Research on Particle Emissions of modern 2-Stroke Scooters

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ABSTRACT

Limited and nonlimited emissions of scooters were analysed during several annual research programs of the Swiss Agency of Environment Forests and Landscape (SAEFL, BUWAL)*⁾.

Small scooters, which are very much used in the congested centers of several cities are a remarkable source of air pollution. Therefore every effort to reduce the emissions is an important contribution to improve the air quality in urban centers.

In the present work detailed investigations of particle emissions of different 2-stroke scooters with direct injection and with carburetor were performed.

The nanoparticulate emissions with different lube oils and fuels were measured by means of SMPS, (CPC) and NanoMet *⁾. Also the particle mass emission (PM) was measured with the same method as for Diesel engines.

Extensive analyses of PM-residuum for PAH & SOF/INSOF, as well as for VOC were carried out in an international project network.

It can be stated, that the oil and fuel quality have a considerable influence on the particle emissions, which are mainly oil condensates.

The engine technology influences the (nano)particle emissions by: mixture preparation, mixture tuning, oil consumption, postoxidation, quality, condition and temperature of the catalyst.

Since the particulate emission of the 2-S consists mainly of lube oil condensates the minimization of oil consumption stays always an important goal.

The amount of total PAH, as well as the toxicity equivalence factor TEQ correlate roughly with the total particle mass PM.

INTRODUCTION AND OBJECTIVES

In the annual investigation programs of AFHB mandated by the Swiss EPA (BUWAL) [1, 2, 3, 4]**⁾ the problem of particle mass and particle counts emissions of 2-S engines was particularly addressed. The work about influences of different lubricating oils, different fuels and different conditions of oxidation catalyst 2003, [5], showed in reality considerable potentials, but also necessities of further more extended, inter-disciplinary research.

The behavior of catalyst raised several open questions, like: aging and light off with different fuel- and oil qualities.

This situation led to the need of participation of several analytical laboratories and industrial partners and due to general interest and support a project network was created. In this network the Swiss Research Partners: TTM, AFHB, EMPA, ME, SUVA collaborate with several industrial partners and foreign research institutes, like JRC Ispra, VTT Finland, Toxicity Network France and ARAI India. This network is open to the interested parties to join it and it exchanges informations about the 2-S 2-wheelers research with the Annex XXXIII of IEA Implementing Agreement AMF, [6].

There are several objectives of the activities. This paper represents a part of results concerning the supplementing investigations and validations of the results from [5] and [7], which showed the influences of lube oils and fuels on the (nano) particulates.

The specific questions where:

- reproducibility of the influences of oils with different S-content,
- influences of different oils with the Aspen fuel,
- influences of engine technology TSDI-Carburetor,
- check of sampling point and sampling procedure for nanoparticles.

It is important to remark that the results from single vehicles and single measurements cannot be generalized and therefore the repetitions on other vehicles are necessary to confirm and complete the findings.

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*⁾ Abbreviations see at the end of paper

**⁾ References see at the end of paper

INVESTIGATED SCOOTERS

The investigated scooters were:
Peugeot Looxor TSDI and Peugeot Looxor Carburetor (see Table 1)

Fig. 1 shows these scooters in the measuring laboratory.

The Peugeot TSDI-System uses crankshaft driven air compressor.Gasoline is injected in the pressurised air of the feed rail where the premixing of air and fuel takes place. The air injector controls the admission of the rich mixture in the combustion chamber. The lubrication oil is dosed in the intake air of the engine by means of the oil pump.

For the vehicles with carburetor simple, conventional carburetors with a cable-controlled throttle body and needle are used. The lubrication oil is also dosed in the intake air of the engine.

Table1. Data of the scooter Peugeot Looxor TSDI and Carburetor

	Peugeot	Peugeot
vehicle identification	Looxor TSDI	Looxor
model year	2002	2004
transmission no. of gears	variomat	variomat
km at beginning	1400	0
engine: type displacement cm^3 number of cylinders	 2 stroke 49.1 1	 2 stroke 49.1 1
cooling	Air forced	Air forced
Rated power kW rated speed rpm idling speed rpm	3.6 7800 1700	3.72 8100 1800
max vehicle speed km/h	45	45
weight empty kg	94	94
mixture preparation	direct injection with automatic oil pump	carburetor with automatic oil pump
catalyst	yes	yes + SAS (secondary air system)
catalyst data	Pt/Rh 5/1 50 g/ft^3 200 cpsi metal support ∅ 60,5 / L 40	Pt/Pd/Rh 1/28/1 50 g/ft^3 100 cpsi metal support ∅ 60,5 / L 40

MEASURING APPARATUS

Chassis dynamometer

- roller dynamometer: Schenk 500 G5 60
- driver conductor system: Zöllner FLG, 2 Typ. RP 0927-3d, Progr., Version 1.4
- CVS dilution system: Horiba CVS 9500T with Roots blower
- air conditioning in the hall (intake-and dilution air) automatic, temperature: 20 - 30 °C, humidity: 5.5 – 12.2. g/kg

Figure 1. Investigated scooters: leftTSDI,right Carburetor

Test equipment for regulated exhaust gas emissions
This equipment fulfils the requirements of the Swiss and European exhaust gas legislation – 70/220/EWG; 98/69/EG/2003/76; 97/24 - chap. 5/2002/51.

- gaseous components:
  exhaust gas measuring system Horiba MEXA-9400H
  CO, CO_2 .infrared analysers (IR)
  HC_{IR}... only for idling
  HC_{FID}... flame ionization detector for total hydrocarbons
  NO/NO_X...chemoluminescence analyser (CLA)
  O_2... Magnos

  The dilution ratio DF in the CVS-dilution tunnel is variable and can be controlled by means of the CO_2-analysis.

- measurement of the particulate mass (PM):
  sampling from the full-flow dilution tunnel
  filter temperature ≤ 52 °C
  conditioning of filter: 8 - 24 h (20°C, rel. humidity 50%)
  scale: Mettler, accuracy ± 1 μg

Particle size analysis
In addition to the gravimetric measurement of particulate mass, the particle size and counts distributions were analysed with following apparatus:

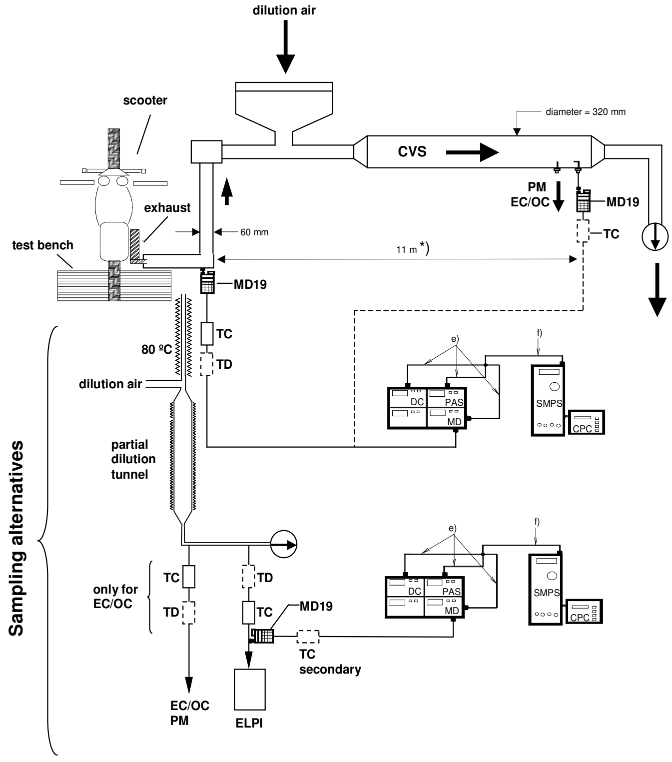
- SMPS – Scanning Mobility Particle Sizer, TSI (DMA TSI 3071, CPC TSI 3025 A)
- NanoMet – System consisting of:
  - PAS – Photoelectric Aerosol Sensor (Eco Chem PAS 2000)
  - DC – Diffusion Charging Sensor (Matter Eng. LQ1-DC)
  - MD19 tunable minidiluter (Matter Eng. MD19-2E, see Fig. 1).

- Thermoconditioner (TC) (i.e. MD19 + postdilution sample heating until 300°C)
- Thermodesorber (TD)

A detailed description of those systems can be found in the manufacturers informations. The sampling and measuring set-up during the tests shows Fig. 2.

In the research of sampling for NP-analysis several variants of sampling were used, which are alternatively represented in Fig. 2.

The nanoparticulates measurements were performed during cold acceleration to a constant speed and a following warm-up period with CPC and NanoMet and at the constant speed (warm) with SMPS and NanoMet.



*) from tailpipe to the sampling in the CVS-tunnel

TC…Thermo-Conditionner
TD…Thermo-Desorber

Figure 2. Sampling and measuring set-up for nanoparticulates analysis of the scooters with different variants of sampling methods

Measuring procedures

The sampling for nanoparticle analysis took place at tailpipe through MD19, as in the previous work, [5, 7]. The gravimetric measurements of PM were performed at the CVS tunnel (with same method as for Diesel cars).

Also the measuring procedure was similar, as in [5]: cold start (20-25°C) – acceleration to 40 km/h and v = const = 40 km/h. It was decided to increase the speed (previously 30 km/h) to guarantee the catalyst light off with all researched combinations “vehicle-fuel-oil”.

During the first 4 min after start the measurement of NP was performed with NanoMet and with CPC (over time) to register the warm-up phase.

The CPC (condensation particles counter) is a part of SMPS, which allows a dynamic measurement of all particle sizes simultaneously. The scanning of particle size distribution with DMA (differential mobility analyser) needs time and makes sense only at stationary emission source (here at 30 km/h warm).

Since the 9th minute after start the SMPS (DMA + CPC) was used, performing usually 3 scans.

The temperature and CO after catalyst were time-measured to see the light off. The stationary warm operation was prolonged until 20 min to get enough mass on the measuring filters for the analytics of PAH and SOF/INSOF.

After measurement of a given configuration there was a change of the configuration (oil, fuel, catalyst), a conditioning period of about 10 min and cooling down with blower during at least 30 min.

Table 2 shows all performed measuring series, which are called with “T” for TSDI and with “C” for Carburetor.

The driving resistances of the test bench were set according to the Swiss exhaust gas legislation for motorcycles.

Table 2. Measurements of scooter Peugeot TSDI and Carburetor with nanoparticle analysis; original catalyst and original oil dosage

name	lube oil-		fuel	Scooter
	type	sulfur		
T11 - T14	Panolin TS	S= 6250 ppm	unleaded	TSDI
T21 - T22	Panolin Synth	S=450 ppm		
T31	Nycolube	S=350 ppm		
T41 - T42	Panolin Synth Aqua	S= 0 ppm		
T51 - T54	Panolin TS	S= 6250 ppm	Aspen	
T61 - T62	Panolin Synth	S=450 ppm		
T71	Nycolube	S=350 ppm		
T81 - T82	Panolin Synth Aqua	S= 0 ppm		

C11 - C14	Panolin TS	S= 6250 ppm	unleaded	Carburetor
C21 - C22	Panolin Synth	S=450 ppm		
C31	Nycolube	S=350 ppm		
C41 - C42	Panolin Synth Aqua	S= 0 ppm		
C51 - C54	Panolin TS	S= 6250 ppm	Aspen	
C61 - C62	Panolin Synth	S=450 ppm		
C71	Nycolube	S=350 ppm		
C81 - C82	Panolin Synth Aqua	S= 0 ppm		

Used lube oils and fuels

The data of used lube oils with decreasing sulfur content are represented in Table 3.

The oils: “Panolin TS & Nycolube” are semi-synthetic.

Two fuels were used during the measurements: standard market gasoline and an Aspen gasoline, which is almost aromats-free (aromats < 0,1 Vol %, benzol < 0,01 Vol %). The sulfur content of both gasolines was analysed and no sulfur was found.

Table 3. Data of the used lube oils

Property	Unit	Panolin TS	Panolin 2-S Synth.	Panolin Synth. Aqua	Nycolube
Viscosity kin 40°C	mm^2/s	90	103	95	
Viscosity kin 100°C	mm^2/s	11.2	8.2	6.3	7.9
Density 15°C	kg/m^3	882	925	946	
Pourpoint	°C	-27	-40	-28	
Flamepoint	°C	> 150	> 150	> 150	
Total Base Number TBN	mg KOH/g	3	3	2.5	
Sulfur	ppm	6250	450	0	350
Fe	ppm	0	5	2	1
Mo	ppm	1	0	0	0
Mg	ppm	2	3	1	2
Zn	ppm	105	18	0	0
Ca	ppm	617	458	11	322
P	ppm	90	36	16	6

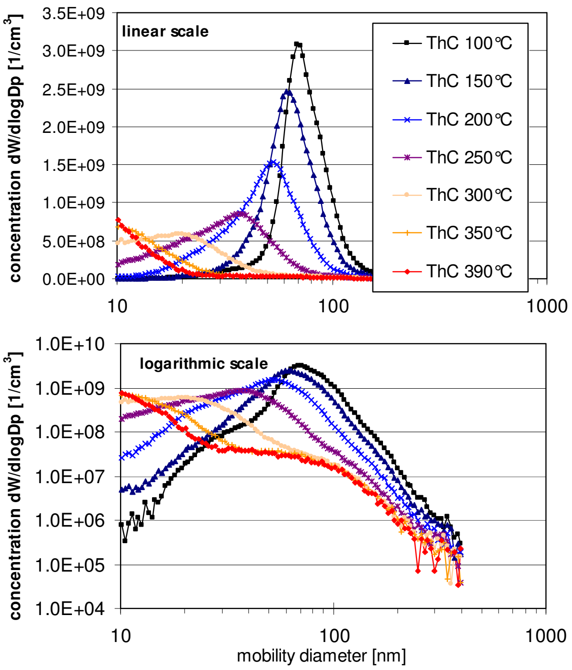


Figure 3. SMPS size spectra with thermo-conditioning of sample

RESULTS

Thermoconditioning of sample for NP-analysis

Several variants of sampling, according to Fig. 2, were investigated and the results were reported separately, [8].

In the present paper the following examples of thermograms at tailpipe shall signalize, how the different engine technologies influence the composition and behaviour of the exhaust aerosol.

This part of research was performed at stationary warm operating condition of engine and catalyst and at maximum speed 45 km/h.

Fig. 3 shows the results with **Peugeot TSDI**, sampling at **tailpipe** with minidiluter (MD) and thermoconditioner (TC, ThC).

Increased sample temperature in the TC provokes evaporation from the surface of particles and moves the SMPS PSD-spectrum to the lower peak-concentrations and smaller median diameters i.e. from the accumulation to the nuclei mode.

In the logarithmic scale a bimodality of the spectra with higher TC-temperatures is visible. This suggests that the particles in accumulation mode (60-90 nm), which remain at highest temperature are either very heavy compounds, or solids. These solids may have been formed already during combustion in the engine, similar to processes known from 4-stroke gasoline DI engines; another hypothesis would be their formation in the TC by thermal dehydration (pyrolysis) of heavy compounds which would imply a conditioning artefact, but due to the temperature level this artefact is probable only to a very little extend.

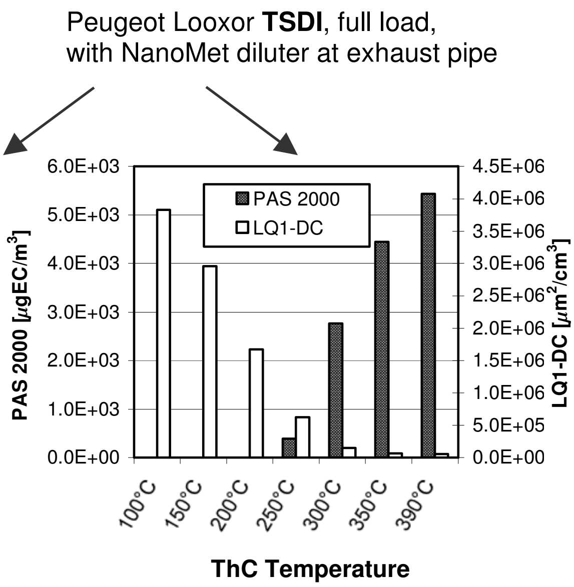


Figure 4. NanoMet signals with thermo-conditioning of sample

The NanoMet signals, Fig. 4, confirm the tendency of increased solid particle ratio showing a decreasing amount of condensates (DC) and increasing amount of carbonaceous surface (PAS) with the higher sample temperature.

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

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

The research of sampling at tailpipe with MD + TC for the Peugeot Carburetor is depicted in Fig. 5. With increasing of the TC-temperature the very high count concentrations in nuclei mode decrease and with application of stronger dilution (5x, 10 x, or 100x by mean of a second MD inline with the first one) it is possible to cut a part of this nuclei mode. This behavior of the aerosol from “Carb.” is quite different form the one of TSDI (Fig. 3). The Carburetor-version has a much higher exhaust gas temperature, which enables the creation of sulfates. The exhaust gas temperature of the TSDI is below the range of intensified sulfate production (oxidation SO_2 to SO_3).

Due to the higher exhaust gas temperature and the applied SAS (secondary air system) in the Carb.-version the oxidation of HC in the oxidation catalyst is more intense and the composition of aerosol is different than for TSDI.

The NanoMet data, Fig. 6, confirm this fact showing almost unchanged DC and no PAS with increasing temperature (compare Fig. 4 & Fig. 6).

Generally it can be stated, that the sampling procedure: conditioning of the sample gas probe, dilution and sampling position have influence on the measured aerosol characteristics (PM, PSD, PAS, DC). About further results of the research of sampling for particle analysis will be reported separately.

Different scooters, oils and fuels

The comparisons: gasoline - Aspen with NanoMet for both scooters, Fig. 7 and Fig. 8, show a quicker light off of the catalyst and a lower total particle surface (DC) at cold start with Aspen.

At the beginning of catalyst light off of the Carburetor-scooter (Fig. 8) – at time scale value ~ 100 s for Aspen and ~ 120 s for gasoline – there is a peak of DC-signal. This type of one, or two DC-peaks during the cat. light off of Carb. is always observed and it is explained with the change of aerosol composition, which is caused by the light off itself. In particular the very rich mixture tuning of this engine offers high values of unburned HC, which start to change their spectrum during the low-temperature oxidation and release some components, which recondensate provoking this DC-peak.

Peugeot Looxor with **Carburetor,**
full load, with NanoMet at exhaust pipe

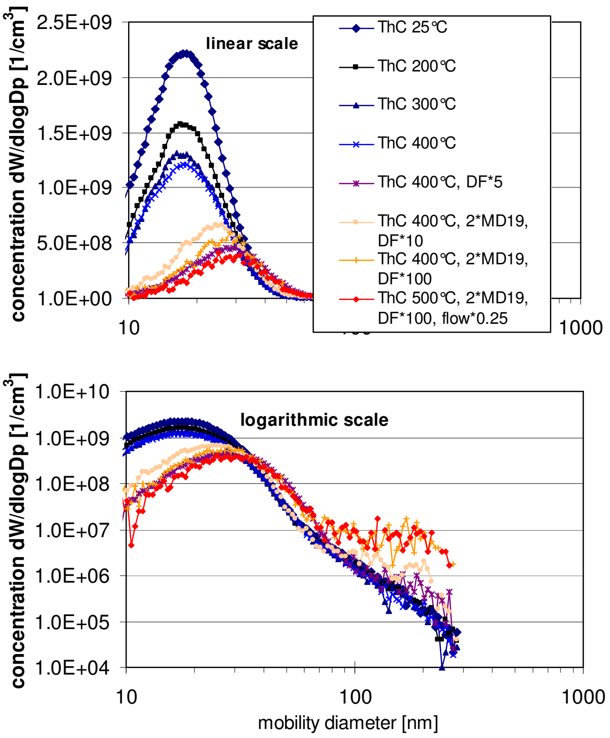


Figure 5. SMPS size spectra with thermo-conditioning of sample

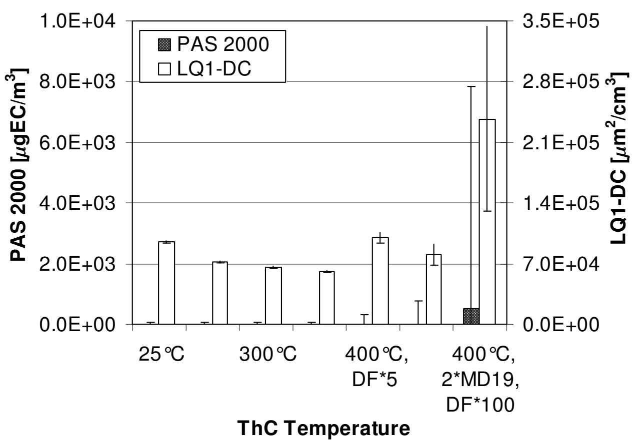


Figure 6. NanoMet Signals with thermo-conditioning of sample

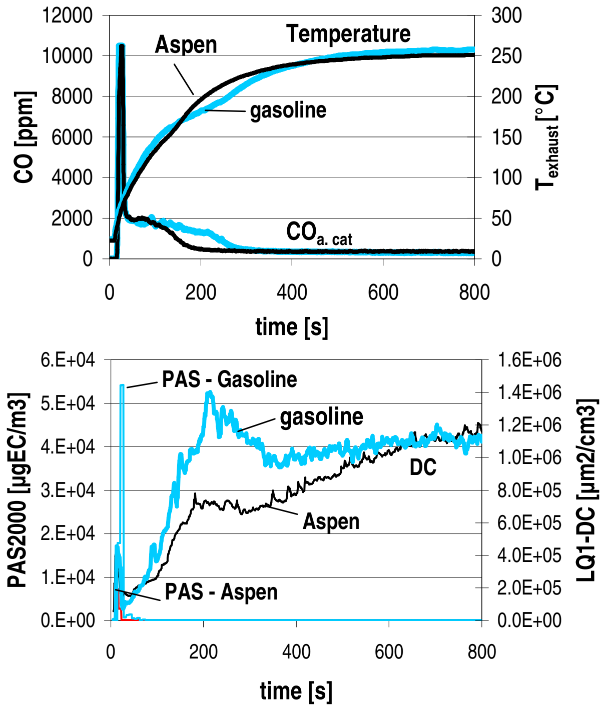


Figure. 7: Cold start - acceleration - 40 km/h with: Gasoline - Aspen, Peugeot TSDI, oil: Panolin TS

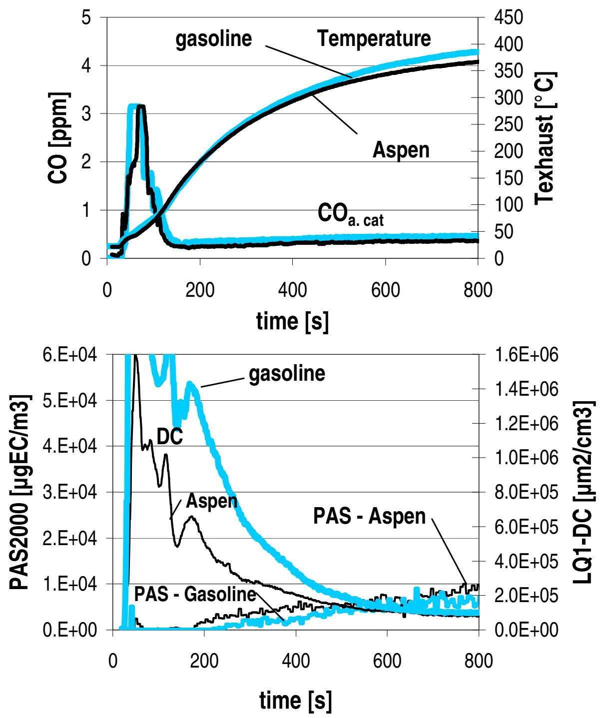


Figure 8: Cold start – acceleration - 40 km/h with: Gasoline - Aspen, Peugeot Carb, oil : Panolin TS

Note that the light off for Carb.-scooter starts already below 100 °C and t_{exh} reaches 380 °C, while for TSDI the light off takes place at temperatures above 160 °C and t_{exh} reaches 260 °C, (t_{exh} measured approx. 40 cm after catalyst).
Due to these differences the NanoMet signals show quite different behaviour at warm operation, p. ex. after 10 min:
For TSDI, which has: lower t_{exh}, leaner tuning of the mixture and less postoxidation in the oxicat, the DC-signal indicates the presence of condensates and no solids are visible (PAS=zero), because if there are any of them, they are enveloped with the condensates.
For Carburetor, which has: higher t_{exh}, richer tuning of the mixture and a very intense postoxidation in the catalyst, the solids appear (PAS increase) after the light off and during the warm-up of the catalyst. Simultaneously the condensates (DC) decrease very much because of the oxidation of VOC and because of deposition on the bigger solid particles. The solids originate from the rich combustion, but they can be also products of the strong postoxidation.

Following figures represent the influences of different oils on the particle emission metrics for both scooters and both fuels.

For TSDI and gasoline the tendency is similar as in the previous research, [7], Fig. 9 – the oil with 0 ppm S has the highest PM- and DC-emission. The integrated SMPS particle numbers don't show this difference because of other PSD-shape for this oil T4. With Aspen, Fig. 10, the relationships and the absolute values are similar, but the SMPS PSD spectra are slightly lower and wider giving also similar integrated nanoparticle counts as with gasoline.

For Carburetor there are generally much lower values of all represented emission parameters. This is due to the intense postoxidation with SAS and high t_{exh}. With gasoline, Fig. 11, the bimodality of SMPS spectra caused by the sulfates is visible. The oil C4 with 0 ppm S has quite other nuclei mode, caused by other substances (ev. components of additive package). Given that DC is also maximal with this oil, the presence of organic condensates must be assumed.

Regarding influence of Aspen, Fig. 12, can be remarked, that oil C8 (0 ppm S) moves the nuclei mode to lower sizes and lower amplitude – this is the result of coinfluence of the HC from fuel and HC from oil during the processes of combustion and postoxidation.
With the same reasons the changes for other oils (C6 and C7) can be explained, of course with addition of sulfates (S ≠ 0).

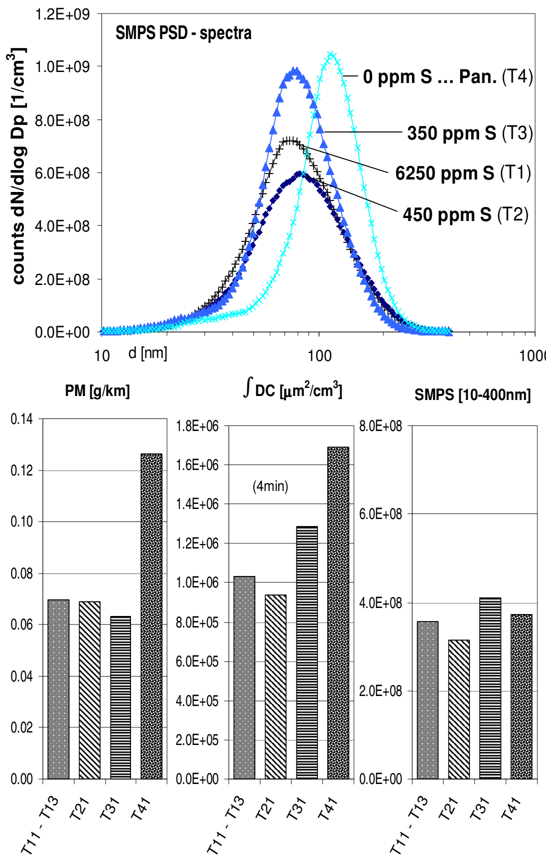


*Figure 9: Particle mass and nanoparticles at 40 km/h warm with **gasoline** and different lube oils, Peugeot Looxor **TSDI***

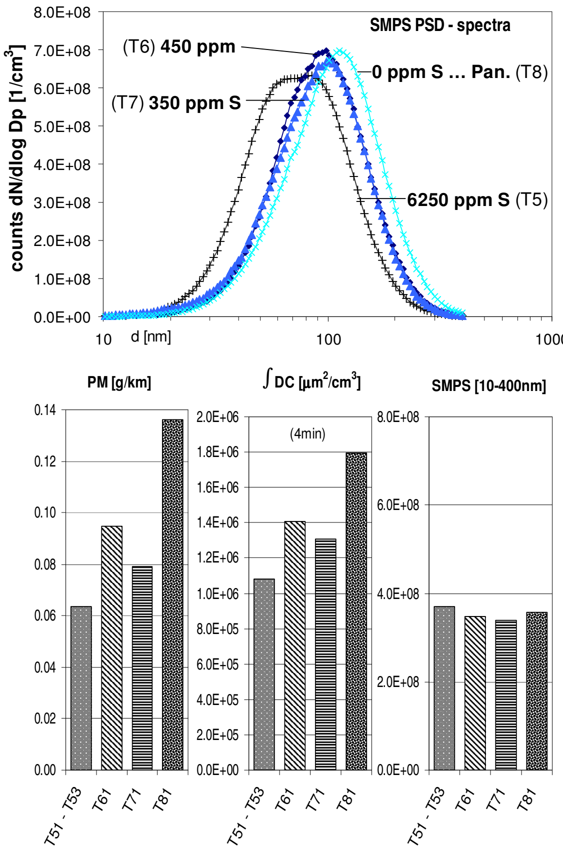


*Figure 10: Particle mass and nanoparticles at 40 km/h warm with **Aspen** and different lube oils, Peugeot Looxor **TSDI***

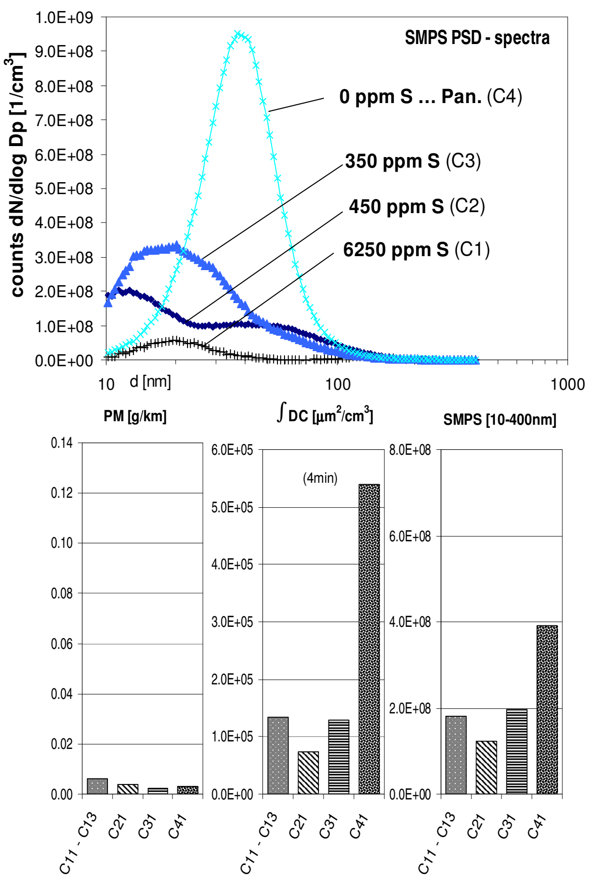


*Figure 11: Particle mass and nanoparticles at 40 km/h warm with **gasoline** and different lube oils, Peugeot Looxor **Carb.***

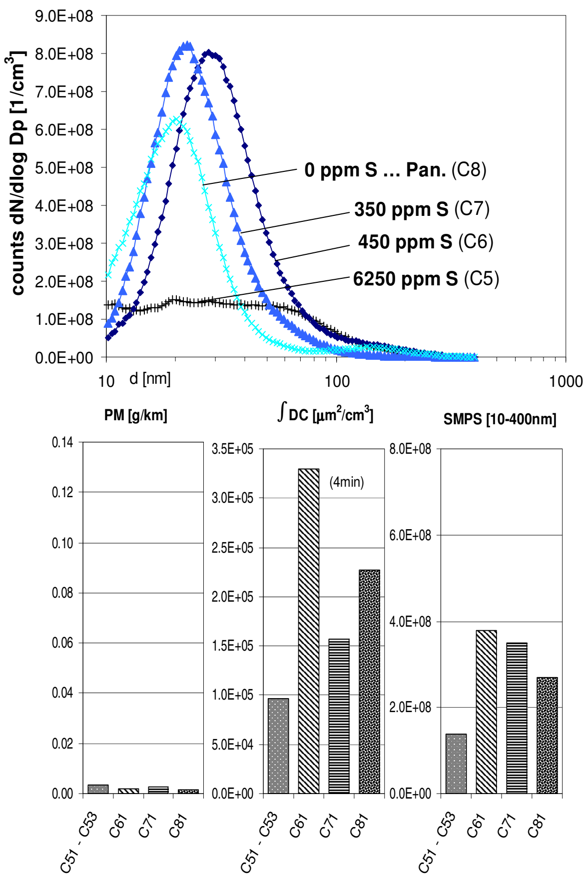


*Figure 12: Particle mass and nanoparticles at 40 km/h warm with **Aspen** and different lube oils, Peugeot Looxor **Carb.***

Fig. 13 compares directly the particle emissions of the scooters TSDI and Carburetor with two oils (with min/max S-content). The explanations of influences and relationships discussed in the previous figures are valid also here:

- due to the intense postoxidation (SAS) of the Carb-version there are lower emissions of mass (PM), condensates (DC) and counts (SMPS) as with the TSDI.
- the oil with zero sulfur causes higher particle emissions.

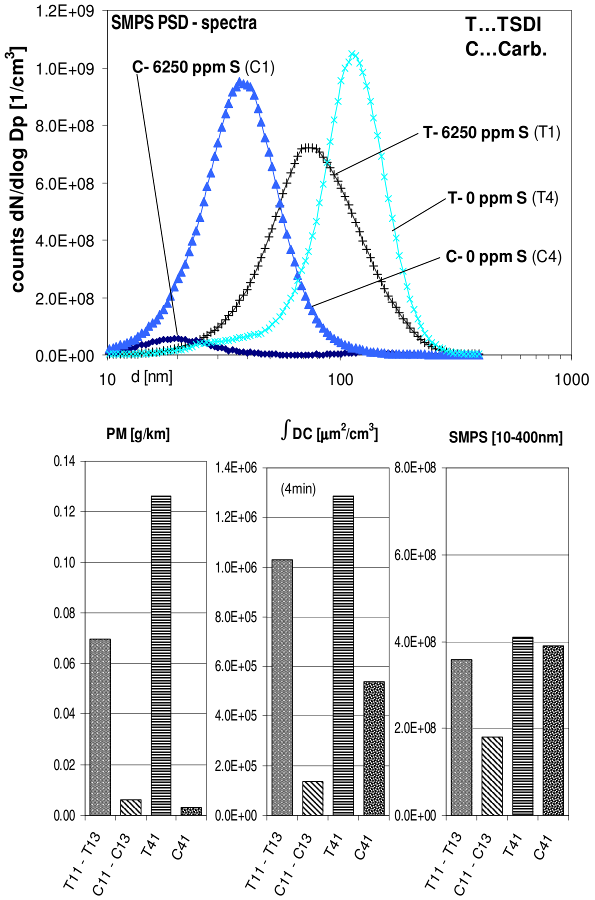


Figure 13: Comparison between Peugeot Looxor TSDI & Carb. with gasoline - Panolin TS & Aqua Synth

Analysis of particle toxicity and of VOC

The diagram in annex 1 summarizes the total emissions of PAH in PM, analysed at JRC and compares them with the particle mass PM for the different variants of oil, fuel, vehicle and driving conditions. More detailed description of analytical method and informations about the individual PAH compounds are given in other JRC publications, [9],[10].

It can be stated, that the Carburator scooter "warm" has the lowest PM & PAH emissions due to the intense oxidation in the exhaust. With cold start, when the catalyst is not active at the beginning of the warm-up phase, the Carb. Scooter has, particularly with the standard gasoline, the highest emissions of PAH.

The PM for both scooters "cold" and for TSDI "warm" shows a clear tendency of higher values with the 0 ppm-oil.

For TSDI the PM-values "cold" are slightly lower, than "warm". The reason could be, that in the cold period the oil droplets are bigger /less evaporation of heavy compounds) and they are stored more on the cold walls of the engine exhaust system. Another reason can be the influence of the gas temperature in the exhaust on the gasdynamic phenomena, on the gas exchange of the engine and finally on the scavenging losses.

The alkylat fuel Aspen is generally better from the point of view of total PAH. Nevertheless, due to different composition of PAH this tendency is not exactly the same for the toxicity equivalence factors, [9], [10].

The lowest PAH-emission values are obtained with the combination : Carb. + SAS, Aspen and oil Pan. Synth Aqua (0 ppm S) at warm stationary operation. For TSDI generally the other oil (450 ppm S) furnishes better results.

In Fig. 14 the coulometric results are represented. There is a very good correlation of OC and TC with the total PM, which confirms the major contribution of OC to the PM.

The share of EC is overestimated due to the artefact mentioned before - pyrolisis of a part of heavy SOF during the thermal extraction and move of some OC to the EC.

It was pointed out during the discussions, that a long sampling, like the 20 min for the hot samples, can create to big filter cake, which makes it difficult to differenciate between SOF/INSOF.

The bottom diagrams of Fig.14 shows the shares of fractions obtained by the EMPA soxhlet extractions. It is confirmed, that during the operating conditions with cold start and warm up there is a higher part of insoluble residue. Also for "Carb. warm" with a very low absolute PM-emission there is a high portion of insolube rest due to a very efficient oxidation of SOF in the exhaust system.

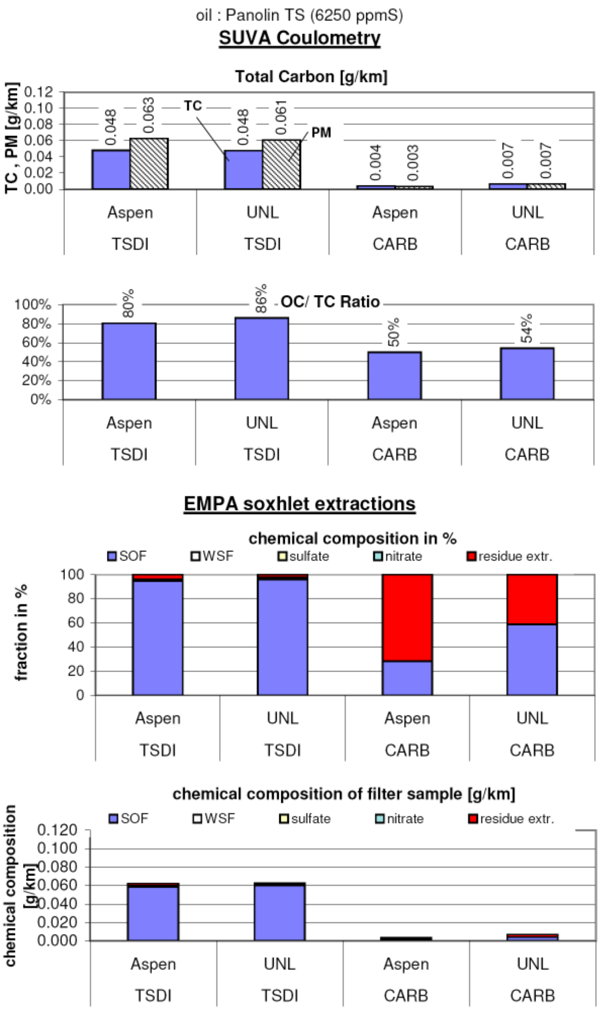


Figure 14a : Results of SOF/INSOF analysis with the same oil – different fuels / vehicles, ***warm operation***

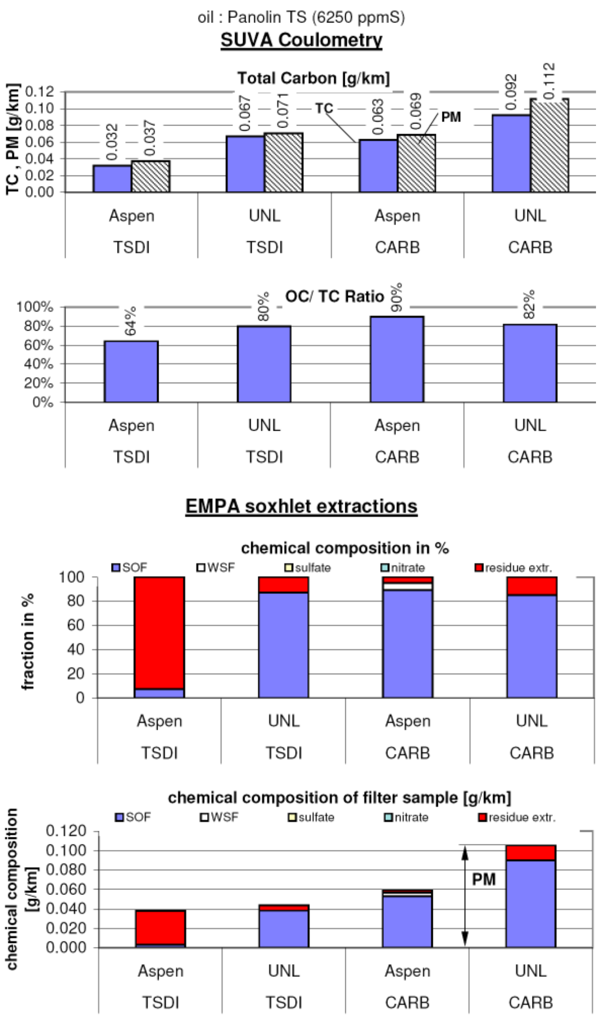


Figure 14b : Results of SOF/INSOF analysis with the same oil – different fuels / vehicles, ***cold start & warm-up***

Conclusions

Following conclusions can be pointed out:

- the composition of emitted aerosol depends on engine technology (DI-Carb.), exhaust gas aftertreatment (texh, SAS) and the used oil and fuel. The differences of the aerosol are visible by thermoconditioning of the sample,
- the influences of lube oils on the particle emissions from previous works could be confirmed on the scooter with DI and gasoline and they are slightly modified on the Carb. scooter,
- changing the fuel quality (Aspen) may increase the condensates with one oil and lower the condensates with another oil,
- due to an intense oxidation in the exhaust of the Carb. scooter the particle mass emission PM is very little and it is almost independent on lube oil quality,
- due to a high exhaust temperature of the Carb. scooter there are sulfates as condensates in the nuclei mode of the PSD-spectra,
- there is a clear evidence of coinfluences of oil & fuel on the spontaneous condensation and on the particle emission parameters,
- the sampling procedure: conditioning of the sample gas probe, dilution and sampling position have influence on the measured aerosol characteristics (PM, PSD, PAS, DC),
- the amount of total PAH, as well as the toxicity equivalence factor TEQ correlate roughly with the total particle mass PM,
- the Carburator scooter "warm" has the lowest PM & PAH emissions due to the intense oxidation in the exhaust. With cold start, when the catalyst is not active at the beginning of the warm-up phase, the Carb. Scooter has, particularly with the standard gasoline, the highest emissions of PAH,
- the alkylat fuel Aspen is generally better from the point of view of total PAH. Nevertheless, due to different composition of PAH this tendency is not exactly the same for the toxicity equivalence factors,
- the lowest PAH-emission values are obtained with the combination : Carb. + SAS, Aspen and oil Pan. Synth Aqua (0 ppm S) at warm stationary operation. For TSDI generally the other oil (450 ppm S) furnishes better results
- there is no combination of oil/fuel/vehicule, which would be the best one for all criteria (NP, PM, PAH, TEQ).

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- SUVA Analytical Laboratory, CH, Mr. R. Wolf, Mrs. S. Dellenbach

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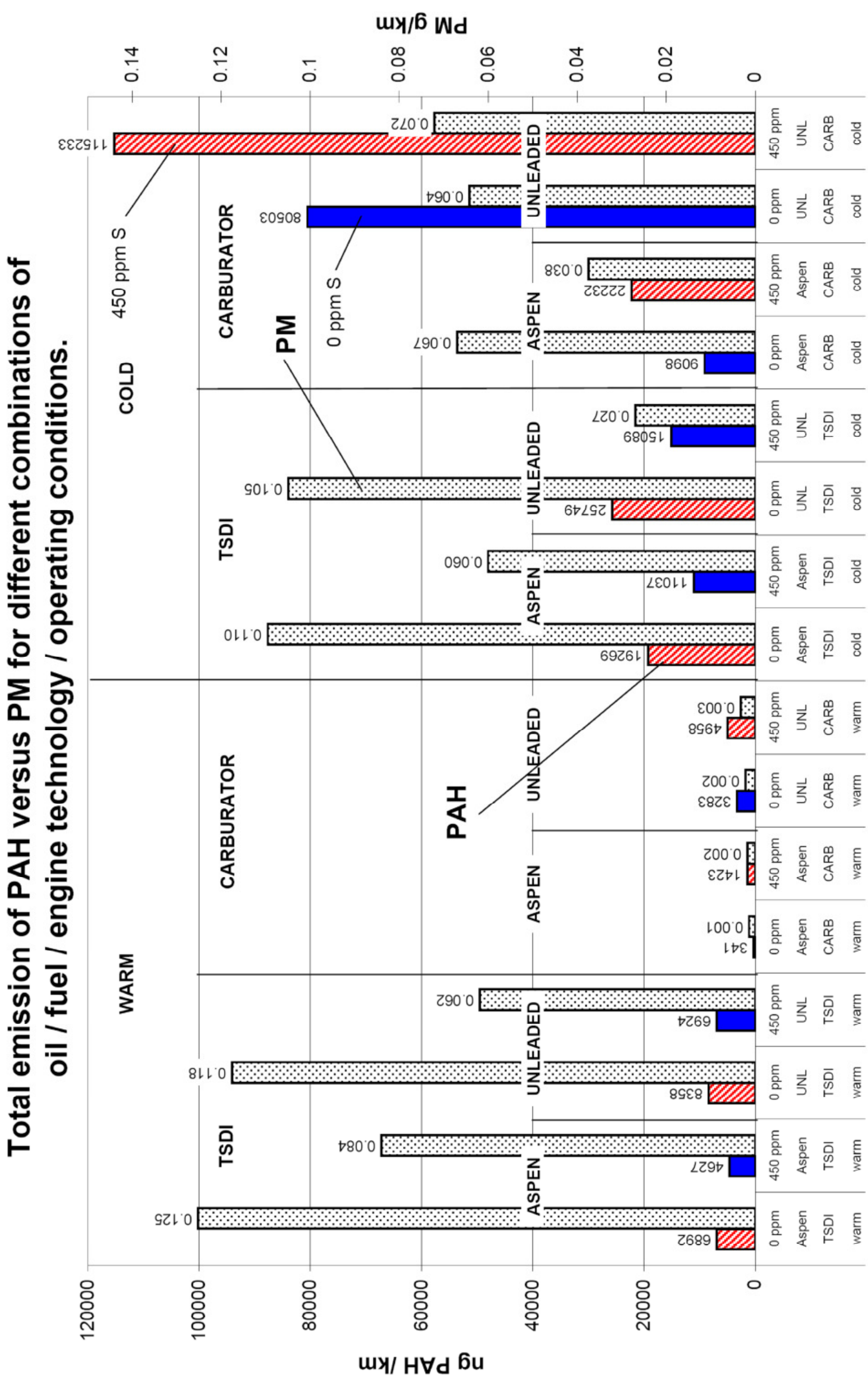
ABBREVIATIONS

AFHB	Abgasprüfstelle der Fachhochschule, Biel CH (Lab. For Exhaust Gas Control, Univ. of Appl. Sciences, Biel-Bienne, Switzerland)
AMF	Implementing Agreement on Advanced Motor Fuels
ARAI	Automotive Research Association of India
BUWAL	Bundesamt für Umwelt, Wald und Landschaft (Swiss EPA, SAEFL)
Carb. (C)	Carburetor
CPC	condensation particle counter
CVS	constant volume sampling
Cx	mensuring serie „X“ with Carburetor
DC	diffusion charging sensor
DMA	differential mobility analyzer
EC	elemental carbon
EMPA	Swiss Federal Laboratories for Materials Testing and Research
EPA	Environmental Protection Agency
ETHZ	Eidgenössische Technische Hochschule Zürich
EV	Erdöl-Vereinigung, Swiss Association of Oil Manufacturers
IEA	International Energy Agency
INSOF	insoluble fraction
JRC	Joint Research Center, EU Laboratories, Ispra, Italy
MD	minidiluter
ME	Matter Engineering AG, CH
NanoMet	minidiluter + PAS + DC (+ ThC), (+TD)
NMOG	non methan organic gases
NP	nanoparticulates
OC	organic carbon
OP	ozon-forming potential
PAS	photoelectric aerosol sensor
PM	particulate matter, particulate mass
PSD	particles size distribution
SAEFL	Swiss Agency for Environment, Forests and Landscape (Swiss EPA, BUWAL)
SAS	secondary air system
SMPS	scanning mobility particles sizer
SOF	soluble organic fractions
SUVA	Schweizerische Unfallversicherungsanstalt
TC	total carbon
TD	thermodesorber
TEQ	toxicity equivalence factor
ThC (TC)	thermoconditioner
TSDI (T)	Two Stroke Direct Injection
Tx	measuring serie “x” with TSDI
TTM	Technik Termische Maschinen, CH
UNL	unleaded gasoline
VOC	volatile organic compounds
VTT	Transport Research Center, Finland
WSF	water soluble fractions

Annex 1



Total emission of PAH versus PM for different combinations of oil / fuel / engine technology / operating conditions.
ng PAH /km
PM g/km
WARM
COLD
TSDI
CARBURATOR
ASPEN
UNLEADED
PAH
PM
0 ppm S
450 ppm S
6892
0.125
4627
0.084
8358
0.118
6924
0.062
341
0.001
1423
0.002
3283
0.002
4958
0.003
19269
0.110
11037
0.060
25749
0.105
15089
0.027
9098
0.067
22232
0.038
80503
0.064
115233
0.072
0 ppm
450 ppm
Aspen
UNL
TSDI
CARB
warm
cold