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Influences of biocomponents (RME) on emissions of a Diesel engine with SCR

Introduction

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 in 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 de NO_x system consists of 4 catalytic parts:

- precatalyst converting 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 de NO_x reactions),
- oxidation catalyst (minimizing of NH_3 slip).

The main de NO_x reactions between NH_3 , NO and NO_2 are widely mentioned in the literature [2, 3, 4, 5]. They have different speeds according to the temperatures of gas and catalysts, space velocity and stoichiometry. All these influences cause a complex situation of reactions 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_4NO_3 (also known as secondary nanoparticles).

The combination of particle filtration (DPF) and of the most efficient de NO_x technology (SCR) is widely considered as the best solution, up to date, to minimize the emissions of Diesel engines.

For the use of biocomponents the limiting of impurities and phosphorus in biofuels according to the present standards is an obligatory prerequisite for successful operation.

The present paper shows some results of research of SCR – and (DPF + SCR) – systems with different rates of biocomponents (RME). The tests were performed at the Laboratories for IC-Engines and Exhaust Emission Control of the University of Applied Sciences Biel, Switzerland (AFHB) in collaboration with the BIODEG project partners.

Some results with the combined exhaust aftertreatment systems with the market fuel and information about the VERdePN project, which focuses on the quality testing of aftertreatment systems for retrofitting are given in [1].

Tested engine, fuels, lubricant

Test engine

Manufacturer:	Iveco, Torino Italy
Type:	F1C Euro 3
Displacement:	3.00 Liters
RPM:	max. 4200 rpm
Rated power:	100 kW @ 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)

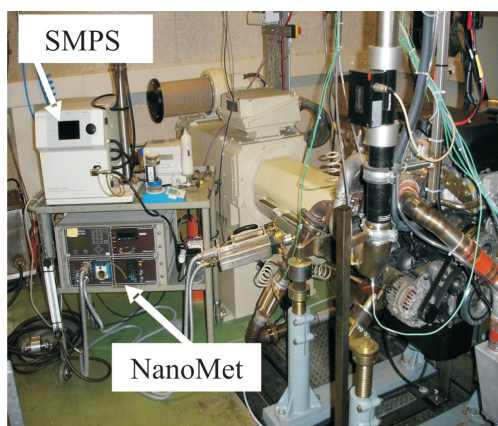


Fig. 1. IVECO engine F1C and equipment for nanoparticle measurements in the engine room

Fig. 1 shows the engine and the apparatus for nanoparticle analytics SMPS and NanoMet in the laboratory for IC-engines, University of Applied Sciences, Biel-Bienne.

Fuels

Following base fuels were used for the research (table 1):

- Shell Formula Diesel fuel Swiss market summer quality (10 ppm S) according to SN EN 590,
- Rapeseed Oil Methyl Ester RME from Flamol, Berne, CH.

Table 1 represents the most important data of the fuels according to the standards and the analysis certificates.

It can be remarked, that there are differences of density, heat value, stoichiometric air requirement and boiling range, which have influences on the engine operation and especially on the full load parameters. These changing fuel parameters were taken into account by the evaluation of measurements.

The resulting fuel parameters for the blend fuels are represented in table 2.

Table 1. Fuel properties as per EU-standards and further analysis of the test fuels

	Diesel	RME
Density at 15°C [g/m]	0.842*	0.885*
Viscosity at 40°C [mm ² /s]	2.0÷4.5	4.6*
Flash point	above 55°C	143°C
Cloud point	max -10°C	-
Filterability CFPP	max -20°C	-15
Ash [%]	max 0.010	traces
Sulfur [ppm]	<10	1.3*
Cetane number	51	56
Calorific value [MJ/kg]	42.7	37.2
C fraction [%]	86.7	77.5
H fraction [%]	13.3	11.8
O fraction [%]	0	10.7
Air _{min} [kg/kg]	14.52	12.49
Boiling range 10÷90% [°C]	180÷340	315÷360

*measured

Table 2. Principal parameters of the blend fuels

	ρ (20°C) [kg/dm ³]	Hu [MJ/kg]	Air _{min} [kg _A /kg _F]
Diesel	0.832	42.70	14.52
RME 7	0.835	42.30	14.38
RME 20	0.842	41.55	14.10
RME 30	0.846	40.98	13.89
RME 100	0.880	37.20	12.49

Measuring set-up and instrumentation

Engine dynamometer and standard test equipment

Fig. 2 represents the special systems 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,
- 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},
- 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 production of secondary nanoparticles, the particle size and number distributions were analysed with following apparatus, fig. 1:

- SMPS – Scanning Mobility Particle Sizer, TSI (DMA TSI 3071, CPC TSI 3025 A),
- NanoMet – System consisting of:
 - PAS – Photoelectric Aerosol Sensor (EcoChem 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).

The nanoparticle results represented in this paper are obtained with sampling at tail pipe with MD19 and with thermoconditioner (300°C).

The nanoparticulate measurements were performed at constant engine speed (warm) with SMPS and NanoMet.

During the dynamic engine operation NanoMet and CPC were used.

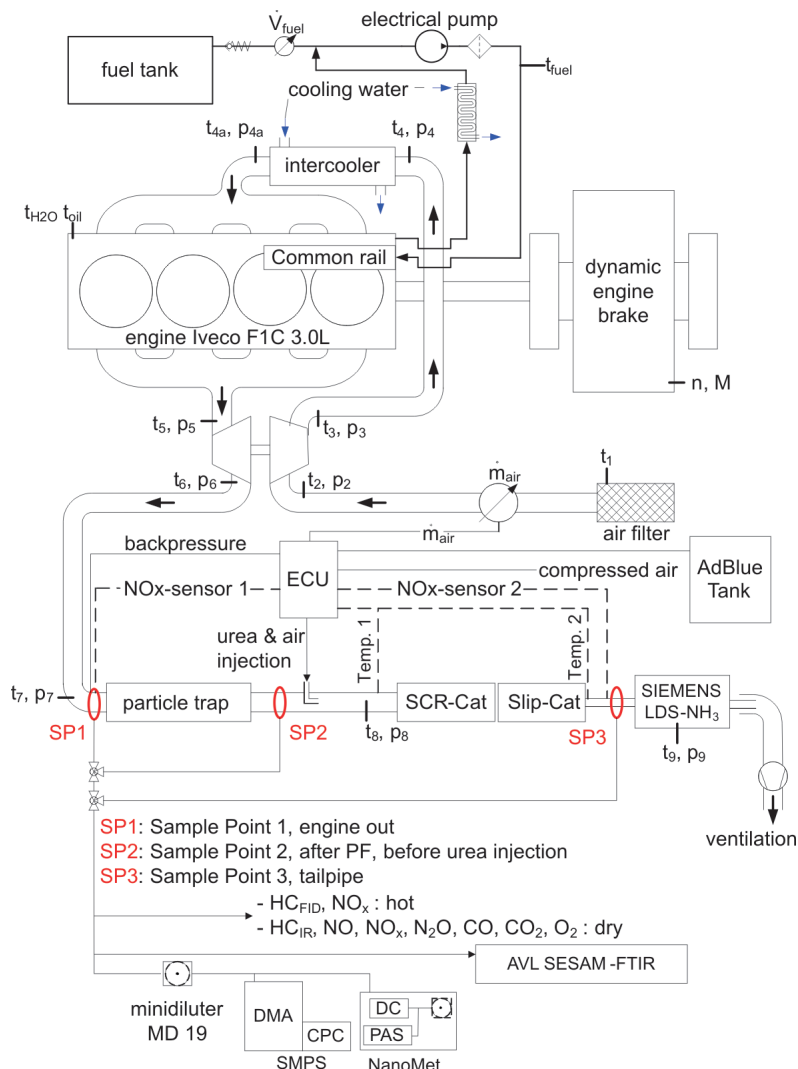


Fig. 2. Engine dynamometer and test equipment

Test procedures

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

After analyzing the backpressure of the system at stationary operation in the entire engine operation map it was decided to limit the operation range. In this limited engine map (LEM) different steps-tests were defined. In the present work a 7 steps-test at 2200 rpm was used, fig. 3.

Fig. 3 shows the limited engine map and the 7 points steps-test. These operating points were chosen in such way that the urea switch-on was included in the test (between 20% and 30% load).

The denomination of the OP's from other measuring

series was not changed in order to keep comparability with other projects and new OP's were named by adding a letter 3a, 3b, 3c).

For a more detailed investigation of the tested system different sampling positions (SP) were used (see fig. 2):

- SP 0 sampling engine out w/o aftertreatment system (same as SP1),
- 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.

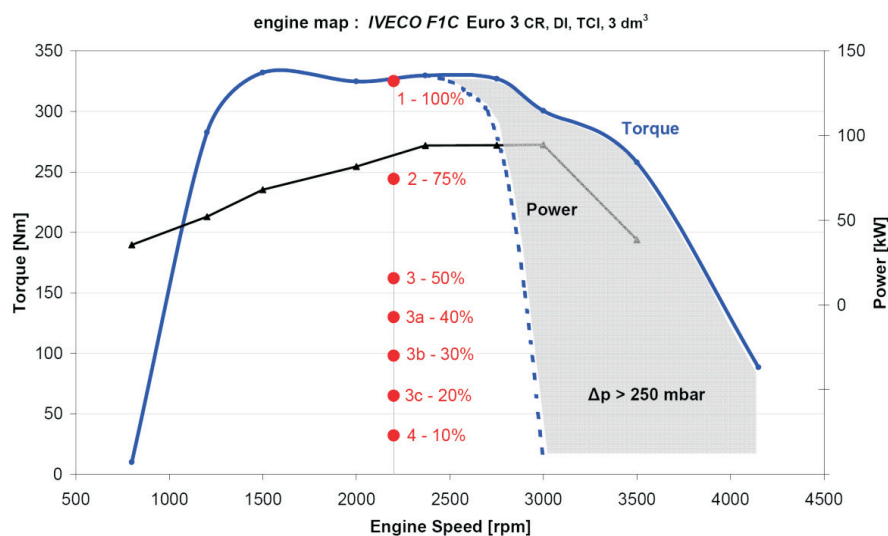


Fig. 3. Limited engine map of the IVECO F1C engine and 7 points test for SCR-investigations

The dynamic testing was performed with the ETC (European Transient Cycle), which in this work was defined on the basis of the non limited engine operation map (NEM), fig. 4.

The tests have shown that the backpressure at dynamic

The test program consisted of:

- test procedures: steps-tests at 2200 rpm and ETC (NEM),
- aftertreatment systems: without, with (DPF + SCR), with SCR only,
- fuels: Diesel (ULSD), B7, B20, B30 and B100.

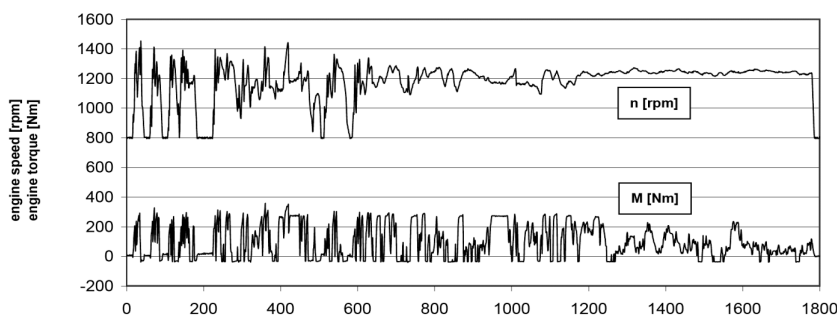


Fig. 4. Torque and speed in ETC IVECO F1C

Tested systems SCR and (DPF + SCR)

The combined exhaust gas aftertreatment system (DPF + SCR) was installed on the IVECO research engine in the ICE-laboratory in Biel, CH. This system is designed for dynamic on-road applications. The filters and catalysts are exchangeable modules, for SCR alone the DPF module was removed.

The investigated combination is: a coated Cordierite DPF upstream and Vanadium-based SCR catalyst downstream of the urea injection point (see scheme fig. 2).

Additionally to the elements in the engine exhaust system an Ad Blue-tank and Ad Blue injection unit with pump, sensors and electronic control were installed in the laboratory.

There are following sensors, which enable the open-loop control of urea dosing:

- 2 × Temperature sensors (PT200),
- 1 × AdBlue level sensor,
- 1 × Mass Air Flow sensor,
- 2 × NO_x sensors (upstream and downstream DPF).

Optional: 1 × NO_x sensor downstream SCR catalysts for monitoring of performance. Urea dosing and control unit has an open loop control.

Optional: GPRS Flight recorder enables:

- data logging of system performance, state and alarms on a remote server/database,

operation is generally lower, as at stationary operation and therefore the dynamic tests were performed with ETC adapted to the entire engine operation map.

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

Before the start of each dynamic cycle the same procedure of conditioning was used to fix as well as possible the thermal conditions of the exhaust gas aftertreatment system.

This conditioning was: 5 min pt. 1 and 0.5 min idling.

- changing and checking of configuration parameters of urea dosing unit via internet. The SCR-system, which was investigated in the present

work is without mixer (only mixing tube 1.0 m). The DPF has a VERT-conform filtration quality, in average for NP filtration efficiency $FE > 99\%$.

Results

Variations of fuel

Fig. 5 – the increased share of RME w/o aftertreatment causes in steps-tests: increase of NO_x by higher engine load, reduction of CO and HC (here always HC_{FID}) and slight lowering of t_{exh} (not represented).

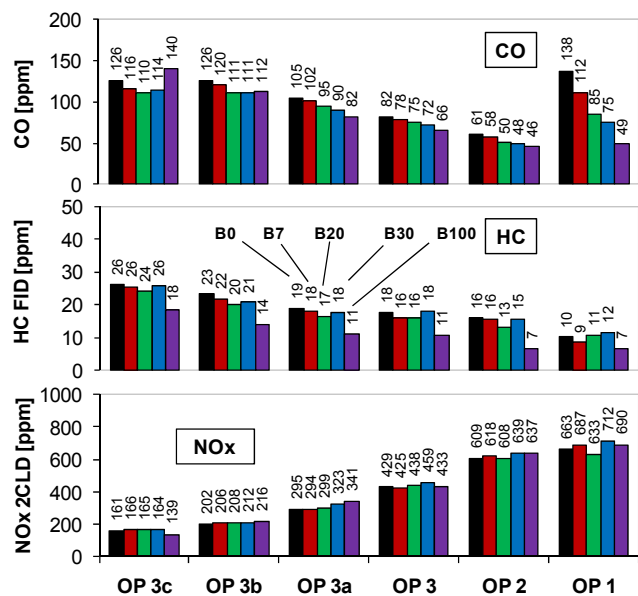


Fig. 5. Limited emissions in steps-test at 2200 rpm with different fuels w/o aftertreatment

It is to remark that all part load operating points are driven exactly at the same torque and speed. The full load point OP 1 in contrary has always the same speed but the torque results from different heat values of the used fuels. That means the results at OP 1 are overlapped by the effect of different torque.

At transient operation in ETC (fig. 6) these tendencies are present, but less pronounced, than at stationary steps-tests.

With DPF + SCR the higher rate of RME provokes principally similar effects, which nevertheless are superimposed by the exhaust gas aftertreatment.

Fig. 7 represents some non-legislated components in steps-test and fig. 8 the emissions and NO_x conversion rates in function of exhaust gas temperature with B0, B30 and B100.

The light-off of the catalysis in DPF starts already at OP 3c (t_{exh8} 180÷200°C) with elimination of CO (not represented here), but the stronger de NO_x effect starts at OP 3b (t_{exh8} approx. 240°C).

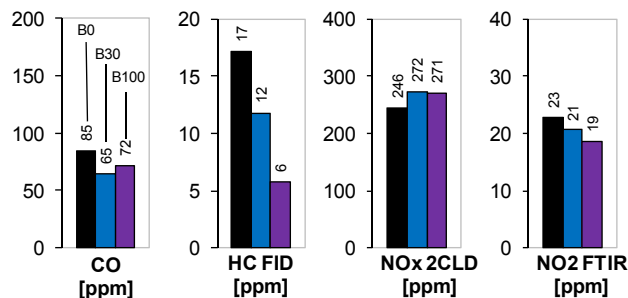


Fig. 6. Emissions in ETC with different fuels w/o aftertreatment

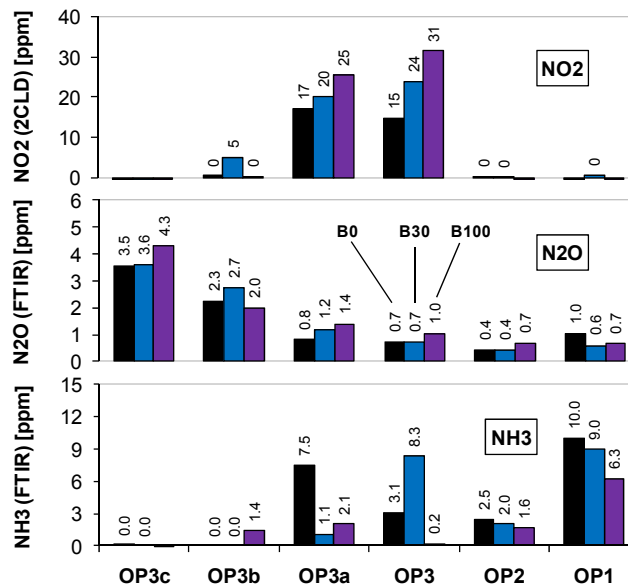


Fig. 7. Unregulated emissions in steps-test at 2200 rpm with different fuels with DPF and SCR; $\alpha = 0.9$

In the conditions, where NO_2 is produced – in the middle range of exhaust gas temperature – RME causes higher NO_2 values.

In the conditions where NH_3 is produced RME causes lower NH_3 values. The differences of NH_3 nevertheless are very little and they can be interfered by some stochastic store-release-effects and reactions in the SCR system. At full load, OP1, there is also the influence of lower torque with increasing B-content. In spite of that the higher NO_x values at high- and full load with B100 are confirmed.

Generally it can be stated, that there are little influences of the biocomponents in fuel on the emissions with DPF + SCR.

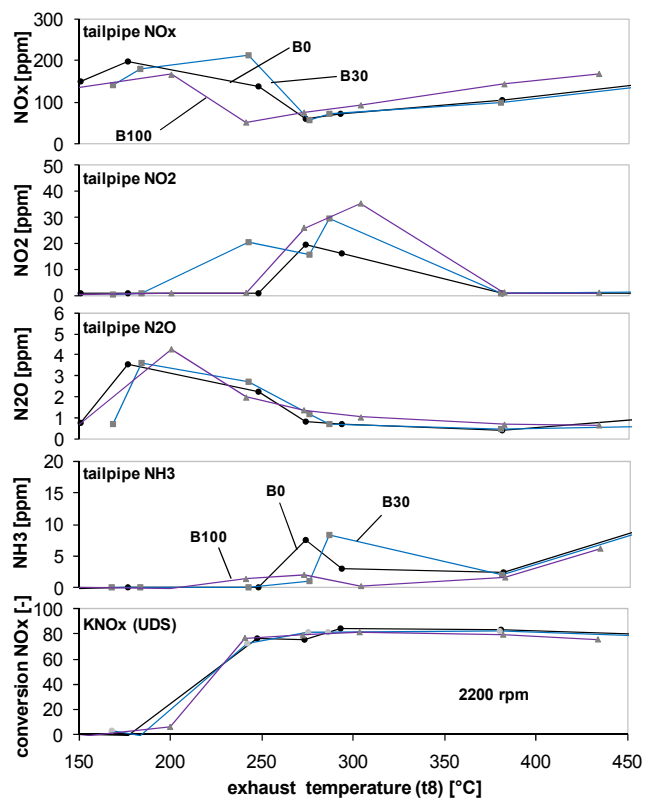


Fig. 8. Comparison of emissions in steps-test with DPF + SCR and B0, B30 and B100; $\alpha = 0.9$; FTIR

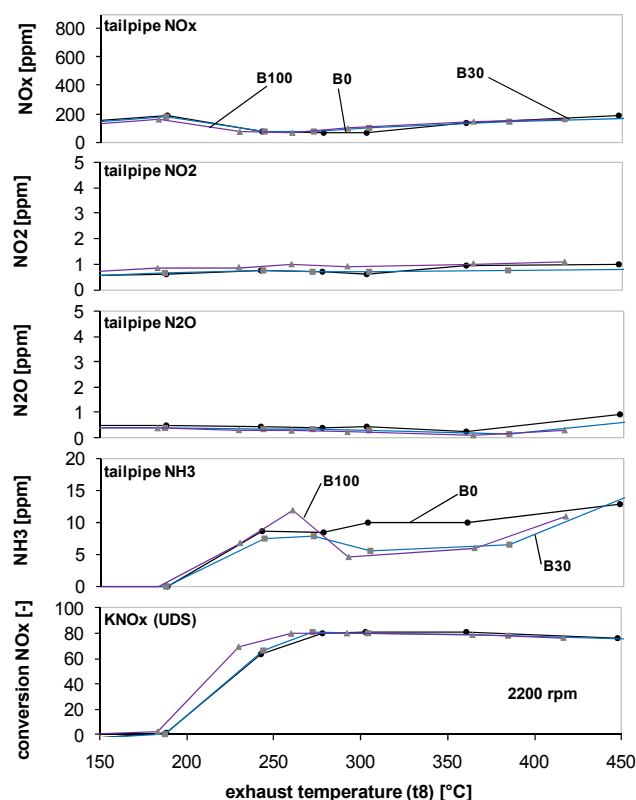


Fig. 9. Comparison of emissions in steps-tests with SCR and B0, B30 and B100; $\alpha = 0.9$; FTIR

Fig. 9 shows the results of interesting NO_x components in function of exhaust gas temperature with B0, B30 and B100 for SCR alone.

In steps-tests there is no clear influence of RME portion on NO_x . There is reduction of CO at higher load and general reduction of HC (not represented here). There are very little influences on NO_2 and NH_3 .

The light-off of the SCR alone is with RME 100 at a slightly lower temperature, than with B0 and B30 ($\Delta t \sim 10 \div 20^\circ\text{C}$).

Except of that there are no other clear effects of the RME-content on the presented parameters.

In dynamic operation (ETC), fig. 10, there are no differences of NO_x , NO_2 and NH_3 and there is lowering of CO and HC with higher RME content.

The influence of RME on NO_2 with DPF + SCR which was remarked at stationary operation (more NO_2 with more RME in certain t_{exh} range) is no more present or even inverted at transient operation. Similarly for NH_3 , which was reduced by RME (with DPF + SCR) in stationary steps-tests and is not reduced or even increased in the dynamic test.

In general, it can be said, that some relationships of results, which are remarked at stationary operation can disappear or even be inverted at transient operation. This

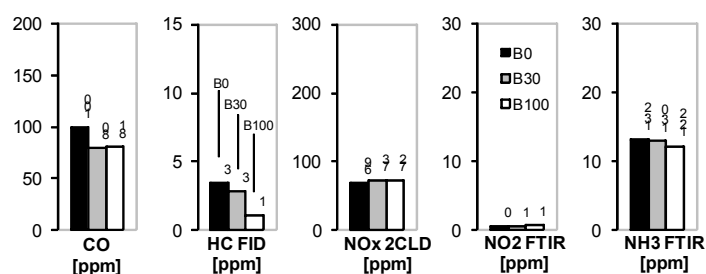


Fig. 10 Emissions in ETC with different fuels with SCR

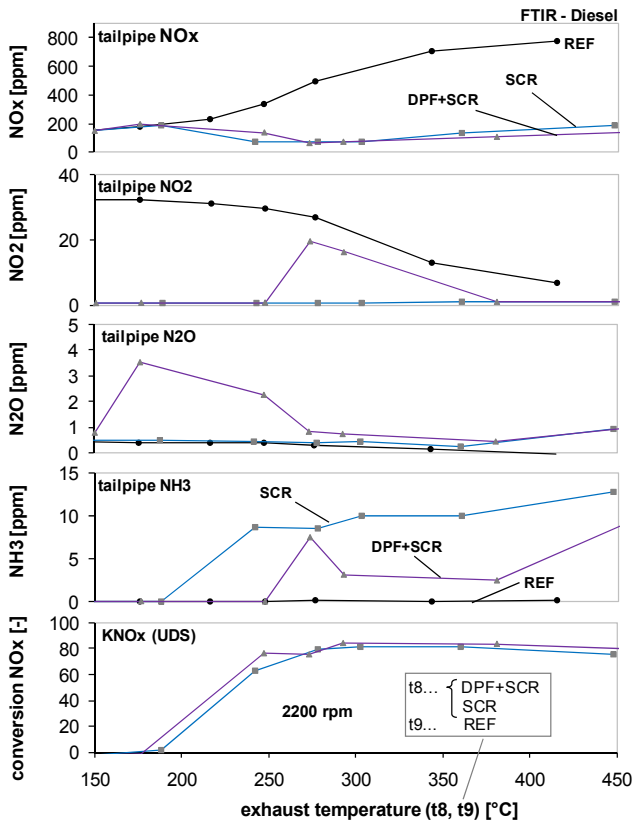
is to explain with the running chemical reactions in the aftertreatment system, which meet quite different changing conditions (p, T) during the transients.

Different exhaust aftertreatment systems

Fig. 11 represents the nitric emissions in function of exhaust gas temperature, with Diesel base fuel, for the three investigated variants:

- reference case (Ref.) without exhaust gas aftertreatment,
- combined aftertreatment system (DPF + SCR) and
- SCR alone.

With the catalyzed DPF there is a production of NO_2 in the temperature range $250 \div 350^\circ\text{C}$. With the combined system (DPF + SCR) there is a slight emission of N_2O



(up to 4 ppm) in the lowest temperature range and there are lower NH_3 values, than with SCR alone.

The increase of NO_x conversion rate K_{NO_x} is with the combined system at a slightly lower temperature ($\Delta t \sim 10 \div 20^\circ\text{C}$).

Fig. 12: summarizes the conversion rates K_{NO_x} resulting from datalogging with OEM-UDS-sensors with B0, B30 and B100 in stationary steps-tests. The remarkable NO_x conversion takes place at OP 3b and all higher operating points. With DPF + SCR K_{NO_x} values are slightly higher due to the production of NO_2 in the catalytic DPF (upstream of SCR).

There are principally no significant differences of K_{NO_x} with different fuels, except of more reduction of NO_x with B100 at the lowest OP3c (easier light-off with B100).

Fig. 13 represents the average NO_x , NO_2 and NH_3 values in ETC. It is to remark that for DPF + SCR there are in average lower NO_x , higher NO_2 and lower NH_3 , than for SCR. The tendency of higher NO_x with RME (B100) is confirmed.

The reduction efficiencies in ETC with B0, B30 and B100 and with both investigated exhaust aftertreatment systems are depicted in Fig. 14 (reduction efficiency RE and conversion rate K_x are synonyms, they are calculated

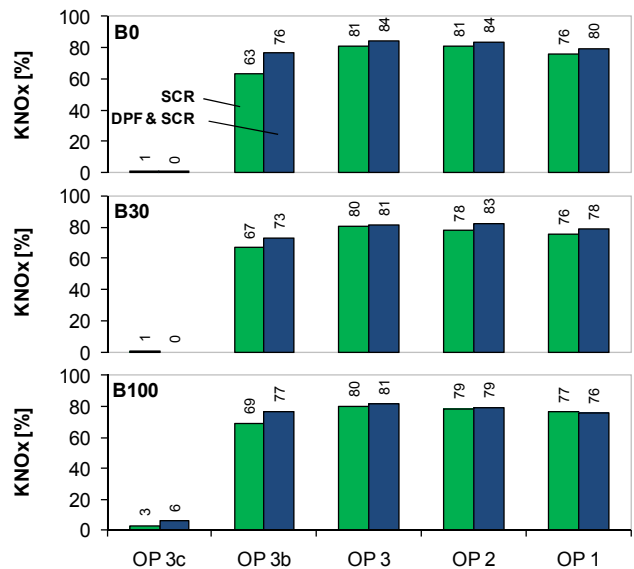


Fig. 12. NO_x conversion rates with different exhaust aftertreatment systems at stationary operation; $\alpha = 0.9$; UDS-sensors; 2200 rpm

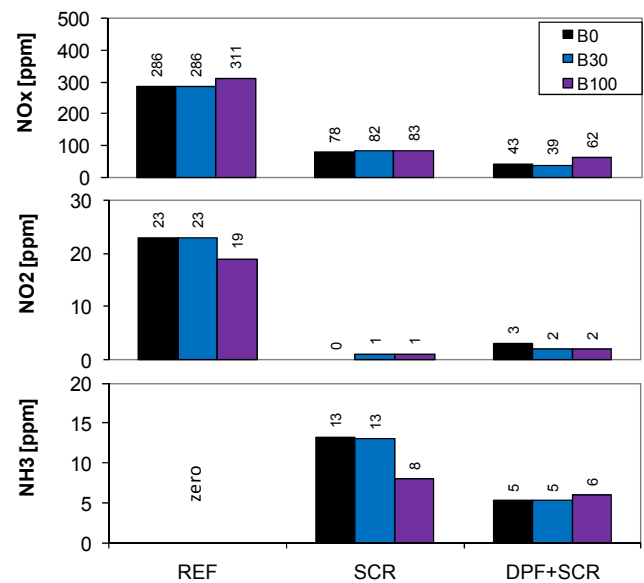


Fig. 13. Average values of NO_x , NO_2 and NH_3 in ETC with different fuels and aftertreatment systems; $\alpha = 0.9$; FTIR

in this figure from the FTIR-results SP0 and SP3. With the combined system (DPF + SCR) there are clearly higher RE for NO_x and lower RE for NO_2 .

There is no clear influence of biocomponent content on the reduction efficiency (except of a slight monotone tendency of lowering RE for NO_2 with SCR alone).

Regarding the comparison of the two aftertreatment systems it can be summarized that:

- there are advantages of catalytic activity and production of NO_2 upstream of SCR in the combined system,
- the combined system has a slightly better conversion

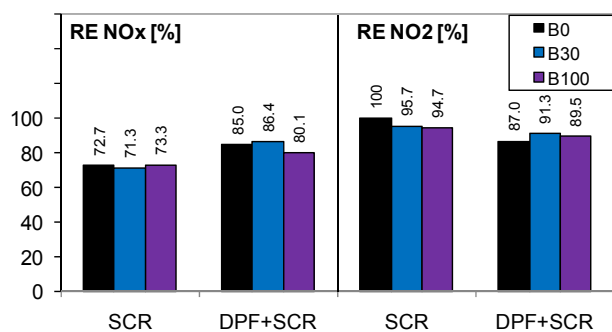


Fig. 14. Comparisons of reduction efficiencies in ETC; $\alpha = 0.9$; FTIR

of NO_x and a lower production of ammonia NH₃; there is an easier light off at slightly lower t_{exh} ,

- there are no influences of biocomponents on the NO_x reduction efficiencies.

Several other non-legislated components have been measured with FTIR, among others: isocyanic acid, hydrocyanic acid and formaldehydes. All these components have very low absolute values in the range of some „ppms” and are not further represented in this paper.

The combined system (DPF + SCR) shows in most cases the tendency to minimize these components.

(Nano) Particles Emissions

The particle filter of the combined system had the filtration efficiency, which fulfilled the actual VERT quality requirements (PCFE > 99%). I was interesting to state if there are some influences of biocomponents on the filtration resp. reduction efficiency of NP's of the combined system (DPF + SCR) and how is the influence of SCR alone on NP's?

Fig. 15 shows the SMPS particle size distribution spectra without and with SCR at OP1 with B0, B30 and B100. There is a reduction of NP count concentration due to increasing B-content. This is in accordance with the other research results which generally state lower PM emissions with FAME's at full load (higher O₂-content in fuel, lower accumulation mode).

The penetration nevertheless stays similar for all fuel variants at approx. 90%. This small reduction of nanoparticles concentration represents the diffusion losses in the mixing tube and in the SCR catalyst.

Penetration is a parameter representing the portion of particulates passing through the aftertreatment device; it is a ratio of down – to upstream concentrations.

$$\text{Penetration} = 1 - \text{filtration efficiency}$$

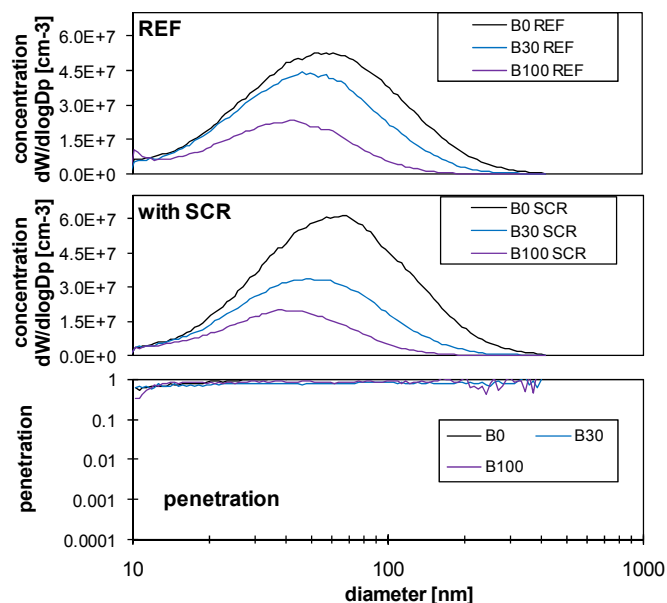


Fig. 15. SMPS-PSD spectra with B0, B30 and B100 and SCR; $\alpha = 0.9$; 2200 rpm/100% load

Further comparisons of trapping efficiencies in stationary and dynamic engine operation (OP1 and ETC) are given in table 3. The filtration efficiencies are estimated according to three parameters: integrated particle counts in the size range 20÷300 nm or CPC for dynamic operation – PCFE; DC-signal – DCFE; particle mass – PMFE.

Table 3. Trapping efficiencies in stationary and dynamic operation; 2200 rpm/100% and ETC

Counts 20÷300 nm					
PCFE [%]	OP1				ETC*
	B0	B30	B100	average	average
SCR	-12.50	22.01	14.81	8.11	12.05
DPF + SCR	99.66	97.06	81.02	92.58	98.95

Aerosol summary surface					
DCFЕ [%]	OP1				ETC*
	B0	B30	B100	average	average
SCR	-13.12	21.79	14.20	7.62	9.05
DPF + SCR	99.67	96.80	77.71	91.39	98.52

Particle mass					
PMFE [%]	OP1				
	B0	B30	B100	average	
SCR	-0.65	9.51	80.07	29.96	
DPF + SCR	93.25	90.73	90.17	91.38	

* for ETC: CPC FE

With DPF + SCR and B0 there is an excellent filtration rate of 99.66%. At this OP urea injection after DPF is active. This trapping efficiency decreases with growing RME portion: 97.06% with B30 and 81.02% with B100. This tendency is confirmed by DCFE and partly by PMFE.

The increase of NP-emission after the system (SP3) is surely not attributed to any failure of DPF, but to the effects of condensation and creation of secondary NP's after the DPF. These effects can be due to the high exhaust gas temperature (production of sulfates, evaporation of higher boiling HC) and to the interaction of the gas after DPF with the injected Ad Blue and with the SCR system. The secondary NP after SCR were found in [5] and they are subject of further investigations. It is probable that both: physical interaction (enabling a more intense condensation of substances) and chemical interaction (new products entering in the aerosol) take place. About a more detailed knowledge in this respect further research is necessary.

For SCR alone the reduction rates of nanoparticles at OP1 (stationary operation) have fluctuating values.

The negative value with B0 signifies an increase of NP and PM emission. With B100 there is exceptional reduction of particle mass (PM), which is not confirmed by the nanoparticles results (PC and DC). This picture leads to a supposition of stochastic store-release effects, a problem, which is difficult accessible for investigations, but has to be kept in mind during the further research.

The average trapping efficiencies in dynamic operation (ETC) depict well the tendencies given by stationary operation.

The most important findings of this section are:

- excellent particle reduction in the (DPF + SCR) system at part load and increase of nanoparticles penetration with growing RME portion (interaction of biocomponents and secondary NP),
- little particle reduction rates with SCR alone, in the range of 10%; hypothesis of store-release-effects with SCR.

Conclusions

From the present tests performed at stationary engine operation in steps-tests and at dynamic engine operation in ETC several results can be remarked. The most important are:

for RME content

- the increased share of RME w/o aftertreatment causes an increase of NO_x by higher engine load and reduction of CO and HC; at transient operation (ETC) these tendencies are less pronounced and only B100 shows an increase of NO_x ,
- with DPF + SCR in the stationary conditions, where NO_2 is produced RME causes higher NO_2 values and in the conditions, where NH_3 is produced RME causes lower NH_3 values,
- in dynamic tests (ETC) with DPF + SCR only higher NO_x emissions with RME 100 are to remark, CO and HC are for all fuels at zero level (catalytic conversion),
- with SCR alone there are no differences of NO_x and of NO_x reduction rate (K_{NO_x}) with increasing RME portion; there is lowering of CO and HC,
- in dynamic tests (ETC) with SCR there are no differences of NO_x and there is lowering of CO and HC with RME,
- there are generally no influences of RME-portion in fuel on the conversion values K_{NO_x} and K_{NO_2} ,
- the light-off of the SCR alone is with RME 100 at

a slightly lower temperature, than with B0 and B30 ($\Delta t \sim 10\text{--}20^\circ\text{C}$),

for exhaust aftertreatment system

- with DPF + SCR K_{NO_x} values are slightly higher, than with SCR alone, due to the production of NO_2 in the catalytic DPF (upstream of SCR),
- with DPF + SCR the CO and HC emissions are mostly eliminated,
- with DPF + SCR in certain range of the exhaust temperature there are higher NO_2 values than with SCR alone; these NO_2 values are further increased with RME,
- with DPF + SCR the NH_3 emissions are lower than for SCR,
- the reduction efficiencies in ETC with the combined system DPF + SCR, are for NO_x higher and for NO_2 lower,

for nanoparticle emissions

- without aftertreatment and with increasing RME-share the maximum of the count concentration of the PSD moves to smaller sizes and it decreases at full load,
- with DPF + SCR there is excellent filtration efficiency of DPF, up to 99.96%,
- at stationary full load operation with DPF + SCR and with RME 100 there is an intense production of secondary nanoparticles from the SCR part; this effect lowers

remarkably the overall NP-reduction efficiency; it is almost not visible at dynamic operation,

- with SCR alone there is usually a small reduction of nanoparticles concentrations (in the range of 10÷20%) losses in the mixing tube and in the two in line SCR catalysts; in dynamic operation this reduction is smaller (below 10%),
- with SCR at full load there is a slight increase of NP-counts due to the secondary NP-production,
- certain results with SCR show surprisingly high variations of reduction rates; this is explained with the emitting dispersion during certain measuring series and

has to be regarded in further research. The emitting dispersion can originate from some memory effects (store-release) of the entire system (engine + exhaust system). The measuring dispersion for nanoparticles is excluded by conformity of results obtained with different measuring methods.

In general it can be said, that some relationships of results, which are remarked at stationary operation can disappear or even be inverted at transient operation. This is to explain with the running chemical reactions in the aftertreatment system, which meet quite different changing conditions (p, T) during the transients.

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Recenzent: prof. dr Michał Krasodomski

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Abbreviations

AFHB Abgasprüfstelle FH Biel, CH
 Air min stoichiometric air requirement
 Bxx blend fuel with biocomponent share xx%
 CFPP cold filter plugging point
 CLD chemoluminescence detector

CNC condensation nuclei counter
 CPC condensation particle counter
 DC Diffusion Charging Sensor
 DCFE diffusion charge filtration efficiency
 dePN de Particles + deNO_x

DMA	differential mobility analyzer	NP	nanoparticles < 999 nm (SMPS range)
DPF	Diesel Particle Filter	OEM	original equipment manufacturer
ECU	electronic control unit	OP	operating point
EMPA	Eidgenössische Material Prüf- und Forschungsanstalt	PAS	Photoelectric Aerosol Sensor
EPA	Environmental Protection Agency	PC	particle counts
ETC	European Transient Cycle	PCFE	particle counts filtration efficiency
FE	filtration efficiency	PM	particulate matter, particle mass
FID	flame ionization detector	PMFE	particle mass filtration efficiency
FL	full load	PSD	particle size distribution
FTIR	Fourrier Transform Infrared Spectrometer	RE	reduction efficiency
HD	heavy duty	RME	rapeseed oil methyl ester
Hu	lower calorific value	SCR	selective catalytic reduction
ICE	internal combustion engines	SMPS	Scanning Mobility Particle Sizer
K_x	conversion rate of „x”	SP	sampling position
LDS	Laser Diode Spectrometer (for NH ₃)	TC	thermoconditioner. Total Carbon
LEM	limited engine map	TTM	Technik Thermische Maschinen
MD19	heated minidiluter	ULSD	ultra low sulfur Diesel
NanoMet	NanoMet nanoparticle summary surface analyser (PAS + DC + MD19)	VERT	<u>Ver</u> ification of <u>E</u> mission <u>R</u> eduction <u>T</u> echnologies
NEM	nonlimited engine map	VERTdePN	VERT DPF + VERT deNO _x
		α	feed factor of urea dosing; ratio: urea injected/ urea stoichiometric; calculated by the ECU