CHANGES OF THE 2-STROKE AEROSOL IN THE EXHAUST SAMPLING SYSTEM

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Abstract

Nanoparticle emissions of two 2-stroke scooters were investigated along the exhaust- and CVS-system (Constant Volume Sampling) with closed and with open line (cone). Due to their technology, the scooters produce different kind of aerosol (state of oxidation & SOF-content) and in addition to that they were operated with and without oxidation catalyst.

The scooters represent a modern technology with direct injection TSDI[)] (two stroke direct injection) and with carburettor.*

The tests were performed at two constant speeds of the vehicles (20 km/h & 40 km/h) according to the measuring procedures, which were established in the previous research in the Swiss Scooter Network.

The nanoparticulate emissions were measured by means of SMPS (CPC) and NanoMet (abbreviations see at the end of this paper).

The most important results are:

- *the changes of the PSD's of the aerosol along the exhaust and CVS-system are connected to the average gas temperature and PC-concentration, which result after the different dilution steps and cooling down in the connecting pipe,*
- *in the "open" variant of exhaust gas extraction there is a dilution step with unfiltered ambient air directly after tailpipe. This causes a stop of agglomeration, reduction of diffusion loses and increased background NP-concentration. There is also lower post oxidation of CO & HC. In some cases spontaneous condensates due to the temperature drop are supposed,*
- *with the "closed" variant there is a stronger reduction of SMPS PC's along the gas way, than with the open variant. This is to explain with the higher temperatures and concentrations in the closed system, which enable more intense thermophoresis – and diffusion losses,*
- *the NP-concentrations measured with "open" variant are always higher,*
- *most intense oxidation is observed with Peugeot Carb: due to the SAS, rich tuning and a relatively high temperature level there are oxidation effects already without catalyst (temp. approx. 350°C). With catalyst the temperature is in the range of 400°C and the oxidation is so intense, that the particles are nearly eliminated.*

The type of sampling: "open", or "closed" as well as the sampling position in the exhaust installation have significant influence on the measured nanoparticles emission results.

Keywords: *scooters, two stroke direct injection, carburettor, 2-stroke aeroso,l nanoparticulate emissions*

1. Introduction & objectives

Laboratories for IC-Engines and Exhaust Emission Control (AFHB) of the University of Applied Sciences, Biel, Switzerland are involved since 2000 in several research projects about emission factors and possibilities of reduction of (nano)particle emissions of 2-wheelers. A special attention was paid to the 2-stroke scooters, which have much higher particle emission, than the 4-strokers.

In an international network project several topics were investigated, [1-7] and the combinations of technical measures to lower the particle emissions of scooters confirmed the expected effects and showed considerable reduction potentials.

In all those previous tests there was a closed passage of the exhaust gas from the tailpipe (TP) of the vehicle to the diluting CVS installation.

Another possibility is to use an open passage with a cone around the tailpipe, like in Fig. 1. The exhaust gas from the vehicle is directly diluted in the cone. In the CVS follows the second step of dilution.

Fig. 1. Passage of exhaust gas from tailpipe to CVS: closed (left), open (right)

The different passages of exhaust gas to the CVS have influences on the physical changes of the aerosol like spontaneous condensation, evaporation, agglomeration, diffusion losses and thermophoresis.

Another changes of the exhaust aerosol were introduced in the research by means of two vehicles, each one with different technology and producing different portion of SOF in the exhaust PM (see next section). Finally each of them was operated with active and with inactive (dummy) oxidation catalyst.

2. Investigated Scooters

The research of emissions was performed on the 2-stroke Peugeot Scooters newer technology: Peugeot Looxor TSDI (two stroke direct injection) and Peugeot Looxor Carburettor (Carb), Fig. 2.

Both vehicles were profoundly investigated in the previous works, [5] and the differences of the emitted nanoparticles can be characterized as follows:

TSDI has leaner mixture tuning and no secondary air (SAS). In the operation at full load (FL), or near to FL there are exhaust gas temperatures at tailpipe (after catalyst) in the range of 300°C.

With Carb there is a reacher mixture tuning and there is an active SAS. As result there is a much stronger oxidation in the ox. cat. at FL-operation. The exhaust gas temperatures of this model are increasing up to the range of 750-800 °C. Due to this stronger oxidation there is less particle mass (PM) emission of the Carb. vehicle and the nanoparticles contain more solid part in the range of 10-17%, while for TSDI the share of solids is in the range of 3-5%, [5].

TSDI Carburettor

Fig. 2. Peugeot scooters: left TSDI, right "carburettor"

3. Measuring apparatus & test procedures

The vehicles were tested on a chassis dynamometer with CVS dilution system.

The CVS is equipped with dilution air filtration required since Euro 5 passenger cars legislation in view of the NP-count limits.

The installation is equipped with emission measuring systems for legislated components and for nanoparticles.

The nanoparticulates measurements in this research program were performed at stationary engine operation with SMPS and with DC.

DC (diffusion charging sensor) measures the total active particle surface independent of the chemical properties. It indicates the solids and the condensates.

The investigations with each variant of exhaust conditions were performed according to the same procedure at constant speed and warm operation: 20 & 40 km/h; closed/open; with/without ox. cat.

In each test variant the nanoparticles measurements were performed at 5 sampling positions (Sp) according to the Fig. 3.

With the closed variant of exhaust gas extraction there is only one dilution step of the tailpipe gas (TP) in the CVS-tunnel.

The dilution air is filtered with the legally required filtration quality.

With the open variant of exhaust gas extraction there is a first step of dilution directly after TP with an unfiltered ambient air. The second step of dilution follows in the CVS.

For the open variant a higher CVS-flow is used to prevent the possibility of undesired reflow of the tailpipe gas in the aspirating cone (before Sp1).

The tests "without catalyst" were performed with a dummy catalyst without catalytic coating, but with identical geometry of the exhaust system. In this way it was assured, that there are no influences on the gasdynamic effects of the engine.

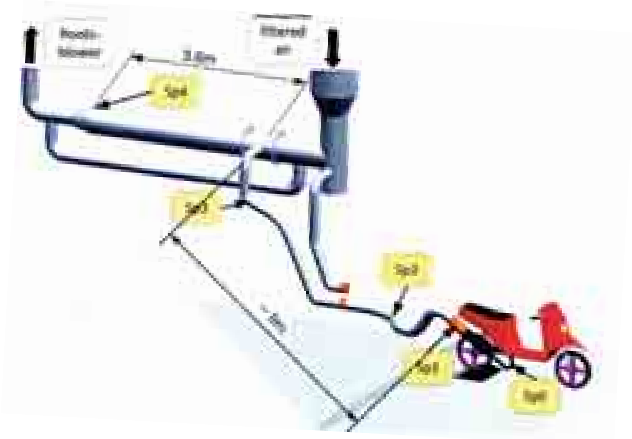

Fig. 3. Sampling positions (Sp) used in the tests

4. Results

Peugeot TSDI

This vehicle has: leaner tuning, no SAS, TP exhaust temperatures at 40km/h approximately 300°C.

Figure 4 shows the PSD spectra of tested variants at 20km/h with catalyst. Generally at Sp0 (engine out) there is the highest count concentration (in the range of 2 x 10^9 $1/cm^3$) of the smallest particles (maximum of PSD by 10-20nm). This engine-out PSD (Sp0) varies from test to test.

Regarding the single results it has to be kept in mind, that there is a certain dispersion of NP-emissions even for the same vehicle at the same operating conditions.

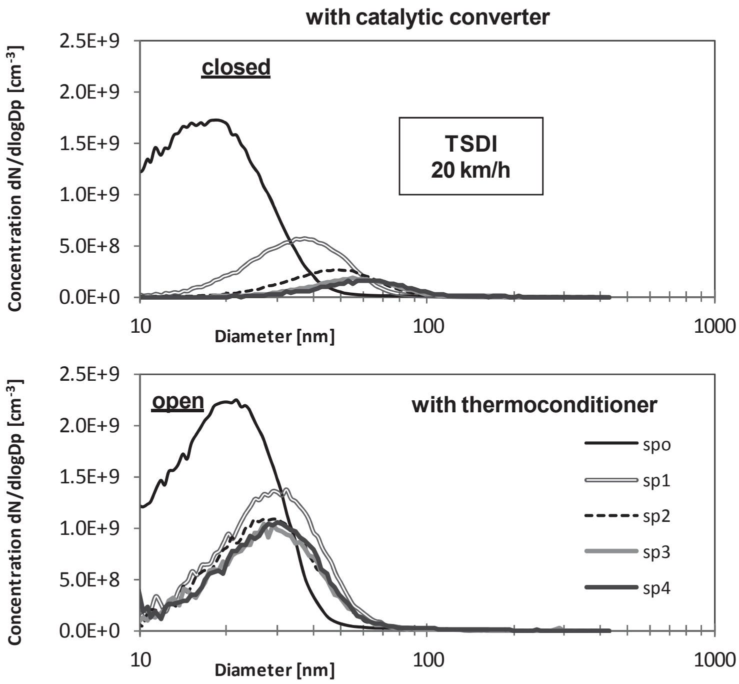

Fig. 4. SMPS - size spectra at constant speed 20 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

Regarding different sampling positions with closed exhaust gas extraction the peak count concentration decreases and the CMD increases i.e. the spectra are moved to higher average NP-sizes. This is a combined effect of agglomeration and loses.

With the open gas extraction there is a substantial change of PSD between Sp0 and Sp1. Due to this 1st dilution step the PC-concentration decreases and the CMD increases – this is a similar tendency, like with closed system. Nevertheless in the further sampling positions of the open system (Sp1 to Sp3) only PC-losses and no more agglomeration are to be remarked. In the CVS-tunnel after the 2nd dilution step there are no differences between Sp. 2, 3 & 4.

The changes of the PSD's of the aerosol along the exhaust and CVS-system are connected to the average gas temperature and PC-concentration, which result after the different dilution steps and cooling down in the connecting pipe, see temperatures and dilution factors in Fig. 5.

At this operating point (20 km/h) the exhaust gas temperature in the catalyst was in the range of 200°C and there is no influence of the catalyst on the PSD's.

Figure 6 shows the integral NP-results (SMPS & DC) of tested variants at 20km with catalyst.

With the closed variant there is a stronger reduction of SMPS PC's along the gas way, than with the open variant. This is to explain with the higher temperatures and concentrations in the closed system, which enables more intense thermophoresis - and diffusion losses.

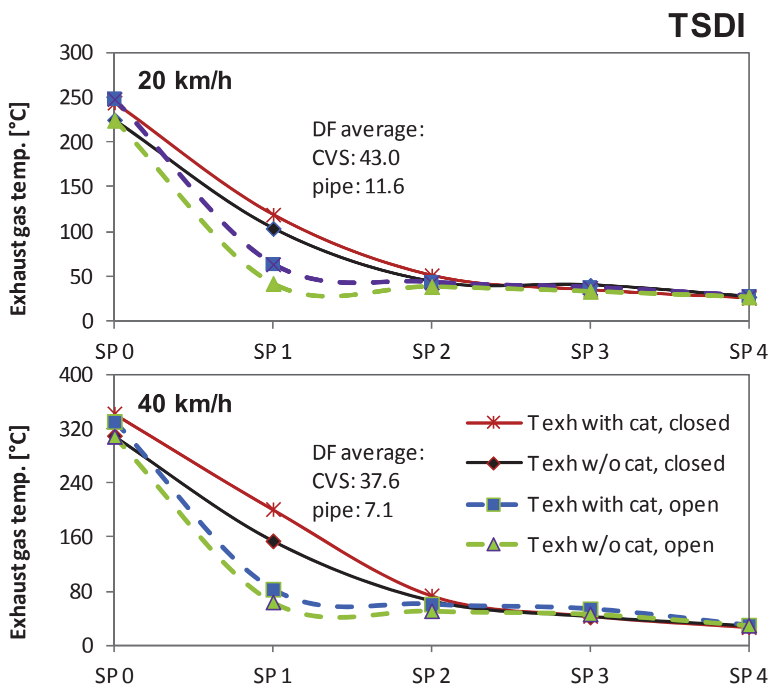

Fig. 5. Gas temperatures and dilution factors in the exhaust system at constant speeds 20 & 40 km/h, with TSDI

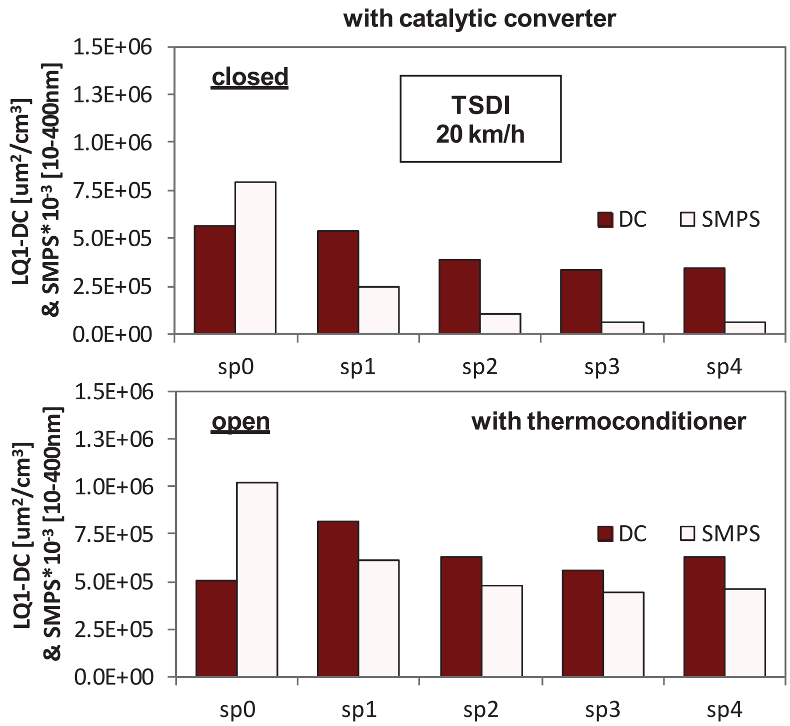

Fig. 6. DC signal & SMPS integral concentration from 10 to 400 nm at constant speed 20 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

The reduction of integrated SMPS PC's between Sp0 and Sp1 is for the open variant much lower, than for the closed variant. In the 1st dilution step of the open variant effects of spontaneous condensation are most probable provoked by the temperature drop. With this, with the higher background PC-concentration of the dilution air and with the lower losses of the open variant is to explain the higher final NP-concentration (SMPS) at Sp4 (with "open").

The NP back-ground concentrations of ambient air are in the range of 3x103 #/cm3 and the filtered dilution air has the near-to-zero NP-concentrations in the range of 4 #/cm3.

Between Sp0 and Sp1 DC-value (summary active surface of the aerosol) varies less, than the integral SMPS. This is caused by the bigger average particle sizes at Sp1 and by the fact that the aerosol surface increases with the 3rd power of the equivalent particle size.

With the variant "open" the DC-level at Sp1 is even higher than at Sp0, because the lower counts at Sp1 have less influence on the summary aerosol surface, than the bigger particle sizes.

Figure 7 shows the PSD spectra of tested variants at 40km/h with catalyst.

Due to the higher exhaust temperature in the catalyst in the range of 300°C there are visible effects of the oxidation:

– with closed system an intense reduction of PC-concentration between Sp0 and Sp1 and slight agglomeration effects at Sp1 to Sp4,
– with open system also an intense oxidation, but superposition of the effects of nanoparticles from the dilution air and of the spontaneous condensates due to the temperature drop before Sp1; as a result there is a high number concentration in the nuclei mode (size range ≤ 20 nm) in the sampling positions Sp1 – Sp4.

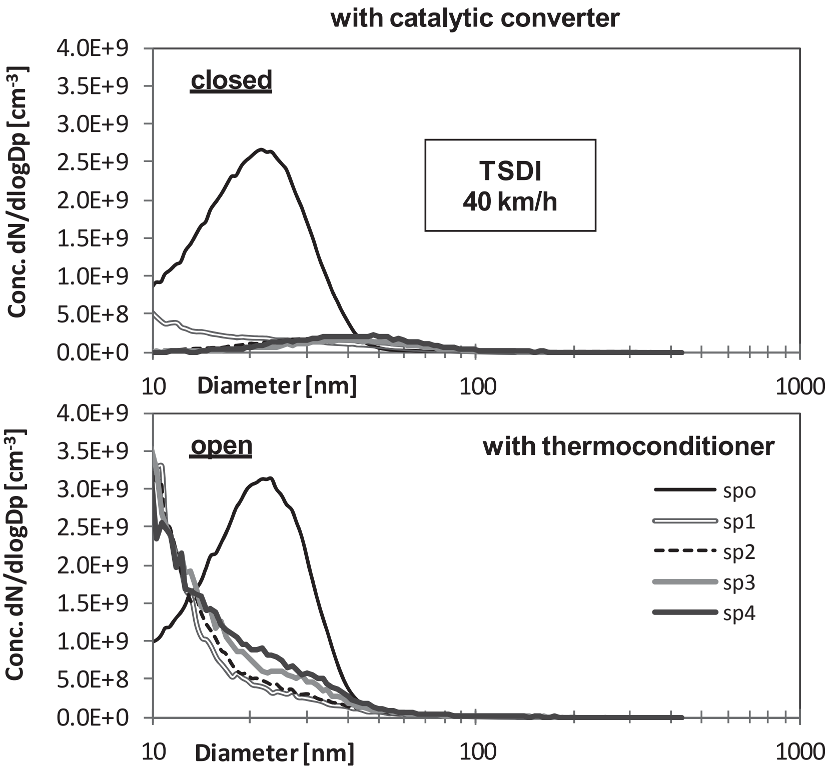

Fig. 7. SMPS - size spectra at constant speed 40 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

Figure 8 shows a direct comparison of NP-values (SMPS & DC) with both sampling variants: closed and open at 40 km/h. With the variant "open" there are always higher PC-concentrations. This is principally due to the lower NP-losses with the variant "open". The unfiltered dilution after TP has only a minor contribution (according to calculation less than 0.1%) to the higher final NP-counts.

The oxidative activity of catalyst is demonstrated by much lower values of DC-signals and by the fact, that with catalysts there are almost no differences of DC between "closed" and "open". This means, that with catalyst there are no precursor substances for condensation (they are oxidized) and the resulting size distributions of both variants are almost the same.

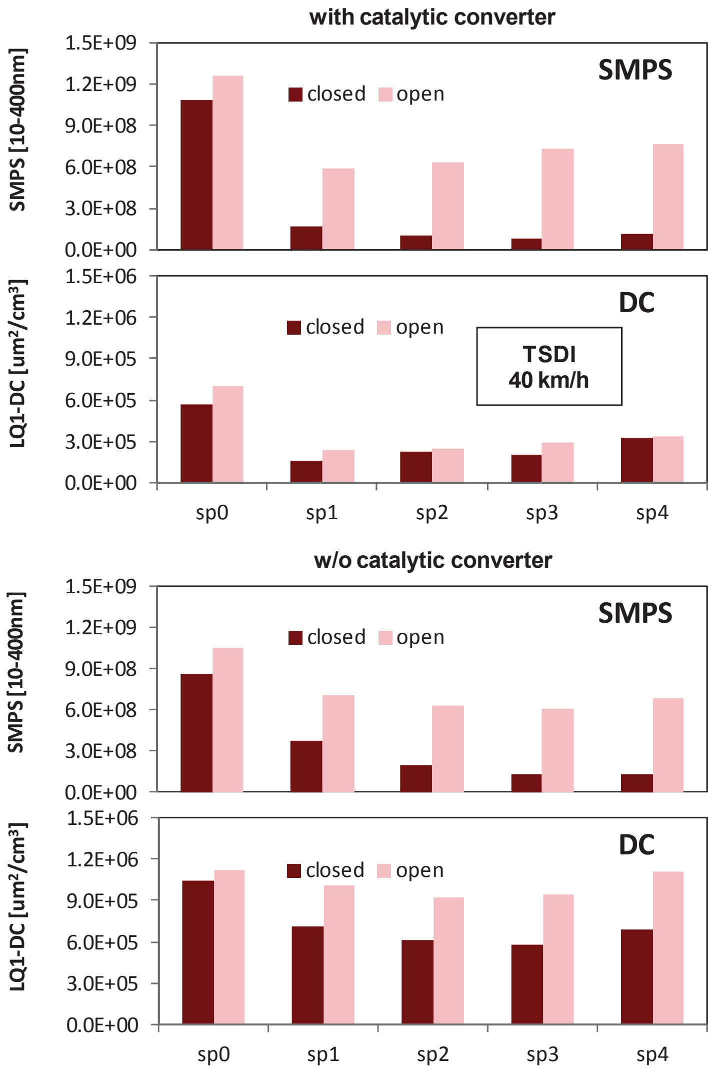

Fig. 8. Comparison of the DC signal & SMPS integral concentration at constant speed 40 km/h with open and closed exhaust sampling.

Peugeot Carburettor

This vehicle has: richer tuning, active SAS, TP exhaust temperatures at Sp1 are approximately 400°C.

Figure 9 shows the exhaust gas temperatures at all sampling positions and at both speeds 20 & 40 km/h. The intense exothermic heating between Sp0 and Sp1 is visible for "closed" gas extraction (for version "open" the thermocouple is placed downstream of the cone, after the 1st dilution step).

The results with catalyst at 20km/h are represented in Fig. 10 – SMPS PSD's and in Fig. 11 – integral NP-values SMPS & DC.

With catalyst there are intense effects of oxidation between Sp0 & Sp1 – nearly disappearing of the NP. The temperature in the catalyst is in the range of 400°C.

The results of SMPS PSD's at 40km/h (not represented graphically) show, that due to the SAS, rich tuning and a relatively high temperature level there are oxidation effects already without catalyst (temp. approx. 350°C). With catalyst the temperature is in the range of 400°C and the oxidation is so intense, that the particles are nearly eliminated.

There is a good repeatability of the results at Sp1 to Sp4.

Figure 12 shows the comparisons of SMPS integral concentrations and DC-values at all sampling positions and at 40 km/h.

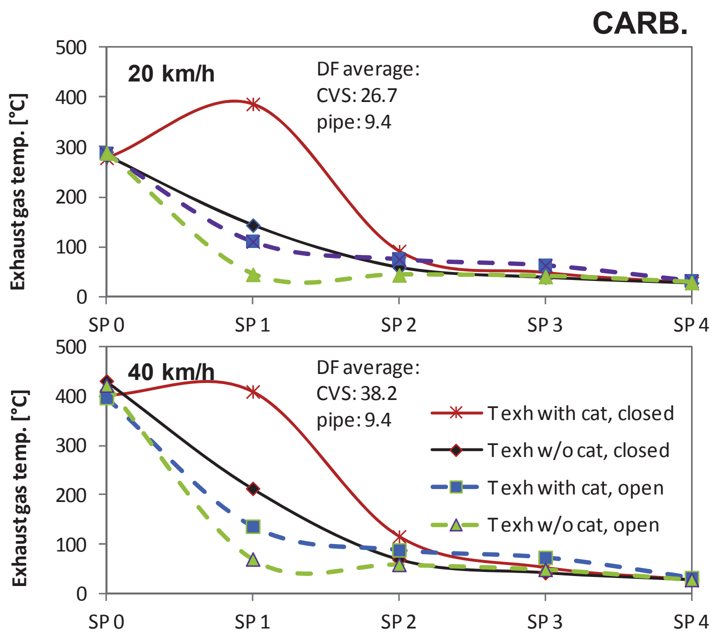

Fig. 9. Gas temperatures and dilution factors in the exhaust system at constant speeds 20 & 40 km/h, with Carb

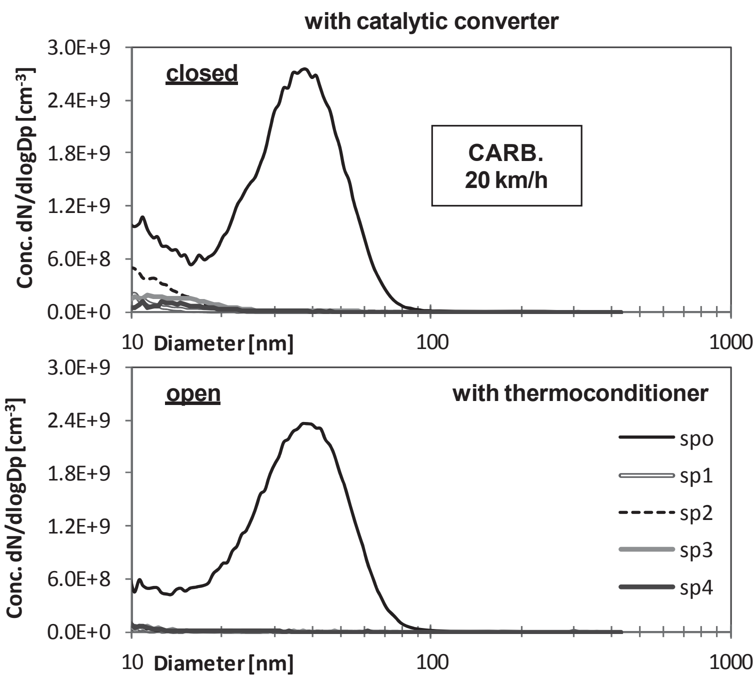

Fig. 10. SMPS - size spectra at constant speed 20 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

The strong oxidation between Sp0 and Sp1 is visible already without catalyst.

The NP count concentrations with the variant "open" are higher. As main reason the lower losses, due to a higher dilution and lower temperature are regarded. The higher background concentration of the unfiltered dilution air has been found to be a negligible factor. The higher NP-concentrations with variant "open" are particularly visible with no catalytic oxidation (without catalytic converter). In this case the particle numbers along the gas way are growing, due to the spontaneous condensation in nuclei mode, while the summary active surface (DC) stays unchanged, or slightly diminishes.

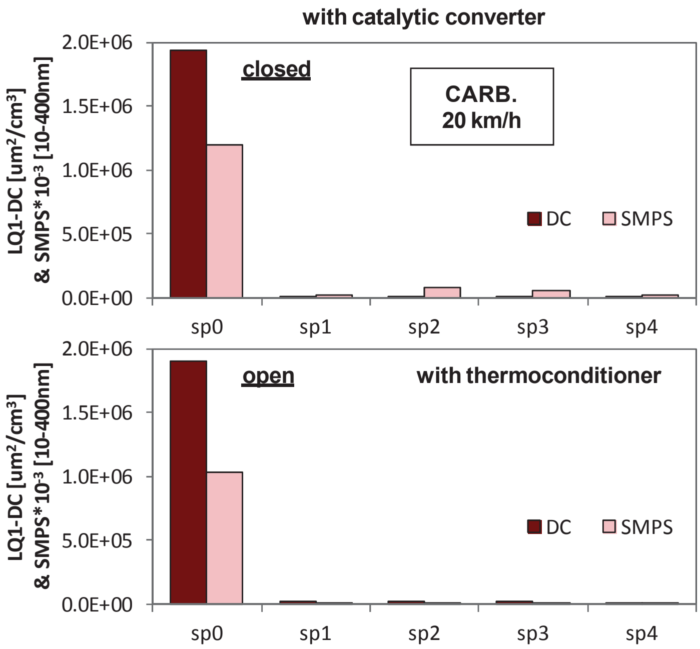

Fig. 11. DC signal & SMPS integral concentration from 10 to 400 nm at constant speed 20 km/h and different sampling points of the exhaust pipe and CVS tunnel with catalyst

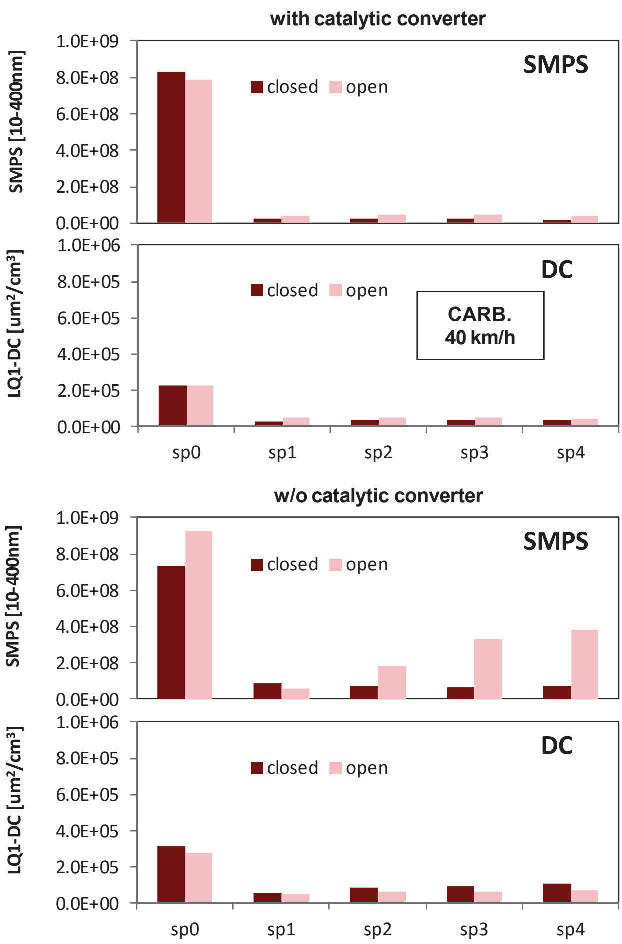

Fig. 12. Comparison of the DC signal & SMPS integral concentration at constant speed 40 km/h with open and closed exhaust sampling

5. Conclusions

It can be concluded that:

1. The changes of the PSD's of the aerosol along the exhaust and CVS-system are connected to the average gas temperature and PC-concentration, which result after the different dilution steps and cooling down in the connecting pipe.
2. The effects influencing the aerosol at different sampling positions are agglomeration, condensation, diffusion loses and thermophoresis.
3. In the "open" variant of exhaust gas extraction there is a dilution step with unfiltered ambient air directly after tailpipe. This causes a stop of agglomeration, reduction of diffusion loses and increased background NP-concentration. There is also lower post oxidation of CO & HC. In some cases spontaneous condensates due to the temperature drop are supposed.
4. With the "closed" variant there is a stronger reduction of SMPS PC's along the gas way, than with the open variant. This is to explain with the higher temperatures and concentrations in the closed system, which enables more intense thermophoresis – and diffusion losses.
5. The NP-concentrations measured with "open" variant are always higher.
6. The oxidation catalyst principally lowers the NP count concentrations and moves the PSD-maximum to the lowest sizes. The intensity of oxidation depends on the exhaust gas temperature.
7. Most intense oxidation is observed with Peugeot Carb: due to the SAS, rich tuning and a relatively high temperature level there are oxidation effects already without catalyst (temp. approx. 350°C). With catalyst the temperature is in the range of 400°C and the oxidation is so intense, that the particles are nearly eliminated.

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Abbreviations

AFHB Abgasprüfstelle der Fachhochschule, Biel-Bienne CH
(Lab. for Exhaust Gas Control, Univ. of Appl. Sciences, Biel-Bienne, CH)

BAFU Bundesamt für Umwelt (Swiss EPA)

Carb	Carburetor
CMD	count median diameter
CPC	condensation particle counter
CVS	constant volume sampling
DC	diffusion charging sensor
DF	dilution factor
DI	direction injection
NP	nanoparticulates
PC	particle counts
PM	particulate matter, particulate mass
PSD	particles size distribution
SAS	secondary air system
SMPS	scanning mobility particles sizer
SOF	soluble organic fraction
Sp	sampling position
TC	thermoconditioner, total arbon
TP	tailpipe
TSDI	two stroke direct injection
TTM	Technik Thermische Maschinen