalysts and cut off the AdBlue-injection at low exhaust gas temperatures to prevent the deposits of residues.

Several side reactions and secondary substances are present. An objective is to minimize the tail pipe emissions of: ammonia NH_3, nitrous oxide N_2O, isocyanic acid HNCO and ammonium nitrate $NH_4\ NO_3$ (also known as secondary nanoparticles) [2, 4, 7].

VERTdePN – Research subjects and objectives

A general objective of VERTdePN is to include the combined systems DPF + SCR in the test procedure, which was previously developed for DPF only.

Since the stationary testing of SCR for onroad application is not sufficient any more, a simplified test procedure consisting of stationary, quasidynamic and dynamic elements was found.

For the VERT DPF quality procedure the research objectives were:

- ◦ filtration quality, durability, control – & auxiliary systems, secondary emissions.

The new objectives for a SCR system in the VERTdePN tests are:

- ◦ NO$_x$ reduction,
- ◦ NO_2- and/or NH_3- slip,
- ◦ temperature window,
- ◦ dynamic operation,
- ◦ field application & durability,
- ◦ auxiliary systems,
- ◦ further secondary emissions.

The main structure of VERTdePN tests for SCR is similar, as the preceding VERT activities for DPF (Fig. 1):

- quality test and basic investigation on dynamic engine dynamometer on a representative HD-engine,
- supervised field test 2000 h,
- analytics of unlimited- and secondary emissions.

It is important to point out, that the strict homologation

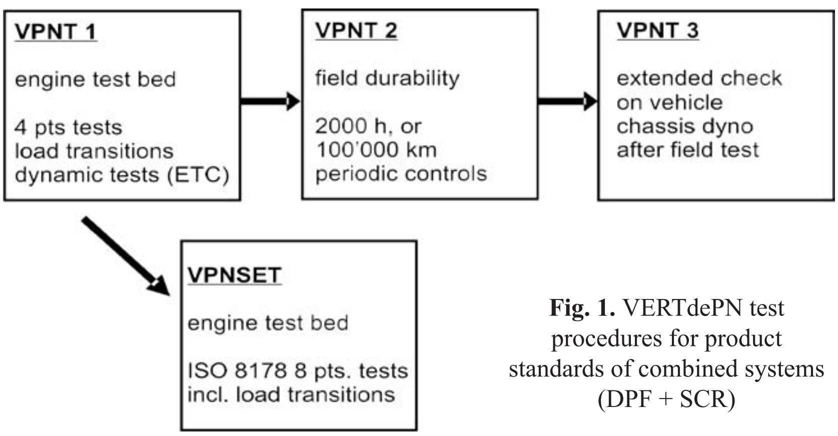

Fig. 1. VERTdePN test procedures for product standards of combined systems (DPF + SCR)

procedures according to the EU-steps would, due to complexity and costs, eliminate the possibility of retrofitting.

In the present state of discussions, the following main points can be remarked:

- retrofitting, as a quicker and more efficient measure to reduce consequently the air pollution makes much sense for the society,
- if any authority wants to support retrofitting it has to do it among others by means of more flexible requirements and procedures; this flexibility can and should be adapted to the different levels of political decisions, (communal, regional, national, international),
- important elements of the test procedures are the extensive tests of the product on engine dynamometer connected with different kind of vehicle testing.

  There are three kinds of on-road testing proposed:
  - on-road real world vehicle benchmarking and comparison with OE vehicles with similar technology (proposed project SNORB to be started during 2008),
  - field test with intermediate and final control on the chassis dynamometer (VPNT2 (VERT de PN test 2) & VPNT3 (VERT dr PN test 3)),
  - simplified acceptance test (vehicle stand still).

Test-engine

Figure 2 shows the Iveco engine on a dynamic dynamometer in the laboratory for IC-engines, University of Applied Sciences, Biel-Bienne.

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 at 3500 rpm
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)

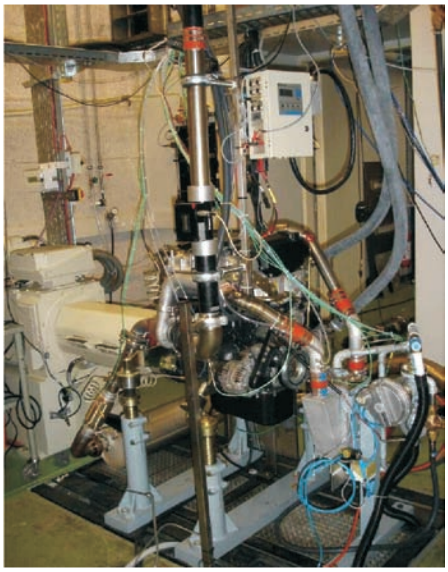

Fig. 2. IVECO engine F1C with the dynamic dynamometer

Measuring set-up and instrumentation

Figure 3 represents the special systems installed on the engine, or in its periphery for analysis of the limited and unlimited emissions.

Test equipment for exhaust gas emissions

Measurement is performed according to the Swiss exhaust gas emissions regulation for heavy duty vehicles (Directive 2005/55/CE & ISO 8178):

- Volatile components: Horiba exhaust gas measurement devices: CO_2, CO, HC_{IR}, O_2, CLD (hot), NO, NO_x, FID HC_{FID}, NH_3 LDS 6 Laser Analyzer, N_2O infrared analyzer.
- FTIR (Fourier Transform Infrared) Spectrometer (AVL SESAM) with possibility of simultaneous, time-resolved measurement of approx. 30 emission components – among others: NO, NO_2, NO_x, NH_3, N_2O, HCN, HNCO.

Particle size analysis

To estimate the filtration efficiency of the DPF, as well as to detect the possible production of secondary nanoparticles, the particle size and counts distributions were analysed with the following apparatus:

- SMPS – Scanning Mobility Particle Sizer, TSI (DMA TSI 3071, CPC TSI 3025 A),
- NanoMet – System consisting of:
  - PAS – Photoelectric Aerosol Sensor (Eco Chem PAS 2000),
  - DC – Diffusion Charging Sensor (Matter Eng. LQ1-DC),
  - MD19 tunable minidiluter (Matter Eng. MD19-2E),
  - Thermoconditioner (TC) (i.e. MD19 + postdilution sample heating until 300°C).

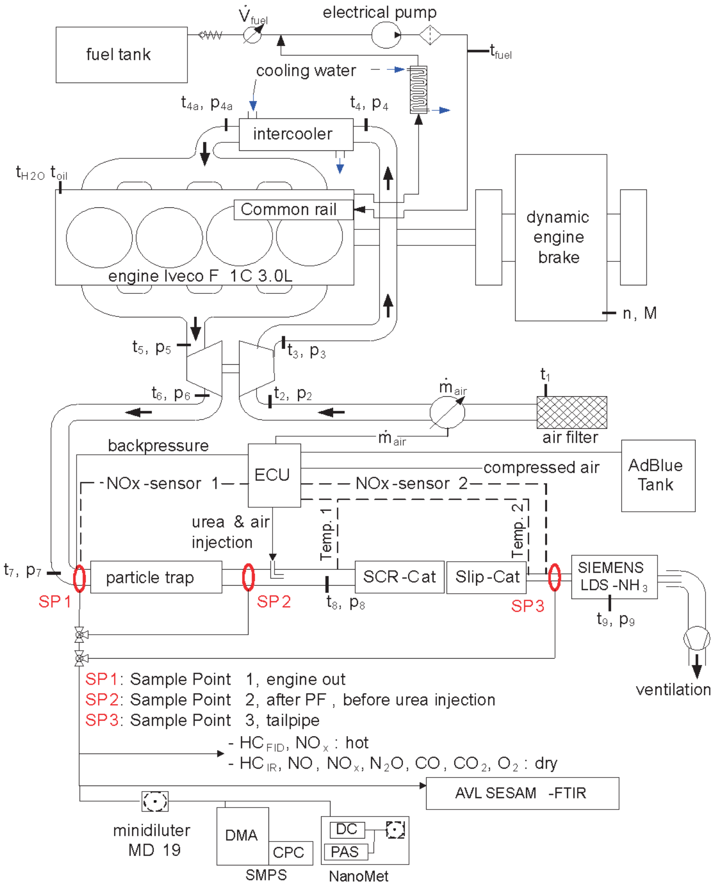

Fig. 3. Engine dynamometer and test equipment

Test procedures

According to the different objectives of the project several test procedures were used.

After analyzing the backpressure of the system in the entire engine operation map it was decided to limit the operation range.

Figure 4 shows the limited engine map, the ISO 8178, 8 points in this limited map and the 4 points test, which was fixed for VPNT1.

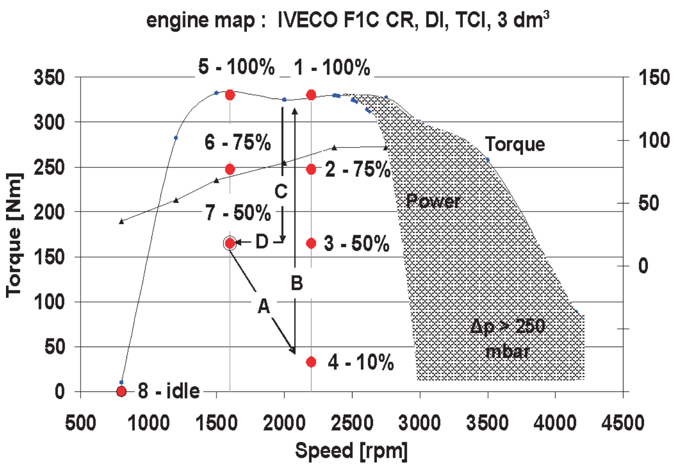

Fig. 4. 8 pts. test (ISO 8178) in the limited engine map and setting of the VPNT1 4 pts. test

8 pts. tests were used for the secondary emission tests VPNSET with EMPA with different feed factors α^2.

For the tests concerning: filtration efficiency, $deNO_x$-rate, unlimited parameters, some basic studies about the investigated systems and about the test procedures 4 pts. tests were used according to VPNT1 (AFHB).

The four operating points were chosen in such a way, that the switching "off" and "on" of the urea-dosing is included in the tests (pt. 7 → pt. 4 and pt. 4 → pt. 1).

For a more detailed investigation of the tested system different sampling positions (SP) were used (see Fig. 3):

SP 0 sampling engine out w/o aftertreatment system,

SP 1 sampling engine out with aftertreatment system,

SP 2 sampling engine after DPF (before urea dosing) with aftertreatment system,

SP 3 sampling engine at tailpipe with aftertreatment system.

This designation of sampling positions is used in the presented Figures and in the discussion of results. The dynamic testing was started with the ETC (European Transient Cycle), which was first defined on the basis of the limited engine operation map (Fig. 5).

[2]see abbreviations at the end of paper

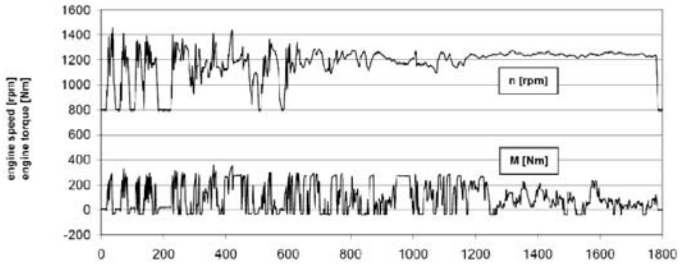

Fig. 5. ETC for the limited version of engine map, IVECO F1C

The tests were driven after a warm-up phase. Before the start of each dynamic cycle the same procedure of conditioning was used to fix as well as possible thermal conditions of the exhaust gas aftertreatment system. This conditioning was: 5 min pt. 1 and 0.5 min idling.

Results

The results are obtained from combined systems consisting of a coated DPF upstream, urea dosing and SCR catalyst downstream (as in Fig. 3).

Between DPF and SCR there was a mixing tube of 1.0 m, without mixer.

Sometimes an ammonia slip catalyst was used as a modulus at the end of the system.

This (DPF + SCR) system is designed for transient application. It has an electronic control unit, which uses the signals of: air flow, NO_x before/after system and temperatures before/after SCR modulus.

<u>Stationary engine operation</u>

Figure 6 shows the time-plots of NO_x and NH_3 in the 8 pts. test with different feed factors α. The increasing feed factor up to $\alpha = 1.2$ enables the deNO_x efficiency up to 98%, but with increased ammonia slip up to 125 ppm.

Figure 7 shows the results obtained with FTIR at different sampling positions. This time there is a direct comparison between SP2 (after DPF, before urea dosing) and SP3 (after system).

As expected there is an efficient reduction of nitric emissions NO_x, NO & NO_2 by passing the SCR catalysts. Exception is at low load OP4 where there is no admission of reduction agent.

The production of NO_2 in the catalyzed DPF is demonstrated by the differences between SP0 and SP2. At OP4 the exhaust gas temperature is too low and no NO_2 is produced.

N_2O has the tendency to be increased partly in the DPF, partly in the SCR – nevertheless its quantities are small (1 < 1 ppm). Also the quantities of formaldehyde, hydrocyanic- & isocyanic acids emitted after the (DPF + SCR) system are below 1 ppm.

Measurements of nanoparticles NP in the 4 pts. test at different sampling positions are represented in Fig. 8. Particularly interesting is the look on the SP2 (after DPF,

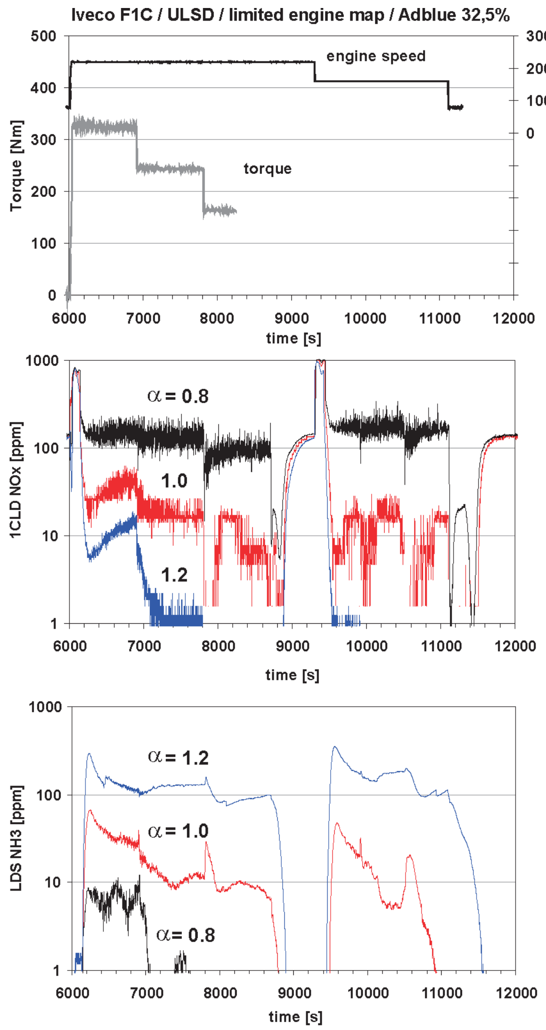

Fig. 6. Comparison of results at 8 points-test with different feed factors *α*

before urea dosing) and SP3 (after the system). There is some production of secondary nanoparticles due to the presence of urea and the other products of deNO_x-reactions. This is indicated by increased CPC- and DC-values between SP2 and SP3.

DC (diffusion charging sensor) measures the total par-

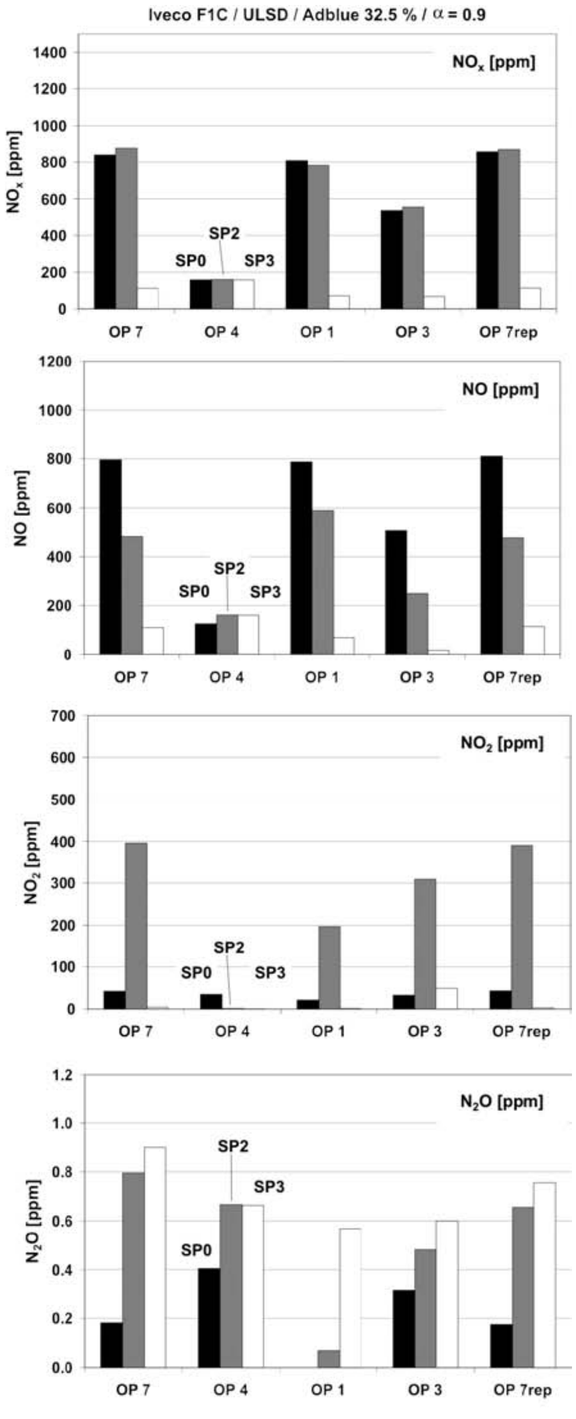

Fig. 7a. FTIR results in 4 pts. test at different SP's

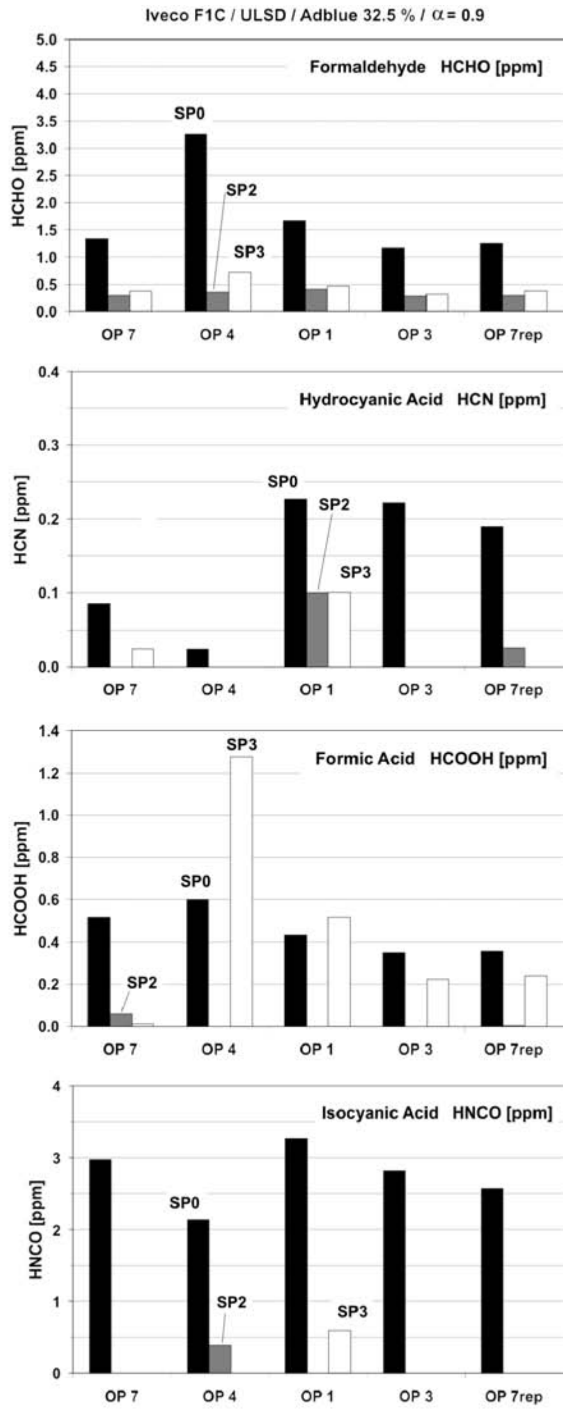

Fig. 7b. FTIR results in 4 pts. test at different SP's

ticle surface independent of the chemical properties. It indicates the solids and the condensates.

PAS (photoelectric aerosol sensor) is sensitive to the surface of particulates and to the chemical properties of the surface. It indicates the solid carbonaceous particles.

The PAS-values between SP2 and SP3 (Fig. 10) decrease, because there is less overall carbonaceous aerosol surface – the previously present carbonaceous particles are enveloped by other products (in liquid, or solid form) and the new particles definitely have no carbon.

As already known from the literature, these new substances can be: urea, cyanuric acid and ammonium nitrate.

The increase of NP count concentration or of the overall surface of the aerosol (DC) in the SCR-part (SP2-SP3) is little in comparison with the reduction of NP in the DPF-part of the system (SP0-SP2). Therefore the secondary NP-production does not impact the overall filtration efficiency of the system (see logarithmic scale of the ordinate). The exception is the operating point OP1 with the highest space velocity and intense secondary NP production.

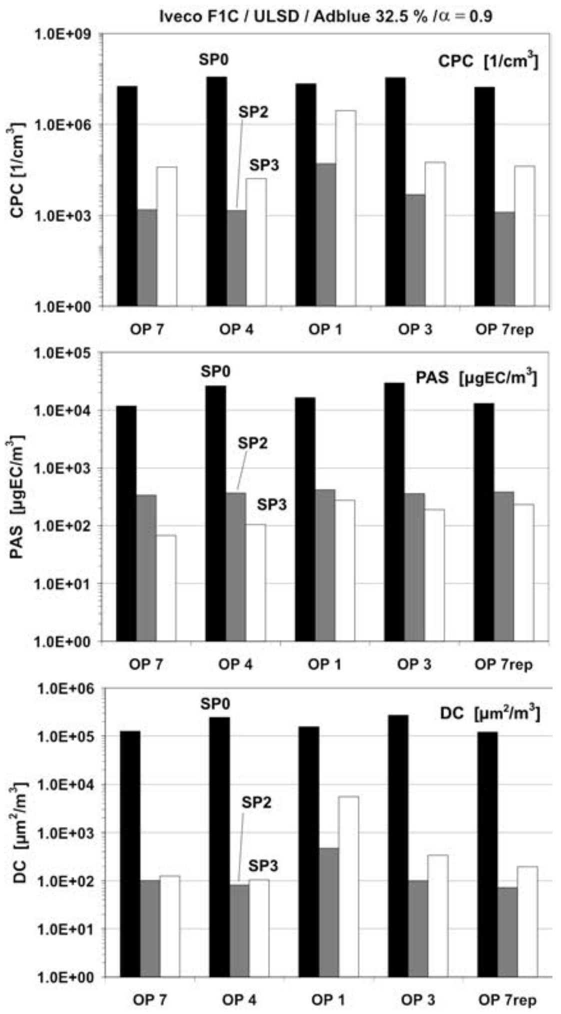

Fig. 8. Secondary nanoparticles at 4 pts. test (w/o slip cat.) indicated with total NP counts (CPC) and surface measuring sensors PAS & DC

A shortened summary of reduction efficiencies RE in the 4-points test without slip cat is represented in Table 1. NO_x and NO_2- values of CLD and FTIR, as well as all NP-values (CPC, PAS, DC) are given.

At operating points 7, 1 and 3 the SCR system is working in the optimal temperature window and deNO_x-efficiencies are in the range of 86-91%.

Concerning the NO_2 reduction rates, there are some open questions: why is the NO_2 efficiency so high at OP4 with no urea dosing and why is it so low at OP3, when the urea injection and temperature range are optimal? These questions can be at least partly explained by the dynamic response of the aftertreatment system in the preceding load transitions.

On one side there are thermal memory effects of the different components (DPF, SCR) in the range of 10 min and on the other side the chemical memory due to store/release effects and secondary reactions.

The presented nanoparticle filtration efficiencies (Table 1) are excellent and confirm the required high quality of the DPF part of the system (except of OP1 with highest space velocity and intense secondary NP formation).

Load transitions

The emissions over time in all transitions A, B, C & D of the 4 pts. test (Fig. 4) were registered.

Figure 9 shows as example the transition B with load increase from 10% to 100% at 2200 rpm and with urea switching on.

NO_2 levels measured before the combined dePN system (SP1) decline at 100% load, as expected, because of thermal NO_2 decomposition at temperatures up to 490°C (Table 1).

Measured after the system (SP3) quite long response times of NO_x-reduction are noticed, in the range of 90 sec. In this time, exhaust temperatures increase and the urea dosing starts.

According to the conditions of flow, space velocity, temperature and urea stoichiometry (α) different SCR reactions proceed.

Table 1. Integral average values and reduction efficiencies of NO_x, NO_2 and NP in the 4-pt. test

	4-Pt. SP3 w/o slip catalyst				4-Pt. SP0 Reference							
$RE_x = \frac{X_{w/o} - X_w}{X_{w/o}} \cdot 100$	with DPF + SCR				with out DPF + SCR				RE [%]			
	7	4	1	3	7	4	1	3	7	4	1	3
Temp. T 7 [°C]	339	177	528	367	337	175	490	350				
NO_x 1CLD [ppm]	100	143	85	52	760	140	740	490	87	-2	89	89
NO_x FTIR [ppm]	113.97	160.22	69.86	65.42	838	160	808	539	86	0	91	88
NO_2 1CLD [ppm]	3	1	0	32	40	30	30	30	93	97	100	-7
NO_2 FTIR [ppm]	4	0.56	0.91	49	42	35	21	33	91	98	96	-51
CPC [1/cm³]	3.9E+04	1.6E+04	2.9E+06	5.6E+04	1.9E+07	3.7E+07	2.2E+07	3.6E+07	100	100	87	100
PAS [µgEC/m³]	67.6	104.9	274.3	190.2	1.2E+04	2.6E+04	1.6E+04	2.9E+04	99	100	98	99
DC [µm/cm³]	125.4	103.2	5542.1	337.5	1.3E+05	2.4E+05	1.6E+05	2.7E+05	100	100	96	100

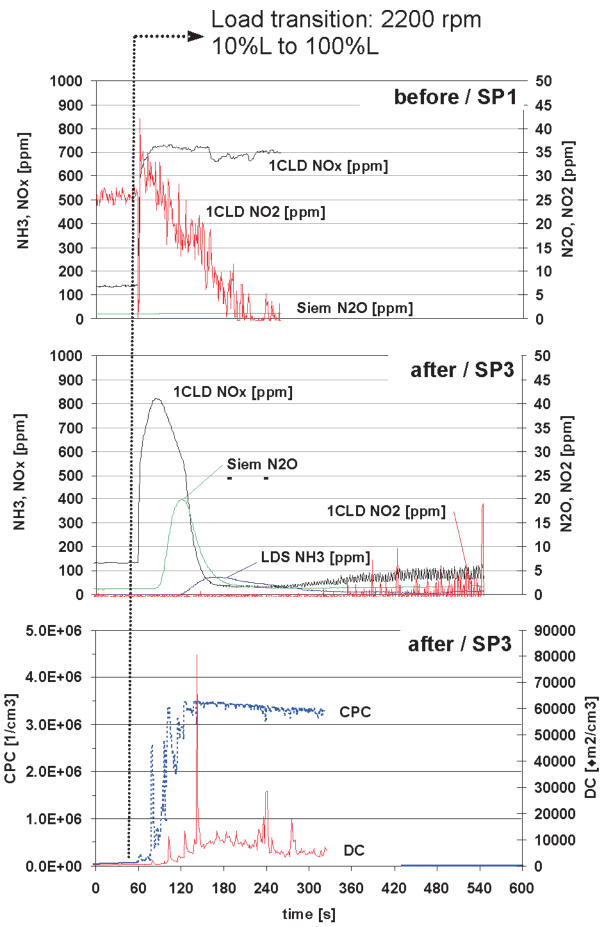

Fig. 9. Load transition B: from 2200 rpm/10% L to 2200 rpm/ 100% L with measurements before and after DPF + SCR

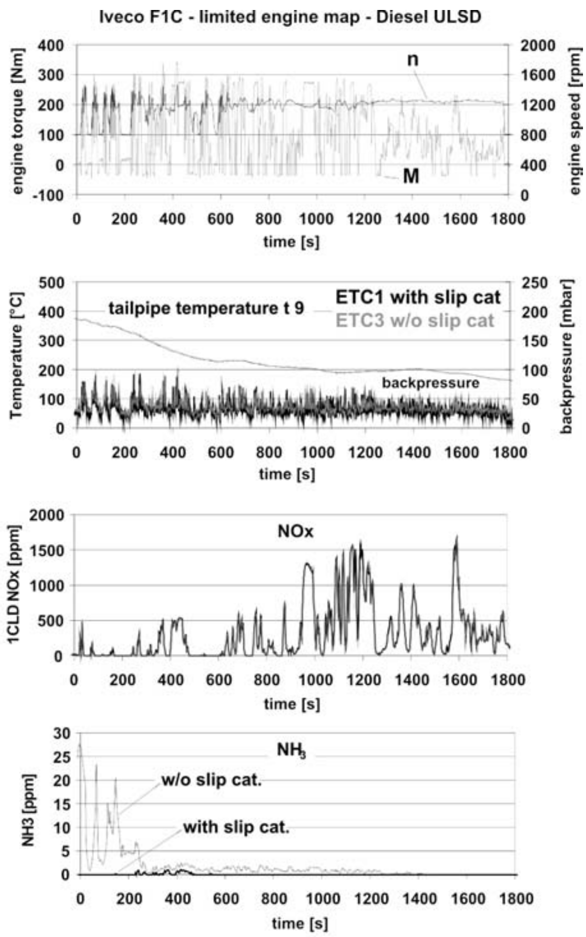

Fig. 10. Comparison of 2 ETC's (ETC1-ETC3), with & w/o slip catalyst α = 0.9

An increase of nanoparticles concentrations is clearly indicated by both, the CPC- and the DC-signals.

Load transitions between two stationary engine conditions are very indicative to study in detail the instationary changes in the combined system. Nevertheless for some specific purposes longer operation times at the final stationary state are recommended as well. Due to extreme load changes (from 0% to 100%) the time necessary for thermal and chemical stabilization of the system can be in the range of up to 20 min.

Dynamic engine operation

These tests were performed in the ETC with limited engine map.

Following results will be shown:

- ETC1 with DPF + SCR + slip cat,
- ETC3 with DPF + SCR without slip cat,
- ETC4 reference (w/o DPF + SCR).

Before starting each test the thermal condition of the exhaust system was fixed by a repetitive conditioning (see chap. Test Procedures).

Figure 10 represents the comparison of two ETC's with and without slip catalyst. During the test the exhaust gas temperature at tailpipe decreases and in the second half of the test there is an increase of NO_x due to urea cut off.

The ammonia slip catalyst eliminates efficiently NH_3 in the first phase of the test (until approx. 200 s). The second part of the test depicts the decreasing NO_x reduction efficiency caused by the cooling down the exhaust system during the test and the respective urea shortage.

The results of target emission were integrated for different test periods:

◦ initial period 0-400 s,
◦ final period 1400-1800 s,
◦ overall test 0-1800 s.

The obtained average emission concentration and the reduction efficiencies are summarized in Table 2.

The NO_x- and NO_2-conversion rates decrease during

Table 2. Integral average values and reduction efficiencies of NO_x, NO_2 & NP in different parts of the ETC (LEM)

$RE_x = \frac{X_{w/o} - X_w}{X_{w/o}} \cdot 100$	ETC 3 w/o slip catalyst with DPF + SCR			ETC Reference with out DPF + SCR			RE [%]		
	0-400 s	1400-1800 s	0-1800 s	0-400 s	1400-1800 s	0-1800 s	0-400 s	1400-1800 s	0-1800 s
Temp. T 7 [°C]	278	197	259	271	195	255			
NO_x 1CLD [ppm]	47	390.9	290.1	605.9	504.7	699.8	92	23	59
NO_x FTIR [ppm]	53	426.2	317	660.8	550.5	759.7	92	23	58
NO_2 1CLD [ppm]	3	42.6	35.9	39	49.2	48.6	92	13	26
NO_2 FTIR [ppm]	2.4	48.5	38	29.2	53.21	40.4	92	9	6
CPC [1/cm³]	3.3E+04	7.6E+03	2.1E+04	4.5E+06	5.9E+06	6.2E+06	99	100	100
PAS [μgEC/m³]	69.9	65.4	60.9	6734.8	8638.5	8635.6	99	99	99
DC [μm/cm³]	293.8	200.1	243.3	37460.6	41075.4	45724.5	99	100	99

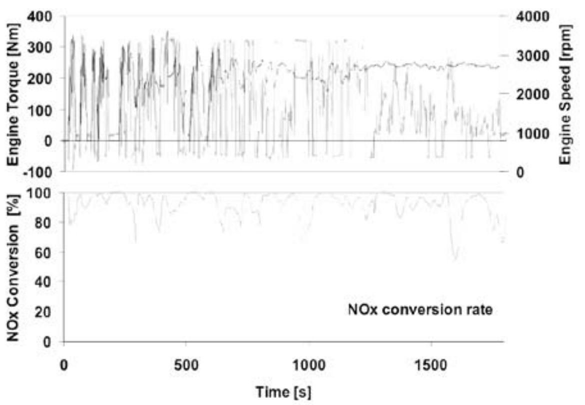

Fig. 11. NO_x conversion rate in ETC with full operating range of the engine, $\alpha = 0.9$ (NEM)

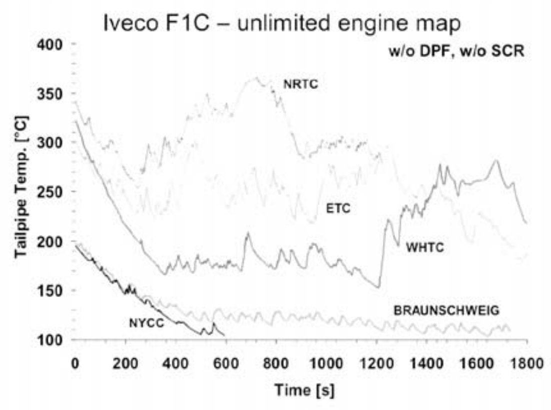

Fig. 12. Engine tailpipe temperature in different cycles (w/o exhaust gas aftertreatement, NEM)

the test, as previously discussed. The NO_x concentrations obtained from CLD and FTIR correspond very well. NO_2 levels are rather low, therefore discrepancies are larger.

Again, very high filtration efficiencies of 99-100% were noticed despite some secondary NP-formation in all periods of the ETC.

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

The conditioning of the engine and exhaust system was identical for ETC and WHTC, as for the previous tests with LEM (see Test Procedures): after warm-up 5 min 2200 rpm/FL and 0.5 min idling.

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

Figure 11 shows in the ETC much better NO_x conversion rates in the later phase of the cycle than with the limited engine map. This is due to the higher average exhaust gas temperature and more advantageous urea dosing.

Figure 12 represents the time-plots of tailpipe temperature over the cycle duration for other investigated test cycles.

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.

It can be seen that the exhaust temperatures in the low load cycles are too low to enable the full working potential of the SCR-system.

Table 3 depicts the conversion rates in different driving cycles.

In the Braunschweig-Cycles there are the lowest NO_x conversion rates. It must be noticed that the investigated SCR-system in the present configuration is a little efficient NO_x reduction measure in the low-load city driving.

Table 3. NO_x conversion rates in different driving cycles ETC, WHTC, NYCC & Braunschweig-Cycle, $\alpha = 0.9$ (NEM)

$RE_x = \frac{X_{w/o} - X_w}{X_{w/o}} \cdot 100$	RE [%]			
	ETC	WHTC	NYCC	BRAUN
NO_x 2CLD [ppm]	91	65	42	16
NO_x FTIR [ppm]	90	64	40	14
NO_2 2CLD [ppm]	93	33	87	76
NO_2 FTIR [ppm]	91	35	98	92

Conclusions

The most important results about the investigated combined DPF + SCR system for transient application can be summarized as follows:

- the combined dePN systems (DPF + SCR) at transient engine operation efficiently reduce the target emissions with $deNO_x$-efficiencies up to 92% (if operated in the right temperature window) and particle number filtration efficiencies up to 100%,
- with increasing feed factor (up to overstoichiometric urea dosing) NO_x conversion efficiencies increase (up to 98%), but also the ammonia slip rises up to 125 ppm,
- with the recommended feed factor $\alpha = 0.9$, without the slip catalyst, and there is only a moderate average slip of ammonia up to 7 ppm in the ETC and there is a release of small amounts of nitrous oxide of up to 3 ppm,
- the ammonia slip can be efficiently eliminated by a slip-cat,
- during transients there are temporarily increased emissions of nitrogen-containing components, due to momentary imbalanced $deNO_x$ reactions,
- in the investigated configuration with urea dosing after the DPF, a secondary formation of nanoparticles is detectable, however with little impact on total number concentrations and overall filtration efficiency of the system,
- the average NO_x conversion efficiency at transient operation (ETC) strongly depends on the exhaust temperatures, which are correlated with the urea-dosing strategy; during low-load operation this efficiency is strongly reduced,
- the nanoparticle filtration efficiency, which is verified at stationary engine operation, is perfectly valid also at transient engine operation.

The present results will be confirmed in the further project activities with other systems and with different testing cycles. A special attention will be paid to the operational profiles, which are representative for low emission zones LEZ.

Recenzent: doc. dr Michał Krasodomski

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Abbreviation

AFHB	Abgasprüfstelle FH Biel, CH
ASTRA	Amt für Strassen, CH, Swiss Road Authority
BAFU	Bundesamt für Umwelt, CH (Swiss EPA)
CLD	chemoluminescence detector
CPC	condensation particle counter
DC	Diffusion Charging Sensor
dePN	de Particles + $deNO_x$
DMA	differential mobility analyzer
DPF	Diesel Particle Filter
ETC	European Transient Cycle
FE	filtration efficiency
FID	flame ionization detector
FTIR	Fourrier Transform Infrared Spectrometer
LDS	Laser Diode Spectrometer (for NH_3)
LEZ	low emission zones
MD19	heated minidiluter
NanoMet	NanoMetnanoparticle summary surface analyser (PAS + DC + MD19) PAS + DC + sampling & dilution unit MD 19
OP	operating point
PAS	Photoelectric Aerosol Sensor
RE	reduction efficiency
SCR	selective catalytic reduction
SMPS	Scanning Mobility Particle Sizer
SP	sampling position
VERT	Verminderung der Emissionen von Realmaschinen in Tunelbau Verification of Emission Reduction Technologies
VERTdePN	VERT DPF + VERT $deNO_x$
VPNT1	VERTdePN Test 1 – engine dyno
VPNT2	VERTdePN Test 2 – field durability 2000h
VPNT3	VERTdePN Test 3 – check after field test chassis dyno
VPNTSET	VERTdePN secondary emissions test – engine dyno
VSET	VERT Secondary Emissions Test