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Nanoparticles in the exhaust gas of scooters

NANOPARTICLES

in the Exhaust Gas of Scooters

by

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➢ **Introduction**

During the emission measurements of two-wheelers for the Swiss Federal Office of Environment, Forests and Landscape (FOEFL) and as a contribution to the European project ARTEMIS *) analysis of limited and nonlimited emissions of scooters was performed.

Exhaust emissions measurements of two Scooters: 4-stroke 125 cc and 2-stroke 50 cc have been performed with and without catalyst.

As nonlimited emissions the nanoparticulate emissions at cold and warm operating conditions were measured by means of SMPS, ELPI and NanoMet *). The measurements were both: at steady state and at transient operating conditions.

A cold start in the temperature range of 20 25 °C can be regarded as a “summer cold start”. In the later Swiss activities similar investigations of a “winter cold start”, which will be represented by the temperature of +5°C, are planned.

The present work cleared up several details about the emissions of small scooters and confirmed the necessity of further activities to reduce these emissions. This would be an important contribution to improve the air quality in the cities.

➢ **Investigated scooters**: Fig. 1

Aprilia Leonardo 15

This type of Aprilia is without catalyst.

For some investigations a non-regulated oxidation catalyst was placed in the exhaust pipe of the vehicle:

manufacturer:	Sengton Transportation Implements Co. Ltd
washcoat:	Pt/Rh = 10/1; 70 g/ft^3
metallic support:	cell density 100 CPSI

Yamaha EW50 Slider

This type of Yamaha is originally equipped with an non-regulated oxidation catalyst (the data of which are not available). For the measurements without catalyst the catalyst body was replaced by an empty tube.

➢ **Experimental set-up**: Fig. 2

This equipment fullfills the requirements of the swiss and european exhaust gas legislation - 70/220/EWG, 98/69/EG.

➢ **Particulate emissions analysis**: Fig. 3

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*) Abbreviations see at the end of paper

- **<u>Measuring procedure</u>:** Fig. 4; Fig. 5

- **<u>Nanoparticles</u>**

<u>v = 30 km/h with cold start</u>: Fig. 6; Fig. 7

Fig. 6 gives an example of results with the 2-stroke scooter with catalyst. During the warm-up period (until about 120 s) there is a blow-out of solid NP, which were deposited before in the catalyst - this is perfectly demonstrated with the PAS-signal. The light-off is visible also by the changed slope of DC (lube-oil condensates) and CPC signals.

The comparison of all variants “scooter-catalyst” in Fig. 7 allows following statements:

- for the 2-stroke engine higher peak values in the first minute after the cold start and slower decrease of particle counts, than for the 4-stroke engine
- higher values of all signals with catalyst with 2-stroke engine, inversely with 4-stroke engine
- mostly solid particles for the 4-stroke engine (high PAS/DC-ratio)
- mostly soluble particles (very low PAS/DC-ratio) for the 2-stroke engine, the particulates of a 2-stroke SI engine consist nearly totally of lube-oil.

(Not all results of PAS/DC are represented in this report).

<u>v = 30 km/h with warm engine</u>: Fig. 8

In this stationary operating condition it is possible to measure the whole size distribution spectra with the SMPS.

Generally the 2-stroke engine (Yamaha 50) has a much higher level of nanoparticle emissions.

Aprilia 125 (4-stroke):

- the catalyst lowers the total nanoparticle counts (SMPS, ELPI, DC), but it increases slightly the solid part of the particles.

Yamaha 50 (2-stroke):

- the catalyst increases the NP-emission level (richer mixture and/or more internal EGR),
- the SMPS-spectra have a maximum number concentration as high (or higher) as the diesel engines, this maximum is placed at the sizes of 50 60 nm (for diesel usually 90 100 nm),
- compared to the SMPS-spectra the ELPI-spectra are shifted to the bigger sizes and lower counts concentrations – this is explained with the coagulation effects in the exhaust gas line between tail pipe sampling (SMPS) and CVS-tunnel-sampling (ELPI), a distance of approx. 8 m,
- the DC-values are much higher than PAS, which confirms a very high portion of SOF (lube-oil condensates).

For both scooters the time-traces of the PAS signal (not represented here) have a very fluctuating character. This is due to a very low level of this signal, but it indicates also certain periodical changes of the chemistry of nanoparticulates transient driving cycle: Fig. 9;   Fig. 10

As in all cases of transient measurements there is a measuring lag consisting of transport time of the gas sample to the analyser and of response time of the last one. Due to that a certain inexactitude of the represented time-plots has to be considered. In spite of that some tendencies can be recognised. With cold start there are higher NP-levels just in the warm-up phase after the start.
There are higher emissions of NP with 2-stroke and the catalyst has no influence, or increases only a little the particle counts.

At warm cycles there are lower NP-levels in the first period of the cycle (warm operation). The tendencies, which were observed before can be confirmed:

- 2-stroke engine has higher nanoparticulates (NP) emission
- the particulates of 2-stroke consist mostly of soluble fraction (lube-oil condensates)
- the catalyst increases the NP of the investigated 2-stroke engine.

Generally the peaks of NP-emissions coincide with the accelerations and with the maxima of driving speed.

Fig. 10 summarises some results of time-integrated particulate counts during the transient cycle for each combination of vehicle/catalyst/driving conditions
These results give a good overlook and confirm the tendencies remarked before:

- the cold operation increases the average nanoparticulate emission
- the catalyst lowers the nanoparticulate emission, except of the 2-stroke engine at cold operation (where in this case the influence of catalyst on the engine is stronger, than the influence on the components of the exhaust gas).

- **Limited emissions:**   Fig. 11

Fig. 11 gives a comparison of all regulated emissions and of particulate mass emissions during the tests with nanoparticulates analysis.

It can be remarked that the cold start increases the CO-, HC- and PM-values and for the 4-stroke engine also the NO_X-values. The cold PM-emissions of the 2-stroke engine, which can be considered as a very good one, exceeds the actual limit value for diesel passenger cars (0,05 g/km).

In later investigations it was stated, that there are no differences of the emission values by sampling from the “gasoline”, or the “diesel” dilution tunnel immediately one after each other. The differences, which are shown in Fig. 11 are due to different days of measurement, (approx. one month apart).

- **Summary**   Fig. 12;   Fig. 13;   Fig. 14

Acknowledgement

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Abbreviations

ARTEMIS	assessment and reliability of transport emission models and inventory systems
BUWAL	Bundesamt für Umwelt, Wald und Landschaft (Swiss EPA, FOEFL)
CPC	condensation particle counter
CVS	constant volume sampling
DMA	differential mobility analyzer
DC	diffusion charging sensor
ELPI	electrical low pressure impactor
EPA	Environmental Protection Agency
ETHZ	Eidgenössische Technische Hochschule Zürich
FOEFL	Federal Office for Environment, Forests and Landscape (Swiss EPA, BUWAL)
NanoMet	minidiluter + PAS + DC
NP	nanoparticulates
PAS	photoelectric aerosol sensor
PM	particulate matter, particulate mass
PN	particles number
PSD	particles size distribution
SMPS	scanning mobility particles sizer
SOF	soluble organic fraction

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Investigated scooters

Aprilia Leonardo 125	Yamaha EW50 Slider
4-stroke, 125 cc	2-stroke, 50 cc
water cooling	air cooling
variomat, v_{max} = 95 km/h	variomat, v_{max} = 60 km/h
8,5 kW at 9000 rpm	2,5 kW at 6800 rpm
weight empty: 136 kg	weight empty: 81 kg
constr. year: 1999 (33 km)	constr. year: 2000 (22 km)
original: without catalyst	orignal: with ox. cat.

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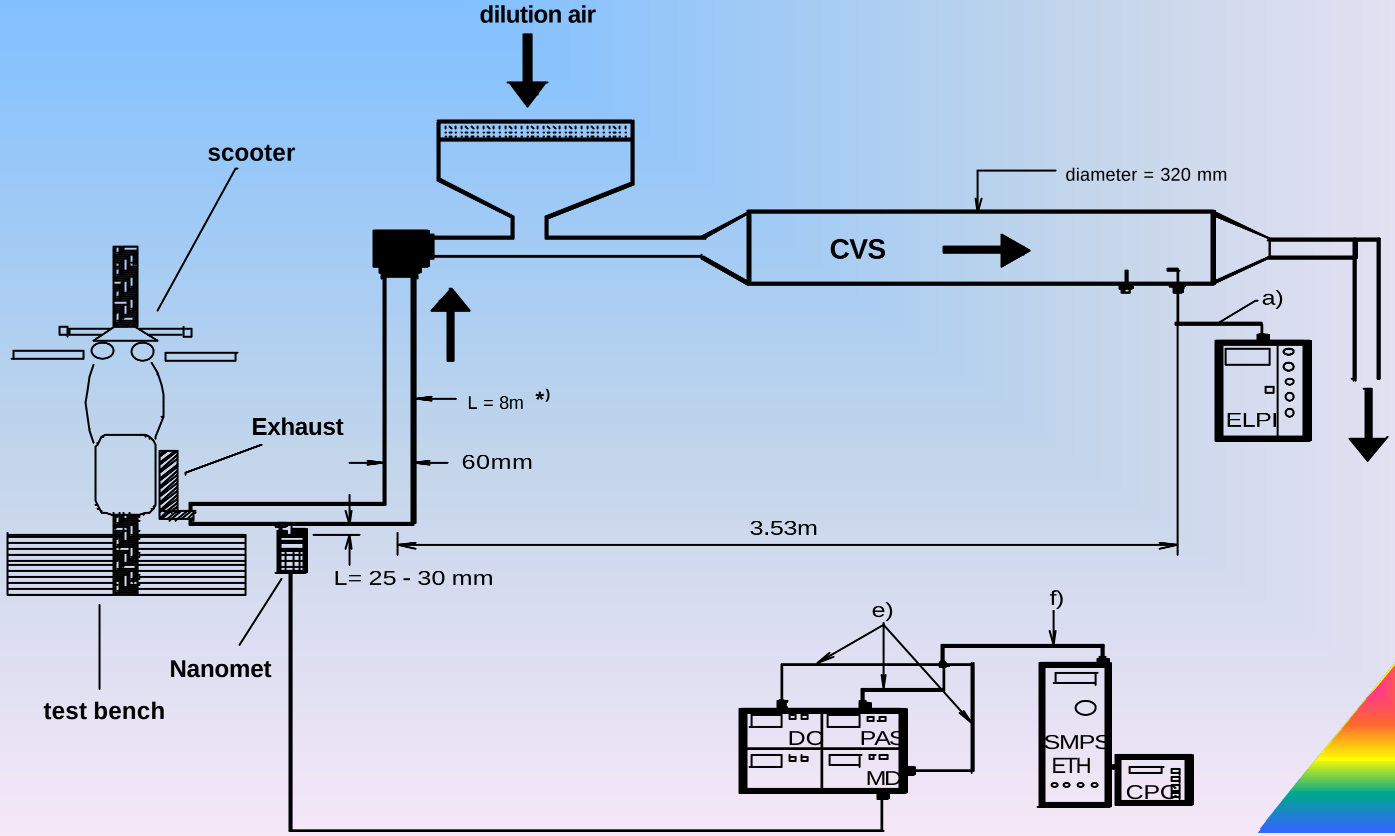
Sampling and measuring set-up for nanoparticulates analysis of the scooters



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Particulate emissions analysis

- PM gravimetric measurement
- SMPS – Scanning Mobility Particle Sizer, TSI
- ELPI – Electrical Low Pressure Impactor, DEKATI
- 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).

Measuring procedure

- cold start - acceleration to 30 km/h - constant speed
- warm cycle - bag sampling, PM
- cooling down during 30 min
- cold cycle - bag sampling, PM

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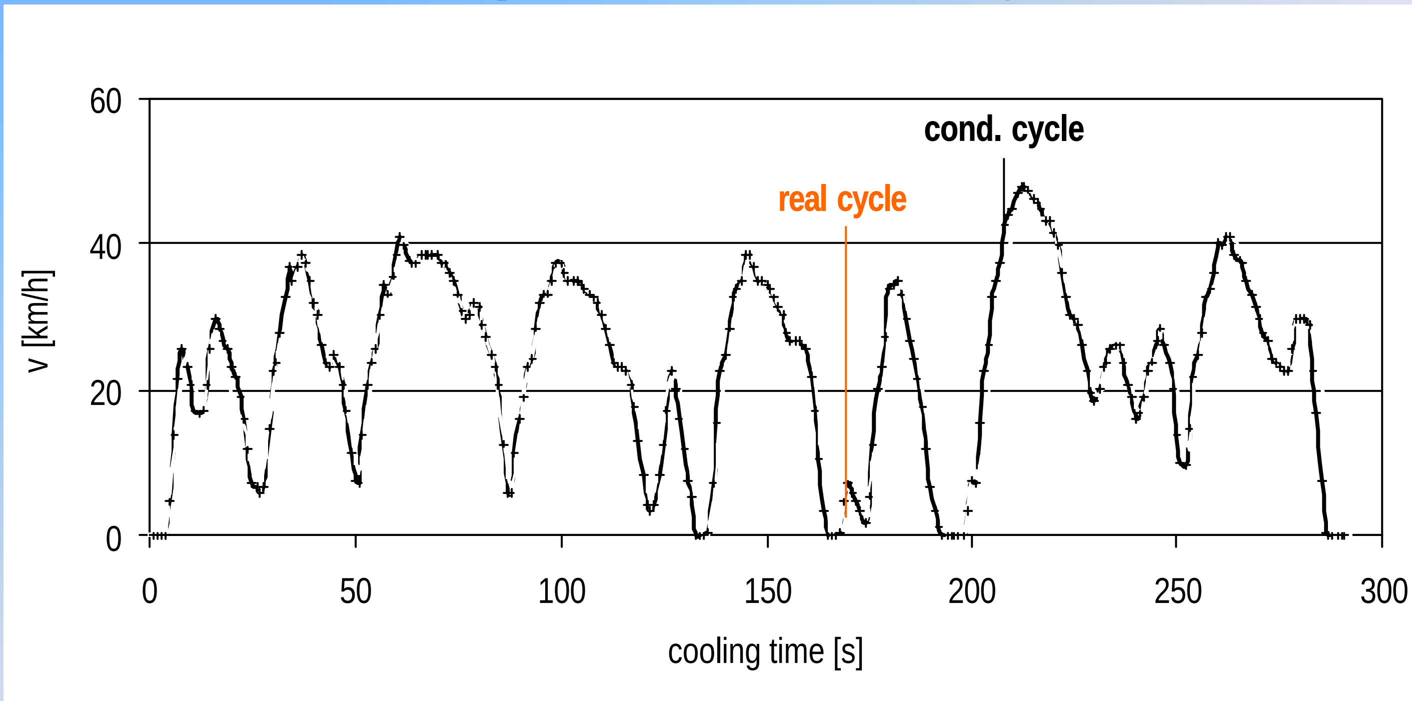
Driving cycle for warm-up after the cold start and for nanoparticulates analysis



Characteristic parameters of the driving cycle (ZUS 98)

cycle	t	s	v=0		v=const		stab v	stab a	v mean	a+	a-
[-]	[s]	[m]	[s]	[%]	[s]	[%]	[m/s]	[m/s²]	[m/s]	[m/s²]	[m/s²]
cond.	291	1888.2	24	8.2	65	22.3	12.592	0.872	23.36	1.062	-0.777
real	291	1895.4	21	7.2	59	20.3	11.956	0.768	23.29	0.909	-0.722

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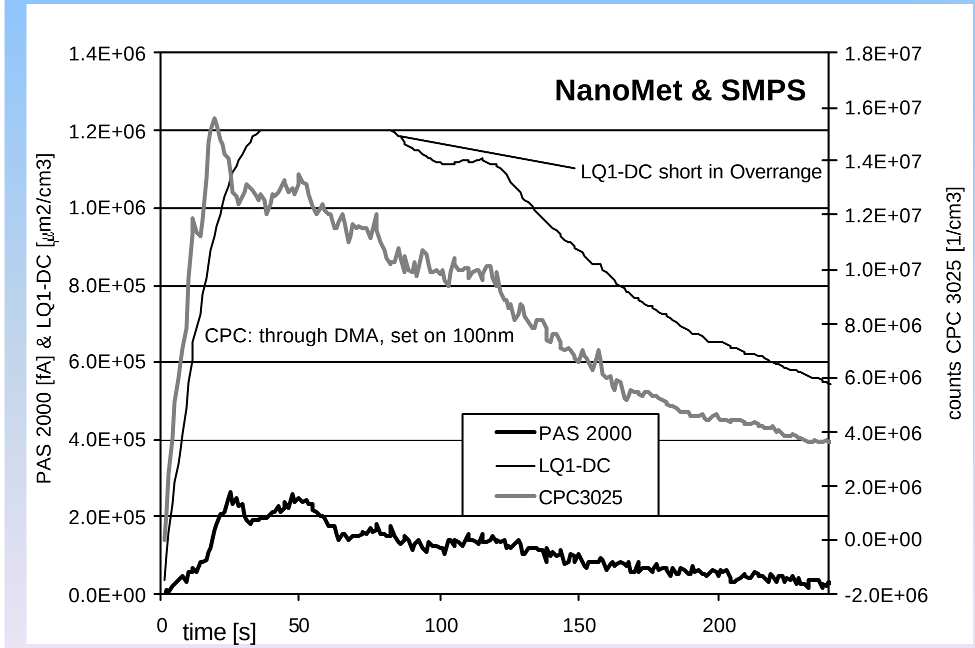
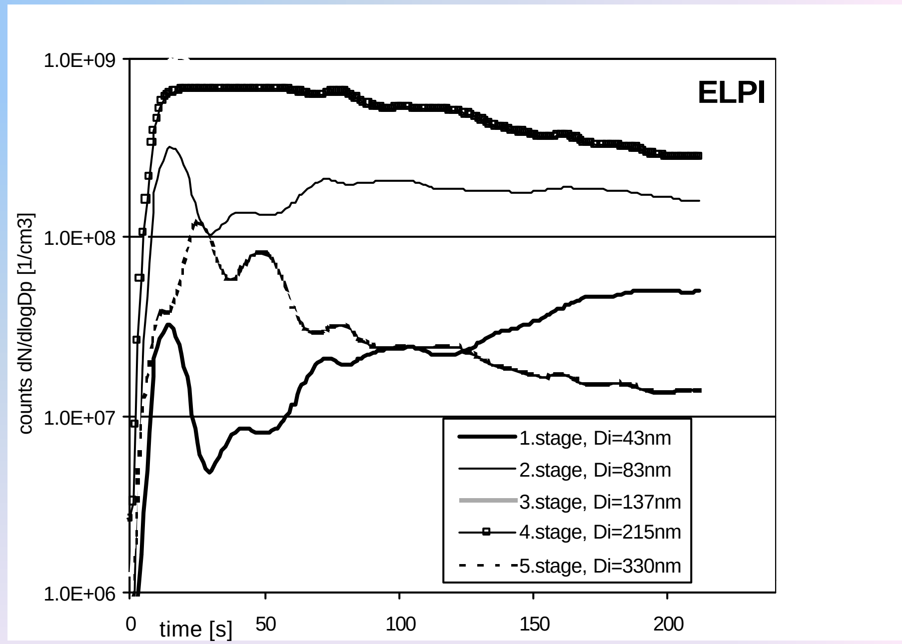
Nanoparticulates at v = 30km/h, with cold start
Yamaha EW 50, with catalyst





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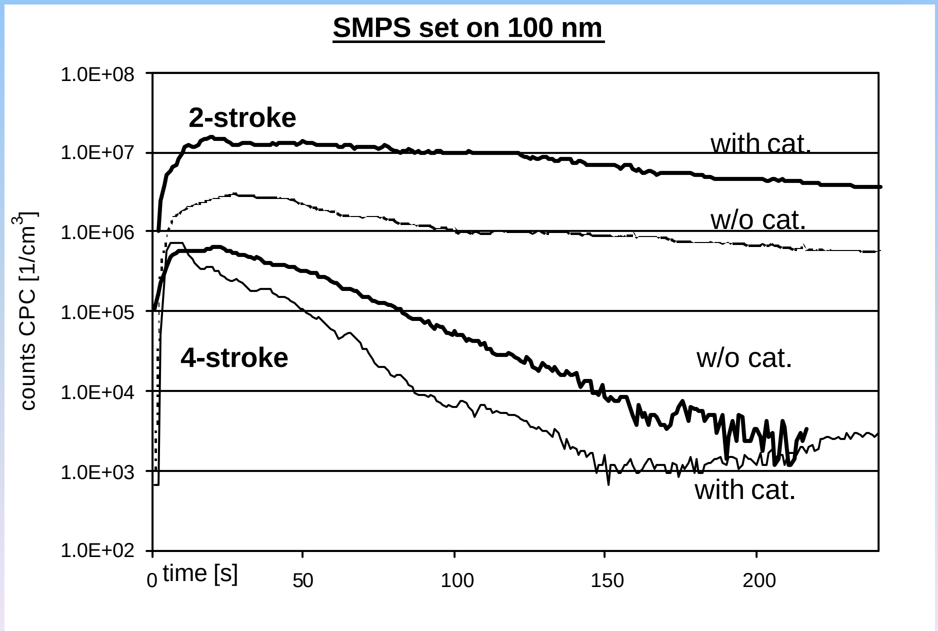
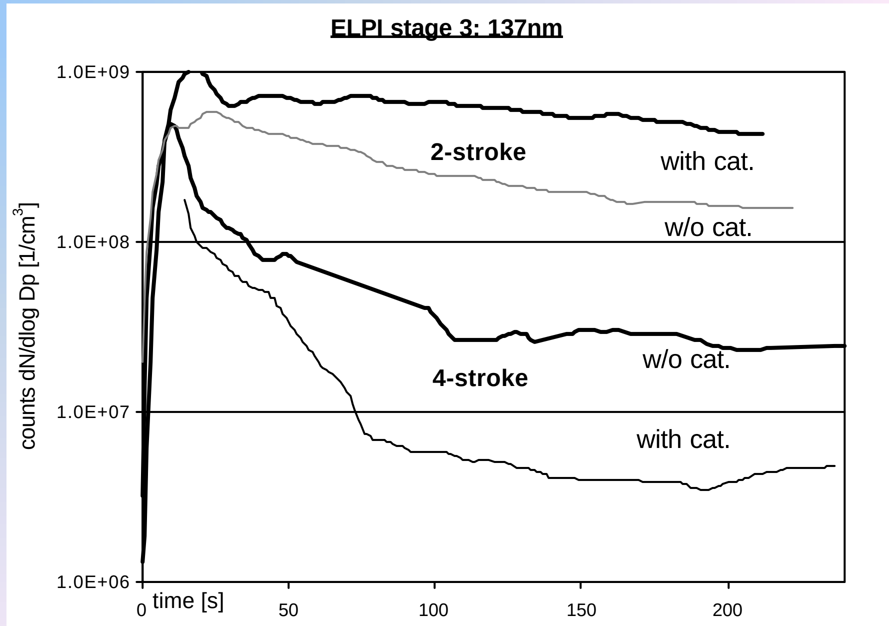
Nanoparticulates at v=30 km/h, with cold start & warm up for 2-stroke / 4-stroke; with/without catalyst





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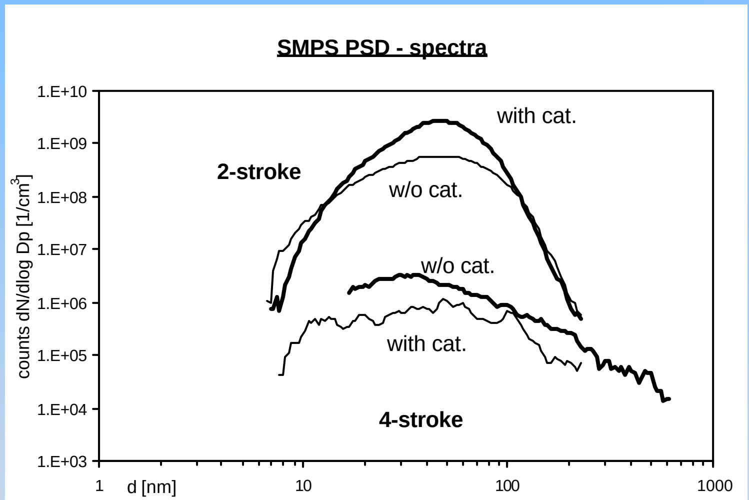
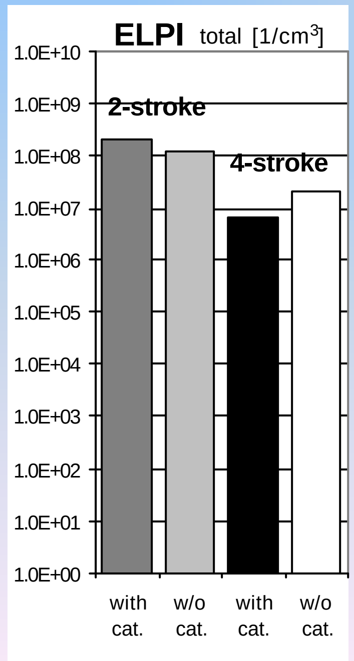
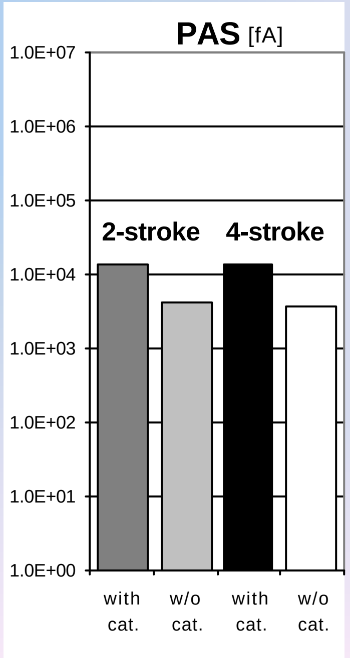
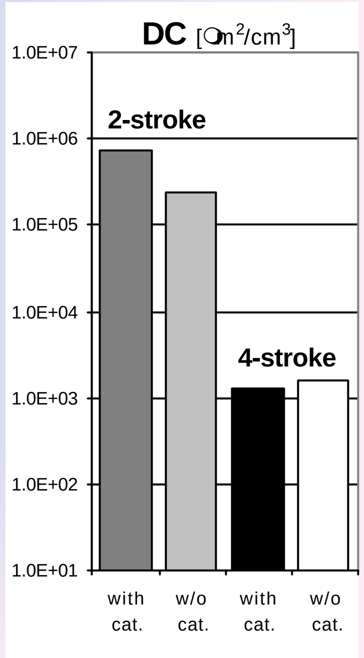
Nanoparticulates at v=30 km/h, with warm engine for 2-stroke / 4-stroke; with/without catalyst









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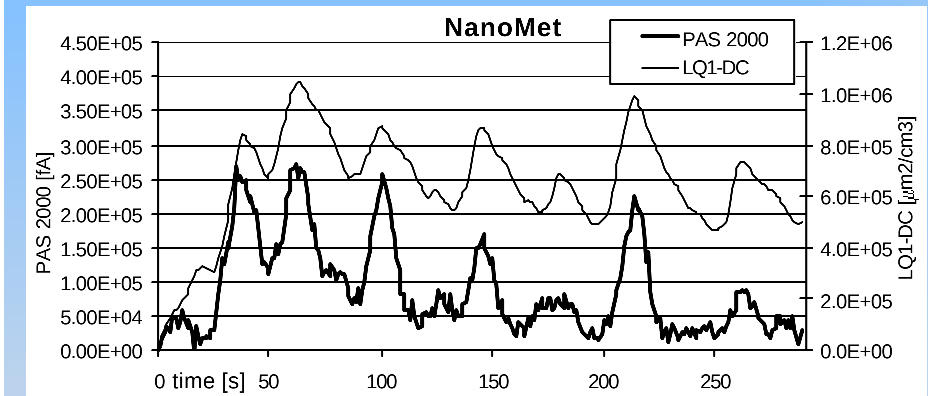
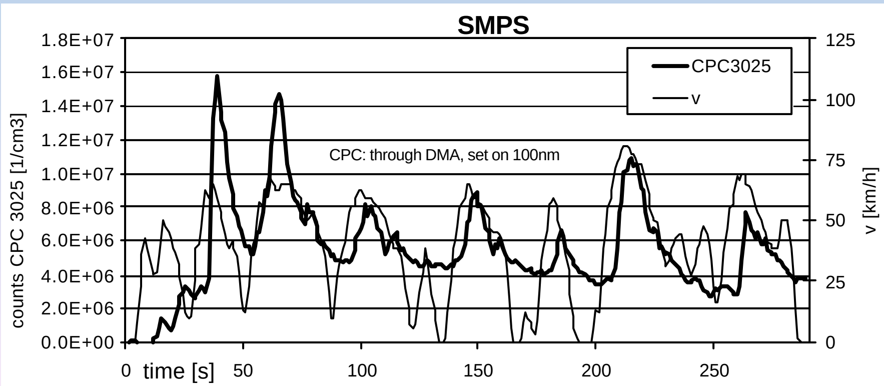
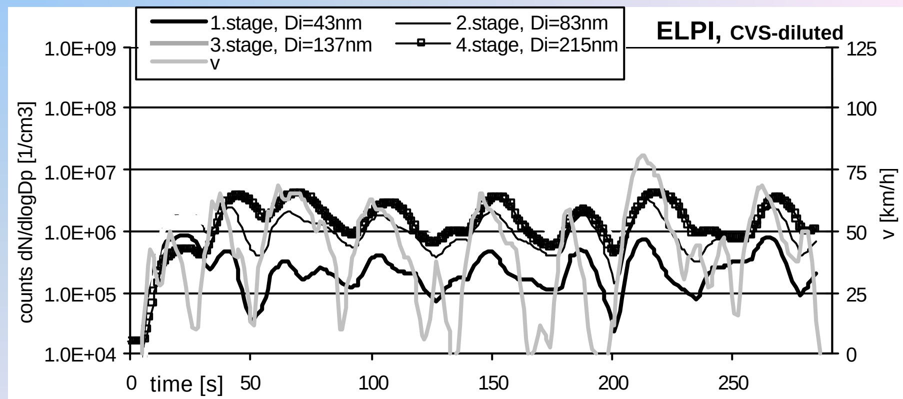
Nanoparticulates at transient cycle, with cold start Yamaha EW 50, with catalyst



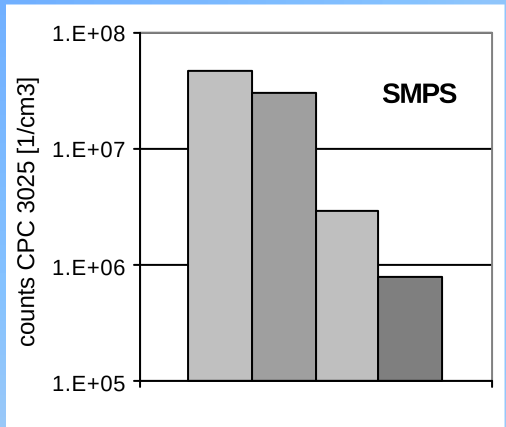


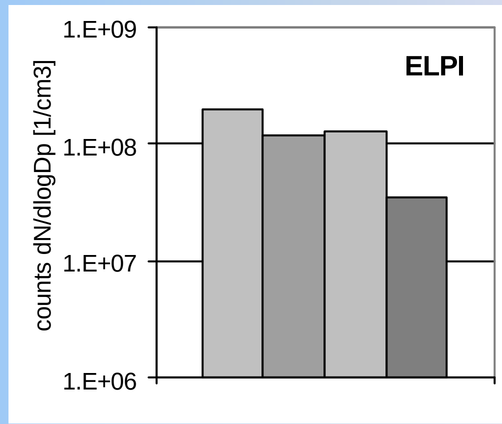


Integrated nanoparticulates of selected size at transient cycle time 250 sec.

Aprilia 125 (4-stroke)

SMSP set on 100nm

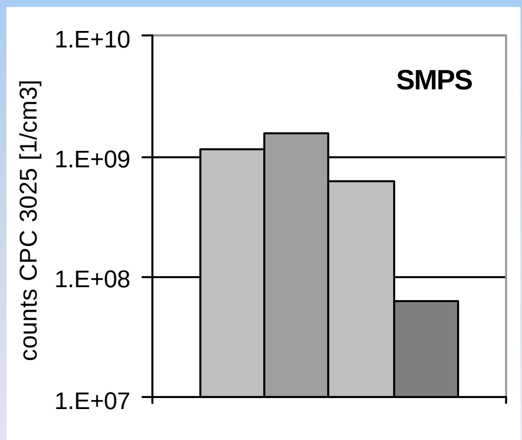


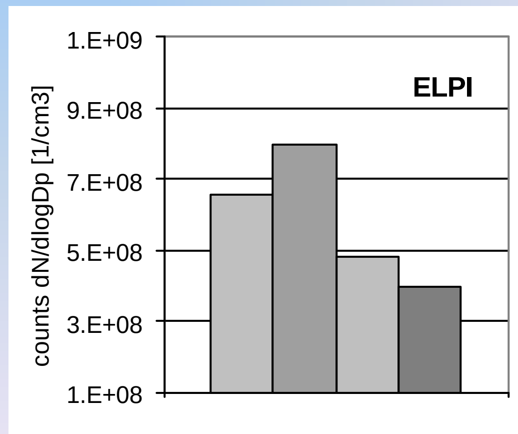


ELPI stage 137nm

Yamaha EW 50 (2-stroke)

SMPS set on 100 nm

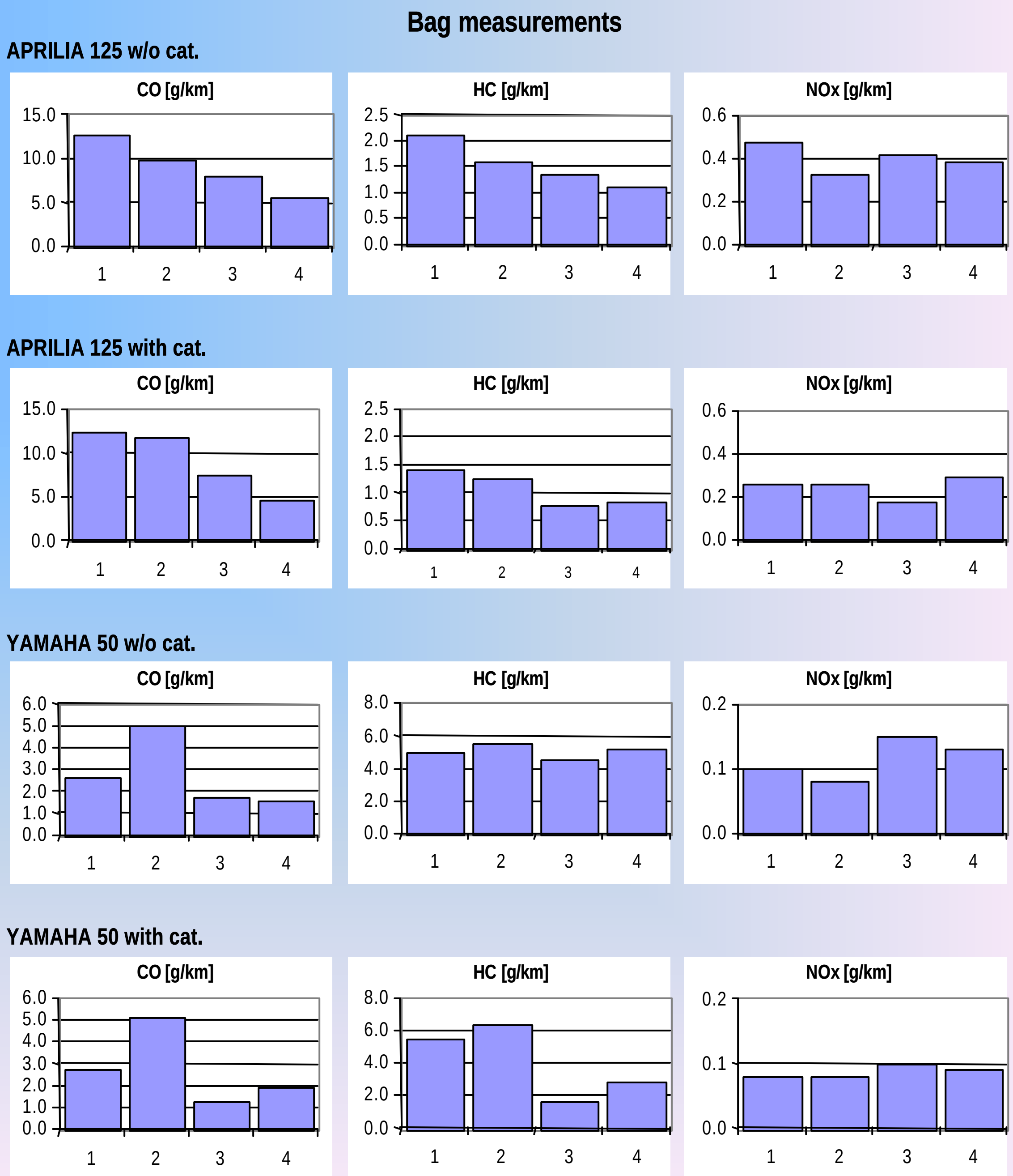




ELPI stage 137nm

without catalyst, cold start | with catalyst, cold start | without catalyst, engine warm | with catalyst, engine warm

Comparison of limited emissions provided from dilution tunnel of Diesel gasoline



1... driving cycle cold*) Diesel tunnel
2... driving cycle cold*) gasoline tunnel
3... driving cycle warm Diesel tunnel
4... driving cycle warm gasoline tunnel

*) cooling time 30 min

Summary (1)

- the cold start causes also higher particle mass- and nanoparticulates emissions
- 2-stroke engine has higher particulate emissions than the 4-stroke engine, this emission riches the level of a diesel engine, but consists mostly of the condensates of unburned lube-oil
- 4-stroke engine has a very low particulate emission, which consists mostly of insoluble fraction

Summary (2)

- the catalyst has different, sometimes controversial influences on the part-culate number concentrations, it can:
  - change the basis engine emissions by influencing the air-fuel ratio and the gas exchange (here: richer operation of the 2-stroke engine)
  - change the number of solid particulates through the deposition and removal effects (here: general reduction of particle counts for the 4-stroke engine)
  - change the number of soluble particulates (condensates) through the oxidation of hydrocarbons (diminishing of part. number) or oxida-tion of sulphur (increasing of part. number)

  Those two later effects depend on the gas flow and temperature of gas and catalyst.

Summary (3)

- for the investigated scooters the catalyst reduces slightly the particle numbers of the 4-stroke engine and increases the particle numbers of the 2-stroke engine at stationary (and particularly cold) operating conditions.
- the emission peak values of nanoparticulates correspond with the peak accelerations and speeds of the driving cycle
- the constant speed driving pattern is more appropriate to study the warm-up effects of the catalyst.